NATIONAL INVENTORY REPORT 1990–2018: 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 ABBREVIATIONS AND UNITS

Abbreviations

CAC ..... Criteria Air Contaminant

CANSIM ..... Statistics Canada's key socioeconomic database

CEPA 1999 ..... *Canadian Environmental Protection Act, 1999*

CESI ..... Canadian Environmental Sustainability Indicators

CFC ..... chlorofluorocarbon

CFS ..... Canadian Forest Service

ECCC ..... Environment and Climate Change Canada

EF ..... emission factor

GDP ..... gross domestic product

GHG ..... greenhouse gas

GHGRP ..... Greenhouse Gas Reporting Program

HFC ..... hydrofluorocarbon

HWP ..... harvested wood products

IPCC ..... Intergovernmental Panel on Climate Change

IPPU ..... Industrial Proccesses and Product Use

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

MSW ..... municipal solid waste

N/A ..... not available

NIR ..... National Inventory Report

NMVOC ..... non-methane volatile organic compound

NPRI ..... National Pollutant Release Inventory

ODS ..... ozone-depleting substance

OECD ..... Organisation for Economic Co-operation and Development

PFC ..... perfluorocarbon

POP ..... persistent organic pollutant

QA ..... quality assurance

QC ..... quality control

RESD ..... Report on Energy Supply and Demand in Canada

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

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

Chemical Formulas

Al ..... aluminium

$Al2O_3$ ..... alumina

CaC_2 ..... calcium carbide

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

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

CaO ..... lime; quicklime; calcined limestone

CF_4 ..... carbon tetrafluoride

C_2F_6 ..... carbon hexafluoride

CH_3OH ..... methanol

CH_4 ..... methane

C_2H_6 ..... ethane

C_3H_8 ..... propane

C_4H_{10} ..... butane

C_2H_4 ..... ethylene

C_6H_6 ..... benzene

$CHCl_3$ ..... chloroform

CO ..... carbon monoxide

CO_2 ..... carbon dioxide

CO_2 eq ..... carbon dioxide equivalent

H_2 ..... hydrogen

H_2O ..... water

H_2S ..... hydrogen sulphide

HCFC ..... hydrochlorofluorocarbon

HCl ..... hydrochloric acid

HF ..... hydrogen fluoride

HNO_3 ..... nitric acid

K_2CO_3 ..... potassium carbonate

Mg ..... magnesium

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

MgO ..... magnesia; dolomitic lime

N ..... nitrogen

N_2 ..... nitrogen gas

Na_2CO_3 ..... sodium carbonate; soda ash

$Na3AlF_6$ ..... cryolite

NF_3 ..... nitrogen trifluoride

NH_3 ..... ammonia

NH_4+ ..... ammonium

NH_4NO_3 ..... ammonium nitrate

N_2O ..... nitrous oxide

N_2O-N ..... Nitrous oxide emissions represented in terms of nitrogen

NO ..... nitric oxide

NO_2 ..... nitrogen dioxide

NO_3- ..... nitrate

NO_x ..... nitrogen oxides

O_2 ..... oxygen

SF_6 ..... sulphur hexafluoride

SiC ..... silicon carbide

SO_2 ..... sulphur dioxide

SO_x ..... sulphur oxides

Notation Keys

IE ..... included elsewhere

NA ..... not applicable

NE ..... not estimated

NO ..... not occurring

Units

g ..... gram

Gg ..... gigagram

Gt ..... gigatonne

ha ..... hectare

kg ..... kilogram

kha ..... kilohectare

km ..... kilometre

kt ..... kilotonne

kWh ..... kilowatt-hour

m ..... metre

Mg ..... megagram

Mha ..... megahectare

mm ..... millimetre

Mt ..... megatonne

MW ..... megawatt

PJ ..... petajoule

t ..... tonne

TWh ..... terrawatt-hour

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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:**

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

$L_{x,t}$	=	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
$\sum_y \|E_{y,t}\|$	=	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 Equation A1–2 and Equation A1–3 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:**

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

$T_{x,t}$	=	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
$\sum_y E_{y,t}$ and $\sum_y E_{y,0}$	=	total inventory estimates in years *t* and 0, respectively

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

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

$T_{x,t}$	=	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*
$\sum_y \lvert E_{y,0} \rvert$	=	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. 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 common reporting format (CRF). Thus, while the UNFCCC CRF categories provide a basis for identifying sources and sinks, some aggregation of these sources and sinks has been made for the purpose of key category analysis. In general, the aggregation of categories has been performed when estimates are based on common emission factors and activity data. An exhaustive list of the aggregated categories is presented in Table A1–1. As a planned improvement, an additional column with explanations regarding the rational for category aggregation is being considered for incorporation into Table A1–1 in subsequent reports.

A1.1.1. Summary Assessment

Key categories were assessed for the 2018 inventory year using level and trend criteria and for the base year using the level criterion only. There were 35 level key categories in 1990, while in 2018 there were 45 with all combined criteria. Combined assessment results are presented in Table A1–2.

Table A1–1 **Aggregation of IPCC Categories**

Source Table	Aggregated IPCC Category	Categories included in the aggregated IPCC categories
1-A-1	Stationary Fuel Combustion—Energy Industries	Public Electricity and Heat Production
		Petroleum Refining
		Manufacture of solid fuels and other energy industries
1-A-2	Stationary Fuel Combustion—Manufacturing industries and construction	Iron and Steel
		Non-ferrous metals
		Chemicals
		Pulp, paper and print
		Non-metallic minerals
		Other
1-A-3-b	Fuel Combustion—Road Transportation	Heavy-Duty Diesel Vehicles
		Heavy-Duty Gasoline Vehicles
		Light-Duty Diesel Trucks
		Light-Duty Diesel Vehicles
		Light-Duty Gasoline Trucks
		Light-Duty Gasoline Vehicles
		Motorcycles
		Natural Gas Vehicles
		Propane Vehicles
		Urban Bus
1-A-4	Stationary Fuel Combustion—Other Sectors	Commercial/institutional
		Residential
		Agriculture/forestry/fisheries
1-B-2-(a+c)	Fugitive Emissions—Oil	Oil
		Venting—Oil
		Flaring—Oil
		Venting—Combined (split with 1-B-2-(b+c))
		Flaring—Combined (split with 1-B-2-(b+c))

Table A1–1 **Aggregation of IPCC Categories** (cont'd)

Source Table	Aggregated IPCC Category	Categories included in the aggregated IPCC categories
1-B-2-(b+c)	Fugitive Emissions—Natural Gas	Natural Gas
		Venting—Natural Gas
		Flaring—Natural Gas
		Venting—Combined (split with 1-B-2-(a+c))
		Flaring—Combined (split with 1-B-2-(a+c))
2-B-8	Petrochemical and Carbon Black Production	Carbide Production
		Methanol Production
		Ethylene Production
		Ethylene Dichloride Production
		Carbon Black Production
		Styrene Production
2-C-1	Iron and Steel Production	Steel Production
		Pig Iron Production
		Metal Industry—Ferroalloys Production
2-D-3	Non-energy Products from Fuels and Solvent Use Other—Other (Other and Undifferentiated)	CO_2 emissions from Carbide Production, Carbon Black Production, Styrene Production, and Ethylene Dichloride and Vinyl Chloride Monomer Production
		Iron and Steel—Sinter production
		Iron and Steel—Pellet production
		Metal Industry—Lead Production
		Metal Industry—Zinc Production
		Non-energy Products from Fuels and Solvent Use—Other (Solvent use)
		Non-energy Products from Fuels and Solvent Use—natural gas, solid fuels and liquid fuels (including lubricant and paraffin wax use)
2-F	Product Uses as Substitutes for Ozone Depleting Substances	Refrigeration and Air conditioning
		Foam Blowing Agents
		Fire Protection
		Aerosols
		Solvents
		Other Applications
3-A	Agriculture—Enteric Fermentation	Cattle
		Sheep
		Swine
		Other Livestock
3-B	Agiculture—Manure Management	N_2O and NMVOC Emissions—Sheep
		N_2O and NMVOC Emissions—Swine
		N_2O and NMVOC Emissions—Other Livestock
		N_2O and NMVOC Emissions—Indirect N_2O Emissions
3-D-1	Agriculture—Direct N_2O Emissions from Managed Soils	Inorganic N Fertilizers
		Organic N Fertilizers
		Urine and Dung Deposited by Grazing Animals
		Crop Residues
		Mineralization/Immobilization Associated with Loss/Gain of Soil Organic Matter
		Cultivation of Organic Soils
3-D-2	Agriculture—Indirect N_2O Emissions from Managed Soils	Atmospheric Deposition
		Nitrogen Leaching and Run-Off
3-I	Agriculture—Other Carbon-Containing Fertilizers	Liming
		Urea Application
		Other Carbon-Containing Nitrogen Fertilizers
4-A-1	LULUCF—Forest Land remaining Forest Land	Forest Land remaining Forest Land
		Biomass Burning, Forest Land remaining Forest Land
		Emissions and removals from drainage and rewetting and other management of organic and mineral soils, Forest Land
4-B-2	LULUCF—Land converted to Cropland	Land converted to Cropland
		Direct nitrous oxide (N_2O) emissions from nitrogen (N) mineralization/ immobilization resulting from change of land use or management of mineral soils
		Biomass Burning
4-D-1	LULUCF—Wetlands remaining Wetlands	Emissions and removals from drainage and rewetting and other management of organic and mineral soils for Peat extraction lands (*only emissions associated to peat extraction remaining peat extraction)
		Flooded land remaining Flooded land
4-D-2	LULUCF—Land converted to Wetlands	Land converted to Flooded land
		Emissions and removals from drainage and rewetting and other management of organic and mineral soils, Peat extraction lands (*only emissions associated to Land converted to peat extraction)
		Biomass Burning, Land converted to Wetlands
4-E-2	LULUCF—Land converted to Settlements	Land converted to Settlements
		Biomass Burning, Settlements
5-A-1	Waste—Solid Waste Disposal	Municipal Solid Waste Landfills
		Wood Waste Landfills

Table A1–2 **Key Category Analysis Summary, 2018 Inventory Year**

Source Table	IPCC Category	Direct Greenhouse Gas	Key Category (1990 / 2018)			Criteria 1990 / 2018 L: Level, T: Trend				
1.A.1	Stationary Fuel Combustion—Energy Industries	CO_2	Yes	/	Yes	L	/	L	,	T
1.A.1	Stationary Fuel Combustion—Energy Industries	CH_4	No	/	No					
1.A.1	Stationary Fuel Combustion—Energy Industries	N_2O	No	/	No					
1.A.2	Stationary Fuel Combustion—Manufacturing industries and construction	CO_2	Yes	/	Yes	L	/	L	,	T
1.A.2	Stationary Fuel Combustion—Manufacturing industries and construction	CH_4	No	/	No					
1.A.2	Stationary Fuel Combustion—Manufacturing industries and construction	N_2O	No	/	No					
1.A.4	Stationary Fuel Combustion—Other sectors	CO_2	Yes	/	Yes	L	/	L	,	T
1.A.4	Stationary Fuel Combustion—Other sectors	CH_4	Yes	/	Yes	L	/			T
1.A.4	Stationary Fuel Combustion—Other sectors	N_2O	No	/	No					
1-A-2-g	Fuel Combustion—Manufacturing Industries and Construction/Other/Off-Road Vehicles and Other Machinery	CO_2	Yes	/	Yes	L	/	L	,	T
1-A-2-g	Fuel Combustion—Manufacturing Industries and Construction/Other/Off-Road Vehicles and Other Machinery	CH_4	No	/	No					
1-A-2-g	Fuel Combustion—Manufacturing Industries and Construction/Other/Off-Road Vehicles and Other Machinery	N_2O	No	/	No					
1-A-3-a & 1-A-5-b	Fuel Combustion—Domestic Aviation	CO_2	Yes	/	Yes	L	/	L		
1-A-3-a & 1-A-5-b	Fuel Combustion—Domestic Aviation	CH_4	No	/	No					
1-A-3-a & 1-A-5-b	Fuel Combustion—Domestic Aviation	N_2O	No	/	No					
1-A-3-b	Fuel Combustion—Road Transportation	CO_2	Yes	/	Yes	L	/	L	,	T
1-A-3-b	Fuel Combustion—Road Transportation	CH_4	No	/	No					
1-A-3-b	Fuel Combustion—Road Transportation	N_2O	Yes	/	Yes	L	/			T
1-A-3-c	Fuel Combustion—Railways	CO_2	Yes	/	Yes	L	/	L		
1-A-3-c	Fuel Combustion—Railways	CH_4	No	/	No					
1-A-3-c	Fuel Combustion—Railways	N_2O	No	/	No					
1-A-3-d	Fuel Combustion—Domestic Navigation	CO_2	Yes	/	Yes	L	/	L		
1-A-3-d	Fuel Combustion—Domestic Navigation	CH_4	No	/	No					
1-A-3-d	Fuel Combustion—Domestic Navigation	N_2O	No	/	No					
1-A-3-e-ii	Fuel Combustion—Other Transport (Off Road)	CO_2	Yes	/	Yes	L	/	L	,	T
1-A-3-e-ii	Fuel Combustion—Other Transport (Off Road)	CH_4	No	/	Yes					T
1-A-3-e-ii	Fuel Combustion—Other Transport (Off Road)	N_2O	No	/	No					
1-A-3-e-i	Fuel Combustion—Pipeline Transport	CO_2	Yes	/	Yes	L	/	L		
1-A-3-e-i	Fuel Combustion—Pipeline Transport	CH_4	No	/	No					
1-A-3-e-i	Fuel Combustion—Pipeline Transport	N_2O	No	/	No					
1-A-4-a	Fuel Combustion—Commercial Institutional/Off-Road Vehicles and Other Machinery	CO_2	No	/	Yes					T
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	,	T
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	,	T
1-B-2-(b+c)	Fugitive Emissions—Natural Gas	N_2O	No	/	No					
1-C-1	CO_2 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	/	Yes					T
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	/	L		
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	/	Yes					T

Table A1–2 **Key Category Analysis Summary, 2018 Inventory Year** (cont'd)

Source Table	IPCC Category	Direct Greenhouse Gas	Key Category (1990 / 2018)			Criteria 1990 / 2018 L: Level, T: Trend					
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-D.3	IPPU- Other (Use of Urea in SCR Vehicles)	PFCs	No	/	No					
2-G-3-a	IPPU—Other (Medical Applications of N_2O)	N_2O	No	/	No					
2-G-3-b	IPPU—Other (Use of N_2O for Propellant)	N_2O	No	/	No					
2-G-4	IPPU—Other Contained Product Uses	CO_2	No	/	No					
3-A	Agriculture—Enteric Fermentation	CH_4	Yes	/	Yes	L	/	L	,	T
3-B	Agriculture—Manure Management	CH_4	No	/	Yes			L		
3-B	Agriculture—Manure Management	N_2O	Yes	/	No	L				
3-B-5	Agriculture—Indirect N_2O Emissions	N_2O	No	/	No					
3-D-1	Agriculture—Direct N_2O Emissions from Managed Soils	N_2O	Yes	/	Yes	L	/	L	,	T
3-D-2	Agriculture—Indirect N_2O 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 $CaCO_3$	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	Yes	/	Yes	L	/	L		
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-Managed Waste Disposal Sites	CH_4	Yes	/	Yes	L	/	L	,	T
5-A-2	Waste—Solid Waste Disposal-Unmanaged Waste Disposal Sites	CH_4	Yes	/	Yes	L	/			T
5-B	Waste—Biological Treatment of Solid Waste	N_2O	No	/	No					
5-B	Waste—Biological Treatment of Solid 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-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)

A1.2. Key Category Tables

A1.2.1. Level Assessment With and Without LULUCF

Table A1–3 shows the 1990 key categories identified from level assessment with and without LULUCF.

Table A1–4 shows the 2018 key categories identified from level assessment with and without LULUCF.

Table A1–3 **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 2018	without LULUCF	with LULUCF	without LULUCF	with LULUCF
4-A-1	LULUCF—Forest Land remaining Forest Land	CO_2	-202 468	-139 990	NA	0.211	NA	0.211
1.A.1	Stationary Fuel Combustion—Energy Industries	CO_2	144 724	188 493	0.240	0.151	0.240	0.361
4-G	LULUCF—Harvested Wood Products (HWP)	CO_2	127 746	128 582	NA	0.133	NA	0.494
1-A-3-b	Fuel Combustion—Road Transportation	CO_2	80 541	150 831	0.134	0.084	0.374	0.578
1.A.4	Stationary Fuel Combustion—Other sectors	CO_2	69 557	77 715	0.115	0.072	0.489	0.651
1.A.2	Stationary Fuel Combustion—Manufacturing industries and construction	CO_2	61 630	48 872	0.102	0.064	0.591	0.715
3-A	Agriculture—Enteric Fermentation	CH_4	22 347	24 142	0.037	0.023	0.629	0.738
1-B-2-(b+c)	Fugitive Emissions—Natural Gas	CH_4	17 585	19 763	0.029	0.018	0.658	0.756
1-B-2-(a+c)	Fugitive Emissions—Oil	CH_4	16 804	18 609	0.028	0.017	0.686	0.774
1-A-3-e-ii	Fuel Combustion—Other Transport (Off Road)	CO_2	15 451	4 997	0.026	0.016	0.711	0.790
5-A-1	Waste—Solid Waste Disposal-Managed Waste Disposal Sites	CH_4	15 422	12 273	0.026	0.016	0.737	0.806
3-D-1	Agriculture—Direct N_2O Emissions from Managed Soils	N_2O	14 260	20 439	0.024	0.015	0.761	0.821
2-C-1	IPPU—Iron and Steel Production	CO_2	10 478	9 331	0.017	0.011	0.778	0.832
2-B-3	IPPU—Adipic Acid Production	N_2O	10 303	0	0.017	0.011	0.795	0.843
1-A-2-g	Fuel Combustion—Manufacturing Industries and Construction/Other/Off-Road Vehicles and Other Machinery	CO_2	9 104	14 212	0.015	0.009	0.810	0.852
1-A-4-c	Fuel Combustion—Agriculture Forestry Fishing/ Off-Road Vehicles and Other Machinery	CO_2	9 015	11 048	0.015	0.009	0.825	0.861
4-B-2	LULUCF—Land converted to Cropland	CO_2	8 947	2 538	NA	0.009	NA	0.871
2-C-3	IPPU—Aluminium Production	PFCs	7 558	591	0.013	0.008	0.838	0.879
1-A-3-a & 1-A-5-b	Fuel Combustion—Domestic Aviation	CO_2	7 101	7 921	0.012	0.007	0.849	0.886
1-A-3-e-i	Fuel Combustion—Pipeline Transport	CO_2	6 685	8 081	0.011	0.007	0.860	0.893
1-B-2-(b+c)	Fugitive Emissions—Natural Gas	CO_2	6 203	5 022	0.010	0.006	0.871	0.899
1-A-3-c	Fuel Combustion—Railways	CO_2	6 200	6 837	0.010	0.006	0.881	0.906
4-E-2	LULUCF—Land converted to Settlements	CO_2	5 856	5 784	NA	0.006	NA	0.912
2-D-1	IPPU—Non-Energy Products from Fuels and Solvent Use	CO_2	5 804	11 545	0.010	0.006	0.891	0.918
2-A-1	IPPU—Cement Production	CO_2	5 756	7 171	0.010	0.006	0.900	0.924
1-B-2-(a+c)	Fugitive Emissions—Oil	CO_2	5 507	10 628	0.009	0.006	0.909	0.930
1.A.4	Stationary Fuel Combustion—Other sectors	CH_4	4 684	3 196	0.008	0.005	0.917	0.935
4-E-2	LULUCF—Settlements remaining Settlements	CO_2	-3 924	-4 113	NA	0.004	NA	0.939
5-A-2	Waste—Solid Waste Disposal-Unmanaged Waste Disposal Sites	CH_4	3 847	3 399	0.006	0.004	0.924	0.943
4-D-2	LULUCF—Land converted to Wetlands	CO_2	3 829	211	NA	0.004	NA	0.947
1-A-3-b	Fuel Combustion—Road Transportation	N_2O	2 923	2 617	0.005	0.003	0.945	NA
1-A-3-d	Fuel Combustion—Domestic Navigation	CO_2	3 723	3 990	0.006	0.004	0.930	NA
1-B-1-a	Fugitive Emissions—Coal Mining and Handling	CH_4	2 824	1 331	0.005	0.003	0.950	NA
2-B-8	IPPU—Petrochemical and Carbon Black Production	CO_2	3 367	3 963	0.006	0.004	0.935	NA
3-B	Agriculture—Manure Management	N_2O	3 062	3 369	0.005	0.003	0.940	NA

Note: NA Not Applicable

Table A1–4 **2018 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 2018	without LULUCF	with LULUCF	without LULUCF	with LULUCF
1.A.1	Stationary Fuel Combustion—Energy Industries	CO_2	144 724	188 493	0.259	0.184	0.26	0.18
1-A-3-b	Fuel Combustion—Road Transportation	CO_2	80 541	150 831	0.207	0.148	0.47	0.33
4-A-1	LULUCF—Forest Land remaining Forest Land	CO_2	-202 468	-139 990	NA	0.137	NA	0.47
4-G	LULUCF—Harvested Wood Products (HWP)	CO_2	127 746	128 582	NA	0.126	NA	0.59
1.A.4	Stationary Fuel Combustion—Other sectors	CO_2	69 557	77 715	0.107	0.076	0.57	0.67
1.A.2	Stationary Fuel Combustion—Manufacturing industries and construction	CO_2	61 630	48 872	0.067	0.048	0.64	0.72
3-A	Agriculture—Enteric Fermentation	CH_4	22 347	24 142	0.033	0.024	0.67	0.74
3-D-1	Agriculture—Direct N_2O Emissions from Managed Soils	N_2O	14 260	20 439	0.028	0.020	0.70	0.76
1-B-2-(b+c)	Fugitive Emissions—Natural Gas	CH_4	17 585	19 763	0.027	0.019	0.73	0.78
1-B-2-(a+c)	Fugitive Emissions—Oil	CH_4	16 804	18 609	0.026	0.018	0.75	0.80
1-A-2-g	Fuel Combustion—Manufacturing Industries and Construction/Other/Off-Road Vehicles and Other Machinery	CO_2	9 104	14 212	0.020	0.014	0.77	0.81
2-F	IPPU—Product Uses as Substitutes for Ozone Depleting Substances	HFCs	0	12 545	0.017	0.012	0.79	0.83
5-A-1	Waste—Solid Waste Disposal-Managed Waste Disposal Sites	CH_4	15 422	12 273	0.017	0.012	0.81	0.84
2-D-1	IPPU—Non-Energy Products from Fuels and Solvent Use	CO_2	5 804	11 545	0.016	0.011	0.82	0.85
1-A-4-c	Fuel Combustion—Agriculture Forestry Fishing/ Off-Road Vehicles and Other Machinery	CO_2	9 015	11 048	0.015	0.011	0.84	0.86
1-B-2-(a+c)	Fugitive Emissions—Oil	CO_2	5 507	10 628	0.015	0.010	0.85	0.87
2-C-1	IPPU—Iron and Steel Production	CO_2	10 478	9 331	0.013	0.009	0.87	0.88
4-B-1	LULUCF—Cropland remaining Cropland	CO_2	-1 327	-8 844	NA	0.009	NA	0.89
1-A-3-e-i	Fuel Combustion—Pipeline Transport	CO_2	6 685	8 081	0.011	0.008	0.88	0.90
1-A-3-a & 1-A-5-b	Fuel Combustion—Domestic Aviation	CO_2	7 101	7 921	0.011	0.008	0.89	0.90
2-A-1	IPPU—Cement Production	CO_2	5 756	7 171	0.010	0.007	0.90	0.91
1-A-3-c	Fuel Combustion—Railways	CO_2	6 200	6 837	0.009	0.007	0.91	0.92
4-E-2	LULUCF—Land converted to Settlements	CO_2	5 856	5 784	NA	0.006	NA	0.92
1-B-2-(b+c)	Fugitive Emissions—Natural Gas	CO_2	6 203	5 022	0.007	0.005	0.91	0.93
1-A-3-e-ii	Fuel Combustion—Other Transport (Off Road)	CO_2	15 451	4 997	0.007	0.005	0.92	0.93
2-C-3	IPPU—Aluminium Production	CO_2	2 715	4 904	0.007	0.005	0.93	0.94
3-D-2	Agriculture—Indirect N_2O Emissions from Managed Soils	N_2O	2 790	4 229	0.006	0.004	0.93	0.94
4-E-2	LULUCF—Settlements remaining Settlements	CO_2	-3 924	-4 113	NA	0.004	NA	0.95
1-A-3-d	Fuel Combustion—Domestic Navigation	CO_2	3 723	3 990	0.005	0.004	0.94	0.95
2-B-8	IPPU—Petrochemical and Carbon Black Production	CO_2	3 367	3 963	0.005	0.004	0.94	NA
3-B	Agriculture—Manure Management	CH_4	2 453	3 846	0.005	0.004	0.95	NA

Note: NA Not Applicable

A1.2.2. Trend Assessment With and Without LULUCF

Table A1–5 and Table A1–6 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 of key categories. For example, a single LULUCF category, Forest Land Remaining Forest Land (CO_2), is ranked as the second highest contributor in the trend assessments.

The trend assessment with LULUCF identifies 33 key categories including six categories from the LULUCF sector, while the same analysis without LULUCF results in 28 key categories.

Table A1–5 **Key Categories by Trend Assessment with LULUCF**

Source Table	IPCC Category	Direct Greenhouse Gas	GHG Emission Estimates (kt CO_2 eq)		Trend Assessment	Contribution to Trend	Cumulative Total
			Base Year 1990	Current Year 2018			
1-A-3-b	Fuel Combustion—Road Transportation	CO_2	80 541	150 831	0.058	0.200	0.20
4-A-1	LULUCF—Forest Land remaining Forest Land	CO_2	-202 468	-139 990	0.027	0.094	0.29
1.A.2	Stationary Fuel Combustion—Manufacturing industries and construction	CO_2	61 630	48 872	0.025	0.086	0.38
4-G	LULUCF—Harvested Wood Products (HWP)	CO_2	127 746	128 582	0.023	0.079	0.46
1.A.1	Stationary Fuel Combustion—Energy Industries	CO_2	144 724	188 493	0.018	0.064	0.52
1-A-3-e-ii	Fuel Combustion—Other Transport (Off Road)	CO_2	15 451	4 997	0.014	0.047	0.57
2-F	IPPU—Product Uses as Substitutes for Ozone Depleting Substances	HFCs	0	12 545	0.013	0.045	0.62
2-B-3	IPPU—Adipic Acid Production	N_2O	10 303	0	0.013	0.044	0.66
2-C-3	IPPU—Aluminium Production	PFCs	7 558	591	0.009	0.030	0.69
4-B-2	LULUCF—Land converted to Cropland	CO_2	8 947	2 538	0.008	0.029	0.72
4-B-1	LULUCF—Cropland remaining Cropland	CO_2	-1 327	-8 844	0.008	0.028	0.75
5-A-1	Waste—Solid Waste Disposal-Managed Waste Disposal Sites	CH_4	15 422	12 273	0.006	0.021	0.77
2-D-1	IPPU—Non-Energy Products from Fuels and Solvent Use	CO_2	5 804	11 545	0.005	0.017	0.78
1.A.4	Stationary Fuel Combustion—Other sectors	CO_2	69 557	77 715	0.005	0.016	0.80
4-D-2	LULUCF—Land converted to Wetlands	CO_2	3 829	211	0.004	0.015	0.81
1-B-2-(a+c)	Fugitive Emissions—Oil	CO_2	5 507	10 628	0.004	0.015	0.83
3-D-1	Agriculture—Direct N_2O Emissions from Managed Soils	N_2O	14 260	20 439	0.004	0.013	0.84
1-A-2-g	Fuel Combustion—Manufacturing Industries and Construction/Other/Off-Road Vehicles and Other Machinery	CO_2	9 104	14 212	0.004	0.012	0.85
2-C-4	IPPU—Magnesium Production	SF_6	2 738	0	0.003	0.012	0.87
2-C-1	IPPU—Iron and Steel Production	CO_2	10 478	9 331	0.003	0.011	0.88
1.A.4	Stationary Fuel Combustion—Other sectors	CH_4	4 684	3 196	0.002	0.008	0.89
1-B-2-(b+c)	Fugitive Emissions—Natural Gas	CO_2	6 203	5 022	0.002	0.008	0.89
3-A	Agriculture—Enteric Fermentation	CH_4	22 347	24 142	0.002	0.008	0.90
1-B-1-a	Fugitive Emissions—Coal Mining and Handling	CH_4	2 824	1 331	0.002	0.007	0.91
2-C-3	IPPU—Aluminium Production	CO_2	2 715	4 904	0.002	0.006	0.91
1-B-2-(a+c)	Fugitive Emissions—Oil	CH_4	16 804	18 609	0.001	0.004	0.92
3-I	Agriculture—Other Carbon-Containing Fertilizers	CO_2	1 191	2 605	0.001	0.004	0.92
1-A-3-e-ii	Fuel Combustion—Other Transport (Off Road)	CH_4	1 235	307	0.001	0.004	0.93
2-B-9-a	IPPU—Fluorochemical Production	HFCs	971	0	0.001	0.004	0.93
5-A-2	Waste—Solid Waste Disposal-Unmanaged Waste Disposal Sites	CH_4	3 847	3 399	0.001	0.004	0.94
4-E-2	LULUCF—Land converted to Settlements	CO_2	5 856	5 784	0.001	0.004	0.94
1-A-4-a	Fuel Combustion—Commercial Institutional/Off-Road Vehicles and Other Machinery	CO_2	1 492	2 805	0.001	0.004	0.94
1-B-2-(b+c)	Fugitive Emissions—Natural Gas	CH_4	17 585	19 763	0.001	0.004	0.95

Table A1–6 **Key Categories by Trend Assessment without LULUCF**

Source Table	IPCC Category	Direct Greenhouse Gas	GHG Emission Estimates (kt CO_2 eq)		Trend Assessment	Contribution to Trend	Cumulative Total
			Base Year 1990	Current Year 2018			
1.A.1	Stationary Fuel Combustion—Energy Industries	CO_2	144 724	188 493	0.022	0.065	0.51
1.A.2	Stationary Fuel Combustion—Manufacturing industries and construction	CO_2	61 630	48 872	0.043	0.124	0.38
1.A.4	Stationary Fuel Combustion—Other sectors	CO_2	69 557	77 715	0.011	0.031	0.71
1.A.4	Stationary Fuel Combustion—Other sectors	CH_4	4 684	3 196	0.004	0.012	0.88
1-A-2-g	Fuel Combustion—Manufacturing Industries and Construction/Other/Off-Road Vehicles and Other Machinery	CO_2	9 104	14 212	0.005	0.015	0.83
1-A-3-b	Fuel Combustion—Road Transportation	CO_2	80 541	150 831	0.089	0.258	0.26
1-A-3-b	Fuel Combustion—Road Transportation	N_2O	2 923	2 617	0.002	0.004	0.95
1-A-3-e-ii	Fuel Combustion—Other Transport (Off Road)	CO_2	15 451	4 997	0.023	0.066	0.45
1-A-3-e-ii	Fuel Combustion—Other Transport (Off Road)	CH_4	1 235	307	0.002	0.006	0.93
1-A-4-a	Fuel Combustion—Commercial Institutional/Off-Road Vehicles and Other Machinery	CO_2	1 492	2 805	0.002	0.005	0.94
1-B-1-a	Fugitive Emissions—Coal Mining and Handling	CH_4	2 824	1 331	0.003	0.010	0.89
1-B-2-(a+c)	Fugitive Emissions—Oil	CO_2	5 507	10 628	0.007	0.019	0.78
1-B-2-(a+c)	Fugitive Emissions—Oil	CH_4	16 804	18 609	0.003	0.008	0.90
1-B-2-(b+c)	Fugitive Emissions—Natural Gas	CO_2	6 203	5 022	0.004	0.012	0.87
1-B-2-(b+c)	Fugitive Emissions—Natural Gas	CH_4	17 585	19 763	0.002	0.007	0.91
2-B-3	IPPU—Adipic Acid Production	N_2O	10 303	0	0.021	0.060	0.63
2-B-9-a	IPPU—Fluorochemical Production	HFCs	971	0	0.002	0.006	0.93
2-C-1	IPPU—Iron and Steel Production	CO_2	10 478	9 331	0.006	0.016	0.80
2-C-3	IPPU—Aluminium Production	CO_2	2 715	4 904	0.003	0.008	0.91
2-C-3	IPPU—Aluminium Production	PFCs	7 558	591	0.014	0.041	0.68
2-C-4	IPPU—Magnesium Production	SF_6	2 738	0	0.005	0.016	0.81
2-D-1	IPPU—Non-Energy Products from Fuels and Solvent Use	CO_2	5 804	11 545	0.008	0.022	0.76
2-F	IPPU—Product Uses as Substitutes for Ozone Depleting Substances	HFCs	0	12 545	0.021	0.061	0.57
3-A	Agriculture—Enteric Fermentation	CH_4	22 347	24 142	0.005	0.014	0.86
3-D-1	Agriculture—Direct N_2O Emissions from Managed Soils	N_2O	14 260	20 439	0.005	0.015	0.84
3-I	Agriculture—Other Carbon-Containing Fertilizers	CO_2	1 191	2 605	0.002	0.006	0.94
5-A-1	Waste—Solid Waste Disposal-Managed Waste Disposal Sites	CH_4	15 422	12 273	0.011	0.031	0.74
5-A-2	Waste—Solid Waste Disposal-Unmanaged Waste Disposal Sites	CH_4	3 847	3 399	0.002	0.006	0.92
2-B-1	IPPU—Ammonia Production	CO_2	2 773	2 437	0.002	0.004	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 the latest year. 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 2018 Greenhouse Gas Emissions and Removals

Separate analyses were conducted for the inventory as a whole with and without LULUCF. The 2018 national emission estimate (not including the LULUCF sector) of 729 Mt CO_2 eq lies within an uncertainty range of 712 Mt CO_2 eq to 747 Mt CO_2 eq (±2%) (Table A2–1). The Energy sector has the lowest uncertainty, at ±2%, while the Waste sector has the highest uncertainty, at ±46%. The IPPU sector and the Agriculture sector have uncertainties of ±12, and ±17%, respectively. The five emission source categories that made the largest contributions to uncertainty at the national level when LULUCF is not included were:

a. Agriculture—Direct Agriculture Soils, N_2O;

b. Waste—Solid Waste Disposal—Unmanaged Waste Disposal Sites—Wood Waste Landfills, CH_4;

c. IPPU—Product Uses as Substitutes for Ozone Depleting Substances, HFCs;

d. Agriculture—Enteric Fermentation, CH_4; and

e. Waste—Solid Waste Disposal—Managed Waste Disposal Sites, CH_4.

The 2018 national emission estimate, including LULUCF emissions and removals, of 716 Mt CO_2 eq, lies within an uncertainty range of 654 Mt CO_2 eq to 779 Mt CO_2 eq (±9%) (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. Agriculture—Direct Agriculture Soils, N_2O;

d. Waste—Solid Waste Disposal—Unmanaged Waste Disposal Sites—Wood waste Landfills, CH_4; and

e. IPPU—Product Uses as Substitutes for Ozone Depleting Substances, HFCs.

The calculation of trend uncertainty was performed with and without the LULUCF sector. The trend uncertainty, excluding LULUCF, was found to be 1%. Therefore, the total increase in emissions since 1990 of 126 Mt CO_2 eq (+21%) falls within an uncertainty range of a minimum of +124 Mt CO_2 eq to a maximum of +128 Mt CO_2 eq. The trend uncertainty, including LULUCF, was found to be 9%.

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.

Uncertainty estimation of National emissions is the topic of a working paper to be released in 2020 (Laferrière et al. 2020). This study compares actual Tier 1 uncertainty estimates with a more general approach, namely Monte Carlo simulations (MCS). The comparison highlights:

1. The impact on emissions uncertainty related with asymmetrical probability distribution function (PDF) and PDF other than normal.
2. The effect of incorporating emission correlation across IPCC source category. Often, it is difficult to justify the Tier 1 assumption that emission factors are uncorrelated across categories. The paper shows the importance of its recognition and compares trend uncertainty and category contribution to uncertainty.
3. The possibility to factor in dual uncertainty levels for the activity variables. For example, categories comprised of multiple activity datasets may individually have high uncertainty values but when aggregated the final result may have a lower uncertainty value.

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	2018 Year Emissions	Activity Data Uncertainty[a]	Emission Factor Uncertainty[a]	Combined Uncertainty	Combined uncertainty as % of 2018 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		**603 222**	**729 348**	**0.60**	**2.40**	**2.4**	**2.4**	**Assumption: Emission factors are fully correlated between years**	**Assumption: Activity data is fully correlated between years**	**1.36**
1.A.1.a	Fuel Combustion—Public Electricity and Heat Production	CO_2	93 982	69 299	0.48	4.70	4.70	0.00	0.35	0.00	0.00
1.A.1.a	Fuel Combustion—Public Electricity and Heat Production	CH_4	44	153	0.64	26.00	26.00	0.00	0.00	0.00	0.00
1.A.1.a	Fuel Combustion—Public Electricity and Heat Production	N_2O	492	440	0.48	150.00	150.00	0.00	0.04	0.00	0.00
1.A.1.b	Fuel Combustion—Petroleum Refining	CO_2	17 300	15 707	1.20	11.00	11.00	0.00	0.09	0.00	0.00
1.A.1.b	Fuel Combustion—Petroleum Refining	CH_4	11	8	0.92	170.00	170.00	0.00	0.00	0.00	0.00
1.A.1.b	Fuel Combustion—Petroleum Refining	N_2O	49	31	0.61	250.00	250.00	0.00	0.01	0.00	0.00
1.A.1.c	Fuel Combustion—Manufacture of Solid Fuels and Other Energy Industries	CO_2	30 791	49 977	0.98	5.50	5.60	0.00	0.12	0.00	0.00
1.A.1.c	Fuel Combustion—Manufacture of Solid Fuels and Other Energy Industries	CH_4	1 558	2 507	1.20	140.00	140.00	0.00	0.14	0.00	0.00
1.A.1.c	Fuel Combustion—Manufacture of Solid Fuels and Other Energy Industries	N_2O	195	287	1.20	540.00	540.00	0.00	0.05	0.00	0.00
1.A.2	Fuel Combustion—Manufacturing Industries and Construction	CO_2	64 281	102 548	2.70	3.80	4.10	0.00	0.16	0.02	0.00
1.A.2	Fuel Combustion—Manufacturing Industries and Construction	CH_4	67	94	2.70	25.00	25.00	0.00	0.00	0.00	0.00
1.A.2	Fuel Combustion—Manufacturing Industries and Construction	N_2O	496	855	2.70	41.00	41.00	0.00	0.02	0.00	0.00
1.A.3.a	Fuel Combustion—Domestic Aviation	CO_2	6 929	7 828	0.98	0.50	1.10	0.00	0.00	0.00	0.00
1.A.3.a	Fuel Combustion—Domestic Aviation	CH_4	11	6	0.71	470.00	470.00	0.00	0.01	0.00	0.00
1.A.3.a	Fuel Combustion—Domestic Aviation	N_2O	65	67	0.95	850.00	850.00	0.00	0.02	0.00	0.00
1.A.3.b	Fuel Combustion—Road Transportation (Gas, Diesel, Natural Gas, Propane)	CO_2	80 541	150 831	1.20	0.13	1.20	0.00	0.01	0.02	0.00
1.A.3.b	Fuel Combustion—Road Transportation (Gas, Diesel, Natural Gas, Propane)	CH_4	308	246	1.00	110.00	110.00	0.00	0.02	0.00	0.00
1.A.3.b	Fuel Combustion—Road Transportation (Gas, Diesel, Natural Gas, Propane)	N_2O	2 923	2 617	1.30	38.00	38.00	0.00	0.06	0.00	0.00
1.A.3.c	Fuel Combustion—Railways	CO_2	6 200	6 837	3.00	0.28	3.00	0.00	0.00	0.00	0.00
1.A.3.c	Fuel Combustion—Railways	CH_4	9	10	3.20	150.00	150.00	0.00	0.00	0.00	0.00
1.A.3.c	Fuel Combustion—Railways	N_2O	709	800	3.20	200.00	200.00	0.00	0.02	0.00	0.00
1.A.3.d	Fuel Combustion—Domestic Navigation	CO_2	3 723	3 990	2.70	0.38	2.80	0.00	0.00	0.00	0.00
1.A.3.d	Fuel Combustion—Domestic Navigation	CH_4	9	10	2.90	45.00	45.00	0.00	0.00	0.00	0.00
1.A.3.d	Fuel Combustion—Domestic Navigation	N_2O	29	32	2.90	130.00	130.00	0.00	0.00	0.00	0.00
1.A.2-3-4[b]	Fuel Combustion—Off-Road	CO_2	35 299	34 238	1.10	0.11	1.10	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	2018 Year Emissions	Activity Data Uncertainty[a]	Emission Factor Uncertainty[a]	Combined Uncertainty	Combined uncertainty as % of 2018 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.2-3-4[b]	Fuel Combustion—Off-Road	CH_4	1 288	529	1.10	11.00	11.00	0.00	0.02	0.00	0.00
1.A.2-3-4[b]	Fuel Combustion—Off-Road	N_2O	118	470	1.80	71.00	71.00	0.00	0.04	0.00	0.00
1.A.5.b.	Fuel Combustion—Domestic Aviation/ Military	CO_2	172	93	0.95	0.54	1.10	0.00	0.00	0.00	0.00
1.A.5.b.	Fuel Combustion—Domestic Aviation/ Military	CH_4	0	0	0.73	370.00	370.00	0.00	0.00	0.00	0.00
1.A.5.b.	Fuel Combustion—Domestic Aviation/ Military	N_2O	1	1	0.85	770.00	770.00	0.00	0.00	0.00	0.00
1.A.3.e	Fuel Combustion—Pipeline Transport	CO_2	6 685	8 081	1.00	1.30	1.60	0.00	0.00	0.00	0.00
1.A.3.e	Fuel Combustion—Pipeline Transport	CH_4	167	201	1.00	15.00	15.00	0.00	0.00	0.00	0.00
1.A.3.e	Fuel Combustion—Pipeline Transport	N_2O	53	63	1.00	490.00	490.00	0.00	0.00	0.00	0.00
1.A.4	Fuel Combustion—Other Sectors	CO_2	69 557	77 549	2.00	1.60	2.20	0.00	0.02	0.00	0.00
1.A.4	Fuel Combustion—Other Sectors	CH_4	4 684	3 196	5.70	15.00	15.00	0.00	0.06	0.00	0.00
1.A.4	Fuel Combustion—Other Sectors	N_2O	958	930	4.80	32.00	32.00	0.00	0.01	0.00	0.00
1.B.1.a	Fugitive Sources—Coal Mining and Handling	CH_4	2 824	1 331	-	57.00	57.00	0.00	0.20	0.00	0.00
1.B.2.(a+b)	Fugitive Sources—Oil & Gas	CO_2	121	672	-	27.00	27.00	0.00	0.02	0.00	0.00
1.B.2.(a+b)	Fugitive Sources—Oil & Gas	CH_4	17 983	17 080	-	22.00	22.00	0.00	0.17	0.00	0.00
1.B.2.(a+b)	Fugitive Sources—Oil & Gas	N_2O	30	105	-	310.00	310.00	0.00	0.03	0.00	0.00
1.B.2.c	Fugitive Sources—Venting	CO_2	6 995	9 028	-	22.00	22.00	0.00	0.02	0.00	0.00
1.B.2.c	Fugitive Sources—Flaring	CO_2	4 594	5 949	-	10.00	10.00	0.00	0.01	0.00	0.00
1.B.2.c	Fugitive Sources—Venting & Flaring	CH_4	16 406	21 292	-	11.00	11.00	0.00	0.03	0.00	0.00
1.B.2.c	Fugitive Sources—Venting & Flaring	N_2O	2	8	-	75.00	75.00	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	7 171	-	12.00	12.00	0.00	0.00	0.00	0.00
2.A.2	IPPU—Lime Production	CO_2	1 795	1 357	5.00	2.00	15.00	0.00	0.00	0.00	0.00
2.A.3	IPPU—Glass Production	CO_2	166	48	-	10.00	10.00	0.00	0.00	0.00	0.00
2.A.4.b	IPPU—Other Uses of Soda Ash	CO_2	100	52	-	6.30	6.30	0.00	0.00	0.00	0.00
2.A.4.c	IPPU—Other (Magnesite Use)	CO_2	147	116	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	108	-	30.00	30.00	0.00	0.02	0.00	0.00
2.B.1	IPPU—Ammonia Production	CO_2	2 773	2 437	-	9.30	9.30	0.00	0.01	0.00	0.00
2.B.2	IPPU—Nitric Acid Production	N_2O	973	1 098	-	2.20	2.20	0.00	0.00	0.00	0.00
2.B.3	IPPU—Adipic Acid Production	N_2O	10 303	0	-	11.00	11.00	0.00	0.23	0.00	0.00
2.B.7	IPPU—Soda Ash Production	CO_2	-	0	-	14.00	14.00	0.00	0.00	0.00	0.00
2.B.8	IPPU—Petrochemical and Carbon Black Production	CO_2	3 367	3 963	-	2.80	2.80	0.00	0.00	0.00	0.00
2.B.8	IPPU—Petrochemical and Carbon Black Production	CH_4	143	147	-	16.00	16.00	0.00	0.00	0.00	0.00
2.B.8	IPPU—Petrochemical and Carbon Black Production	N_2O	15	13	-	9.40	9.40	0.00	0.10	0.00	0.00
2.B.9	IPPU—Fluorochemical Production	HFCs	971	0	-	50.00	50.00	0.00	0.03	0.00	0.00
2.C.1	IPPU—Iron and Steel Production	CO_2	10 478	9 331	-	5.40	5.40	0.00	0.00	0.00	0.00
2.C.1	IPPU—Iron and Steel Production	CH_4	2	2	1.00	410.00	410.00	0.00	0.02	0.00	0.00

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

	IPCC Source Category	Gas	Base Year Emissions	2018 Year Emissions	Activity Data Uncertainty[a]	Emission Factor Uncertainty[a]	Combined Uncertainty	Combined uncertainty as % of 2018 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.3	IPPU—Aluminium Production	CO_2	2 715	4 904	-	7.10	7.10	0.00	0.13	0.00	0.00
2.C.3	IPPU—Aluminium Production	PFCs	7 558	591	-	9.10	9.10	0.00	0.00	0.00	0.00
2.C.3	IPPU—Aluminium Production	SF_6	56	13	-	3.30	3.30	0.00	0.04	0.00	0.00
2.C.4	IPPU—Magnesium Production	SF_6	2 738	0	-	6.80	6.80	0.00	0.00	0.00	0.00
2.C.7	IPPU—Other (Magnesium Casting)	SF_6	225	134	-	6.80	6.80	0.00	0.15	0.00	0.00
2.D.1	IPPU—Non-Energy Products from Fuels and Solvent Use	CO_2	5 804	11 545	-	20.00	20.00	0.00	0.00	0.00	0.00
2.E.1	IPPU—Integrated Circuit or Semiconductor	PFCs	-	2	-	50.00	50.00	0.00	0.00	0.00	0.00
2.E.1	IPPU—Integrated Circuit or Semiconductor	SF_6	4	2	-	19.00	19.00	0.00	0.00	0.00	0.00
2.E.1	IPPU—Integrated Circuit or Semiconductor	NF_3	0	0	-	45.00	45.00	0.00	0.00	0.00	0.00
2.E.5	IPPU—Other	PFCs	-	0	-	300.00	300.00	0.00	1.04	0.00	0.00
2.F	IPPU—Product Uses as Substitutes for Ozone Depleting Substances	HFCs	-	12 545	-	50.00	50.00	0.01	0.00	0.00	0.01
2.F	IPPU—Product Uses as Substitutes for Ozone Depleting Substances	PFCs	-	2	-	36.00	36.00	0.00	0.00	0.00	0.00
2.G.1	IPPU—Electrical Equipment	SF_6	202	161	-	23.00	23.00	0.00	0.01	0.00	0.00
2.G.2	IPPU—SF_6 and PFCs from Other Product Use	PFCs	146	438	-	32.00	32.00	0.00	0.00	0.00	0.00
2.G.3.a	IPPU—Other (Medical Applications of N_2O)	N_2O	26	80	-	23.00	23.00	0.00	0.00	0.00	0.00
2.G.3.b	IPPU—Other (Uses of N_2O for Propellant)	N_2O	-	32	-	23.00	23.00	0.00	0.00	0.00	0.00
2.G.4	IPPU—Other (Use of Urea in SCR Vehicles)	CO_2	-	26	-	51.00	51.00	0.00	0.07	0.00	0.00
	Agriculture—Total CH_4	CH_4	24 970	28 025	-	19.00	20.00	0.01	0.00	0.00	0.00
3.A	Agriculture—Enteric Fermentation	CH_4	22 347	24 142	-	-	22.00	0.01	0.00	0.00	0.00
3.B.1	Agriculture—Manure Management	CH_4	2 453	3 846	-	-	32.00	0.00	0.00	0.00	0.00
	Agriculture—Total N_2O	N_2O	20 778	28 751	7.90	29.00	29.00	0.01	0.17	0.00	0.00
3.B.2	Agriculture—Manure Management Direct Emissions	N_2O	3 062	3 369	1.40	44.00	51.00	0.00	0.02	0.00	0.00
3.B.2	Agriculture—Manure Management Indirect Emissions	N_2O	613	703	1.40	100.00	100.00	0.00	0.01	0.00	0.00
3.D.1	Agriculture—Direct Agriculture Soils	N_2O	14 260	20 439	7.90	27.00	34.00	0.01	0.15	0.00	0.00
3.D.2	Agriculture—Indirect Agrictulure Soils	N_2O	2 790	4 229	7.90	75.00	100.00	0.00	0.11	0.00	0.00
3.F	Agriculture—Field Burning of Agricultural Residues	CH_4	170	37	50.00	40.00	64.00	0.00	0.01	0.00	0.00
3.F	Agriculture—Field Burning of Agricultural Residues	N_2O	53	12	50.00	48.00	69.00	0.00	0.00	0.00	0.00
	Agriculture—Total CO_2	CO_2	1 191	2 605	4.00	42.00	44.00	0.00	0.08	0.00	0.00
3.G.1	Agriculture—Limestone $CaCO_3$	CO_2	385	180	30.00	50.00	58.00	0.00	0.02	0.00	0.00
3.H	Agriculture—Urea Application	CO_2	754	2 177	15.00	50.00	52.00	0.00	0.10	0.00	0.00
3.I	Agriculture—Other Carbon-Containing Fertilizers	CO_2	52	249	15.00	50.00	52.00	0.00	0.02	0.00	0.00
5.A.1	Solid Waste Disposal—Managed Waste Disposal Sites	CH_4	15 422	12 273	-	40.00	40.00	0.00	0.42	0.00	0.00

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

	IPCC Source Category	Gas	Base Year Emissions	2018 Year Emissions	Activity Data Uncertainty[a]	Emission Factor Uncertainty[a]	Combined Uncertainty	Combined uncertainty as % of 2018 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.2	Solid Waste Disposal—Unmanaged Waste Disposal Sites—Wood Waste Landfills	CH_4	3 847	3 399	-	190.00	190.00	0.01	0.39	0.00	0.00
5.B.1	Biological Treatment of Solid Waste—Composting	CH_4	32	260	110.00	110.00	170.00	0.00	0.04	0.00	0.00
5.B.1	Biological Treatment of Solid Waste—Composting	N_2O	23	186	110.00	110.00	170.00	0.00	0.03	0.00	0.00
5.C.1.1.b.iii	Incineration and Open Burning of Waste—Waste Incineration—Sewage Sludge	CH_4	0	0	-	60.00	60.00	0.00	0.00	0.00	0.00
5.C.1.1.b.iii	Incineration and Open Burning of Waste—Waste Incineration—Sewage Sludge	N_2O	38	72	5.00	110.00	110.00	0.00	0.00	0.00	0.00
5.C.1.2.a	Incineration and Open Burning of Waste—Waste Incineration—Municipal Solid Waste	CO_2	41	8	-	85.00	85.00	0.00	0.01	0.00	0.00
5.C.1.2.a	Incineration and Open Burning of Waste—Waste Incineration—Municipal Solid Waste	CH_4	128	1	-	85.00	85.00	0.00	0.02	0.00	0.00
5.C.1.2.a	Incineration and Open Burning of Waste—Waste Incineration—Municipal Solid Waste	N_2O	2	0	-	85.00	85.00	0.00	0.00	0.00	0.00
5.C.1.2.b.ii	Incineration and Open Burning of Waste—Waste Incineration—Hazardous Waste	CO_2	166	197	5.00	94.00	94.00	0.00	0.00	0.00	0.00
5.C.1.2.b.ii	Incineration and Open Burning of Waste—Waste Incineration—Hazardous Waste	CH_4	0	1	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—Hazardous Waste	N_2O	95	113	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—Clinical Waste	CO_2	1	2	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—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—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	571	656	-	45.00	45.00	0.00	0.00	0.00	0.00
5.D	Wastewater Treatment and Discharge	N_2O	345	487	-	65.00	65.00	0.00	0.01	0.00	0.00

Notes:

a. 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.

b. 1.A.2.g.vii, 1.A.3.e.ii, 1.A.4.a.ii., 1.A.4.b.ii, 1.A.4.c.ii

Table A2–2 **Uncertainty Assessment Level and Trend with LULUCF**

	IPCC Source Category	Gas	Base Year Emissions	2018 Year Emissions	Activity Data Uncertainty[a]	Emission Factor Uncertainty[a]	Combined Uncertainty	Combined uncertainty as % of 2018 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		**543 595**	**716 488**	**0.61**	**8.80**	**8.8**	**8.7**	**Assumption: Emission factors are fully correlated between years**	**Assumption: Activity data is fully correlated between years**	**9.15**
1.A.1.a	Fuel Combustion—Public Electricity and Heat Production	CO_2	93 982	69 299	0.48	4.70	4.70	0.00	0.47	0.00	0.00
1.A.1.a	Fuel Combustion—Public Electricity and Heat Production	CH_4	44	153	0.64	26.00	26.00	0.00	0.00	0.00	0.00
1.A.1.a	Fuel Combustion—Public Electricity and Heat Production	N_2O	492	440	0.48	150.00	150.00	0.00	0.06	0.00	0.00
1.A.1.b	Fuel Combustion—Petroleum Refining	CO_2	17 300	15 707	1.20	11.00	11.00	0.00	0.14	0.00	0.00
1.A.1.b	Fuel Combustion—Petroleum Refining	CH_4	11	8	0.92	170.00	170.00	0.00	0.00	0.00	0.00
1.A.1.b	Fuel Combustion—Petroleum Refining	N_2O	49	31	0.61	250.00	250.00	0.00	0.02	0.00	0.00
1.A.1.c	Fuel Combustion—Manufacture of Solid Fuels and Other Energy Industries	CO_2	30 791	49 977	0.98	5.50	5.60	0.00	0.10	0.00	0.00
1.A.1.c	Fuel Combustion—Manufacture of Solid Fuels and Other Energy Industries	CH_4	1 558	2 507	1.20	140.00	140.00	0.00	0.11	0.00	0.00
1.A.1.c	Fuel Combustion—Manufacture of Solid Fuels and Other Energy Industries	N_2O	195	287	1.20	540.00	540.00	0.00	0.03	0.00	0.00
1.A.2	Fuel Combustion—Manufacturing Industries and Construction	CO_2	64 281	102 548	2.70	3.80	4.10	0.00	0.13	0.01	0.00
1.A.2	Fuel Combustion—Manufacturing Industries and Construction	CH_4	67	94	2.70	25.00	25.00	0.00	0.00	0.00	0.00
1.A.2	Fuel Combustion—Manufacturing Industries and Construction	N_2O	496	855	2.70	41.00	41.00	0.00	0.02	0.00	0.00
1.A.3.a	Fuel Combustion—Domestic Aviation	CO_2	6 929	7 828	0.98	0.50	1.10	0.00	0.00	0.00	0.00
1.A.3.a	Fuel Combustion—Domestic Aviation	CH_4	11	6	0.71	470.00	470.00	0.00	0.01	0.00	0.00
1.A.3.a	Fuel Combustion—Domestic Aviation	N_2O	65	67	0.95	850.00	850.00	0.00	0.03	0.00	0.00
1.A.3.b	Fuel Combustion—Road Transportation (Gas, Diesel, Natural Gas, Propane)	CO_2	80 541	150 831	1.20	0.13	1.20	0.00	0.01	0.02	0.00
1.A.3.b	Fuel Combustion—Road Transportation (Gas, Diesel, Natural Gas, Propane)	CH_4	308	246	1.00	110.00	110.00	0.00	0.03	0.00	0.00
1.A.3.b	Fuel Combustion—Road Transportation (Gas, Diesel, Natural Gas, Propane)	N_2O	2 923	2 617	1.30	38.00	38.00	0.00	0.09	0.00	0.00
1.A.3.c	Fuel Combustion—Railways	CO_2	6 200	6 837	3.00	0.28	3.00	0.00	0.00	0.00	0.00
1.A.3.c	Fuel Combustion—Railways	CH_4	9	10	3.20	150.00	150.00	0.00	0.00	0.00	0.00
1.A.3.c	Fuel Combustion—Railways	N_2O	709	800	3.20	200.00	200.00	0.00	0.05	0.00	0.00
1.A.3.d	Fuel Combustion—Domestic Navigation	CO_2	3 723	3 990	2.70	0.38	2.80	0.00	0.00	0.00	0.00
1.A.3.d	Fuel Combustion—Domestic Navigation	CH_4	9	10	2.90	45.00	45.00	0.00	0.00	0.00	0.00
1.A.3.d	Fuel Combustion—Domestic Navigation	N_2O	29	32	2.90	130.00	130.00	0.00	0.00	0.00	0.00
1.A.2-3-4[b]	Fuel Combustion—Off-Road	CO_2	35 299	34 238	1.10	0.11	1.10	0.00	0.00	0.00	0.00

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

	IPCC Source Category	Gas	Base Year Emissions	2018 Year Emissions	Activity Data Uncertainty[a]	Emission Factor Uncertainty[a]	Combined Uncertainty	Combined uncertainty as % of 2018 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.2-3-4[b]	Fuel Combustion—Off-Road	CH_4	1 288	529	1.10	11.00	11.00	0.00	0.02	0.00	0.00
1.A.2-3-4[b]	Fuel Combustion—Off-Road	N_2O	118	470	1.80	71.00	71.00	0.00	0.04	0.00	0.00
1.A.5.b.	Fuel Combustion—Domestic Aviation/ Military	CO_2	172	93	0.95	0.54	1.10	0.00	0.00	0.00	0.00
1.A.5.b.	Fuel Combustion—Domestic Aviation/ Military	CH_4	0	0	0.73	370.00	370.00	0.00	0.00	0.00	0.00
1.A.5.b.	Fuel Combustion—Domestic Aviation/ Military	N_2O	1	1	0.85	770.00	770.00	0.00	0.00	0.00	0.00
1.A.3.e	Fuel Combustion—Pipeline Transport	CO_2	6 685	8 081	1.00	1.30	1.60	0.00	0.00	0.00	0.00
1.A.3.e	Fuel Combustion—Pipeline Transport	CH_4	167	201	1.00	15.00	15.00	0.00	0.00	0.00	0.00
1.A.3.e	Fuel Combustion—Pipeline Transport	N_2O	53	63	1.00	490.00	490.00	0.00	0.01	0.00	0.00
1.A.4	Fuel Combustion—Other Sectors	CO_2	69 557	77 549	2.00	1.60	2.20	0.00	0.04	0.01	0.00
1.A.4	Fuel Combustion—Other Sectors	CH_4	4 684	3 196	5.70	15.00	15.00	0.00	0.08	0.00	0.00
1.A.4	Fuel Combustion—Other Sectors	N_2O	958	930	4.80	32.00	32.00	0.00	0.02	0.00	0.00
1.B.1.a	Fugitive Sources—Coal Mining and Handling	CH_4	2 824	1 331	-	57.00	57.00	0.00	0.25	0.00	0.00
1.B.2.(a+b)	Fugitive Sources—Oil & Gas	CO_2	121	672	-	27.00	27.00	0.00	0.03	0.00	0.00
1.B.2.(a+b)	Fugitive Sources—Oil & Gas	CH_4	17 983	17 080	-	22.00	22.00	0.00	0.27	0.00	0.00
1.B.2.(a+b)	Fugitive Sources—Oil & Gas	N_2O	30	105	-	310.00	310.00	0.00	0.04	0.00	0.00
1.B.2.c	Fugitive Sources—Venting	CO_2	6 995	9 028	-	22.00	22.00	0.00	0.01	0.00	0.00
1.B.2.c	Fugitive Sources—Flaring	CO_2	4 594	5 949	-	10.00	10.00	0.00	0.00	0.00	0.00
1.B.2.c	Fugitive Sources—Venting & Flaring	CH_4	16 406	21 292	-	11.00	11.00	0.00	0.01	0.00	0.00
1.B.2.c	Fugitive Sources—Venting & Flaring	N_2O	2	8	-	75.00	75.00	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	7 171	-	12.00	12.00	0.00	0.01	0.00	0.00
2.A.2	IPPU—Lime Production	CO_2	1 795	1 357	5.00	2.00	15.00	0.00	0.00	0.00	0.00
2.A.3	IPPU—Glass Production	CO_2	166	48	-	10.00	10.00	0.00	0.00	0.00	0.00
2.A.4.b	IPPU—Other Uses of Soda Ash	CO_2	100	52	-	6.30	6.30	0.00	0.00	0.00	0.00
2.A.4.c	IPPU—Other (Magnesite Use)	CO_2	147	116	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	108	-	30.00	30.00	0.00	0.03	0.00	0.00
2.B.1	IPPU—Ammonia Production	CO_2	2 773	2 437	-	9.30	9.30	0.00	0.02	0.00	0.00
2.B.2	IPPU—Nitric Acid Production	N_2O	973	1 098	-	2.20	2.20	0.00	0.00	0.00	0.00
2.B.3	IPPU—Adipic Acid Production	N_2O	10 303	0	-	11.00	11.00	0.00	0.27	0.00	0.00
2.B.7	IPPU—Soda Ash Production	CO_2	-	0	-	14.00	14.00	0.00	0.00	0.00	0.00
2.B.8	IPPU—Petrochemical and Carbon Black Production	CO_2	3 367	3 963	-	2.80	2.80	0.00	0.00	0.00	0.00
2.B.8	IPPU—Petrochemical and Carbon Black Production	CH_4	143	147	-	16.00	16.00	0.00	0.00	0.00	0.00
2.B.8	IPPU—Petrochemical and Carbon Black Production	N_2O	15	13	-	9.40	9.40	0.00	0.12	0.00	0.00
2.B.9	IPPU—Fluorochemical Production	HFCs	971	0	-	50.00	50.00	0.00	0.04	0.00	0.00
2.C.1	IPPU—Iron and Steel Production	CO_2	10 478	9 331	-	5.40	5.40	0.00	0.00	0.00	0.00
2.C.1	IPPU—Iron and Steel Production	CH_4	2	2	1.00	410.00	410.00	0.00	0.02	0.00	0.00
2.C.3	IPPU—Aluminium Production	CO_2	2 715	4 904	-	7.10	7.10	0.00	0.16	0.00	0.00
2.C.3	IPPU—Aluminium Production	PFCs	7 558	591	-	9.10	9.10	0.00	0.00	0.00	0.00

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

	IPCC Source Category	Gas	Base Year Emissions	2018 Year Emissions	Activity Data Uncertainty[a]	Emission Factor Uncertainty[a]	Combined Uncertainty	Combined uncertainty as % of 2018 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.3	IPPU—Aluminium Production	SF_6	56	13	-	3.30	3.30	0.00	0.04	0.00	0.00
2.C.4	IPPU—Magnesium Production	SF_6	2 738	0	-	6.80	6.80	0.00	0.00	0.00	0.00
2.C.7	IPPU—Other (Magnesium Casting)	SF_6	225	134	-	6.80	6.80	0.00	0.14	0.00	0.00
2.D.1	IPPU—Non-Energy Products from Fuels and Solvent Use	CO_2	5 804	11 545	-	20.00	20.00	0.00	0.00	0.00	0.00
2.E.1	IPPU—Integrated Circuit or Semiconductor	PFCs	-	2	-	50.00	50.00	0.00	0.00	0.00	0.00
2.E.1	IPPU—Integrated Circuit or Semiconductor	SF_6	4	2	-	19.00	19.00	0.00	0.00	0.00	0.00
2.E.1	IPPU—Integrated Circuit or Semiconductor	NF_3	0	0	-	45.00	45.00	0.00	0.00	0.00	0.00
2.E.5	IPPU—Other	PFCs	-	0	-	300.00	300.00	0.00	1.15	0.00	0.00
2.F	IPPU—Product Uses as Substitutes for Ozone Depleting Substances	HFCs	-	12 545	-	50.00	50.00	0.01	0.00	0.00	0.01
2.F	IPPU—Product Uses as Substitutes for Ozone Depleting Substances	PFCs	-	2	-	36.00	36.00	0.00	0.00	0.00	0.00
2.G.1	IPPU—Electrical Equipment	SF_6	202	161	-	23.00	23.00	0.00	0.01	0.00	0.00
2.G.2	IPPU—SF_6 and PFCs from Other Product Use	PFCs	146	438	-	32.00	32.00	0.00	0.00	0.00	0.00
2.G.3.a	IPPU—Other (Medical Applications of N_2O)	N_2O	26	80	-	23.00	23.00	0.00	0.00	0.00	0.00
2.G.3.b	IPPU—Other (Uses of N_2O for Propellant)	N_2O	-	32	-	23.00	23.00	0.00	0.00	0.00	0.00
2.G.4	IPPU—Other (Use of Urea in SCR Vehicles)	CO_2	-	26	-	51.00	51.00	0.00	0.17	0.00	0.00
	Agriculture—Total CH_4	CH_4	24 970	28 025	-	19.00	20.00	0.01	0.00	0.00	0.00
3.A	Agriculture—Enteric Fermentation	CH_4	22 347	24 142	-	-	22.00	0.01	0.00	0.00	0.00
3.B.1	Agriculture—Manure Management	CH_4	2 453	3 846	-	-	32.00	0.00	0.00	0.00	0.00
	Agriculture—Total N_2O	N_2O	20 778	28 751	7.90	29.00	29.00	0.01	0.07	0.00	0.00
3.B.2	Agriculture—Manure Management Direct Emissions	N_2O	3 062	3 369	1.40	44.00	51.00	0.00	0.05	0.00	0.00
3.B.2	Agriculture—Manure Management Indirect Emissions	N_2O	613	703	1.40	100.00	100.00	0.00	0.02	0.00	0.00
3.D.1	Agriculture—Direct Agriculture Soils	N_2O	14 260	20 439	7.90	27.00	34.00	0.01	0.08	0.00	0.00
3.D.2	Agriculture—Indirect Agrictulure Soils	N_2O	2 790	4 229	7.90	75.00	100.00	0.00	0.08	0.00	0.00
3.F	Agriculture—Field Burning of Agricultural Residues	CH_4	170	37	50.00	40.00	64.00	0.00	0.01	0.00	0.00
3.F	Agriculture—Field Burning of Agricultural Residues	N_2O	53	12	50.00	48.00	69.00	0.00	0.01	0.00	0.00
	Agriculture—Total CO_2	CO_2	1 191	2 605	4.00	42.00	44.00	0.00	0.08	0.00	0.00
3.G.1	Agriculture—Limestone $CaCO_3$	CO_2	385	180	30.00	50.00	58.00	0.00	0.03	0.00	0.00
3.H	Agriculture—Urea Application	CO_2	754	2 177	15.00	50.00	52.00	0.00	0.11	0.00	0.00
3.I	Agriculture—Other Carbon-Containing Fertilizers	CO_2	52	249	15.00	50.00	52.00	0.00	0.02	0.00	0.00
4.A	LULUCF—Forest Land Remaining Forest Land	CO_2	(202 468)	(139 990)	-	38.00	38.00	0.54	8.83	0.00	0.78
4.A	LULUCF—Forest Land Remaining Forest Land	CH_4	409	385	-	130.00	130.00	0.00	0.04	0.00	0.00
4.A	LULUCF—Forest Land Remaining Forest Land	N_2O	204	210	-	140.00	140.00	0.00	0.01	0.00	0.00
4.A	LULUCF—Land Converted to Forest Land	CO_2	(1 069)	(334)	-	100.00	100.00	0.00	0.20	0.00	0.00
4.B	LULUCF—Cropland	CO_2	(1 223)	(10 287)	-	23.00	23.00	0.00	0.36	0.00	0.00
4.B	LULUCF—Cropland	N_2O	14	12	-	40.00	40.00	0.00	0.00	0.00	0.00
4.C	LULUCF—Grasslands	CH_4	0	1	-	64.00	64.00	0.00	0.00	0.00	0.00
4.C	LULUCF—Grasslands	N_2O	0	0	-	69.00	69.00	0.00	0.00	0.00	0.00
4.D	LULUCF—Wetlands	CO_2	2 498	1 592	-	-	-	0.00	0.00	0.00	0.00

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

	IPCC Source Category	Gas	Base Year Emissions	2018 Year Emissions	Activity Data Uncertainty[a]	Emission Factor Uncertainty[a]	Combined Uncertainty	Combined uncertainty as % of 2018 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	%	%	%	%	%	%	%
4.D	LULUCF—Wetlands	CH_4	6	14	-	-	-	0.00	0.00	0.00	0.00
4.D	LULUCF—Wetlands	N_2O	2	4	-	-	-	0.00	0.00	0.00	0.00
4.E	LULUCF—Settlements	CO_2	(3 876)	(4 094)	-	19.00	19.00	0.00	0.04	0.00	0.00
4.F	LULUCF—Conversion of Forest Land	CO_2	17 469	10 765	-	15.00	15.00	0.00	0.33	0.00	0.00
4.F	LULUCF—Conversion of Forest Land	CH_4	440	185	-	21.00	21.00	0.00	0.02	0.00	0.00
4.F	LULUCF—Conversion of Forest Land	N_2O	219	96	-	20.00	20.00	0.00	0.01	0.00	0.00
4.G	LULUCF—Harvested Wood Products (HWP)	CO_2	127 746	128 582	-	23.00	23.00	0.17	1.68	0.00	0.03
5.A.1	Solid Waste Disposal—Managed Waste Disposal Sites	CH_4	15 422	12 273	-	40.00	40.00	0.00	0.59	0.00	0.00
5.A.2	Solid Waste Disposal—Unmanaged Waste Disposal Sites—Wood Waste Landfills	CH_4	3 847	3 399	-	190.00	190.00	0.01	0.58	0.00	0.00
5.B.1	Biological Treatment of Solid Waste—Composting	CH_4	32	260	110.00	110.00	170.00	0.00	0.04	0.00	0.00
5.B.1	Biological Treatment of Solid Waste—Composting	N_2O	23	186	110.00	110.00	170.00	0.00	0.03	0.00	0.00
5.C.1.1.b.iii	Incineration and Open Burning of Waste—Waste Incineration—Sewage Sludge	CH_4	0	0	-	60.00	60.00	0.00	0.00	0.00	0.00
5.C.1.1.b.iii	Incineration and Open Burning of Waste—Waste Incineration—Sewage Sludge	N_2O	38	72	5.00	110.00	110.00	0.00	0.00	0.00	0.00
5.C.1.2.a	Incineration and Open Burning of Waste—Waste Incineration—Municipal Solid Waste	CO_2	41	8	-	85.00	85.00	0.00	0.01	0.00	0.00
5.C.1.2.a	Incineration and Open Burning of Waste—Waste Incineration—Municipal Solid Waste	CH_4	128	1	-	85.00	85.00	0.00	0.03	0.00	0.00
5.C.1.2.a	Incineration and Open Burning of Waste—Waste Incineration—Municipal Solid Waste	N_2O	2	0	-	85.00	85.00	0.00	0.00	0.00	0.00
5.C.1.2.b.ii	Incineration and Open Burning of Waste—Waste Incineration—Hazardous Waste	CO_2	166	197	5.00	94.00	94.00	0.00	0.00	0.00	0.00
5.C.1.2.b.ii	Incineration and Open Burning of Waste—Waste Incineration—Hazardous Waste	CH_4	0	1	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—Hazardous Waste	N_2O	95	113	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—Clinical Waste	CO_2	1	2	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—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—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	571	656	-	45.00	45.00	0.00	0.01	0.00	0.00
5.D	Wastewater Treatment and Discharge	N_2O	345	487	-	65.00	65.00	0.00	0.00	0.00	0.00

Notes:

a. 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.

b. 1.A.2.g.vii, 1.A.3.e.ii, 1.A.4.a.ii., 1.A.4.b.ii, 1.A.4.c.ii

ANNEX 3

METHODOLOGIES

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.

A3.1.1. Methodology

In general, estimating greenhouse gas (GHG) emissions from fuel combustion activities uses 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). As illustrated by Equation A3.1–1, to calculate the emission for each source category, the quantity of fuel at the national and/or provincial level is multiplied by the corresponding fuel specific emission factor. Sections A3.1.4.1 and A3.1.4.2 discuss refinements and deviations from the general approach to estimating combustion emissions for the stationary combustion and transport sections, 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. The Energy chapter (Chapter 3) of this report discusses specific methodological issues.

Equation A3.1–1 **for general fuel combustion**

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

$E_{Category,G}$	=	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)

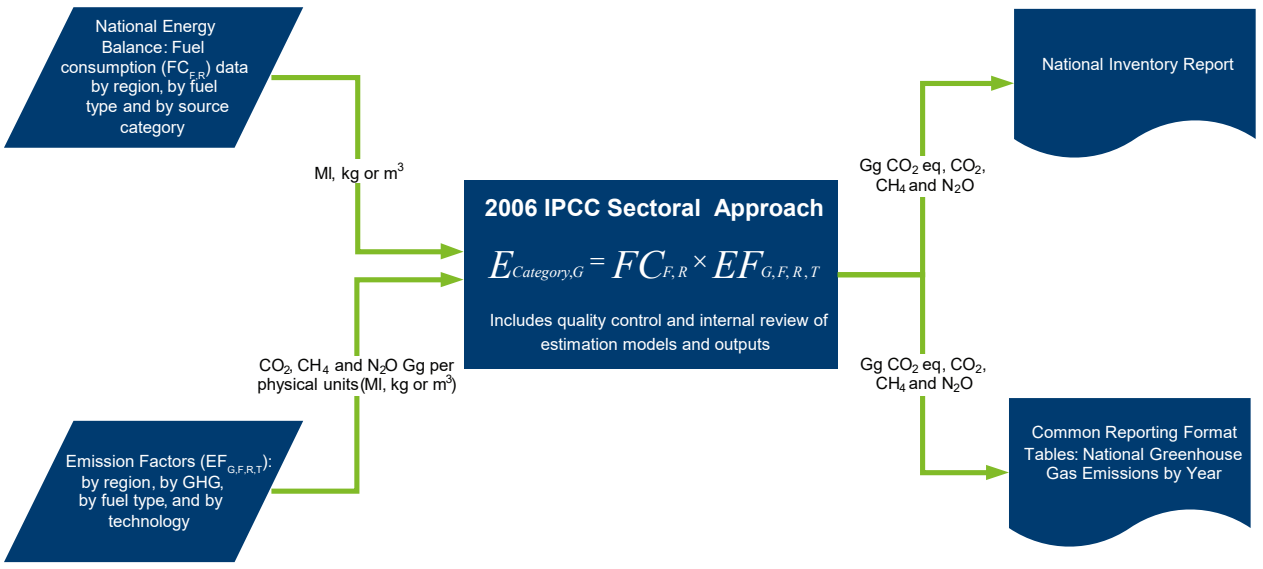
The stationary combustion and transport models primarily use relational databases to process activity data and emission factors at national and provincial levels used to estimate GHG emissions (Figure A3.1–1).

Statistics Canada prepares the national energy balance using data reported in physical units by the producing and consuming sectors. For this reason, the physical units were 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. The uncertainty of estimates are further reduced by applying available higher-resolution emission factors at the provincial/regional level rather than national level (e.g. regional coal and natural gas emission factors are used to account for the variation in carbon content). Non-CO_2 emission factors address any existing combustion technology differences.

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 1990–) also referred to as the national energy balance. 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 is allocated using The North American Industrial Classification System (NAICS). Currently, the RESD reports energy used to generate electricity or steam by industry (auto producers) in two separate lines (one for electricity and one for steam), without any further disaggregation by industrial subcategories. Prior to 1998, the *Industrial Consumption of Energy Survey* (ICE) (Statistics Canada 2013) provided these summary

Figure A3.1–1 **GHG Estimation Process Flow**



line quantities. From 1998 on, the electricity line (from auto producers) is based on the quantities reported in the *Electric Power Thermal Generating Station Fuel Consumption Survey* (EPTGS) (Statistics Canada 2013). Statistics Canada implemented this improvement 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 populated using the ICE data.

While the RESD provides fuel use data at a provincial level, the accuracy of these data is generally not as high as that of the national data. Statistics Canada typically allocates final fuel demand by subcategories for the RESD through a number of surveys directed at producers and suppliers of energy, provincial energy ministries and some users of energy. The accuracy following these allocations is less than that of the total available energy supply at the national level. As a result, the total emission estimates for Canada are more certain than the emissions from specific subcategories. Since 1995, Statistics Canada has been collecting energy statistics directly from end users through the annual ICE Survey. Estimating fuel-use-by-industry using a bottom-up approach provides more accurate subcategory information. 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 provide verification of 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 Statistics Canada collects data from reporting facilities under the *Statistics Act*. The quantities of fossil fuel consumed are also available in gross calorific units; however, as discussed, this is assumed less accurate. When converting to energy values, with the exception of natural gas, 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 variability in fuels such as coal, petroleum coke and refinery fuel gas (still 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 calculations (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 (ECCC) 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 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 A3.1.4.1 and A3.1.4.2).

A3.1.3. Fuel Combustion Emission and Oxidation Factors

Annex 6 provides a detailed description of emission factors used in the current fossil fuel combustion models, while the following is a brief summary for fuels that are the largest contributors to Canadian GHG emissions:

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, provinces have varying emission factors 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): Refined petroleum products include but are not limited to fuels such as diesel, gasoline, light fuel oil and heavy fuel oil. 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.

The IPCC default oxidation value applies to all fuels except coal, where country-specific oxidation factors applied at the provincial level reflect regional variations in combustion efficiencies. 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 applied emission factors vary by fuel type and by region, where applicable. There is discussion of CO_2 emission factor derivation in Annex 6, in *Fossil Fuel and Derivative Factors* (McCann 2000), in *Updated CO_2 Emission Factors for Gasoline and Diesel Fuel* (ECCC 2017b) and in *Updated Carbon Dioxide Emission Factors for Coal Combustion* (ECCC 2019). 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 waste fuel emission factor is based on energy content since activity data reported by the Cement Association of Canada (CAC) are in energy units.

A3.1.3.2. Non-CO_2 Emission Factors

Emission factors for all non-CO_2 GHGs from combustion activities vary to a greater or lesser 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 were developed for sectors based on typical technology splits and available emission factors.

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 needed to better establish N_2O emission factors for many combustion processes. Overall factors were developed for sectors based on typical technologies and available emission factors. Annex 6 lists non-CO_2 emission factors used in this inventory.

A3.1.4. Methodology for Stationary Combustion and Transport

This section discusses methods used to calculate and report emissions associated with the Energy sector, and specifically stationary combustion and transport.

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. The Land Use, Land-use Change and Forestry (LULUCF) sector accounts for CO_2 emissions from biomass fuel combustion as a loss of biomass (forest) stocks. CO_2 emissions from biomass combustion for energy use is a memo item in the UNFCCC's Common Reporting Format (CRF) tables and provided for information purposes. The Energy sector reports CH_4 and N_2O emissions from biomass fuel combustion in the appropriate subcategories and includes it in the inventory totals.

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 Industrial Processes and Product

Use sector (Annex 3.3) presents the methodology for calculating SF_6 emissions from electrical transmission systems.

Emission calculations use nationally reported activity data, except when emission factors are available at the provincial/territorial level. In these instances, the national total is the aggregated sum of the provincial/territorial emissions.

Emission estimates are calculated using Equation A3.1–1 exclusively.

Table A3.1–1 presents activity data sources used in the stationary combustion model methodology. The data provided to ECCC is in electronic format and may differ slightly when compared with Statistics Canada's published values, which are rounded.

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, the allocation of all fuel types uses the CRF fuel grouping (solid, liquid, gaseous, biomass and other) (see Table A4–2 in 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), 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 using 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 ECCC), 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). In addition, solid wood waste and spent pulping liquor used by industry are allocated to Table 10—Solid Wood Waste and Spent Pulping Liquor.

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, as follows:

- 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.

Table A3.1–1 **Activity Data Model References**

Statistics Canada. 1990. *Report on Energy Supply and Demand in Canada*. Annual Report, Statistics Canada Catalogue no. 57-003-X.
Waste fuel data—Based on CEEDC. CEEDC Database on Energy, Production and Intensity Indicators for Canadian Industry. NAICS 327310 Cement Manufacturing. Canadian Energy and Emissions Data Centre.
Residential fuelwood consumption—Environment Canada. 2014. *Residential Fuelwood Consumption in Canada*. Unpublished report. Prepared by K. Tracey, Pollutant Inventories and Reporting Division, Environment Canada.
Landfill Gas Utilization & Waste Incineration—Environment and Climate Change Canada. 2020. *National Inventory Report* (NIR). Section A3.6: Methodology for Waste Sector.

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 and Spent Pulping Liquor 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 corresponding 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.

Two lines in the RESD (one for electricity and one for steam) report activity data from this subcategory; 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 need to be reallocated to the appropriate subcategory where the fuel is used. Section A3.1.4.1 has a detailed discussion of the method used.

CO_2, CH_4 and N_2O emissions are estimated by applying Equation A3.1–1 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 A3.1–2 provides a summary of the methodology for the public electricity and heat production CRF category.

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 to 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 A3.1–1 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. To avoid double counting, the model subtracts fuel use, energy content and emission data associated with flaring and reallocates them to the Fugitive category 1.B.2.

Determining the activity data associated with the Petroleum Refining subcategory requires the reallocation of some of the data reported as Producer Consumption in the RESD. The Petroleum Refining subcategory includes all refined petroleum products reported as Producer Consumption, except in provinces where no refinery exists; these producer-consumed RPPs are assigned to Oil and Gas Extraction. Physical quantities of liquefied petroleum gases (LPGs) reported in the RESD as producer consumption 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 A3.1–1 to:

- petroleum coke;
- still gas;
- kerosene;

Table A3.1–2 **Emission Estimation Methodology for Public Electricity and Heat Production**

CRF Source Category[a]	Fuel Type[b]	Data Source		
		Publication[b]	Table	Line
1.A.1.a.i Electricity Generation	Solid Fuels	RESD	1—Primary and Secondary Energy Coal Details (unpublished)	Electricity by Utilities[c] Steam Generation[c]
	Liquid Fuels	RESD	3—Refined Petroleum Products	
	Gaseous Fuels	RESD	1—Primary and Secondary Energy 6—Details of Natural Gas Liquids	
	Biomass	RESD	10—Solid Wood Waste and Spent Pulping Liquor, Total Consumption[c]	
1.A.1.a.ii Combined Heat and Power Generation	Solid Fuels	RESD	1—Primary and Secondary Energy Coal Details (unpublished)	Electricity by Utilities[c] Steam Generation[c]
	Liquid Fuels	RESD	3—Refined Petroleum Products	
	Gaseous Fuels	RESD	1—Primary and Secondary Energy 6—Details of Natural Gas Liquids	
	Biomass	RESD	10—Solid Wood Waste and Spent Pulping Liquor, Total Consumption[c]	
1.A.1.a.iii Heat Plants	NO			

Notes:
NO Not occurring

a. The CRF categories listed are the lowest-level subcategories for which emissions are estimated.
b. Publication references are provided in Table A3.1–1.
c. A portion of this data source is allocated to this CRF source category prior to calculating emissions.

- 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 need reallocation to the appropriate industry where the fuel is used. This reallocation uses one of two methods discussed in detail in section A3.1.4.1. Because of a lack of resolution in the RESD 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 calculations from the following transportation fuels, for the Petroleum Refining subcategory, uses activity data reported in the RESD under Producer Consumption together with Equation A3.1–1:

- aviation gasoline;
- aviation turbo;
- diesel; and
- motor gasoline.

The estimated N_2O emissions for petroleum coke and motor gasoline use IPCC default emission factors, which use the calorific value of the fuel. The RESD reports the gross calorific value (GCV) for petroleum coke and this can change annually. As a result, 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, uses 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 A3.1–1:

- 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, national level coal emissions, from combusted coal, use aggregated provincial/territorial level estimates.

As previously mentioned, to avoid double counting, the model subtracts fuel use, energy content and emission data associated with flaring from Petroleum Refining (1.A.1.b) and reallocates them to the Fugitive category 1.B.2. In addition, the model subtracts other flaring emissions from Oil and Gas Extraction (1.A.1.c.ii) and reallocates them to the relevant Fugitive category under 1.B.2. See section A.3.2.2.6 for a more detailed description.

Table A3.1–3 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 need to be reallocated to the appropriate industry where the fuel is used. Section A3.1.4.1 describes this reallocation method in detail.

Emissions are calculated for the following categories:

- Mining;
- Iron and Steel;
- Non-ferrous Metals;

Table A3.1–3 **Estimation Methodology for Petroleum Refining, Manufacture of Solid Fuels and Oil and Gas Extraction**

CRF Source Category[a]	Fuel Type[b]	Data Source		
		Publication[c]	Table	Line
1.A.1.b Petroleum Refining	Solid Fuels	NA		
	Liquid Fuels	RESD	3—Refined Petroleum Products	Electricity by Industry[c] Steam Generation[c]
			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[c] Steam Generation[c] Petroleum Refining
	Biomass	NA		
1.A.1.c.i Manufacture of Solid Fuels	Solid Fuels	RESD	1—Primary and Secondary Energy Coal Details (unpublished)	Producer Consumption
	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[c] Producer Consumption
			11—Estimated Additions to Still Gas, Diesel, Petroleum Coke and Crude Oil	NA
	Gaseous Fuels	RESD	1—Primary and Secondary Energy	Electricity by Industry[c] Producer Consumption
	Biomass	NA		

Notes:
NA Not applicable. National aggregation only.

a. The CRF categories listed are the lowest-level subcategories for which emissions are estimated.
b. Publication references are provided in Table A3.1–1.
c. A portion of this data source is allocated to this CRF source category prior to calculating emissions.

- 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 A3.1–1 to activity data reported in the RESD and emission factors for specific fuels on a national basis. Section A3.1.4.1.1 describes the handling of coal emissions. The Industrial Processes sector reports emissions from fuels used as feedstocks, while the Transport category reports emissions generated from the use of transportation fuels (e.g. diesel and gasoline).

The Industrial Processes sector reports all emissions associated with the manufacture and use of metallurgical coke in the iron and steel industry for the reduction of iron ore in blast furnaces.

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 are used to reallocate 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%.

The Other Manufacturing category also includes GHG emissions associated with the combustion of waste for energy purposes. A portion of the waste is considered biogenic, so CO_2 emissions associated with combustion of this portion are reported but not included in the national total. The CO_2 emissions associated with the combustion of the non-biogenic portion, along with the total CH_4 and N_2O emissions, are included in the national total.

CO_2 emissions from the combustion of waste fuels in the cement industry are calculated using data provided by the Cement Association of Canada and reported by CIEEDAC (2013) on an energy basis. Table A3.1–4 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 A3.1–1 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:

- Fireplaces;
- Fireplace Inserts;
- Wood Stoves;
- Wood Furnaces;
- Pellet Stoves; and
- Other Equipment.

Some of these appliance types were further broken down into either advanced technology (catalytic or non-catalytic) or conventional technology (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 were collected on a volume basis, an average density value was determined by province, based on the proportion of the different types 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).

The mass of firewood consumed for the other years was extrapolated from 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.

The Commercial category also includes GHG emissions associated with the combustion of waste for energy purposes. A portion of the waste is biogenic, so CO_2 emissions associated with combustion of this portion are reported but not included in the national total. The CO_2 emissions associated with the combustion of the non-biogenic portion, along with the total CH_4 and N_2O emissions, are included.

Table A3.1–4 Estimation Methodology for Manufacturing Industries and Construction

CRF Source Category[a]	Fuel Type[b]	Data Source		
		Publication[c]	Table	Line
1.A.2.a. Iron and Steel	Solid Fuels	RESD	1—Primary and Secondary Energy Coal Details (unpublished)	Electricity by Industry[c] Steam Generation[c] Iron and Steel Manufacturing
	Liquid Fuels	RESD	3—Refined Petroleum Products	
	Gaseous Fuels	RESD	1—Primary and Secondary Energy 6—Details of Natural Gas Liquids	
	Biomass	RESD	10—Solid Wood Waste and Spent Pulping Liquor, Total Consumption[c]	
1.A.2.b. Non-Ferrous Metals	Solid Fuels	RESD	1—Primary and Secondary Energy Coal Details (unpublished)	Electricity by Industry[c] Steam Generation[c] Aluminum and Non-ferrous Metal Manufacturing
	Liquid Fuels	RESD	3—Refined Petroleum Products	
	Gaseous Fuels	RESD	1—Primary and Secondary Energy 6—Details of Natural Gas Liquids	
	Biomass	RESD	10—Solid Wood Waste and Spent Pulping Liquor, Total Consumption[c]	
1.A.2.c. Chemicals	Solid Fuels	RESD	1—Primary and Secondary Energy Coal Details (unpublished)	Electricity by Industry[c] Steam Generation[c] Chemicals and Fertilizer Manufacturing
	Liquid Fuels	RESD	3—Refined Petroleum Products	
	Gaseous Fuels	RESD	1—Primary and Secondary Energy 6—Details of Natural Gas Liquids	
	Biomass	RESD	10—Solid Wood Waste and Spent Pulping Liquor, Total Consumption[c]	
1.A.2.d. Pulp, Paper and Print	Solid Fuels	RESD	1—Primary and Secondary Energy Coal Details (unpublished)	Electricity by Industry[c] Steam Generation[c] Pulp and Paper Manufacturing
	Liquid Fuels	RESD	3—Refined Petroleum Products	
	Gaseous Fuels	RESD	1—Primary and Secondary Energy 6—Details of Natural Gas Liquids	
	Biomass	RESD	10—Solid Wood Waste and Spent Pulping Liquor, Total Consumption[c]	
1.A.2.e. Food Processing, Beverages and Tobacco	Emissions for this subcategory are included in 1.A.2.g.viii.1—Other Manufacturing.			
1.A.2.f. Non-Metallic Minerals	Solid Fuels	RESD	1—Primary and Secondary Energy Coal Details (unpublished)	Electricity by Industry[c] Steam Generation[c] Cement
		Waste fuel data from the Canadian Industrial Energy End-use Data and Analysis Centre (CIEEDAC)		
	Liquid Fuels	RESD	3—Refined Petroleum Products	Electricity by Industry[c] Steam Generation[c] Cement
	Gaseous Fuels	RESD	1—Primary and Secondary Energy 6—Details of Natural Gas Liquids	
	Biomass	RESD	10—Solid Wood Waste and Spent Pulping Liquor, Total Consumption[c]	
1.A.2.g.iii Mining	Solid Fuels	RESD	1—Primary and Secondary Energy Coal Details (unpublished)	Electricity by Industry[c] Steam Generation[c] Total Mining & Oil & Gas Extraction
	Liquid Fuels	RESD	3—Refined Petroleum Products	
	Gaseous Fuels	RESD	1—Primary and Secondary Energy 6—Details of Natural Gas Liquids	
	Biomass	RESD	NA	
1.A.2.g.v Construction	Solid Fuels	RESD	1—Primary and Secondary Energy Coal Details (unpublished)	Construction
	Liquid Fuels	RESD	3—Refined Petroleum Products	
	Gaseous Fuels	RESD	1—Primary and Secondary Energy 6—Details of Natural Gas Liquids	
	Biomass	RESD	NA	
1.A.2.g.viii.1 Other Manufacturing	Solid Fuels	RESD	1—Primary and Secondary Energy Coal Details (unpublished)	Electricity by Industry[c] Steam Generation[c] Other Manufacturing
	Liquid Fuels	RESD	3—Refined Petroleum Products	
	Gaseous Fuels	RESD	1—Primary and Secondary Energy 6—Details of Natural Gas Liquids	
	Other Fossil Fuels	NIR	Table A3.6–15: National Summary of Emissions from MSW Incineration[d]	
	Biomass	RESD	10—Solid Wood Waste and Spent Pulping Liquor, Total Consumption[c]	
		NIR	Table A3.6–15: National Summary of Emissions from MSW Incineration[d]	

Notes:

NA Not applicable (national aggregation only)

a. The CRF categories listed are the lowest-level subcategories for which emissions are estimated.

b. Publication references are provided in Table A3.1–1.

c. A portion of this data source is allocated to this CRF source category prior to calculating emissions.

d. The non-biogenic portion of MSW incineration is included under Other Fossil Fuels, the biogenic portion is included under biomass.

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 fuel use data needs reallocation to the appropriate subcategory. Section A3.1.4.1 discusses the disaggregation method used.

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 using 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 the Transport category.

Table A3.1–5 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 category are divided into six subcategories:

- 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 category are calculated using various adaptations of Equation A3.1–1.

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.

Table A3.1–5 **Estimation Methodology for Other Sectors**

CRF Source Category[a]	Fuel Type[b]	Data Source		
		Publication[c]	Table	Line
1.A.4.a.i Commercial/Institutional—Stationary Combustion	Solid Fuels	RESD	1—Primary and Secondary Energy Coal Details (unpublished)	Electricity by Industry[c] Commercial and Other Institutional Public Administration
	Liquid Fuels	RESD	3—Refined Petroleum Products	
	Gaseous Fuels	RESD	1—Primary and Secondary Energy 6—Details of Natural Gas Liquids	
	Other Fossil Fuels	NIR	Table A3.6–15: National Summary of Emissions from MSW Incineration[d]	
	Biomass	RESD	10—Solid Wood Waste and Spent Pulping Liquor, Total Consumption[c]	
		NIR	Table A3.6–15: National Summary of Emissions from MSW Incineration[d]	
		NIR	Table A3.6–6: Methane Generated, Captured, Oxidized, Flared and Emitted from MSW Landfills in Canada	
1.A.4.b.i Residential—Stationary Combustion	Solid Fuels	RESD	1—Primary and Secondary Energy Coal Details (unpublished)	Residential
	Liquid Fuels	RESD	3—Refined Petroleum Products	Residential
	Gaseous Fuels	RESD	1—Primary and Secondary Energy 6—Details of Natural Gas Liquids	Residential
	Biomass	Estimated using Environment Canada residential fuelwood consumption model.		
1.A.4.c.i Agriculture/Forestry/Fishing—Stationary Combustion	Solid Fuels	RESD	1—Primary and Secondary Energy Coal Details (unpublished)	Electricity by Industry[c] Steam Generation[c] Forestry and Logging and Support Activities for Forestry Agriculture
	Liquid Fuels	RESD	3—Refined Petroleum Products	
	Gaseous Fuels	RESD	1—Primary and Secondary Energy 6—Details of Natural Gas Liquids	
	Biomass	RESD	10—Solid Wood Waste and Spent Pulping Liquor, Total Consumption[c]	

Notes:
a. The CRF categories listed are the lowest-level subcategories for which emissions are estimated.
b. Publication references are provided in Table A3.1–1.
c. A portion of this data source is allocated to this CRF source category prior to calculating emissions.
d. The non-biogenic portion of MSW incineration is included under Other Fossil Fuels, and the biogenic portion is included under biomass.

For the Road Transportation and Other Transportation (Off-road) categories, Canada uses the Motor Vehicle Emissions Simulator (MOVES) model, MOVES2014 version, developed by the U.S. EPA, and a modified version of the U.S. EPA's NONROAD model (NONROAD2012c). The primary reasons for these updates are to remain current with regulatory changes in the Canadian vehicle fleet, which are harmonized with those of 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. Therefore, under the CRF classification system, some emissions that were previously reported in the 1.A.3 categories are allocated to the 1.A.2 and 1.A.4 categories. The Aviation Greenhouse Gas Emission Model (AGEM) is used to calculate aviation emissions. The Marine Emissions Inventory Tool (MEIT) is used to calculate Navigation emissions and Railway emissions are derived from 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 Categories 1.A.2.g.vii, 1.A.3.e.ii, 1.A.4.a.ii, 1.A.4.b.ii and 1.A.4.c.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 categories are collectively normalized to fuel available as reported in the RESD, a combined methodology for the two categories 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 vehicle and truck populations for 1990–2002 and 2005–2015 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 2005–2015. 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 2016–2018 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 Table 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 2014–2018 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, estimates of the number of vehicles on the road equipped with catalytic converters and other control technologies were developed. The vast majority of on-road vehicles in use in 2018 are subject to Tier 1 and Tier 2 regulatory tiers, approximately representing model years 1996 and onwards. However, since the National Inventory estimates a time series starting at 1990, as well as considering a small number of pre-1996 model year vehicle still in active fleet, additional technology emission rates for CH_4 and N_2O emission factors are also used. These include emission controls ranging from completely uncontrolled vehicles to those using Tier 1 regulatory standards.

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, Power Systems Research Inc. provided growth rates.

2 The 2005–2015 light- and heavy-duty populations received from DesRosiers and Polk were in a new format when compared with previously received data sets and were derived using updated vehicle identification algorithms. As a result, when the 1990–2004 data set was merged with the 2005–2015 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.

Similarly, heavy-duty gasoline vehicles (HDGVs), heavy-duty diesel vehicles (HDDVs) and motorcycles (MCs) have advanced emissions controls starting with the 1996 model year. Emission factors for uncontrolled and/or moderate controls are used for 1995 and older model years. CH_4 and N_2O emission factors for the full range of emissions controls are listed in Table A6.1–13.

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 kilojoules per second (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://www.epa.gov/moves/moves-technical-reports.

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 in *Updated CO_2 Emission Factors for Gasoline and Diesel Fuel* (ECCC 2017b), 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). Given 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

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 are 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 by selecting appropriate emission factors in Table A6.1–13 and applying Equation A3.1–1.

Step 2: On-road Fuel Calculation

Using the inputs from Step 1, on-road fuel consumption is estimated by converting MOVES2014 energy outputs into litres of fuel volume. 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); and
- 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 A3.1–1 is applied using the emissions factors in Table A6.1–13.

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 size, load factor and hours of use for the years 1990 to 2018. Where possible, the hours-of-use parameter provided by PSR was replaced using Canada-specific information collected from resale markets. As an example, activity data from nearly 2000 used snowmobile advertisements were used to derive hours–of-use data, by engine stroke (ECCC 2018a). In addition, the methodology used to estimate construction equipment populations for oil sands mining operations was replaced with a mining equipment database provided by The Parker Bay Company (ECCC 2018b). 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 1990).

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 the degree of correlation between the two estimates is higher. Please refer to Table A3.1–6 and Table A3.1–7 for the normalization factors calculated on a national basis for gasoline and diesel fuel respectively.

Step 5: Emission Calculation

Once a final allocation of fuel is complete for all vehicle and equipment types, emissions are calculated using Equation A3.1–1 with the emission factors in Table A6.1–13.

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 emissions from 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.

Table A3.1–6 **Gasoline Normalization Values, Selected Years**

		1990	2005	2012	2013	2014	2015	2016	2017	2018
Raw	Bottom-up On-Road Fuel Consumption Estimate (ML)	37 113	40 653	46 898	48 301	49 418	50 529	50 340	50 203	51 356
	Bottom-up Off-Road Fuel Consumption Estimate (ML)	7 463	3 189	3 084	3 158	3 463	3 531	3 335	3 457	3 580
	Total Bottom-Up Fuel Consumption Estimate (ML)	44 576	43 842	49 982	51 459	52 881	54 060	53 675	53 661	54 936
	Bottom-up On-Road Portion (%)	83	93	94	94	93	93	94	94	93
	Bottom-up Off-Road Portion (%)	17	7	6	6	7	7	6	6	7
Target	Total Top-down Fuel Available (ML)	33 943	40 850	43 082	44 263	43 437	44 423	46 046	46 390	47 997
	National Scaling Factor (%)	76	93	86	86	82	82	86	86	87
Scaled	Final On-Road Fuel Estimate (ML)	28 298	37 868	40 406	41 528	40 567	41 493	43 160	43 386	44 859
	Final Off-Road Fuel Estimate (ML)	5 645	2 981	2 676	2 735	2 870	2 930	2 886	3 004	3 138
	Sum of Final On and Off-Road Fuel (ML)	33 943	40 850	43 082	44 263	43 437	44 423	46 046	46 390	47 997

Table A3.1–7 **Diesel Fuel Normalization Values, Selected Years**

		1990	2005	2012	2013	2014	2015	2016	2017	2018
Raw	Bottom-up On-Road Fuel Consumption Estimate (ML)	5 324	14 638	18 794	18 974	19 489	19 344	20 196	21 105	21 899
	Bottom-up Off-Road Fuel Consumption Estimate (ML)	9 404	10 322	9 342	9 278	9 254	9 851	9 892	10 594	11 281
	Total Bottom-Up Fuel Consumption Estimate (ML)	14 728	24 960	28 135	28 252	28 743	29 195	30 089	31 699	33 180
	Bottom-up On-Road Portion (%)	36	59	67	67	68	66	67	67	66
	Bottom-up Off-Road Portion (%)	64	41	33	33	32	34	33	33	34
Target	Total Top-down Fuel Available (ML)	13 188	22 766	26 899	27 613	27 475	27 462	26 186	27 885	29 574
	National Scaling Factor (%)	90	91	96	98	96	94	87	88	89
Scaled	Final On-Road Fuel Estimate (ML)	5 266	13 872	18 303	18 797	18 771	18 393	17 805	18 741	19 698
	Final Off-Road Fuel Estimate (ML)	7 922	8 894	8 596	8 816	8 704	9 070	8 381	9 144	9 876
	Sum of Final On and Off-Road Fuel (ML)	13 188	22 766	26 899	27 613	27 475	27 462	26 186	27 885	29 574

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 2018) 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 it as well as validation of airports, aircraft types and various data fields that are not crucial to modelling fuel use.

Military emissions are estimated on the basis of 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 called the Aviation Environmental Design Tool (AEDT) (formerly System for Assessing Aviation's Global Emissions [SAGE]) that is based on true radar data. The FAA provided Environment Canada with an extract from its 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 (GCD [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.

Airport coordinates

All possible airport entries within the AGEM movement data were extracted and defined. Information on the airports, such as latitude, longitude, name, and elevation, 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 data required to calculate a GCD for use in determining the flight path length are the geographical coordinates.

Aircraft fuel use characteristics

Once the flight path length is determined, the fuel consumed by the aircraft for that movement can be calculated using 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 predominantly 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 by 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, given the lack of any additional information, this modification was made as it was recognized 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

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.

4 Maximum takeoff weight.

published CH_4 emission factor will be a fleet average across the entire time series and will be 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. 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 A3.1–2

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

$FuelConsumption_{FlightTotal}$	=	total fuel consumed on a per-flight basis
$FuelConsumption_{LTO}$	=	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 using 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 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 consumed in Canada is reported in the RESD (Statistics Canada 1990–2018). 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 A3.1–1. 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 methodology used to estimate GHG emissions from the domestic navigation category is considered an IPCC Tier 2 method for CO_2 emissions and an IPCC Tier 1 for CH_4, and N_2O emissions.

This category includes emissions from vessels navigating between Canadian ports. In accordance with the 2006 IPCC Guidelines, military marine transportation emissions are reported in the Other-Mobile category (CRF Category 1.A.5.b). Likewise, emissions from fishing vessels are reported in the Fishing category (CRF Category 1.A.4.c.iii). Excluded are emissions from smaller recreational vessels (reported under Other Transportation (Off-road)). Emissions from international voyages are designated as “bunker” emissions and are not included in national totals but are estimated and reported separately under International Bunkers as a Memo Item.

Marine emissions are developed using the Marine Emissions Inventory Tool (MEIT), a model developed using vessel tracking information. Unlike previous inventories, where emissions estimates were based on fuel sales data and organized by flag of vessel, MEIT is based on vessel movements and domestic or international emissions are assigned according to port origin-destination information. Therefore, and similar to the Aviation subcategory, careful consideration should be paid when comparing fuel consumption (in terms of energy) in this subcategory against the national energy balance reported in the RESD and IEA data. Due to design and operating procedures of marine vessels, it is not uncommon for vessel to store significant amounts of fuel onboard. This means that it is possible for vessels to navigate in Canadian waters without purchasing fuel from a Canadian supplier. Since the RESD is based on fuel transactions in Canada, it is possible to have more fuel consumed in the marine sector than what is reported in the national energy balance. When using the reference approach, excess fuel is accounted for as a "temporary import".

Step 1: Activity Data: Marine Emission Inventory Tool

The marine emission inventory tool uses vessel traffic data and vessel characteristics to estimate the quantity of fuel required for each vessel manoeuver within Canadian waters. Vessel traffic data was only available for the 2010 and 2015 calendar years. However, MEIT developed back-casts/forecasts for 1990 to 2050 in 5-year increments. Fuel quantities between those years were linearly interpolated. Since the 2015 calendar year is the only year that estimates are available at a detailed level, the proportions of fuel use for that year are applied to the other calendar years to further break down the fuel quantity.

For 2010 and 2015 calendar years the MEIT data is based on vessel traffic data from the Information System on Marine Navigation (Canadian Coast Guard), Automatic Identification System (AIS) and Department of Fisheries and Oceans Fishing License Data. The vessel movements are grouped into 1km segments, which provide the distance and time between each point. To estimate the fuel use the vessel characteristics/ classifications are taken into consideration. Three sources of fuel consumption are considered; main engines, auxiliary engines and boilers. MEIT uses general assumptions for the auxiliary engines and boilers, however, more parameters are used to determine the fuel consumed by the main engine. The load factor has a significant influence on the fuel estimate from the main engine; therefore, it is calculated for each data point based on the propeller law.

From 1990 to 2010 the data was back-casted using multiple factor including: Transport Canada commodity data for 1990 to 2005, port 'dry bulk' and 'containerized (TEU)' data, Northwest and Canada Cruise Association (NWCCA) passenger data, and Statistic Canada population data.

From 2015 to 2050 the data was forecasted by scaling the ship movements per vessel class on the basis of estimated sector growth/contraction, and adjusting the emission factors on the basis of regulations and policies in place for that future year.

Step 2: Fuel allocation and time series consistency

The amount of fuel from the RESD is compared against the values estimated by the Marine Emissions Inventory Tool. The purpose of this is to determine how much of the fuel burned is likely to have been obtained from Canadian fuel suppliers. The comparison is performed systematically at a regional and category level.

In the event that the RESD is greater than the fuel consumption values estimated by MEIT (Scenario 1), it is assumed that fuel values from MEIT for military, fishing, domestic and international navigation are all purchased from Canadian suppliers. Any fuel difference between the RESD and MEIT is attributed to the international navigation (bunkers) category. It is assumed in this scenario that the MEIT model underestimated the amount of fuel used for international navigation, which is likely due to the MEIT only covering movement within Canadian waters.

In the event that the RESD is less than the fuel consumption values estimated by MEIT (Scenario 2) the following procedure is followed:

Case 1—Military. If the amount of fuel available in the RESD is greater than the amount of fuel estimated by MEIT to be used by military vessels, then it is assumed that all the fuel used for military operations was obtained from Canadian suppliers. If the RESD is less than the amount from MEIT, the portion of fuel equal to that of the RESD is assumed to be purchased from Canadian fuel suppliers while the remainder of fuel used in that region is assumed to be purchased from a foreign fuel supplier.

Case 2—Fishing. If the amount of fuel available in the RESD (minus that used for military operations) is greater than the amount of fuel estimated by MEIT to be used by fishing vessels, then it is assumed that all the fuel used for commercial fishing was obtained from Canadian

suppliers. If the RESD is less than the amount from MEIT, the portion of fuel equal to that of the RESD is assumed to be purchased from Canadian fuel suppliers while the rest of fuel used in that region is assumed to be purchased from a foreign fuel supplier.

Case 3—Domestic navigation. If the amount of fuel available in the RESD (minus that used for military and fishing operations) is greater than the amount of fuel estimated by MEIT used by vessels involved in domestic voyages, then it is assumed that all the fuel used for domestic navigation was obtained from Canadian suppliers. If the RESD is less than the amount from MEIT, the portion of fuel equal to that of the RESD is assumed to be purchased from Canadian fuel suppliers while the rest of fuel used in that region is assumed to be purchased from a foreign fuel supplier.

Case 4—International navigation (bunkers). The portion of fuel equal to the amount of fuel available in the RESD (minus that used for military, fishing and domestic navigation) is assumed to be purchased from a Canadian supplier to be used for international navigation (bunkers). Then the difference between the MEIT fuel and the RESD fuel is assumed to be purchased from foreign fuel suppliers.

Step 3: Emission Calculation

Emissions are calculated by multiplying the fuel quantity by the fuel specific emission factors (see Annex 6).

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 1990–) 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 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 also based on information collected from Canada's Renewable Fuels Regulations. Currently, it is assumed that no biofuels are used in the aviation sector.

In lieu of 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 A3.1–1 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. For a description of all sources of fugitive emissions, refer to Chapter 3.

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). These three studies contain mine-specific information upon which Canada has based its country-specific data, parameters and information regarding surface and underground mines, and they are confidential.

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 had, in most years, 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 for surface and underground mines is a modified version of a process developed for the International Energy Agency by the Coal Industry Advisory Board (CIAB). Further discussion of some 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 then 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 multiplexer sampling system; (3) an ultrasonic 3-D wind anemometer; (4) a GPS and inertial system; (5) a vehicle equipped with a vertical sampling mast; and (6) a computer and software.

The emissions model is a hybrid of IPCC Tier 2 and Tier 3 methodologies that depends on the availability of mine-specific data. Gross production values provided by Statistics Canada, before any 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 in their respective sections.

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 A3.2–1.

Equation A3.2–1

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

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 0.67 kg/m^3 CH_4.

Between 1992 and 1999, all underground mining ceased in eastern Canada. The remaining underground mines were located in Alberta and British Columbia and were less gassy than mines in eastern Canada. Between 2015 and 2017 there were no active underground coal mines in Canada, however, the Donkin mine in Nova Scotia resumed operation in 2018.

Surface Mines

The CIAB methodology was modified to incorporate confidential Canadian and U.S. site-specific data (from King, Hollingshead and Cheminfo/Clearstone) for the three coal types mined in Canada, rather than using a generalized international data set to represent country-specific circumstances. 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. A field testing campaign to measure fugitive emissions of CH_4, CO_2 and VOCs was performed on four coal mines in late February 2014:

- Sites 1 and 2: two sub-bituminous coal mines in central Alberta
- Site 3: one bituminous coal mine in northeast BC
- Site 4: one bituminous coal mine in northwest Alberta

Methane (CH_4) emissions were measured remotely using a ground-based mobile plume transect system (MPTS) for area sources and tracer tests for volume and point sources (Cheminfo/Clearstone 2014). Data from this field testing was used to modify the CH_4 emission factors of 7 of the 23 producing mines in Canada. The EFs in Table A3.2–1 incorporate these data and assumptions. In addition, the overall CH_4 emission factor uncertainty is reported in Table A2–1 category 1.B.1.a Fugitive Sources—Coal mining and Handling.

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

Table A3.2–1 **Fugitive Emission 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	0.55	t CH_4/kt coal mined
Alberta	Bituminous	Underground	1.69	t CH_4/kt coal mined
Alberta	Sub-bituminous	Surface	0.20	t CH_4/kt coal mined
British Columbia	Bituminous	Surface	0.86	t CH_4/kt coal mined
British Columbia	Bituminous	Underground	2.78	t CH_4/kt coal mined

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

for surface mining were increased by 50% (King 1994) to account for this out-gassing adjustment and are reflected in the emission factors in Equation A3.2–2.

To obtain the emissions from coal mining, Equation A3.2–2 is used.

Equation A3.2–2

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

$EF_{i,j,k,l}$	=	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.

Despite the closing of east coast underground 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.

Activity Data

The model requires the gross mine output data for each type of coal mined in each province. Until 2002, the data was 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.

These weighted emission factors, by mine and coal type, were developed using the King (1994) and Cheminfo/Clearstone (2014) studies and are listed in Table A3.2–1.

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 gases, methane is of greatest concern, while others releases, such as CO_2, are considered small and are not reported since the IPCC provides no method for estimating these emissions (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. Though no Canadian data is available on post-mining venting and capping, provincial regulations require all recently abandoned mines to be capped for safety.

The IPCC Tier 2 equation for abandoned mines takes the general form in Equation A3.2–3.

Equation A3.2–3 **IPCC Tier 2**

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

$CH_4\ Emissions$	=	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 A3.2–4.

Equation A3.2–4 **IPCC Tier 3**

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

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 was only available for five mines in Nova Scotia (King 1994). This data allowed the use of Equation A3.2–4, following the IPCC Tier 3 approach, to estimate 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 A3.2–1 were used to estimate emissions in the final year of production. On the basis of this estimate, Equation A3.2–3 was used to calculate emissions. Calculations were done using five time intervals, which can be seen in Table A3.2–4 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 modelled 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 A3.2–2 for a list of constants applied to Canadian data. This IPCC EF formula was used for all provincial estimates.

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 A3.2–3 characterizes the condition of abandoned mines by flooded and non-flooded, for all regions of Canada that have underground coal mines. In 2018 the Donkin mine in Nova Scotia returned to production and is no longer included in the data for abandoned 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 A3.2–2 **IPCC 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

Table A3.2–3 **IPCC Tier 2/3—Abandoned Underground Coal Mines, 2018**

Region	Number of Abandoned Coal Mines[a]	Number of Abandoned Mines Flooded[b]
Nova Scotia[c]	281	281
Saskatchewan[d]	245	0
Alberta	855	13
British Columbia	51	0
CANADA	**1432**	**294**

Notes:
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 4.27, Equation 4.1.12).

Table A3.2–4 **IPCC Tier 2, % Gassy Mines per Time Interval**

Time Interval	Low	High
1900–1925	0%	10%
1926–1950	3%	50%
1951–1975	5%	75%
1976–2000	8%	100%
2001–present	9%	100%

The IPCC defaults in Table A3.2–4 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 was unavailable for mine gassiness, flooded status and emission factors. As previousely noted, in 2018 the Donkin mine in Nova Scotia returned to production and is no longer included in the data for abandoned mines.

Emissions

The results of emission calculations, for select years, are shown 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 in 1993 and 2000 correspond to closures of large mines in that province. There were two recent mine abandonments in western Canada and the effect of these closures on the model's decline curves are visible in the latest reporting years.

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 (EC 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 A3.2–5 lists the sectors and sources that were estimated in the CAPP and UOG studies (CAPP 2005a; EC 2014) and the 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 follows, 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.

Table A3.2–5 **Allocation of UOG Inventory Emissions to CRF Fugitive Categories**

CRF Fugitive Category	Emission Sector Categories	Emission Source Categories
1.B.2.a.2 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 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

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
- 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.)
- 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
- composition of the inlet and outlet streams

Refer to the CAPP study (CAPP 2005a) and UOG study (EC 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 curve fitting methods, to interpolate the 2001–2004 and 2006–2010 time periods.

Equation A3.2–5 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. Various types of activity data for each province/territory and year were used, such as natural gas and crude oil production volumes, fuel, flare and vent volumes, number of wells drilled, number of spills, ruptures and blowouts, total capable oil and gas wells, and shrinkage. Not all activity data is available for all years or all regions. Emission sources for specific sectors and regions were extrapolated using the most appropriate activity data. Where activity data was not available for the entire time series, the methodology to interpolate intermediate years, which is described later in this section, was used to provide one consistent time series.

Table A3.2–6 lists the publicly available activity data used to extrapolate emissions along with the corresponding data source. Table A3.2–7 contains a list of the activity data used to estimate flaring emissions for each region, sector category and time period while Table A3.2–8 contains the same information for reported venting. Table A3.2–9 displays the activity data that is used to extrapolate emissions for all other UOG fugitive sources such as fugitive equipment leaks, unreported venting,[6] storage losses, etc.

Equation A3.2–5

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

$ER_{i,j}^{k}$	=	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

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 (EC 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 previously. 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.

6 Unreported venting includes venting from processes or equipment that is not typically included in reported venting volumes. This includes pneumatic devices (e.g. chemical injection pumps, natural gas operated instrumentation), compressor start gas, purge gas and blanket gas that is discharged directly to the atmosphere and gas vented from drill-stem tests.

Table A3.2–6 **Required Activity Data and Their Sources**

Publisher	Publication	Activity Data
Alberta Energy Regulator (AER)	ST60B: Upstream Petroleum Industry Flaring and Venting Report (AER 2019a)	Reported venting and flaring volumes
	ST3: AER Industries Monthly Statistics, Gas Supply and Disposition (AER 2019b)	Shrinkage
	Alberta's Energy Reserves and Supply/Demand Outlook (AER 2019c)	In-situ bitumen production
	AER Compliance Dashboard (AER 2019d)	Number of incidents
British Columbia Government	Production and distribution of natural gas (BC 2019)	Reported venting volumes Shrinkage
British Columbia Oil and Gas Commission	Drilling Kicks and Blowouts by Area (BCOGC 2019a)	Sum of kicks and blowouts
	Air Summary Report (BCOGC 2019b)	Reported flaring volumes
Canada Energy Regulator (CER)	Canada's Energy Future (CER 2019)	Non-associated gas production
Canada–Newfoundland and Labrador Offshore Petroleum Board (CNLOPB)	Development Wells—Hibernia (CNLOPB 2019a)	Number of capable wells
	Development Wells—Terra Nova (CNLOPB 2019b)	Number of capable wells
	Development Wells—White Rose (CNLOPB 2019c)	Number of capable wells
	Development Wells—North Amethyst (CNLOPB 2019d)	Number of capable wells
	Development Wells—Hebron (CNLOPB 2019e)	Number of capable wells
	Environment Statistics—Spill Frequency and Volume Annual Summary (CNLOPB 2019f)	Number of spills
	Monthly Gas Flaring (CNLOPB 2019g)	Reported flaring volumes
Canadian Association of Petroleum Producers (CAPP)	Statistical Handbook for Canada's Upstream Petroleum Industry (CAPP 2019)	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)
Manitoba Government	Petroleum Industry Spill Statistics (MB 2019)	Number of spills
New Brunswick Energy and Resource Development	Monthly Production Statistics (NBERD 2019)	Light/medium crude oil production Natural gas production
Saskatchewan Ministry of Energy and Resources	2018 Crude Oil Volume and Value Summary (SK MER 2019a)	Light/medium crude oil production Heavy crude oil production
	2018 Natural Gas Volume and Value Summary (SK MER 2019b)	Non-associated gas production
	Saskatchewan Fuel, Flare and Vent (SK MER 2019c)	Reported flaring and venting volumes
	Saskatchewan Upstream Oil and Gas IRIS Incident Report (SK MER 2019d)	Number of spills
	Saskatchewan Annual Petroleum Statistics (SK MER 2009–2011)	Reported flaring and venting volumes Shrinkage
	Saskatchewan Mineral Statistics Yearbook, Petroleum and Natural Gas. (SK MER 1990–2008)	Reported flaring and venting volumes Shrinkage
Statistics Canada	Table 25-10-0047-01 (formerly CANSIM 131-0001) Natural gas, monthly supply and disposition (Statistics Canada No date [a])	Gross production Field flared and waste Field disposition and usage Gathering system disposal and use Plant uses Shrinkage
	Table 25-10-0055-01 (formerly CANSIM 131-0004) Supply and disposition of natural gas, monthly (Statistics Canada No date [b])	Gross withdrawals
	Table 25-10-0014-01 (formerly CANSIM 126-0001) Crude oil and equivalent, monthly supply and disposition (Statistics Canada No Date [c])	Heavy crude oil production Light/medium crude oil production Synthetic crude oil production Crude bitumen production
	Table 25-10-0063-01 (formerly CANSIM 126-0003) Supply and disposition of crude oil and equivalent (Statistics Canada No Date [d])	Heavy crude oil production Light/medium crude oil production Synthetic crude oil production Non-upgraded production of crude bitumen
	Table 25-10-0044-01 (formerly CANSIM 134-0004) Supply and Disposition of refined petroleum products, monthly (Statistics Canada No Date [e])	RPP domestic sales

Table A3.2–7 **Activity Data Used to Extrapolate Flaring Emissions by Region and Year**

Region	Emission Sector Category	Time Period	Activity Data	Time Period	Activity Data
AB	Light/Medium Crude Oil Production	1990–2000	Field flared and waste	2000–2018	Flaring—Oil batteries
	Heavy Crude Oil Cold Production				Flaring—Oil batteries + Bitumen batteries
	Heavy Crude Oil Thermal Production				Flaring—Bitumen batteries
	Natural Gas Production				Flaring—Gas batteries + Gas gathering systems
	Natural Gas Processing				Flaring—Gas plants
	Well Testing				Flaring—Well testing
	Petroleum Liquids Transportation				Flaring—Total
	Disposal and Waste Treatment				Flaring—Total
BC	Light/Medium Crude Oil Production	1990–1995	Field flared and waste	1996–2018	Flaring—Solution Gas
	Natural Gas Production				Flaring—Production Facilities
	Natural Gas Processing				Flaring—Gas Processing Plants
	Well Testing		Wells Drilled		Flaring—Well Cleanup and Testing
	Well Drilling				Flaring—Underbalanced Drilling
SK	Light/Medium Crude Oil Production	1990–2000	Field flared and waste	2000–2018[a]	Flaring—Non-heavy oil
	Heavy Crude Oil Cold Production				Flaring—Heavy oil
	Heavy Crude Oil Thermal Production				Flaring—Heavy oil
	Natural Gas Production				Flaring—Gas batteries + Gas gathering systems
	Natural Gas Processing				Flaring—Gas plants
NL	Light/Medium Crude Oil Production	1997–2018	Total flaring		
MB, NB, NT	Light/Medium Crude Oil Production	1990–2018	Light/medium crude production		
NB, NS, ON, YT	Natural gas production	1990–2018	Natural gas production		
NT	Natural gas processing	1990–2018	Field flared and waste		
NS, ON	Natural gas processing	1990–2018	Natural gas production		
BC, ON, SK	Petroleum Liquids Transportation	1990–2018	Total crude production		
AB	Well Servicing	1990–2018	Wells Drilled		
SK	Well Testing	1990–2018	Wells Drilled		

Note:

a. Delineation of flaring volumes by oil type (e.g. non-heavy oil, heavy oil) only available from 2012 onwards. Prior to this, flaring volumes from crude oil facilities in Saskatchewan were available as Associated flaring. Associated flare volumes were used to extrapolate cold heavy, thermal heavy and light/medium crude flaring.

Table A3.2–8 **Activity Data Used to Extrapolate Reported Venting Emissions by Region and Year**

Region	Emission Sector Category	Time Period	Activity Data	Time Period	Activity Data
AB	Light/Medium Crude Oil Production	1990–2000	Light/medium crude production	2000–2018	Venting—Oil batteries
	Heavy Crude Oil Cold Production		Heavy crude production		Venting—Oil batteries + Bitumen batteries
	Heavy Crude Oil Thermal Production		In-situ thermal production		Venting—Bitumen batteries
	Natural Gas Production		Natural gas production		Venting—Gas batteries + Gas gathering systems
	Natural Gas Processing		Natural gas production		Venting—Gas plants
	Well Testing		Wells drilled		Venting—Well testing
	Petroleum Liquids Transportation		Total crude production		Venting—Total
BC	Light/Medium Crude Oil Production	1990–2011	Light/medium crude production	2011–2018	Field vented
	Natural Gas Production		Natural gas production		Field vented
	Natural Gas Processing		Natural gas production		Natural gas production
SK	Light/Medium Crude Oil Production	1990–2005	Light/medium crude production	2005–2018[a]	Venting—Non-heavy oil
	Heavy Crude Oil Cold Production		Heavy crude production		Venting—Heavy oil
	Heavy Crude Oil Thermal Production		Heavy crude production		Venting—Heavy oil
	Natural Gas Production	1990–2011	Natural gas production	2011–2018	Venting—Gas batteries + Gas gathering systems
MB	Light/Medium Crude Oil Production	1990–2018	Light/medium crude production		
NT	Natural gas processing	1990–2018	Natural gas production		
AB, SK, BC	Well Servicing, Well Drilling	1990–2018	Wells Drilled		

Note:

a. Delineation of venting volumes by crude oil type (e.g. non-heavy oil, heavy oil) only available from 2012 onwards. Prior to this, venting volumes in Saskatchewan were available as non-associated and associated venting. Non-associated vent volumes were used to extrapolate reported venting from Natural gas production, while associated vent volumes were used to extrapolate cold heavy, thermal heavy and light/medium crude reported venting.

Table A3.2–9 **Activity Data Used to Extrapolate Other Fugitive Emissions by Region for All Years**			
Emission Sector Category	Emission Source Category	Region	Activity Data
Accidents and Equipment Failures	Spills/Pipeline Ruptures	All	Total number of spills, ruptures and blowouts
Accidents and Equipment Failures	Surface Casing Vent Flow/Gas Migration	All	Total number of capable oil and gas wells
Light/Medium Crude Oil Production	Fugitive Equipment Leaks Glycol Dehydrator Off-gas Loading/Unloading Storage Losses Unreported Venting	All	Light/medium crude oil production
Heavy Crude Oil Cold Production	Fugitive Equipment Leaks Glycol Dehydrator Off-gas Loading/Unloading Storage Losses Unreported Venting	AB, SK	Heavy crude oil production
Heavy Crude Oil Thermal Production	Fugitive Equipment Leaks Glycol Dehydrator Off-gas Loading/Unloading Storage Losses Unreported Venting	AB	In-situ bitumen production
		SK	Heavy crude oil production
Natural Gas Production	Fugitive Equipment Leaks Glycol Dehydrator Off-gas Loading/Unloading Storage Losses Unreported Venting	AB, BC, SK	Non-associated gas production
		All other provinces	Natural gas production
Natural Gas Processing	Fugitive Equipment Leaks Glycol Dehydrator Off-gas Loading/Unloading Storage Losses Unreported Venting	All	Natural gas production
Natural Gas Processing	Formation CO_2	All	Shrinkage
Disposal and Waste Treatment	Fugitive Equipment Leaks Storage Losses Unreported Venting	AB	Total crude production
Petroleum Liquids Transportation	Fugitive Equipment Leaks Storage Losses Unreported Venting	PE and QC	RPP domestic sales
		All other provinces	Total crude production
Well Servicing Well Testing	Fugitive Equipment Leaks Glycol Dehydrator Off-gas Storage Losses Loading/Unloading Unreported Venting	All	Wells drilled
Gas Storage	Fugitive Equipment Leaks Unreported Venting	All	Natural gas delivered to and received from storage
Gas Transmission Gas Distribution	Fugitive Equipment Leaks Glycol Dehydrator Off-gas Spills/Pipeline Ruptures Unreported Venting	All	Kilometres of pipeline

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 A3.2–6.

Equation A3.2–6

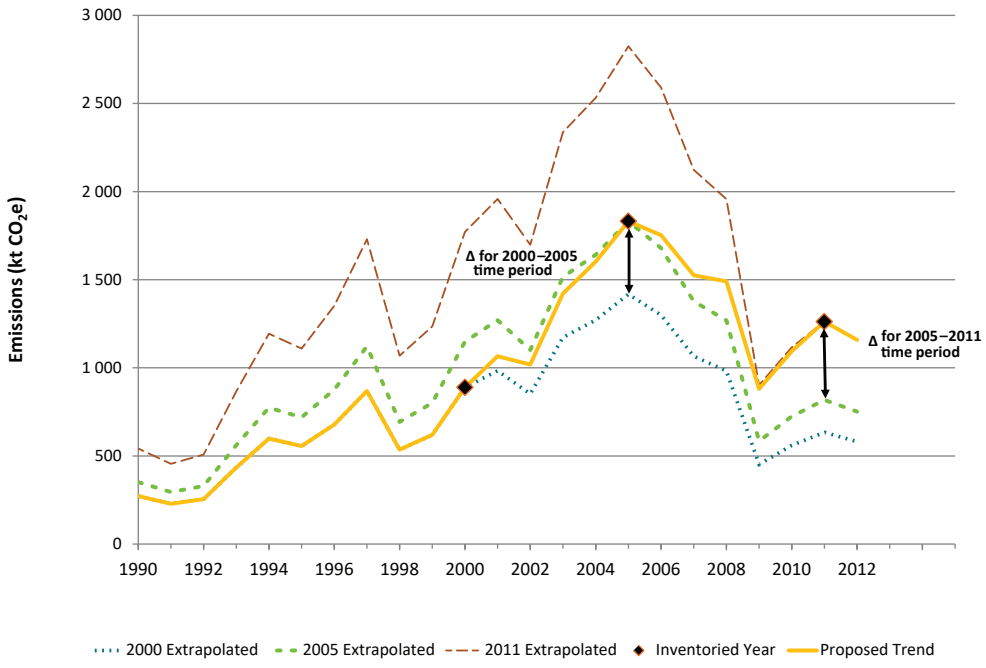
$$ER_{i,j}^{k} = ER_{i,j}^{k,k1\_exp} + \frac{\left(ER_{i,j}^{k2\_inv} - ER_{i,j}^{k2,k1\_exp}\right)}{(k2 - k1)} \times (k - k1)$$

$ER_{i,j}^{k}$	=	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 A3.2–6 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 method will maintain the emission estimates for the inventoried years, while interpolating the intermediate years and maintaining the emissions trend.

Figure A3.2–1 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 was 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.

Figure A3.2–1 **Graphical Representation of the "Wedging" Method**



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 was 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 A3.2–7.

Equation A3.2–7

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

$ER_{i,j}^{k}$	=	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 A3.2–7 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 and Storage

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.

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 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 (EC 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 was compiled by ORTECH Consulting Inc. (2013) for the Canadian Energy Partnership for Environmental Innovation (CEPEI). Data for the years 2000–2004, 2006–2010 and 2012–2014 was provided directly by CEPEI, again following an IPCC Tier 3 approach. Emission estimates for 2015–2018 were extrapolated from 2014 data using the same extrapolation method as described for the UOG sector (see Equation A3.2–5), 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.

Similar to natural gas transmission, fugitive emissions from natural gas storage are taken from the UOG study (EC 2014) for the years 2005 and 2011. Data

for the years 2000–2004, 2006–2010 and 2012–2014 was provided directly by CEPEI. Emission estimates for 1990–1999 and 2015–2018 were extrapolated using the previously described extrapolation methods, with the volume of gas delivered to and withdrawn from storage as the activity factor.

Activity Data

The activity data required to estimate the fugitive emissions from natural gas transmission for 1997–1999 and 2015–2018 is the annual length of the natural gas transmission pipeline by region. Transmission pipeline lengths were published annually by Statistics Canada in *Natural Gas Transportation and Distribution*. Statistics Canada has discontinued this publication but still collects the data and releases it to Environment and Climate Change Canada (ECCC) (Statistics Canada 2019). However, pipeline length data was only available up to and including 2017; pipeline lengths for 2018 were therefore estimated. For Quebec, Ontario, Manitoba, Saskatchewan, Alberta, British Columbia and the Northwest Territories, the 2018 pipeline lengths were estimated based on the average annual change in length between 2000 and 2017. The 2018 values were assumed to be the same as 2017 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.

For natural gas storage, annual volumes of natural gas delivered to storage and withdrawn from storage are taken from *Canadian natural gas storage, Canada and provinces* (Statistics Canada No Date (f)) for the 2015–2018 time period and *Natural gas utilities, monthly receipts and disposition* (Statistics Canada No Date (g)) for data prior to 2015.

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 this 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 A3.2–8.

Equation A3.2–8

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

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 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 is listed in Table A3.2–10.

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 was 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 2000 and onwards, emissions are based on data from the UOG study (EC 2014), following an IPCC Tier 3 approach that rolled up the reported GHG emissions from individual natural gas companies 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 was provided directly by CEPEI, again following an IPCC Tier 3 approach. Emission estimates for 2015–2018 were estimated using the length of natural gas distribution pipeline, taking the approach governed by Equation A3.2–5.

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 is the length of natural gas distribution pipeline per province, which was historically published in Statistics Canada's *Natural Gas Transportation and Distribution* report. Statistics Canada discontinued this publication in 2003 but still collects the data and releases it to ECCC (Statistics Canada 2019). However, pipeline length data was only available up to and including 2017; pipeline lengths for 2018 were therefore estimated for all provinces based on the change in length between 2016 and 2017.

For New Brunswick and Nova Scotia, pipeline lengths for 2000–2006 were provided by Enbridge Gas New Brunswick[7] and Heritage Gas,[8] respectively. In the Northwest Territories, the Ikhil Pipeline began providing Inuvik with natural gas in 1999. Distribution lengths for 1999–2006 were backcast based on the change in distribution length between 2007 and 2008.

7 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).

8 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).

Table A3.2–10 **Required Refinery Activity Data and Their Sources**

Publisher	Publication	Activity Data
Statistics Canada	*Report on Energy Supply and Demand in Canada* (RESD) (Statistics Canada 2003–)	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

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 was 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.

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). Fugitive emissions from the mining, processing and upgrading of bitumen and heavy oil are taken from two separate reports: *An Inventory of GHGs, CACs, and H_2S Emissions by the Canadian Bitumen Industry: 1990 to 2003* (CAPP 2006), prepared by Clearstone Engineering Ltd. for CAPP (referred to hereafter as the bitumen study), and an update to the study that was completed in 2017 by Clearstone for Environment and Climate Change Canada titled *An Inventory of GHGs, CACs, and Other Priority Emissions by the Canadian Oil Sands Industry: 2003 to 2015* (ECCC 2017) (referred to hereafter as the oil sands study).

In general, the bitumen study (CAPP 2006) is the basis for the 1990–2003 fugitive emissions estimates, and the oil sands study (ECCC 2017) is the basis for the 2004–2018 fugitive emission estimates for the OS/HOU industry. 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
- CH_4 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 CH_4) in 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
- 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

Bitumen Study: 1990–2003 Emission Estimates

The bitumen study (CAPP 2006) is a compilation of the individual Tier 3 inventories of facilities involved in the OS/HOU industry from 1990–2003. Table A3.2–11 lists the OS/HOU facilities included in the study.

The facility boundaries were determined to ensure that all target emissions, including those from cogeneration facilities, were included.

The bitumen study (CAPP 2006) used emissions from individual facility reports, where available. These emissions were verified against inventories and data reported to Alberta Environment. When this was not possible, emissions were estimated on the basis of 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 no activity data were available, the emission factor ratio technique was applied. Refer directly to the bitumen study (CAPP 2006) for a discussion of the specific methodologies.

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
- environmental impact assessment files as part of recent energy development applications in the OS/HOU industry
- open literature

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

Oil Sands Study: 2003–2018 Emission Estimates

The oil sands study (ECCC 2017) is a facility-based Tier 3 emissions inventory for the OS/HOU industry completed for the 2015 reference year. It was used as the basis for extrapolating emissions both forwards and backwards in

Table A3.2–11 **List of OS/HOU Facilities in the Bitumen Study (CAPP 2006)**

Operator	Facility Name
Husky Energy Inc.	Lloydminster Upgrader
Consumer's Co-operative Refineries Ltd.	Regina Upgrader
Suncor Energy Inc.	Tar Island
Syncrude Canada Ltd.	Mildred Lake & Aurora

time. Where facility emission reports were available from operators, extrapolation was not required and actual emissions were used. These emission records were verified by Clearstone Engineering Ltd. Table A3.2–12 is a list of the OS/HOU facilities included in the study.

The Regina Upgrader operated by Consumers' Co-operative Refineries Limited was excluded from the oil sands study because it is defined strictly as a refinery even though it does upgrade heavy crude oil. The refinery began operation in 1935 and added upgrading capabilities in 1988. It was included in the bitumen study (CAPP 2006) due to its capabilities to upgrade heavy crude oil. Fugitive emissions for this facility are estimated using the refinery model (see section A3.2.2.3).

In 2016, the Horizon liquid extraction plant operated by Inter Pipeline Offgas Ltd. came online. Emissions from this facility were estimated using emissions data from the Suncor liquid extraction plant (ECCC 2017) and facility-level activity data (AER 2019e) for the two facilities. This method is justified due to the similar operations at the two facilities. In late 2017, both the Fort Hills mine and Sturgeon refinery started operations. Emission estimates for these facilities were developed using emissions data reported to the Greenhouse Gas Reporting Program (GHGRP) (ECCC 2019).

Depending on when each facility commenced operation, emissions were estimated using data from either the bitumen study (CAPP 2006), the oil sands study (ECCC 2017), or both. Table A3.2–13 shows the study used to estimate emissions for each year of the time series for each facility.

Methodology for Extrapolating Emission Estimates

The oil sands model provides emission estimates for the OS/HOU industry for 2003–2018 by multiplying base year emissions data (i.e. 2015) by the ratio of the activity data for the non-inventoried year to that of the base year, as shown in Equation A3.2–9. The base year emissions data were taken from the oil sands study (ECCC 2017).

Equation A3.2–9

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

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

$ER_{i,j}^{baseYr}$ = base year (e.g. 2015) emission rate for compound i and source j, t/year

AF_{j}^{k} = activity values for source j and year k

AF_{j}^{baseYr} = base year (e.g. 2015) activity factor for source j

Activity Data

Table A3.2–14 lists the activity data used to estimate fugitive emissions for each oil sands operation and emission subcategory.

A3.2.2.6. Abandoned Oil and Gas Wells

When an oil or gas well reaches the end of its productive life, the well operator is required to properly abandon the well by removing all the equipment and plugging the well. This is done to prevent gas leakage from the well and to prevent the migration of oil and gas to the surrounding strata. However, methane can be emitted into the atmosphere even when well abandonment best practices are followed. Additionally, abandoned wells that were not properly decommissioned exist. There are a number of reasons for this, including abandonment prior to the enactment of regulations and bankruptcy of the well owner.

Table A3.2–12 **List of OS/HOU facilities in the ECCC bitumen study (ECCC 2017)**

Operator	Facility Name	Oil Sands Operations
Suncor Energy Inc.	Millennium & Steepbank Mines and Upgrader	Integrated Mining and Upgrading
Syncrude Canada Ltd.	Mildred Lake & Aurora Mines and Upgrader	
Canadian Natural Resources Ltd.	Horizon Mine and Upgrader	
Husky Energy Inc.	Lloydminster Upgrader	Upgrading
Shell Canada Energy	Scotford Upgrader	
Nexen Energy ULC	Long Lake Upgrader	
Imperial Oil Resources	Kearl Mine	Mining and Ore Processing
Canadian Natural Upgrading Ltd.	Muskeg River and Jackpine Mines	
Aux Sable Canada Ltd.	Heartland Offgas Plant	Hydrocarbon Liquids Extraction
Inter Pipeline Offgas Ltd.	Suncor Liquids Extraction Plant	

Table A3.2–13 **Basis of emission estimates for each facility in the OS/HOU industry**

Operator	Facility Name	Bitumen Study	Oil Sands Study
Suncor Energy Inc.	Millennium & Steepbank Mines and Upgrader	1990–2003	2004–2018
Syncrude Canada Ltd.	Mildred Lake & Aurora Mines and Upgrader	1990–2003	2004–2018
Husky Energy Inc.	Lloydminster Upgrader	1992–2003	2004–2018
Canadian Natural Upgrading Ltd.	Muskeg River and Jackpine Mines	-	2002–2018
Shell Canada Energy	Scotford Upgrader	-	2003–2018
Inter Pipeline Offgas Ltd.	Suncor Liquid Extraction Plant	-	2003–2018
Canadian Natural Resources Ltd.	Horizon Mine and Upgrader	-	2008–2018
Nexen Energy ULC	Long Lake Upgrader	-	2009–2018
Aux Sable Canada Ltd.	Heartland Offgas Plant	-	2011–2018
Imperial Oil Resources	Kearl Mine	-	2013–2018
Inter Pipeline Offgas Ltd.	Horizon Liquid Extraction Plant	Emission estimates for 2016–2018 were developed using emissions data for the Suncor Liquid Extraction Plant (ECCC 2017) and facility level activity data (AER 2019e).	
Fort Hills Energy Corporation	Fort Hills Mine	Emission estimates for 2018 were developed from data reported to the Greenhouse Gas Reporting Program (ECCC 2019).	
North West Redwater Holdings Corp.	Sturgeon Refinery		

Table A3.2–14 **Activity Data Required for the Oil Sands Model**

Oil Sands Operation	Source Category	Subcategory	Activity Data for Extrapolation
Hydrocarbon Liquids Extraction	Flaring and Incineration	All	Process Gas Receipts (AER 2019e)
	Fugitive	Equipment Leaks	
	Venting	All	
Mining and Ore Processing	Flaring and Incineration	All	Crude Bitumen Production (AER 2019e)
	Fugitive	Equipment Leaks	
		Exposed Mine Face	
		Other	
		Storage Losses	
		Tailings Ponds	
	Process Emissions	Sulphur Recovery	
	Venting	All	
Upgrading	Flaring and Incineration	All	Synthetic Crude Oil Production (AER 2019e; Husky Energy Inc. 2019)
	Fugitive	Equipment Leaks	
		Other	
		Spills and Pipeline Ruptures	
		Storage Losses	
	Venting	All	
	Process Emissions	Sulphur Recovery	
		H_2 Production	

There are two main categories of abandoned wells: plugged and unplugged wells. Unplugged wells are wells without recent production (i.e. inactive, temporarily abandoned/suspended or dormant) or without an operator (i.e. orphaned wells). Plugged wells are wells that have been plugged with cement or any mechanical plug to prevent migration of fluid. Emissions result from both plugged and unplugged wells, but emissions from unplugged wells are significantly higher than emissions from plugged wells. Emissions may also vary depending on the type of production. However, due to data limitations, the approach described here does not differentiate on the basis of the type of production.

Estimation Methodology

A Tier 1 approach was used to estimate emissions from abandoned oil and gas wells using the following equation:

Equation A3.2–10

$$ER_{i,j}^{k} = \sum_{j=1}^{n} EF_{i,l} \times WellCount_{j,l}^{k}$$

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

$EF_{i,l}$ = emission rate per abandoned well for compound i and well type l, tonnes/year

$WellCount_{j,l}^{k}$ = well count for province j, well type l and year k

Emission Factors

The CH_4 emission factors were taken from a study titled *Emissions of Coalbed and Natural Gas Methane from Abandoned Oil and Gas Wells in the United States* (Townsend-Small et al. 2016) on abandoned oil and gas wells in the United States. There are currently no emissions data from abandoned oil and gas wells in Canada.

Table A3.2–15 shows the emission factors used for estimating emissions for both abandoned oil and gas wells. The emission factors are presented in terms of plugging status (i.e. plugged or unplugged) and location (i.e. onshore or offshore). For provinces where limited data is available on the well plugging status, the emission factor for all well types is used.

Activity Data

Annual counts of abandoned wells by province were developed using the data sources shown in Table A3.2–16.

The count of abandoned wells for each year of the time series was further subcategorized into well type (gas or oil), well status (plugged, unplugged or unknown) and location (onshore or offshore). Several assumptions were made to assign the plugging status of a well.

- An unplugged well is a well with a well status of suspended or inactive.
- A plugged well is a well with a well status of abandoned, downhole abandoned, or junked and abandoned.
- Any offshore well that is abandoned or not producing for an extended period is considered plugged.
- Where the plugging status could not be determined, it was considered unknown and a default emission factor was used to estimate emissions.

For the Northwest Territories, Nova Scotia and New Brunswick, this level of disaggregation of activity data was not possible. For the Northwest Territories, there is no publicly available data on abandoned wells for oil and gas operations, and it was therefore difficult to evaluate the number of abandoned wells. For this reason, data from CAPP (CAPP 2019) was used to estimate the abandoned well count. It was assumed that the abandoned well count is the difference between the total number of wells drilled in the province and the number of oil and gas wells completed in the province. Following that, it is assumed that the average lifespan of completed wells is 20 years. For Nova Scotia, monthly production data by well was used to determine the abandonment date of the well. It was assumed that wells were abandoned 6 months after last production. For New Brunswick, the inventory of wells drilled in the province was used to estimate the number of abandoned oil and gas wells. It was assumed that the average life span of a well is 20 years before it is abandoned.

For the remaining provinces (i.e. Alberta, British Columbia, Saskatchewan, Yukon, Manitoba, Newfoundland and Ontario), sufficient information was available in the provincial datasets to determine the number of abandoned wells by well type, well status and location.

Occasionally, the well type was not known. In this case, the emissions from these wells are allocated to oil or gas based on the known ratio of abandoned oil to gas wells in the same year.

A3.2.2.7. Flaring Special Case—Avoiding Double Counting

As defined in the *Report on Energy Supply and Demand in Canada* (Statistics Canada 2003–), producer 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, field uses, gathering uses, plant uses and metering adjustments."

Table A3.2–15 **Emission Factors for Abandoned Oil and Gas Wells**

Abandoned Well Type	Value (kg CH_4/well/yr)	Uncertainty
Plugged wells[a] (onshore)	0.02	-87% to +130%
Unplugged wells[a] (onshore)	87.78	-99% to +150%
Plugged wells[a] (offshore)	0.0035	-87% to +130%
Unplugged wells[a] (offshore)	17.6	-99% to +150%
All well types (plugged and unplugged, onshore)[a,b]	12.09	-83% to 124%
All well types (plugged and unplugged, offshore)[a,b]	2.4	-83% to 124%

Notes:
a. Emission factors taken from Townsend-Small et al. 2016, based on abandoned well results in the United States
b. Assumption for all well types EF: Based on 86% plugged wells and 14% unplugged wells.

Table A3.2–16 **Activity Data Required for Abandoned Oil and Gas Wells**

Region	Source	Publication
Alberta	Alberta Energy Regulator	ST37: List of Wells in Alberta (AER 2019)
British Columbia	British Columbia Oil and Gas Commission	Well Surface Hole Locations (BCOGC 2019c)
Saskatchewan	Saskatchewan Ministry of Energy and Resources	Abandoned well counts were provided upon request[a]
Manitoba	Government of Manitoba: Oil & Gas	Petroleum Statistics, Unique Well Identifier Key List Report (MB 2019)
Ontario	Ontario Oil, Gas & Salt Resource Library	Petroleum Well Data (OGSRL 2019)
Newfoundland & Labrador	Canada–Newfoundland & Labrador Offshore Petroleum Board	Schedule of Wells Summary (CNLOPB 2019h)
Nova Scotia	Canada–Nova Scotia Offshore Petroleum Board	Cohasset Panuke production report (CNSOPB 2019)
		Sable Offshore production report (CNSOPB 2019)
		Deep Panuke production report (CNSOPB 2019)
Yukon	Yukon Government: Energy Mines and Resources	Yukon Well Listing (YK 2019)
Northwest Territories	CAPP Statistical Handbook	Land, Exploration, Drilling Categories (CAPP 2019)
		• Oil wells completed
		• Gas wells completed
		• Wells drilled
New Brunswick	New Brunswick Borehole Database	New Brunswick Borehole Catalog (NB 2019)

Note:

a. Saskatchewan Ministry of Economy. 2019. Personal communication (email from Dolter, A, to Smyth S, Pollutant Inventories and Reporting Division, Environment and Climate Change Canada, dated October 29, 2019).

Statistics Canada determines natural gas producer consumption volumes by summing the following fields from *Natural gas, monthly supply and disposition* (Statistics Canada No Date (a)) for each province:

- field flared and waste
- field disposition and use
- gathering system and processing plant
- plant use
- adjustment

Up until and including the 2015 data year, the data contained in *Natural gas, monthly supply and disposition* was 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 Statistics Canada data and subsequently the RESD. In 2015 Statistics Canada stopped publishing the detailed data contained in the *Natural gas, monthly supply and disposition report*. They now use publically available provincial data to determine the producer consumption volumes reported in the RESD. ECCC has access to this same provincial data and knows the method used by Statistics Canada to determine the producer consumption volumes. The correct amount of gas flared is therefore able to be subtracted to avoid double counting for the years 2015 onwards.

Combustion emissions from the consumption of producer-consumed fuels are estimated using the fuel volumes reported in the RESD (See Annex 3.1). Since flaring emissions are estimated separately using the various fugitive models and reported as fugitives, it is necessary to subtract the volume of flared gas, and the associated emissions, from the combustion estimates in order to avoid double counting, as described in section A3.1.4.1.2.

Based on the previously discussed information, the volume of gas reported as field flared and waste is subtracted from producer consumption.

The provinces that have producer consumption of natural gas values in the RESD accounted for over 98% of total crude oil production in Canada in 2018 and 99.9% of gross natural gas production.

In situations where flaring emissions are estimated for a particular province that has no producer consumption reported in the RESD, the flaring emissions and associated natural gas volumes are not subtracted to ensure there is no underestimation of emissions.

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) since the method used by Statistics Canada to determine producer consumption of still gas is currently not well understood.

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 (EC)'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. Of the nine plants in operation, seven (two of which have two SMR units each) provided ammonia-to-feed fuel factors. One of the two plants that did not provide information does not operate an SMR unit. 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 m^3 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. Furthermore, at plant level, the variability of ammonia-to-feed fuel factor is very steady (it varies less than 0.001% from one year to another over the 5 surveyed years). Similarly, the average ammonia-to-feed fuel factor varies less than 0.001% from year to year over the 5 surveyed years.

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 A3.3–1).

Equation A3.3–1

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

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*, m^3 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 A6.1–1 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 A3.3–2.

Equation A3.3–2

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

$Generated\ CO_2$	=	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 A3.3–3, 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 A3.3–3

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

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 national CO_2 emissions from ammonia production are then calculated by subtracting the recovered CO_2 for urea production in Equation A3.3–2 from the gross generated CO_2 emissions in Equation A3.3–3.

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 2018 were obtained from the following sources: 1990 to 2004 from the Cheminfo Services (2006) study; 2005 to 2009 from EC's voluntary data collection; and 2008 to 2018 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 2018 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 2018, the Canadian steel sector consisted of 14 facilities, namely 4 integrated mills and 10 non-integrated mills (9 mini-mills and 1 ilmenite mill). Of the 14 facilities, 8 are located in Ontario (including 4 integrated mills), 3 in Quebec and 1 in each of Alberta, Saskatchewan, and Manitoba. Table A3.3–1 provides a list of these facilities along with the type of manufacturing processes involved.

Table A3.3–1 **Iron, Steel and ilmenite smelting facilities (2018)**

Integrated mills	
ArcelorMittal Dofasco	Hamilton, ON
Essar Steel Algoma	Sault Ste. Marie, ON
U.S. Steel Canada—Hamilton Works	Hamilton, ON
U.S. Steel Canada—Lake Erie Works	Nanticoke, ON
Mini-mills[a, b]	
AltaSteel Ltd.	Edmonton, AB
Arcelor Mittal Contrecoeur	Contrecoeur, QC
Arcelor Mittal Contrecoeur—Ouest	Contrecoeur, QC
ASW Steel	Welland, ON
Evraz Inc. NA	Regina, SK
Gerdau Ameristeel—Cambridge	Cambridge, ON
Gerdau Ameristeel Manitoba	Selkirk, MB
Gerdau Ameristeel—Whitby	Whitby, ON
Ivaco Inc.	L'Orignal, ON
Ilmenite smelting facility	
Rio Tinto—Fer et Titane Inc.	Sorel-Tracy, QC

Notes:
Information adapted from ECCC 2017.

a. Removed Mini-mill: Hamilton Specialty Bar Corp., Hamilton, ON, which closed permanently in 2018.
b. Added ASW Steel, Welland, ON, which is a small mini mill that was excluded from the Gazette notice.

Canadian Iron and Steel Process Technologies

Steel is produced in Canada by two main steelmaking processes (see Figure A3.3–1): basic oxygen furnaces and electric arc furnaces. 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. operates the only integrated steel plant in Canada that produces part of its steel by the electric arc furnace process. ArcelorMittal Contrecoeur operates the only Canadian steel mill that produces and uses DRI as part 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 materials that are considered in the CO_2 emission estimates for CRF category 2.C.1, Iron and Steel Production.

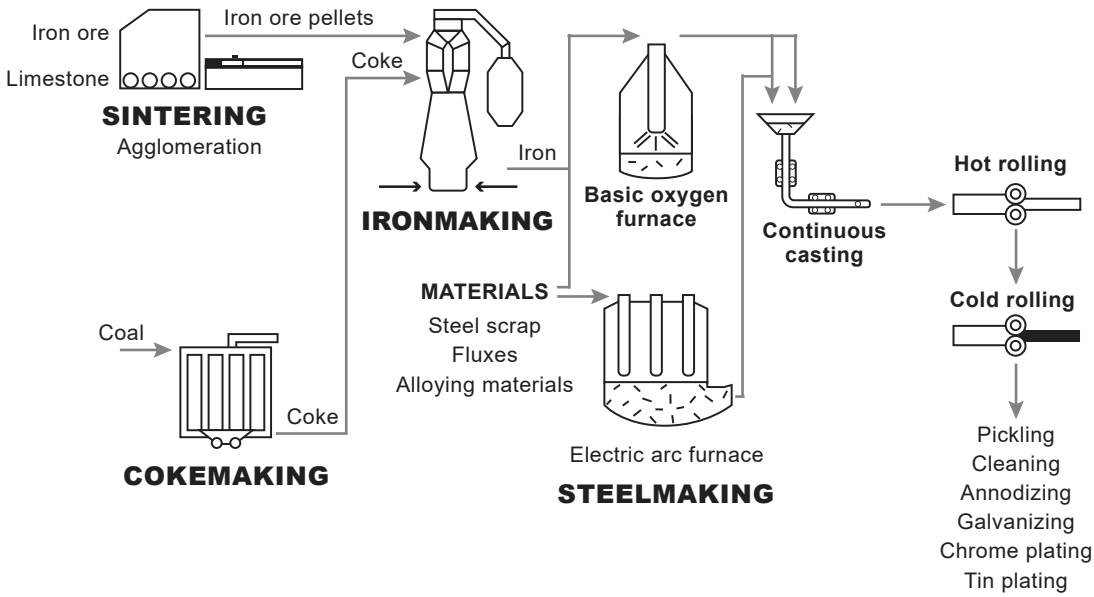
Process materials:

- metallurgical coke (source: Statistics Canada 1990–2018)
- pig iron production (source: Statistics Canada 1990–2012, CSPA 2013–2018)
- pig iron charge to steel furnance (including direct reduced) (source: Statistics Canada 1990–2012, CSPA 2013–2018)
- scrap steel (own and purchased) (source: Statistics Canada 1990–2012, CSPA 2013–2018)
- limestone and dolomite use (source: NRCan 1990–2018)

Emission factors and carbon contents applied are included in Annex 6.

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 4–8), 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.

Figure A3.3–1 **Canadian Steelmaking Processes**



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 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 1990–2018]) 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/m^3) 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 A6.1–5, A6.1–8 and A6.1–9 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 A6.1–5 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 resulting from the use of liquid fuels (feedstock use) in the production of ethylene are estimated and reported in CRF source category 2.B.8.b. The quantities of feedstock use of liquid fuels (specifically propane, butane, ethane, petrochemical feedstocks) in the production of ethylene 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 A6.2–9 in Annex 6 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 A6.2–9 in Annex 6.

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 A6.2–9 in Annex 6. To estimate emissions at national and provincial/territorial levels, the volume of non-energy product used is multiplied by its corresponding emission factor.

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 EC in 1996.[9] 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).[10] 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

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). Use Patterns and Control Implementation Section (UPCIS).

10 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.

for 2005–2010[11] were collected by EC 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 EC 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).[12] Information on HFC-245fa received in these surveys has been incorporated for 2001 through 2007 and 2010 for bulk and in-item data respectively. Data sets from 1995 to 2000 were verified for use, import and export of HFC-245fa, and no instances were found. Where data was unavailable, the quantities were extrapolated to the current inventory year.

In 2014, EC performed a mandatory survey of bulk importers for the data years 2008 to 2012, and the results of the survey and update (ECCC 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. No surveys were performed for the 2016 data year.

In 2018 and 2019, ECCC collected bulk import and export HFC data under the mandatory reporting system set out under the Ozone-depleting Substances and Halocarbon Alternatives Regulations (ODS Regulations) for 2017 and 2018 data which came into force December 29, 2016 (ECCC 2018). Updates to the mandatory surveys of bulk importers for the data years 2008–2015 were also received in 2019 and implemented in this submission.

Table A3.3–2 shows the years where there is activity data for bulk HFC imports and exports, the years when the activity data was collected, and the source of the data. Table A3.3–3 shows the years where there is activity data for HFCs contained in imported and exported manufactured items, the years when the activity data was collected, and the source of the data.

Table A3.3–2 **Years of Activity Data for Bulk HFC Imports and Exports, Years of Collection, and Data Source**

Data Year	Data Collection Year	Data Source
1995	1996	Mandatory survey from UPCIS
1996	1998	Mandatory survey from UPCIS
1997	1998	Mandatory survey from UPCIS
1998	1999	Mandatory survey from UPCIS
1999	2001	Mandatory survey from UPCIS
2000	2001	Mandatory survey from UPCIS
2001	2005	Voluntary survey from Cheminfo Services
2002	2005	Voluntary survey from Cheminfo Services
2003	2005	Voluntary survey from Cheminfo Services
2004	2005	Mandatory survey from UPCIS
2008	2014	Mandatory survey from section 71 of CEPA 1999
2009	2014	Mandatory survey from section 71 of CEPA 1999
2010	2014	Mandatory survey from section 71 of CEPA 1999
2011	2014	Mandatory survey from section 71 of CEPA 1999
2012	2014	Mandatory survey from section 71 of CEPA 1999
2013	2016	Mandatory survey from section 71 of CEPA 1999
2014	2016	Mandatory survey from section 71 of CEPA 1999
2015	2016	Mandatory survey from section 71 of CEPA 1999
2017	2018	Mandatory survey from ODS Regulations of CEPA 1999
2018	2019	Mandatory survey from ODS Regulations of CEPA 1999

Table A3.3–3 **Years of Activity Data for HFCs Contained in Imported and Exported Manufactured Items, Years of Collection, and Data Source**

Data Year	Data Collection Year	Data Source
1996	1998	Mandatory survey from UPCIS
1997	1998	Mandatory survey from UPCIS
1998	1999	Mandatory survey from UPCIS
2004	2005	Mandatory survey from UPCIS
2005	2006	Voluntary survey from UPCIS
2006	2007	Voluntary survey from UPCIS
2007	2008	Voluntary survey from UPCIS
2008	2009	Voluntary survey from UPCIS and voluntary additional data from section 71 mandatory survey of CEPA 1999
2009	2010	Voluntary survey from UPCIS and voluntary additional data from section 71 mandatory survey of CEPA 1999
2010	2011	Voluntary survey from UPCIS and voluntary additional data from section 71 mandatory survey of CEPA 1999
2011	2014	Voluntary additional data from section 71 mandatory survey of CEPA 1999
2012	2014	Voluntary additional data from section 71 mandatory survey of CEPA 1999
2013	2016	Voluntary additional data from section 71 mandatory survey of CEPA 1999
2014	2016	Voluntary additional data from section 71 mandatory survey of CEPA 1999
2015	2016	Voluntary additional data from section 71 mandatory survey of CEPA 1999

11 Except for 2010, data collected by EC 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.

12 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.

A3.3.4.2. **Methodology**

Canada uses a relatively detailed sector breakdown of HFC sub-applications (Table A3.3–4), 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 data collected at an application level had to be broken down to sub-application levels.

A variety of techniques were used to fill in the data gaps from reporters between voluntary surveys. For instance, when a company did not report in subsequent years, the data was held constant. Another technique used for years in which no surveys were 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, ECCC used two approaches to break down the 1995 to 2004 application- level data to the sub-application level. In a given year, the HFCs reported at an application level were broken down based on the proportions of the corresponding sub-application levels if a large amount of HFCs were reported in those corresponding sub-application levels in the same year. If sufficient breakdown was not available for the year and application level, the breakdown from the closest historical year for the same HFC and application level was used.

For the 2008 to 2012 mandatory survey data, the HFCs reported at an application level were broken down based on the 2004 breakdown. The 2004 data was used because the breakdown for this year was the most complete and is currently the best information available. For the 2013 to 2015 data from the mandatory surveys, the HFCs reported at an application level were broken down to sub-application levels based on the 2012 breakdown and, when sufficient information was not available, the 2004 breakdown. For some of the 2008–2015 data, when bulk importers had initially only reported HFCs (by HFC type) without specifying the associated applications or sub-applications, the surveyed bulk importers were asked to provide, to the best of their knowledge, a list of sub-application levels for the reported HFCs. This list of sub-applications was then used by ECCC to evenly distribute the reported HFC quantities.

For the 2017 and 2018 bulk import and export data collected under the ODS Regulations, all the reported data needed to be broken down to sub-application levels. The 2015 breakdown was determined to be the most appropriate because it was the most recent mandatory survey where breakdowns by sub-application were available.

Table A3.3–4 **Canadian HFC Applications and Sub-Applications**

Application/Sub-application 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 A3.3–5 **Proxy Variables Used for HFC Trend Extrapolation**

Proxy Variable Description
Commercial Floor Space
Residential Floor Space
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

For the information on new HFCs received under the ODS Regulations, existing breakdowns of an application to the sub-application level of other HFCs (generally HFC-134a) were used.

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

The 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.

The data were reviewed with respect to time series consistency (IPCC 2006, Volume 1, Chapter 5, section 5.3.3.4) and some gaps were noted for data on bulk imports and exports ,and data on imported and exported MIs containing HFCs. The 2016 data year is a year for which bulk import and export data do not exist, while the 2011 to 2018 data years are years for which complete set of data on HFC-containing imported and exported MIs do not exist. Extrapolation using proxy variables were applied to fill in the data gaps as required. Table A3.3–5 lists the various proxy variables applied for the extrapolation process.

A3.3.4.3. Emission Factors and Lifetimes

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

The information was reviewed (Environmental Health Strategies Inc. [EHS] 2013; ECCC 2015b), taking into account the IPCC Good Practice Guidance, specifically the chapter on quality control measures (IPCC 2000). Emission factors developed based on the collected information were also compared to values published in the 2006 IPCC Guidelines and most were found to be within the same range. Certain emission factors (e.g., the one for equipment decommissioning) did not meet the requirements as per the IPCC Good Practice Guidance for expert elicitation; 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 sub-application 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 sub-applications.

For the air conditioning and refrigeration applications, 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 applications, emission factors and lifetimes were chosen from the 2006 IPCC Guidelines.

Table A6.2–11 in Annex 6 presents the emission factors used to estimate the HFC emissions.

A3.3.4.4. Emission Estimations

The net consumption of a HFC in a specific sub-application are calculated using Equation A3.3–4. This equation is a modified version of equation 7.1 of the 2006 IPCC Guidelines, Volume 3 (IPCC 2006) that has been adapted to the Canadian context. The total quantity of each HFC that remains in products after assembly, in-service and end-of-life losses, also known as a HFC bank, is also calculated.

Equation A3.3–4

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

$C_{net,i}$	=	net consumption of HFC i, kg
$IM_{bulk,i}$	=	imports of bulk of HFC i, kg
$IM_{manufacture,i}$	=	imports of manufactured items of HFC i, kg
$EX_{manufacture,i}$	=	exports of manufactured items of HFC i, kg

Annual emissions for each applicable lifecycle stage are estimated for each sub-application by multiplying the HFC quantity in that stage by its corresponding emission factor. It is assumed that once an item is manufactured, the technology and its inherent in-service emissions rate will remain constant throughout its lifetime. The in-service emission estimate takes into consideration the quantity of HFC that has already been emitted during the assembly stage. Likewise, the emission estimate from the end-of-life of the product is based on the quantity of HFC available after the assembly and in-service emissions have taken place and on the corresponding emission factor for the sub-application. The end-of-life emission factor used also considers regulations in place at the time of decommissioning.

The following sections explain the HFC emission estimation equations applied for each unique application/sub-application in more details.

A3.3.4.4.1. HFC Emissions from Aerosols

HFC emissions from aerosols application are estimated using Equation A3.3–5, which is equation 7.6 of the 2006 IPCC Guidelines, volume 3 (IPCC 2006).

Equation A3.3–5

$$EA_t = (A_t \times EF_A) + (A_{t-1} \times (1 - EF_A))$$

EA_t	=	emissions from aerosols in year t, tonnes
A_t	=	quantity of HFC contained in aerosol products sold in year t, tonnes
A_{t-1}	=	quantity of HFC contained in aerosol products sold in year t-1, tonnes
EF_A	=	in-service emission factor for aerosols, fraction

A3.3.4.4.2. HFC Emissions from Blowinig Agent in Open-cell Foams

HFC emissions from open-cell foam blowing are estimated using Equation A3.3–6, which is equation 7.8 of the 2006 IPCC Guidelines, Volume 3 (IPCC 2006).

Equation A3.3–6

$$EOCF_t = M_t$$

$EOCF\_t$	=	emissions from blowing agent in open-cell foams in year t, tonnes
M_t	=	quantity of HFC used in manufacturing new open-cell foams in year t, tonnes

A3.3.4.4.3. HFC Emissions from Blowing Agent in Closed-cell Foams

HFC emissions from closed-cell foam blowing are estimated using Equation A3.3–7, which is a modified version of IPCC equation 7.7 in the 2006 IPCC Guidelines, Volume 3IPCC 2006). The reason for the modifiction is because no information on recovery and destruction of HFCs in closed-cell foams and their blowing agents are available.

Equation A3.3–7

$$ECCF_t = (CCF_t \times (EF_A + EF_{IS})) + (CCFBank_{t-n} \times EF_{IS}) + (DL_t \times EF_{EOL})$$

$ECCF_t$	=	emissions from blowing agent in closed-cell foams in year t, tonnes
CCF_t	=	quantity of HFC used in manufacturing new closed-cell foams in year t, tonnes
EF_A	=	assembly emission factor for closed-cell foams, fraction
$CCFBank_{t-n}$	=	quantity of HFC charged into closed-cell foam manufacturing between year t and year t-n, tonnes
EF_{IS}	=	in-service emission factor for closed-cell foams, fraction
DL_t	=	decommissioning losses in year t = remaining losses of HFC at the end of service life that occur when the product/equipment is scrapped, tonnes
EF_{EOL}	=	end-of-life emission factor for closed-cell foams, fraction
n	=	product lifetime of closed-cell foam
t	=	current year

A3.3.4.4.4. HFC Emissions from Air Conditioners and Refrigerators Manufactured in Canada

HFC emissions from air conditioning and refrigeration equipment manufactured in Canada are estimated using Equation A3.3–8, which is a modified version of equation 7.10 in the 2006 IPCC Guidelines, Volume 3 (IPCC 2006).

Equation A3.3–8

$$EACROEM_t = (ACROEM_t \times (EF_A + EF_{IS})) + (ACROEMBank_{t-n} \times EF_{IS}) + (DL_t \times EF_{EOL})$$

$EACROEM_t$	=	emissions from air conditioners or refrigerators manufactured in Canada in year t, tonnes
$ACROEM_t$	=	quantity of HFC used in manufacturing new air conditioners or new refrigerators in year t, tonnes
EF_A	=	assembly emission factor for new air conditioners or new refrigerators, fraction
$ACROEMBank_{t-n}$	=	quantity of HFC charged into air conditioners or refrigerators between year t and year t-n, tonnes
EF_{IS}	=	in-service emission factor for air conditioners or refrigerators, fraction
DL_t	=	decommissioning losses in year t = remaining losses of HFC at the end of service life that occur when the air conditioner or refrigerator is scrapped, tonnes
EF_{EOL}	=	end-of-life emission factor for air conditioners or refrigerators, fraction
n	=	product lifetime of air conditioner or refrigerator
t	=	current year

A3.3.4.4.5. HFC Emissions from Air Conditioners and Refrigerators Manufactured Elsewhere

Equation A3.3–8 is applied for estimating HFC emissions from air conditioners and refrigerators manufactured elsewhere, except that assembly emission in this case is zero.

A3.3.4.4.6. HFC Emissions from Solvents

HFC emissions from solvents are estimated using Equation A3.3–9, which is a modified version of equation 7.5 of the 2006 IPCC Guidelines, Volume 3 (IPCC 2006). The reason for the modification is because no information on destruction of HFCs used as solvents is available.

Equation A3.3–9

$$ES_t = (S_t \times EF_S) + (S_{t-1} \times (1 - EF_S))$$

ES_t	=	emissions from solvents in year t, tonnes
S_t	=	quantity of HFC contained in solvents sold in year t, tonnes
S_{t-1}	=	quantity of HFC contained in solvents sold in year t-1, tonnes
EF_S	=	in-service emission factor for aerosols, fraction

A3.3.4.4.7. HFC Emissions from Fire Suppression and Extinguishing Systems

HFC emissions from fire suppression/extinguishing systems are estimated using Equation A3.3–10, which is a modified version of equation 7.17 in the 2006 IPCC Guidelines, Volume 3 (IPCC 2006). The reason for the modification is because no information on the destruction of HFCs used in fire suppression and extinguishing systems is available.

Equation A3.3–10

$$EFSES_t = ((FSES_t + FSESBank_{t-n}) \times EF_{IS}) + (DL_t \times EF_{EOL})$$

$EFSESM_t$	=	emissions from fire suppression and extinguishing systems in year t, tonnes
$FSES_t$	=	quantity of HFC used in fire suppression and extinguishing systems in year t, tonnes
$FSESBank_{t-n}$	=	quantity of HFC charged into fire suppression and extinguishing systems between year t and year t-n, tonnes
EF_{IS}	=	in-service emission factor for fire suppression and extinguishing systems, fraction
DL_t	=	decommissioning losses in year t = remaining losses of HFC at the end of service life that occur when the fire suppression and extinguishing system is scrapped, tonnes
EF_{EOL}	=	end-of-life emission factor for fire suppression and extinguishing systems, fraction
n	=	product lifetime of fire suppression and extinguishing system
t	=	current year

A3.3.4.4.8. HFC Emissions from Miscellaneous and Other Applications

HFC emissions from miscellaneous and other application are estimated using Equation A3.3–11, which is equation 7.18 of the 2006 IPCC Guidelines, Volume 3 (IPCC 2006).

Equation A3.3–11

$$EMOA_t = (MOA_t \times EF_{MOA}) + (MOA_{t-1} \times (1 - EF_{MOA}))$$

$EMOA_t$	=	emissions from miscellaneous and other applications in year t, tonnes
MOA_t	=	quantity of HFC contained in miscellaneous and other products sold in year t, tonnes
MOA_{t-1}	=	quantity of HFC contained in miscellaneous and other products sold in year t-1, tonnes
EF_{MOA}	=	in-service emission factor for miscellaneous and other products, fraction

A3.3.4.4.9. Total Annual HFC Emission Estimations

The total annual emission estimates for each HFC are estimated by summing the emissions from all applicable applications. Once the total annual emission estimates at the national level are obtained, they are distributed by province/territory based on proxy variables, such as gross output of accommodation and food services for commercial refrigeration, and number of households for residential refrigeration.

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 2006–2018), 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 decommissioning and failure are calculated, as shown in Equation A3.3–12.

Equation A3.3–12

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

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 A3.3–13

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

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 (5) is extracted from the *SF_6 Emission Estimation and Reporting Protocol for Electric Utilities* (ECCC and Canadian Electricity Association 2008), available 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 ECCC, 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 2006–2018 were provided by the Canadian Electricity Association and BC Hydro.

A3.4. Methodology for the Agriculture Sector

Overview of Agricultural Emission Methodologies

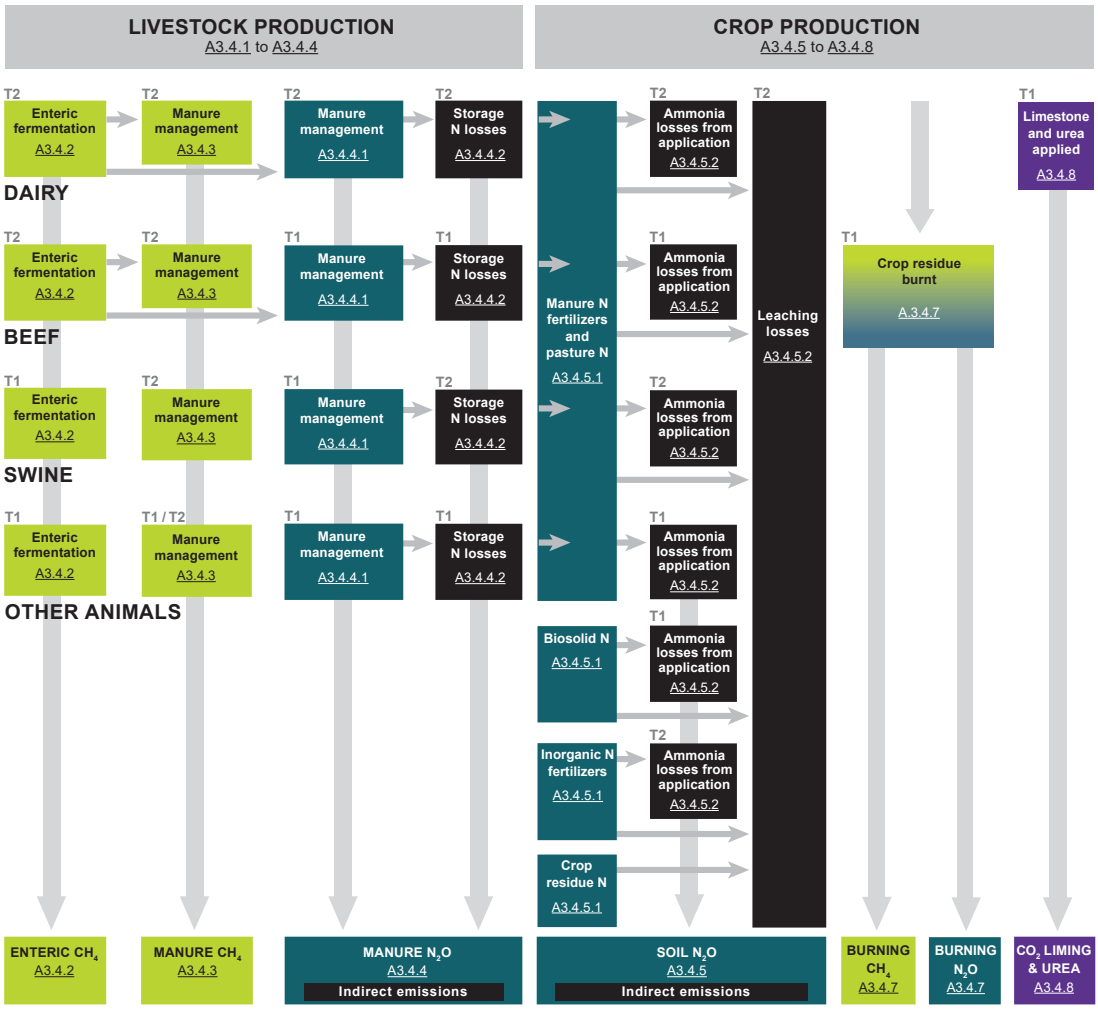
This section of Annex 3 describes the estimation methodologies, equations, activity data, emission factors and parameters that are used to derive the greenhouse gas (GHG) estimates in the Agriculture sector, namely:

- 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 A3.4.2 to 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).

Livestock and crop production are integrated systems that interact in the production of greenhouse gas (GHG) emissions. The GHG estimation methodology described in Annex 3.4 begins with an estimation of emissions related to livestock production, followed by emissions related to crop production (Figure A3.4–1). All approaches prescribed by IPCC (2006) for calculating emissions follow the basic formula of "Activity Data" x "Emission factor." In the case of agricultural emissions, "Activity Data" refers mainly to the number of animals or amount of nitrogen applied to soils. "Emission factor" is an average emission rate for a specific

Figure A3.4–1 **Overview of the Key Methodologies and IPCC Tier Levels Used in Livestock and Crop Production**



GHG from a given source, relative to a unit of activity data. The calculation of emissions is sequential because activity data in the form of nitrogen are passed from the livestock system to the cropping system and nitrogen is tracked as it moves from one source to another.

Livestock emissions are primarily driven by animal populations, but emission factors are dependent on other drivers. The quality and quantity of animal feed influences how quickly animals grow and how much they produce (milk production for example) but animal feed also affects the amount of methane that is produced by an individual animal and how much manure (and therefore both carbon and nitrogen) they excrete back into the environment. As a result, feed quality and animal productivity can be drivers that change livestock emission factors over time. Furthermore, changes in manure management infrastructure (for manure storage and spreading), or farming practices such as changes to the amount of time animals spend on pasture, may further alter the quantity or profile of emissions. Therefore, activity data changes from year to year, but so do emission factors in some cases.

Livestock estimation methodologies used in the NIR can generally be grouped into four categories: (i) dairy, (ii) beef (non-dairy), (iii) swine and (iv) others, based on the estimation methodologies (Figure A3.4–1). For the Beef sector, estimates for enteric fermentation and manure management are based on IPCC Tier 2 methodologies populated with country-specific parameters collected through an expert consultation (Boadi et al., 2004a; Marinier et al., 2004), and animal production data in the form of carcass weight increase (Agriculture and Agri-Food Canada, N.D.). For the Dairy sector, the expert consultation was improved by the introduction of better feed data and production data, and the introduction of information derived from Statistics Canada's farm environmental survey data. For the Swine and All Other Animals sector, the default IPCC tier 1 methodology is used for enteric fermentation. Swine manure management emissions are estimated using a Tier 2 methodology with expert consultation data (Marinier et al., 2004), animal production data in the form of carcass weight increases and information derived from farm environmental surveys. For most other livestock, manure management emissions are calculated from expert consultations or IPCC Tier 1 methods.

Emissions of nitrous oxide from crop production on agricultural soils are primarily driven by nitrogen fertilizer sales and annual crop yields, but where and how much nitrogen is applied to the land are also influenced by nitrogen from manure and human biosolids. A combination of activity data (animal populations) and drivers feed quality and quantity; animal productivity and manure management infrastructure influence the total quantity of nitrogen that is passed from the livestock system to agricultural soils and the amount of nitrogen lost to the environment during these transfers.

Spatially, nitrogen is distributed to agricultural "ecodistricts," and application rates are calculated as a function of the total manure N in the ecodistrict and crop requirements, which are then adjusted to provincial fertilizer sales as outlined in section A3.4.5. A country-specific emission factor for agricultural soils is calculated for each ecodistrict (section A3.4.5.1) that is adjusted based on the topography, soils and climate of the ecodistrict, as well as management practices such as tillage, summerfallow and irrigation. Emissions are then calculated from the amount of nitrogen applied to the soil, multiplied by the unique emission factor for the ecodistrict in which it was applied. The quantity of emissions that results from a given unit of nitrogen added to soils therefore varies by ecodistrict. Sources of nitrogen include inorganic fertilizers, organic fertilizers and crop residue (nitrogen contained in plant matter remaining in fields after harvest).

Nitrogen is tracked throughout the process of crop production and ammonia losses after application of fertilizer and manure to croplands are calculated at a Tier 2 level for fertilizer and manure nitrogen from dairy and swine (Tier 1 IPCC default loss factors are used for all other animals). Indirect emissions of nitrous oxide from nitrogen that is lost from the agriculture system are estimated using Tier 1 IPCC 2006 emission factors (section A3.4.5.2).

Minor emission sources, such as CO_2 emissions from agricultural use of lime and urea and CH_4 and N_2O emissions from field burning of agricultural residues, are described in sections A3.4.8 and A3.4.7, respectively.

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 subcategory and by province, were obtained from Statistics Canada and other sources, as described in Table A3.4–1.

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 *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,[13] llamas and alpacas, deer and elk, wild boars, rabbits and poultry are taken from the COA exclusively, and annual

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

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[14] 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, 1996 and 2016 were received via personal communication[15, 16] and were compiled from responses to the COA. Wild boar and buffalo populations were not collected 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

14 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.

15 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.

16 Taylor, P. 2016. Personal communication (e-mail from Taylor P to Flemming C, Agriculture, Forestry and Other Land Use, dated September 21, 2018).

Table A3.4–1 **Animal Categories and Sources of Population Data**

Category	Sources/Notes
Cattle	Statistics Canada. Table: 32-10-0130-01 (formerly: CANSIM 003-0032)—Number of cattle, by class and farm type, annual (head). https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3210013001 (accessed September 18, 2019)
—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, Deer 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 and 2016 Census of Agriculture: Statistics Canada. Table: 32-10-0427-01 (formerly CANSIM 004-0224). https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3210042701 – linear interpolation between census years, remains constant after last census
Wild Boars	Census year 2016[a]: Taylor, Patrick (Statistics Canada). Personal communication received September 21, 2018. Census years 2001 to 2011: 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). https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3210042701 – linear interpolation between census years, remains constant after last census Census years[a] 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 32-10-0116-01 (formerly CANSIM Table 003-0015) - Supply and disposition of mink and fox on fur farms, annual (Number). https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3210011601 (accessed November 6, 2019).
Mules and Asses[a]	Census year 2016: Laborde, Leon (Statistics Canada). Personal communication received May 16, 2018. Census years 2001 to 2011: Laborde, Leon (Statistics Canada). Personal communication received September 2, 2015. – population held constant prior to 2001 Ccensus, 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/canadian-agri-food-sector-intelligence/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 32-10-0129-01 (formerly CANSIM 003-0031) - Number of sheep and lambs on farms, annual (head). https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3210012901 (accessed October 1, 2019)
Swine	Statistics Canada. Table 32-10-0290-01 (formerly CANSIM 003-0004) - Number of hogs on farms at end of quarter, quarterly (head), CANSIM (database). Years 1990-2006. Statistics Canada. Table 32-10-0145-01 (formerly CANSIM 003-0100 - Hogs statistics, number of hogs on farms at end of semi-annual period, (Head). Years 2007-2018. https://www150.statcan.gc.ca/t1/tbl1/en/cv.action?pid=3210014501 (accessed October 1, 2019)
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 Catalogue No. 95-632). (Statistics Canada [2007b]) 2011 and 2016 Census: Statistics Canada. Table: 32-10-0428-01 (formerly CANSIM 004-0225). Poultry inventory on census day. https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3210042801 (accessed October 22, 2018) – linear interpolation between census years and remains constant after latest census

Note:
a. These data may be affected by errors due to coverage.

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 A3.4–1), but were modified based on expert opinion[17] using a correction factor in order to estimate the number of does, as opposed to total rabbits.

To populate an IPCC Tier 2 enteric fermentation model for the Beef and Dairy sectors, the subcategories of provincial cattle populations collected by Statistics Canada were further disaggregated into sub-annual production stages (i.e. "production subcategory") 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 (i) production and management practices published in scientific journals, (ii) a survey of dairy and beef production practices conducted and administered to regional and provincial beef and dairy livestock specialists across the country, (iii) consultation with scientists at universities and federal research institutions, and (iv) provincial/national associations and 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 eight cattle subcategories were broken down into 38 distinct cattle production stages, 29 for the Beef sector and 9 for the Dairy sector, observed throughout the different provinces of Canada (Table A3.4–2). The model characterizes cattle by physiological status, diet, age, sex, weight, growth rate, activity level and production environment. Further work on the dairy sector was implemented in the 2018 inventory analysis to refine estimates of certain Tier 2 parameters. This update created a time series datum that better captures changes in production practices in the Dairy sector and introduced an analysis of changes in dairy nutrition considering more recent Canadian and North American research (Ellis et al., 2007; Ellis et al., 2010; Sheppard et al., 2011a; Sheppard et al., 2011b; Vanderzaag et al., 2013; Appuhamy et al., 2016; Chai et al., 2016; Jayasundara et al., 2016).

The feeding practices for Beef and Dairy sector livestock are detailed in the next section.

Dairy Sector Production and Performance

Dairy production practices vary across the country because of differences in land prices, climate, forage availability and market access. They have also changed significantly between 1990 and the present. The predominant management practices for each province are reflected in the province-specific parameters entered into the IPCC Tier 2 equations for both enteric fermentation and manure management emissions.

Table A3.4–3 provides an example of production performance data collected for the Canadian Dairy sector, originally used as a quality assurance (QA) verification of the data incorporated in the Tier 2 model at the inception of the Boadi et al. (2004a) study. While the basic subcategory classes developed by Boadi et al. (2004a) were accurate for the mid-2000s when the Tier 2 model was populated, it was recognized that certain production parameters were not static over time and these parameters could impact all aspects of emissions from the sector. Since 1990, with the increase in milk production in the dairy herd, there has also been a shift in the diet of an average dairy cow, both in the quantity and quality of feed consumed.

There are no consistent national data sources for complete dairy feed quality linked to dairy production and performance. However, certain regional and partial resources exist, specifically the feed quality database from Valacta Dairy Services[18] for parts of Eastern Canada and Cost of Production[19] (COP) surveys for Quebec and Ontario. However, consistent milk production statistics do exist for the entire country. Production statistics identifying the relative proportions of the national dairy herd that fall into high, medium and low productivity classes and are linked to herd characteristics such as farm size are collected by Can West DHI, and managed and prepared for the inventory by Valacta Dairy Services.

To develop parameters that link productivity with production practice, the feed quality database developed by Valacta, consisting of feed data collected and analyzed for more than 2000 dairy herds in Quebec and Atlantic Canada, was used as a model to develop a matrix of animal diets that could be related to specific farm sizes and productivity classes. Feed composition, digestibility, crude protein content and some herd characteristics such as lactation lengths and cattle weights were grouped according to five categories of farm size and three categories of productivity class. The feed composition statistics required for Tier 2 calculations were attributed to provinces based on the proportions of their animal populations that fell into different farm size

17 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.

18 valacta.com/EN/publications/Pages/default.aspx

19 cdc-ccl.gc.ca/CDC/index-eng.php?id=3941

Table A3.4–2 **Cattle Production Stage Model**

Subcategory	Production Environment	Period of Year[a]	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[b]	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:
a. Actual period of the year could vary slightly from province to province.
b. Variable dependent on farm, province and animal cycles.

and productivity classes. As the data used in this analysis from Valacta were collected between 2000 and 2010, further cost of production survey data were used as a proxy to project changes in certain feed components, specifically the proportion of silage in diets relative to the proportion of hay for the period of 1990 to 1999.

A time series consisting of the annual weighted provincial averages for feed digestibility, lactation lengths and crude protein content in feed was transferred into the Boadi model structure. Furthermore, provincial Dairy Cattle weights were modified based on average measurements included in the Valacta database for each farm size and productivity class. The percentage change in cattle weight was used as an indicator of changes in body weight, mature weight and weight gain from the 2001 benchmark values established by Boadi et al. (2004a). The resulting Dairy Cow weight time series is also incorporated into the Tier 2 methodology.

Table A3.4–3 **Typical Characteristics of Dairy Production in 2001 in Canada**

Animal Category/Parameters	Production Characteristics[b]	Data Sources[c]
Dairy cows[a]		
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[d] %	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:
a. Values represent typical values observed in Canada but not population-weighted averages quantitatively representing Canadian dairy production, as reported in the CRF.
b. The numbers in parentheses are the standard deviation.
c. Values with no reference were obtained from expert consultations (see Boadi et al., 2004b).
d. "Calf crop" is the percentage of the overwintering cows that produced a live calf.

Milk Yield and Fat Data

Milk productivity has increased in all Canadian provinces (Table A3.4–4), as documented by CanWest DHI,[20] which collects a sample of milk production representing more than two thirds of the Canadian dairy cow population for the 1999–2018 period compiled and prepared for use in the inventory by Valacta Dairy Services. 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. Lactation cycles were on average 320 days; however, cycles vary regionally and are based on herd productivity.

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

Ration Digestibility (DE)

Digestibility of rations (DE) was based on feed data in the Valacta database and cost of production surveys. The values used in the Tier 2 calculations are weighted averages based on measured digestibility in the different diets associated with a specific farm size and productivity class from the data collected by Valacta. For individual provinces not represented directly by Valacta's data, DE values were obtained by multiplying the DE by the proportion of animals in each farm size and productivity

20 canwestdhi.com/publications.htm

Table A3.4–4 **Average Milk Production from 1990 to 2018 at a Provincial Level**

	Average Milk Production (kg/head/day)									
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
1995	23.1	23.1	23.2	23.0	22.2	24.0	24.2	24.2	25.5	26.8
2000	27.4	26.1	26.8	26.4	25.5	26.5	27.9	27.7	29.0	30.0
2005	27.0	27.1	26.9	26.4	25.9	26.7	27.4	29.3	29.3	30.4
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
2016	30.9	30.0	29.7	27.6	29.3	31.0	31.5	35.6	35.5	34.0
2017	30.5	31.3	30.8	28.4	29.8	31.3	31.5	35.0	34.6	32.2
2018	31.8	31.6	31.1	29.8	30.3	31.3	32.0	37.0	35.5	33.9

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

class for each province. The provincial DE time series was then inserted into the existing Tier 2 approach, replacing the fixed values from Boadi et al. (2004a).

Since 1990, the proportion of hay in feed has decreased, while the proportion of silages has increased. Silages typically have a higher feed value as the digestible portion of the feed is better preserved and, as a result, more of the feed is available for digestion by the animal. Furthermore, there has been a small overall increase in the amount of concentrates and supplements used in diets. Overall, DE ranges from 69% to 72% for lactating cows, and 63% to 65% for dry cows, while heifers were assumed to have a diet similar to dry cows.

A3.4.1.1. 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 A3.4–5 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 A3.4–6. Carcass weight data are collected by the Canadian Beef Grading Agency (CBGA) and published by Agriculture and Agri-Food Canada (AAFC 1990–2018). Carcass weights increased from 1990 to 2003 for beef cows, heifers for slaughter, steers and bulls (Figure A3.4–2). 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 2018, the slaughter weight of bulls was used in the time series again. 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 either are 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.

Table A3.4–5 **Typical Characteristics of Beef Production in Canada in 2001 from Various Sources**

Animal Category/Parameters	Production Characteristics[a]	Data Sources[b]
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:
Values represent typical values observed in Canada but not population-weighted averages quantitatively representing Canadian beef production, as reported in the CRF.

a. The numbers in parentheses are the standard deviations.
b. Values with no reference were obtained from expert consultations compiled in Boadi et al. (2004b).

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.

Figure A3.4–2 **Non-Dairy Cattle Carcass Weight, Based on Data Collected by CBGA and Published by Agriculture and Agri-Food Canada**

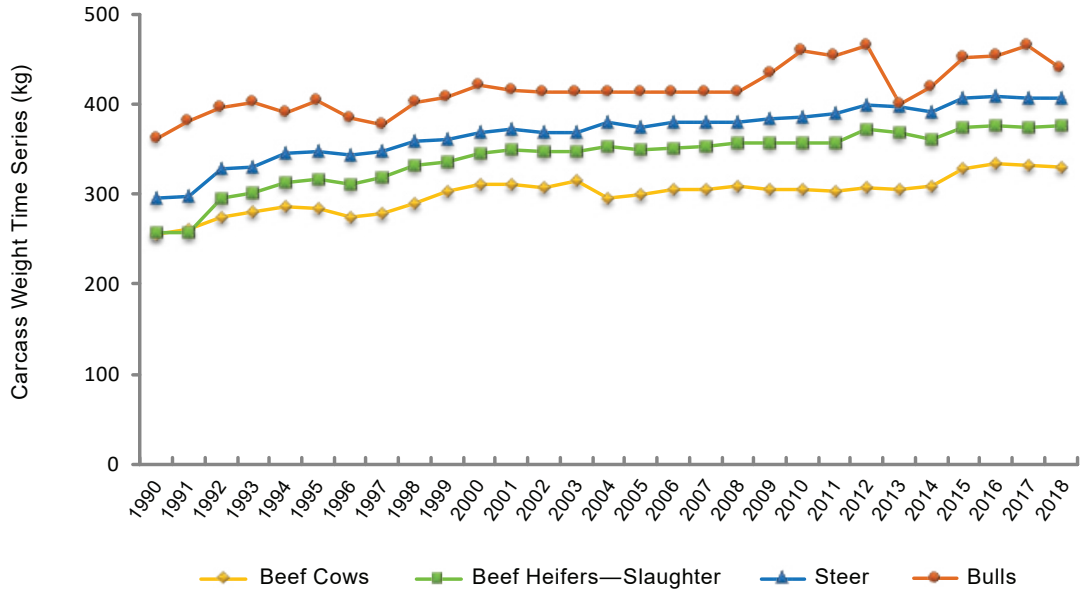


Table A3.4–6 **Indicators of Live Body Weight Change Over Time for Cattle Subcategories**

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–Present uses carcass weight trend again.
Calves	No change
Dairy cows	Provincial trends in dairy cow productivity are used along with average body weight by productivity class, as an indicator of live weight.
Dairy heifers	Trends in dairy cow live weight used as an indicator of dairy heifer live weight.

A3.4.1.2. Swine

Production Performance

Trends in carcass weights are used as an indicator of changes in mature weight. Carcass weight data are collected and published by Statistics Canada as part of the quarterly Farm Cash Receipts (FCR) survey (Statistics Canada, No date. Table 32-10-0126-01 [formerly CANSIM 003-0028]—Hogs, sheep and lambs, farm and meat production). Average cold-trimmed carcass weights are converted to live weights using the corresponding conversion factor (Agriculture and Agri-Food Canada. 2018). Since 1990, hog carcass weights have increased steadily from 77 kg to 99 kg (+29%), as a result of a change in production practices and genetics. Relationships between live weight and average daily weight gain, and changes in average daily weight gain over time by animal weight class, were developed based on data from the Prairie Swine Research Centre (PSRC) and combined with the time series of mature weights to develop a time series of typical animal mass (TAM) for market swine. The TAM for market swine varies by weight class (Figure A3.4–3) based on increased rates of growth and, in the case of the upper weight

class, an increase in carcass weights since 1990. Animal mass for breeding animals was held constant using the default IPCC value.

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 A3.4–1. CH_4 emissions from enteric fermentation for cattle are estimated using the country-specific emission factors derived from IPCC (2006) Tier 2 equations (Table A3.4–7). For the other animal categories, the IPCC Tier 1 methodology and default emission factors are applied (see Annex 6).

Equation A3.4–1

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

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 A3.4–7 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 A3.4–2.

Equation A3.4–2

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

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, %

Figure A3.4–3 **Typical Animal Mass for Swine, by Weight Class**

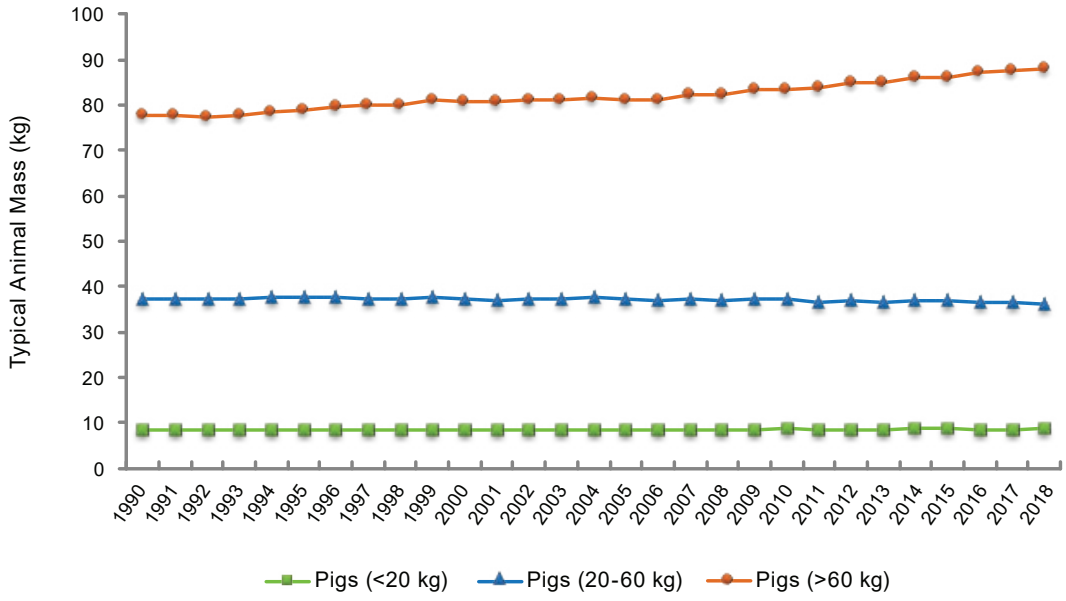


Table A3.4–7 **CH_4 Emission Factors for Enteric Fermentation for Cattle from 1990 to 2018**

	$EF_{(EF)T}$ – (kg CH_4/head/year)[a]							
Year	Dairy Cows	Dairy Heifers	Bulls	Beef Cows	Beef Heifers	Heifers for Slaughter[b]	Steers[b]	Calves
1990	115.4	79.4	108.0	105.9	82.5	44.7	41.4	43.8
1995	119.1	78.6	117.2	112.1	85.9	48.8	43.6	43.8
2000	125.4	78.0	121.0	117.5	89.4	53.0	47.8	43.8
2005	125.0	77.2	119.9	114.4	87.0	52.8	46.0	43.6
2010	128.6	76.8	128.5	115.2	87.8	52.8	47.0	43.7
2011	129.2	76.8	127.6	115.0	87.5	52.7	47.4	43.7
2012	129.6	76.8	129.8	115.6	87.6	53.8	48.0	43.7
2013	134.0	76.8	117.1	115.3	87.5	53.7	48.0	43.8
2014	134.1	76.7	121.1	116.3	88.1	53.2	48.1	43.8
2015	135.2	76.7	127.5	120.0	90.7	53.8	48.8	43.8
2016	137.5	76.7	128.0	121.3	91.6	53.9	48.8	43.8
2017	138.1	76.7	130.1	120.8	91.3	53.6	48.4	43.8
2018	139.6	76.7	125.3	120.5	91.2	53.7	48.5	43.8

Notes:
a. 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.
b. Reported as kg/hd/yr; however, emissions are calculated based on time to slaughter.

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 A3.4–3) was implemented for Non-Dairy Cattle.

Equation A3.4–3

$$Cf_i(in\ cold) = Cf_i + 0.0048 \times (20 - {}^{o}C)$$

Cf_i = A coefficient that varies for each animal category relating weight to energy requirements for body maintenance, MJ/day/kg

${}^{o}C$ = Mean daily temperature during the winter season

The cold-adjusted Cf_i 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. It 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 and the cold-adjusted Cf_i. As a result of this implementation, considering the different production stages of the animal, average annual Cf_i values varied between 0.43 for non-dairy cows in Manitoba, the coldest province, and 0.37 for non-dairy cows in Ontario and some of the Maritime provinces. Based on a weighting of production stages, the Cf_i would typically be 0.35, not considering the temperature effect. The lower Cf_i 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 supplied within a production stage.

For each province, an emission factor (EF(EF)) is calculated according to Equation A3.4–4. 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 A3.4–7). For Non-Dairy Cattle, the IPCC

default of 6.5% GEI was used to calculate non-feedlot cattle emission factors and 3% GEI used for animals in feedlots.

The dairy Y_m factor was derived directly from production data and empirical CH_4 prediction equations developed from North American research. Briefly, the farm size by productivity matrix used to derive digestible energy was also used to provide more detailed feed characteristics such as neutral detergent fibre (NDF), fat content and non-fibre carbohydrate (NFC) content. These feed, herd and production characteristics separated by farm size and productivity class were inserted into 12 predictive methane equations, compiled from three scientific publications (Ellis et al., 2007; Ellis et al., 2010; Appuhamy et al., 2016). Gross energy for each production and farm size class was calculated according to Equation A3.4–2 based on the herd specific characteristics. Finally, the methane conversion rates (Y_m) were back-calculated from predicted methane emissions and calculated gross energy intake.

An average Y_m per productivity and farm size class was calculated based on the results of the 12 predictive equations. This value was then weighted for each province based on the proportional breakdown of the population of animals in each productivity and farm size class in the same way as a provincial digestibility value was derived. The Y_m that was derived varied between 5.9% for the lowest productivity classes and 5.4% for the highest productivity class. Weighted provincial Y_m values varied between 5.5% and 5.7%.

Equation A3.4–4

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

$EF_{(EF)T}$	=	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 were carried out. These results were then evaluated in light of the implementation of the 2006 IPCC Guidelines.

The 2011 analysis 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 5.7% (±0.9) 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; Jayasundara et al., 2016). For Non-Dairy Cattle, these values agree broadly with the values published in the 2006 IPCC Guidelines. Recent work by Escobar-Bahamondes et al. (2016) suggests that further differentiation of Y_m factors by production subcategory is possible, which could aid in improving the accuracy of emission estimates. 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) and Dairy Cattle (i.e. 115 to 137 kg CH_4/head/year). A recent publication by Jayasundara et al. (2016) compiled literature data from 11 studies and found that Y_m factors for Canadian Dairy Cattle were on average 5.7 (±0.9)%. In the current Canadian cattle model, Y_m for dairy cows is varied over time and by province, averaging 5.5%–5.7% of GE, while a fixed Y_m of 6.5% is used for dry dairy cows, dairy heifers.

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.

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).

Improvements to the dairy model in the 2018 national inventory report, in particular with the Y_m derived directly from empirical relationships from North American studies, assure that emission rates are consistent with recent measurements of CH_4 emissions, greatly improving the accuracy of emission estimates. Similar approaches would significantly improve estimates from the Non-dairy sector; however, data are still being compiled to carry out these studies. In general, it is difficult to improve Canadian estimates through updates of single parameters. Improving on the current model requires a comprehensive approach effectively linking regional animal production characteristics to animal productivity, as has been done in the Dairy sector.

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 A3.4–8); and (iii) used the provincial distribution of manure management systems with improved estimates of probability distributions (Table A3.4–8). 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. Uncertainty analysis on the new dairy model, however, has not yet been carried out and reported uncertainty estimates are based on the Boadi et al. (2004a) methodology.

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

Table A3.4–8 **Uncertainties in Inputs, Sources of Uncertainty and the Spatial Scale and Animal Category to Which Uncertainty is Assigned, for Parameters Used for Estimating Methane Emissions from Enteric Fermentation**

Parameter Category	Parameter	Coefficient/Parameter Source	Distribution Type	Uncertainty Range[a]	Uncertainty Distribution Source and Notes	Spatial Allocation/Animal Category Allocation
Population Data[g]						
Cattle Biannual Surveys						
	Dairy	Statistics Canada (Table 003-0032)	normal	±6% – ±42%	Karimi-Zindashty et al. (2012) from Statistics Canada, personal communication[d]	Provincial/subcategory
	Non-dairy			±5% – ±73%		
Other Survey-based Populations						
	Swine	Statistics Canada (Tables 003-0004 and 003-0031)		±8% – ±89%		
	Sheep			±14% – ±80%		
Census of Agriculture						
	Goats	*Census of Agriculture* (Statistics Canada, 2012a)		±9% – ±21%	Statistics Canada, *Census of Agriculture* plus uncertainty associated with linear extrapolation, function of time from census	
	Poultry			±5% – ±12%		
	Bison			±18% – ±85%		
	Llamas and Alpacas			±16% – ±42%		
	Horses			±5% – ±16%		
Cattle Production Parameters and Performance						
	Milk production[g]	Valacta/Canwest DHI	normal	±8%	Karimi-Zindashty et al. (2012) – from expert opinion	Provincial/subcategory
	Fat content[g]	Valacta/Canwest DHI				
	Dairy herd efficiency[g]	Valacta/Canwest DHI				
	Pregnancy coefficient	Boadi et al. (2004b)	normal	±5%	Karimi-Zindashty et al. (2012) – from expert opinion	
	Average daily gain (ADG)	Boadi et al. (2004b)				
	Pregnancy period	Boadi et al. (2004b)				
	Production stage duration	Boadi et al. (2004b)	normal except slaughter animals, triangular, non-symetric	±5%, Slaughter animals: MLV[e] 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[f]
	Production stage population fraction	Boadi et al. (2004b)	normal	±5% – ±30%		
Cattle Weight Estimates[g]						
	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)				
	Carcass weight	CBGA[b] and published AAFC[c] (1990–2010)				National/subcategory
Emissions Factors for Cattle (IPCC Tier 2 Equations)						
	Methane conversion rate (Y_m)		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 A3-18						
	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
Net Energy for Cattle Tier 2 Equations 4.1 to 4.10, IPCC Good Practice Guidance (2000)						
	Animal activity coefficient (C_a)	IPCC (2000)	normal	±30%	Karimi-Zandashty et al. (2012) – Monni et al. (2007)	National/cattle
	Gender coefficient (C)		normal	±30%		
	Maintenance coefficient Cf_i			±30%		
	Lactation coefficient			±30%		
	Weight loss rate		normal	5%	Karimi-Zindashty et al. (2012) – from expert opinion	Provincial/subcategory
	Weight loss duration		uniform	LB: 0 UB: 20% of lactation period.	Interpretation of differences between 2000 and 2006 IPCC Guidelines	
Non-cattle Emission Factors						
	Swine	IPCC (2000)	normal	±37%	Karimi-Zandashty et al. (2012) – Monni et al. (2007)	National/category
	Other animals			±50%		

Notes:

a. Where differences in uncertainty exist for different provinces or animal categories, maximum and minimum uncertainties are given.
b. Canadian Beef Grading Agency.
c. Agriculture and Agri-Food Canada.
d. Personal communication. Plourde R, Statistics Canada, Livestock and Food Section, Ottawa, ON. April 4, 2010.
e. MLV = most likely value; LB = lower bound; UB = upper bound.
f. Internal correlation indicates values that vary in terms of a fraction of the whole, i.e., a fraction of a total equalling 100%.
g. Values that were allowed to vary independently during trend analysis.

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 (NEmob) 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 “g” in Table A3.4–8). The parameters in 1990 and 2012 are considered 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 between 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 of 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 major drivers of uncertainty in emission estimates were 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 (Cf_i), 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. It is suspected that the recent revisions to the dairy model will have reduced the overall uncertainty of enteric emission estimates; however, further analysis is required to quantify the impact of improvements on the uncertainty estimates.

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 A3.4–5 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 using IPCC Tier 1 emission factors. 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 A3.4–1.

When default emission factors or country-specific information sources are not available for the minor livestock categories, logical proxies are used to estimate emissions. These proxies are based on species similarities as well as similarities in production practices. When proxies are used at a provincial level, weighted national values may not match between the native and proxy livestock categories due to differences in provincial populations used for weighting.

The following proxies and expert judgement are used for minor animal categories:

1. Non-Dairy Cattle manure management parameters are used to represent Bison, including the Maximum CH_4 Producing Potential (B_0) and Provincial AWMS distributions.
2. Provincial AWMS distributions for Horses are used to represent Mules and Asses.
3. Provincial AWMS distributions for Non-Dairy Cattle are used for Deer and Elk, except that liquid systems are distributed to PRP based on expert judgement that Deer and Elk manure is unlikely to be handled by liquid manure systems.
4. Volatile solids for Swine are used to represent Wild Boar at a provincial level. The disaggregation of swine subcategories and scaling of VS with animal mass (section A3.4.3.6) are not used for this proxy relationship. Lastly, all Wild Boar manure is allocated to solid AWMS based on expert judgement.
5. Sheep manure management parameters are used to represent Llamas and Alpacas, including volatile solids (VS) and Provincial AWMS distributions.

The total emissions from minor animal categories Mules and Assess, Deer and Elk, Llamas and Alpacas, Mink, Fox, Rabbits and Wild Boar represented a total of 91 kt CO_2e in 2018 (0.2% of total agricultural emissions), including direct and indirect emissions and emissions from application to agricultural soils. Changes to these proxies could not have a significant impact on emission

estimates from the agricultural sector, and based on the insignificant impact of these animal categories on agricultural emissions, improvements to these animal categories are of the lowest priority in the agricultural inventory.

Equation A3.4–5

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

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 A3.4–6

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 A3.4–6. The following equation represents an IPCC Tier 2 estimate of CH_4 emission factors from manure management systems:

Equation A3.4–6

$$EF_{(MM)T} = VS_T \times 365 \times B_{0T} \times 0.67 kg/m^3 \times \sum_{ij} MCF_{ij} \times AWMS_{Tij}$$

$EF_{(MM)T}$	=	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 A3.4–3. Estimates of VS were derived for each cattle subcategory at the provincial level based on regional and seasonal stages of production (Equation A3.4–7). 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; however, increases of DE in dairy feed over time have moderated this effect for Dairy Cattle.

Equation A3.4–7

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

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 (unitless)
ASH	=	ash fraction of the manure, %

Swine (VS)

Volatile solids for swine (Table A3.4–10) were estimated by first calculating provincial VS excretion 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. Typical animal mass was used to convert the temporally fixed VS into units of VS per 1000 kg body weight (kg VS/1000 kg animal mass/day), which was then applied to the full animal mass time series.

All Other Animals (VS)

Volatile solids for animal categories other than cattle and swine 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 A3.4–8). 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 A3.4–9).

Table A3.4–9 **Mean Volatile Solids in Manure of Non-Cattle Animal Categories in 2018 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[a]	0.60	31
Mature Horses	3.6	16
Goats	0.72	41
Bison	3.1	16
Wild Boars[b]	0.23	50
Poultry	0.02	20

Notes:
a. Llamas and alpacas are given the same values as sheep, at the provincial level, and weighted based on the population of llamas and alpacas in each province.
b. Wild boars value calculated based on swine.

Table A3.4–10 **Mean Volatile Solids in Swine Manure in 2018**

Animal Category	VS (kg / 1000 kg body mass / day)	Typical Animal Mass (kg)	VS (kg / day)
Sows	1.57	198	0.31
Boars	1.57	198	0.31
Pigs (<20 kg)	10.78	8.7	0.09
Pigs (20-60 kg)	5.14	36	0.19
Pigs (>60 kg)	4.56	88	0.40

Equation A3.4–8

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

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

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 Cattle are detailed in section A3.4.1.1.

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.

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 A3.4–11). This method does not, however, account for additives that

Table A3.4–11 **Approximate Digestible Energy (DE) for Selected Livestock Subcategories and Data Sources**

Animal Category	DE (%)	Data Sources[a]
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:
a. Data sources: Expert consultations (Marinier et al., 2004).

Table A3.4–12 **Dry Matter Intake for Selected Livestock**

Animal Category	DMI (kg/head/day)	Data Sources[b]
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 [a]	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)

Notes:
a. Calculated as 3.5% of body weight.
b. Data sources: Expert consultations (Marinier et al., 2004).

may increase or decrease digestibility. The DMI for non-cattle was determined through consultation with experts and published values (Table A3.4–12).

Manure Ash Content (ASH)

The ash content in the manure is the inorganic portion of the manure. Table A3.4–13 contains the values used in this inventory for ash content in volatile solid calculations and their sources.

Table A3.4–13 **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)

A3.4.3.2. 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 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.

A3.4.3.3. 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.

Anaerobic treatment lagoons and daily spread are not typically used for manure storage in Canada. Though some examples may exist, they cannot be quantified and, for this reason, are currently considered non-significant and are not estimated. The existence of these types of systems was not identified in the expert consultation carried out by Marinier et al. (2004) or across Farm

Environmental Management Surveys, which are the sources of AWMS allocation data for Canada. Therefore the amount of manure treated by these systems is assumed to be negligible. Earthen storage systems exist in Canada, but in these storage systems, solids are removed regularly when the storage systems are emptied on an annual basis and there is no long-term accumulation and anaerobic treatment of solids in the lagoon, as is the case with "anaerobic treatment lagoons" as defined by the IPCC guidelines.

Dairy

For the Dairy Cattle category, a relationship between farm size and time spent on pasture, in exercise yards and in barns was developed from Sheppard et al. (2011) for each province. The proportion of manure excreted in each of these locations is assumed to be equal to the time spent in each area. Time spent on pasture was found to decrease with increasing farm size, and the fraction of manure deposited on pasture decreased on average from 19% in 1990 to 16% in 2016 due to a shift towards larger farm operations.

For manure deposited in barns, a manure storage time series was developed from a combination of data from the Farm Inputs Management Survey (1995), the Farm Environmental Management Surveys (2001, 2006, 2011) and the Livestock Farm Practices Survey (2005). The use of liquid systems was estimated based on a relationship to farm size, for Eastern and Western Canada respectively, derived from the survey data. Liquid system use increased from 17% in 1990 to 64% in 2011, the most recent survey year, while solid manure is assumed to be inversely related to liquid use. Survey data were used to disaggregate liquid systems into three AWMS sub-systems: earthen basin, tank and slatted floor. A portion of total solid manure is composted, while the remainder is disaggregated into two solid AWMS sub-systems: Pack and Pile based on survey data. For each liquid subsystem, manure was separated by the presence or absence of crust formation based on data collected from the Livestock Farm Practices Survey compiled in Sheppard et al. (2011a). Lastly, for each liquid and solid subsystem in a given province, manure was further divided based on the use of manure covers during storage.

Swine

For swine, a manure storage time series was developed from a combination of data from the Farm Inputs Management Survey (1995), the Farm Environmental Management Surveys (2001, 2006, 2011) and the Livestock Farm Practices Survey (2005). The use of liquid systems was estimated based on a relationship with farm size, and was modelled based on provincial farm sizes from the *Census of Agriculture*. Liquid system use increased from 80% in 1990 to 97% in 2011, the most recent survey year included, while solid manure was assumed to be inversely related to liquid use. Survey data were used to disaggregate liquid systems into three AWMS sub-systems:

Table A3.4–14 **Percentage of Manure Handled by Animal Waste Management Systems (AWMS) for Canada (per Animal Category, Based on the Distribution of Animal Populations in 2018)**

Animal Category	Liquid Systems (NL)	Solid Storage and Drylot (NSSD)	Pasture, Range and Paddock (NPRP)	Other Systems (NO)
Non-dairy Cattle	5.2	45	46	4.2
Dairy Cattle	64	18	16	2.9
Poultry	7.0	92	0.6	0.6
Sheep and Lamb	0.1	34	66	0.02
Llamas and Alpacas[a]	0.03	28	72	0.02
Swine	97	3	0	0
Goat	0	42	58	0
Horse	0	31	68	0.7
Bison	0.2	46	50	4.0
Deer and Elk[b]	0	47	50	3.5
Fur-bearing Animals[c]	0	100	0	0
Mules and Asses[d]	0	32	68	0.7
Wild Boars[c]	0	100	0	0

Notes:
Totals may not add up to 100% due to rounding.

a. Assumes that manure handled by AWMS is the same for llamas and alpacas as for sheep and lambs, at the provincial level.
b. Identical distributions to non-dairy cattle, except that liquid systems are distributed to pasture, range and paddock (PRP).
c. Assumed 100% solid manure.
d. Assumes that manure handled by AWMS is the same for mules and asses as for horses.

earthen basin, tank and slatted floor. Solid manure was disaggregated into two solid AWMS sub-systems: Pack and Pile, based on survey data. For each liquid subsystem, manure was separated by the presence or absence of crust formation based on data collected from the Livestock Farm Practices Survey (Sheppard et al., 2010b). Lastly, for each liquid and solid subsystem in a given province, manure was further divided based on the use of manure covers during storage.

All Other Animals

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 A3.4–11. Briefly, among the dominant animal production categories across the country, poultry manure is stored as solid manure, and 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.

For minor livestock categories where the default IPCC Tier 1 methodology is used to estimate manure management CH_4 emissions, AWMS distributions are reported in CRF tables for consistency with reporting of manure management N_2O emissions (see A3.4.4.1), but are not incorporated in the calculations.

A3.4.3.4. 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.

For the Dairy and Swine sectors, MCF values from the 2006 IPCC Guidelines were assigned to each AWMS subsystem (section A3.4.3.3). In liquid subsystems, the Liquid/Slurry MCF value was used for Tank and Earthen Basin, while Pit Storage Below Animal Confinements was used for Slatted Floor systems. For solid subsystems, the Drylot MCF was used for Pack, while the Solid Storage MCF was used for manure heaps. For Dairy sector animals, the Drylot MCF was also used for Exercise Yards.

A3.4.3.5. Cattle Manure Management CH_4 Emission Factors

Cattle emission factors that are developed to calculate CH_4 emissions from manure management vary by animal subcategory and over time (Table A3.4–15). As VS was calculated based on the GE derived from the enteric fermentation cattle production model, an emission

Table A3.4–15 **Emission Factors to Estimate CH_4 Emissions from Manure Management for Cattle Subcategories from 1990 to 2018**

	$EF_{(MM)T}$ (kg CH_4/head/year)							
Year	Dairy Cows	Dairy Heifers[a]	Bulls	Beef Cows	Beef Heifers	Heifers for Slaughter[b]	Steers[b]	Calves
1990	13	8	4.5	4.1	3.2	1.9	1.8	2.2
1995	15	9	4.7	4.3	3.2	2.0	1.9	2.1
2000	20	11	4.7	4.5	3.3	2.1	1.9	2.3
2005	26	12	4.6	4.3	3.1	2.1	1.9	2.4
2010	33	15	5.0	4.4	3.1	2.1	2.0	2.8
2011	35	16	5.0	4.4	3.1	2.1	2.0	2.9
2012	35	16	5.0	4.4	3.1	2.1	2.0	2.9
2013	36	16	4.5	4.3	3.1	2.1	2.0	2.8
2014	36	17	4.7	4.4	3.1	2.1	2.0	2.9
2015	37	17	4.9	4.5	3.2	2.2	2.0	2.9
2016	37	17	4.9	4.5	3.2	2.2	2.0	2.9
2017	38	17	5.0	4.5	3.2	2.1	2.0	2.9
2018	38	17	4.8	4.5	3.2	2.2	2.0	3.0

Notes:

a. For dairy heifers, emission factors were estimated using B_0, MCF and manure management systems for dairy cows.

b. Reported as kg/hd/year, but emissions are calculated based on time to slaughter.

factor time series was derived for cattle to reflect (i) the increase in milk productivity of dairy cows, (ii) the variation in overall methane conversion rates as impacted by changes to manure storage practices and (iii) the change in live weight of Non-Dairy Cattle as explained in sections A3.4.1, A3.4.3.4 and A3.4.1.1, respectively. Emission factors are highest from Dairy Cattle, reflecting their high rates of confinement, use of liquid manure management systems and high dietary intake for sustained milk production. Dairy emission factors have more than doubled since 1990 due to the increasing use of liquid manure management systems. 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. Swine Manure Management CH_4 Emission Factors

Swine emission factors are developed to calculate CH_4 emissions from manure management and vary by animal subcategory and over time (Table A3.4–16).

A provincial emission factor time series was derived for swine to reflect (i) the variation in overall methane conversion rates as impacted by changes to manure storage practices, and (ii) changes in the growth rates and live weights of market swine by weight class, as explained in sections A3.4.3.4 and A3.4.1.2, respectively. The swine emission factor is first calculated using VS derived from Marinier et al. (2004), and incorporating the latest scientific information available on B_0 and MCF taken from the 2006 IPCC Guidelines (IPCC, 2006). The annual swine VS excretion rates are then recalculated using animal mass from the Marinier survey year, and expressed as VS per 1000 kg animal mass. Lastly, VS is scaled over time using the swine TAM time series.

Emission factors for pigs in the low-weight and middleweight classes decrease slightly over time due to increases in the rate of weight gain and increases in the methane conversion factor. In contrast, a steady increase in the upper-weight class emission factor reflects increases in live weight. A small decrease in the emission factor for sows over time is the result of proportional changes to provincial animal populations, leading to an overall decrease in VS.

A3.4.3.7. Manure Management CH_4 Emission Factors for All Other Livestock

Manure management emission factors for animals other than swine and cattle vary by animal subcategory but are constant over time (Table A3.4–17). For the largest other animal categories—sheep and poultry—growth stages for animals are taken into account. Emission factors for Sheep, Lamb, Goat, Horses, Bison, Llamas and Alpacas, and Poultry are calculated using the 2006 IPCC Tier 2 methodology. Volatile solids are derived from Marinier et al. (2004); however, since this report was based on the 2000 IPCC Guidelines, the emission factors were recalculated to incorporate the latest scientific information available on B_0 and MCF taken from the 2006 IPCC Guidelines (IPCC, 2006). Proxies are used for very minor livestock categories that account for less than 0.2% of total agricultural emissions, as described in A3.4.3.

Emission factors for other minor categories tend to be low due to the large portion of manure that is deposited either on pasture, range or paddock or in solid form in pens and holding yards. Default Tier 1 IPCC emission factors from Table 10.15 of Chapter 10 of the 2006 IPCC guidelines are used for deer and elk, foxes, mink, rabbits, and mules and asses, and represent less than 0.1% of total agricultural emissions.

Table A3.4–16 **Emission Factors to Estimate CH_4 Emissions from Manure Management for Swine Subcategories from 1990 to 2018**

	EF(MM)T (kg CH_4/head/year)				
Year	Boars	Sows	Pig (< 20 kg)	Pig (20-60 kg)	Pig (> 60 kg)
1990	7.0	7.3	2.1	4.5	8.2
1995	7.0	7.2	2.1	4.5	8.3
2000	7.0	7.2	2.1	4.4	8.5
2005	7.0	7.1	2.1	4.4	8.5
2010	7.0	7.0	2.1	4.3	8.6
2011	7.0	7.0	2.1	4.3	8.7
2012	7.0	7.0	2.1	4.3	8.8
2013	7.0	7.0	2.1	4.3	8.8
2014	7.0	7.0	2.1	4.3	8.9
2015	7.0	7.0	2.1	4.3	8.9
2016	7.0	7.0	2.1	4.3	9.0
2017	7.0	7.0	2.1	4.2	9.0
2018	7.0	7.0	2.1	4.2	9.0

Table A3.4–17 **2018 CH_4 Emission Factors for Manure Management for All Other Livestock**

Non-Cattle Animal Categories	Manure Management Emission Factors $EF_{(MM)}$ (kg CH_4/head/year)
Other Livestock	
Sheep	0.33
Lambs	0.22
Goats	0.32
Horses	2.6
Bison	2.1
Elk and Deer	0.22
Wild Boars[a]	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:
a. Emission factor based on swine VS, assuming 100% solid manure.

A3.4.3.8. 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 submission (MacDonald and 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 varied 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 makes comparisons to IPCC parameters difficult.

Godbout et al. (2010) carried out an analysis on a small sample set from Eastern Canadian farms and suggested that the B_0 values for Swine, Beef and Dairy sector livestock were 0.47–0.42, 0.21–0.19 and 0.35–0.30, respectively. 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.

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.

Desjardins et al. (2018) measured CH_4 flux for full farm systems, including both manure management and enteric fermentation emissions using an aircraft-based platform and compared top-down estimates with a bottom-up footprint adjusted inventory estimate of emissions for an agricultural region in eastern Ontario, Canada. They concluded that when a wetland area in the flux footprint was less than 10%, the top-down and bottom-up estimates were within the measurement error. They noted, however, that top-down CH_4 fluxes significantly over-estimated methane emissions when contributions from wetlands were not considered in the potential sources. Fine-scale mapping of wetlands was required to effectively quantify natural methane emission sources. Where estimates from the two methods were inconsistent, the discrepancy was related to both increasing fractional area of wetlands in the flux footprint and increasing surface temperature.

A3.4.3.9. Uncertainty in Manure Management CH_4 Emissions

Methane emissions from manure management were included in the comprehensive uncertainty analysis discussed in section A3.4.2.4. 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 A3.4–18). 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 current year and no new uncertainty analysis was carried out for the changes to the Dairy Cattle model.

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 A3.4–8.

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 because 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%).

Table A3.4–18 **Uncertainties in Inputs, Sources of Uncertainty and the Spatial Scale and Animal Category to Which Uncertainty is Assigned, for Parameters Used in Estimating Methane Emissions from Manure Management**

Parameter Category	Parameter/Animal Category or Subcategory	Distribution Type	Uncertainty Range		Spatial Allocation/Animal Category Allocation	Uncertainty Distribution Estimate Source and Notes
			Range	Most Likely Value[a]		
Volatile Solid Calculations (Equation A3.4–6 and A3.4–7)						
Dry Matter Intake (DMI)						
- Swine		Triangular			National/Subcategory	Marinier et al. (2004)
	Boars		1.2–3.4	2.28		
	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		
	Broilers		0.085–0.088	0.086		
	Turkeys		0.23–0.53	0.27		
- Other livestock						
	Sheep		1.2–3.0	2		
	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						
- Cattle		Triangular	3.9–11	8	National/Category[b]	Marinier et al. (2004)
- Swine			3.9–11	4.8–5.1		
- Poultry	Laying hens		3.9–11	10		
	Broilers		3.9–11	7		
	Turkeys		3.9–11	5		
- Other livestock						
	Sheep		3.9–11	8		
	Lambs		3.9–11	8		
	Goats		3.9–11	8		
	Horses		3.9–11	4		
	Buffalo		3.9–11	8		

Table A3.4–18 **Uncertainties in Inputs, Sources of Uncertainty and the Spatial Scale and Animal Category to Which Uncertainty is Assigned, for Parameters Used in Estimating Methane Emissions from Manure Management** (cont'd)

Parameter Category	Parameter/Animal Category or Subcategory	Distribution Type	Uncertainty Range		Spatial Allocation/Animal Category Allocation	Uncertainty Distribution Estimate Source and Notes
			Range	Most Likely Value[a]		
Digestible Energy (DE)						
-Cattle		Normal	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	
	Broilers					
	Turkeys					
-Other livestock						
	Sheep		±9%		Provincial/Category	
	Lambs				Provincial/Category	
	Goats				Provincial/Category	
	Horses				Provincial/Category	
	Buffalo				Provincial/Category	
Emission Factor Calculation (Equation A3.4–5)						
Methane Conversion Factor (MCF)						
	All Animals	Normal	±45%		National	Karimi-Zindashty et al. (2012) – expert opinion
Maximum Methane Producing Potential (B_0)						
	Dairy cattle	Triangular	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		
	Sheep and lambs		0.19–0.36	0.19		
	Goats		0.15–0.19	0.18		
	Horses		0.30–0.36	0.3		
	Buffalo		0.19–0.33	0.19		
Animal Waste Management Systems (MS)[e]						
	Dairy cattle	Triangular	LB: MLV-10% UB: MLV+25%	MLV[d] from Marinier et al. (2005)	Provincial/Category	Expert opinion, bounds based on interpretation of multiple data sources Internally correlated variable[c] Liquid systems allowed to vary to non-symmetric triangular distributions
	Swine		LB: MLV-10% UB: 100%	MLV from Marinier et al. (2005)		
	Non-dairy cattle	Normal	±17%			Marinier et al. (2005). Internally correlated variable[c]
	Poultry					
	Sheep and lambs					
	Goats					
	Horses					
	Buffalo					

Notes:
a. Most likely value when triangular distribution, normal distributions given as simple ±%.
b. Ash for swine varies among some provinces.
c. Internal correlation indicates values that vary in terms of a fraction of the whole, i.e., a fraction of a total equalling 100%.
d. MLV = most likely value; LB = lower bound; UB = upper bound.
e. Values that vary independently during trend analysis.

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. A 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 "g" in Table A3.4–8 and superscript "e" in Table A3.4–18). 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 2018 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 was 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 the data 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. As the MCF factor is driving uncertainty for manure management, it is not suspected that changes to the Dairy or Swine models would have a large impact on the national manure management uncertainty. However, the introduction of a time series of AWMS for the Dairy and Swine sectors may play an important role in influencing the trend uncertainty for manure management emissions.

A3.4.4. N_2O Emissions from Manure Management

N_2O emissions from manure management systems result from mineralization of organic materials, and the 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 from 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.

As previously described in section A3.4.3, default emission factors or country-specific information sources are sometimes used for minor livestock categories as logical proxies based on species similarities when no other information is available. The following proxies and expert judgement are used in the calculation of N_2O emissions, in addition to those already listed in A3.4.3:

1. The nitrogen excretion rate for Swine is used to represent Wild Boar.
2. The nitrogen excretion rate for Sheep is used to represent Lamb, as well as Llamas and Alpacas.
3. The nitrogen excretion rate for Buffalo is used to represent Bison.
4. The nitrogen excretion rate for Other Cattle is used to represent Deer and Elk.

Nitrogen Excretion Rates for Various Domestic Animals

For Dairy Cattle, the Tier 2 methodology from the 2006 IPCC guidelines is used. Nitrogen intake from feed has increased steadily since 1990 in order to meet the protein requirements of increased milk production (Table A3.4–4) and, as a result, a corresponding increase in dairy cow N excretion rates (Table A3.4–19) was calculated.

For Non-Dairy Cattle, annual live weights (see section A3.4.1.1) were multiplied by the IPCC default N excretion rate (IPCC, 2006) to produce a time series of manure N excretion rates (Table A3.4–19).

For swine, distinct parameters were used to estimate N excretion from subcategories of breeding animals and market animals. In the case of market swine, increases in growth rates and live weights were used to develop a country-specific time series of animal mass per production stage, which was multiplied by an N

excretion rate derived from Table 10.19 in the 2006 IPCC guidelines. For breeding animals, the IPCC default N excretion rate was multiplied by the IPCC default animal mass.

Annual manure N excretion rates for all other animals vary by livestock category according to IPCC Tier 1 default values (IPCC, 2006). Poultry have high excretion rates (Table A3.4–21), while horses and bison have the lowest excretion rates. However, on a per-head basis, bison have the highest N excretion rates due to their size. Tier 1 default values for fur-bearing animals and rabbits have exceptionally high excretion rates relative to their size (Table A3.4–21), 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. For livestock from the Dairy and Swine sectors, weighted N_2O emission factors are calculated using the proportion of manure in each AWMS subsystem (see section A3.4.3.3) and the corresponding default emission factors (Annex 6), to produce a time series of N_2O emission factors by AWMS.

Table A3.4–19 **Time Series of Manure N Excretion Rates for Cattle (kg N/head/year)**

(kg N/head/year)

Year	Dairy Cows	Dairy Heifers	Bulls	Beef Cows	Beef Heifers	Heifers for Slaughter[a]	Steers[a]	Calves
1990	107	72	88	58	45	45	48	27
1995	110	72	99	65	50	55	57	27
2000	114	73	103	70	54	60	61	27
2005	116	73	102	68	52	61	61	26
2010	123	76	113	69	53	62	63	27
2011	122	76	112	69	53	62	64	27
2012	122	76	114	69	53	65	65	27
2013	126	76	99	69	53	64	65	27
2014	125	76	103	70	53	63	64	27
2015	123	76	111	74	56	65	66	27
2016	123	76	112	75	58	66	67	27
2017	121	76	114	75	57	65	66	26
2018	122	76	108	75	57	66	67	26

Notes:

N excretion rate for non-dairy cattle is 0.31 kg N-1000 kg $^{-1}$-day $^{-1}$ (IPCC, 2006, Table 10.19). Data source: IPCC (2006), Volume 4, Agriculture, Forestry and Other Land Use.

a. Values are adjusted for the life-span of slaughter animals.

Table A3.4–20 **Time Series of Manure N Excretion Rates for Swine (kg N/head/year)**

(kg N/head/year)

Year	Sow	Boar	Pig (<20 kg)	Pig (20-60 kg)	Pig (>60 kg)
1990	17	17	1.6	7.3	15.0
1995	17	17	1.7	7.3	15.2
2000	17	17	1.7	7.3	15.6
2005	17	17	1.7	7.2	15.7
2010	17	17	1.7	7.2	16.2
2011	17	17	1.7	7.1	16.2
2012	17	17	1.7	7.1	16.4
2013	17	17	1.7	7.1	16.5
2014	17	17	1.7	7.2	16.6
2015	17	17	1.7	7.1	16.7
2016	17	17	1.7	7.1	16.9
2017	17	17	1.7	7.1	16.9
2018	17	17	1.7	7.0	17.0

Notes:

N excretion rate for breeding swine is 0.24 kg N-1000 kg $^{-1}$-day $^{-1}$ (IPCC, 2006, Table 10.19). Data source: IPCC (2006), Volume 4, Agriculture, Forestry and Other Land Use.

N excretion rate for market swine is 0.53 kg N-1000 kg $^{-1}$-day $^{-1}$ and was calculated based on market value of 0.24, overall swine excretion of 0.50, and weighting proportion indicated in the footnote of Table 10.19. Data source: IPCC (2006), Volume 4, Agriculture, Forestry and Other Land Use.

Table A3.4–14 summarizes the distribution of manure 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 A3.4–9), as follows:

Equation A3.4–9

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

$N_2O_{D(mm)}$	=	emissions for all AWMS and livestock categories, excluding emissions from urine and dung deposited on pasture, range and paddock, kg N_2O/year
$N_{i,T}$	=	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 A3.4–14)
$N_{EX,T}$	=	N excretion rate for the T^{th} animal category or subcategory (see Table A3.4–19 for cattle and Table A3.4–21 for non-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. Leaching is estimated only for the Dairy and Swine sectors, where country-specific information on the fraction of nitrogen loss due to leaching and runoff was available. These losses of manure N can result in N_2O emissions (Equation A3.4–10 and Equation A3.4–11).

In the case of the Dairy and Swine sectors, the introduction of a manure management time series that considered a wider variety of manure storage conditions results in changes in the fraction of manure N that is lost over the reporting period (Table A3.4–22). A shift from solid manure storage to liquid, an increase in the number of covered manure storage systems and, in the case of the Dairy sector, a shift in time in pasture, resulted in a decrease in the proportion of total N lost to the environment over time.

Table A3.4–21 **Manure N Excretion Rates for All Other Animals**

Animal Categories	N Excretion Rate[a] (kg N/1000 kg/day)	Average Body Weight[b] (kg)	Annual Manure N (kg N/head/year)
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	67.7
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	13.6
Wild Boars[c]	0.5	61	11.1
Foxes	12.1	1.8	7.9
Mink	4.6	1.8	3.0
Rabbits	8.1	1.6	4.7
Mules and Asses	0.3	245	26.8

Notes:
a. Data source: IPCC (2006).
b. For buffalo, average live weight was taken from the U.S. NIR.
c. Equivalent to overall swine excretion rate of 0.50 kg N-1000 kg $^{-1}$-day $^{-1}$ (IPCC, 2006, Table 10.19). Data source: IPCC (2006), Volume 4, Agriculture, Forestry and Other Land Use.

Equation A3.4–10

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

$N_2O_{G(mm)}$	=	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 A3.4–14)
$N_{EX,T}$	=	N excretion rate for livestock category or subcategory, T (see Table A3.4–19 for cattle and Table A3.4–21 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 A3.4–22 and Table A3.4–23)
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 A3.4–11

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

$N_2O_{L(mm)}$	=	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/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 A3.4–14)
$N_{EX,T}$	=	N excretion rate for livestock category or subcategory, T (see Table A3.4–19 for cattle, Table A3.4–20 for swine, and Table A3.4–21 for all other livestock), kg N/head/year
$Frac_{LeachMS(T,AWMS)}$	=	fraction of managed manure N losses for dairy (see Table A3.4–23) and swine (see Table A3.4–24) and other livestock (see Table A3.4–22) for livestock category T due to leaching and runoff during solid and liquid storage of manure, AWMS
EF_5	=	emission factor from N leaching and runoff, 0.0075 kg N_2O-N/(kg N leaching/runoff) (IPCC, 2006)
$44/28$	=	coefficient converting N_2O-N to N_2O

Table A3.4–22 **Total N, NH_3- and NO_x-N Losses Associated with Various Livestock and Manure Management Systems**

Animal Category	Manure Management Systems	$Frac_{(LossMS)}$ (%)[a]	NH_3-N and NO_x-N Loss (%)[a, b, c] ($FRAC_{GasMS}$)
Non-dairy Cattle	Liquid	40 (15–45)	40 (15–45)
	Solid Storage	40 (20–50)	30 (20–50)
	Pasture and Range	-	20 (5–50)
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)	12 (5–20)
	Pasture and Range	-	20 (5–50)
Elk and Deer	Solid Storage	15 (5–20)	12 (5–20)
Wild Boars	Solid Storage	15 (5–20)	12 (5–20)
Foxes	Solid Storage	15 (5–20)	12 (5–20)
Mink	Solid Storage	15 (5–20)	12 (5–20)
Rabbits	Solid Storage	15 (5–20)	12 (5–20)
Mules and Asses	Solid Storage	15 (5–20)	12 (5–20)
Poultry	Liquid	50	50
	Solid Storage	53 (20–80)	48 (10–60)
	Pasture and Range	-	20 (5–50)

Notes:

a. Numbers in parentheses indicate a range.

b. Data sources: Hutchings et al. (2001); U.S. EPA (2004); Rotz (2004).

c. 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.

Table A3.4–23 **Total N, NH_3- and NO_x-N Losses Associated with Dairy Cattle and Manure Management Systems**

	$Frac_{(LossMS)}$ (%)			Leaching Loss (%) ($Frac_{LeachMS}$)			NH_3-N and NO_x-N Loss (%) ($Frac_{GasMS}$)		
Year	Liquid	Solid	Other[a]	Liquid	Solid	Other	Liquid	Solid	Other
1990	12	23	0	0	3	0	11	16	0
1995	12	23	0	0	3	0	11	16	0
2000	13	23	0	0	3	0	11	16	0
2005	13	23	37	0	3	7	12	16	23
2010	10	23	35	0	3	5	9	17	24
2011	10	23	35	0	3	5	8	17	24
2012	10	23	35	0	3	5	8	17	24
2013	10	23	35	0	3	5	8	17	24
2014	10	23	35	0	3	5	8	17	24
2015	10	23	35	0	3	5	8	17	24
2016	10	23	35	0	3	5	8	17	24
2017	10	23	35	0	3	5	8	17	24
2018	10	23	35	0	3	5	8	17	24

Note:
a. Other in the case of dairy cattle refers only to composting of solid manures.

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.

Nitrogen is allocated to the landscape according to the following procedure: (i) region-specific N application rates are calculated for each crop type; (ii) a "recommended" amount of nitrogen is allocated to each of 405 ecodistricts in Canada based on the application rate and the area of each crop type within the ecodistrict; (iii) the total amount of manure N available to be applied to agricultural soils is calculated based on the population of livestock within the ecodistrict; (iv) biosolids are applied to select crop types according to remaining "recommended" N, after subtracting the available manure N from step iii; (v) Manure N is applied to crops in each ecodistrict, according to remaining crop requirements following biosolids application; (vi) the amount of organic N applied (manure + biosolids) is subtracted from the initial "recommended" amount to calculate the amount of "theoretical" crop N requirements not met by organic sources alone; and (vii) the amount of "theoretical" N is scaled to match total provincial fertilizer sales reported by Statistics Canada, and this corrected amount represents inorganic N fertilizer applied to each ecodistrict.

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 and cultivation of organic soils. Tillage practices, summerfallow and irrigation can also influence soil N_2O emissions. 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 emission (Rochette et al., 2008).

The approach involves determining base emission factors "EF_{BASE}" for each of 405 ecodistricts,[21] using long-term growing season precipitation and potential evapotranspiration. The EF_{BASE} is subsequently modified "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. to reflect site-specific practices and conditions. Data on long-term climate normals and topographic characteristics are used to develop an EF_{BASE} (Equation A3.4–12).

21 "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.

Equation A3.4–12

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

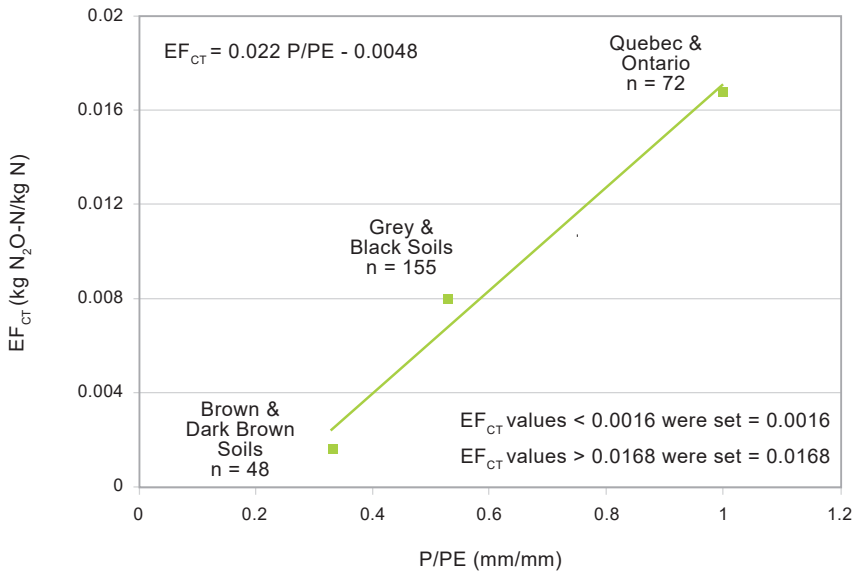
EF_{BASE}	=	a weighted average of emission factors for ecodistrict i, taking into account moisture regimes and topographic conditions, kg N_2O-N/kg N/yr
EF_{CT}	=	emission factor, estimated at actual P/PE in an ecodistrict, kg N_2O-N/kg N (see Figure A3.4–3)
$EF_{CT,\ P/PE=1}$	=	emission factor of 0.017 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 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 A3.4–4). 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) (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

Figure A3.4–4 **EF_{CT} as a Function of Long-Term Ratio of Precipitation over Potential Evapotranspiration (P/PE) from 1971 to 2000**



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[22] 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).

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 added to emissions calculated through the relationship between EF_{CT} and P/PE shown in Figure A3.4–4.

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.[23] These stations (80º00′N–41º55′N, 139º08′W–52º40′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. The Meteorological Service of Canada, Environment and Climate Change Canada provided the Canadian weather data.

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., 2002a; 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 A3.4–13). A value of 0.8 was assigned to the $R_{FTEXTURE-COARSE}$ and $RF_{TEXTURE-MEDIUM}$ and 1.2 for $RF_{TEXTURE-FINE}$ (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.

Equation A3.4–13

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

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

22 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.

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

Organic Nitrogen Fertilizers

Emissions of N_2O from organic N sources include emissions from the application of sewage sludge (biosolids), manure from drylot and solid storage, liquid and other waste management systems on agricultural soils. A country-specific Tier 2 methodology was used for estimating N_2O emissions from organic N fertilizers.

Equation A3.4–14

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

N_2O_{ON}	=	emissions from organic nitrogen fertilizer applied to cropland, kg N_2O/year
$N_{ON\text{-}CROPS,i}$	=	organic nitrogen (i.e. biosolids and 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

Manure Nitrogen

The methodology is based on the quantity of manure N produced by domestic animals (see section A3.4.4.1) and country-specific EF_{BASE}, taking into account the moisture regime and topographic conditions at the ecodistrict level. Manure was allocated to crops preferentially, based on a modified version of Yang et al. (2011), in order to better reflect practices and to ensure consistency in Canada's manure allocation methodology used in environmental indicators in Canada. Estimates of N_2O emissions from this source are calculated using Equation A3.4–14, in combination with our organic N sources.

The amount of animal manure applied as fertilizer at an ecodistrict level was calculated using Equation A3.4–15. It was assumed that all manure, excluding that deposited on pasture, range and paddock, is applied to cropland soils.

Equation A3.4–15

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

$N_{MAN\text{-}CROPS,i}$	=	animal manure applied as N fertilizers on cropland in ecodistrict i, kg N/yr
N_T	=	population for animal category or subcategory T, heads
$N_{EX,T}$	=	N excretion rate for animal category or subcategory (Table A3.4–19 and Table A3.4–21)
$N_{PRP,T}$	=	fraction of manure N on pasture, range and paddock for each animal category or subcategory T in ecodistrict i (see Table A3.4–14)
$FRAC_{(LossMS,T)}$	=	fraction of manure N loss during storage and handling (volatilization, leaching, etc.) for each animal category or subcategory T excluding pasture, range and paddock in ecodistrict i (Table A3.4–22 and Table A3.4–23)

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.

Table A3.4–24 **Total N, NH_3- and NO_x-N Losses Associated with Swine Manure Management Systems**

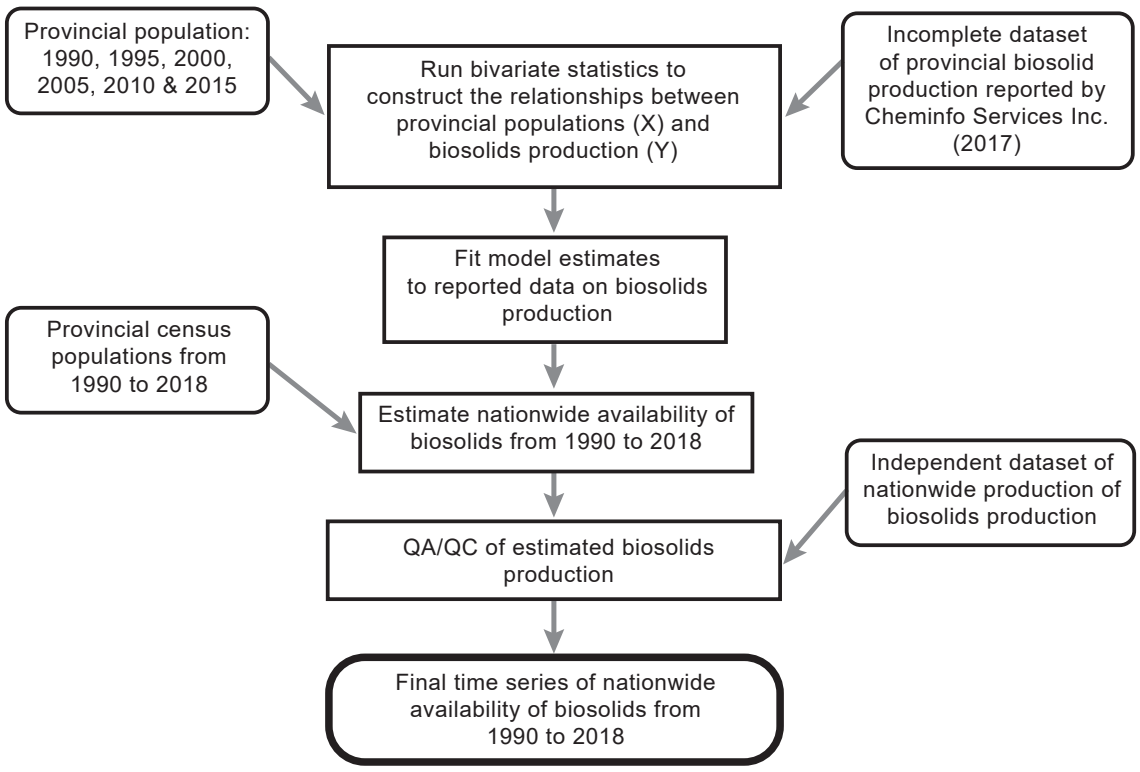
	$Frac_{(LossMS)}$ (%)		Leaching Loss (%) ($Frac_{LeachMS}$)		NH_3-N and NO_x-N Loss (%) ($Frac_{GasMS}$)	
Year	Liquid	Solid	Liquid	Solid	Liquid	Solid
1990	23	31	0	3.3	21	23
1995	23	31	0	3.3	21	23
2000	23	31	0	3.4	21	23
2005	23	31	0	3.3	21	23
2010	20	30	0	3.1	19	23
2011	19	30	0	3.0	18	23
2012	20	30	0	3.0	18	23
2013	20	30	0	3.0	18	23
2014	20	30	0	2.9	18	23
2015	20	30	0	2.9	18	23
2016	20	30	0	2.9	18	23
2017	20	30	0	2.9	18	23
2018	20	30	0	2.9	18	23

Biosolids Nitrogen

Data on the production and management of biosolids were derived from an Environment Canada–commissioned report (Cheminfo Services Inc., 2017). The data set was generated through a combination of telephone surveys and reports by the municipal wastewater treatment services in 33 Census Metropolitan Areas (CMAs) and from municipal and provincial environment departments/ministries across Canada. This survey represented only 63% of the Canadian population based on the wastewater treatment plants (WWTPs) located in CMAs and did not include PEI and the three Canadian territories. The data were compiled at five-year intervals (1990–2015) and had gaps and inconsistencies owing to a lack of complete management information and changes in provincial regulations on biosolids. Nevertheless, these data are the only known source for a quantitative analysis of biosolids available at a national scale.

Biosolid production data were produced through a series of analytical steps (Figure A3.4–5, Table A3.4–25). First, a provincial-level per capita model was constructed to establish a "baseline biosolid production." Production was assumed to be directly proportional to the population of a geographical area. Different spatially scaled roll-ups of Statistics Canada population estimates were evaluated for best fit of the data. Population estimates used for testing included CMA populations, aggregated CMA populations and provincial populations. Upon regression analysis, the provincial population-based model was chosen based on the strength of the correlation coefficients. Fortunately, the data generated using this approach were not significantly different from the data reported during the years that Cheminfo Services Inc. (2017) was doing the reporting. Therefore, the smoothed annual provincial biosolid production was derived using the linear model. For PEI, annual estimates for biosolid production were developed based on expert opinion

Figure A3.4–5 **Schematic details of the procedures and data sources used to determine the time series of biosolids production at the provincial scale**



and using a national average per capita figure (22.5 kg /person/year). This analysis created a complete time series of biosolid production at a provincial scale.

Secondly, the regional rates of land application of biosolids (dry tonnes) were derived using the proportions reported in Cheminfo Services Inc. (2017) adjusted for federal, provincial and municipal regulations,bylaws and restrictions (Table A3.4–25). At the federal level, the regulations imposed by the CCME were applied. Afterwards, provincial restrictions based on the nutrient content of the biosolid and any restrictions on the frequency of biosolid application to lands were incorporated (Table A3.4–25).

Biosolids are typically subject to various digestion and decomposition methods in WWTPs prior to land application. These methods have significant implications for the nutrient content of the biosolids and therefore influence the emission potential when land-applied. Accordingly, as the final step, a combination of survey results and literature analyses was used to identify the major digestion processes, and estimates from Dad et al. (2018) were used to establish the nutrient content of the biosolids.

Quality Control and Quality Assurance

For the production data, quality control was conducted at the provincial and national levels. To verify the validity of our data, comparisons were made between the estimated values against independent data points available from literature and from other data sources at the national level. Our data reasonably reflected the production volume of biosolids at the provincial level and represented the changes in provincial regulations that occurred at specific years (Table A3.4–26). At the national level, the data aligned well with the national figures (Figure A3.4–6).

Table A3.4–25 **Data sources used for determination of the annual biosolid production and characteristics at the provincial scale**

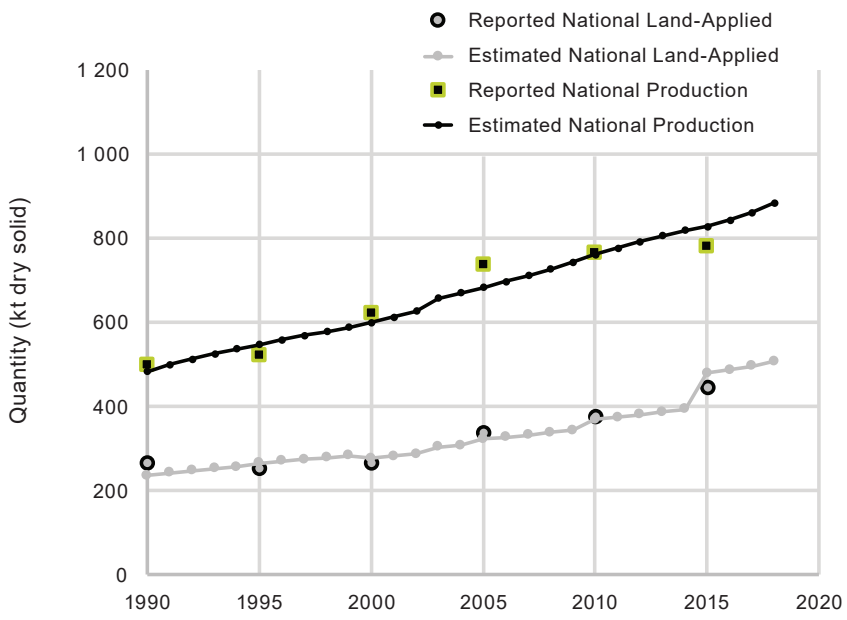
Category	Data source	Notes/Comments
Biosolid Production	Cheminfo Services Inc. (2017)	Survey data for biosolid production and fractions that are land-filled, incinerated, land applied, and land-reclamation
CMA population	https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=1710013501	Statistics Canada. Population estimates, July 1, by census metropolitan area and census agglomeration, 2016 boundaries
Provincial population	https://www12.statcan.gc.ca/census-recensement/2016/dp-pd/prof/index.cfm?Lang=E	Statistics Canada. Census Profile 2016
Federal and provincial regulations	https://www.ccme.ca/files/Resources/waste/biosolids/pn_1446_biosolids_leg_review_eng.pdf	CCME. A Review of the Current Canadian Legislative Framework for Wastewater Biosolids
Biosolids – fractions by digestive processes	Cheminfo Services Inc. (2017)	
	Hydromantis Ltd. (2007). GPS-X 5.0 software. General Purpose Simulator—default parameters.	
	Environmental Dynamics Inc. (2017). Beneficial Reuse of Biosolids Jurisdictional Review	British Columbia commissioned work.
Nutrient content of biosolids under varied digestion / treatment processes	Dad K, Wahid A, Khan A, Anwar A, Ali M, Sarwar N, Ali S et al. "Nutritional status of different biosolids and their impact on various growth parameters of wheat (Triticum aestivum L.)." *Saudi Journal of Biological Sciences* (2018).	

Table A3.4–26 **Performance statistics of the estimated production data against the reported figures at provincial CMA and city scale**

Location	Reported Production (kt)	Estimated Production (kt)	% Deviation	Year	Source
Calgary CMA, AB	20.5	23	12.2	Annually	EDI (2017)
City of Edmonton, AB	18	15.6	13.33	1990 to 2004	City of Edmonton (2012)
Halifax CMA, NS	30	13	56.67	Since 2014	EDI (2017)
City of North Battleford, SK	3.5	0.6	82.86	2003–2004	EDI (2017)
City of Toronto, ON	55	64	16.36	Since 2007	AECOM (2009)
City of Kelowna, BC	36.4	3.7	89.84	Since 2006	EDI (2017)

Note:
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.

Figure A3.4–6 **National biosolid production (kt dry solid) versus the estimated total biosolid production by the proposed approach**



Allocation of Biosolids to Ecodistricts and Crops

The amount of biosolids applied as fertilizer at an ecodistrict level was calculated using Equation A3.4–16. Human population was used as a proxy to distribute provincial land-applied biosolid N to the ecodistrict spatial scale. In order to avoid over-application of N in an ecodistrict, a correction procedure was implemented to coordinate the application of manure and biosolids with recommended crop application rates per ecodistrict. First, the total amount of manure N within each ecodistrict was subtracted from the total amount of N required for crop growth, and compared with the amount of biosolid N initially allocated to the ecodistrict. In cases where biosolid N exceeded remaining crop N requirements, the required amount was applied and the excess N was reallocated to other ecodistricts in the province. Next, biosolid N was applied to select crops within each ecodistrict as per provincial and municipal regulations and bylaws limiting the application of biosolids. The amount of biosolid N applied to each crop in a given ecodistrict was then subtracted from the initial crop N requirements, and the modified parameter was used to distribute manure N to crops, following the manure application methodology.

Equation A3.4–16

$$N_{BIO-CROPS,i} = \sum_{i} \left[Prod \times Frac_{LAND} \times Frac_{POP,i} \times \sum (TN_k \times Frac_{TYPE,k}) \times Frac_{CROP,im} \right]$$

$N_{BIO-CROPS,i}$	=	biosolid applied as N fertilizer on cropland in ecodistrict i, kg N/yr
$Prod$	=	Biosolid production by province (kg)
$Frac_{LAND}$	=	Fraction of provincial biosolids that are land-applied
$Frac_{POP,i}$	=	Fraction of provincial human population in each ecodistrict i
TN_k	=	Total nitrogen content (%) by biosolids type k
$Frac_{TYPE,k}$	=	Fraction of each biosolids treatment type k
$Frac_{CROP,im}$	=	Fraction of biosolids N applied to crop type m, in ecodistrict i

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 A3.4–17 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 A3.4–17

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

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 A3.4–18
$EF_{BASE,i}$	=	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 A3.4–18) 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 A3.4–18

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

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

Based on the work of Yang et al. (2007), NRCMD 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 A3.4–19).

Equation A3.4–19

$$N_{RCMD,i} = \sum_{ij} \left(CROPA_{ij} \times N_{RECRT,ij}\right)$$

$N_{RCMD,i}$	=	recommended fertilizer application in ecodistrict i, kg N/year
$CROPA_{ij}$	=	area of crop type j in ecodistrict i, ha
$N_{RECRTij}$	=	recommended annual N application rate for crop type j in ecodistrict i, kg N/ha-year

$N_{MAN\text{-}AV,CROPS}$ was calculated as the sum of all manure N from all farm animals (Equation A3.4–20) in the ecodistrict as follows:

Equation A3.4–20

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

$N_{MAN\text{-}AV,CROPS,i}$	=	available N from manure applied to crops in ecodistrict i, kg N/year
$N_{MAN\text{-}CROPS,i}$	=	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:

Equation A3.4–21

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

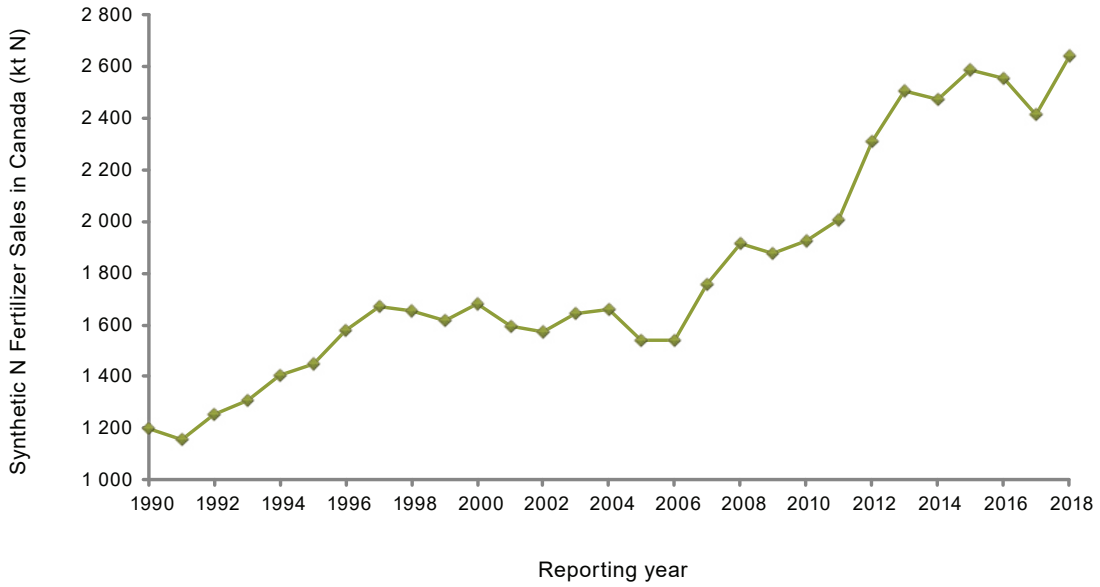
N_{FERTi}	=	total fertilizer N actually applied to all crops in ecodistrict i, kg
$\sum_i^n N_{APPLDi}$	=	total fertilizer N potentially applied to all crops in all ecodistricts in a province, kg
N_{SALESp}	=	total amount of fertilizer N sold in province p, kg

For years between census years (census years were 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 A3.4–7).

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.[24] Since 2007, Statistics Canada has collected and published fertilizer sales data annually (Statistics Canada, 2016a).

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

Figure A3.4–7 **Synthetic Nitrogen Fertilizer Sales in Canada from 1990 to 2018**



Urine and Dung 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 A3.4–25 (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 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 A3.4–13, 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 A3.4–27). Emissions of N_2O are calculated using a fixed emission factor-based approach (Equation A3.4–22).

Equation A3.4–22

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

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 A3.4–19 and Table A3.4–21)
$N_{PRP,T}$	=	fraction of manure N excreted on pasture, range and paddock by animal category or subcategory T (Table A3.4–14)
$EF_{PRP,i}$	=	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.

Table A3.4–27 **Emissions of Nitrous Oxide from Beef Urine and Dung on Pasture in Western Canada**

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

Note:
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.

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 method similar to that for inorganic and organic N fertilizers is used to estimate N_2O emissions from crop residues, based on Equation A3.4–23, Equation A3.4–24 and Equation A3.4–25. The amount of N contained in the aboveground 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 A3.4–23

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

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 soils for ecodistrict i, excluding N losses due to residue burning, kg N/year (see Table A3.4–23)

$EF_{BASE,i}$ = 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 A3.4–24

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

$N_{RES,i}$ = total amount of crop residue N that is returned to soils 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 A3.4–25)

$FRAC_{RENEW,T,i}$ = 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 A3.4–25

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

$P_{T,i}$	=	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_2O_T	=	water content of crop T, kg/kg

Statistics Canada collects and publishes annual field crop production data by province (Statistics Canada, No date. Table 32-10-0359-01 (formerly CANSIM 001-0017)—Estimated areas, yield, production and average farm price of principal field crops, in metric units). 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, chickpeas 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). Statistics Canada survey data are based on the *Census of Agriculture* (COA), and therefore general revisions to the survey time series may occur when COA data are modified due to refinements of the calibration model or other changes.

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. 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 A3.4–26 and Equation A3.4–27).

Equation A3.4–26

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

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 A3.4–27

$$N_2O_{FSOM} = \sum_i (F_{SOM,i} \times EF_{BASE,i} \times RF_{TEXTURE,i}) \times \frac{44}{28}$$

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 over the time series that is reported in the LULUCF Cropland remaining Cropland category are used for soil N_2O estimates associated with the loss of soil organic matter.

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 A3.4–28).

Equation A3.4–28

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

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 in Canada was 16 kha (Liang et al., 2004) and remains constant over time.

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 emissions, 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 A3.4–29 is used (Rochette et al., 2008):

Equation A3.4–29

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

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 soils 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 4 – Cropland in Annex 3.5).

These data are published at the census agricultural region, census division, and provincial and national levels. Annual $FRAC_{NT-RT}$ 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 A3.4–30

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

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, inorganic 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 A3.4–31

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

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, $N_2O_{FALLOW\text{-}EFFECT}$ can be empirically estimated as follows:

Equation A3.4–32

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

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
$N_2O_{FALLOW\text{-}EFFECT}$	=	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, inorganic N fertilizers and organic N fertilizers) to the area of the ecodistrict under summerfallow:

Equation A3.4–33

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

N_2O_{FALLOW}	=	emissions from summerfallow, kg N_2O
$N_2O_{SFN,i}$	=	emissions from inorganic N fertilizers in ecodistrict i, kg N_2O
$N_2O_{RES,i}$	=	emissions from crop residue decomposition in ecodistrict i, kg N_2O
$N_2O_{MAN,i}$	=	emissions from organic N fertilizers in ecodistrict i, kg N_2O
$FRAC_{FALLOW,i}$	=	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 inorganic N fertilizers, organic N 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 4: 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 agricultural 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 A3.4–34

$$N_2O_{IRRI} = \sum_i \left[\left(N_{FERT,i} + N_{MAN-CROPS,i} + N_{RES,i}\right) \times \left(0.017 - EF_{BASE,i}\right) \times FRAC_{IRRI,i}\right] \times \frac{44}{28}$$

N_2O_{IRRI}	=	emissions from irrigation, kg N_2O/year
$N_{FERT,i}$	=	inorganic N fertilizer consumption in ecodistrict i, kg N/year
$N_{MAN\text{-}CROPS,i}$	=	amount of organic N fertilizers applied to the 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 4 – 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 inorganic and organic N. The emission calculation is shown in Equation A3.4–35.

Equation A3.4–35

$$N_2O_{VD} = \sum_i \left[\left(N_{FERT\,TN,i} \times FRAC_{GASF\,NT,i}\right) + \left(MAN_{PRP,iT} \times FRAC_{GasMS-PRP,T}\right) + \left(N_{MAN-CROPS,i} \times FRAC_{GASM,i}\right)\right] \times EF_4 \times \frac{44}{28}$$

N_2O_{VD}	=	emissions from volatilization and redeposition of N, kg N_2O/year
$N_{FERT,\,TN,i}$	=	inorganic N consumption for each type of N fertilizers including urea, urea ammonium nitrate, anhydrous ammonia and others in ecodistrict i, kg N/year
$FRAC_{GASF\,NT,i}$	=	fraction of inorganic N fertilizers applied to soils that volatilizes as NH_3-N, kg NH_3-N/kg N, determined by a country-specific method in an ecodistrict i (see Equation A3.4–17)
$MAN_{PRP,iT}$	=	amount of urine and dung 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 subcategory T: 0.2 kg (NH_3-N + NO_x-N)/kg N for all livestock (IPCC, 2006). Except dairy categories (Table A3.4–33)
$N_{MAN-CROPS,i}$	=	organic N fertilizers applied on cropland in ecodistrict I, kg N/year (see Table A3.4–31)
$FRAC_{GASM,i}$	=	fraction of volatilized organic N fertilizers in ecodistrict i: 0.2 kg (NH_3-N + NO_x-N)/kg N for all livestock (IPCC, 2006) except Dairy and Swine categories (Table A3.4–31).
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

A country-specific method was used to estimate ammonia emissions from inorganic N application. The method for deriving ammonia emission factors closely follows the approach of Sheppard et al. (2010a), who applied the regression model developed by Bouwman et al. (2002b) 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 A3.4–36).

Equation A3.4–36

$$FRAC_{GASF\,TN,\,i} = 100 \times EXP^{(sum\ of\ relevant\ coefficients)}$$

$FRAC_{GASF\,TN,\,i}$	=	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 A3.4–28)
100	=	conversion of fraction to percent
EXP	=	exponential

The method of application for each type of inorganic N fertilizers for Eastern and Western Canada is provided in Sheppard et al. (2010a). 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 (2016a) 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 A3.4–29) 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 A3.4–30). More detail on methods of estimating ammonia emission factors

Table A3.4–28 **Coefficients for Crop Type, Inorganic N Fertilizers, Method of Fertilizer Application, Soil Chemical Properties and Climate Developed by Bouwman et al. (2002b)**

Conditions where coefficient used		Coefficients
Crop Type	Annual crops	-0.045
	Perennial crops	-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

from inorganic N fertilizers can be found in Sheppard et al. (2010a), 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. (2010a), it is assumed that inorganic N fertilizers are applied in either 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 5% to a maximum of 10% (Table A3.4–30), depending on the year and province.

Table A3.4–29 **Ammonia Emission Factors of Inorganic Nitrogen Fertilizers Applied to Annual Crop Weighted Based on Soil Properties for Each Province (%)**

	Annual			
PROVINCE	Urea	Anhydrous 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

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:

Equation A3.4–37

$$N_2O_L = \sum_i \left[\left(N_{FERT,i} + N_{MAN-CROPS,i} + MAN_{PRP,i} + N_{RES,i} \right) \times FRAC_{LEACH,i} \times EF_5 \right] \times \frac{44}{28}$$

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 applied 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,

Table A3.4–30 **Fractions of N Volatilized (FRACGASF) as Ammonia Resulting from the Application of Inorganic N Fertilizer, from Select Years, 1990–2018, at a Provincial Scale**

	Implied EF (kg NH_3-N volatilized/kg inorganic fertilizer N applied)									
Year	AB	BC	MB	NB	NL	NS	ON	PE	QC	SK
1990	0.06	0.09	0.06	0.07	0.00	0.07	0.08	0.06	0.09	0.05
1995	0.06	0.09	0.07	0.07	0.08	0.08	0.08	0.06	0.08	0.06
2000	0.06	0.10	0.07	0.06	0.00	0.07	0.08	0.05	0.08	0.06
2005	0.06	0.10	0.07	0.06	0.02	0.07	0.08	0.06	0.07	0.06
2010	0.06	0.09	0.07	0.05	0.07	0.06	0.08	0.05	0.07	0.06
2011	0.06	0.09	0.07	0.05	0.07	0.06	0.08	0.05	0.07	0.06
2012	0.06	0.09	0.07	0.05	0.07	0.06	0.08	0.05	0.07	0.06
2013	0.06	0.09	0.07	0.06	0.08	0.07	0.08	0.06	0.07	0.06
2014	0.06	0.09	0.06	0.05	0.07	0.06	0.07	0.05	0.07	0.06
2015	0.06	0.09	0.07	0.06	0.07	0.06	0.07	0.05	0.07	0.06
2016	0.06	0.09	0.07	0.05	0.07	0.06	0.08	0.05	0.07	0.06
2017	0.06	0.08	0.07	0.05	0.07	0.06	0.07	0.05	0.07	0.06
2018	0.06	0.08	0.07	0.05	0.07	0.06	0.08	0.05	0.08	0.06

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 a per area 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 A3.4–8).

Data sources for N_{FERT}, $N_{MAN\text{-}CROPS}$, MAN_{PRP} and N_{RES} (section A3.4.5.1) at an ecodistrict level are provided in the previous sections.

Figure A3.4–8 **Determination of the Ecodistrict $FRAC_{LEACH}$ Values**

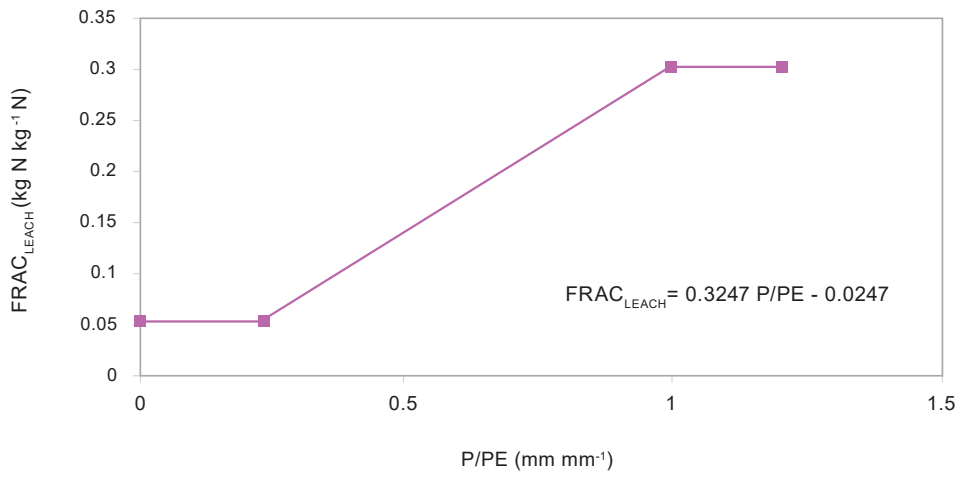


Table A3.4–31 **Fractions of Dairy Cattle N Volatilized as Ammonia Resulting from the Application of Manure N Fertilizer, from Select Years, 1990–2018, at a Provincial Scale**

	Implied EF (kg NH_3-N volatilized/kg manure N applied)									
Year	AB	BC	MB	NB	NL	NS	ON	PE	QC	SK
1990	0.14	0.10	0.16	0.20	0.19	0.20	0.18	0.18	0.17	0.15
1995	0.13	0.09	0.16	0.19	0.19	0.19	0.18	0.18	0.17	0.15
2000	0.12	0.09	0.15	0.18	0.19	0.18	0.17	0.18	0.16	0.14
2005	0.11	0.08	0.14	0.17	0.19	0.16	0.17	0.18	0.15	0.13
2010	0.11	0.09	0.13	0.16	0.19	0.15	0.16	0.17	0.15	0.12
2011	0.11	0.09	0.13	0.16	0.19	0.15	0.16	0.17	0.15	0.12
2012	0.11	0.09	0.13	0.16	0.19	0.15	0.16	0.17	0.15	0.12
2013	0.11	0.09	0.13	0.16	0.19	0.15	0.16	0.17	0.15	0.12
2014	0.11	0.09	0.13	0.16	0.19	0.15	0.16	0.17	0.15	0.12
2015	0.11	0.09	0.13	0.16	0.19	0.15	0.16	0.17	0.15	0.12
2016	0.11	0.09	0.13	0.16	0.19	0.15	0.16	0.17	0.15	0.12
2017	0.11	0.09	0.13	0.16	0.19	0.15	0.16	0.17	0.15	0.12
2018	0.11	0.09	0.13	0.16	0.19	0.15	0.16	0.17	0.15	0.12

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 the current year. 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 A3.4–32). 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 A3.4.3.9; the distributions used to define uncertainties can be found in Table A3.4–8 and Table A3.4–18. 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

Table A3.4–32 **Fractions of Swine N Volatilized as Ammonia Resulting from the Application of Manure N Fertilizer, from Select Years, 1990–2018, at a Provincial Scale**

	Implied EF (kg NH_3-N volatilized/kg manure N applied)									
Year	AB	BC	MB	NB	NL	NS	ON	PE	QC	SK
1990	0.14	0.22	0.14	0.28	0.23	0.28	0.21	0.28	0.26	0.15
1995	0.13	0.22	0.12	0.27	0.23	0.27	0.21	0.27	0.25	0.13
2000	0.13	0.22	0.11	0.26	0.23	0.25	0.20	0.26	0.25	0.12
2005	0.12	0.22	0.11	0.25	0.23	0.24	0.20	0.25	0.24	0.12
2010	0.12	0.21	0.11	0.24	0.23	0.23	0.20	0.25	0.24	0.12
2011	0.12	0.21	0.11	0.24	0.22	0.24	0.20	0.25	0.24	0.13
2012	0.12	0.21	0.11	0.24	0.22	0.24	0.20	0.25	0.24	0.13
2013	0.13	0.21	0.11	0.24	0.22	0.24	0.20	0.25	0.24	0.13
2014	0.13	0.21	0.11	0.24	0.22	0.25	0.20	0.25	0.24	0.13
2015	0.13	0.21	0.11	0.25	0.22	0.25	0.20	0.25	0.24	0.13
2016	0.13	0.21	0.11	0.25	0.23	0.25	0.20	0.25	0.24	0.13
2017	0.13	0.21	0.11	0.24	0.23	0.25	0.20	0.25	0.24	0.13
2018	0.13	0.21	0.11	0.24	0.23	0.25	0.20	0.25	0.24	0.13

Table A3.4–33 **Fractions of Dairy Cattle N Volatilized as Ammonia Resulting from Deposition on Pasture, Range and Paddock, in 2018, at a Provincial Scale**

Province	Implied EF (kg NH_3-N volatilized/kg manure N)
AB	0.035
BC	0.042
MB	0.036
NB	0.039
NL	0.036
NS	0.039
ON	0.042
PE	0.039
QC	0.036
SK	0.036

uncertainty is associated with indirect emissions and specifically with the indirect emission factors for volatilized and leached N, with the 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 smaller 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.

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:

Equation A3.4–38

$$Q_{BURN} = \sum_{T} (PRODUCTION_T \times (1 - MOISTURE_T) \times RatioAR/P_T \times PCB_T \times RATIO_{SCALE})$$

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)[25] 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 A3.4–35. To establish a complete time series of activity data, additional information on crop residue

25 Available at http://www23.statcan.gc.ca/imdb/p2SV.pl?Function=getSurvey&SDDS=5044.

Table A3.4–34 **Uncertainty Parameters Used in the Calculation of Agricultural N_2O Emissions**

Parameter	Coefficient/Parameter Source	Distribution Type	Uncertainty Range	Most Likely Value[b]	Uncertainty Distribution Source and Notes
IPCC and National Scale Parameters					
Animal populations and characterization data[a]					Karimi-Zindashty et al. (2012) from Statistics Canada, personal communication
N excretion	2006 IPCC Guidelines	Normal	±50%	IPCC default	
$FRAC_{GAS}/FRAC_{LOSSMS}$		Triangular	IPCC default	IPCC default	See Table 10.22/10.23 of 2006 IPCC Guidelines
AWMS emission factor		Triangular	Liquid 0.0005–0.002 PRP -0.007–0.06	Minimum liquid 0.001 Maximum PRP -0.02	2006 IPCC Guidelines 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, aboveground and belowground)					
$FRAC_{Renew}$ (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 consultations
$FRAC_{LEACH}$ calculation parameters			Intercept ±54% Slope ±21%		
F_{TILL}			±100%		
$RF_{TEXTURE}$			±30%		
EF_{LEACH}	2006 IPCC Guidelines	Triangular	0.002–0.12	0.025	2006 IPCC 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[c] literature and modelling studies	Normal	±15%		Expert consultation
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[c] geographically referenced soil landscape agricultural database, derived from Census of Agriculture, 1990–2011	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					
FTOPO (proportion of lowland soils in ecodistrict)					
Extent of organic soils					
Irrigated soil area					
Annual soil texture					
Perennial soil texture					

Note:

a. 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 A3.1–7 and Table A3.2–8.

b. Reported where applicable when using a triangular distribution.

c. Agriculture and Agri-Food Canada.

Table A3.4–35 **Burning of Crop Residues by Crop Types in 2006**

	Spring Wheat	Winter Wheat	Oats	Barley	Mixed Grains	Flaxseed	Canola
	% of 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

Table A3.4–36 **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

Note:
Data for 2001 and 2006 were extracted from FEMS 2001 and FEMS 2006, collected by Statistics Canada; data for 1991 and 1996 were gathered through consultations by Coote et al. (2008).

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. Janzen et al. (2003) report basic characteristics of crops, such as moisture content of crop product and ratio of aboveground crop residue to crop product. Annual production of each crop subject to residue burning is available (Statistics Canada, No date. Table 32-10-0359-01 [formerly CANSIM 001-0017]—Estimated areas, yield, production and average farm price of principal field crops, in metric units.). Other parameters, such as fraction of biomass actually burned, and emission factors required for emission estimates, were obtained from the 2006 IPCC Guidelines.

Emissions of N_2O and CH_4 from crop residue burning are estimated using the following equation:

Equation A3.4–39

$$EMISSION_{BURN} = \sum(Q_{BURN,i} \times C_F \times G_{EF})/1000$$

$EMISSION_{BURN}$ = 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), 0.00007 kg N_2O or 0.0027 kg 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

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 environment. 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 A3.4–40

$$CO_2 - C\ Emission = \sum(M_{Limestone/dolomite,i} \times EF_{Limestone/dolomite})$$

$CO_2 - C\ Emission$	=	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

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.[26] 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 uncertainty in the emission factor was assumed to be -50% based on the 2006 IPCC Guidelines.

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:

$$(NH_2)_2CO + H_2O \rightarrow NH_4^+ + OH^- + CO_2$$

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 A3.4–41:

Equation A3.4–41

$$CO_2 - C\ Emission = \sum(M_{Urea,i} \times EF_{Urea})$$

$CO_2 - C\ Emission$	=	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

Statistics Canada collects and publishes annual fertilizer shipment data, including urea and urea ammonium nitrate (Statistics Canada, 2016a). 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.

26 [NRCan] Natural Resources Canada. 2007–2016. Canada, Production of Limestone – Stone. Unpublished data. Natural Resources Canada, Mineral & Mining Statistics Division.

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 (C) 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 (HWP) 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 (A3.5.6) and Settlements (A3.5.7) 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 A3.5–1). 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.

The most suitable spatial framework for GHG monitoring of cropland are the polygons of the Soil Landscapes of Canada[27] (SLC). A soil landscape describes a group of soils and their associated landscapes and provides information, such as surface form, slope, typical soil C 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 landscape components. SLC polygons are also the basic units of Canada's National Ecological Framework, a hierarchical,

27 Available online at http://sis.agr.gc.ca/cansis.

Table A3.5–1 **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 Columbia	65
Yukon	13
Northwest Territories	30
Nunavut	0
Canada	**607**

spatially consistent national classification system within which ecosystems of various scales can be described, monitored and reported on (Marshall et al., 1999). 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 A3.5–6) 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 C 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 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 C 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-cut, shelterwood harvest, seed tree harvest, selection harvest, commercial thinning, precommercial thinning, salvage logging, residential firewood harvest and the burning of harvest residues. Different practices of forest conversion are also simulated, including controlled burning.

The forest C pools represented in the CBM-CFS3 can be matched with the Intergovernmental Panel on Climate Change (IPCC) forest C pools (Table A3.5–2). Although not shown here, living biomass pools are further subdivided into two sets, for each of hardwood and softwood tree species.

Annual ecosystem process events are simulated as C transfers between C pools executed at each time step (annually) in every inventory record (Figure A3.5–1). During annual processes, C is taken up in the biomass pool and some biomass C is transferred to dead organic matter (DOM) pools. The decay of DOM results in C 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 C 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 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 gross 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 gross 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.

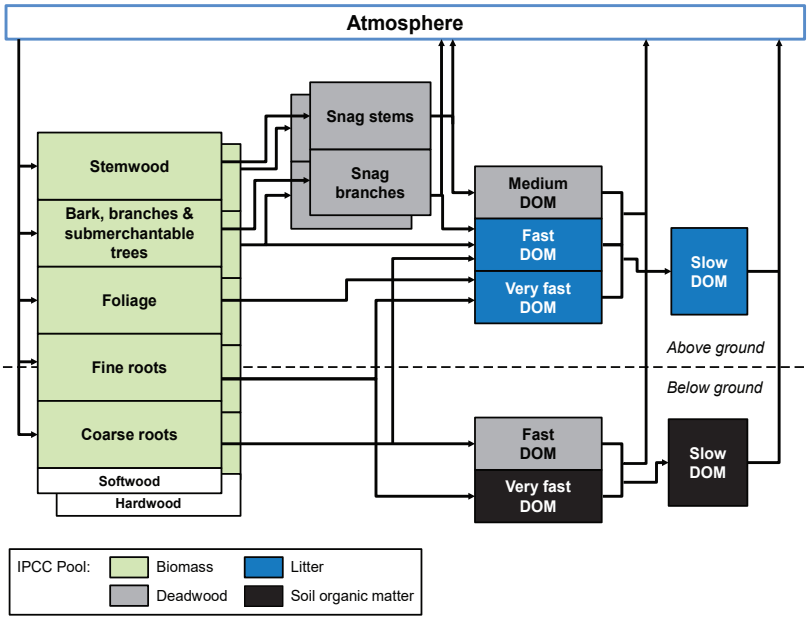
Modelling of C transfers triggered by disturbances is based on the disturbance type and severity, the forest ecosystem affected and the ecological region. For modelling purposes, different practices of forest conversion are also implemented as disturbances. The impact of a disturbance is represented by a disturbance matrix, which specifies, for one or more disturbance types, the proportion of C in each ecosystem pool that is transferred to other pools, released to the atmosphere or transferred to Harvested Wood Products (Figure A3.5–2). In the current submission, the simulation uses a total of 157 disturbance matrices. The number of different

Table A3.5–2 **Forest Carbon Pools in IPCC and CBM-CFS$_3$**

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)	Deadwood	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[a] Below-ground slow Black carbon[b] Peat[b]

Notes:
a. Below-ground very fast pool includes dead and decaying fine roots, which in practice cannot be separated from soil.
b. Black carbon and peat are currently not estimated.

Figure A3.5–1 **Carbon Pools and Transfers Simulated by the CBM-CFS$_3$**



Source: White et al. (2008), updated

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 C emitted in each C-containing GHG (CO_2, CO and CH_4) due to fire is constant: 90% of C is emitted as CO_2, 9% as CO and 1% as CH_4 (Cofer et al., 1998; Kasischke and Bruhwiler, 2003).

Carbon emissions emitted as CO oxidize in the atmosphere resulting in indirect CO_2 emissions. These indirect CO_2 emissions are calculated on a unit C basis as the original emissions in units of C-CO multiplied by 28/12 to convert to CO, and multiplied by 44/28 to convert to indirect CO_2 emissions. More details on the reporting of these indirect CO_2 emissions can be found in Chapter 6 and Annex 7.

While the CBM-CFS3 can model C 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. Forest drainage

Forest drainage is used to lower the water table, thereby improving soil aeration and promoting root development and tree growth on low-productivity organic soils. A consultation with forestry industry experts and an extensive literature review carried out in 2015 and 2016 suggested that the only province in Canada where operational drainage of organic soils for forestry occurred was Quebec (Gillies, 2016). This management activity occurred from the 1980s through to the mid-2010s on a small percentage of peatlands corresponding to three RUs (11, 12 and 15) on both private and public lands. Forest drainage has progressively declined since 2003 due to the end of government subsidies and changes to Quebec's forest management tenure.

Data on forest drainage were compiled from a combination of historical documents, consultations and provincial statistics to develop a time series from 1980–2018 of annual peatland areas drained for forestry on both private and publicly owned forests

Figure A3.5–2 **Disturbance Matrix Simulating the Carbon Transfers Associated with Clear-cut Harvest 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	

of Quebec. Provincial statistics (Gouvernement du Québec, 2018) were reported by Administrative Regions (ARs) for 1994–2008 and by province for 1986–1993 and for 2009–2017. Drainage data for 1980–1985 were assumed to be constant, resulting in a cumulative area drained equivalent to the 1986 value reported by Quebec statistics, which was also consistent with values cited in Hillman (1987). Given the absence of drainage activity data for 2018 and the fact that there were no areas drained in 2016 and 2017, drained areas in 2018 were assumed to be zero. Estimates of drained areas by AR (1994–2008) were allocated to the three RUs by overlaying the ARs to create a spatially weighted area average that was applied to the provincial values for all years.

Emissions of CO_2, CH_4 and N_2O from drained organic soils were calculated using a Tier 1 method and emission factors from Tables 2.1, 2.2 and 2.3, respectively, of the 2013 IPCC Wetland Supplement to the 2006 Guidelines (IPCC, 2014). Emission factors are associated with the temperate (RUs 11 and 12) and boreal (RU 15) climate zones. The fraction of area covered by ditches was also determined using the default values for drainage ditches from Table 2.3 of the 2013 Wetland Supplement (IPCC, 2014).

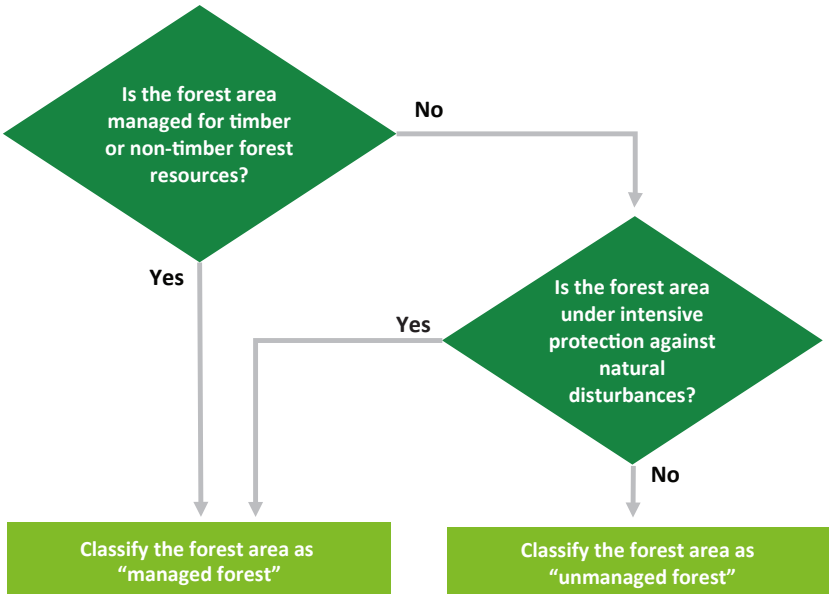
A3.5.2.3. Data Sources

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 A3.5–3). Managed forests occur within all provinces and territories of Canada, with the exception of Nunavut (Figure A3.5–4). 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. (2011).

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 originating after harvesting or following 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 (given that insect disturbances are not

Figure A3.5–3 **Decision Tree for the Determination of Managed Forest Area**



stand replacing). These distinctions are used to separate stands dominated by anthropogenic and natural emissions and removals (see section A3.5.2.4).

Forest management activities are documented in the National Forestry Database[28] 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, provide 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 curve), site indices—and regional expertise (Table A3.5–3). 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., 2011).

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.[29] 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 the current inventory year (Table A3.5–3). 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.

28 National Forestry Database, available online at http://nfdp.ccfm.org/about_us_e.php.

29 In British Columbia, expert opinion indicates that the proportion of areas harvested using clear-cut where slash burning is applied is 15% on the coast and 50% for the rest of the province.

Figure A3.5–4 **Lands with Managed and Unmanaged Forests in Canada**

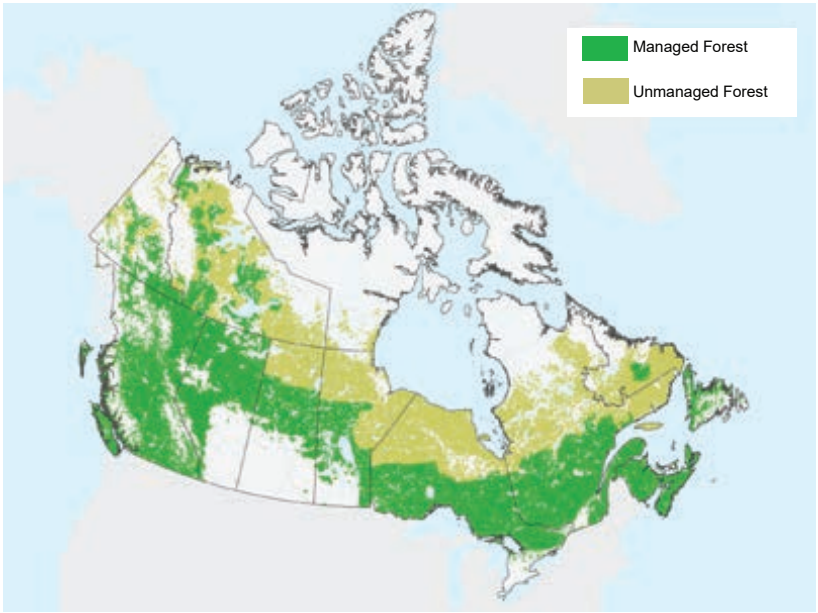


Table A3.5–3 **Main Sources of Information and Data, Managed Forests**

Description	Source	Spatial Resolution	Temporal Coverage	Reference
Climate data	CFS	Analysis units	1961–1990 normals	McKenney et al., 2001
Forest inventories & merchantable volume data[a]	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[b]	Analysis units	1949–1999	Provincial experts
	British Columbia	Analysis units	2011	Provincial experts
Conventional harvest data[c]	National Forestry Database	Provincial boundaries	1990–2018	http://nfdp.ccfm.org/
	National Forestry Database	Analysis units	1990–2016	http://nfdp.ccfm.org/
Slash burning	National Forestry Database and British Columbia	Provincial boundaries	1990–2018	Provincial experts and http://nfdp.ccfm.org/
Residential firewood harvest data	Energy Sector data for residential firewood use	Provincial boundaries	1990–2018	Section A3.1.4.1.4
Insect data	Forest Insect and Disease Survey	Spatially explicit	1990–2017	Atlantic Forestry Centre and Pacific Forestry Centre
	Newfoundland	Spatially explicit	2000–2003	Provincial experts
	Quebec	Spatially explicit	1985–2018	Provincial experts
	Manitoba	Spatially explicit	1990–1998	Provincial experts
	Saskatchewan	Spatially explicit	1998–2001	Provincial experts
	Alberta	Spatially explicit	1990–2018	Provincial experts
	British Columbia	Spatially explicit	1990–2018	Provincial experts
	Yukon	Spatially explicit	1994–2005	Provincial experts
Fire data	National Burned Area Composite	Spatially explicit	2004–2018	http://www.nrcan.gc.ca/node/13159
	Canadian National Fire Database	Spatially explicit	1959–2003	http://www.nrcan.gc.ca/node/13159
Drainage data[d]	Quebec	Province of Quebec boundaries	1980–1985	Provincial experts; historical records; Hillman, 1987; Gillies, 2016
	Ministère des Forêts, de la Faune et des Parcs du Québec	Province of Quebec boundaries	1986–1994	https://mffp.gouv.qc.ca/les-forets/connaissances/statistiques-forestieres
	Ministère des Forêts, de la Faune et des Parcs du Québec	Administrative regions of Quebec	1994–2008	https://mffp.gouv.qc.ca/les-forets/connaissances/statistiques-forestieres
	Ministère des Forêts, de la Faune et des Parcs du Québec	Province of Quebec boundaries	2008–2018	https://mffp.gouv.qc.ca/les-forets/connaissances/statistiques-forestieres

Notes:

a. Forest inventory and merchantable wood volume yield data were obtained from Canada's National Forest Inventory and/or from provincial experts where specified.

b. Alberta's forest inventory database comprises provincial forest inventory for the province's Forest Management Areas, and CanFI inventory for the remainder of the managed forest landbase.

c. Given the absence of complete harvest data for the most recent reporting year for all provinces and territories, 2018 harvest data are estimated by assuming them to be equal to 2017 values.

d. No new drainage activity has been registered in the Province of Quebec since 2016.

Insect disturbances are monitored by aerial surveys (Table A3.5–3), which record the area impacted by the disturbance and assign an impact severity 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).

Areas drained for forestry (Table A3.5–3) on private and publicly owned forests in Quebec are estimated using historical documents, consultations and Quebec statistics. Spatial allocation by RU was performed using Quebec statistics.

A3.5.2.4. Quantifying Anthropogenic Emissions and Removals

Interannual variations and trends in emissions and removals from managed forests in Canada are dominated by the impact of wildfires and periodic forest insect outbreaks, making it difficult to detect trends due to human actions in the forest (Kurz et al., 2008a,b; 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 capability to track and separate emissions and removals in managed forest stands dominated by the impact of anthropogenic activities from those in which emissions and removals result from a significant natural disturbance that has masked the legacy of human management and affected the commercial value of the stand.

The management and natural disturbance history of each individual stand (inventory record) in the managed forest area is used to assign stands to two groups. Emissions and removals are identified as being anthropogenic when i) a stand's growth trajectory has been significantly modified by human intervention—this definition includes commercial clear-cut and partial harvest, commercial and pre-commercial thinning, salvage logging, site preparation, and rehabilitation and planting on stands that have undergone both stand replacement and partial natural disturbances; and 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 are switched to 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. Only partial disturbances causing > 20% mortality are included in the natural disturbance category.

In the initial implementation of this approach in the 2017 NIR, a fixed value of 60 years was assumed to be generally applicable to represent a minimum return period to commercial maturity across Canada. Since the 2018 NIR, regionally specific return periods based on differences in forest management practices, species distributions and stand dynamics among regions have been used.

To develop regionally representative definitions of commercial maturity, a questionnaire was distributed to provinces and territories in March 2017. The objective of this consultation process was to document forest management practices across Canada, with a focus on the treatment of naturally disturbed forest stands in operational planning. As such, work with provincial experts provided a minimum return period to commercial maturity ranging from 45 to 99 years, with an average of 76 years.

In most cases, provincial agencies defined species-specific commercial maturity based on the maximum mean annual increment of species-specific yield curves for a high productivity site class in a given region. Other provincial agencies used empirical data based on observed regional minimum harvest ages or an age to achieve a specific piece size. Based on the species-specific commercial age, a weighted minimum return period was determined for each reporting zone based on the proportional breakdown of the commercial species that were attributed a minimum operable age, or minimum harvest age, in that area. Greater detail on the methodological approach used to track anthropogenic emissions and removals can be found in Kurz et al. (2018).

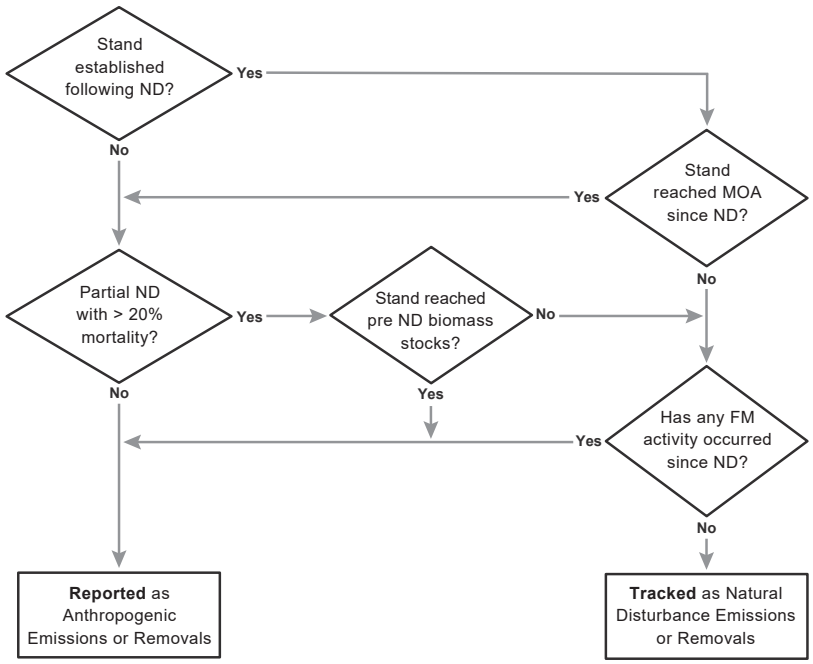
In the current modelling framework, partial natural disturbances occur mainly due to insect infestations. In these cases, aboveground biomass recovery was used to define a recovery period as the growth trajectory of the stand is only temporarily modified. Stands subject to insect disturbances causing less than or equal to 20% biomass mortality are not deemed to be dominated by natural disturbances; at this low mortality level, disturbances are considered agents that contribute to stand density reductions.

This improvement in the reporting approach assures that emissions from stands affected by uncontrollable natural disturbances and the subsequent removals by the regrowth of these stands are tracked separately from commercially managed stands, allowing an improved separation of emissions and removals associated with direct forest management actions and non-anthropogenic emissions and removals occurring due to natural disturbances.

Tracking stands in which 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 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 (Figure A3.5–5).

After exclusion of the non-anthropogenic emissions and removals, the final reported values represent all forest stands in the managed forest land base 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 +3.6/-3.7 Mha, 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

Figure A3.5–5 **Decision Tree for Differentiating Emissions and Removals from Anthropogenic and Natural Origin**



Note: ND = Natural disturbance, MOA = Minimum operable age, FM = Forest management.

sum of emissions and removals quantified using the methodological approach for reporting total emissions from the managed forest in previous inventory submissions.

A3.5.2.5. 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, 2010b). 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,[30] 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

30 See Chapter 6 for the definitional parameters of "forest."

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 A3.5–7). 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 A3.5–6), with spatially complete mapping.

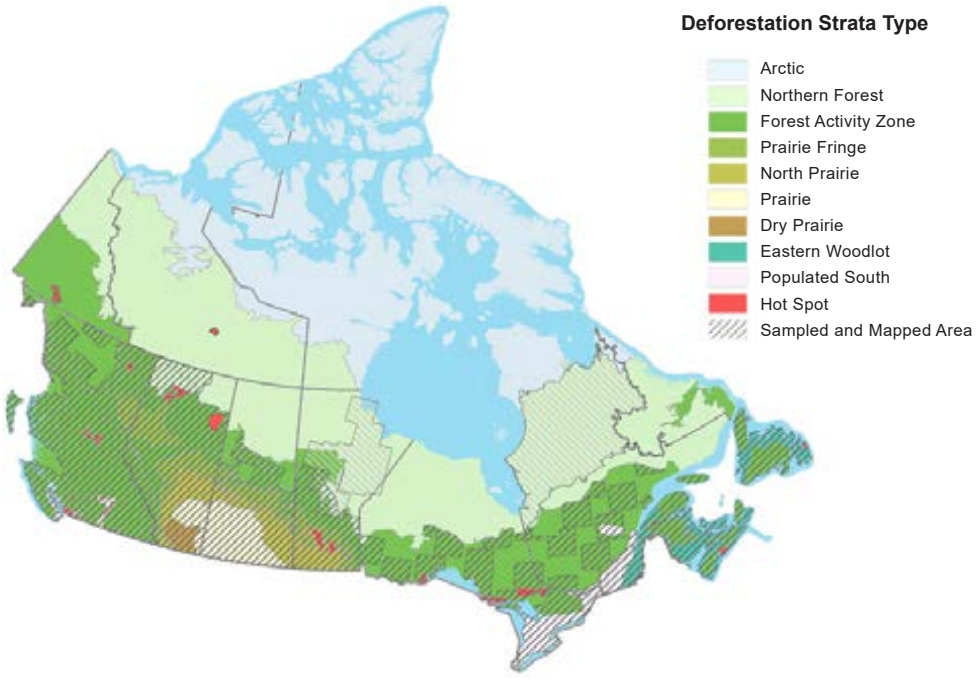
In practice, resource constraints limit the size of the remote sensing sample; wherever possible, a target sampling rate of 12% or 6% was achieved. It is also important to note that different sampling rates may be applied for each time period, in an effort to track differing activity rates between time periods. The total areas, either fully mapped or sampled, cover a large portion of the Canadian land base (Figure A3.5–6), e.g. approximately 346 million hectares (Mha). This total area was mapped over different time periods, 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.

Mapping is updated on a roughly five-year time cycle and may be integrated progressively by project for the most recent time period.

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. 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 each mapped time period (e.g. 1975–1990, 1990–2000, 2000–2008, 2008–2013) area estimate. 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.,

Figure A3.5–6 **Forest Conversion Strata and Areas Sampled**



2010a; 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 RU. 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 dated a specific year, the rates cover different time periods. At the data compilation phase, forest conversion events are assigned a time period, 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]/km^2 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 RU.

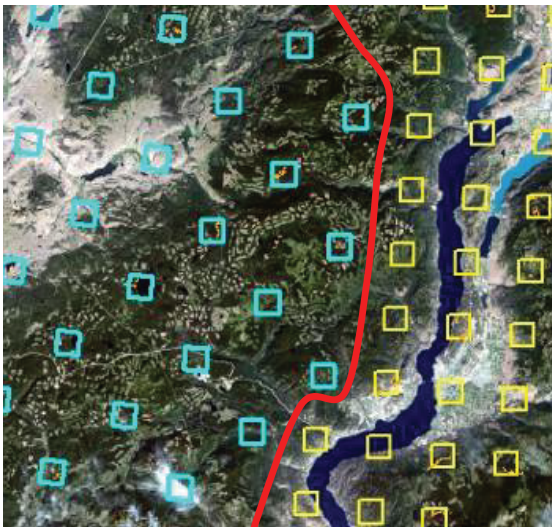
The remote sensing data are derived using medium-resolution imagery from circa 1975, 1990, 2000, 2007, 2011 and more recent years as new imagery has become available, whereas records data are annual or summarized over time periods. As explained, the remote sensing core method provides, to date, five distinct average rates of forest conversion for the mapped time periods, but no annual estimates of these rates. The preparation of annual forest conversion rates for 1970 to the current inventory year requires the simultaneous application of two procedures: (1) extrapolation of annual rates prior to 1983 and beyond the mid-point of the latest time period available; and (2) linear interpolation between the mid-points in the mapped time periods and recent analyses that are completed at the time of submission (Figure A3.5–8). Added to the interpolated data are individual large events for which actual disturbance information is known either from records information or a 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., 2010b; 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

Figure A3.5–7 **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

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:

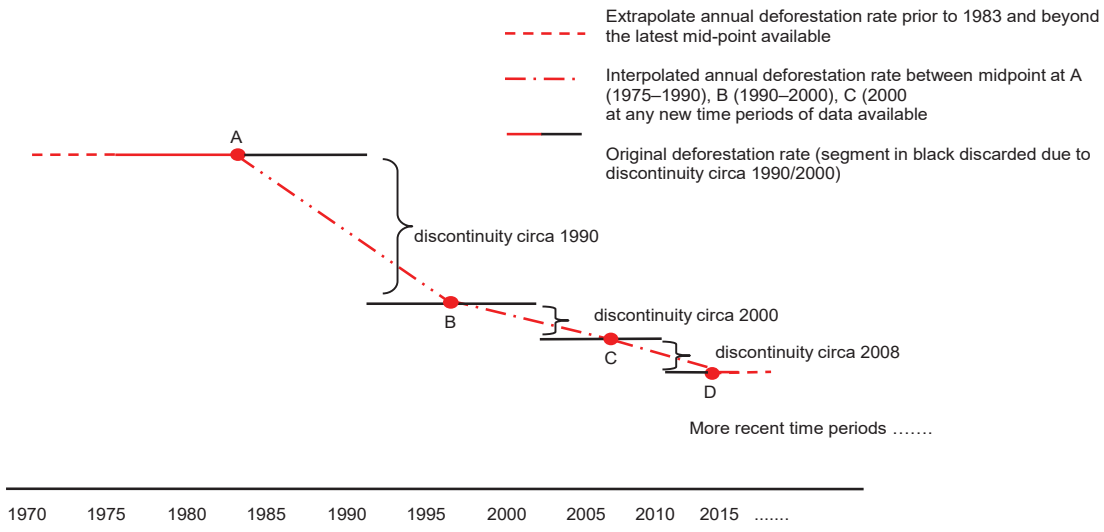
1. Expanded data sets with additional Earth Observation (EO) data, Landsat, SPOT-5, aerial photography and high-resolution satellite imagery.
2. Expansion of the sampled area for targeted and other areas.
3. Analysis and validation of records data with high-resolution imagery (for example, co-disturbance of pipelines and access roads).
4. Extending the temporal coverage to the most recent time period.
5. Reviewing the 1970–2004 deforestation time series based on more current spatial analysis.
6. 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.

Figure A3.5–8 **Procedure for Developing a Consistent Time Series of Rates of Forest Conversion**



The empirical estimate was developed by making estimates of extreme low, low, high and extreme high forest conversion rates for each RU 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/RU). 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 from 2000–2008. Each event, regardless of date, source, type or location, was converted to an inventory record for the purposes of C 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 2009 to the current inventory year. Efforts continue 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 RU.

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. It was assumed that no woody biomass is present on the site prior to afforestation. Changes in soil C stocks are highly uncertain. It was assumed that the ecosystem would generally accumulate soil C at a slow rate; the limited time frame of this analysis and the scale of the activity relative to other land-use and land-use change activities suggest that the impact of this uncertainty is minimal.

A3.5.2.6. 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 C 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 C 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 (C stock changes, C 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 outputs are available on converted forest lands (except tree growth), but are reported in the new land category—e.g., the Forest Land converted to Cropland (CRF Table 4.B subcategory 2.1), Land converted to Wetlands (CRF Table 4.D subcategories 2.1 and 2.2.1) and Forest Land converted to Settlements (CRF Table 4.E subcategory 2.1) 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 C stock changes) from forest land converted to flooded lands are described in section A3.5.6.2.

A3.5.2.7. 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 DOM 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 (Metsaranta et al., 2017). 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 C 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 limited total forestry drainage area suggests that the impact of the uncertainty associated with this activity is minimal.

The uncertainties about the C removed in harvested material are regionally specific and incorporate error ranges in harvested volume (±1%) and standard deviations about roundwood-specific gravity and the bark adjustment factor (Table A3.5–4). No error was assumed

Table A3.5–4 **Uncertainty Ranges for Harvested Carbon, by Canadian Province and Territory**

Province or 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

Note:
Metsaranta et al. (2014).

for the C 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 C. 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 C emissions from the DOM and soil pools revealed that the most influential model parameters included decay rates for soil organic matter and the decay and release to the atmosphere of C 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 C stocks, the parameters of the disturbance matrices that reallocate C 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 are developed for both reported emissions and removals representing anthropogenic drivers and non-reported emissions and removals due to natural disturbances. In years where there are no substantial changes, no comprehensive uncertainty analysis using Monte Carlo simulation is performed. Instead, confidence intervals for each category for the current year of submission are statistically extrapolated for both forest and HWP estimates. These extrapolations use the results of the previous submission, where numerical estimates of uncertainty were derived using Monte Carlo simulations as explained above and further described in Metsaranta et al. (2017). Total uncertainty estimates are allocated to the reported and non-reported categories using the same categorization procedures used to estimate reported and excluded values (see section A3.5.2.4).

Additional considerations may be warranted to identify the direct human-induced effects, and their uncertainties, on forest C 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 resulting 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 Simple Decay Approach, as described in the Annex to Volume 4, Chapter 12 of the 2006 IPCC Guidelines (IPCC, 2006). The approach is similar to, but differs from, the Production Approach in that the HWP pool is treated as a C transfer related to forest harvest and hence does not assume instant oxidation of wood in the year of harvest. 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 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), 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 1941–1989 period. For the 1900–1940 period, the C inputs are backcast based on historical production data, by extrapolating information from the 1941–1989 period, while the consumed and exported magnitudes are calculated using average proportions from statistics in the five-year period from 1961 to 1965.

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 A3.5–9). 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.

Recent statistics available in the FAO database of forestry trade flows were used to determine the proportion of Canadian roundwood and commodity production exported to three main destinations (FAO, 2010). For example, according to current statistics from the FAO, 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 20% 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 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 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 C content were used for all countries (Table A3.5–5). Default parameters were used to convert product volume to units of C for countries other than Canada and the United States and where country-specific parameters are not available for Canada or the United States (Table A3.5–6). 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.

All wood transferred from the forest to the HWP pool is included in the HWP model, but some of the products associated with portions of the wood, such as wood chips and pellets, are not explicitly identified due to a lack of information on firewood produced in Canada, e.g. the export of wood chips/pellets is not considered. Hence, wood used for bioenergy, such as pellets and chips, is assumed to be associated with the "milling

Table A3.5–5 **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[a]	0.5	IPCC, 2006 (Vol. 4, Table 12.4)

Note:
a. Tonnes carbon per oven dry tonne of wood material.

Table A3.5–6 **Wood Densities of Commodities**

Country/Countries	Description	Units[a]	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:
a. od tonne = oven dry tonne of wood material, ad tonne = air dry tonne of product

waste" output category in the model (see Figure A3.5–9). This C is quantified and allocated to bioenergy but is undifferentiated from other residual waste, all of which is assumed to be oxidized on disposal.

The model starts the pool in 1900 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 A3.5–7).

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 some remaining unaccounted C likely found in VOCs, unburned hydrocarbons and charcoal, 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

Figure A3.5–9 **A Simplified Schematic of Carbon Flows in Harvested Wood Products**

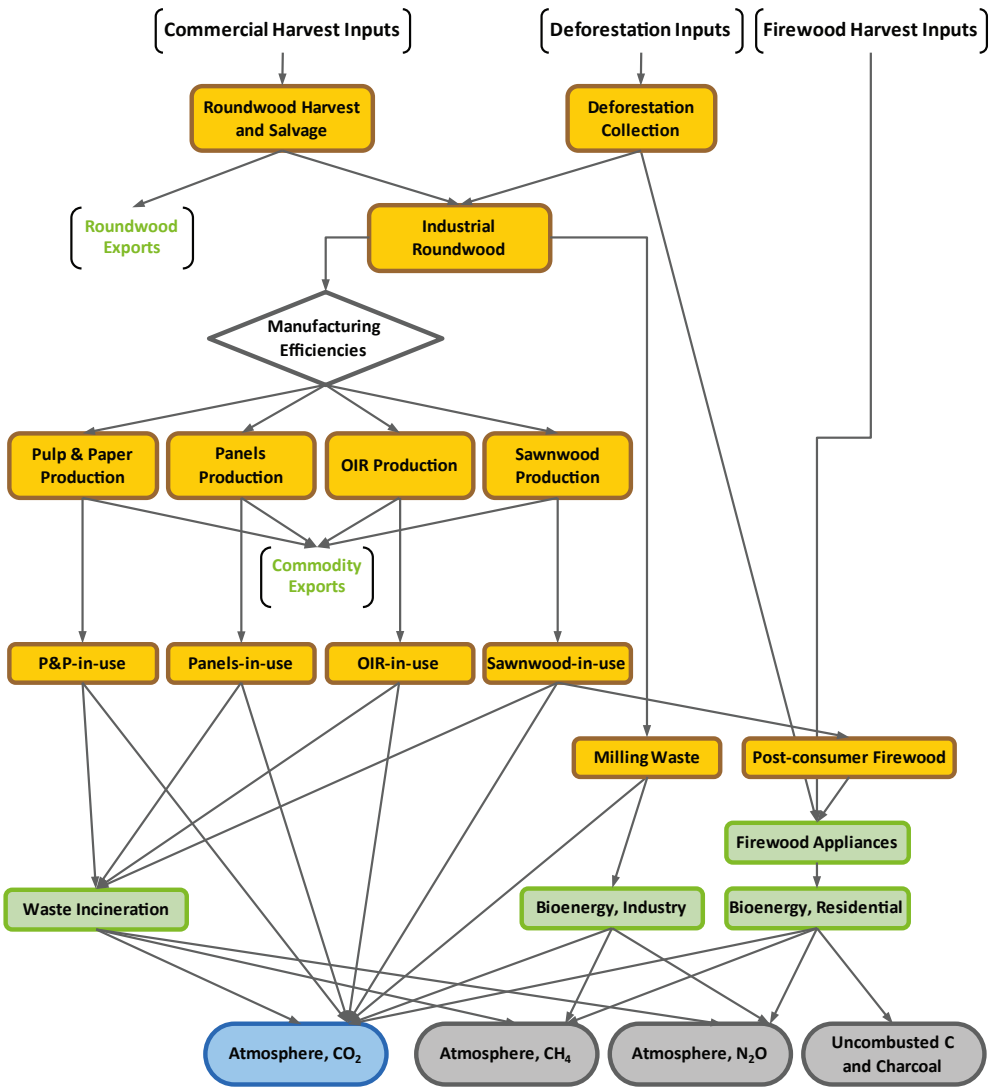


Table A3.5–7 **Half-Life Parameters (Years) of Harvested Wood Products In-Use**

Country/Countries	Description[a]	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)

Note:
a. Firewood and mill residue assumed to be burned for the former, or disposed of for the latter, in the year of harvest.

Table A6.6–1 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 A6.6–1. 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 45% is direct harvest and 8% is from forest conversion; (ii) 34% comes from the DOM 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 C inputs, namely: (i) the C 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 C inputs constant based on the output from the CBM-CFS3 forest ecosystem model; (ii) model parameters are held constant while C 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 C 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.

As already noted in A3.5.2.7, in years where there are no substantial changes, no comprehensive uncertainty analysis is performed and, instead, confidence intervals for each category for the current year of submission are statistically extrapolated using the results of the previous submission.

A3.5.4. Cropland

The methodologies described in this section apply to C 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 C stock changes and GHG emissions from the biomass and DOM pools upon conversion of forest land to cropland are provided in section A3.5.2.6.

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 C 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 A3.5–1

$$\Delta C = F \times A$$

ΔC	=	change in SOC stock for inventory year, Mg C
F	=	average annual change in SOC subject to LMC, or C factor, 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 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).

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 A3.5–10 and Figure A3.5–11). These 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).

A 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.

Figure A3.5–10 **Method for Deriving Carbon Factors for a Land Management Change of Interest**

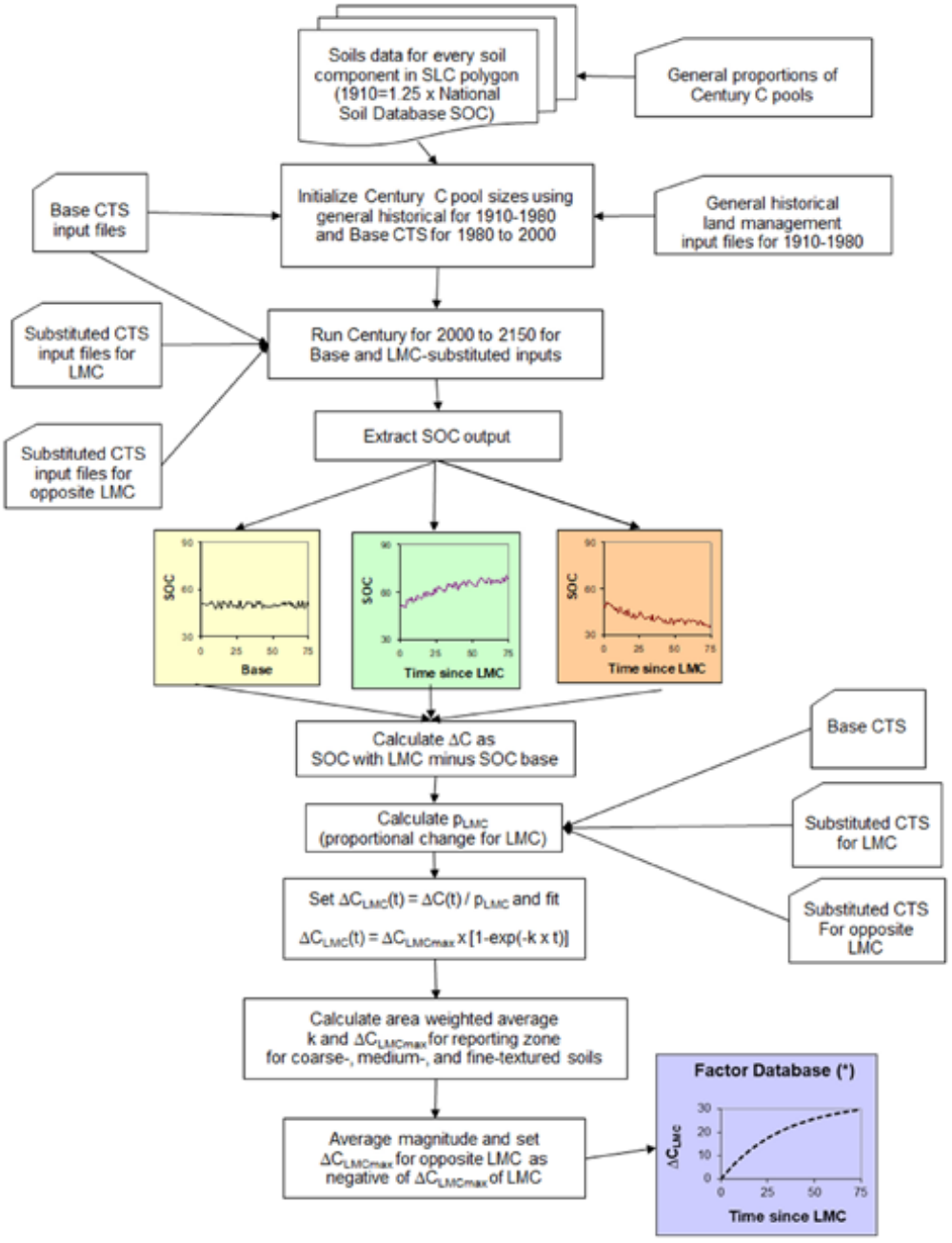
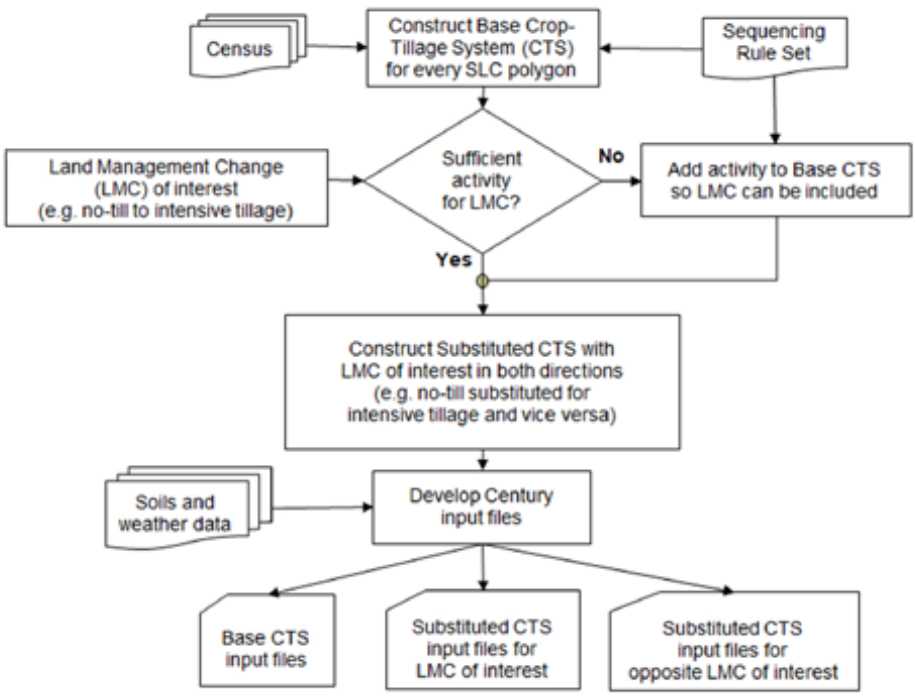


Figure A3.5–11 **Method for Deriving Land Management Input Files to Use with Century Model to Estimate the Carbon Factor for a Land Management Change of Interest**



Equation A3.5–2

$$\Delta C_{LMC(t)} = \frac{\Delta C}{P_{LMC}}$$

$\Delta C_{LMC(t)}$ = the change in SOC between land management systems in year "t" (Mg SOC/ha)

ΔC = the change in SOC due to the LMC (Mg SOC)

P_{LMC} = the proportion of the land area under a given land management system subject to the LMC, ha

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 A3.5–3

$$P_{LMC} = P_{LMbase} - P_{LMnew}$$

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 Semiarid 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. As a separate exercise, NT was substituted for IT 4 years out of 10 in the base mixture (Figure A3.5–12). 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 A3.5–2). Finally, the $\Delta C_{LMC}(t)$ was calculated as the proportion of area of farming system divided by the P_{LMC}. 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 A3.5–13).

Figure A3.5–12 **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**

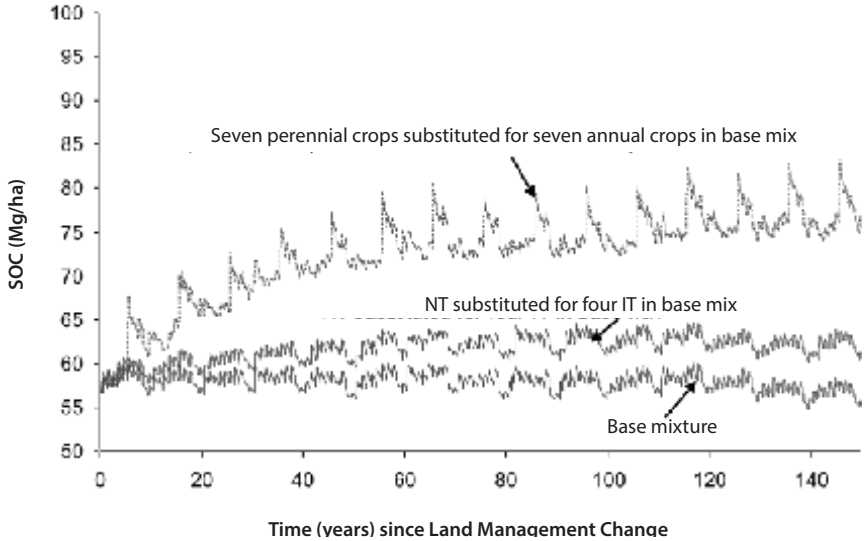
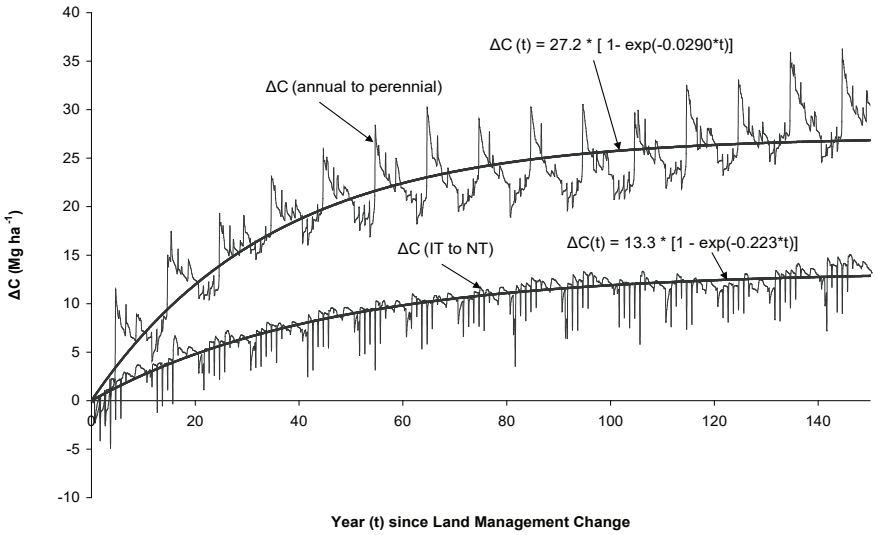


Figure A3.5–13 **Change in SOC for Simulations with Substitutions Relative to Simulations with Base Crop Mix**



SOC dynamics are believed to be governed by first-order kinetics, and thus C change can be expressed as:

Equation A3.5–4

$$\Delta C_{LMC}(t) = \Delta C_{LMCmax} \times [1 - exp^{(-k \times t)}]$$

$\Delta C_{LMC(t)}$	=	the change in SOC due to the LMC at a time, t (Mg ha^{-1})
ΔC_{LMCmax}	=	the maximum SOC change induced by the LMC (Mg ha^{-1})
k	=	the rate constant, year^{-1}
t	=	year after LMC

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 A3.5–5

$$F_{LMC}(t) = \Delta C_{LMCmax} \times [exp^{(-k \times [t-1])} - exp^{(-k \times t)}]$$

$F_{LMC(t)}$	=	the instantaneous C factor value due to the LMC at a time t, Mg C ha^{-1} year^{-1}
ΔC_{LMCmax}	=	the maximum SOC change induced by the LMC (Mg ha^{-1})
k	=	the rate constant, year^{-1}
t	=	Year after LMC

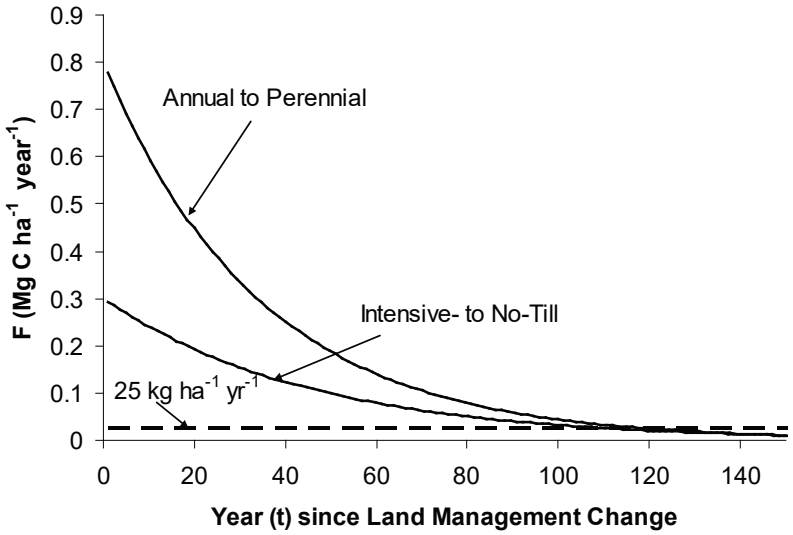
Since perfect steady-state conditions are never reached, the exponential equation should theoretically apply forever. In practice, however, the exponential equation was truncated when the $F_{LMC}(t)$ dropped to 25 kg C/ha per year. This rate was below a practical measurement limit (Figure A3.5–14).

Estimating Mean k and ΔC_{LMCmax} 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 (Table A3.5–8). 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_{LMCmax} 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

Figure A3.5–14 **Carbon Factors as a Function of Time**



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 Semiarid 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.

Table A3.5–8 **Effective Linear Coefficients of Soil Organic Carbon for Land Management Change (LMC)**

Zone[a]	LMC[b]	k/year	ΔC_{LMCmax} (Mg/ha)	Final Year of Effect after LMC[c]	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

Notes:

Effective Linear Coefficients of SOC were generated using $F_{LMC(t)} = \Delta C_{LMCmax} \times [1 - \exp(-k \times t)]$.

a. 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.

b. For LMCs in the opposite direction to that listed, the FLMCmax will be the negative of the value listed.

c. No further C changes once the absolute value of the rate of change is less than 25 kg C/ha per year.

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, Semiarid Prairies and West reporting zones (Table A3.5–8). 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 all inventory years since 1990. 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 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 A3.5–6

$$\Delta C_{LMC} = \sum_{1951-n} \sum_{ALLSLC} (\Delta C_{TILL} + \Delta C_{SF} + \Delta C_{CROPPING})$$

ΔC_{LMC}	=	change in SOC stocks due to LMC for a specific year since 1951 until year n (latest inventory year)
$ALLSLC$	=	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

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 soil C stock change. The data mainly used for modelling C factors include SLC, crop-tillage systems derived from the *Census of Agriculture*, 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 soil 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.[31] Although the current version of the SLC in the National Soil Database (NSDB) data holdings is 3.2, the SLC 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. The current version of the SLC in the National Soil Database (NSDB) data holdings is 3.2.

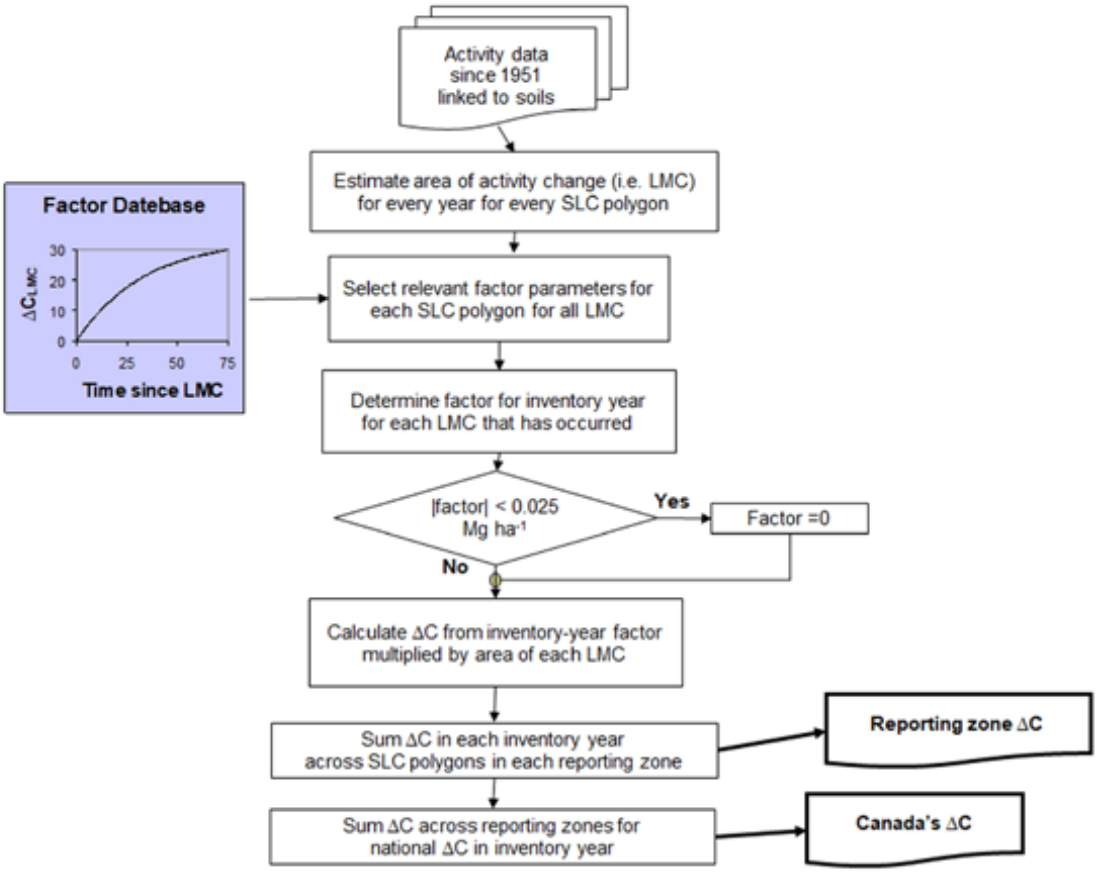
In all provinces within the agricultural region of Canada, detailed soil survey information with map scales greater than 1:1 million was used to delineate the SLC polygons and compile the associated database files. The SLC Component Soil Names Files and Soil Layer Files provided specific input data, 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

31 Available online at http://sis.agr.gc.ca/cansis.

Figure A3.5–15 **Method of Using Factors for Land Management Change to Estimate Carbon Change over Large Areas**



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 crop 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 database archived by Agriculture and Agri-Food Canada (AAFC). Long-term normals of monthly maximum and minimum temperatures (ºC) 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 were attributed to the SLC polygons (McConkey et al., 2007a).

Earth observation 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., 2015a). 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 the latest inventory year, 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*. 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 (2019).

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 EO 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.[32]

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 development are provided in McConkey et al. (2007b). Results of this analysis are provided in Chapter 6.

CO_2 Emissions and Removals from Woody Biomass

Estimates of emissions and removals from woody biomass on croplands include those originating from trees and shrubs in agricultural land as well as vineyards, fruit orchards and Christmas trees. A remote sensing-based sampling approach was used to determine areas of trees and shrubs over the reporting period, whereas the *Census of Agriculture* was used to acquire area estimates of vineyards, fruit orchards and Christmas trees.

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

32 Huffman T. 2006. Personal communication (from Huffman T, Agriculture and Agri-Food Canada to McConkey BG, Agriculture and Agri-Food Canada).

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.

Trees and shrubs in agricultural land include perennial woody cover types in farmyards, shelterbelts and hedgerows. Carbon storage on the landscape in woody biomass changes over time as trees and shrubs grow and die, or areas of lands with woody biomass change due to planting or colonization of cropland areas or the clearing of trees.

The EO-based sampling approach used to quantify changes in woody biomass on Canadian croplands was developed by Huffman et al. (2015b). Briefly, the national ecological framework (Marshall et al., 1999) was used to develop a spatially stratified random sampling approach. A target of 30 sample sites per ecozone was identified. High-resolution historical aerial photos from the National Air Photo Library and provincial databases were selected to digitize trees and shrubs land cover within a 2 km by 2 km plot for circa 1990 and circa 2000 at 1:10000 scale. The “Trees” land cover class was defined as having less than 25% crown closure and being less than 1 ha in size. The “Shrubs” land cover class represents non-agricultural woody plants that would not be expected to meet the forest or “Trees” definition when mature. Wood volume yield estimates for each ecozone were derived based on published literature and consultations with provincial forestry and agriculture specialists, conservation associations and academia. Overall, estimates of aboveground wood volume varied between 99.3 and 181.7 m^3/ha across ecozones, and mean annual increments varied between 1.2 and 3.8 m^3/ha/year. The analysis, coefficients and parameters used to estimate C stock changes were based on the methodology described by Huffman et al. (2015b).

Uncertainty

Poorly growing orchards and vineyards 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 uncertainty for vineyards, orchards and Christmas trees. Therefore, the default uncertainty of ±75% for woody biomass on cropland from the 2006 IPCC Guidelines was used for these land cover types. An error propagation approach described in Huffman et al. (2015b) was applied for trees and shrubs. 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 A3.5–7

$$C = \sum(A_i \times EF)$$

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 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 DOM 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.

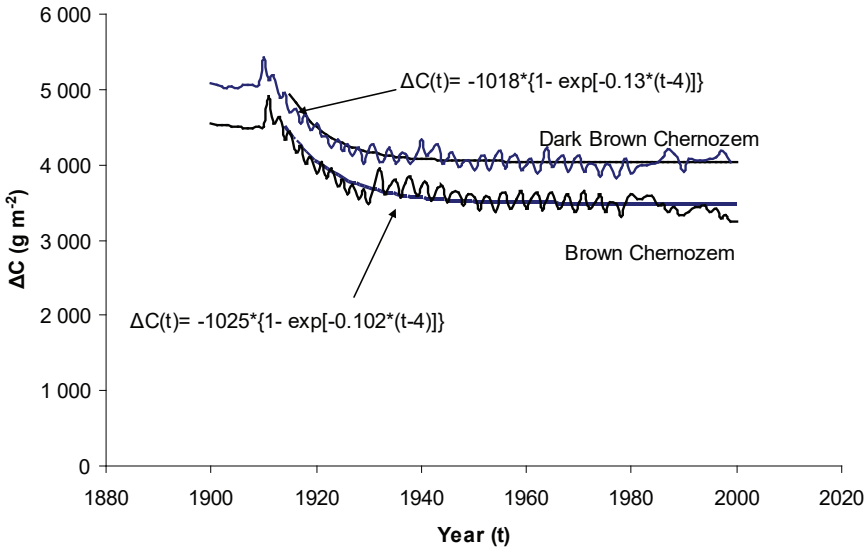
The SOC dynamics from breaking of grassland to cropland for the Brown and Dark Brown Chernozemic soils (Figure A3.5–16) can be estimated with the Century model (Version 4.0). Shortly after breaking, there is an increase in soil organic matter, as below-ground biomass of the grass becomes part of SOC. 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 A3.5–8

$$\Delta C(t) = \Delta C_{Bmax} \times [1 - exp^{(-k[t-t_{lag}])}]$$

$\Delta C(t)$	=	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, $year^{-1}$
t	=	time since breaking of grassland, years
t_{lag}	=	time lag before ΔC becomes negative, years

Figure A3.5–16 **Century-Simulated SOC Dynamics after Breaking of Grassland to Cropland for Brown and Dark Brown Chernozemic Soils**



Assuming that the 22% loss at about 50–60 years after initial breaking represents the total loss, the ΔC_{Bmax} 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:

Equation A3.5–9

$$\Delta C(t) = 0.28 \times SOC_{agric} \times [1 - exp^{(-0.12 \times t)}]$$

$\Delta C(t)$	=	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 A3.5–10

$$\Delta C_{GLCL} = \sum_{1951-n} \sum_{ALLSLC} \sum_{t} (\Delta C_t \times AREA_{GLCL})$$

ΔC_{GLCL}	=	losses of SOC in the inventory year n due to conversion of grassland to cropland since 1951 until year n, Mg C
$ALLSLC$	=	all soil polygons that contain grassland conversion to cropland
t	=	time after grassland conversion, years
ΔC_t	=	change in SOC for the t[th] year after conversion, Mg C/ha
$AREA_{GLCL}$	=	area of grassland converted to cropland annually since 1951, ha

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 A3.5–11

$$N_2O_{GLCL} = \sum_{1951-n} \sum_{ALLSLC} \sum_{t} (\Delta C_{GLCL} \times AREA_{GLCL}) \times 0.06 \times EF_{BASE} \times \frac{44}{28}$$

N_2O_{GLCL}	=	emissions of N_2O in the year n due to the conversion of grassland to cropland since 1951 until year n, kt
$ALLSLC$	=	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 section 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 C 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 sections A3.5.2.1 and 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 A3.5–9), indicating that, on average, SOC 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 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.

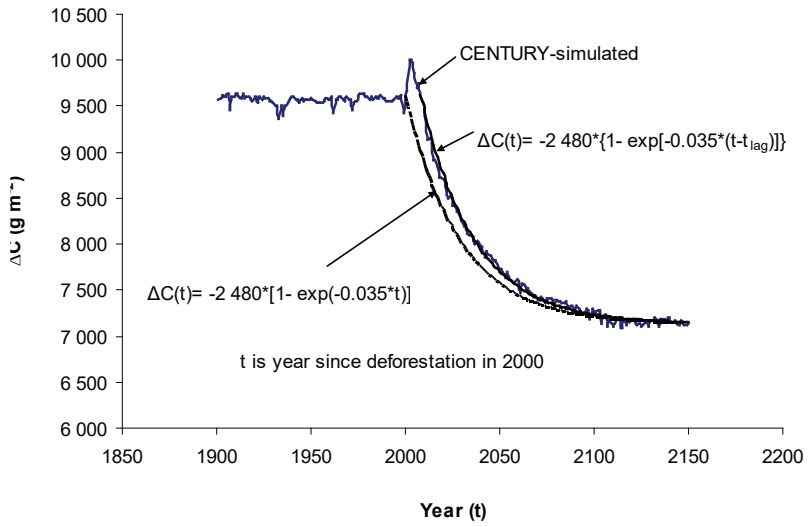
The Century model (Version 4.0) was used to estimate the SOC dynamics from forest conversion (Figure A3.5–17). In the first years after conversion, there is an increase in soil organic matter, as litter and above-ground and below-ground DOM become part of SOC. After a few years,

Table A3.5–9 **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[a]	Cropland[a]	
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:
a. Standard deviation in parentheses.

Figure A3.5–17 **Century-Simulated Soil Organic Carbon Following Conversion of Deciduous Forest to Cropland**



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 A3.5–15, neglecting the initial SOC increase:

Equation A3.5–12

$$\Delta C(t) = \Delta C_{Dmax} \times [1 - exp^{(-k \times [t - t_{lag}])}]$$

$\Delta C(t)$	=	change in SOC for the tth year after conversion, Mg C/ha
ΔC_{Dmax}	=	maximum change in SOC from forest conversion to agriculture, Mg C/ha
k	=	rate constant for describing the decomposition, year^{-1}
t	=	time since conversion of forest land, years
t_{lag}	=	time lag before ΔC becomes negative, years

In the case of simulated SOC after conversion of deciduous forest to cropland (Figure A3.5–17), 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 A3.5–14) 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 C has been lost after 100 years, based on the integration of Equation A3.5–13, 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 A3.5–13

$$\Delta C(t) = 0.284 \times SOC_{agric} \times [1 - exp^{(-0.0262 \times t)}]$$

$\Delta C(t)$	=	change in SOC for the tth 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 A3.5–14

$$\Delta C_{FLCL} = \sum_{1970-n} \sum_{ALLSLC} \sum_{t} (\Delta C_t \times AREA_{FLCL})$$

ΔC_{FLCL}	=	total SOC loss in year n from the conversion of forest land to cropland since 1970 until year n, Mg C/ha
t	=	time after the conversion, year
$ALLSLC$	=	all soil polygons that contain forest land converted to cropland
ΔC_t	=	change in SOC for the tth year after conversion, Mg C/ha (see Equation A3.5–13)
$AREA_{FLCL}$	=	area of forest land converted to cropland annually since 1970, ha

Note that the SOC loss predicted by Equation A3.5–14 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 C 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 A3.5–15

$$N_2O_{FLCL} = \sum_{1970-n} \sum_{ALLSLC} \sum_{t} (\Delta C_t \times REA_{FLCL}) \times 0.02 \times EF_{BASE} \times \frac{44}{28} \times 1 \times e^{-3}$$

N_2O_{FLCL}	=	emissions of N_2O subject to conversion of forest to cropland since 1970 until year n (latest inventory year), kt
$ALL\ SLC$	=	all soil polygons that contain forest land conversion
ΔC_t	=	change in SOC for the tth 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 A3.4.5)
t	=	time after the conversion, year
$44/28$	=	coefficient converting N_2O-N to N_2O
e^{-3}	=	Converting from Mg to kt

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 A3.5–9). 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 N 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 A3.5.2.3. The annual forest conversion by RU 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 RU.

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 A3.5–16

$$SOC = SOC_{REF} \times F_{MG} \times F_I$$

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 A3.5–17

$$A_{n} = GLGL_{1990} - \sum_{1990}^{n} GLCL$$

A_{2017}	=	the total area of Grassland remaining Grassland in the inventory year n, 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 A3.5–18

$$\Delta C_{GGMineral} = [(SOC_{0} - SOC_{0-T}) \times A] / T$$

$\Delta C_{GGMineral}$	=	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-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, years (default 20 years)

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 semiarid 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 A3.5–19

$$EMISSION_{BURN} = \sum(AREA_{i} \times FUELLOAD_{i} \times C_{F,i} \times G_{EF}) /1000$$

$EMISSION_{BURN}$	=	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, 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). Activity data from 2013 to 2015 were updated in 2017 and were kept constant after the sampling period.

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 2013 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 C 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 A3.5–10). 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 result in a loss of CO_2 uptake, enhanced peat decomposition and 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 A3.5–10), but due to a lack of domestic N_2O measurements, the default emission factor for peat extraction sites from the 2013 IPCC Wetlands Supplement (IPCC, 2014) 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 C in the peat using a country-specific C fraction parameter (Table A3.5–10) 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 (González 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.

Table A3.5–10 **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 CH_4 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}	0.00047	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; Strack 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 N2O emissions from rewetted/restored areas

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 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, 2019).

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. (2014). It is believed that the default approach, assuming that all biomass C 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 C 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 C 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 of measurement procedures and measurement comparability. The emission curve was developed from 25 reservoirs and a total of 34 measurements (Figure A3.5–18). It is important to note that each of these measurements (data points in Figure A3.5–18) 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 A3.5–20

$$CO_{2\ rate\ L\_reservoir} = b_0 + b_1 \times In(t)$$

$CO_{2\ rate\ L\_reservoir}$	=	rate of CO_2 emissions from land converted to wetlands (reservoirs), mg/m^2 per day
b_0, b_1	=	curve parameters, unit less
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 A3.5–21

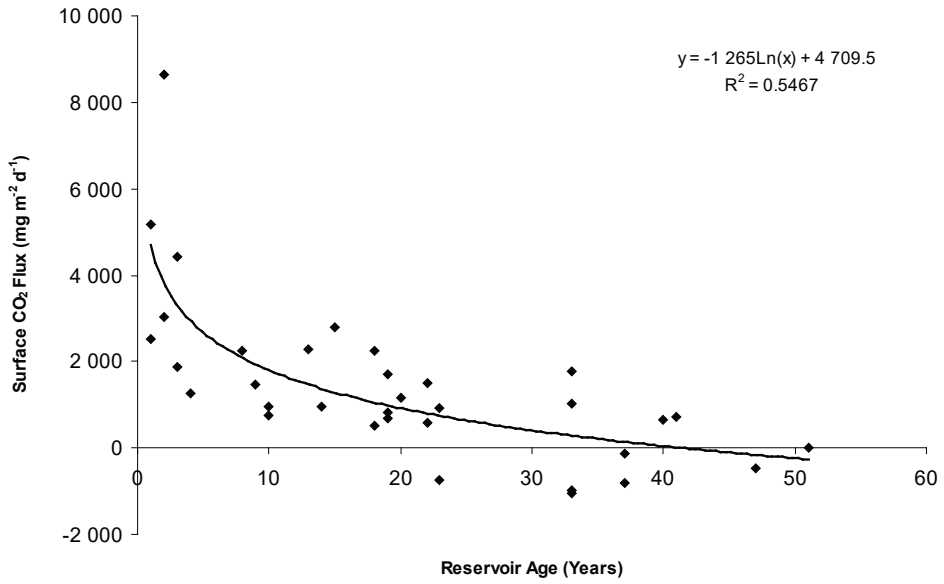
$$CO_{2\ L\_reservoirs} = \sum(CO_{2\ rate\ L\_reservoir}) \times A_{reservoir} \times Days_{ice\ free} \times 10^{-8})$$

$CO_{2\ L\_reservoirs}$	=	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
10^{-8}	=	Conversion factor from mg to Gg

$A_{reservoir}$ 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.

Figure A3.5–18 **Logarithmic Curve Fit for National Reservoir Emission Factors**



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 A3.5.2.3, Forest Conversion); (2) the Canadian Reservoir Database (Duchemin, 2002); and (3) official industry numbers, derived from industry correspondence (Eichel, 2006; Tremblay).[33]

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 CO_2 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 CO_2 emission pathways (e.g. degassing).

33 Tremblay A, Hydro-Québec. 2010. Personal communication dated November 19, 2010, to Dominique Blain, Environment Canada.

A3.5.7. Settlements

This category comprises estimates of removals of CO_2 from land classified as Settlements remaining Settlements (C 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 C 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 sections A3.5.2.1 and A3.5.2.3.

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 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 A3.5–22

$$\Delta C_{-G} = \sum AT \times CRW$$

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,[34] as it was the most nationally consistent delineation of urban areas

34 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.

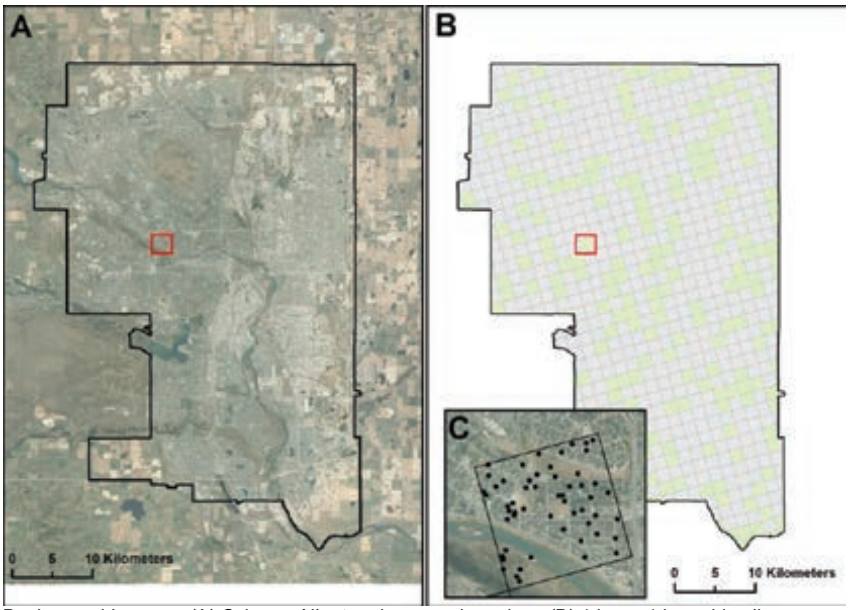
available. The urban boundaries of 1990 were based on Statistics Canada 1990 polygon layer, but manually edited through visual interpretation of aerial photos and the 1990 GeoCover (MDA-Federal, 2004) ortho-rectified image data set, to reduce known over-bounding errors (Statistics Canada, 2010). The 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 79% and 76% of Canada's population in 1990 and 2012, respectively (Statistics Canada, 2011; McGovern and Pasher, 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 69 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 A3.5–19). Random points at a density of 55 points/km^2 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.

Figure A3.5–19 **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.

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).

The CRW values for the 18 RUs (see Table A3.5–11) are derived from assessments carried out in 16 Canadian cities using the same methodology used to develop CRW values for the US. In RUs where cities were not assessed using that approach, values from proxy cities were used based on an ecologically similar Canadian RU, with the exception that the assessment for the city of Seattle in the US was used for the Pacific Maritime RU 41 (Steenberg et al., 2019). These assessments take into consideration the tree species, age and environmental conditions for each RU to determine gross sequestration rates. Net C 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 rates are applied to the 18 RUs and, as a result, estimates of UTC cover area and the sequestration rate are the main driver of overall removal estimates. Interpolation and extrapolation were used to develop a consistent time series for the period 1990 to the latest inventory year.

Table A3.5–11 **Carbon storage and sequestration densities for Canadian RUs**

Reconcilliation Unit (RU)	Carbon Storage (t/ha)	Carbon Sequestration (t/ha)
1 NF—Boreal Shield East	40	3.00
5 NS—Atlantic Maritime	61.6	3.40
6 PE—Atlantic Maritime	61.6	3.40
7 NB—Atlantic Maritime	61.6	3.40
11 QC—Atlantic Maritime	61.6	3.40
12 QC—Mixedwood Plains	57.8	2.40
15 QC—Boreal Shield East	40	3.00
16 ON—Boreal Shield West	40	3.00
17 ON—Mixedwood Plains	57.8	2.40
19 ON—Boreal Shield East	40	3.00
24 MB—Subhumid Prairies	54.7	2.90
28 SK—Boreal Plains	40	3.00
30 SK—Semiarid Prairies	54.7	2.90
34 AB—Boreal Plains	40	3.00
35 AB—Subhumid Prairies	54.7	2.90
37 AB—Semiarid Prairies	54.7	2.90
41 BC—Pacific Maritime	97.4	6.90
42 BC—Montane Cordillera	22.6	1.40

Note:
Source: Steenberg et al., 2019

Uncertainty

The uncertainties associated with the estimates of urban area, UTC and C 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 19% 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 C sequestration rate (12%) was developed from a weighted sampling error associated with each RU for the urban tree field data collected in Canada and for the city of Seattle. 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. (2015a). 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 ortho-rectified Landsat imagery over urban centres. The sampling strategy for this assessment was to perform the analysis on five main census metropolitan areas (CMA[35]), 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. (2015a).

A3.5.7.3. Grassland Converted to Settlements

General Approach and Methods

Nearly half of Canada's land mass is in the Arctic and sub-Arctic regions and includes all land categories (IPCC, 2006), excluding Cropland. An assessment of land-use change was carried out over about 359 million hectares, including reporting zones 1, 2, 3, 4, 5, 8, 10, 13, 16, 17 and 18, north of 60°N latitude. The analysis covers the north part of the Boreal Cordillera, Taiga Plains, Taiga Shield (East and West), Arctic (Southern and Northern) and Arctic Cordillera. 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:

1. Manual digitizing of land-use polygons in Canada's Arctic/sub-Arctic for 1990, 2000 and 2010 based on ortho-rectified Landsat imagery.
2. Estimation of above-ground biomass based on field samples taken in Canada's Arctic/sub-Arctic regions between 2004 and 2010.

A comprehensive, wall-to-wall analysis of land-use circa 1990, 2000 and 2010 was carried out based on image interpretation followed by manual digitization of the sites undergoing change (McGovern et al., 2016). A wide range of human disturbances such as airstrips, roads, power lines, seismic lines, urban areas, mines, reservoirs and even smaller features like well sites and some roadside clearings were identified using snow- and ice-free imagery. Analysis of existing GIS data sets denoting the occurrence of anthropogenic development were used to guide the search for areas with high probability of land-use change. Mapping was then expanded outwards from these regions based on the observation of additional disturbances. The resulting spatial data set provided the most comprehensive and complete mapping product for human disturbances in Canada's Northern region, and builds on previous boreal disturbance mapping activities conducted by Environment and Climate Change Canada (ECCC). An interpretation guide similar to that of the Canadian Forest Service (Dyk et al., 2015) was used to guarantee consistency in the detection, digitization and categorization of disturbances. A total of 1135 scenes were used for the interpretation process (395 for 1990, 348 for 2000 and 392 for 2010).

Land-use change was derived from the difference in polygon areas for each date, providing an area of change between the time periods (i.e.1990–2000, 2000–2010), that was divided by the total years in the time period to produce a constant annual rate of change. The same annual rate of land-use change was applied for the years prior to 1990 and following 2010. The pre-conversion land-use type for each of the land-use change polygons was based on available land cover maps (Wulder et al., 2008; Hermosilla et al., 2016), visual interpretation and vegetation indices of concurrent imagery to avoid including areas in other land-use categories (e.g. Forest Land, Cropland, Wetlands and Other Land). Furthermore, deforestation events above 60 degrees were also used to confirm that areas determined as forest conversion to settlements were excluded, to avoid double-counting.

The biomass lost was derived from statistical analysis of field samples surveyed between 2004 and 2011 over the Canadian north (Figure A3.5–20). Over 116 samples were collected in different land cover types (e.g. shrubs, grass tundra, wetland, forest and barren land) in eight reporting zones. The vegetation in this region consists of forest patches in the Boreal Cordillera and Taiga Plains, but predominantly low vegetation composed of sparse shrubs, mixed grass-dwarf shrub, lichen, moss tussock sedge, bare soil and Arctic willow tundra for the remaining reporting zones. Due to diversity of vegetation types and landscapes over the extent of this region, field samples on forest were excluded and the remaining samples were grouped into two classes: high and low vegetation. This grouping was based on the fact that, after statistical

35 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.

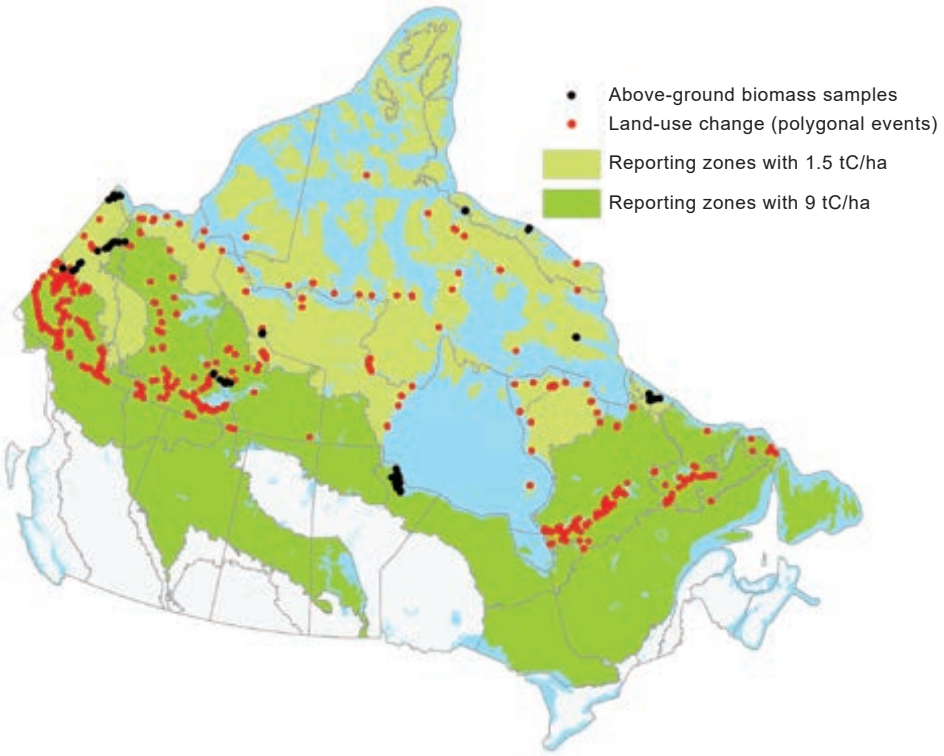
examination of the above-ground biomass values, there was significant variability in the sampled vegetation types between reporting zones. As an initial implementation, the mean of the samples for reporting zones 1 (Arctic Cordillera), 2 (Northern Arctic), 3 (Southern Arctic) and 17 (Taiga Cordillera) was used to obtain a single value of above-ground biomass (1.5t C/ha) that was applied to all of them—areas with "low" vegetation types. Similarly, a single average value (9 tC/ha) from all samples in the remaining reporting zones (Taiga Plain, Taiga Shield West, Boreal Cordillera and Hudson Plains) was used and applied for the remaining areas—areas with "high" vegetation. Reporting zones with land-use change data but without field samples (i.e. Taiga Shield East, Boreal Shield East and Boreal Plains) were assigned to either of the two groups of low or high vegetation based on an analysis of vegetation indices. Emissions from land-use change were estimated by multiplying the annual area of land-use change by their respective biomass lost factor to obtain C stock changes. Annual area rates and emissions for years after 2010 were extrapolated from the 2000–2010 period, assuming a constant yearly rate.

The biomass factor obtained for each of the two vegetation groups was assessed based on the vegetation characteristics of each ecozone (Marshall et al., 1999), values in the literature (Shaver and Chapin, 1991; Hudson and Henry, 2009; Gould et al., 2003) and also compared against values reported by the IPCC for the boreal and cool temperate regions. All land-use change activities involved conversion of Arctic tundra vegetation to settlements, and all pre-conversion biomass C was deemed emitted upon clearing.

Uncertainty

The error propagation approach was used to estimate uncertainty using a 95% confidence interval. The percentage of uncertainty for the above-ground biomass volume was 70% for ecozones with low vegetation and 80% for all the other ecozones, based on the coefficient of variation. The uncertainty of the total land-use change area was estimated to be 30%, based on random sampling and image interpretation. A 20% uncertainty was used for the C content, estimated to be 50% of the dry biomass weight, based on the IPCC guidelines. Using these values, an overall uncertainty of 87% was estimated for this category.

Figure A3.5–20 **Location of Land-Use Events and Field Samples of Above-Ground Biomass in Canada's North**



A3.6. Methodology for Waste Sector

The Waste sector consists of four categories: Solid Waste Disposal, Biological Treatment of Solid Waste, Incineration and Open Burning of Waste, and Wastewater Treatment and Discharge. This section of Annex 3 details the accounting methodologies that are used to describe the greenhouse gas (GHG) emission estimates for these categories with a focus on the following categories and gases:

- CH_4 emissions from solid waste disposal (landfills);
- CH_4 and N_2O emissions from biological treatment of solid waste (composting);
- CO_2, CH_4, and N_2O emissions from waste incineration (municipal solid waste, hazardous, clinical and sewage sludge waste); and
- CH_4 and N_2O emissions from wastewater treatment (municipal and industrial).

A3.6.1. Emissions from Solid Waste Disposal

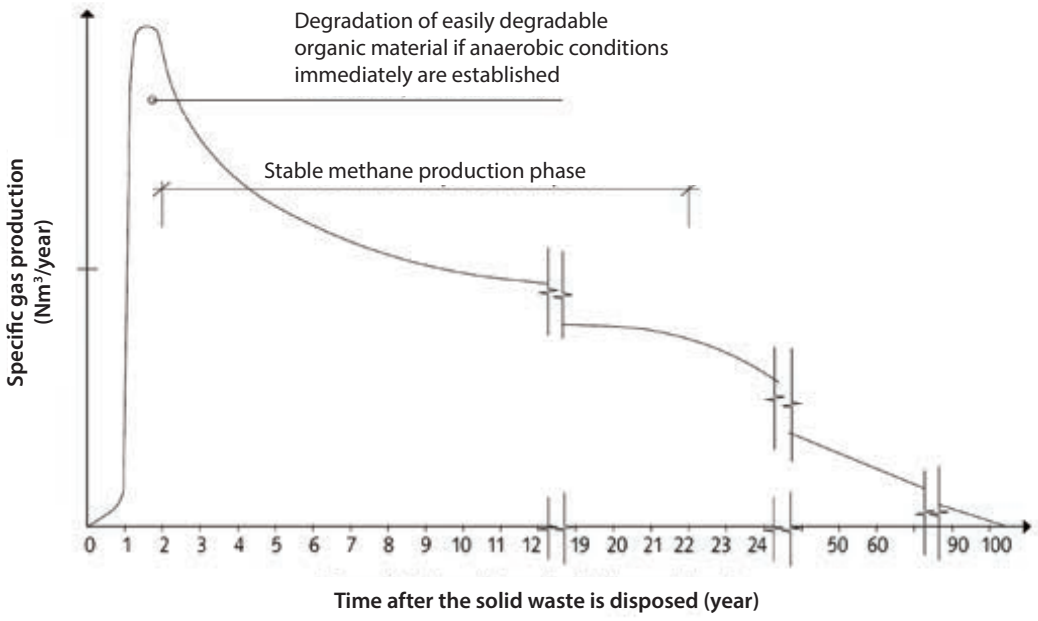
A3.6.1.1. General Approach and Methods

In Canada, the Solid Waste Disposal category comprises two types of landfills: municipal solid waste (MSW) landfills and wood waste (WW) landfills. The treatment and disposal of solid waste produces significant amounts of CH_4, in addition to smaller amounts of CO_2. However, as the CO_2 is primarily from biogenic sources, it is not included in total waste emissions and instead is accounted for in the Agriculture, Forestry and Other Land Use (AFOLU) sector. Emissions of N_2O from landfills are not estimated, as they are not significant, and no quantification methodology is provided by the IPCC (IPCC 2006).

Methane generated from both MSW landfills and wood waste landfills is calculated using the first-order decay (FOD) method, as per Volume 5, Chapter 3, of the 2006 *IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2006). The FOD method considers that waste deposited in any given year decays slowly over several decades. The amount of CH_4 generated is highest in the first few years after deposition of waste, followed by a gradual decline (Figure A3.6–1).

Not all CH_4 generated in a landfill is released to the atmosphere as emissions. Landfill gas (LFG) capture, flaring, and utilization practices are increasingly common in Canadian landfills. The amount of LFG captured by facilities is subtracted from the total amount of LFG generated within the landfill to determine the amount that is actually released annually from the decomposing waste.

Figure A3.6–1 **Scholl Canyon Model Representation of Landfill Degradation**



Note:
Figure is from IPCC (2002) and is shown as published without modification.

A small amount of methane is released from flaring activities, as combustion by flaring is considered to be 99.7% efficient. CH_4 released from flaring is added to the CH_4 released from landfills to get the total CH_4 emitted.

Finally, the amount of CH_4 ultimately emitted by a landfill is reduced further by the oxidation of some of the CH_4 into CO_2 by methanotrophic bacteria in landfill cover material. Therefore, the calculation of CH_4 emissions from SWD can be summarized with Equation A3.6–1. The stepwise calculations that make up the FOD model are represented by Equation A3.6–2 to Equation A3.6–5.

Equation A3.6–1 **(modified from the 2006 IPCC Guidelines Eq. 3.1)**

$$CH_4\ emitted_T = [\sum CH_4\ generated_T - R_T] \times (1 - OX) + (CH_4\ flared_T \times (1 - f))$$

$CH_4\ emitted_T$	=	CH_4 emitted from landfills in year *T*
T	=	inventory year
$CH4\ generated_T$	=	CH_4 generated by landfilled waste in year *T*
R_T	=	CH_4 recovered through landfill gas capture in year *T*
OX	=	oxidation factor
$CH_4\ Flared_T$	=	Amount of CH_4 flared in year *T*
f	=	Flaring efficiency

Equation A3.6–2 **(2006 IPCC Guidelines Eq. 3.2)**

$$DDOCm = W \times DOC \times DOC_f \times MCF$$

$DDOCm$	=	mass of decomposable DOC deposited
W	=	mass of waste deposited
DOC	=	Fraction of degradable organic carbon in the year of deposition
DOC_f	=	fraction of DOC that can decompose
MCF	=	CH_4 correction factor for aerobic decomposition in the year of deposition (fraction)

Equation A3.6–3 **(modified from the 2006 IPCC Guidelines Eq. 3.4)**

$$DDOCma_T = DDOCmd_T + (DDOCma_{T-1} \times e^{-k})$$

T	=	inventory year
$DDOCma_T$	=	DDOCm accumulated in the SWDS at the end of year *T*
$DDOCma_{T-1}$	=	DDOCm accumulated in the SWDS at the end of year (*T*-1)
$DDOCmd_T$	=	DDOCm deposited into the SWDS in year *T*
k	=	reaction constant

Equation A3.6–4 **(modified from the 2006 IPCC Guidelines Eq. 3.5)**

$$DDOCm\ decomp_T = DDOCma_{T-1} \times (1 - e^{-k})$$

T	=	inventory year
$DDOCm\ decomp_T$	=	DDOCm decomposed in the SWDS in year *T*
$DDOCma_{T-1}$	=	DDOCm accumulated in the solid waste disposal sites (SWDS) at the end of year (*T*-1)
k	=	reaction constant

Equation A3.6–5 **(2006 IPCC Guidelines Eq. 3.6)**

$$CH_4\ generated = DDOCm\ decomp_T \times F \times 16/12$$

$CH_4\ generated$	=	amount of CH_4 generated from decomposable material
$DDOCm\ decomp_T$	=	DDOCm decomposed in year *T* , 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.
$16/12$	=	molecular weight ratio CH_4/C

Emissions are calculated at the provincial/territory level using separate FOD models for MSW and WW landfills and are added together to get the national values. Emissions from MSW landfills are reported to the UNFCCC under category 5.A.1, Managed Waste Disposal Sites, while emissions from WW landfills are reported under category 5.A.2, Unmanaged Waste Disposal Sites.

Table A3.6–1 describes parameters used in the above calculations. Emissions are determined using several factors, some of which are customized to be Canada-specific, while others are IPCC default parameters. For example, methane generation potential is most influenced by the composition of the waste, specifically how much degradable organic carbon (DOC) is in the waste, as well as environmental conditions. For more details on the parameters themselves, such as how they are developed and guidance on selecting appropriate values, see Volume 5, Chapter 3, of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 2006). Details on how the parameters used for Canadian estimates were selected or calculated are discussed further in this section.

Table A3.6–1 **FOD Model Parameters and Descriptions**

Parameter	Description
Degradable organic carbon (DOC)	DOC represents the portion of the organic carbon in the waste that is available for decomposition and is determined by the composition of the waste entering the landfill. Waste composition changes over time as different waste management practices come into effect (e.g. recycling and composting). Waste composition also varies across the country due to provincial/territorial regulations and consumer habits.
Fraction of DOC that decomposes (DOC_f)	DOC_f is an estimate of the amount of DOC in solid waste that actually decomposes in landfills.
Methane correction factor (MCF)	MCF accounts for the decomposition of waste under different management practices. MCF can differ based on whether waste is disposed in unmanaged or managed landfills.
Reaction constant (k)	k represents the rate at which CH_4 is generated in the first-order decay reaction after the waste has been deposited in the landfill. The value of k is affected by moisture content, nutrient availability, pH, and temperature.
Fraction of landfill gas that is CH_4 (F)	F represents the amount of gas generated by anaerobic decomposition within the landfill that is CH_4.
Oxidation factor (OX)	OX represents the amount of CH_4 that is oxidized by methanotrophic microorganisms into CO_2 as it passes through material covering the landfill.

A3.6.1.2. Municipal Solid Waste (MSW) Landfills

A3.6.1.2.1. Data Sources

The first-order decay (FOD) model used to calculate CH_4 generated from MSW landfills requires data on the annual amount of waste landfilled across Canada. While there is no consistent dataset of waste specifically sent to landfills in Canada, there are data available on the total amount of waste disposed. However, not all waste disposed in Canada ends up in landfills. Some waste is exported to the United States, while some is sent to incineration facilities. Therefore, to isolate the amount of waste sent to landfills, the amount of waste incinerated and exported is removed from the total waste disposed (Equation A3.6–6). Note that although emission estimates are calculated from 1990 onwards, the amount of waste landfilled is required as far back as 1941 because of the cumulative effect of historically disposed waste on current emission production.

Equation A3.6–6

$$\textit{waste landfilled}_T = \textit{waste disposed}_T - \textit{waste incinerated}_T - \textit{waste exported}_T$$

T = inventory year

Waste Disposed

Waste disposed includes waste from residential, institutional, commercial, industrial, and construction and demolition sources. Waste disposal tonnage for 1941–1990 for all provinces and territories is obtained from Levelton (1991). This report estimates annual waste disposed for each province and territory by multiplying a waste-disposal-per-capita factor by rounded provincial/territory populations. Rather than use the tonnage reported in the document, which was estimated using rounded population data, the per-capita disposal rates from Levelton were multiplied by the most up-to-date population data available from Statistics Canada (Statistics Canada, no date, Table 051-0001).

Waste disposal data from 1998 to present are obtained through Statistics Canada's biennial Waste Management Industry Survey (Statistics Canada, no date (a)) which produces waste disposal data for every even year from 1996 to the present. The survey data include waste managed by businesses, governments, and other waste management bodies in Canada. When survey data has not yet been released for the latest inventory year, the most recent survey results are held constant.

A lack of data for the years 1991 to 1995 necessitates the interpolation of waste disposal data from the final data point provided by Levelton in 1990, to the beginning of the Statistics Canada data in 1996. Therefore, disposed waste for each province and territory is estimated through linear interpolation for the years 1991 to 1996.

Waste disposal data for Prince Edwards Island, Yukon, Northwest Territories and Nunavut must be estimated separately from the rest of provinces because of data availability issues. Although the total amount of waste reported for Canada in the Waste Management Industry Survey includes PEI and the territories, the amount attributed to these provinces/territories is suppressed due to data confidentiality requirements. Instead, disposal data for PEI was received directly from a provincial representative for the years 1995–2018. Data gaps were bridged through linear interpolation. The amount of waste disposed in the territories is assumed to be the difference in Canada's total reported waste disposal data, the provincial data reported, and the data sourced directly from PEI. Disposed waste is then distributed among the territories on the basis of relative population.

Waste Incinerated

Data on the amount of waste incinerated are discussed in section A3.6.3.

Waste Exported

Waste exports to the United States are considered for the years 1989–present. The annual amount of waste exported is determined by contacting state officials in New York, Michigan, Indiana, Pennsylvania, Washington and Ohio. Where data are not available for the most recent reporting years, the last data point is held constant. It is assumed that Ontario, Quebec and British Columbia are the only provinces exporting waste to these states. Data on the amount of waste exported to the United States is shown in Table A3.6–2.

Waste Landfilled

The final amount of waste landfilled, as determined from waste disposed, incinerated and exported, is shown in Table A3.6–3.

A3.6.1.2.2. Model Parameters

Degradable Organic Carbon (DOC)

The DOC represents the portion of the organic carbon in the waste that is available for decomposition; it is determined by the composition of the waste entering into the landfill. Waste composition changes over time as different waste management practices come into effect (e.g. recycling and composting).

DOC factors for landfilled waste are calculated using the weighted average of the DOC of individual waste types. The waste types that contain the majority of the DOC in municipal solid waste are as follows (IPCC 2006):

- Food waste
- Garden (yard) and park waste
- Paper and cardboard
- Wood
- Textiles
- Disposable diapers
- Rubber and leather

Table A3.6–2 **Canadian Exports of Municipal Solid Waste to the United States (Tonnes)**

Year	Waste Exported by Province (Tonnes)					Total Canadian Waste Exported to the United States (Tonnes)
	ON	QC	BC	AB	MB	
1989	3 031	0	0	0	0	3 031
1990	2 099	0	0	0	0	2 099
1991	91 311	0	188	0	0	91 499
1992	1 668 574	0	26 882	0	0	1 695 456
1993	522 074	90 720	22 456	0	0	635 249
1994	59 215	0	14 486	0	0	73 701
1995	48 494	26 751	6 385	0	0	81 629
1996	821 907	0	16 632	0	0	838 539
1997	757 523	0	39 952	0	0	797 475
1998	785 076	14 010	51 687	0	0	850 774
1999	782 274	73 826	46 871	0	0	902 970
2000	1 366 361	91 205	52 318	0	0	1 509 885
2001	1 792 257	9 718	66 677	0	0	1 868 653
2002	2 083 621	85 438	65 823	0	0	2 234 882
2003	2 940 856	85 354	42 949	0	0	3 069 158
2004	3 629 114	133 761	85 938	0	0	3 848 813
2005	3 718 248	126 372	92 382	0	0	3 937 002
2006	3 857 369	202 333	107 564	0	0	4 167 266
2007	3 567 210	245 985	121 582	0	0	3 934 777
2008	3 622 182	379 853	108 328	0	0	4 110 364
2009	3 092 470	353 285	120 309	0	0	3 566 064
2010	2 819 323	171 246	155 858	0	0	3 146 427
2011	2 203 568	82 021	239 006	0	0	2 524 595
2012	2 529 930	483 661	239 764	0	0	3 253 354
2013	2 842 826	442 897	235 115	0	0	3 520 838
2014	2 755 712	413 685	289 183	0	0	3 458 581
2015	2 826 604	24 022	289 183	-947	0	3 138 862
2016	2 959 980	32	289 183	23 689	23 709	3 296 593
2017	3 440 976	58 286	380 240	-36	0	3 879 466
2018	3 275 490	19 332	298 866	2 581	6 031	3 602 300

Notes:
Negative exports values indicate net import to Province from U.S.
New York State reported imports from BC, and MB as single value. Each Province assumed to contribute half this value.

Table A3.6–3 **Municipal Solid Waste Landfilled 1990–2018 (tonnes)**

Year	AB[b]	BC[b]	MB[b]	NB	NL	NS	NT[c]	NU[c]	ON[b]	PE[a]	QC[b]	SK	YT[c]	Canada
1941–1989[d]	Data available upon request													
1990[5]	1 627 400	1 843 564	706 088	472 775	290 907	527 551	24 071	13 558	6 430 463	48 138	3 843 269	643 686	17 858	16 489 326
1991[e]	1 762 147	1 892 324	746 387	478 305	284 368	522 898	26 645	15 252	6 397 472	50 056	4 018 371	686 440	19 854	16 900 519
1992[e]	1 896 894	1 917 130	786 686	483 835	272 030	537 246	29 019	16 856	4 697 048	54 233	4 188 650	729 194	22 140	15 630 963
1993[e]	2 031 642	1 968 530	826 986	489 366	264 614	532 594	31 560	18 681	5 904 963	55 021	4 409 157	771 948	24 039	17 329 101
1994[e]	2 166 389	2 023 119	867 285	494 896	258 175	527 942	34 521	20 772	6 431 236	55 823	4 866 294	814 702	25 252	18 586 406
1995[e]	2 301 137	2 094 390	907 585	500 427	255 296	504 290	37 131	22 394	6 493 819	58 177	5 028 894	857 456	27 285	19 088 280
1996[f]	2 431 339	2 143 238	947 884	505 957	246 716	499 638	40 393	24 835	5 765 069	55 115	5 221 807	900 210	30 368	18 812 570
1997[f]	2 477 645	2 134 654	956 305	487 264	268 140	493 808	37 569	23 356	5 877 427	62 021	5 245 373	874 309	28 692	18 966 563
1998[f]	2 523 950	2 159 722	964 726	468 571	291 057	456 449	36 623	23 664	5 886 094	57 912	5 254 345	848 408	27 949	18 999 469
1999[f]	2 635 382	2 218 236	939 619	441 815	307 462	403 552	30 896	20 384	6 863 337	61 173	5 320 671	835 177	23 396	20 101 100
2000[f]	2 746 815	2 272 651	914 511	415 058	324 611	351 087	26 377	17 918	7 266 028	60 429	5 435 239	821 946	19 829	20 672 497
2001[f]	2 816 803	2 321 266	905 534	414 332	315 265	349 771	26 163	18 020	7 203 181	53 076	5 529 337	808 535	19 317	20 780 598
2002[f]	2 887 918	2 358 046	896 556	413 606	303 384	335 194	25 996	17 968	7 272 062	47 447	5 471 197	795 124	18 912	20 843 410
2003[f]	2 982 259	2 435 300	912 337	427 890	316 498	340 581	32 161	22 137	6 625 056	42 042	5 759 522	795 029	23 359	20 714 168
2004[f]	3 074 903	2 406 545	928 117	442 173	335 595	345 967	38 264	26 381	6 027 115	35 556	6 009 558	794 933	27 793	20 492 900
2005[f]	3 446 577	2 472 415	916 195	476 940	365 364	325 536	34 097	23 836	5 899 983	28 829	6 194 430	814 343	25 064	21 023 607
2006[f]	3 818 998	2 535 995	904 272	511 706	385 036	359 105	29 889	21 329	5 705 321	24 336	6 283 240	833 753	22 339	21 435 317
2007[f]	3 983 679	2 452 842	924 857	495 584	368 843	356 668	24 630	17 828	5 971 022	30 637	5 916 394	868 348	18 486	21 429 818
2008[f]	4 147 520	2 428 206	945 441	479 461	359 203	354 231	19 345	14 228	5 857 030	35 691	5 448 420	902 943	14 760	21 006 479
2009[f]	4 032 506	2 337 960	982 961	477 363	376 639	360 739	26 627	20 112	6 193 342	32 162	5 317 341	920 106	20 812	21 098 669
2010[f]	3 917 430	2 218 136	1 020 481	475 265	386 301	367 246	33 765	26 016	6 335 724	26 831	5 325 128	937 268	26 987	21 096 579
2011[f]	3 915 706	2 111 044	1 019 072	484 102	387 261	366 163	34 595	27 190	6 848 629	25 985	5 310 422	947 469	28 160	21 505 797
2012[f]	3 913 922	2 083 123	1 017 663	492 938	386 166	365 079	35 482	28 185	6 502 979	24 922	4 806 244	957 670	29 455	20 643 829
2013[f]	4 005 752	2 147 442	1 003 947	500 527	400 887	364 636	35 890	28 952	6 168 313	27 303	4 761 990	949 133	29 922	20 424 694
2014[f]	4 097 582	2 156 866	990 230	508 115	414 360	364 193	36 163	29 642	6 233 657	27 139	4 722 759	940 595	30 603	20 551 903
2015[f]	4 153 073	2 122 113	979 760	505 619	404 443	369 726	35 130	28 976	6 217 060	27 401	5 118 249	919 500	29 931	20 910 977
2016[f]	4 182 979	2 070 660	945 580	503 123	394 937	375 258	34 058	28 204	6 211 055	29 042	5 088 857	898 404	29 403	20 791 560
2017[g]	4 206 704	1 974 099	969 289	503 123	394 937	375 258	33 167	27 717	5 718 808	30 997	5 022 368	898 404	29 249	20 184 121
2018[g]	4 204 087	2 055 473	963 258	503 123	394 937	375 258	33 631	28 992	5 884 294	27 946	5 061 322	898 404	30 562	20 461 287

Notes:
All waste landfill data are based on total waste disposed data after accounting for any waste incinerated and/or exported.

a. Data from 1995–2018 was provided directly by PEI provincial representatives.
b. From 1989 onwards, the amount of waste exported is accounted for when calculating amount of waste landfilled for ON, QC, BC, AB, and MB.
c. Given the confidential nature of regional data from Statistics Canada, the waste disposal data for the territories is estimated from the reamainder of national and provincial disposal amounts, distributed between territories according to population.
d. Landfill data for 1941–1990 was determined from Levelton (1991).
e. Linear interpolation was used to fill in the following data gaps: 1991–1995 for all provinces except PEI, and the territories.
f. Waste disposal data from 1996 to present are obtained from the results of the biennial Waste Management Industry Survey conducted by Statistics Canada (Statistics Canada 2003, Statistics Canada 2004, Statistics Canada n.d. CANSIM table 153-0041). This excludes PEI (see footnote a), and the territories (see footnote c). Disposal amounts for the years in between the Statistics Canada data points are estimated using linear interpolation of preceeding and proceeding values.
g. When the latest Statistics Canada data are not yet available, the last known data point is carried forward. This excludes PEI (see footnote a).

Landfilled waste composition studies are used to calculate DOC values for each province. Since waste composition changes over time due to evolving waste management practice and consumer habits, DOC values are also calculated for different time periods. Five time periods were chosen as representative time frames over which waste composition changed across Canada: 1941–1975, 1976–1989, 1990–2001, 2002-2014, and 2015–present.

Default DOC content values for the individual waste types are from Table 2.4, Volume 5, of the 2006 IPCC Guidelines.[36, 37] These default values are multiplied by the percentage of waste types in MSW, as determined through waste composition studies, to obtain the final DOC values shown in Table A3.6–4. Equation A3.6–7 was used to calculate DOC parameters for the first three time periods (1941–1975, 1976–1989, 1990–2001), while Equation A3.6–8 was used to calculate DOC parameters for the most recent time periods (2002-2014, 2015–present).

Several waste composition studies were used to determine the composition of MSW across the time series. The DOC values for the most recent time period, 2015 and later, were determined from an Environment and Climate Change Canada study (ECCC 2020). DOC values for the 2002–2014 period were determined from the results of a national waste composition study conducted in 2014 and 2015 (ECCC 2016a). The DOC values for

36 Default DOC content in % of wet waste.

37 The default factor for textiles is 0.24, though for the first three time series (1941–1975, 1976–1989 and 1990–2001) it is revised to 0.4. The default factor is for textiles that are assumed to be 40% synthetic, and this is adjusted for earlier time series where the biogenic component of textiles is assumed to have been higher.

Table A3.6–4 **Provincial and Territorial Degradable Organic Carbon (DOC) Values (%) for MSW**

Province/Territory	1941 to 1975	1976 to 1989	1990 to 2001	2002 to 2014	2015-Present
Newfoundland	0.31	0.19	0.19	0.20	0.20
Prince Edward Island	0.28	0.17	0.16	0.16	0.17
Nova Scotia	0.27	0.16	0.16	0.15	0.17
New Brunswick	0.25	0.17	0.16	0.18	0.18
Quebec	0.39	0.21	0.20	0.21	0.17
Ontario	0.37	0.21	0.21	0.21	0.18
Manitoba	0.35	0.19	0.19	0.20	0.19
Saskatchewan	0.38	0.22	0.22	0.19	0.19
Alberta	0.29	0.19	0.19	0.22	0.19
British Columbia	0.28	0.18	0.17	0.18	0.18
Northwest Terrotories	0.23	0.15	0.17	0.16	0.18
Nunavut	0.23	0.15	0.17	0.16	0.18
Yukon	0.23	0.15	0.17	0.16	0.19

Note:
Sources—Derived from data obtained from Environment Canada (2016b), NRCan (2006), Statistics Canada (2007a) and CRC Press (1973).

the 1990–2002 time period were determined from the results of a waste composition study by Natural Resources Canada for waste characteristics in 2002 (NRCan 2006).

Given the lack of data on waste composition for the 1976–1989 time period, results from NRCan 2006 were used with the assumption that the waste diverted through recycling in 2002 would have been sent to landfill. Statistics Canada data on waste diverted from landfill were therefore added to the total landfilled waste as reported by NRCan (Statistics Canada no date (b)). Waste audits conducted in 1976, 1978 and 1980 (Ontario Ministry of the Environment 1991) indicate that waste composition from the 1976–1989 period are more similar to 2002 generation estimates than to 1967 estimates.

Finally, DOC values for the time period of 1941–1975 were determined from the results of a 1967 national study (CRC Press 1973, Table 1.1-9). This report derives national waste composition using national waste compositions provided in the article "World Survey Finds Less Organic Matter" (Anon. 1967). The report produced data at the national level, so provincial ratios from the 1976–1989 time period were used to estimate provincial waste composition values.

Equation A3.6–7

$$DOC = (0.4 \times A) + (0.2 \times B) + (0.15 \times C) + (0.43 \times D)$$

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

Equation A3.6–8

$$DOC = (0.4 \times A) + (0.24 \times B) + (0.15 \times C) + (0.43 \times D) + (0.20 \times E) + (0.24 \times F) + (0.39 \times G)$$

A = % of MSW that is paper/cardboard
B = % of MSW that is textiles
C = % of MSW that is food waste
D = % of MSW that is wood
E = % of MSW that is garden and park waste
F = % of MSW that is infant diapers
G = % of MSW that is rubber and leather

Fraction of Degradable Organic Carbon Which Decomposes (DOC_f)

The DOC_f value is an estimate of the amount of DOC in solid waste that actually decomposes in the landfill. Canada uses the default DOC_f factor of 0.5, as recommended by the 2006 IPCC Guidelines (IPCC 2006) for all provinces/territories and years.

Methane Correction Factor (MCF)

The MCF accounts for the decomposition of waste under different management practices. The MCF can differ depending on whether waste is disposed of in managed or unmanaged landfills. Canada uses an MFC factor of 1.0 for managed, anaerobic solid waste disposal sites as recommended in the IPCC 2006 Guidelines (IPCC 2006).

Reaction Constant (k)

The k value represents the rate at which CH_4 is generated in the FOD reaction after waste has been landfilled. While the value of k can be affected moisture content, nutrient availability, temperature and pH, moisture is the only

parameter considered in the calculated k values. It is assumed that the landfill temperature is independent of the ambient temperature at depths exceeding 2 metres, and the exothermic anaerobic biodegradation of the wastes keeps the methanogens within the optimum mesothermic range (25–40 °C). 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).

The k values used to estimate emissions from MSW landfills are based on provincial precipitation data from 1941 to 2017 (ECCC 2018). The weather stations from which the average annual precipitations were calculated are those located near major landfills, as indicated in the Levelton study (Levelton 1991), with additional data for British Columbia from a study by Golder Associates Ltd. (2008). Average precipitation was calculated for each station for the four time intervals used in the DOC calculations (1941–1975, 1976–1989, 199–2007 and 2008–2017).

From these precipitation values, k values were determined using a relationship prepared by the Research Triangle Institute for the U.S. Environmental Protection Agency and verified with a study done by Golder Associates Ltd. (2008). The calculation is shown in Equation A3.6–9. K values are calculated on an annual basis, but averaged at the provincial level for each of the four time intervals. These values are provided in Table A3.6–5.

Equation A3.6–9

$$k(yr^{-1}) = 7 \times 10^{-5} \times precipitation\ (mm) - 0.0172$$

k = reaction constant

yr = year of interest

Fraction of landfill gas that is CH_4 (F)

The F value represents the fraction of landfill gas generated by anaerobic decomposition within the landfill that is made up by CH_4. The recommended 2006 IPCC Guidelines (IPCC 2006) default of 0.5 is used for all time periods and regions.

A3.6.1.2.3. Determining Methane Release

The FOD model produces estimates of the amount of CH_4 generated by the waste decaying within the landfill. However, not all CH_4 generated is released into the atmosphere. To calculate the CH_4 emitted to the atmosphere, the amount of waste oxidized by the landfill cover, as well as the amount of landfill gas (LFG) captured for utilization and/or flaring, must be accounted for. Additionally, a small amount of CH_4 is added from the flaring process, as it is assumed that flares are not 100% efficient. This calculation is shown in Equation A3.6–1.

A recent study commissioned by ECCC found that approximately 90% of medium and large-sized landfills surveyed currently employ LFG capture technologies (GHD 2017). Additionally, the amount of CH_4 ultimately emitted by a landfill is reduced further by the oxidation of CH_4 into CO_2 by methanotrophic bacteria in landfill cover material. A broad range of provincial regulations mandate that Canadian landfills are capped with a daily cover of material such as soil, compost, woody material or fill. When a landfill is no longer operational, it is capped with a final, more robust cover.

Methane Recovery

Landfill gas (LFG) capture at large municipal solid waste facilities is common across Canada. Facilities can capture landfill gas and, given the relatively high concentration of CH_4 in the gas, use it for heat and/or electricity production. Facilities may also choose to simply flare the captured gas. Note that any emissions resulting from the production of heat or electricity using landfill gas are reported under the Energy sector.

Table A3.6–5 **Mean Annual Precipitation and MSW Landfill k Value Estimates by Province/Territory**

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	1 315	1 391	1 356	1 387	0.075	0.080	0.078	0.080
Prince Edward Island	1 052	1 136	1 123	1 086	0.056	0.062	0.061	0.059
Nova Scotia	1 331	1 377	1 334	1 396	0.076	0.079	0.076	0.080
New Brunswick	1 103	1 150	1 089	1 128	0.060	0.063	0.059	0.062
Quebec	1 008	1 059	1 085	1 048	0.053	0.057	0.059	0.056
Ontario	834	911	902	884	0.041	0.047	0.046	0.045
Manitoba	527	493	521	493	0.020	0.017	0.019	0.017
Saskatchewan	383	375	422	412	0.010	0.009	0.012	0.012
Alberta	424	421	417	390	0.012	0.012	0.012	0.010
British Columbia	872	880	912	815	0.044	0.044	0.047	0.040
Yukon	264	262	272	292	0.001	0.001	0.002	0.003
Northwest Territories & Nunavut	341	361	330	323	0.007	0.008	0.006	0.005

Data on landfill gas capture are collected through surveys conducted by various groups within Environment and Climate Change Canada (ECCC) (Perkin 2008; Environment Canada 2003a; Environment Canada 2007). From 2006 to 2018, the survey was conducted on a biennial basis by the Pollutant and Inventories Reporting Division at ECCC.

Where data points are missing or unavailable, averages of surrounding data points are used. If survey results for the latest years are not yet available, the most recent data are held constant. Where historical records are not available for years in which the facility was known to be capturing LFG, data from the closest available year is used.

The amount of methane recovered for each province is calculated from the volume of gas captured by facilities.

CH_4 from Flare

While flaring of captured LFG greatly reduces CH_4 emissions when utilization is not viable, it is not a 100% efficient process. A flaring efficiency (f) of 99.7% is used to calculate the total CH_4 generated from landfills (U.S. EPA 1995).

Oxidation Factor

The oxidation factor (OX) has been incorporated into the estimation model this year and represents the fraction of CH_4 generated in the landfill that is oxidized as it passes through the landfill cover. The 2006 IPCC Guidelines' (IPCC 2006) recommended default factor of 0.1 for managed landfills covered with CH_4 oxidizing material is used for all regions and time periods. The vast majority of municipal solid waste in Canada is disposed of in managed landfills, which are required by provincial and territorial regulations to cover waste with soil or other materials.

Note that the oxidation factor is used in the calculation of CH_4 emissions after methane recovery has been accounted for.

Methane Emitted

Table A3.6–6 outlines the estimates used to calculate the CH_4 emitted from landfills for 1990–2018.

Table A3.6–6 **Methane Generated, Flared, Used for Energy, Oxidized by Landfill Cover and Emitted from MSW Landfills in Canada**

Year	CH_4 Generated in Landfills (kt)	CH_4 Flared (kt)	CH_4 Utilized[a] (kt)	CH_4 Oxidized by Landfill Cover (kt)	CH_4 Emitted from Flaring (kt)	Total CH_4 Emitted (kt)
1990	765.93	80.78	0.00	68.51	0.24	616.88
1991	776.25	92.40	0.00	68.38	0.28	615.74
1992	787.00	109.63	0.00	67.74	0.33	609.96
1993	792.94	110.20	0.12	68.26	0.33	614.70
1994	803.57	115.09	0.69	68.78	0.35	619.35
1995	817.46	120.68	21.70	67.51	0.36	607.93
1996	831.86	105.92	58.86	66.71	0.32	600.68
1997	844.37	88.88	228.95	52.65	0.27	474.15
1998	856.82	75.80	272.61	50.84	0.23	457.80
1999	868.77	72.01	223.17	57.36	0.22	516.44
2000	883.50	69.28	219.85	59.44	0.21	535.14
2001	899.27	114.25	222.70	56.23	0.34	506.43
2002	914.61	106.20	218.59	58.98	0.32	531.16
2003	930.59	133.22	207.21	59.02	0.40	531.55
2004	945.50	142.81	197.83	60.49	0.43	544.80
2005	959.09	162.75	186.22	61.01	0.49	549.61
2006	973.12	148.27	210.56	61.43	0.44	553.31
2007	987.13	161.63	216.39	60.91	0.48	548.68
2008	948.87	160.99	222.96	56.49	0.48	508.90
2009	959.59	215.88	219.83	52.39	0.65	472.14
2010	970.30	242.83	228.48	49.90	0.73	449.83
2011	980.83	248.98	231.74	50.01	0.75	450.85
2012	992.25	251.65	230.76	50.98	0.75	459.62
2013	1000.24	237.06	239.81	52.34	0.71	471.75
2014	1007.13	228.51	254.85	52.38	0.69	472.09
2015	1014.04	204.35	262.83	54.69	0.61	492.79
2016	1016.27	203.18	261.23	55.19	0.61	497.28
2017	1018.21	197.92	265.64	55.47	0.59	499.78
2018	1018.48	201.67	272.01	54.48	0.60	490.93

Notes:
a. CH_4 emitted from combustion for utilization as heat and power is captured in Energy

A3.6.1.3. Wood Waste Landfills

A3.6.1.3.1. Data Sources

Wood waste (WW) estimates are based on the amount of wood waste products estimated to be disposed of in private landfills. This category captures wood waste that does not enter waste management streams in Canada and thus is not accounted for in the MSW component of the SWD category. As with the MSW category, the FOD model used to produce CH_4 emission estimates from WW landfills requires historical data on the amount of waste sent to landfill.

The amount of wood waste disposed of in 1990 is estimated at a national level based on the National Wood Residue Data Base (NRCan 1997), and that estimate is used for the time period 1970–1990. Two other data points are available for 1998 and 2004 in subsequent publications (NRCan 1999, 2005). Given that the repurposing of wood waste is increasingly preferred over landfilling, it is assumed that the amount of wood waste disposed of is decreasing rapidly. Therefore, exponential extrapolation from the three available data points is used to estimate the amount of wood waste disposed of in 1991–1997, 1999–2003 and 2005 to present.

Wood waste disposed of in Canada is assumed to come from two sources; the solid wood industry and the pulp and paper industry. It is estimated that 80% of wood waste is disposed of by the solid wood industry, while the remaining 20% is disposed of by the pulp and paper industry (MWA Consultant Paprican 1998). Of the total volume of waste disposed, the amount sent to private landfills is assumed to be 15% for the solid wood industry and 86% for the pulp and paper industry (NRCan 1997). The estimated amount of wood waste disposed of is then converted from “bone dry” units to “hydrated” units using a wood waste moisture content of 20% (Tchobanoglous et al. 1993). The national values for wood waste disposed of and landfilled are shown in Table A3.6–7.

The national amount of wood waste landfilled is then distributed to provinces and territories using ratios. The 1970–1997 values are derived using provincial/territorial ratios from NRCan 1997, the 1998–2003 values are derived using ratios from NRCan 1999, and the 2005-present values are derived using ratios from NRCan 2005. The final estimated amount of wood waste landfilled is shown in Table A3.6–8.

A3.6.1.3.2. Model Parameters

Degradable Organic Carbon (DOC)

It is assumed that all waste sent to private wood waste lots is composed entirely of wood. Therefore, the recommended 2006 IPCC Guidelines (IPCC 2006) default DOC value for wood, i.e. 0.43, is used for all regions and time periods.

Fraction of Degradable Organic Carbon Which Decomposes (DOC_f)

The IPCC 2006 Guidelines’ (IPCC 2006) recommended default DOC_f value of 0.5 is used for all regions and time periods.

Methane Correction Factor (MFC)

The IPCC 2006 Guidelines’ (IPCC 2006) recommended default MCF value of 0.8 for unmanaged deep landfill sites was selected, as it best represents industry practices.

Reaction Constant (k)

The default k value of 0.03/year recommended by the National Council for Air and Stream Improvement Inc. for estimating the wood products industry’s landfill CH_4 emissions was used for all regions and time frames (NCASI 2003).

Fraction of landfill gas that is CH_4 (F)

The default of 0.5 recommended by the 2006 IPCC Guidelines (IPCC 2006) is used for all time periods and regions.

Oxidation Factor (OX)

The IPCC 2006 Guidelines (IPCC 2006) default recommended factor of 0.1 is used for all time periods and regions.

Methane Recovery

It is assumed that no landfill gas capture technologies are used at private wood lots. Use of these sites is rapidly decreasing, and it is unlikely that facilities would invest in such infrastructure given the more popular practice of repurposing wood waste.

Methane Emitted

Table A3.6–9 outlines the final estimated CH_4 emissions from wood waste landfills in Canada.

Table A3.6–7 **Quantity of Wood Waste Disposed and Landfilled in Canada (1990–2018)**

Year[e]	Total Disposed Wood Waste (BDt)[a]	Landfilled		
		Pulp & Paper[b] (BDt)	Solid Wood[c] (BDt)	Total[d] (Hydrated Tonnes)
1970–1990[f]	9 055 310	1 557 513	1 086 637	3 305 188
1991	8 726 019	1 500 875	1 047 122	3 184 997
1992	8 020 433	1 379 514	962 452	2 927 458
1993	7 371 900	1 267 967	884 628	2 690 744
1994	6 775 808	1 165 439	813 097	2 473 170
1995	6 227 915	1 071 201	747 350	2 273 189
1996	5 724 326	984 584	686 919	2 089 379
1997	5 261 457	904 971	631 375	1 920 432
1998[g]	5 400 000	928 800	648 000	1 971 000
1999	4 444 974	764 536	533 397	1 622 416
2000	4 085 553	702 715	490 266	1 491 227
2001	3 755 195	645 894	450 623	1 370 646
2002	3 451 550	593 667	414 186	1 259 816
2003	3 172 457	545 663	380 695	1 157 947
2004[h]	2 737 805	470 902	328 537	999 299
2005	2 680 150	460 986	321 618	978 255
2006	2 463 433	423 710	295 612	899 153
2007	2 264 239	389 449	271 709	826 447
2008	2 081 153	357 958	249 738	759 621
2009	1 912 871	329 014	229 544	698 198
2010	1 758 196	302 410	210 984	641 742
2011	1 616 028	277 957	193 923	589 850
2012	1 485 356	255 481	178 243	542 155
2013	1 365 250	234 823	163 830	498 316
2014	1 254 856	215 835	150 583	458 022
2015	1 153 388	198 383	138 407	420 987
2016	1 060 125	182 342	127 215	386 946
2017	974 403	167 597	116 928	355 657
2018	895 613	154 045	107 474	326 899

Notes:

a. BDt = Bone dry tonnes

b. Estimated 20% of wood waste is disposed of by P&P industry, and 86% of that waste is landfilled in private lots.

c. Estimated 80% of wood waste is disposed of by SW industry, and 15% of that waste is landfilled in private lots.

d. Converted from bone-dry tonnes (BDt) to hydrated tonnes using a moisture content of 20%.

e. All years that are not associated with a specific reference were derived using exponential extrapolation.

f. Natural Resources Canada. 1997. National Wood Residue Data Base. Natural Resources Canada. This data point is used for 1970–1990.

g. Natural Resources Canada. 1999. Canada's Wood Residues: A Profile of Current Surplus and Regional Concentrations.

h. Natural Resources Canada. 2005. Estimated Production, Consumption and Surplus Mill Wood Residues in Canada–2004.

Table A3.6–8 **Wood Waste Landfilled by Province (Hydrated Tonnes)**

Year	NL	PE	NS	NB	QC	ON	MB	SK	AB	BC
1970–1990[a]	49 702	674	50 587	32 527	418 671	285 928	21 592	89 629	472 427	1 883 451
1991	47 895	649	48 747	31 344	403 447	275 530	20 807	86 370	455 248	1 814 960
1992	44 022	597	44 805	28 809	370 824	253 251	19 124	79 386	418 436	1 668 203
1993	40 463	548	41 182	26 480	340 839	232 773	17 578	72 967	384 602	1 533 312
1994	37 191	504	37 852	24 339	313 279	213 951	16 156	67 067	353 503	1 409 328
1995	34 184	463	34 792	22 371	287 947	196 651	14 850	61 644	324 919	1 295 370
1996	31 419	426	31 978	20 562	264 664	180 749	13 649	56 659	298 646	1 190 626
1997	28 879	391	29 393	18 899	243 263	166 134	12 546	52 078	274 497	1 094 352
1998	7 884	-	21 681	65 043	601 155	165 564	7 884	17 739	329 157	754 893
1999	6 490	-	17 847	53 540	494 837	136 283	6 490	14 602	270 943	621 385
2000	5 965	-	16 403	49 210	454 824	125 263	5 965	13 421	249 035	571 140
2001	5 483	-	15 077	45 231	418 047	115 134	5 483	12 336	228 898	524 958
2002	5 039	-	13 858	41 574	384 244	105 825	5 039	11 338	210 389	482 509
2003	4 632	-	12 737	38 212	353 174	97 268	4 632	10 422	193 377	443 494
2004	9 993	-	9 993	-	39 972	39 972	9 993	59 958	179 874	649 544
2005	9 783	-	9 783	-	39 130	39 130	9 783	58 695	176 086	635 866
2006	8 992	-	8 992	-	35 966	35 966	8 992	53 949	161 848	584 449
2007	8 264	-	8 264	-	33 058	33 058	8 264	49 587	148 761	537 191
2008	7 596	-	7 596	-	30 385	30 385	7 596	45 577	136 732	493 754
2009	6 982	-	6 982	-	27 928	27 928	6 982	41 892	125 676	453 829
2010	6 417	-	6 417	-	25 670	25 670	6 417	38 504	115 513	417 132
2011	5 899	-	5 899	-	23 594	23 594	5 899	35 391	106 173	383 403
2012	5 422	-	5 422	-	21 686	21 686	5 422	32 529	97 588	352 401
2013	4 983	-	4 983	-	19 933	19 933	4 983	29 899	89 697	323 906
2014	4 580	-	4 580	-	18 321	18 321	4 580	27 481	82 444	297 715
2015	4 210	-	4 210	-	16 839	16 839	4 210	25 259	75 778	273 641
2016	3 869	-	3 869	-	15 478	15 478	3 869	23 217	69 650	251 515
2017	3 557	-	3 557	-	14 226	14 226	3 557	21 339	64 018	231 177
2018	3 269	-	3 269	-	13 076	13 076	3 269	19 614	58 842	212 484

Note:
a. Values for 1990 are used for 1970–1990.

A3.6.2. Biological Treatment of Solid Waste (5.B)

The Biological Treatment of Solid Waste category consists of the following two emission sources: Composting and Anaerobic Digestion.

A3.6.2.1. Composting (5.B.1)

The greenhouse gas emissions estimated from composting in Canada include CH_4 and N_2O. Since CO_2 emissions released by composting result from the decomposition of organic material from biomass sources, these emissions are not included in the national total. Net CO_2 emissions resulting from biogenic sources are accounted for under the AFOLU sector.

A3.6.2.1.1. Methodology

A Tier 1 method is used to estimate emissions from composting since country-specific emission factors or facility/site-specific measurements are not available.

The 2006 IPCC Guidelines' (IPCC 2006) recommended default equations (i.e. Equations 4.1 and 4.2) are used to estimate CH_4 and N_2O emissions, respectively, for all time periods and regions. Equation A3.6–10 and Equation A3.6–11 present the default equations used:

Equation A3.6–10 **CH_4 Emissions from Biological Treatment (IPCC 2006, Equation 4.1, Chapter 4, Volume 5)**

$$CH_4\ Emissions = \sum_i (M_i \cdot EF_i) \cdot 10^{-3} - R$$

$CH_4\ Emissions$	=	total CH_4 emissions in inventory year, Gg CH_4
M_i	=	mass of organic waste treated by biological treatment type *i*, Gg
EF	=	emission factor for treatment *i*, g CH_4/kg waste treated
i	=	composting or anaerobic digestion
R	=	total amount of CH_4 recovered in inventory year, Gg CH_4

Table A3.6–9 **Methane generated, oxidized and emitted from wood waste landfills in Canada (1990–2018)**

Year	CH_4 Generated (kt)	CH_4 Oxidized by Landfill Cover (kt)	CH_4 Emitted (kt)
1970–1990[a]	171.00	17.10	153.90
1991	177.15	17.71	159.43
1992	182.70	18.27	164.43
1993	187.22	18.72	168.50
1994	190.81	19.08	171.73
1995	193.55	19.36	174.20
1996	195.54	19.55	175.98
1997	196.84	19.68	177.15
1998	197.53	19.75	177.78
1999	198.37	19.84	178.53
2000	198.01	19.80	178.20
2001	197.21	19.72	177.49
2002	196.02	19.60	176.42
2003	194.50	19.45	175.05
2004	192.68	19.27	173.41
2005	190.37	19.04	171.33
2006	188.06	18.81	169.25
2007	185.55	18.55	166.99
2008	182.86	18.29	164.58
2009	180.03	18.00	162.03
2010	177.08	17.71	159.37
2011	174.02	17.40	156.62
2012	170.88	17.09	153.79
2013	167.66	16.77	150.90
2014	164.40	16.44	147.96
2015	161.09	16.11	144.98
2016	157.76	15.78	141.98
2017	154.40	15.44	138.96
2018	151.05	15.10	135.94

Note:
a. Values for 1990 are used for 1970–1990.

Equation A3.6–11 **N_2O Emissions from Biological Treatment (IPCC 2006, Equation 4.2, Chapter 4, Volume 5)**

$$N_2O\ Emissions = \sum_i (M_i \cdot EF_i) \cdot 10^{-3}$$

$N_2O\ Emissions$	=	total N_2O emissions in inventory year, Gg N_2O
M_i	=	mass of organic waste treated by biological treatment type *i*, Gg
EF	=	emission factor for treatment *i*, g N_2O/kg waste treated
i	=	composting or anaerobic digestion

It should be noted that for Equation A3.6–10, Canada does not have data on recovered CH_4 at composting facilities. As a result, this process is assumed to not be occurring.

A3.6.2.1.2. Data Sources

The activity data used to estimate CH_4 and N_2O emissions from composting is the amount of organic waste diverted in Canada (Statistics Canada, no date (b)). This data was collected by Statistics Canada through the *Waste Management Industry Survey: Business and Government Sectors* (CANSIM 153-0043) and is available for the provinces and territories on a biennial basis from 1998 to 2016. To address the missing amount of organic waste diverted for the odd years in this time series, the average is taken of the known value for the year before with the known value for the year after.

To address the activity data for the years prior to 1998 in the inventory time series, the last known data point is trended backwards using the last known two data points. This method assumes composting activities were in fact occurring in the province/territory prior to 1998 for the years where the trending produced values greater than zero. Additionally, it is assumed that all diverted organics in Canada are composted since data on the distribution of the organic waste to different treatment methods are not available.

One additional issue with using the Statistics Canada data is that the amount of organic waste diverted is suppressed for the Canadian territories and one province, due to confidentiality. In these cases, the amount of organic waste diverted is obtained directly from the authorities responsible for waste management in these jurisdictions. A summary of the quantities of organic waste composted for the years 1990 to 2018 is presented in Table A3.6–10.

The emission factors used to estimate the emissions of CH_4 and N_2O from composting in Canada are the default factors on a wet weight basis that are provided in the IPCC 2006 Guidelines, Volume 5, Chapter 4, Table 4.1. These emission factors include a value of 4 g CH_4/kg of waste treated and 0.24 g N_2O/kg of waste treated.

A3.6.2.2. Anaerobic Digestion at Biogas Facilities (5.B.2)

Presently, greenhouse gas emissions from anaerobic digestion of solid waste at biogas facilities are not estimated for Canada. There are five large anaerobic digesters known to be operating in Canada that process source-separated organics from municipal and commercial waste streams. Based on calculations for 2016, the approximate level of emissions from these identified facilities is 7 kt CO_2 eq or 0.001% of the total national emissions. This is assumed to be representative of the estimates for all years. As this is less than 0.05% of total emissions and less than the 500 kt threshold as specified in paragraph 37(b) of the UNFCCC Annex I Inventory Reporting guidelines, this source can be considered insignificant.

Table A3.6–10 **Quantity of Organic Waste Composted by Province for 1990 to 2018 (Tonnes), Wet Basis**

Year	NL[a]	PE[b]	NS	NB[c]	QC	ON	MB	SK	AB	BC	YT[d]	NT[d]	NU[e]	Canada
1990	0	0	0	35 565	0	282 629	2 764	127	0	0	0	0	0	321 085
1991	0	0	0	39 495	0	282 593	2 928	262	0	5 446	0	0	0	330 722
1992	0	0	0	43 425	0	282 556	3 091	396	0	24 854	0	0	0	354 322
1993	0	0	0	47 355	0	282 520	3 254	531	0	44 263	0	0	0	377 922
1994	0	0	0	51 285	0	282 483	3 418	665	6 651	63 671	0	0	0	408 173
1995	0	6 596	0	55 215	20 750	282 447	3 581	800	27 386	83 080	0	0	0	479 854
1996	0	8 037	0	59 145	72 000	282 410	3 745	935	48 122	102 488	0	0	0	576 881
1997	0	8 741	0	63 075	123 250	282 374	3 908	1 069	68 857	121 897	0	0	0	673 170
1998	0	9 831	16 751	67 005	174 500	282 337	4 071[f]	1 204[f]	89 5937	141 305	0	0	0	786 597
1999	0	9 702	38 266	70 935	225 750	282 301	4 235	1 338	110 328	160 714	0	0	0	903 568
2000	0	10 113	59 780	74 865	277 000	282 264	4 398	1 473	131 064	180 122	229	0	0	1 021 308
2001	0	10 217	71 061	78 795	261 500	337 796	10 330	2 710	196 067	189 559	388	0	0	1 158 421
2002	0	14 233	82 341	82 725	246 000	393 328	16 261	3 947[f]	261 069	198 996	852	0	0	1 299 752
2003	0	21 561	87 900	86 655	235 500	483 213	15 949	3 911	248 020	226 937	943	0	0	1 410 587
2004	0	28 888	93 458	90 585	225 000	573 098	15 636	3 875[f]	234 970	254 878	1 005	0	0	1 521 393
2005	0	27 931	113 696	98 203	292 500	652 649	14 063	3 751	233 215	273 455	1 041	0	0	1 710 503
2006	0	26 973	133 934	105 821[f]	360 000	732 200	12 490	3 627	231 459	292 031	977	0	0	1 899 512
2007	0	27 846	146 177	114 342	372 000	880 855	14 195	7 909	231 502	317 809	1 131	0	0	2 113 764
2008	0	28 719	158 419	122 863	384 000	1 029 510	15 9017	12 190	231 544	343 586	1 314	0	0	2 328 046
2009	0	25 238	153 585	108 790	318 500	1 043 891	17 786	13 168	221 101	360 863	1 828	85	0	2 264 833
2010	0	21 756	148 750	94 716	253 000	1 058 272	19 672	14 146[f]	210 657	378 139	2 149	205	0	2 201 462
2011	0	20 905	144 758	95 094	319 500	1 064 447	21 899	21 175	225 261	412 000	2 569	331	0	2 327 937
2012	0	20 053	140 765	95 471	386 000	1 070 622	24 125	28 204[f]	239 864	445 860	2 117	200	0	2 453 281
2013	0	20 204	146 094	94 585	404 346	1 112 038	36 072	29 826	247 852	476 326	2 267	101	0	2 569 708
2014	0	20 355	151 423	93 698	422 691	1 153 454	48 018	31 447	255 839	506 792	2 222	163	0	2 686 102
2015	0	20 355	154 013	95 828	345 346	1 143 529	49 921	31 388	247 635	549 543	2 789	364	0	2 640 710
2016	401	20 484	156 603	97 958	268 000	1 133 603	51 824	31 329	239 431	592 294	2 752	483	0	2 595 162
2017	401	20 078	156 603	97 958	268 000	1 133 603	51 824	31 329	239 431	592 294	2 457	684	0	2 594 662
2018[g]	401	20 445	156 603	97 958	268 000	1 133 603	51 824	31 329	239 431	592 294	2 457	684	0	2 595 029

Notes:

Except where otherwise noted, data were trended backwards using the last known two datapoints for the years 1990 to 1997. For even years between 1998 and 2017, data were obtained from the biennial Waste Management Industry Survey conducted by Statistics Canada (2018). For odd years between 1998 to 2017, values were averaged from the preceding years' and following years' values. For 2018, the 2017 values were carried forward.

a. For even years between 1998 and 2014, data reported for Newfoundland by Statistics Canada (2018) were zero or suppressed. Statistics Canada (2018) provided an estimate that was not zero for 2016 and this value was carried forward to 2018.

b. For the years 1990 to 1994, data for Prince Edward Island were trended backwards using the last known two datapoints. For the years 1995 to 2002 and for even years between 2002 and 2016, data was received directly from provincial representatives. For odd years between 2002 and 2016, values were averaged from the preceding years' and following years' values. For 2017 and 2018, data was received directly from provincial representatives.

c. Data were trended backwards using the last known two datapoints for the years 1990 to 2001. For even years between 2002 and 2017, data were obtained from Statistics Canada (2018). For odd years between 2002 and 2017, values were averaged from the preceding years' and following years' values. The 2017 values were carried forward for 2018.

d. Data was obtained directly from territorial representatives.

e. No data available for Nuavut. Assumed no large-scale composting programs.

f. Datapoint was suppressed in Statistics Canada (2018). Value was derived using nearest known datapoints.

g. When the latest Statistics Canada data is not yet available the last known data point is carried forward. This excludes PEI (see footnote 3).

A3.6.3. Incineration and Open Burning of Waste (5.C)

Waste incineration is defined in the 2006 IPCC Guidelines as the combustion of solid and liquid waste in controlled incineration facilities. Incineration emissions in Canada come from municipal solid waste (MSW) incineration, hazardous waste incineration, clinical waste incineration and sewage sludge incineration. Open burning of waste occurs mainly in rural areas and includes burning garbage in backyard barrels and/or open pits. This section of Annex 3 details the accounting methodologies that are used to describe the GHG emission estimates for these categories.

In keeping with the IPCC 2006 Guidelines (IPCC 2006), only CO_2 emissions resulting from oxidation of carbon in waste of fossil origin (e.g. plastics, certain textiles, rubber, liquid solvents, and waste oil) are considered net emissions and are included in the national CO_2 emissions estimate. CO_2 emissions from combustion of biomass materials (e.g. paper, food, and wood waste) contained in the waste are biogenic emissions and are not included in national total emission estimates.

A3.6.3.1. Municipal Solid Waste Incineration (5.C.1.1.a/5.C.1.1.b)

Although municipal solid waste (MSW) incineration is not a common practice in Canada, it does occur at a number of large facilities across the country. Some facilities generate energy in the form of electricity and/or heat from waste incineration. These facilities are referred to as energy-from-waste (EFW) facilities. Other facilities simply incinerate waste for disposal purposes and are referred to as non-energy-from-waste (non-EFW) facilities. As per IPCC 2006 Guidelines, emissions from waste incineration with energy recovery are reported in the Energy sector, while emissions from waste incineration without energy recovery are reported in the Waste sector. The following section describes the methodology for all MSW incinerators, though final emissions are reported under the appropriate sector.

The Greenhouse Gas Reporting Program (GHGRP) has almost complete coverage of the MSW incineration sector in more recent years due to the small number of incineration facilities operating in Canada and the lowered GHGRP reporting threshold. Where GHGRP does not have coverage, facility-specific emission estimates were developed using the best available information. This bottom-up, facility-specific approach to developing emissions estimates was implemented in 2019s inventory cycle. In previous inventory cycles a top-down approach was used (Figure A3.6–2).

A3.6.3.1.1. Data Sources

Tonnage of Waste Incinerated

It is important to note that the total amount of waste incinerated is not directly used to develop emission estimates from MSW incineration. Rather, the amount of waste incinerated at a facility is used to determine emissions only where GHGRP-reported emissions are not available. However, as discussed in section A3.6.1.2.1 of this chapter, the total amount of waste incinerated annually in Canada is required to isolate the amount of waste landfilled from the total amount of waste disposed. Therefore, even where a facility reports emission totals to GHGRP, annual tonnage incinerated is still collected. The amount of waste incinerated at facilities across Canada is obtained through voluntary biennial surveys of incineration facilities conducted by ECCC. The survey has collected data every two years since 2008, with the most recent data collection occurring in the summer of 2018. The survey requests data for all operational years from 1990. Where facilities are not included in the survey, either due to non-response or because the facility closed before the first survey cycle in 2008, tonnage is estimated using old reports (Sawell et al. 1996; Environment Canada 1999; Environment Canada 2003(b)). Where the time series of tonnage incinerated is incomplete for the operational lifetime of a facility, the nearest data are carried forward or backward.

The estimates for amount of MSW incinerated for the period 1990–2018 are shown in Table A3.6–11.

Figure A3.6–2 **Decision Tree for Collecting, Estimating and Reporting GHG Emissions from MSW Incineration Facilities**

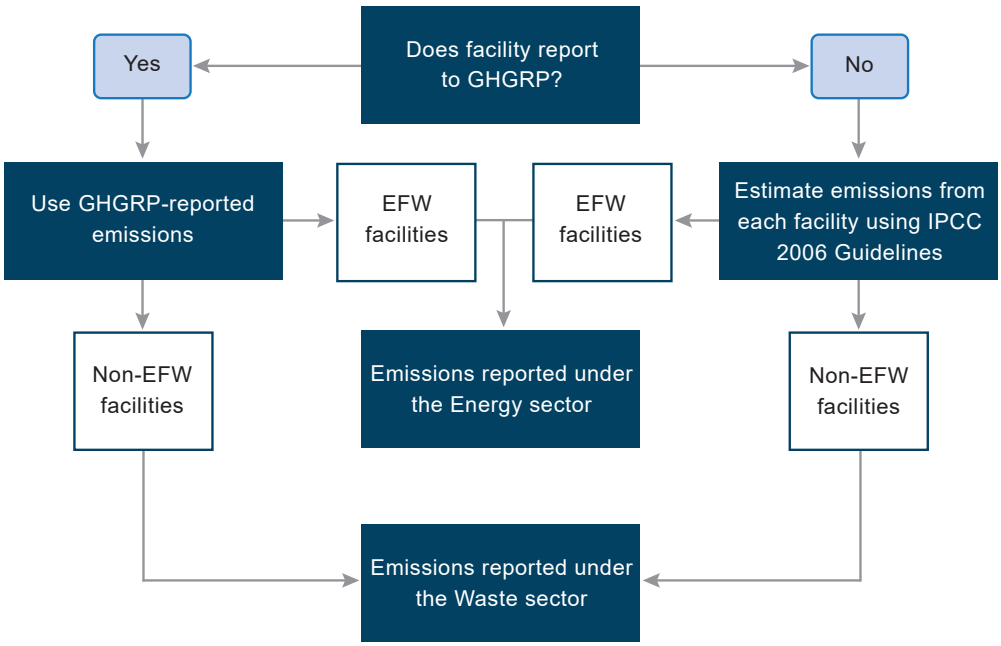


Table A3.6–11 **Estimated Tonnes of MSW Incinerated by Province for 1990–2018**

	MSW Incinerated (t)									
	EFW Facilities						Non-EFW Facilities			Total
Year	PE	NS	QC	ON	AB	BC	NL	QC	BC	Canada
1990	35 158	54 000	598 271	143 900	-	238 372	77 886	27 785	20 900	**1 196 272**
1991	34 627	54 000	593 395	143 900	-	241 206	77 514	27 838	20 900	**1 193 380**
1992	31 837	35 000	593 568	323 282	-	241 488	82 940	27 665	20 900	**1 356 680**
1993	32 436	35 000	454 034	318 088	-	248 296	83 444	26 251	18 900	**1 216 449**
1994	33 021	35 000	256 275	310 894	-	252 359	82 972	27 873	20 000	**1 018 394**
1995	32 054	54 000	237 288	315 252	-	254 871	78 940	27 788	6 100	**1 006 293**
1996	33 981	54 000	241 602	326 810	4 545	249 558	80 608	27 591	4 100	**1 022 794**
1997	29 907	34 300	241 862	316 021	4 206	257 300	78 662	26 998	4 100	**993 355**
1998	32 250	46 128	245 165	316 987	3 867	247 075	75 223	23 945	-	**990 640**
1999	32 135	43 650	251 688	314 267	3 528	254 803	75 087	25 648	-	**1 000 806**
2000	33 018	40 740	253 883	299 211	3 189	256 367	74 207	25 873	-	**986 488**
2001	32 224	40 740	259 743	293 178	3 346	246 666	72 441	27 532	-	**975 870**
2002	29 706	54 000	263 291	289 950	2 376	264 013	73 210	26 533	-	**1 003 079**
2003	26 963	54 000	279 073	161 537	1 544	249 521	71 823	26 281	-	**870 742**
2004	25 302	54 000	283 890	153 035	2 408	275 174	64 453	26 791	-	**885 053**
2005	26 580	54 000	284 162	141 631	2 014	277 571	49 065	26 256	-	**861 279**
2006	25 623	-	293 313	147 769	874	273 521	43 773	29 554	-	**814 428**
2007	24 282	-	286 010	132 777	36	289 900	45 153	28 990	-	**807 149**
2008	24 188	-	289 480	152 347	38	275 034	39 981	28 566	-	**809 633**
2009	23 911	-	274 240	153 675	19	276 650	20 071	26 147	-	**774 713**
2010	25 436	-	273 333	92 368	62	284 277	7 934	26 000	-	**709 410**
2011	26 099	-	279 965	175 930	2	281 159	5 642	17 756	-	**786 553**
2012	26 978	-	272 772	175 930	2	281 260	5 405	21 944	-	**784 291**
2013	25 257	-	274 531	175 930	2	280 171	2 477	20 162	-	**778 530**
2014	26 081	-	257 657	175 930	2	275 260	798	20 438	-	**756 166**
2015	26 871	-	224 807	276 722	0	256 402	798	18 259	-	**803 859**
2016	26 281	-	245 990	304 437	-	254 244	387	21 255	-	**852 594**
2017	25 857	-	252 690	315 688	-	259 748	387	22 790	-	**877 160**
2018	25 515	-	252 690	315 688	-	259 748	387	22 790	-	**876 818**

A3.6.3.1.2. Methodology

Emission estimates are compiled at a facility level, and a distinction is made between EFW facilities and non-EFW facilities. Where GHGRP emissions are available, they are used. Where GHGRP emissions are not available, facility-specific emissions are estimated using methodologies prescribed in the 2006 IPCC Guidelines (IPCC 2006).

Facilities Reporting to the GHGRP

GHGRP facility data are available annually from 2004 onwards, though most MSW incinerators started reporting in 2009. Where facilities were operating before 2009, the emissions time series was completed by assuming that tonnage incinerated is directly correlated with emissions. The “Surrogate Data” method prescribed in Volume 1, Chapter 5.3.3.2, of the 2006 IPCC Guidelines (IPCC 2006) is used to complete the time series of emissions using annual tonnage incinerated by the facility, obtained through surveys and/or reports, as well as GHGRP data for all years for which such data are available.

Note that GHGRP reporting guidelines require that facility-reported CO_2 emissions are derived only from wastes of fossil origin (e.g. plastics, certain textiles, rubber, liquid solvents and waste oil). CO_2 from the biogenic portion of waste (e.g. food, wood, garden waste) are excluded from emissions totals.

Non-reporting Facilities

There are a large number of incinerators that either closed before the GHGRP was launched or operated under the reporting threshold. Many of these facilities were small incinerators across Newfoundland and Labrador, but also include some larger facilities in Ontario, Quebec, British Columbia and Alberta. Emission estimates for these facilities were developed using the IPCC 2006 Guidelines and the best available parameters for each facility.

CO_2 Emissions

Emissions of CO_2 from MSW incineration are estimated using the mass-balance approach prescribed by equation 5.2 in the IPCC 2006 Guidelines.

Equation A3.6–12 **(modified from IPCC 2006 Guidelines Equation 5.2)**

$$CO_2\ Emissions = MSW \times \sum(WF_j \times dm_j \times CF_j \times FCF_j \times OF) \times 44/12$$

$CO_2\ Emissions$	=	CO_2 emissions in inventory year
MSW	=	total amount of MSW incinerated
J	=	Component of MSW incinerated, such as paper/ cardboard, textiles, food waste, wood, plastic, garden waste, plastics, metal, glass, etc.
WF_j	=	fraction of waste type/material *j* in total MSW waste incinerated
dm_j	=	dry matter content of component *j* in total MSW waste incinerated
CF_j	=	fraction of carbon in the dry matter (i.e. carbon content) of component *j*
FCF_j	=	fraction of fossil carbon in the total carbon of component *j*
OF	=	oxidation factor
$44/12$	=	conversion factor from C to CO_2¬

Where available, facility-specific waste characterization data was used to determine the different types of waste in the MSW incinerated (factor "WFj" in Equation A3.6–12). Where facility-specific characterization data were not available, provincial characterization data were taken from Environment Canada (1996). This report contains waste characterization data for EFW and non-EFW streams of waste incineration.

Table A3.6–12 Default Factors Used in Equation A3.6–12 to Determine CO_2 from MSW Incineration

Waste Type (j)	Dry Matter Content (dmj) (% Wet Weight)	Total Carbon Content (CFj) (% Dry Weight)	Fossil Carbon Fraction (FCFj) (% of Total Carbon)
Paper	0.9	0.46	0.01
Glass	1	NA	NA
Metal	1	NA	NA
Plastic	1	0.75	1
Organics[a]	0.4	0.435	0
Food[a]	0.4	0.38	0
Garden[a]	0.4	0.7	0.1
Wood	0.85	0.5	0
Inorganics	1	0.03	1
Textiles/Rubber[b]	0.82	0.585	0.2
Other[c]	1	0.34	0.35

Notes:

a. In cases where facility waste characterization includes organics in general, the organics parameters are used. If the facility distinguishes between food and garden waste, those specific factors are used.

b. Textile and rubber parameters are combined, as their composition is often reported together.

c. Many facilities report "other" waste, without identifying what it includes. Therefore, an average of textiles, food, garden, rubber and inert waste are used in these cases. Note that paper and plastic are always characterized separately and so are not incorporated into the "other" parameter.

Table A3.6–12 contains the default factors from the 2006 IPCC Guidelines that were used to determine the CO_2 emissions from each waste type incinerated.

A default factor of 1 is used as the oxidation factor (OF) for all waste types and facilities.

CH_4 Emissions

Emissions of CH_4 from MSW incineration are determined for each facility using default emission factors from IPCC 2006 Guidelines. Emission factors are multiplied by the total annual waste incinerated at the facility (Equation A3.6–13). Emission factors vary depending on how the incinerator is fed (continuous, semi-continuous, or batch-type incineration) and on the incinerator type (stoker vs fluidized bed) (Table A3.6–13). The most appropriate emission factor was chosen for each facility.

Equation A3.6–13 **(modified from IPCC 2006 Guidelines Equation 5.4)**

$$CH_4\ Emissions = \sum(W_f \times EF_f)$$

$CH_4\ Emissions$	=	CH_4 emissions from MSW incineration in inventory year
W_f	=	total amount of MSW incinerated at facility *f*
EF_f	=	emission factor most appropriate for facility *f*

N_2O Emissions

As with CH_4 emissions, N_2O emissions from MSW incineration are determined for each facility using default emission factors from IPCC 2006 Guidelines. Emission factors are multiplied by the total annual waste incinerated at the facility (Equation A3.6–14). Emission factors for MSW incineration vary depending on the operation type of the incinerator (continuous and semi-continuous vs batch-type incineration) (Table A3.6–14). Note that although the IPCC 2006 Guidelines provide a MSW incinerator emission factor for open burning, it is assumed that no MSW incineration facilities in Canada practice open burning. The most appropriate emission factor was chosen for each facility.

Table A3.6–13 Default CH_4 Emission Factors for MSW Incineration Facilities

Type of Incinerator/Technology		CH_4 Emission Factor (Tonne CH_4/Tonne MSW Incinerated, Wet Weight)
Continuous incineration	Stoker	0.0002
	Fluidized bed	0
Semi-continuous incineration	Stoker	0.006
	Fluidized bed	0.188
Batch type incineration	Stoker	0.06
	Fluidized bed	0.237

Equation A3.6–14 **(modified from IPCC 2006 Guidelines Equation 5.5)**

$$N_2O\ Emissions = \sum(W_f \times EF_f)$$

N_2O Emissions	=	N_2O emissions from MSW incineration in inventory year
Wf	=	total amount of MSW incinerated at facility *f*
EFf	=	emission factor most appropriate for facility *f*

Table A3.6–14 **Default N_2O Emission Factors for MSW Incineration Facilities**

Type of incinerator/technology	N_2O Emission Factor (Tonne N_2O /Tonne MSW Incinerated, Wet Weight Basis)
Continuous/semi-continuous incineration	0.00005
Batch type incineration	0.00006

Total Emissions

Table A3.6–15 summarizes emissions from EFW and non-EFW facilities. The EFW emissions are reported under the Energy sector, while the non-EFW emissions are reported under the Waste sector.

A3.6.3.2. Hazardous Waste Incineration (5.C.1.2.b)

A3.6.3.2.1. Data Sources

Hazardous waste incineration activity data were obtained directly from facilities. Biennale surveys were conducted by Environment and Climate Change Canada between 2006 and 2018 (ECCC 2018c). The waste quantities and emissions are presented at a national level in Table A3.6–16.

These amounts of incinerated waste include contaminated substrates such as soils, wood, metal and other material. The hazardous waste quantities may also include inorganic wastes such as aqueous solutions containing

Table A3.6–15 **National Summary of Emissions from MSW Incineration**

	EFW (Reported under Energy) (kt)				Non-EFW (Reported under Waste) (kt)			
Year	CO_2 Emissions	CH_4 Emissions	N_2O Emissions	Total CO_2e Emissions	CO_2 Emissions	CH_4 Emissions	N_2O Emissions	Total CO_2e Emissions
1990	356	1.7	0.089	424	46	5.1	0.0061	171
1991	355	1.7	0.088	423	46	5.1	0.0060	170
1992	415	1.7	0.091	483	48	5.3	0.0064	178
1993	377	1.2	0.084	432	47	5.3	0.0063	176
1994	321	0.59	0.073	358	47	5.5	0.0065	181
1995	324	0.67	0.071	361	40	5.0	0.0055	162
1996	329	0.71	0.073	368	40	5.1	0.0055	164
1997	315	0.70	0.071	354	39	4.9	0.0054	160
1998	319	0.73	0.073	359	34	4.6	0.0050	149
1999	324	0.66	0.073	362	35	4.6	0.0050	150
2000	321	0.61	0.073	358	35	4.6	0.0049	148
2001	315	0.59	0.074	352	35	4.5	0.0048	146
2002	324	0.61	0.075	361	35	4.5	0.0049	147
2003	282	0.22	0.071	309	34	4.5	0.0048	145
2004	289	0.22	0.072	316	32	4.0	0.0044	131
2005	287	0.22	0.072	314	28	3.1	0.0035	101
2006	272	0.05	0.071	294	28	2.8	0.0031	93
2007	269	0.04	0.069	291	28	2.7	0.0031	91
2008	271	0.05	0.070	293	25	2.2	0.0025	76
2009	269	0.05	0.067	290	19	1.1	0.0014	43
2010	255	0.03	0.068	276	15	0.37	0.0007	21
2011	282	0.07	0.070	305	10	0.23	0.0007	14
2012	328	0.06	0.033	339	12	0.21	0.0006	15
2013	324	0.06	0.024	332	10	0.15	0.0005	12
2014	283	0.13	0.027	294	10	0.05	0.0004	9
2015	360	0.17	0.031	373	9	0.05	0.0004	8
2016	396	0.19	0.043	414	10	0.02	0.0003	8
2017	373	0.21	0.056	395	11	0.02	0.0003	9
2018	376	0.20	0.045	394	11	0.02	0.0003	9

Table A3.6–16 **Activity Data and Emissions from Hazardous Waste Incineration for 1990–2018**

	Quantity of Hazardous Waste Incinerated	Estimated GHG Emissions			
Year	(tonnes)	(kt CO_2)	(kt CH_4)	(kt N_2O)	(kt CO_2e)
1990	100 762	166	0.017	0.319	261.69
1991	109 111	180	0.018	0.345	283.37
1992	117 879	195	0.020	0.373	306.14
1993	125 109	206	0.021	0.396	324.92
1994	142 050	234	0.024	0.449	368.91
1995	164 727	272	0.028	0.521	427.81
1996	146 125	241	0.025	0.462	379.50
1997	132 348	218	0.022	0.419	343.72
1998	155 513	257	0.026	0.492	403.88
1999	140 820	232	0.024	0.446	365.72
2000	168 379	278	0.029	0.533	437.29
2001	179 525	296	0.030	0.568	466.24
2002	185 025	305	0.031	0.585	480.52
2003	145 836	241	0.025	0.461	378.74
2004	161 891	267	0.027	0.512	420.44
2005	157 788	260	0.027	0.499	409.79
2006	147 775	244	0.025	0.468	383.78
2007	134 878	223	0.023	0.427	350.29
2008	147 924	244	0.025	0.468	384.17
2009	134 453	222	0.023	0.425	349.18
2010	138 522	229	0.023	0.438	359.75
2011	131 019	216	0.022	0.415	340.27
2012	86 470	143	0.015	0.274	224.57
2013	90 940	150	0.015	0.288	236.18
2014	108 648	179	0.018	0.344	282.17
2015	123 426	204	0.021	0.391	320.54
2016	119 665	197	0.020	0.379	310.78
2017	119 686	197	0.020	0.379	310.83
2018	119 686	197	0.020	0.379	310.83

heavy metals, or wastes such as water-based urethanes, as opposed to solvent-based urethane wastes that have high fossil fuel carbon content.

A3.6.3.2.2. Methodology

The IPCC Good Practice Guidance defaults were used for the CO_2 estimation: carbon content (50%) and fossil carbon as a percentage of total carbon (90%). CO_2 emissions are then calculated by multiplying the mass of hazardous waste incinerated by its carbon content, the percentage of fossil carbon and the CO_2 conversion factor.

In the absence of IPCC default emission factor values for N_2O and CH_4, emission factors were derived using data 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 tonnes of hazardous waste (HW) and emitted 0.03 tonnes of CH_4 and 0.56 tonnes of 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. N_2O and CH_4 emissions from hazardous waste incineration were estimated by multiplying these emissions factors by the mass of waste incinerated.

A3.6.3.3. Sewage Sludge Incineration (5.C.1.1.b)

A3.6.3.3.1. Data Sources

Sewage sludge incineration activity data were obtained directly from facilities. Biennial surveys were conducted by Environment and Climate Change Canada between 2006 and 2018 (ECCC 2018. Sewage sludge incineration estimates and activity data for the period 1990–2018 are shown in Table A3.6–17.

A3.6.3.3.2. Methodology

It is assumed that all of the sewage sludge incinerators operating in Canada are of the fluidized bed type.

Emissions of N_2O from sewage sludge incineration have been updated using the IPCC 2006 default emission factor 0.99 kg/t of dried sewage sludge incinerated (IPCC 2006). To estimate emissions, the calculated factor is multiplied by the amount of waste incinerated by each province. The national emission values are then determined as the summation of these emissions for all provinces.

Equation A3.6–15 **(IPCC 2006, Equation 5.5, Chapter 5, Volume 5)**

$$N_2O_{SS} = M_{SS} \times EF_{N_2O-SS}$$

N_2O_{SS} = N_2O emissions from sewage sludge incineration, t/year

M_{SS} = mass of dried sewage sludge incinerated, t/year

EF_{N_2O-SS} = sewage sludge N_2O emission factor (0.99 kg N_2O/t dried sludge incinerated/1000 kg/t)

Emissions of CH_4 are estimated using emission factor of 9.7 kg/kt of total dried solids for fluidized bed sewage incinerators obtained from the U.S. Environmental Protection Agency (U.S. EPA 1995). 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.

CH_4 emissions are calculated as follows (Equation A3.6–16).

Table A3.6–17 **Estimated Sewage Sludge Incinerated for 1990–2018**

	Quantity of Sewage Sludge Incinerated	Estimated GHG Emissions			
Year	kt	(kt CO_2)	(kt CH_4)	(kt N_2O)	(kt CO_2e)
1990	128	0	0.001	0.127	37.91
1991	137	0	0.001	0.136	40.56
1992	145	0	0.001	0.143	42.69
1993	162	0	0.002	0.160	47.80
1994	181	0	0.002	0.180	53.56
1995	182	0	0.002	0.180	53.63
1996	202	0	0.002	0.200	59.64
1997	195	0	0.002	0.193	57.70
1998	196	0	0.002	0.194	57.88
1999	207	0	0.002	0.205	61.06
2000	208	0	0.002	0.206	61.30
2001	212	0	0.002	0.209	62.47
2002	226	0	0.002	0.223	66.59
2003	215	0	0.002	0.213	63.52
2004	215	0	0.002	0.212	63.36
2005	211	0	0.002	0.209	62.44
2006	216	0	0.002	0.214	63.72
2007	214	0	0.002	0.212	63.31
2008	210	0	0.002	0.208	62.13
2009	213	0	0.002	0.211	62.83
2010	214	0	0.002	0.212	63.13
2011	229	0	0.002	0.227	67.62
2012	224	0	0.002	0.222	66.10
2013	223	0	0.002	0.221	65.82
2014	231	0	0.002	0.229	68.35
2015	239	0	0.002	0.236	70.48
2016	228	0	0.002	0.226	67.26
2017	240	0	0.002	0.238	70.85
2018	244	0	0.002	0.241	71.98

Equation A3.6–16 **(IPCC 2006, Equation 5.4, Chapter 5, Volume 5)**

$$CH_{4(s)} = S_{Inc} \times EF_{CH_4 - FB}$$

$CH_4(s)$ = CH_4 emissions from waste incineration, t/year

S_{Inc} = sewage sludge incinerated, dry t/year

$EF_{CH_4 - FB}$ = CH_4 emission factor for fluidized bed incinerators: 9.7 kg CH_4/kt sewage sludge incinerated / 1000 kg/t

A3.6.3.4. Clinical Waste Incineration (5.C.1.2.b)

A3.6.3.4.1. Data Sources

Similar to MSW incineration, some facilities generate energy in the form of electricity and/or heat from waste incineration. These facilities are referred to as energy-from-waste (EFW) facilities. Other facilities simply incinerate waste for disposal purposes and are referred to as non-energy-from-waste (non-EFW) facilities. As per IPCC 2006 Guidelines, emissions from waste incineration with energy recovery are reported in the Energy sector, while emissions from waste incineration without energy recovery are reported in the Waste sector. The following section describes the methodology for all MSW incinerators, though final emissions are reported under the appropriate sector.

The types of clinical waste incinerated in Canada include cytotoxic waste, human or animal anatomical waste and pharmaceutical waste (Stericycle 2014). The activity data were identified as from either continuous or batch-type incineration; no semi-continuously operated incinerators were identified.

Clinical waste incineration activity data were obtained directly from facilities. Biennale surveys were conducted by Environment and Climate Change Canada between 2006 and 2018 (ECCC 2018). There are currently believed to be under twenty clinical waste incinerators operating in Canada.

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). For clinical waste incineration, linear interpolation was used between data points and extrapolated from provincial totals of clinical waste. For values outside of data point ranges, the extrapolation was based on population data

The waste quantities and emissions are presented at a national level in Table A3.6–18.

A3.6.3.4.2. Methodology

The 2006 IPCC Guidelines (IPCC 2006) Tier 1 method for CO_2 emissions was used (Equation A3.6–17). There are two types of clinical waste incinerators, stoker-type and fluidised bed. The stoker-type emission factors were found to be more representative of the clinical waste incinerators in Canada and therefore stoker type emission factors were used where applicable.

Table A3.6–18 **Activity data and Emissions for Clinical Waste Incineration 1990–2018**

	EFW (Reported under Energy) (kt)					Non-EFW (Reported under Waste) (kt)				
Year	Waste Incinerated	CO_2 Emissions	CH_4 Emissions	N_2O Emissions	Total CO_2e Emissions	Waste Incinerated	CO_2 Emissions	CH_4 Emissions	N_2O Emissions	Total CO_2e Emissions
1990	1.35	0.77	0.00	0.00	0.79	1.28	0.73	0.00	0.00	0.76
1991	1.35	0.77	0.00	0.00	0.79	1.29	0.74	0.00	0.00	0.76
1992	1.35	0.77	0.00	0.00	0.79	1.30	0.74	0.00	0.00	0.77
1993	1.35	0.77	0.00	0.00	0.79	2.87	1.64	0.00	0.00	1.69
1994	1.35	0.77	0.00	0.00	0.79	2.88	1.65	0.00	0.00	1.70
1995	1.35	0.77	0.00	0.00	0.79	2.93	1.68	0.00	0.00	1.73
1996	5.48	3.14	0.00	0.00	3.22	2.94	1.68	0.00	0.00	1.73
1997	5.22	2.99	0.00	0.00	3.06	2.94	1.68	0.00	0.00	1.73
1998	4.95	2.83	0.00	0.00	2.91	2.94	1.68	0.00	0.00	1.73
1999	4.69	2.68	0.00	0.00	2.75	2.95	1.69	0.00	0.00	1.74
2000	4.33	2.48	0.00	0.00	2.54	3.04	1.74	0.00	0.00	1.79
2001	3.46	1.98	0.00	0.00	2.03	3.83	2.19	0.00	0.00	2.25
2002	3.50	2.00	0.00	0.00	2.06	3.96	2.26	0.00	0.00	2.33
2003	3.81	2.18	0.00	0.00	2.23	3.91	2.24	0.00	0.00	2.30
2004	4.09	2.34	0.00	0.00	2.40	4.52	2.58	0.00	0.00	2.66
2005	4.66	2.67	0.00	0.00	2.74	5.00	2.86	0.00	0.00	2.94
2006	2.65	1.51	0.00	0.00	1.55	5.45	3.12	0.00	0.00	3.21
2007	2.80	1.60	0.00	0.00	1.64	3.99	2.28	0.00	0.00	2.34
2008	3.38	1.93	0.00	0.00	1.98	5.21	2.98	0.00	0.00	3.06
2009	3.22	1.84	0.00	0.00	1.89	4.69	2.68	0.00	0.00	2.76
2010	3.12	1.78	0.00	0.00	1.83	4.34	2.48	0.00	0.00	2.55
2011	3.26	1.87	0.00	0.00	1.91	4.70	2.69	0.00	0.00	2.76
2012	3.26	1.87	0.00	0.00	1.91	4.25	2.43	0.00	0.00	2.50
2013	3.26	1.87	0.00	0.00	1.91	4.39	2.51	0.00	0.00	2.58
2014	3.26	1.87	0.00	0.00	1.91	4.37	2.50	0.00	0.00	2.57
2015	0.00	0.00	0.00	0.00	0.00	4.56	2.61	0.00	0.00	2.68
2016	0.00	0.00	0.00	0.00	0.00	3.13	1.79	0.00	0.00	1.84
2017	0.00	0.00	0.00	0.00	0.00	2.94	1.68	0.00	0.00	1.73
2018	0.00	0.00	0.00	0.00	0.00	2.94	1.68	0.00	0.00	1.73

Equation A3.6–17 **(IPCC 2006, Equation 5.1, Chapter 5, Volume 5)**

$$CO_2\ Emissions = \sum_i (SW_i \cdot dm_i \cdot CF_i \cdot FCF_i \cdot OF_i) \cdot 44/12$$

$CO_2\ Emissions$ = 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 CO_2

i = type of waste incinerated (MSW, sewage sludge, hazardous waste, clinical waste, etc.)

The default values of 60% for total carbon (% of dry weight) and 40% for fossil carbon as a percentage of total carbon and the default oxidation factor of 100% for clinical waste from the 2006 IPCC Guidelines (IPCC 2006) were used.

For quantification of N_2O emissions, the 2006 IPCC Guidelines Tier 1 method (IPCC 2006) was used (Equation A3.6–18).

Equation A3.6–18 **(IPCC 2006, Equation 5.5, Chapter 5, Volume 5)**

$$N_2O\ Emissions = \sum_i (IW_i \cdot EF_i) \cdot 10^{-6}$$

$N_2O\ Emissions$ = N_2O emissions in inventory year, Gg/yr

IW_i = amount of incinerated waste of type *i*, Gg/yr

EF_i = N_2O emission factor (kg N_2O/Gg of waste) for waste of type *i*

10^{-6} = conversion factor from kilogram to gigagram

i = type of waste incinerated (clinical waste, etc.)

MSW default emission factors were used in accordance with the IPCC Good Practice Guidance (IPCC 2000) as no clinical-waste-specific values are provided. The N_2O emissions for a given site were therefore calculated using the stoker default emission factors for continuous incineration (50 g N_2O/t waste incinerated) and batch-type incineration (60 g N_2O/t waste incinerated) in IPCC 2006.

For quantification of CH_4 emissions, the 2006 IPCC Guidelines Tier 1 method (IPCC 2006) was used (Equation A3.6–19).

Equation A3.6–19 **(IPCC 2006, Equation 5.4, Chapter 5, Volume 5)**

$$CH_4\ Emissions = \sum_i (IW_i \cdot EF_i) \cdot 10^{-6}$$

$CH_4\ Emissions$	=	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 CH_4 emissions for a given site were calculated using the stoker default emission factors for continuous (0.2 kg/Gg waste incinerated) and batch-type incineration (60 kg/Gg waste incinerated) based on MSW in IPCC 2006, Volume 5, Chapter 5, Table 5.3 (IPCC 2006).

A3.6.3.5. Open Burning of Waste (5.C.2)

Canada does not currently estimate GHG emissions from open burning of waste. While open burning at landfills is banned by regulation in most provinces and territories, there is anecdotal evidence that some open burning still occurs in rural areas of the country. However, this is a minor source of emissions relative to other activities. The likely level of emissions from open burning of MSW in Canada (as estimated for 2010) was nearly 100 kt or 0.015% of total national emissions. This is less than 0.05% of total emissions and less than the 500 kt threshold as specified in paragraph 37(b) of the UNFCCC Annex I Inventory Reporting guidelines. As this emissions value can be considered representative for all years, this source can be considered insignificant.

A3.6.4. Emissions from Wastewater Treatment and Discharge (5.D)

The emissions estimates for the Wastewater Treatment and Discharge category includes CH_4 emissions from the treatment of municipal and industrial wastewater and from the discharge of untreated wastewater, and N_2O emissions from treated and untreated wastewater. Because wastewater is considered to be of biogenic origin, CO_2 emissions are not considered for the wastewater treatment sector.

Most wastewater treatment in Canada occurs at centralized municipal wastewater treatment plants (78% in 1990, 83% in 2018), which receive influent from domestic, commercial and industrial users. There are some coastal municipalities that collect and discharge untreated wastewater to sea. Many Canadians in rural and remote areas use private or communal septic systems for wastewater treatment. Larger industries treat or pre-treat their wastewater on-site and are considered separately from municipal wastewater treatment facilities in the Industrial On-Site Wastewater Treatment, section A3.6.4.2.

A3.6.4.1. Municipal Wastewater Treatment/ Discharge—CH_4

Emissions estimates for municipal wastewater treatment facilities follow the 2006 IPCC Guidelines for CH_4 emissions, and the 1996 IPCC Guidelines for N_2O emissions (IPCC 2006; IPCC 1996). Emissions from municipal wastewater treatment are determined on a per-capita basis: The per-capita organics loading to wastewater and the population served by treatment type are the primary activity data for CH_4 emissions. Nitrogen loading to wastewater, estimated from per-capita protein consumption, is the primary activity data for N_2O emissions.

Treatment technologies vary, but can be broadly classified as anaerobic or aerobic process. A well-managed aerobic treatment process is assumed to generate no CH_4 emissions. Estimates of CH_4 emissions can, therefore, be limited to anaerobic treatment processes. In Canada, anaerobic systems include facultative lagoons, septic systems, and collected untreated wastewater discharge, which is considered partially anaerobic. CH_4 estimates for municipal wastewater treatment are determined on the basis of organics loading to anaerobic wastewater treatment systems, determined from per-capita organics loading (which includes both domestic and industrial sources). Estimates are based on the theoretical maximum amount of methane generated and a methane correction factor to account for the actual amount of methane expected from a given treatment type.

A3.6.4.1.1. CH_4 Emissions from Municipal Wastewater Treatment/Discharge

Methodology

Methane emissions from municipal domestic wastewater treatment are calculated according to the 2006 IPCC Guidelines Tier 2 approach (IPCC 2006), using country-specific factors where available. Methane emissions are estimated for each province based on organics loading to wastewater and an emission factor as shown in Equation A3.6–20.

Equation A3.6–20

$$CH_{4(x)} = EF_{CH_4} \times OrganicLoad_{(x)}$$

$CH_{4(x)}$ = CH_4 emissions from wastewater treatment for province, x, t/year

EF_{CH_4} = CH_4 emission factor for wastewater treatment, t/capita/year

$OrganicLoad_{(x)}$ = organic load to the wastewater treatment/discharge system, for province x, t BOD_5/yr

Organics removed from wastewater as sludge and methane recovery from municipal wastewater treatment, as would normally be included in IPCC 2006 Equation 6.1 (IPCC 2006 Guidelines Chapter 6, Volume 5), are not accounted for because of insufficient data. These parameters are effectively treated as zero (i.e. no reduction in emissions from sludge removal and methane recovery).

Emission Factor

The emission factor for wastewater treatment and discharge is a function of the theoretical maximum CH_4 production capacity (B_0) for wastewater and a methane correction factor (MCF) for the wastewater treatment system, as shown in Equation A3.6–21 and Table A3.6–19. The maximum methane producing capacity was determined be 0.36 kg CH_4 per kg BOD_5 by AECOM (2011). The MCF is the fraction of the potential methane that is produced by each treatment type and ranges from 0 to 1 (IPCC 2006), depending on the treatment system type.

Equation A3.6–21

$$EF_{CH_4} = B_0 \times MCF$$

EF_{CH_4} = emission factor, kg CH_4/kg BOD_5

B_0 = theoretical maximum CH_4 producing capacity, kg CH_4/kg BOD_5

MCF = methane correction factor (MCF), fraction

As noted above, there is insufficient data to determine the amount of sludge removed from wastewater treatment (set as zero, in accordance with IPCC 2006 Guidelines, Equation 6.1). Consequently there is insufficient data to estimate the amount of anaerobic sludge digestion or to estimate methane recovery from anaerobic sludge digesters (anaerobic sludge digesters are known to have methane recovery systems).

Table A3.6–19 **Emission Factors for CH_4 from Wastewater Treatment and Discharge**

Treatment	MCF	EF	Source
Aerobic Lagoon	0	0	IPCC 2006 Guidelines
Anaerobic Lagoon	0.8	0.288	IPCC 2006 Guidelines
Facultative Lagoon	0.2	0.072	IPCC 2006 Guidelines
Lagoon/Unspecified Lagoon	0.2	0.072	IPCC 2006 Guidelines[a]
No Treatment	0.1	0.036	IPCC 2006 Guidelines
Preliminary	0	0	IPCC 2006 Guidelines
Centralized Aerobic—Primary	0	0	IPCC 2006 Guidelines
Centralized Aerobic—Secondary	0	0	IPCC 2006 Guidelines
Centralized Anaerobic	0.8	0.288	IPCC 2006 Guidelines
Septic	0.5	0.18	IPCC 2006 Guidelines
Unknown/Other	0.15	0.054	ECCC Estimate[b]
Wetland	0.17	0.0612	IPCC Suppmenent to 2006 Guidelines for Wetlands (2014)[c]
Sequence Batch Reactor	0.05	0.018	Taseli 2018
Storage	-	-	Not Estimated

Notes:
Emissions from storage and storage lagoons are not estimated.

a. It is assumed that unspecified lagoon types are facultative lagoons.
b. Assumption that most unknown systems are likely to be facultative lagoons or untreated discharge to sea.
c. Mean value of MCF's of the three wetland types in IPCC Guideline Supplement (2014) is used.

Activity Data

Emissions of CH_4 from municipal wastewater treatment systems are determined according to the organic loading to the anaerobic wastewater treatment systems, by province (measured as biogeochemical oxygen demand, 5-day test, or BOD_5). The organic loading is determined from the per-capita organics loading rate (BOD_5/capita/day), the population of each province, and the percentage of the population of that province that is serviced by anaerobic treatment systems (septic, facultative lagoons or collected and untreated discharge).

The 2006 IPCC Guidelines default BOD_5 per-capita organic loading rate of 0.06 kg/person/day is used (IPCC 2006).

The organic loading to wastewater is calculated as shown in Equation A3.6–22.

Equation A3.6–22

$$OrganicLoad_{(x)} = Pop_{(x)} \times Frac_{An(x)} \times BOD_5 \times 365 \times 0.001$$

$OrganicLoad_{(x)}$	=	organic load to the wastewater treatment/ discharge system, for province x, t BOD_5/yr
$Pop_{(x)}$	=	population of province, x
$Frac_{An(x)}$	=	fraction (percentage) of population of province, x, that is served by anaerobic wastewater treatment systems/discharge
BOD_5	=	per-capita organic loading to the wastewater system, kg BOD_5/capita/day
365	=	conversion from day to year
0.001	=	conversion from kg BOD_5 to tonne BOD_5

Treatment Technology Use, By Province

Canada has over 3000 municipal wastewater treatment or discharge systems, and much of the population uses private septic systems. Few treatment systems have directly enumerated serviced populations.

The percentage of population using each treatment type is estimated using survey data (Statistics Canada no date (c)), regional populations (Statistics Canada no date (d)), treatment system technology, and effluent volumes reported via the Effluent Regulatory Reporting Information System (ERRIS) under the *Wastewater System Effluent Regulations* (WSER), as well as data compiled from a variety of sources, such as treatment facility annual reports, municipal websites, and provincial reports, inventories and datasets.

Scale

The percentage of population using each treatment technology was determined at the geographic scale of census metropolitan area (CMA) (i.e. urban areas), with the remaining (rural or smaller city) regions of each province treated as a single unit (non-CMA area).

The 34 largest CMAs (Ottawa and Gatineau are considered separately) represent approximately 70% of Canada's population and have seen faster growth in population since 1990 than the non-CMA areas. There is also a notable difference in septic use between urban (CMA) and rural (non-CMA) regions.

Municipal treatment systems serve both domestic users (people) and some industrial users (industrial wastewater inputs). Many older treatment systems receive wastewater from combined sewers, meaning there are also inputs of rainwater runoff received at the treatment facility. By analyzing treatment at the CMA level (by city), the variances in septic use, industrial wastewater input and precipitation input are minimized.

Septic/Sewer

For wastewater treatment in Canada, the population can be divided into those using private (or communal) septic systems and those connected to municipal sewer systems, which either convey wastewater to centralized treatment facilities or, in some coastal regions, discharge to sea.

The population of each province identified as using either septic systems or connected to municipal sewage systems is based on Statistics Canada's *Households and the Environment Survey* (Statistics Canada no date (c)), a biennial survey of approximately 14 000 households that includes a question pertaining to wastewater destination (broadly, septic or municipal sewer system), presented in a usable form for this analysis from 2007 onward. The estimate of the population using septic systems prior to 2007 is held constant from the 2007 value. Intermediary years are linearly interpolated between survey years. The estimated population using septic systems in years successive to the last survey is held constant from that year.

Treatment Systems (Treatment Facilities, Plants, or Discharge Systems)

The population connected to each treatment facility or discharge system and details of the technology used by the facility/system are used to estimate the fraction of the provincial population using each treatment type. The population served by each wastewater treatment or discharge system is estimated on the basis of the population of the region (CMA or non-CMA region) in which that system is located, the percentage of that

population estimated to be connected to municipal sewer systems (discussed above), and the relative proportion of wastewater volume treated by that system compared to the regional total wastewater treated in a given year, as shown in Equation A3.6–23. For example, a facility that treats 30% of the total annual wastewater of a CMA in a given year is assumed to serve 30% of the population in that CMA that is connected to the municipal sewer systems in that year.

Equation A3.6–23

$$PopulationSystem_{i,j} = \frac{Volume\ Treated_{i,j}}{TotalVolumeTreated_{region,j}} * Population_{sewer,region,j}$$

$PopulationSystem_{i,j}$	=	the estimated population served by the municipal wastewater treatment system (facility or sewer discharge system), *i*, in year *j*
j	=	year
$region$	=	the census metropolitan area (or non-CMA portion of the province) in which system *i* is located in year *j* (Note: CMA boundaries change over time)
$VolumeTreated_{i,j}$	=	the volume of wastewater treated by, or discharged from, facility *i* in the year *j*
$TotalVolumeTreated_{region,j}$	=	the total volume of wastewater treated by all systems in the region in which system i is located.
$Population_{region,sewer,j}$	=	the population of the region in which system *i* is located in the year *j*

The fraction of the provincial population using each treatment technology is determined from the sum of the estimated population served by systems of each treatment technology, divided by the provincial population, as shown in Equation A3.6–24. The population served by septic systems was determined directly from analysis of the *Households and the Environment Survey* results, as discussed earlier.

Equation A3.6–24

$$PercentTech, t, j, prov = \frac{\sum_t PopSystem_{i,j,t}}{Population_{prov,j}}$$

$PercentTech, t, j, prov$	=	the percentage of the population using treatment technology *t*, in year *j*, in province *prov*.
$PopSystemi,j$	=	the estimated population served by the municipal wastewater treatment system (facility or sewer discharge system), *i*, in year *j*, having treatment technology *t*
$Population,prov,j$	=	the population of the province in year *j*

Volume Treated and Technology Used by Each Municipal Wastewater Treatment System

The volume of wastewater treated or discharged by each wastewater treatment system and the treatment technology employed by each treatment system are determined from data gathered from multiple sources with interpolation between known values.

The volume of wastewater discharged from most (>2500) wastewater treatment systems in Canada (assumed to be equal to the volume treated) and the treatment technology used are reported through the Effluent Regulatory Reporting Information System (ERRIS) under the WSER. Records from this source begin in 2013. To complete the time series and fill any data gaps, the reported volumes, treatment technology, and details of facility construction, upgrade and decommissioning were also gathered from provincial reports and inventories, annual reports of treatment facilities, municipal websites, engineering reports, scholarly articles, news reports, and other available sources. Notable data sources, in addition to data gathered through ERRIS, include the national inventory of municipal waterworks and wastewater systems in Canada, 1996 (Minister of Supply and Services Canada, 1987) the Government of Quebec (Québec 2003, 2005 and 2013), the Ontario Ministry of the Environment (1985), and the Newfoundland Water Resources Portal (accessed 2018).

Volumes of each wastewater treatment or discharge system for years without information are interpolated between years with known volumes. Alternatively, volumes were extrapolated by scaling the last known value according to population change. For example, if the population increased by 5%, the extrapolated volume is increased by 5%. Many small systems have no reported

volumes (791 small systems). This may be because the systems are below the mandatory reporting threshold of the *Wastewater System Effluent Regulations* of 100 m^3/day or because they closed before the regulations came into effect in 2014. These systems are given a token treatment volume of 100 m^3/day (which corresponds to populations of approximately 100 to 300 people). Even with token volumes assigned, these 'small' systems represent a negligible contribution to the overall volume of wastewater treated in Canada.

For systems with more than one concurrent treatment type (i.e., both aerobic and facultative lagoon cells operating at the same time), the annual volume of wastewater treated (and thus the estimate of population served) is divided evenly between the treatment types. This is equivalent to assuming that each concurrent treatment type at a facility (or part of a treatment system) treats the same proportion of the wastewater. Accurately proportioning the volume of wastewater treated between concurrent processes is not yet available because of a lack of data.

Treatment technology is assumed to remain unchanged prior to the earliest known value and after the latest known value. When technology has changed between two records, indicating different technologies at different times, the intermediary years are assigned to the earlier technology (i.e. it is assumed that the first instance or record of the newer technology corresponds to the year of upgrade).

The estimated population served by each treatment type, by year and by province, is shown in Figure A3.6–3, nationally in Figure A3.6–4 and Table A3.6–20.

Table A3.6–20 **Percentage of Canadian Population Using Each Wastewater Treatment Technology**

Treatment Category	Year			
	1990	2000	2010	2018
Aerobic Lagoon	5.5	6.1	6.6	7.5
Anaerobic Lagoon	0.7	0.7	0.7	0.4
Centralized Aerobic—Primary	26.7	24.1	24.8	16.4
Centralized Aerobic—Secondary	38.9	46.8	45.4	54.3
Centralized Anaerobic	0.2	0.2	0.2	0.0
Facultative Lagoon	4.9	3.1	2.8	2.5
No Treatment	5.8	3.4	1.7	1.7
Other	0.0	0.0	0.0	0.2
Septic	15.8	14.5	16.0	15.3
Sequence Batch Reactor	0.4	0.4	1.0	1.5
Unknown	0.1	0.0	0.0	0.0
Unspecified Lagoon	1.0	0.6	0.6	0.1
Wetland	0.1	0.1	0.1	0.1

A3.6.4.1.2. N_2O Emissions from Municipal Wastewater Treatment/Discharge

Methodology

Nitrous oxide emissions are estimated using the IPCC 2006 Tier 1 method (IPCC 2006). Nitrous oxide (N_2O) is associated with the degradation of nitrogen components in wastewater, which is introduced from urea, nitrate and protein in human sewage as well as inputs from other household wastewater, including inputs from shower drains, sink drains, washing machines, etc. (IPCC 2006).

The N_2O emissions from municipal wastewater treatment facilities are estimated using the amount of nitrogen discharged to the aquatic environment, based on nitrogen introduced to the wastewater stream, and an emission factor of 0.005 kg N_2O-N / kg N_2O-N in wastewater, as shown in Equation A3.6–25.

Equation A3.6–25

$$N_2O = EF_{N_2O\text{-}N} \times N_{Effluent} \times 44/28$$

N_2O	=	N_2O emissions in the inventory year, kg N_2O/year
$EF_{N_2O\text{-}N}$	=	emission factor for N_2O emissions from discharged to wastewater, kg N_2O-N/kg N.
$N_{Effluent}$	=	nitrogen in the effluent discharged to aquatic environments, kg N/yr
$44/28$	=	stoichiometric factor to convert nitrogen to N_2O

The default IPCC emission factor for N_2O emissions from domestic wastewater nitrogen effluent, namely 0.005 kg N_2O-N/kg N (from a range of 0.0005 to 0.25), is used.

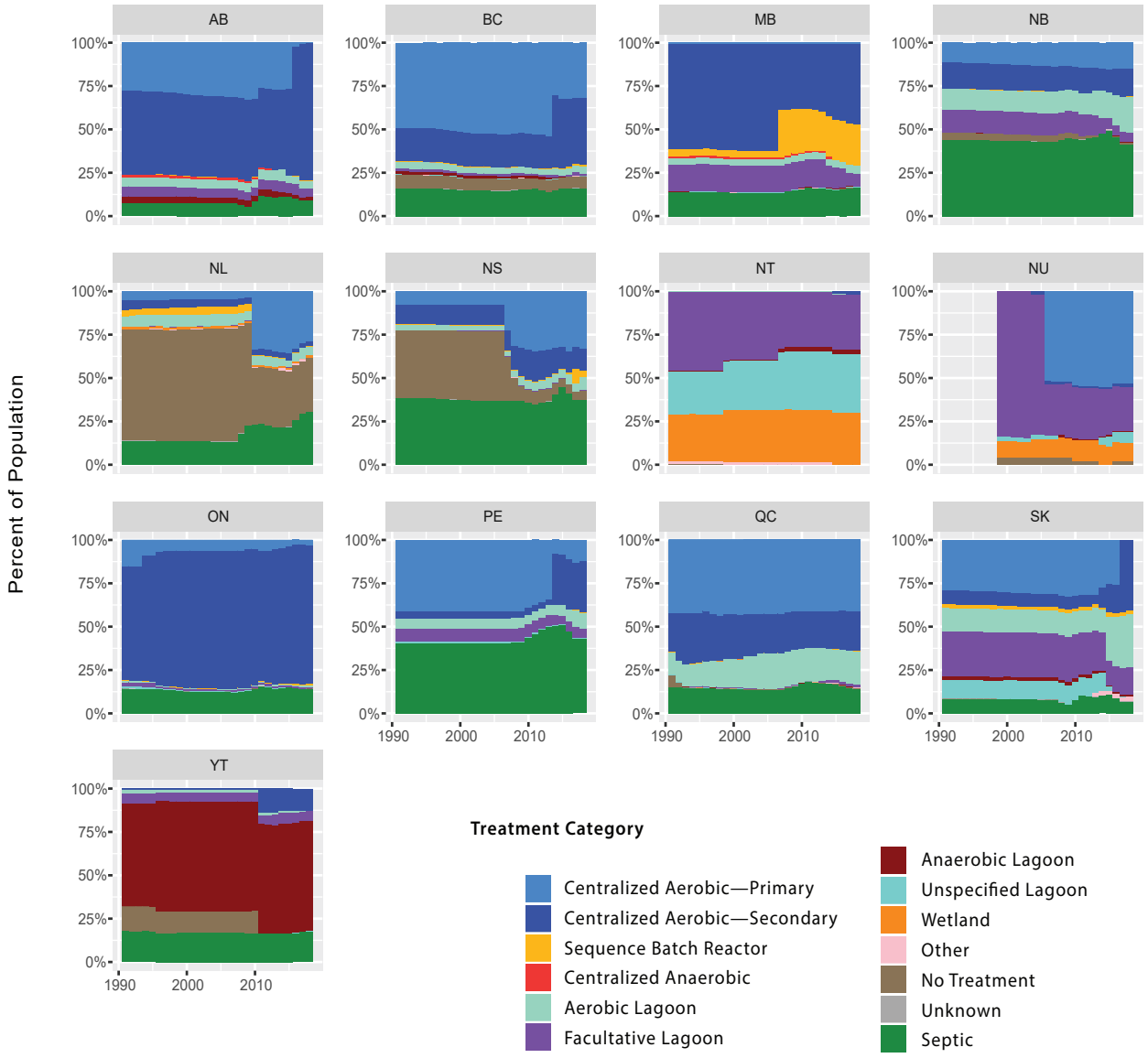
The amount of nitrogen introduced to wastewater sewage is determined on a per-capita basis, based on protein consumption and factors for industrial inputs and other household inputs, as shown in Equation A3.6–26.

Equation A3.6–26

$$N_{Effluent} = (Protein_{Consm} \times Population \times FRAC_{N\text{-}PR} \times F_{NON\text{-}CON} \times F_{IND\text{-}CON}) - N_{SLUDGE}$$

$N_{Effluent}$	=	nitrogen in the effluent discharged to aquatic environments, kg N/yr
$Protein_{Consum}$	=	annual per capita protein consumption, kg/capita per year, kg/person/yr
$Population$	=	the human population
$FRAC_{N\text{-}PR}$	=	fraction of nitrogen in protein (0.16 kg N/kg protein)
$F_{NON\text{-}CON}$	=	factor for non-consumed protein added to the wastewater
$F_{IND\text{-}COM}$	=	factor for industrial and commercial co-discharged protein into the sewer system
N_{SLUDGE}	=	nitrogen removed with sludge (taken as the IPCC 2006 default value of 0 because of limited data), kg N/yr

Figure A3.6–3 **Percentage of Population Using Each Treatment Technology, by Province**

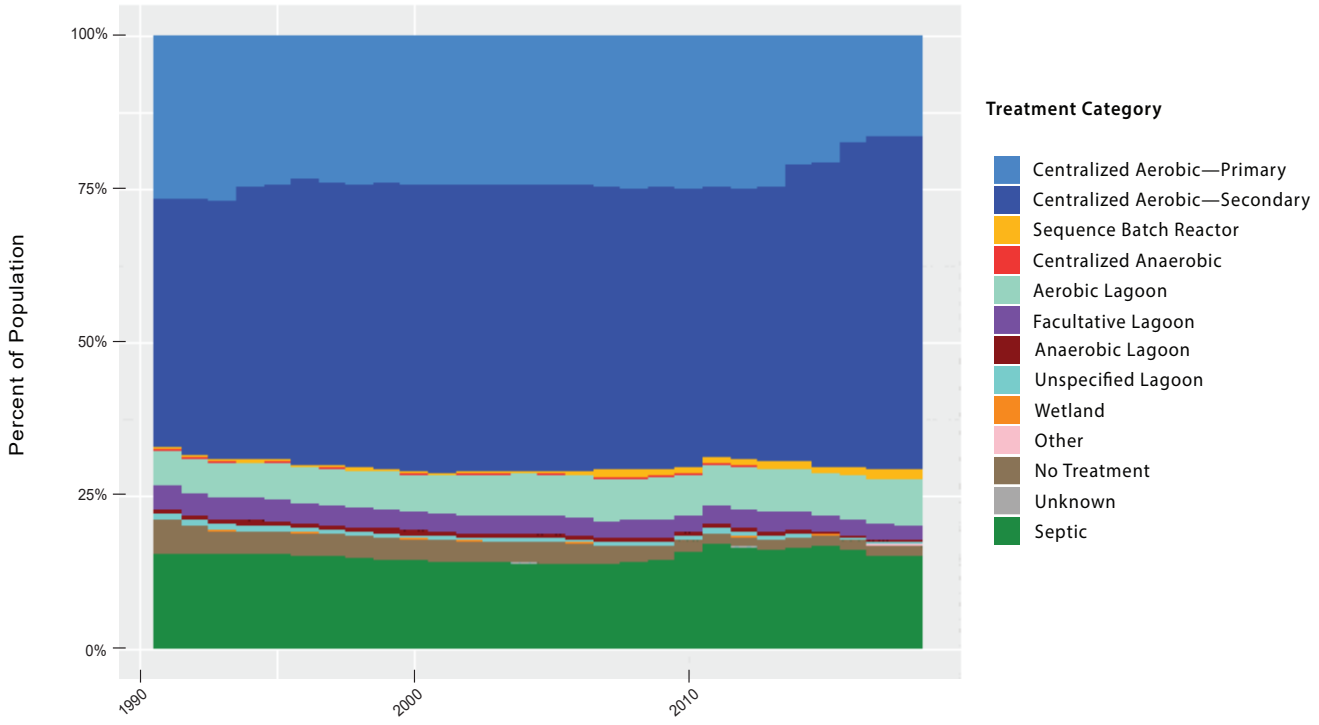


Protein consumption is determined from Canadian protein consumption data, which are obtained from the annual food statistics publication (Statistics Canada 2009). Statistics Canada data are provided for the years 1991, 1996 and 2001–2009 from the protein (nutrients) available adjusted for losses from the Canadian food supply, as shown in Table A3.6–21. It is assumed that protein is 16% nitrogen.

Protein consumed accounts for retail, household, and cooking and plate loss, which generally goes to municipal solid waste and composting streams, rather than wastewater. Use of protein available without adjusting for losses would result in an overestimate of wastewater N_2O emissions (AECOM 2012).

The factor for industrial and commercial co-discharged protein to the sewer system ($F_{IND-COM}$) is taken as the IPCC 2006 Guidelines default value of 1.25. The factor for non-consumed protein added to the wastewater ($F_{NON-CON}$), which represents nitrogen inputs from other household sources, such as shower drains, sink drains, washing machines etc., is taken as the IPCC default value of 1.1, for countries with no garbage disposal, interpreted as meaning

Figure A3.6–4 **Percentage of Population Using Each Treatment Technology, National**



no in-sink garbage disposal such as garburators (although garburators are used in some Canadian districts, most regions do not permit in-sink waste disposal).

Nitrogen removed from sludge is not estimated because of a lack of data on nitrogen concentration in sewage sludge. The IPCC 2006 Guidelines default value of 0 is used.

A3.6.4.1.3. CO_2 Emissions from Municipal Wastewater Treatment/Discharge

CO_2 emissions from wastewater are of biogenic origin. According to the IPCC 2006 Guidelines, CO_2 from the combustion or decay of short-lived biogenic material removed from where it was grown is reported as zero in the Waste sector. Therefore, these emissions are not considered for wastewater treatment.

A3.6.4.2. Industrial Wastewater Treatment—CH_4 & N_2O

Estimates for CH_4 emissions from industrial facilities with on-site wastewater treatment are handled facility by facility following a Tier 3 approach (IPCC 2006). Industrial on-site wastewater treatment systems can receive varying organics loads, depending on industry type, facility size and production levels. Methane recovery varies facility by facility. Therefore, industries with on-site anaerobic systems are estimated individually.

Emissions are not estimated for on-site anaerobic sludge digesters at industrial facilities. N_2O emissions from industrial wastewater treatment are not currently estimated.

A3.6.4.2.1. Data Sources and Methodology

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. Volumes of wastewater treated, COD or BOD_5 levels, and volumes of biogas flared, used and vented were collected through surveys of industrial facilities either known or likely to be employing anaerobic units to treat their effluent on-site, conducted every two years from 2008 to 2016. Industry sectors considered for the survey include 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

Table A3.6–21 **Canadian Protein Consumption**	
Year	Protein Consumption (g/capita per day)
1990	66.17
1991[a]	66.17
1992	66.65
1993	67.14
1994	67.62
1995	68.11
1996[a]	68.59
1997	69.46
1998	70.34
1999	71.21
2000	72.09
2001[a]	72.96
2002	73.42
2003	73.88
2004	74.34
2005[a]	71.12
2006[a]	71.03
2007[a]	71.79
2008[a]	70.25
2009[a]	69.85
2010	69.85
2011	69.85
2012	69.85
2013	69.85
2014	69.85
2015	69.85
2016	69.85
2017	69.85
2018	69.85

Notes:
Values for intermediary years without data from Statistics Canada are estimated by linear interpolation. Values extrapolated by holding the nearest value constant.

a. Statistics Canada (2009), Food Statistics, Catalogue Number 21-020-X: Total nutrients available adjusted for losses from the Canadian food supply.

Producers (CAPP), Rubber Association of Canada (RAC) and Forest Products Association of Canada (FPAC) to obtain a confirmation of the number, and identity, of industries with on-site anaerobic wastewater treatment systems 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),[38] fifteen in the food industry, two in the beverage industry and one in the chemicals 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: petroleum and coal products,[39] rubber products,[40] plastic products,[41] [42] and total textiles.[43]

The facilities surveyed provided volumes of biogas vented, flared and used for heat or energy purposes. The CH_4 mass of each biogas stream (used, flared, vented) was determined from the facility-reported biogas methane concentration (or a default value of 60% CH_4 if not reported) and the reported biogas density, pressure and temperature. Fugitive losses were estimated to be 0.5%. Methane emissions from the inefficiencies of the flare and utilization devices were also accounted for. The CH_4 destruction efficiencies were estimated to be 99.5% for an enclosed flare and 98% for a boiler (Climate Action Reserve 2009). The total emissions were determined from the sum of CH_4 in vented biogas, CH_4 in piping (fugitive) losses and the quantities of CH_4 circumventing combustion in the flare and boiler.

In the absence of survey-reported data for two facilities known to have anaerobic wastewater treatment systems, design parameters (process wastewater volumes and COD) were used from the engineering firm that supplied the units to these facilities to estimate methane production values. 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.

38 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.

39 CAPP. Personal communication (email dated October 24, 2006). Sonia Simard, Canadian Association of Petroleum Producers, to Paula Critchley, Waste Sector, Greenhouse Gas Division.

40 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.

41 $C_{PI}A$. 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.

42 $C_{PI}A$. 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.

43 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.

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. Section A4.4 contains a general discussion on the merits of using implied emission factors.

A4.1. Comparison of Reference Approach with Sectoral Approach

A comparison of results from the RA and the SA serve as a check of energy available versus that consumed by all sectors, and the corresponding CO_2 emissions from fossil fuel combustion. Checks of RA and SA results for all years from 1990 to 2018 are 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 an 11.7% or larger variation in energy. Excluding the non-combustion energy of certain feedstocks and fossil fuels ensures 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 -2.27 to 0.81%. Table 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 emissions associated with non-energy and feedstock use and allocates them to industrial processes and product use sectors. Comparison of the RA and SA emission estimates, as seen in Table A4–1, shows an overall -1.93% to 1.53% 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. Canada and the United States, use HHVs to report the energy content of fuels. Fuel supply and demand reported by industries to the various surveys that feed into the compilation of the Report on Energy Supply–Demand in Canada (RESD) (Statistics Canada 1990–) are in physical units. Fuel allocation for International bunker is presented in Chapter 3, section 3.2.2 International Bunker Fuels, and annex sections A3.2.2.1 Civil Aviation, and A3.2.2.2 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, all of which are reported separately in the RESD and all of which directly impact fuel availability. Apparent consumption is determined using this adjusted stock change number. Similarly, the stock change data for secondary fuels takes into consideration inter-product transfers, international bunkers, stock variation and other adjustments.

Once the apparent consumption is determined, country-specific energy conversion factors and carbon emission factors allow for the calculation of carbon content and emissions. Energy conversion factors come from the following sources: RESD (Statistics Canada 1990–), 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), and the 2006 IPCC Guidelines.

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	2003
Overall Energy Comparison														
Reference Approach (PJ)	7 188	7 029	7 235	7 302	7 545	7 714	8 083	8 284	8 333	8 697	8 982	8 898	9 043	9 268
Sectoral Approach (PJ)	6 388	6 214	6 456	6 491	6 719	6 882	7 106	7 258	7 347	7 652	8 005	7 903	8 016	8 236
Percent Difference without Adjustment (%)	12.5	13.1	12.1	12.5	12.3	12.1	13.8	14.1	13.4	13.7	12.2	12.6	12.8	12.5
Reference Approach with Non-Energy Use of Fossil Fuels and Feedstock Adjustment (PJ)	6 406	6 224	6 416	6 466	6 706	6 841	7 053	7 205	7 273	7 559	7 930	7 802	7 935	8 116
Percent Difference with Adjustment—100% x (RA-SA)/SA	0.28	0.16	-0.61	-0.38	-0.20	-0.59	-0.75	-0.74	-1.01	-1.21	-0.93	-1.28	-1.01	-1.46
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	159
Non-Energy Use of Liquid Fuels (PJ)	517	508	532	531	535	564	681	712	696	759	696	785	850	886
Non-Energy Use of Solid Fuels (PJ)	103	116	115	113	105	110	108	107	109	112	113	106	107	107
Overall Emission Comparison														
Reference Approach (Gg CO_2)	419 732	407 942	418 386	417 872	431 529	440 490	452 373	465 191	471 702	486 918	511 098	505 107	511 647	523 553
Sectoral Approach (Gg CO_2)	415 460	404 657	418 430	416 980	429 990	441012	454 295	467 309	474 179	490 798	513 715	508 344	512 277	526 901
Percentage Difference (%)	1.03	0.81	-0.01	0.21	0.36	-0.12	-0.42	-0.45	-0.52	-0.79	-0.51	-0.64	-0.12	-0.64
Liquid Fuels														
Reference Approach (Gg CO_2)	208 656	195 462	196 046	199 095	204 599	205 688	208 386	215 136	219 470	219 867	224 021	225 819	228 781	241 000
Sectoral Approach (Gg CO_2)	203 500	191 388	194 609	196 403	201 319	203 969	208 893	216 390	219 994	222 188	224 787	228 216	227 609	241 598
Percentage Difference (%)	2.53	2.13	0.74	1.37	1.63	0.84	-0.24	-0.58	-0.24	-1.04	-0.34	-1.05	0.51	-0.25
Solid Fuels														
Reference Approach (Gg CO_2)	87 307	90 621	92 759	84 378	88 517	89 620	92 255	99 900	104 640	105 084	114 196	113 622	110 205	108 309
Sectoral Approach (Gg CO_2)	87 009	90 261	92 689	84 924	89 346	90 769	92 754	99 911	105 744	105 923	115 548	113 826	111 514	110 523
Percentage Difference (%)	0.34	0.40	0.07	-0.64	-0.93	-1.27	-0.54	-0.01	-1.04	-0.79	-1.17	-0.18	-1.17	-2.00
Gaseous Fuels														
Reference Approach (Gg CO_2)	123 292	121 446	129 074	133 849	137 742	144 577	151 117	149 700	147 060	161 434	172 315	165 115	171 966	173 600
Sectoral Approach (Gg CO_2)	124 472	122 594	130 624	135 102	138 652	145 669	152 029	150 550	147 907	162 152	172 812	165 749	172 456	174 133
Percentage Difference (%)	-0.95	-0.94	-1.19	-0.93	-0.66	-0.75	-0.60	-0.56	-0.57	-0.44	-0.29	-0.38	-0.28	-0.31

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Overall Energy Comparison															
Reference Approach (PJ)	9 265	9 087	9 021	9 437	9 170	8 707	9 005	9 293	9 381	9 485	9 702	9 752	9 587	9 625	10 022
Sectoral Approach (PJ)	8 168	8 072	7 967	8 354	8 139	7 792	7 943	8 190	8 203	8 373	8 482	8 498	8 325	8 473	8 811
Percent Difference without Adjustment (%)	13.4	12.6	13.2	13.0	12.7	11.7	13.4	13.5	14.4	13.3	14.4	14.8	15.2	13.6	13.7
Reference Approach with Non-Energy Use of Fossil Fuels and Feedstock Adjustment (PJ)	8 023	7 970	7 817	8 231	8 039	7 619	7 786	8 004	8 022	8 240	8 551	8 526	8 323	8 467	8 827
Percent Difference with Adjustment—100% x (RA-SA)/SA	-1.78	-1.26	-1.89	-1.47	-1.23	-2.22	-1.98	-2.27	-2.21	-1.59	0.81	0.33	-0.02	-0.07	0.18
Adjusted Non-Energy Fossil Fuels and Feedstocks															
Non-Energy Use of Gaseous Fuels (PJ)	171	158	162	161	128	142	142	162	165	150	126	154	149	146	154
Non-Energy Use of Liquid Fuels (PJ)	961	856	930	935	901	868	991	1 021	1 093	1 007	933	997	1 032	926	954
Non-Energy Use of Solid Fuels (PJ)	111	102	112	110	101	77	86	106	100	88	92	75	83	85	88
Overall Emission Comparison															
Reference Approach (Gg CO_2)	515 556	513 426	502 032	528 418	513 612	481 624	491 473	496 986	495 961	507 072	523 590	522 173	507 649	516 164	529 060
Sectoral Approach (Gg CO_2)	523 144	517 287	509 074	533 116	516 674	490 036	499 032	506 779	505 154	513 597	515 696	516 676	505 734	514 909	526 977
Percentage Difference (%)	-1.45	-0.75	-1.38	-0.88	-0.59	-1.72	-1.51	-1.93	-1.82	-1.27	1.53	1.06	0.38	0.24	0.40
Liquid Fuels															
Reference Approach (Gg CO_2)	244 261	244 258	238 052	247 617	240 431	232 695	236 388	235 023	239 045	238 375	250 598	248 033	242 788	247 248	256 422
Sectoral Approach (Gg CO_2)	249 627	246 125	243 190	250 407	242 040	237 904	242 465	243 315	244 082	244 568	240 777	242 548	240 384	244 865	253 535
Percentage Difference (%)	-2.15	-0.76	-2.11	-1.11	-0.66	-2.19	-2.51	-3.41	-2.06	-2.53	4.08	2.26	1.00	0.97	1.14
Solid Fuels															
Reference Approach (Gg CO_2)	101 156	102 790	99 277	104 593	99 282	81 101	84 629	74 649	68 858	69 646	64 143	67 901	61 712	61 362	48 609
Sectoral Approach (Gg CO_2)	102 787	104 219	100 545	105 628	99 784	83 472	85 174	75 172	69 578	69 127	65 337	67 110	61 301	61 580	48 525
Percentage Difference (%)	-1.59	-1.37	-1.26	-0.98	-0.50	-2.84	-0.64	-0.70	-1.03	0.75	-1.83	1.18	0.67	-0.35	0.17
Gaseous Fuels															
Reference Approach (Gg CO_2)	169 451	165 807	164 147	175 546	173 237	167 251	169 871	186 728	187 374	198 421	208 294	205 592	202 519	206 947	223 420
Sectoral Approach (Gg CO_2)	170 040	166 370	164 780	176 417	174 186	168 082	170 806	187 705	190 807	199 272	209 025	206 371	203 419	207 857	224 308
Percentage Difference (%)	-0.35	-0.34	-0.38	-0.49	-0.54	-0.49	-0.55	-0.52	-1.80	-0.43	-0.35	-0.38	-0.44	-0.44	-0.40

Table A4–2 presents the applied emission factor, energy conversion factor and oxidation value in the RA. The RESD supplies the energy conversion factors, with the exceptions of bituminous coal, lignite, crude oil, heavy fuel oil, LPGs, natural gas, NGLs, petroleum coke and still gas, where weighted factors, calculated yearly, account for the quantity and variation of energy content at the point of consumption, such as commercial usage or self-generated usage. For example, in provinces with natural gas production, there are two emission factors for natural gas: marketable natural gas, sold to consumers, and non-marketable natural gas, combusted by the producers of natural gas. The composition of non-marketable natural gas includes more complex hydrocarbons unlike marketable natural gas which, typically, contains over 95% CH_4.

A4.3. National Energy Balance

This section provides a general background on the national energy balance and its data quality framework. In Canada, the Energy and Environment Statistics Division (EESD) of Statistics Canada is responsible for the collection, compilation and dissemination of energy data under the authority of the *Statistics Act*.[1] The RESD is the primary source of activity data used to estimate GHG emissions for the Energy sector and is available on Statistics Canada's website.[2] Emission estimates for the Industrial Processes and Product Use sector also use the non-energy and feedstock information from the RESD as a source of activity data. The RESD is an accounting of energy forms in Canada from import and export activities through to production, stock change 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 Canadian Energy Regulator [CER]), provincial energy departments and agencies (such as the Alberta Energy Regulator [AER] and the Alberta Utilities Commissions [AUC]), and the Canadian Energy and Emissions Data Centre (CEEDC). Refer to Figure A4–2, RESD Data Input, for a sample of the energy and fossil fuel data input. The oil and gas information as provided by the AER is understood to be 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)**

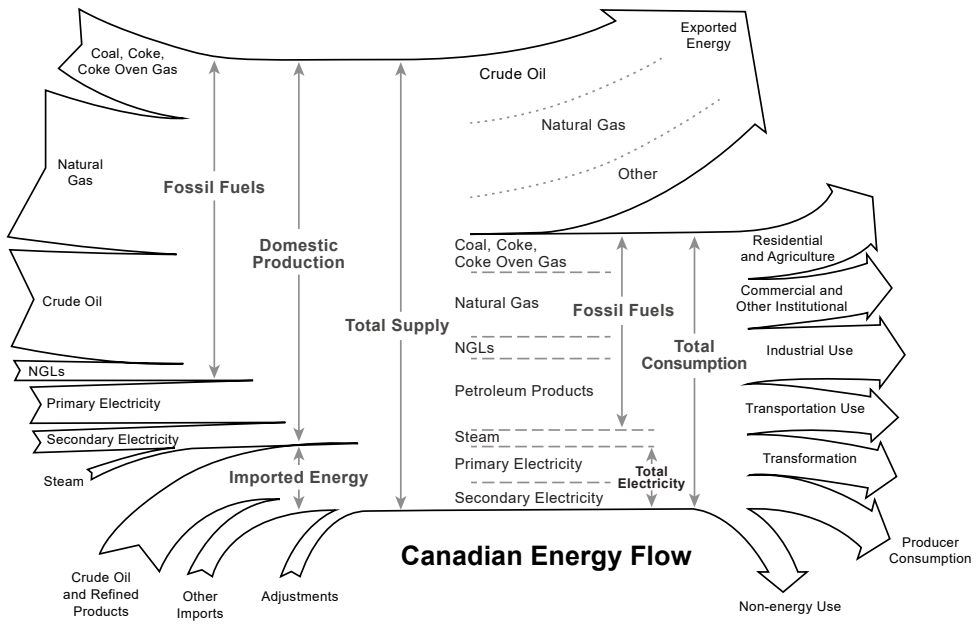


Table A4–2 **Reference Approach Energy Conversion and Emission Factors for Canada**

Fuel Types			Energy Conversion Factor, GCV			Carbon Emission Factor—2018 Value (t C/TJ GCV)	Reference	Oxidation Factors	Comments
			2018 Value	Unit	Reference				
Liquid	Primary Fuels	Crude Oil	39.4	TJ/ML	See Comments	18.9	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	25.34	TJ/ML	–	16.33	–	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	38.35	TJ/ML	4	19.07	2	1.0	Use of diesel fuel oil.
		Gasoline	33.45	TJ/ML	4	18.81	2	1.0	
		Jet Kerosene	37.4	TJ/ML	4	18.67	2	1.0	Use of aviation turbo fuel.
		Liquefied Petroleum Gases (LPG)	27.1	TJ/ML	4	16.58	2	1.0	Country-specific weighted factors for 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	44.38	TJ/ML	4	22.62	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	20.27	2	1.0	Use of heavy fuel oil.
		Shale Oil	NA	–	–	NA	–	–	
		Still Gas	39.95	TJ/ML	4	14.74	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	19.24	3	1.0	
		Other Product Feedstocks	39.82	TJ/ML	4	19.84	3	1.0	
Solid	Primary Fuels	Anthracite	27.7	TJ/kt	4	23.45	3	0.988	
		Other Bituminous Coal	28.37	TJ/kt	4	22.04	6	0.995	Use of Canadian bituminous coal
		Sub-bituminous Coal	18.48	TJ/kt	4	26.00	6	0.994	
		Lignite	16.29	TJ/kt	4	24.39	5, 6	0.996	
		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	23.54	5, 6	0.989	
Gaseous	Primary Fuels	Natural Gas	39.86	TJ/GL	4	13.51	2	1.0	Country-specific weighted emission factor based on proportion of marketable and non-marketable natural gas.
Biomass		Municipal Solid Waste	–	–	1	24.47	1	1.0	1) Consists of biomass combustion, for energy purposes, at landfills.
		Solid Biomass	17.89	TJ/kt	4	24.59	7	1.0	1) Consists of industrial and residential biomass consumption.
		Liquid Biomass	16.43	TJ/kt	4	18.82	3, 8	1.0	1) Consists of spent pulping liquor, ethanol and biodiesel.
		Gas Biomass	36.35	TJ/GI	1	13.54	1	1.0	1) Consists of methane from landfill gas.

Notes:

References: (1) IPCC (2006); (2) McCann (2000); (3) Jaques (1992); (4) Statistics Canada, #57-003 (2015 data); (5) Environment Canada, 2016; (6) Environment Canada, 2019; (7) US EPA (2003); (8) ICFPA/NCASI (2019) .

NA = Not applicable; BKB = Charcoal briquettes; NGL = natural gas liquids; LPG = liquified petroleum gas.

Various federal departments use the RESD for energy efficiency programs, policy development, energy and emission forecasting, and reporting to the UNFCCC. As such, EESD'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] EESD 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.

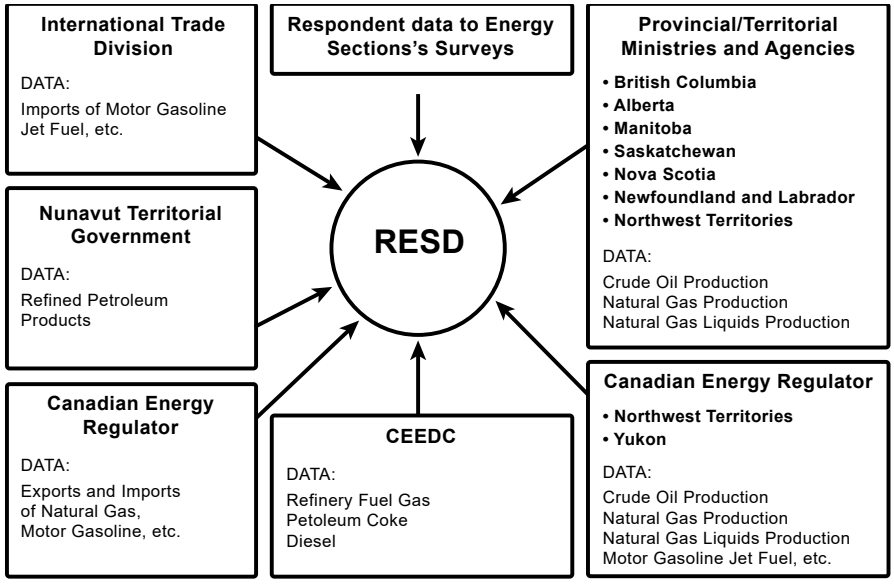
The following quality criteria are essential to the development of the RESD as set out by Statistics Canada: relevance, accuracy and reliability, timeliness and punctuality, accessibility and clarity, coherence and comparability, and interpretability and metadata.

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 quantities of crude oil reported by the producer are compared to reported receipts from pipeline companies, and the volume data reported by pipelines is verified against refinery receipts. EESD 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 (SSDRPP) collects data on sale volumes for use in reallocating volumes of heavy fuel oil, light fuel oil, diesel, biodiesel blended diesel fuel, and ethanol blended gasoline to the appropriate consuming sectors. The SSDRPP survey was necessary due to the deregulation of allowable sales of these products from only primary producers (refineries) to include secondary resellers/distributers. Prior to this improvement, fuel volumes reported in the commercial sector incorrectly included all sales by refineries to secondary distributors. 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 from 2009 onward.

Also, as part of EESD's quality framework, an annual "work-in-progress" review has been established with Environment and Climate Change 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. CEEDC also participates in the review of refinery data and the industrial energy statistics.

3 Statistics Canada. Quality Assurance Framework. http://www.statcan.gc.ca/pub/12-539-x/manage-gestion/4058322-eng.htm.

Figure A4–2 **Fossil Fuel and Energy Data Input into the RESD**



A4.4. CRF Implied Emission Factors

Implied emission factors (IEFs) are generated by the CRF reporting software and are used by UNFCCC expert reviewers as an initial check for possible outliers. There is merit in the use of IEF checks, especially for a direct comparison of the same commercial fuel between countries, since each of these fuels is produced to a standardized specification for quality and composition, with an accepted range of carbon content and heating value. Commercial fuels like motor gasoline, diesel and light fuel oil have similar specifications globally, resulting in IEFs that differ by only a few percentage points. However, the percentage difference for fuels like non-marketable (raw) natural gas, crude oil or coal (i.e. bituminous, sub-bituminous, etc.) can vary greatly due differences in local geology, deposits or fuel categorizations (the latter being especially true in the case of coal).

These checks for IEF outliers are less reliable when fuels are grouped as solid, liquid, gaseous and biomass in CRF Tables 1A1 to Table 1A4. For countries consuming both commercial and non-commercial fuels, and particularly for energy producing nations where non-commercial/non-marketable fuels are readily available and consumed in significant quantities, IEF checks can result in more outliers for certain sectors and fuel groupings (i.e. gaseous and liquid fuels). Generally, countries with large primary energy production (crude oil, synthetic oil, natural gas, etc.) will consume a greater proportion of non-commercial fuels compared to countries with little or no primary energy production and who mostly consume commercial fuels. For these situations, recognizing the impact on IEFs of national circumstances by either increasing its range or conducting IEF checks on a fuel by fuel basis would provide more relevant quality checks.

In Canada's case, shifting the focus of IEF checks from groups of fuels to individual fuels allows a better understanding of their influence on the generation of outliers.

- It allows for an appreciation of the relative proportion of commercial and non-commercial fuel consumed within each fuel grouping.
- It demonstrates how the mix of commercial and non-commercial fuels with wide ranging carbon and energy densities affects the IEF for each fuel.

For example, Canada's implied emission factors can be relatively high for liquid fuels due to the combustion of significant quantities of crude oil, petroleum coke and still gas. In the case of gaseous fuels IEFs can also be high, a result of certain energy producers consuming large quantities of non-marketable natural gas.

Information presented in Table A4–2, illustrates the range of carbon content between each group of fuels, and where even within the group of commercial secondary liquid fuels, the carbon conversion factors range from 14.74 to 22.62 t C/TJ. For CRF categories consuming a greater portion of still gas or petroleum coke (refinery and upgrader fuels) relative to commercial grade refined petroleum products, the overall IEF for liquid fuels will appear to be an outlier since it will be higher than international averages.

As Canada is a country producing large quantities of fossil fuels, the following categories will most likely generate IEF outliers; 1A1b Petroleum Refining, 1A1ci Manufacture of Solid Fuels, and 1A1cii Oil and Gas Extraction. As mentioned, IEF checks of these categories should be considered on a fuel by fuel basis or by assessing Parties that have similar industry makeup; this may generate more comparable results and analysis.

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), for the latest year of the Common Reporting Format (CRF) tables available online here:

https://unfccc.int/process-and-meetings/transparency-and-reporting/reporting-and-review-under-the-convention/greenhouse-gas-inventories-annex-i-parties/national-inventory-submissions-2020

Table A5–1 **Summary of GHG Sources and Sinks Not Estimated (NE)**

GHG	Sector	Source/sink category	Explanation
$C_{10}F_{18}$	Industrial Processes and Product Use	2.G Other Product Manufacture and Use / 2.G.2 SF_6 and PFCs from Other Product Use	An internet search was conducted and found that the applications for CRF Category 2.G.2 seemed to not exist at a detectable level
C_2F_6	Industrial Processes and Product Use	2.G Other Product Manufacture and Use / 2.G.2 SF_6 and PFCs from Other Product Use	An internet search was conducted and found that the applications for CRF Category 2.G.2 seemed to not exist at a detectable level
C_3F_8	Industrial Processes and Product Use	2.G Other Product Manufacture and Use / 2.G.2 SF_6 and PFCs from Other Product Use	An internet search was conducted and found that the applications for CRF Category 2.G.2 seemed to not exist at a detectable level
C_4F_{10}	Industrial Processes and Product Use	2.G Other Product Manufacture and Use / 2.G.2 SF_6 and PFCs from Other Product Use	An internet search was conducted and found that the applications for CRF Category 2.G.2 seemed to not exist at a detectable level
C_5F_{12}	Industrial Processes and Product Use	2.G Other Product Manufacture and Use / 2.G.2 SF_6 and PFCs from Other Product Use	An internet search was conducted and found that the applications for CRF Category 2.G.2 seemed to not exist at a detectable level
C_6F_{14}	Industrial Processes and Product Use	2.G Other Product Manufacture and Use / 2.G.2 SF_6 and PFCs from Other Product Use	An internet search was conducted and found that the applications for CRF Category 2.G.2 seemed to not exist at a detectable level
CF_4	Industrial Processes and Product Use	2.G Other Product Manufacture and Use / 2.G.2 SF_6 and PFCs from Other Product Use	An internet search was conducted and found that the applications for CRF Category 2.G.2 seemed to not exist at a detectable level
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	The emissions from briquette manufacturing, as a source, has less than 0.05% of total emissions and does not exceed 500 kt CO_2 eq.
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.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.

Table A5–1 **Summary of GHG Sources and Sinks Not Estimated (NE)** (cont'd)

GHG	Sector	Source/sink category	Explanation
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	No suitable activity data for this estimation. Efforts are underway to develop improved LULUCF AD, which could potentially aid in these estimates.
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	No suitable activity data for this estimation. Efforts are underway to develop improved LULUCF AD, which could potentially aid in these estimates.
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)	Currently there are no estimates reported under Other wetlands
CH_4	LULUCF	4.E Settlements / 4.E.1 Settlements Remaining Settlements	Currently neither suitable activity data or methodology exists for estimation
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.
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.
CH_4	Waste	5.D Wastewater Treatment and Discharge / 5.D.1 Domestic Wastewater	The methane emissions presented here are from facultative and anaerobic lagoons and septic tanks. No gas collection systems are used for these sources. Emissions from anaerobic digesters are not yet estimated. It is assumed that these would be minimal since both the utilization and flaring units would be of high destruction efficiency.
CO_2	Agriculture	3. Agriculture	CO_2 emissions from indirect sources of non-agricultural origin are not estimated.
CO_2	Energy	1.B Fugitive Emissions from Fuels / 1.B.1 Solid Fuels / 1.B.1.b Solid Fuel Transformation	The emissions from briquette manufacturing, as a source, has less than 0.05% of total emissions and does not exceed 500 kt CO_2 eq.
CO_2	Industrial Processes and Product Use	2.A Mineral Industry / 2.A.4 Other Process Uses of Carbonates / 2.A.4.a Ceramics	Emission considered insignificant as defined in paragraph 37(b) of the UNFCCC Annex I inventory reporting guidelines
CO_2	Industrial Processes and Product Use	2.B Chemical Industry / 2.B.6 Titanium Dioxide Production	Based on a study conducted in 2010, CO_2 emissions from this facility's chloride process is very small, less than 0.01% of the national level, and is therefore considered insignificant (level for insignificance is below 0.05% of national total and below 50
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) / Other (please specify) / Other and Undifferentiated	Only aggregated CO_2 emissions are included under 2.D.3.
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.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.D Wetlands / 4(II) Emissions and removals from drainage and rewetting and other management of organic and mineral soils / Other Wetlands (please specify)	Currently there are no estimates reported under Other wetlands.

Table A5–1 **Summary of GHG Sources and Sinks Not Estimated (NE)** (cont'd)

GHG	Sector	Source/sink category	Explanation
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
CO_2	Waste	5.F Memo Items / 5.F.1 Long-term Storage of C in Waste Disposal Sites	Work is ongoing to incorporate long term storage of C in waste disposal sites
CO_2	Waste	5.F Memo Items / 5.F.2 Annual Change in Total Long-term C Storage	Work is ongoing to incorporate long term storage of C in waste disposal sites
CO_2	Waste	5.F Memo Items / 5.F.3 Annual Change in Total Long-term C Storage in HWP Waste	Work is ongoing to incorporate long term storage of C in waste disposal sites
N_2O	Agriculture	3. Agriculture	N_2O emissions from indirect sources of non-agricultural origin are not estimated.
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	Energy	1.B Fugitive Emissions from Fuels / 1.B.1 Solid Fuels / 1.B.1.b Solid Fuel Transformation	The emissions from briquette manufacturing, as a source, has less than 0.05% of total emissions and does not exceed 500 kt CO_2 eq.
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
N_2O	LULUCF	4. 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	Direct N_2O emissions associated with loss of soil organic matter in FLFL are considered to be insignificant in accordance with para 37(b) of the UNFCCC reporting guidelines, see more details in Chapter 6 of NIR.
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	Direct N_2O emissions associated with loss of soil organic matter in L-FL are considered to be insignificant in accordance with para 37(b) of the UNFCCC reporting guidelines, see more details in Chapter 6 of NIR.
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)	Currently there are no estimates reported under Other wetlands.
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	Management-induced changes in soil organic carbon are not available because of limited management activity data over the entire time series
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	Management-induced changes in soil organic carbon are not available because of limited management activity data over the entire time series
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	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
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 N_2O emissions from industrial wastewater where there is primary discharge.
PFCs	Industrial Processes and Product Use	2.G Other Product Manufacture and Use / 2.G.2 SF_6 and PFCs from Other Product Use	An internet search was conducted and found that the applications for CRF Category 2.G.2 seemed to not exist at a detectable level
SF_6	Industrial Processes and Product Use	2.G Other Product Manufacture and Use / 2.G.2 SF_6 and PFCs from Other Product Use	An internet search was conducted and found that the applications for CRF Category 2.G.2 seemed to not exist at a detectable level
Unspecified mix of PFCs	Industrial Processes and Product Use	2.G Other Product Manufacture and Use / 2.G.2 SF_6 and PFCs from Other Product Use	An internet search was conducted and found that the applications for CRF Category 2.G.2 seemed to not exist at a detectable level
c-C_3F_6	Industrial Processes and Product Use	2.G Other Product Manufacture and Use / 2.G.2 SF_6 and PFCs from Other Product Use	An internet search was conducted and found that the applications for CRF Category 2.G.2 seemed to not exist at a detectable level
c-C_4F_8	Industrial Processes and Product Use	2.G Other Product Manufacture and Use / 2.G.2 SF_6 and PFCs from Other Product Use	An internet search was conducted and found that the applications for CRF Category 2.G.2 seemed to not exist at a detectable level

Note:
"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)**

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.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	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 / Liquid Fuels	1.A.2.e Food Processing, Beverages and Tobacco	1.A.2.g.viii Other	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	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 / 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	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 / Other Liquid Fuels / Propane	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 Propane and Natural Gas Vehicles
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 Propane and Natural Gas Vehicles
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 / Other Liquid Fuels / Propane	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 Propane and Natural Gas Vehicles
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 Propane and Natural Gas Vehicles
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 / Other Liquid Fuels / Propane	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 Propane and Natural Gas Vehicles
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 Propane and Natural Gas Vehicles
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 / Other Liquid Fuels / Propane	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 Propane and Natural Gas Vehicles

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.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 Propane and Natural Gas Vehicles
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.1.ii Underground Mines—Mining Activities	1.B.1.a.1.i 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.2.ii Surface Mines—Post-Mining Activities	1.B.1.a.2.i 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 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.3 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_2O Emissions	2.B.8.f Carbon Black	2.B.8.f Carbon Black	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) / Carbon Black Production—N_2O 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_2O Emissions	2.B.8.b Ethylene	2.B.8.b Ethylene	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_2O Emissions	2.B.8.a Methanol	2.B.8.a Methanol	CRF does not allow the input of N_2O 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) / Other (please specify) / Other and Undifferentiated	2.B.8	2.B.8	Only aggregated CO_2 emissions are included under 2.D.3.
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	2.D.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 do 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

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.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 do 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 / Controlled Burning / Organic Soils	Organic Soils	Mineral Soils	AD do 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 / Wildfires / Organic Soils	Organic Soils	Mineral Soils	AD do not allow the disaggregation of activity into organic and mineral soils
CH_4	4.D Wetlands / 4.D.2 Land Converted to Wetlands / 4(V) Biomass Burning / Controlled Burning / Organic Soils	Organic soils	Mineral Soils	AD do 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	AD do not allow the disaggregation of activity into organic and mineral soils
CH_4	4.E Settlements / 4.E.2 Land Converted to Settlements	Table 4, if possible to differentiate	Table 4(V)	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.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	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	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	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 / 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	Only aggregated 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 / Other Liquid Fuels / Propane	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 Propane and Natural Gas Vehicles
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 Propane and Natural Gas Vehicles
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 / Other Liquid Fuels / Propane	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 Propane and Natural Gas Vehicles

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.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 Propane and Natural Gas Vehicles
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 / Other Liquid Fuels / Propane	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 Propane and Natural Gas Vehicles
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 Propane and Natural Gas Vehicles
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 / Other Liquid Fuels / Propane	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 Propane and Natural Gas Vehicles
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 Propane and Natural Gas Vehicles
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.C CO_2 Transport and Storage / Injection and Storage / Injection	1.C.2.a CO_2 Transport and Storage / Injection and Storage / Injection	1.B.2.c.1 Venting	Fugitive emissions from above-ground operations that uses captured CO_2 for enhanced oil and gas recovery operations are reported under 1.B.2.a.2 Oil Production.
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_2O Emissions	2.B.8.f Carbon Black	2.B.8.f Carbon Black	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) / Carbon Black Production—N_2O 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_2O Emissions	2.B.8.b Ethylene	2.B.8.b Ethylene	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) / Methanol Production—N_2O Emissions	2.B.8.a Methanol	2.B.8.a Methanol	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.8 Petrochemical and Carbon Black Production / 2.B.8.f Carbon Black	2.B.8 Petrochemical and Carbon Black Production / 2.B.8.f Carbon Black	2.D.3 Other and Undifferentiated	Refer to 2.D.3 Other and Undifferentiated. Disaggregated data currently not 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	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 Rep
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 is 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 is currently not available.
CO_2	2.D Non-energy Products from Fuels and Solvent Use / 2.D.3 Other (please specify) / Solvent use	2.D.3 Other and Undifferentiated.	2.D.3 Other and Undifferentiated	Disaggregated data are 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 do 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 the Agriculture Sector	AD do 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 do 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	Organic Soils	Mineral Soils	AD do 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	AD do not allow the disaggregation of activity into organic and mineral soils
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.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	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
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	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 / Solid Fuels	1.A.2.e Food Processing, Beverages and Tobacco	1.A.2.g.viii Other	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	Only aggregated activity 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 / Other Liquid Fuels / Propane	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 Propane and Natural Gas Vehicles
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 Propane and Natural Gas Vehicles
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 / Other Liquid Fuels / Propane	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 Propane and Natural Gas Vehicles
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 Propane and Natural Gas Vehicles
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 / Other Liquid Fuels / Propane	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 Propane and Natural Gas Vehicles
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 Propane and Natural Gas Vehicles
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 / Other Liquid Fuels / Propane	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 Propane and Natural Gas Vehicles
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 Propane and Natural Gas Vehicles

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.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. Emissions of N_2O are reported under section 2.B.10 other (chemical industry), specifically in relation to emissions form methanol, carbon black and ethylene production.
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.8	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	2.D.3 Other and undifferentiated	2.D.3 Other and undifferentiated	Disaggregated data are unavailable.
N_2O	4(IV) Indirect N_2O Emissions from Managed Soils / Atmospheric Deposition	Agriculture for agricultural soils, under LULUCF for non-agricultural soils	Agriculture for agricultural soils, NE for non-agricultural soils	N_2O emissions from volatized N of Managed Soils are reported in the Agriculture Sector. Indirect N_2O emissions from Leaching and Runoff of N from fertilizers and other N sources are reported in the Agriculture Sector. N_2O emissions associated with nitrogen leaching and runoff of N mineralised in mineral soils as a result of loss of soil organic carbon in FLFL are considered to be insignificant
N_2O	4(IV) Indirect N_2O Emissions from Managed Soils / Nitrogen Leaching and Run-off	Agriculture for agricultural soils, under LULUCF for non-agricultural soils	Agriculture for agricultural soils, NE for non-agricultural soils	N_2O emissions from volatized N of Managed Soils are reported in the Agriculture Sector. Indirect N_2O emissions from Leaching and Runoff of N from fertilizers and other N sources are reported in the Agriculture Sector. N_2O emissions associated with nitrogen leaching and runoff of N mineralised in mineral soils as a result of loss of soil organic carbon in FLFL are considered to be insignificant
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	If data are available, under the specific LULUCF category, where emissions actually occur	Reported in the Agriculture Sector	AD do 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 do 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
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

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 / 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
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 do 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	Organic Soils	Mineral Soils	AD do 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 / Wildfires / Organic Soils	Organic Soils	Mineral Soils	AD do not allow the disaggregation of activity into organic and 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)	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.2.1 Forest land converted to wetlands	Table 4(III)	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)	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 do 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 do 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	If data are available, under the specific LULUCF category, where emissions actually occur	Reported in Agriculture Sector	AD do 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	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 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 do 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 category
SF_6	2.G Other Product Manufacture and Use / 2.G.1 Electrical Equipment / SF_6	2.G.1 dis-aggregated From stocks and From disposal	2.G.1 Electrical Equipment / SF_6 (From stocks)	Dis-aggregated From Stocks and From disposal data is not available and the total is reported as "From stocks"

Note:
"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 used to estimate greenhouse gas (GHG) emissions in Canada's official national GHG inventory. Additional details on sector-specific methodologies for the use of these factors are presented in Annex 3[1].

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 A6.1–1) 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 (see Table A6.1–3) 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 (CH_4)

Emissions of CH_4 from fuel combustion are technology-dependent. Sectoral emission factors (Table A6.1–2 and Table A6.1–3) 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 A6.1–2 and Table A6.1–3) 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 A6.1–1 **CO_2 Emission Factors for Natural Gas**

Province	Emission Factor[a] (g/m^3)	
	Marketable[b]	Non-marketable[c]
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 (prior to 2012)[d]	2 466	2 466
Northwest Territories (since 2012)[d]	1 901	2 466

Notes:
NO Not occurring

a. McCann (2000)
b. The term "marketable" applies to fuel consumed by the Electric Utilities, Manufacturing
c. Industries, Residential/Commercial and Transport subsectors.
d. The term "non-marketable" applies to raw gas consumption, mainly by natural gas producers.
e. Prior to 2012, natural gas consumption was locally-produced non-marketable natural gas. Since 2012, marketable natural gas has been imported from outside the territory.

1 See *National Inventory Report: Greenhouse Gas Sources and Sinks in Canada* online: http://www.publications.gc.ca/pub?id=9.506002&sl=0

Table A6.1–2 **CH_4 and N_2O Emission Factors for Natural Gas**

Source	Emission Factor (g/m^3)[a]	
	CH_4	N_2O
Electric Utilities	0.490	0.049
Industrial	0.037	0.033
Producer Consumption (Non-marketable)	6.4[b]	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:
a. SGA Energy (2000)
b. Adapted from U.S. EPA (1996b) and CAPP (1999)

Table A6.1–3 **Emission Factors for Natural Gas Liquids**

Source	Emission Factor (g/L)		
	CO_2	CH_4	N_2O
Propane			
Residential	1 515[a]	0.027[b]	0.108[b]
All Other Uses	1 515[a]	0.024[b]	0.108[b]
Ethane	986[a]	0.024[b]	0.108[b]
Butane	1 747[a]	0.024[b]	0.108[b]

Notes:
a. McCann (2000)
b. 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 density (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 A6.1–5) 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[2] (CIEEDAC 2003). 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 A6.1–5) from refining operations and upgrading facilities were also derived from data provided by industry1 and reported by CIEEDAC (2003).

A6.1.2.2. CH_4

Emissions of CH_4 from fuel combustion are technology-dependent. Emission factors were developed (Table A6.1–4) 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 A6.1–4) 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 A6.1–7) 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).

A6.1.2.3. N_2O

Emissions of N_2O from fuel combustion are technology-dependent. Emission factors for RPPs, with the exception of petroleum coke, have been developed (Table A6.1–4) 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).

Emission factors for petroleum coke (Table A6.1–6) were based on 2006 IPCC default emission factors and were calculated on an annual basis using energy conversion factors provided by Statistics Canada (2014).

2 Griffin, B. 2016. Personal communication (email from Griffin, B., CIEEDAC to Tracey, K., Program Engineer, PIRD dated Nov 18, 2016). Canadian Industrial Energy End-Use Data Analysis Centre (CIEEDAC)

Table A6.1–4 Emission Factors for Refined Petroleum Products

Source	Emission Factor (g/L)		
	CO_2[a]	CH_4[b]	N_2O[b]
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[c]	0.006	0.031
Industrial	2 560[c]	0.006	0.031
Producer Consumption	2 560[c]	0.006	0.031
Residential	2 560[c]	0.026	0.006
Forestry, Construction, Public Administration and Commercial/Institutional	2 560[c]	0.026	0.031
Diesel—Refineries and Others[e]	2 681[d]	0.078	0.022
Diesel—Upgraders[e]	2 681	0.078	0.022
Petroleum Coke	(see Table A6.1–5)	0.12	(see Table A6.1–6)
Still Gas—Refineries and Others	(see Table A6.1–5)	(see Table A6.1–7)	0.00002
Still Gas—Upgraders	(see Table A6.1–5)	0.0389	0.00002
Motor Gasoline[e]	2 307	0.100	0.02

Notes:

a. McCann (2000); except Kerosene, Diesel and Motor Gasoline

b. SGA Energy (2000); except Diesel and Motor Gasoline

c. Assumed McCann (2000) aviation turbo-fuel emission factor

d. ECCC (2017b)

e. CO_2 from ECCC (2017b); CH_4 and N_2O from Oak Leaf Environmental Inc. (2017)

Table A6.1–5 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	2016	2017	2018
Petroleum Coke	g/L																
Upgrading Facilities[a]	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	3 494	3 494	3 494
Refineries & Others[b]	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	3 790	3 814	3 778
Still Gas	$g/10^3\ m^3$																
Upgrading Facilities[a]	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	2 140	2 140	2 140
Refineries & Others[b]	1 740	1 800	1 683	1 719	1 753	1 760	1 705	1 723	1 840	1 830	2 075	2 099	2 111	2 135	2 159	2 219	2 183

Notes:

a. CIEEDAC (2003)

b. Griffin B. 2019. Personal communication (email from Griffin B to Tracey K, Senior Program Engineer, PIRD dated Sept 26, 2019). Canadian Emissions and Energy Data Centre.

Table A6.1–6 **N_2O Emission Factors for Petroleum Coke**

	Emission Factor											
	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001–2018
Petroleum Coke	g/m³											
Upgrading Facilities[a, b]	21.9	22.1	22.3	22.5	22.7	22.7	22.7	23.0	23.5	23.7	24.2	24.0
Refineries & Others[a, b]	24.6	24.8	25.0	25.2	25.5	25.5	25.4	25.8	27.0	27.1	27.6	27.5

Notes:

a. Adapted from IPCC (2006)

b. Energy content from Statistics Canada (2014)

Table A6.1–7 **CH_4 Emission Factors for Still Gas (Refineries & Others)**

	Emission Factor[a]																
	1990	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Still Gas	g/10³ m³																
Refineries & Others[a]	32.6	33.5	33.8	32.0	32.0	32.2	31.6	32.0	32.1	32.6	30.5	31.1	31.0	32.5	31.7	33.3	31.7

Notes:

a. Adapted from IPCC (2006) using energy content taken from Griffin B. 2019. Personal communication (email from Griffin B to Tracey K, Senior Program Engineer, PIRD dated Sept 26, 2019). Canadian Emissions and Energy Data Centre.

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 A6.1–8) 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 A6.1–8 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, 2017a). Based on an analysis of this study and Radovan et al (2012), updated emission and oxidation factors as well as uncertainty estimates for many coal-types have been determined (ECCC, 2019).

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 A6.1–8 now incorporate Canada-specific oxidation factors (ECCC 2017a).

Coke and coke oven gas emission factors are presented in Table A6.1–9. 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.

A6.1.3.2. CH_4

Emissions of CH_4 from fuel combustion are technology-dependent. Emission factors for sectors (Table A6.1–10) 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).

Table A6.1–8 **CO_2 Emission Factors for Coal**

Province	Coal Type	Source	Emission Factor ($kg\ CO_2/tonne$)[a, b, c, d, e]			Moisture (wt %)
			Mean	Uncertainty (95% CI)		
				Low	High	
Newfoundland & Labrador, P.E.I. (Prior to 2000)	Canadian Bituminous[b]	Nova Scotia	2 315	-33%	22%	3.2
Newfoundland & Labrador, P.E.I.(2000 onward)	Canadian Bituminous[b]	Alberta	2 185	-26%	26%	7.7
Quebec (Prior to 2000)	Canadian Bituminous[b]	Nova Scotia	2 329	-33%	22%	3.2
Quebec (2000 onward)	Canadian Bituminous[b]	Alberta	2 198	-26%	26%	7.7
Nova Scotia	Canadian Bituminous[b]	Nova Scotia	2 329	-33%	22%	3.2
New Brunswick (Prior to 2010)	Canadian Bituminous[b]	New Brunswick	2 319	-14%	14%	3.2
New Brunswick (2010 on)	Canadian Bituminous[b]	Alberta	2 198	-26%	26%	7.7
Ontario, Alberta, Saskatchewan, B.C.	Canadian Bituminous[b]	Alberta	2 198	-26%	26%	7.7
Atlantic[e]	Foreign Bituminous[b]	Non-U.S.	2 540	-7%	7%	8.3
Ontario, Manitoba	Foreign Bituminous[c]	U.S. (Pennsylvania)	2 651	-7%	7%	N/A
Quebec, Alberta, B.C.	Foreign Bituminous[c]	U.S. (Pennsylvania)	2 662	-7%	7%	N/A
All Provinces & Territories, except Saskatchewan	Lignite[c]	Saskatchewan	1 462	-13%	13%	24
Saskatchewan	Lignite[c]	Saskatchewan	1 457	-13%	13%	36
Quebec, Ontario, Manitoba, Atlantic	Sub-bituminous[c]	Foreign	1 865	-8%	8%	24
Alberta, Saskatchewan, B.C.	Sub-bituminous[c]	Alberta	1 763	-11%	11%	21
All Provinces & Territories	Anthracite	--	2 382	-6%	6%	N/A

Notes:
N/A not available

a. Factors presented on a "wet basis." Moisture content shown is that for the "weighted average" emission factor.
b. Carbon content, Radovan et al. (2012), oxidation factor, ECCC 2019.
c. Carbon content and oxidation factor, ECCC 2019.
d. 95 % Confidence Intervals, which were determined through statistical analysis of Canadian coal data.
e. Atlantic refers to the Maritime provinces and Newfoundland & Labrador.

Table A6.1–9 **CO_2 Emission Factors for Coal Products**

Coal Product—Fuel Type	Emission Factor
Coke Oven Gas[a]	687 g/m^3
Coke[b]	3 173 g/kg

Notes:
a. McCann (2000)
b. CRA (2014)

Table A6.1–10 **CH_4 and N_2O Emission Factors for Coals**

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:
SGA Energy (2000)

A6.1.3.3. N_2O

Emissions of N_2O from fuel combustion are technology-dependent. Emission factors for sectors (Table A6.1–10) 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).

A6.1.4. Fugitive Emission Factors for Coal Mining

The factors in Table A6.1–11 are for fugitive emissions from coal mining only. Although derived from measurements at individual mines or coal seams, these emission factors are aggregated, province-wide averages for a given mine type. They are to be applied to total gross (not net) quantities of coal mined and include small quantities of minerals, stone and other inert materials mined with the coal, but later removed before sale or consumption.

Table A6.1–11 **Fugitive Emission 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	0.55	t CH_4/kt coal mined
Alberta	Bituminous	Underground	1.69	t CH_4/kt coal mined
Alberta	Sub-bituminous	Surface	0.20	t CH_4/kt coal mined
British Columbia	Bituminous	Surface	0.86	t CH_4/kt coal mined
British Columbia	Bituminous	Underground	2.78	t CH_4/kt coal mined

Notes:

The emission factors are based on 'gross', not 'net', quantities of coal mined. The gross amount includes small quantities of minerals, stone and other inert materials mined with the coal, but later removed.

The factors in the above table are for fugitive emissions from coal mining only. Although derived from measurements at individual mines or coal seams, these emission factors are aggregated, province-wide averages for a given mine type. They are to be applied to total gross (not net) quantities of coal mined throughout a province or region to estimate fugitive emissions, and are not applicable to individual mines. See NIR (2018) Annex 3, section A-3.2.1.1 for more information.

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

A6.1.5. Other Fuels

A6.1.5.1. 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 A6.1–12.

Some municipal solid waste and medical waste are combusted in energy-to-waste facilities. See A6.7.2 for the emission factors associated with these other fuels.

A6.1.5.2. CH_4

CH_4 emission factors for alternative fuels were adapted from the 2006 IPCC Guidelines (IPCC 2006).

Some municipal solid waste and medical waste are combusted in energy-to-waste facilities. See A6.7.2 for the emission factors associated with these other fuels.

A6.1.5.3. N_2O

N_2O emission factors for alternative fuels were adapted from the 2006 IPCC Guidelines (IPCC 2006).

Some municipal solid waste and medical waste are combusted in energy-to-waste facilities. See A6.7.2 for the emission factors associated with these other fuels.

A6.1.6. Mobile Combustion

A6.1.6.1. 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.

A6.1.6.2. 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 A6.1–13. The factors were initially adopted from a review of available knowledge and an analysis of combustion technologies. 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).

Table A6.1–12 **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	2011-2018
Cement Industry Waste Fuel	CO_2[a]	78.8	77.6	78.6	80.6	82.6	81.5	81.2	83.8	87.7	86.3	79.2	80.1	81.5
	CH_4[b]	0.03	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[b]	0.004	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:

a. Adapted from WBSCD (2005)

b. Adapted from IPCC (2006)

Table A6.1–13 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	2 307 [a]	0.14 [c]	0.022 [d]
Tier 1	2 307 [a]	0.23 [e]	0.47 [e]
Tier 0	2 307 [a]	0.32 [f]	0.66 [g]
Oxidation Catalyst	2 307 [a]	0.52 [h]	0.20 [f]
Non-catalytic Controlled	2 307 [a]	0.46 [h]	0.028 [f]
Light-duty Gasoline Trucks (LDGTs)			
Tier 2	2 307 [a]	0.14 [c]	0.022 [d]
Tier 1	2 307 [a]	0.24 [e]	0.58 [e]
Tier 0	2 307 [a]	0.21 [h]	0.66 [g]
Oxidation Catalyst	2 307 [a]	0.43 [h]	0.20 [f]
Non-catalytic Controlled	2 307 [a]	0.56 [f]	0.028 [f]
Heavy-duty Gasoline Vehicles (HDGVs)			
Three-way Catalyst	2 307 [a]	0.068 [h]	0.20 [h]
Non-catalytic Controlled	2 307 [a]	0.29 [f]	0.047 [f]
Uncontrolled	2 307 [a]	0.49 [f]	0.084 [f]
Motorcycles			
Non-catalytic Controlled	2 307 [a]	0.77 [c]	0.041 [c]
Uncontrolled	2 307 [a]	2.3 [f]	0.048 [f]
Diesel Vehicles			
Light-duty Diesel Vehicles (LDDVs)			
Advanced Control*	2 681 [a]	0.051 [f]	0.22 [f]
Moderate Control	2 681 [a]	0.068 [f]	0.21 [f]
Uncontrolled	2 681 [a]	0.10 [f]	0.16 [f]
Light-duty Diesel Trucks (LDDTs)			
Advanced Control*	2 681 [a]	0.068 [f]	0.22 [f]
Moderate Control	2 681 [a]	0.068 [f]	0.21 [f]
Uncontrolled	2 681 [a]	0.085 [f]	0.16 [f]
Heavy-duty Diesel Vehicles (HDDVs)			
Advanced Control	2 681 [a]	0.11 [i]	0.151 [i]
Moderate Control	2 681 [a]	0.14 [f]	0.082 [f]
Uncontrolled	2 681 [a]	0.15 [f]	0.075 [f]
Natural Gas Vehicles	1.9 [b]	9E-03 [f]	6E-05 [f]
Propane Vehicles	1 515 [b]	0.64 [f]	0.028 [f]
Off-road			
Off-road Gasoline 2-stroke	2 307 [a]	10.61 [l]	0.013 [m]
Off-road Gasoine 4-stroke	2 307 [a]	5.08 [l]	0.064 [m]
Off-road Diesel <19kW	2 681 [a]	0.073 [l]	0.022 [l]
Off-road Diesel >=19kW, Tier 1 - 3	2 681 [a]	0.073 [l]	0.022 [l]
Off-road Diesel >= 19kW, Tier 4	2 681 [a]	0.073 [l]	0.227 [l]
Off-road Natural Gas	1.9 [b]	0.0088 [f]	0.00006 [f]
Off-road Propane	1 515 [b]	0.64 [f]	0.087 [l]
Railways			
Diesel Train	2 681	0.15 [m]	1.0 [m]
Marine			
Gasoline	2 307 [a]	0.22 [m]	0.063 [m]
Diesel	2 681 [a]	0.25 [m]	0.072 [m]
Light Fuel Oil	2 753 [b]	0.26 [m]	0.073 [m]
Heavy Fuel Oil	3 156 [b]	0.29 [m]	0.082 [m]
Kerosene	2 560 [p]	0.25 [m]	0.071 [m]
Aviation			
Aviation Gasoline	2 365 [j]	2.2 [j]	0.23 [j]
Aviation Turbo Fuel	2 560 [b]	0.029 [k]	0.071 [m]
Renewable Fuels			
Ethanol	1 508 [a, n]	**	**
Biodiesel	2 472 [a, n, o]	***	***

Notes:

† In the context of Transportation Modes, Tiers refer to increasingly stringent emission standards, enabled through advancements in emission control technologies. It should not be confused with IPCC GHG estimation methodologies.

* 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.

a. ECCC (2017b)
b. McCann (2000)
c. Adapted from Environment Canada (2006)
d. Adapted from Environment Canada (2006) and Graham et al. (2009)
e. Adapted from Environment Canada (2009)
f. SGA Energy (2000)
g. Adapted from Barton & Simpson (1994)
h. ICF Consulting (2004)
i. Graham et al. (2008)
j. Jaques (1992)
k. 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.
l. Oak Leaf Environmental Inc. (2017)
m. IPCC (2006)
n. Refer to section 3.5.1 Chapter 3 for further information.
o. BioMer (2005)
p. Assumed McCann (2000) aviation turbo-fuel emission factor

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 A6.1–13 displays a national overall average implied emission factor (refer to section A3.4.2.3 for more information on AGEM).

A6.1.6.3. N_2O

Emissions 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. 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).

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 A6.2–1.

A6.2.2. Chemical Industry

Table A6.2–2, Table A6.2–3, Table A6.2–4 and Table A6.2–5 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 A6.2–1 **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[a]
	TOC	11.5[b]
Lime Production	High-Calcium Lime	751[c]
	Dolomitic lime	889[c]
Limestone and Dolomite Use	Limestone	418[d]
	Dolomite	468[d]
Soda Ash Use	Soda Ash	415[d]
Magnesite Use	Magnesite	522[d]

Notes:

a. Cement Association of Canada (CAC) (2015). 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.

b. CAC (2015).

c. Developed based on information provided by Kenefick (2008). Personal communication (email to Shen A, Environment Canada, dated October 7, 2008). Canadian Lime Institute (CLI).

d. AMEC (2006).

Table A6.2–2 Emission Factors for Ammonia Production

	Average Ammonia-to-Feed Fuel Factor[a] m^3 natural gas/tonne of NH_3	Emission Factor g CO_2/ m^3 of natural gas	Emission Recovery Factor g CO_2 / kg of urea
Ammonia Production	671	Marketable natural gas emission factors found in Table A6.1-1 are used.	728

Note:
a. Facility-specific fuel factors are used and these are confidential.

Table A6.2–3 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[a]
	Dual-pressure plants with extended absorption "Type 2"	12[a]
	High-pressure plants with non-selective catalytic reduction	0.66[a]
	High-pressure plants with selective catalytic reduction	8.5[b]
Adipic Acid Production	Oxidation reaction of cyclohexanone and cyclohexanol mixture without N_2O abatement	300[b]

Notes:
a. Collis G. 1992. Personal communication (letter from Collis G to Jaques A, Greenhouse Gas Division, dated March 23, 1992). Canadian Fertilizer Institute.
b. Source: IPCC (2000)

Table A6.2–4 Emission Factors for Petrochemical Products

Petrochemical Product	Emission Factor	Type
Silicon Carbide	11.6 kg CH_4 / t (tonne) product	IPCC default[a]
Calcium Carbide	4.8 kg CH_4 / t product	Derived from CH_4 emission factor for silicon carbide and the ratio of IPCC default Calcium Carbide CO_2 emission factor to IPCC default Silicon Carbide CO_2 emission factor (i.e. 11.6 (kg CH_4/t SiC) * (1.09 $tCO_2/tCaC_2$ / 2.62 $tCO_2/tSiC$))
Carbon Black	1.29 kg CH_4 / t product	Sector-wide weighted average[b]
	0.032 kg N_2O / t product	Sector-wide weighted average[b]
Ethylene	0.039 kg CH_4 / t product	Sector-wide weighted average[b]
	0.0055 kg N_2O / t product	Sector-wide weighted average[b]
	0.411 t CO_2 / t product	Sector-wide weighted average[c]
Ethylene Dichloride	0.4 kg CH_4 / t product	IPCC default[a]
Ethylene Oxide	0.5202 t CO_2 / t product	Sector-wide weighted average[b]
	1.79 kg CH_4/ t product	IPCC default[d]
Styrene	4 kg CH_4 / t product	IPCC default[a]
Methanol	0.031 kg CH_4 / t product	Sector-wide weighted average[b]
	0.010 kg N_2O / t product	Sector-wide weighted average[b]
	0.790 t CO_2 / t product	Sector-wide weighted average[c]
Other Uses of Urea	0.733 t CO_2 / t product	IPCC default[d]

Notes:
a. Default value from Revised 1996 IPCC Guidelines (IPCC/OECD/IEA 1997)
b. Cheminfo Services (2010)
c. Cheminfo Services (2015); emission factors may vary if changes are made to the composition of feed.
d. 2006 IPCC Guidelines

Table A6.2–5 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[a]

Note:
a. IPCC (2006)

Table A6.2–6 CO_2 Emission Factors for the Iron and Steel Industry		
Parameter	Emission Factor	Unit
Iron ore reduction with coke	3.2–3.3[a]	t CO_2 / t (tonne) coke used
Electrode consumption in electric arc furnaces	4.53[b]	kg CO_2 / t steel
Electrode consumption in basic oxide furnaces	0.23[b]	kg CO_2 / t steel
Limestone use	418[c]	CO_2/kg $CaCaO_3$
Dolomite use	468[c]	CO_2/kg $MgCO_3$

Notes:

a. Year-specific emission factors provided in Cheminfo Services (2010).

b. 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.

c. AMEC 2006

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 A6.2–6, Table A6.2–7 and Table A6.2–8.

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 A6.2–8.

Table A6.2–7 Carbon Contents for the Iron and Steel Industry	
Parameter	Carbon Contents (%)[a]
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	0.13
Crude steel produced in EAF	0.14
Scrap steel (own)	0.1
Scrap steel (purchased)	0.11

Note:

a. CSPA (2009)

Table A6.2–8 Tier 1 Emission Factors for Aluminium Production			
Cell Technology Type	Emission Factors[a] (kg / t product)		
	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:

a. IAI (2006)

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/m^3 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 A6.2–9 shows the emission factors used to develop CO_2 emission estimates for non-energy applications of natural gas liquids and non-energy petroleum products, respectively. The emission factors for NEU petroleum coke are found in Table A6.1–5. The 2011 emission factor value for Upgrading Facilities in Table A6.1–5 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 A6.1–8.

Table A6.2–9 **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[a]	303[b]
Butane	0.8[a]	349[b]
Ethane	0.8[a]	197[b]
Petroleum Products		
Petrochemical Feedstocks[d]	0.8[a]	500[h]
Naphthas[e]	0.75[a]	625[h]
Lubricating Oils and Greases[f]	0.2[c]	2 260[h]
Petroleum Used for Other Products[g]	0.5[a]	1 450[h]

Notes:

a. IPCC/OECD/IEA (1997)
b. McCann (2000)
c. IPCC (2006)
d. Carbon factor for Petrochemical Feedstocks is 680 g of carbon per litre (C/L) (Jaques 1992).
e. Carbon factor for Napthas is 680 g C/L (Jaques 1992).
f. Carbon factor for Lubricating Oils and Greases is 770 g C/L (Jaques 1992).
g. Carbon factor for Petroleum Used in Other Products is 790 g C/L (Jaques 1992).
h. 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).

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 A6.2–10.

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 A6.2–11 and Table A6.2–12 summarize emission rates used to estimate HFC and PFC emissions.

Table A6.2–10 **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	90	N/A
	CF_4	T2B—Etching	70	N/A
	C_2F_6	T2B—CVD	60	0.1 kg CF_4 / kg C_2F_6
	C_2F_6	T2B—Etching	40	0.4 kg CF_4 / kg C_2F_6
	c-C_4F_8	T2B—Etching	20	0.2 kg CF_4 / kg c-C_4F_8
	SF_6	T2A	20	N/A
	NF_3	T2A	20	0.09 kg CF_4 / kg NF_3
	NF_3	T2B—Etching	20	N/A
Other Emissive Applications	PFCs	T2	50% first year / 50% second year[a]	N/A

Notes:

N/A not available

a. IPCC (2006)

Table A6.2–11 **HFC as ODS Substitute—Assembly, In-Service and End-of-Life Emission Factors (%)**

Application/Sub-Application	Assembly[a]	In-Service[b]	End-of-Life[c]	Life Time (years)
Aerosols *	0	50% of orginal charge	100% of remaining charge	2
Blowing agent in foams *				
Open-cell foam	100	-	-	-
Closed-cell foam	10	4.5	100	23
Air conditioning (equipment manufactured in Canada) **				
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 (manufactured elsewhere) **				
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 (equipment manufactured in Canada) **				
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 (manufactured elsewhere) **				
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 *	0	50% of orginal charge	100% of remaining charge	2
Fire suppression/extinguishing systems *				
Portable (mobile) systems	-	4	5	18
Total flooding (fixed) systems	-	2	5	18
Miscellaneous *	-	50% of orginal charge	100% of remaining charge	2
Other (specify) *	-	50% of orginal charge	100% of remaining charge	2

Notes:

a. Percentage of losses of the HFC charged into new equipement

b. Release percentage of HFC bank (by application) during operation

c. Release percentage of HFC bank (by application) during disposal

* IPCC (2006)

** Environment Canada (2015)

Table A6.2–12 **PFC as ODS Substitute—Assembly, In-Service and End-of-Life Emission Factors (%)**	
Application	PFC Emission Rate (%)
Assembly	
Industrial Refrigeration including Food Processing and Cold Storage	1.75% (of charge)
Medium and Large Commercial Refrigeration	1.75% (of charge)
Residential and Commercial A/C including Heat Pumps	0.6% (of charge)
Mobile AC	0.35% (of charge)
Operation	
Industrial Refrigeration including Food Processing and Cold Storage	16% (of stock in existing systems)
Medium and Large Commercial Refrigeration	22.5% (of stock in existing systems)
Residential and Commercial A/C including Heat Pumps	5.5% (of stock in existing systems)
Mobile AC	15% (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
Note: IPCC (2006)	

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 in Table A6.3–1.

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 A6.3–2.

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 A6.3–3.

Table A6.3–1 **Emission Factors for N_2O Usage (Medical & Propellant)**		
Product	Application	N_2O Emission Rate (%)
N_2O Use	Anaesthetic Usage	100
	Propellant Usage	100
Note: IPCC (2006)		

Table A6.3–2 **Emission Factor 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: IPCC (2000)	

Table A6.3–3 **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: IPCC (2000)		

A6.4. Agriculture

The sources of agricultural GHGs are enteric fermentation, manure management, field burning of crop residues, agricultural soils (including nitrous oxide emissions from mineralization/immobilization associated with loss/gain of soil organic matter), and agricultural use of lime, urea and other-carbon containing fertilizers. The most significant sources use country-specific Tier 2 methodologies. 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 nitrogen leaching are calculated based on the IPCC default emission factors provided in Table A6.4–27.

Those emission factors for agriculture calculated based on country-specific methodologies are described in detail in Annex 3.4. For enteric fermentation emissions from cattle, weighted national emission factors and the methodology for generating emission factors are detailed in section A3.4.2.1. In the case of manure management CH_4, the methodology for generating emission factors is described in A_3.4.3, and weighted national emission factors are presented in A_3.4.3.5. For manure management N_2O emissions, the methodologies for calculating direct and indirect N_2O emissions are described in sections A3.4.4.1 and A3.4.4.2, respectively. Finally, the methodologies for generating N_2O emission factors for direct emissions from agricuiltural soils and pasture, range and paddock (PRP), are described in A_3.4.5.1. Cattle are described using an approach consistent with common reporting format (CRF) tables[3]. For enteric fermentation, Dairy Cattle includes only dairy cows, while for manure management and PRP, Dairy Cattle includes dairy cows and dairy heifers.

A compilation of emission factors for agriculture are provided here in Table A6.4–1 to Table A6.4–29.

3 Canada's 2020 CRF tables are available online at: https://unfccc.int/ghg-inventories-annex-i-parties/2020

A6.4.1. Enteric Fermentation

Table A6.4–1 **CH_4 Emission Factors for Enteric Fermentation for Cattle from 1990 to 2018**

Year	EF(EF)T—(kg CH_4/head/year)[a]							
	Dairy Cows	Dairy Heifers	Bulls	Beef Cows	Beef Heifers	Heifers for Slaughter[b]	Steers[b]	Calves
1990	115.4	79.4	108.0	105.9	82.5	44.7	41.4	43.8
1995	119.1	78.6	117.2	112.1	85.9	48.8	43.6	43.8
2000	125.4	78.0	121.0	117.5	89.4	53.0	47.8	43.8
2005	125.0	77.2	119.9	114.4	87.0	52.8	46.0	43.6
2010	128.6	76.8	128.5	115.2	87.8	52.8	47.0	43.7
2011	129.2	76.8	127.6	115.0	87.5	52.7	47.4	43.7
2012	129.6	76.8	129.8	115.6	87.6	53.8	48.0	43.7
2013	134.0	76.8	117.1	115.3	87.5	53.7	48.0	43.8
2014	134.1	76.7	121.1	116.3	88.1	53.2	48.1	43.8
2015	135.2	76.7	127.5	120.0	90.7	53.8	48.8	43.8
2016	137.5	76.7	128.0	121.3	91.6	53.9	48.8	43.8
2017	138.1	76.7	130.1	120.8	91.3	53.6	48.4	43.8
2018	139.6	76.7	125.3	120.5	91.2	53.7	48.5	43.8

Notes:

a. Enteric emission factors are derived from Boadi et al. (2004), modified to take into account trends in milk production in dairy cattle and carcass weights for several beef cattle categories.

b. Reported as kg/hd/yr; however, emissions are calculated based on time to slaughter.

Table A6.4–2 **Methane Emission Factors for Enteric Fermentation for Non-Cattle Animals**

Non-cattle Animal Category	Enteric Fermentation Emission Factor[a] ($kg\ CH_4$/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:
N/A Not available

a Data source: IPCC (2006), Volume 4: Agriculture, Forestry and Other Land Uses, Table 10.10

A6.4.2. Manure Management

Table A6.4–3 **Maximum Methane-Producing Potential (B_0) by Animal Category**

Animal Category	Maximum CH_4-Producing Potential (B_0) (m^3/kg VS)
Dairy Cattle[a]	0.24
Non-dairy Cattle[b]	0.19
Sheep	0.19
Goats	0.18
Horses	0.3
Swine	0.48
Hens	0.39
Broilers	0.36
Turkeys	0.36

Notes:
VS volatile solids
Data source: IPCC (2006), Volume 4: Agriculture, Forestry and Other Land Uses, Tables 10A-5 to 10A-9

a. Dairy cattle include dairy cows and dairy heifers.
b. The non-dairy cattle value is also used for bison.

Table A6.4–4 **Methane Conversion Factors (MCFs) by Animal Category and Manure Management System**

Animal Categories	Liquid Systems (MCF_L)	Solid Storage and Drylot (MCF_{SSD})	Pasture, Range and Paddock (MCF_{PRP})	Other Systems (MCF_O)
Non-dairy Cattle[a]	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:
NA Not applicable
IPCC (2006), Volume 4: Agriculture, Forestry and Other Land Uses, Tables 10A-5 to 10A-9 (cool climate, average annual temperature 12°C)

a. Non-dairy cattle values are also used for bison.

Table A6.4–5 **Methane Conversion Factors (MCFs) for Dairy Cattle and Swine**

Manure Management System	Manure Management Subsystem	Crust Formation	MCF
Liquid	Earthen Basin	No crust	0.2
	Earthen Basin	Crust	0.13
	Tank	No crust	0.2
	Tank	Crust	0.13
	Slatted floor	N/A	0.2
Solid	Exercise Yard	N/A	0.01
	Pack	N/A	0.01
	Pile	N/A	0.02
Compost		N/A	0.005
Pasture Range Paddock		N/A	0.01
		N/A	0.01

Notes:
N/A Not available
IPCC (2006), Volume 4: Agriculture, Forestry and Other Land Uses, Table 10.17 (cool climate, average annual temperature 12°C)

Table A6.4–6 **Emission Factors to Estimate CH_4 Emissions from Manure Management for Cattle Subcategories from 1990 to 2018**

Year	EF(MM)T (kg CH_4/head/year)							
	Dairy Cows	Dairy Heifers[a]	Bulls	Beef Cows	Beef Heifers	Heifers for Slaughter[b]	Steers[b]	Calves
1990	13	8	4.5	4.1	3.2	1.9	1.8	2.2
1995	15	9	4.7	4.3	3.2	2.0	1.9	2.1
2000	20	11	4.7	4.5	3.3	2.1	1.9	2.3
2005	26	12	4.6	4.3	3.1	2.1	1.9	2.4
2010	33	15	5.0	4.4	3.1	2.1	2.0	2.8
2011	35	16	5.0	4.4	3.1	2.1	2.0	2.9
2012	35	16	5.0	4.4	3.1	2.1	2.0	2.9
2013	36	16	4.5	4.3	3.1	2.1	2.0	2.8
2014	36	17	4.7	4.4	3.1	2.1	2.0	2.9
2015	37	17	4.9	4.5	3.2	2.2	2.0	2.9
2016	37	17	4.9	4.5	3.2	2.2	2.0	2.9
2017	38	17	5.0	4.5	3.2	2.1	2.0	2.9
2018	38	17	4.8	4.5	3.2	2.2	2.0	3.0

Notes:
a. For dairy heifers, emission factors were estimated using B_0, MCF and manure management systems for dairy cows.
b. Reported as kg/hd/year, but emissions are calculated based on time to slaughter.

Table A6.4–7 **Emission Factors to Estimate CH_4 Emissions from Manure Management for Swine Subcategories from 1990 to 2018**

Year	EF(MM)T (kg CH_4/head/year)				
	Boars	Sows	Pig (< 20 kg)	Pig (20-60 kg)	Pig (> 60 kg)
1990	7.0	7.3	2.1	4.5	8.2
1995	7.0	7.2	2.1	4.5	8.3
2000	7.0	7.2	2.1	4.4	8.5
2005	7.0	7.1	2.1	4.4	8.5
2010	7.0	7.0	2.1	4.3	8.6
2011	7.0	7.0	2.1	4.3	8.7
2012	7.0	7.0	2.1	4.3	8.8
2013	7.0	7.0	2.1	4.3	8.8
2014	7.0	7.0	2.1	4.3	8.9
2015	7.0	7.0	2.1	4.3	8.9
2016	7.0	7.0	2.1	4.3	9.0
2017	7.0	7.0	2.1	4.2	9.0
2018	7.0	7.0	2.1	4.2	9.0

Table A6.4–8 **2018 CH_4 Emission Factors for Manure Management for Other Livestock**

Non-Cattle Animal Categories	Manure Management Emission Factors EF(MM) (kg CH_4/head/year)
Other Livestock	
Sheep	0.33
Lambs	0.22
Goats	0.32
Horses	2.6
Bison	2.1
Elk and Deer	0.22
Wild Boars[a]	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:
a. Emission factor based on swine VS, assuming 100% solid manure.

Table A6.4–9 **Dairy Cattle and Swine Emission Factors (EFs) for Manure Nitrogen (N) Lost as N_2O-N by Animal Waste Management Systems**

Manure Management System	Manure Management Subsystem	Crust Formation	Emission Factor
Liquid	Earthen Basin	No crust	0
	Earthen Basin	Crust	0.005
	Tank	No crust	0
	Tank	Crust	0.005
	Slatted floor	NA	0.002
Solid	Exercise Yard	NA	0.02
	Pack	NA	0.02
	Pile	NA	0.005
Other	Compost	NA	0.01

Notes:
IPCC (2006), Volume 4, Agriculture, Forestry and Other Land Uses, Table 10.21
NA Not Applicable

Table A6.4–10 **Emission Factors (EFs) for Manure Nitrogen (N) Lost as N_2O-N by Animal Category and Animal Waste Management Systems**

	Liquid Systems (EF_L)	Solid Storage and Drylot (EF_{SSD})	Other Systems (EF_O)
Non-dairy Cattle	0.001	0.02	0.005
Poultry	0.001	0.02	0.005
Sheep and Lambs	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

Note:
IPCC (2006), Volume 4, Agriculture, Forestry and Other Land Uses, Table 10.21.

Table A6.4–11 Emission Factors (EFs) for Manure Nitrogen (N) Lost as N_2O During Storage of Cattle and Swine

Year	EF (g N_2O head^{-1} year^{-1})				
	1990	2005	2010	2015	2018
Cattle					
Dairy Cows[b]	1 268	1 128	956	930	921
Beef Cows	862	999	1 016	1 093	1 099
Bulls	1 305	1 495	1 665	1 641	1 598
Dairy Heifers[b]	938	906	775	745	744
Beef Heifers	680	769	784	838	844
Heifers for Slaughter	320	425	435	458	459
Steers	336	426	439	468	472
Calves	382	383	382	382	379
Swine[c]					
Sows	74	29	25	24	24
Boars	95	58	53	58	58
Pigs (<20 kg)	7	3	3	2	2
Pigs (20-60 kg)	32	15	13	12	12
Pigs (>60 kg)	66	32	29	28	28

Notes:

a. Emission factors are derived from information in Boadi et al. 2004, Marinier et al. 2004 and 2005, and default factors in the 2006 IPCC Guidelines. Derivation of the Tier 2 emission factors is explained in NIR Annex 3.4.

b. For dairy cows and heifers, nitrogen excretion rates are derived from feed intake information from Valacta Inc., and manure storage practices are taken from farm management surveys, as described in NIR Annex 3.4.

c. For swine, nitrogen excretion rates are calculated using default IPCC parameters and country-specific animal mass time series, and manure storage practices are taken from farm management surveys, as described in NIR Annex 3.4.

Table A6.4–12 2018 Emission Factors (EFs) for Manure Nitrogen (N) Lost as N_2O During Storage of Non-Cattle and Non-Swine Manure

Livestock Category	Emission Factors (EF)[a] (g N_2O head^{-1} year^{-1})
Poultry	
Turkey	54
Hens	12
Pullets	6
Broiler	11
Other Livestock	
Sheep	46
Goat	139
Buffalo	991
Horse	485
Llama and alpacas	150
Lamb	42
Deer	220
Elk	220
Wild boars	350
Rabbit	255
Mink	176
Fox	671
Mules and Asses	265

Note:

a. Emission factors are derived from information in Marinier et al. 2004 and 2005, and default factors in the 2006 IPCC Guidelines. Derivation of the Tier 2 emission factors is explained in NIR Annex 3.4.

Table A6.4–13 Emission Factors (EFs) for Cattle and Swine Manure Nitrogen (N) Lost Indirectly as N_2O Due to Volatilization and Leaching During Storage

	EF (g N_2O head^{-1} year^{-1})				
	1990	2005	2010	2015	2018
Volatilization[a]					
Dairy Cow	207	209	186	175	174
Beef Cow	140	161	164	176	177
Bull	213	241	269	264	257
Dairy heifer	155	150	136	128	127
Beef heifer-bred	111	124	127	135	136
Beef heifer-slaughter	52	70	72	75	75
Steer	55	70	72	77	78
Calf	61	61	61	61	60
Sow	58	58	52	51	51
Boar	58	56	50	50	50
Pig (<20 kg)	6	6	5	5	5
Pig (20-60 kg)	25	25	22	21	21
Pig (>60 kg)	50	51	47	48	49
Leaching[b]					
Dairy Cow	23	15	11	10	9
Beef Cow	0	0	0	0	0
Bull	0	0	0	0	0
Dairy heifer	16	12	10	9	9
Beef heifer-bred	0	0	0	0	0
Beef heifer-slaughter	0	0	0	0	0
Steer	0	0	0	0	0
Calf	0	0	0	0	0
Sow	1.2	0.2	0.1	0.1	0.1
Boar	1.6	0.7	0.6	0.7	0.7
Pig (<20 kg)	0.13	0.03	0.02	0.02	0.02
Pig (20-60 kg)	0.6	0.2	0.1	0.1	0.1
Pig (>60 kg)	1.2	0.4	0.3	0.2	0.2

Notes:

a. Indirect N_2O emission factors are taken from default parameters in the 2006 IPCC Guidelines. Volatilization is calculated based on Sheppard et al. 2010, Sheppard et al. 2011b and Chai et al. 2016. Derivation of the Tier 2 emission factors is explained in NIR Annex 3.4.

b. A tier 2 method for the calculation of swine and dairy cattle leaching is based on Sheppard et al. 2010, Sheppard et al. 2011b and Chai et al. 2016. Derivation of the Tier 2 emission factors is explained in NIR Annex 3.4.

Table A6.4–14 Annual Emission Factors (EFs) for Cattle and Swine Manure Nitrogen (N) Lost as NH_3 Due to Volatilization During Storage

	EF (kg NH_3 $head^{-1}$ $year^{-1}$)				
	1990	2005	2010	2015	2018
Cattle					
Dairy Cow	16	16	14	14	13
Beef Cow	11	12	13	14	14
Bull	16	19	21	20	20
Dairy heifer	12	12	11	10	10
Beef heifer-bred	8.6	10	10	10	11
Beef heifer-slaughter	4.0	5.4	5.5	5.8	5.8
Steer	4.2	5.4	5.6	5.9	6.0
Calf	4.7	4.7	4.7	4.7	4.6
Swine					
Sow	4.5	4.5	4.0	3.9	3.9
Boar	4.4	4.3	3.9	3.8	3.8
Pig (<20 kg)	0.5	0.5	0.4	0.4	0.4
Pig (20-60 kg)	1.9	1.9	1.7	1.6	1.6
Pig (>60 kg)	3.9	4.0	3.7	3.7	3.8

Note:
Volatilization is calculated based on Sheppard et al. 2010, Sheppard et al. 2011b and Chai et al. 2016. Derivation of the emission factors is explained in NIR Annex 3.4.

Table A6.4–15 2018 Emission Factors (EFs) for Manure Nitrogen (N) Lost Indirectly as N_2O Due to Volatilization and Leaching During Storage

Livestock Category	Volatilization Emission Factor (EF)[a] ($g\ N_2O\ head^{-1}\ year^{-1}$)	Leaching Emission Factor (EF)[b] ($g\ N_2O\ head^{-1}\ year^{-1}$)
Poultry		
Turkey	13	0
Hens	4	0
Pullets	2	0
Broiler	3	0
Other Livestock		
Sheep	3	0
Goat	8	0
Buffalo	159	0
Horse	31	0
Llama and alpacas	9	0
Lamb	3	0
Deer	33	0
Elk	33	0
Wild boars	52	0
Rabbit	22	0
Mink	6	0
Fox	15	0
Mules and Asses	17	0

Notes:

a. Volatilization and indirect N_2O emission factors are taken from default parameters in the 2006 IPCC Guidelines. Derivation of the Tier 2 emission factors is explained in NIR Annex 3.4.

b. Leaching is not calculated as there are no tier 1 leaching factors available in the 2006 IPCC Guidelines.

Table A6.4–16 2018 Emission Factors (EFs) for Manure Nitrogen (N) Lost as NH_3 Due to Volatilization During Storage

Livestock Category	Emission Factor (EF) (kg NH_3 $head^{-1}$ $year^{-1}$)
Poultry	
Turkey	1.0
Hens	0.3
Pullets	0.1
Broiler	0.2
Other Livestock	
Sheep	0.2
Goat	0.6
Buffalo	12
Horse	2.4
Llama and alpacas	0.7
Lamb	0.2
Deer	2.6
Elk	2.6
Wild boars	4.1
Rabbit	1.7
Mink	0.4
Fox	1.2
Mules and Asses	1.3

Note:
Volatilization factors are taken from default parameters in the 2006 IPCC Guidelines. Derivation of the emission factors is explained in NIR Annex 3.4.

Table A6.4–17 Emission Factors (EFs) for Manure Nitrogen (N) Lost as N_2O From Deposition of Cattle Manure on Pasture, Range and Paddock

Year	EF (g N_2O kg-N^{-1} $year^{-1}$)									
	AB	BC	MB	NB	NL	NS	ON	PE	QC	SK
1990	0.68	0.68	0.68	8.8	9.4	8.8	9.7	7.5	9.5	0.68
2005	0.68	0.68	0.68	8.8	9.5	8.8	9.6	7.5	9.4	0.68
2010	0.68	0.68	0.68	8.8	9.6	8.8	9.6	7.5	9.4	0.68
2018	0.68	0.68	0.68	8.8	9.5	8.8	9.6	7.5	9.4	0.68

Notes:

Emission factors are derived from Rochette et al. 2014 for eastern Canada, and Lemke et al. 2012 for western Canada

The proportion of excreted manure deposited on pasture is taken from Marinier et al. 2005, for all livestock except dairy cows and heifers.

The proportion of excreted manure deposited on pasture by dairy cows and heifers is based on a farm size relationship derived from Sheppard et al. (2011a), as described in Annex 3.4 of the NIR.

Derivation of the Tier 2 emission factors is explained in NIR Annex 3.4.

Table A6.4–18 Emission Factors (EFs) for Manure Nitrogen (N) Lost Indirectly as N_2O Due to Volatilization and Leaching of Manure Deposited on Pasture, Range and Paddock

Year	EF (g N_2O kg-N^{-1} $year^{-1}$)									
	AB	BC	MB	NB	NL	NS	ON	PE	QC	SK
Volatilization[a]										
1990	3.0	2.7	2.9	2.0	1.6	2.0	2.1	1.8	1.6	3.1
2005	3.1	2.9	3.1	2.1	1.5	2.2	2.3	2.1	1.9	3.1
2010	3.1	2.8	3.0	2.1	1.3	2.0	2.3	1.9	1.9	3.1
2018	3.1	2.8	3.0	2.0	1.3	2.0	2.3	1.9	1.7	3.1
Leaching[b]										
1990	1.9	1.8	2.1	3.5	3.5	3.5	3.1	3.5	3.4	1.6
2005	1.8	1.8	2.1	3.5	3.5	3.5	3.1	3.5	3.4	1.6
2010	1.8	1.8	2.1	3.5	3.5	3.5	3.1	3.5	3.4	1.6
2018	1.8	1.8	2.1	3.5	3.5	3.5	3.1	3.5	3.4	1.5

Notes:

a. For dairy cattle, volatilization is calculated based on Sheppard et al. 2011b and Chai et al. 2016, and the IPCC default indirect N_2O emission factor is used. For all other livestock the IPCC Tier 1 methodology is used to estimate indirect N_2O emission factors from volatilization. Default parameters are used from the 2006 IPCC Guidelines as described in NIR Annex 3.4.

b. A modified IPCC Tier 1 methodology is used to estimate N_2O emissions from leaching in agricultural soils, as described in NIR Annex 3.4.

Table A6.4–19 Emission Factors (EFs) for Manure Nitrogen (N) Lost Indirectly as NH_3 Due to Volatilization of Manure Deposited on Pasture, Range and Paddock

Year	EF (kg NH_3 kg N^{-1} $year^{-1}$)									
	AB	BC	MB	NB	NL	NS	ON	PE	QC	SK
1990	0.19	0.17	0.18	0.13	0.10	0.13	0.13	0.12	0.10	0.19
2005	0.20	0.18	0.19	0.14	0.09	0.14	0.15	0.13	0.12	0.20
2010	0.20	0.18	0.19	0.13	0.08	0.13	0.15	0.12	0.12	0.20
2018	0.20	0.18	0.19	0.13	0.08	0.13	0.14	0.12	0.11	0.20

Note:

For dairy cattle, volatilization is calculated based on Sheppard et al. 2011b and Chai et al. 2016. For all livestock except dairy cattle, the IPCC Tier 1 methodology is used to estimate volatilization. Further detail can be found in NIR Annex 3.4.

Table A6.4–20 Emission Factors (EFs) for Crop Residue, Organic and Inorganic Fertilizer Nitrogen (N) Lost as N_2O Following Application to Agricultural Soils

Year	EF (g N_2O kg^{-1} N $year^{-1}$)[a]									
	AB	BC	MB	NB	NL	NS	ON	PE	QC	SK
1990	14	16	14	25	26	24	23	21	26	12
2005	13	16	15	25	26	24	23	21	26	11
2010	13	16	15	25	26	24	23	21	26	11
2018	13	16	14	25	26	24	23	21	26	12

Note:
a. Country-specific Tier 1 soil N_2O emission factors are calculated as described in NIR Annex 3.4.

Table A6.4–21 Emission Factors (EFs) for Manure Nitrogen (N) Lost as NH_3 from Agricultural Soils

Year	EF (g NH_3 kg^{-1} N $year^{-1}$)									
	AB	BC	MB	NB	NL	NS	ON	PE	QC	SK
1990	225	209	219	291	262	289	250	291	267	229
2005	225	198	187	261	249	253	237	275	256	224
2010	224	193	181	249	245	241	234	263	252	225
2018	223	190	173	246	245	240	233	261	252	224

Notes:
For dairy cattle and swine, volatilization is calculated based on Sheppard et al. 2010, Sheppard et al. 2011b and Chai et al. 2016.
For all other livestock the IPCC Tier 1 methodology is used to estimate volatilization. Further detail can be found in Annex 3.4.

Table A6.4–22 Emission Factors (EFs) for Manure Nitrogen (N) Lost Indirectly as N_2O Due to Volatilization and Leaching of Manure Applied to Agricultural Soils

	EF (g N_2O kg^{-1} N applied $year^{-1}$)									
Volatilization[a]	AB	BC	MB	NB	NL	NS	ON	PE	QC	SK
1990	2.9	2.7	2.8	3.8	3.4	3.8	3.2	3.8	3.5	3.0
2005	2.9	2.6	2.4	3.4	3.2	3.3	3.1	3.6	3.3	2.9
2010	2.9	2.5	2.3	3.2	3.2	3.1	3.0	3.4	3.3	2.9
2018	2.9	2.5	2.2	3.2	3.2	3.1	3.0	3.4	3.3	2.9
Leaching[b]	AB	BC	MB	NB	NL	NS	ON	PE	QC	SK
1990	1.9	2.4	2.1	3.5	3.5	3.5	3.1	3.5	3.5	1.6
2005	1.8	2.3	2.1	3.5	3.5	3.5	3.1	3.5	3.5	1.6
2010	1.8	2.4	2.1	3.5	3.5	3.5	3.1	3.5	3.5	1.6
2018	1.8	2.5	2.1	3.5	3.5	3.5	3.1	3.5	3.5	1.6

Notes:
a. For dairy cattle and swine, volatilization is calculated based on Sheppard et al. 2010, Sheppard et al. 2011b and Chai et al. 2016 and the IPCC default indirect N_2O emission factor is used. For all other livestock the IPCC Tier 1 methodology is used to estimate volatilization. Default parameters are used from the 2006 IPCC Guidelines as described in NIR Annex 3.4.
b. A modified IPCC Tier 1 methodology is used to estimate N_2O emissions from leaching in agricultural soils, as described in Annex 3.4.

Table A6.4–23 Fraction of N Volatilized (FRACGASM) as Ammonia Resulting from the Application of Biosolid N to Agricultural Soils

IPCC default emission factor, $FRAC_{GASM}$	0.2 kg NH_3-N volatilized/kg N applied

Note: IPCC (2006)

Table A6.4–24 N_2O Emission Factor for Mid-latitude Cultivation of Organic Soils

IPCC default emission factor for mid-latitude cultivation of organic soils	8.0 kg N_2O-N/ha-year

Note: IPCC (2006)

Table A6.4–25 **Emission Factors (EFs) for Biosolid Nitrogen (N) Lost Indirectly as N_2O Due to Leaching of Biosolids Applied to Agricultural Soils**

	EF (g N_2O kg^{-1} N applied year-1)									
Leaching[b]	AB	BC	MB	NB	NL[a]	NS	ON	PE	QC	SK
1990	2.0	2.0	2.1	3.5	-	3.5	3.1	3.5	3.4	1.5
2005	2.0	2.1	2.1	3.5	-	3.5	3.0	3.5	3.4	1.5
2010	2.0	2.1	2.1	3.5	-	3.5	3.0	3.5	3.4	1.5
2018	2.0	2.0	2.1	3.5	-	3.5	3.0	3.5	3.4	1.5

Notes:

a. Activity data is not available to quantify land application of biosolids in Newfoundland.

b. A modified IPCC Tier 1 methodology is used to estimate N_2O emissions from leaching in agricultural soils, as described in Annex 3.4.

Table A6.4–26 **Fractions of N Volatilized (FRACGASF) as Ammonia Resulting from the Application of Inorganic N Fertilizer, from Select Years, 1990–2018, at a Provincial Scale**

Year	Implied EF (kg NH_3-N volatilized/kg inorganic fertilizer N applied)									
	AB	BC	MB	NB	NL	NS	ON	PE	QC	SK
1990	0.06	0.09	0.06	0.07	0.00	0.07	0.08	0.06	0.09	0.05
1995	0.06	0.09	0.07	0.07	0.08	0.08	0.08	0.06	0.08	0.06
2000	0.06	0.10	0.07	0.06	0.00	0.07	0.08	0.05	0.08	0.06
2005	0.06	0.10	0.07	0.06	0.02	0.07	0.08	0.06	0.07	0.06
2010	0.06	0.09	0.07	0.05	0.07	0.06	0.08	0.05	0.07	0.06
2015	0.06	0.09	0.07	0.06	0.07	0.06	0.07	0.05	0.07	0.06
2018	0.06	0.08	0.07	0.05	0.07	0.06	0.08	0.05	0.08	0.06

Table A6.4–27 **Indirect N_2O Emissions from Agricultural Soils**

Emission factor due to volatilization and redeposition of Nitrogen	0.01 kg N_2O-N/kg N
Emission factor due to leaching/runoff	0.0075 kg N_2O-N/kg N

Note: IPCC (2006)

A6.4.5. Other Sources

Table A6.4–28 **CH_4 and N_2O Emissions from Field Burning of Agricultural Residues**

CH_4 emission factor	2.7 g CH_4 kg^{-1} dry matter burnt
N_2O emission factor	0.07 g N_2O kg^{-1} dry matter burnt

Note: IPCC (2006)

Table A6.4–29 **CO_2 Emissions from Liming and Urea Fertilization**

Dolomite emission factor	0.13 Mg C/ Mg dolomite applied
Limestone emission factor	0.12 Mg C/ Mg limestone applied
Urea emission factor	0.20 Mg C/ Mg urea

Note: IPCC (2006)

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-CFS_3 model is used for estimating growth, litter fall, tree mortality and decomposition, as well as the effects of natural disturbances for Forest Land and the emissions due to forest conversion to other land uses. 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, forest conversion and Cropland is provided in Annex 3.5, sections A3.5.2 and A3.5.4.

A country-specific model (NFCMARS-HWP) is used to estimate the emissions from the use and disposal of Harvested Wood Products (HWP). For details on the methods and parameters used in the model, see section A3.5.3.

Emissions due to the conversion and management of peatlands for peat extraction, the creation of flooded lands (reservoirs) on areas with no evidence of forest clearing and from the conversion of grasslands to Settlements, are estimated using IPCC Tier 2 methods and country-specific parameters (see sections A3.5.6.1, A3.5.6.2 and A3.5.7.3). Net CO_2 removals from the growth of urban trees are estimated using an IPCC Tier 2A approach (see section A3.5.7.1). In addition, emissions due to the occasional burning of grassland are estimated using an IPCC Tier 1 method and default emissions factors (see section A3.5.5.1).

A6. Biomass Combustion

A6.1. 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. Emissions from prescribed burning and from the combustion of biomass for energy use are estimated and reported in the Land Use, Land-use Change and Forestry (LULUCF) sector, in common reporting format (CRF) tables 4(V) and 4.G respectively. Forest wildfires are considered uncontrollable natural disturbances in the modelling and reporting approach used in the LULUCF sector by which these emissions and subsequent removals are estimated and tracked separately from emissions/removals resulting from commercially managed forest stands, more details on his approach can be found in Annex A3.5.2.4.

The emissions related to energy use are reported as memo items in the CRF tables of the Energy sector 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 A6.6–1) 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 0% moisture content (m.c.) using a higher heating value (HHV) of 20.44 MJ/kg, which was developed from an internal review of available moisture content and heating value data. The emission factor for spent pulping 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 0% m.c. using a HHV of 13.7 MJ/kg (Tran 2014).

Table A6.6–1 **Emission Factors for Biomass**

Source[a]	Description	Emission Factor (g/kg fuel)		
		CO_2	CH_4	N_2O
Wood Fuel / Wood Waste	Industrial Combustion	1 715[b]	0.1[c]	0.07[c]
Forest Wildfires	Open Combustion	NA	NA[d]	NA[e]
Controlled Burning	Open Combustion	NA	NA[d]	NA[e]
Spent Pulping Liquor	Industrial Combustion	1 250[f]	0.03[g]	0.005[g]
Stoves and Fireplaces	Residential Combustion			
Conventional Stoves		1 539[h]	12.9[h]	0.12[h]
Conventional Fireplaces and Inserts		1 539[h]	12.9[h]	0.12[h]
Stoves/Fireplaces with Advanced Technology or Catalytic Control		1 539[h]	5.9[h]	0.12[h]
Pellet Stove		1 652[b]	4.12[h]	0.059[h]
Other Wood-burning Equipment		1 539[h]	4.12[h]	0.059[h]

Notes:
NA not applicable

a. 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.
b. Adapted from U.S. EPA (2003).
c. Adapted from U.S. EPA (2003) and NCASI TB_{998} (2012).
d. Emission ratio for CH_4 is 1/90th CO_2. See section A3.4 in Annex 3.
e. Emission ratio for N_2O is 0.017% CO_2. See section A3.4 in Annex 3.
f. Adapted from NCASI (2011).
g. Adapted from NCASI (2012).
h. Adapted from IPCC (2006).

Table A6.6–2 **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

Note: Adapted from IPCC (2006), Volume 2, Energy, Table 2.2.

CO_2 emission factor for residential combustion (Table A6.6–1) 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 A6.6–1) 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 collected by the National Council for Air and Stream Improvements (NCASI) in units of kg/MMBTU and converted to kg/tonne at 0% m.c. as discussed in section A6.6.1. The emission factor for CH_4 from spent pulping liquor has been developed using source sampling data from NCASI in units of kg/MMBTU, converted to kg/tonne at 0% m.c. using a HHV of 13.7 MJ/kg as discussed in section A6.6.1.

Emission factors from landfill gas (Table A6.6–2) 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.

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 A6.6–1) for 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 collected by the National Council for Air and Stream Improvements (NCASI) in units of kg/MMBTU and converted to kg/tonne at 0% m.c. as discussed in section A6.6.1. The emission factor for N_2O from spent pulping liquor has been developed using source sampling data from NCASI in units of kg/MMBTU, converted to kg/tonne at 0% m.c. using a HHV of 13.7 MJ/kg as discussed in section A6.6.1.

Emission factors for landfill gas (Table A6.6–2) 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

A6.7.1.1. CH_4

Emissions from municipal wastewater handling are dependent on the organic loading of the effluent stream (which is a function of population), and the type of wastewater treatment provided. Emission factors are the product of the methane correction factor (MCF), which is the technology-specific estimate of the fraction of biological oxygen demand (BOD) that will ultimately degrade anaerobically, and the maximum methane producing capacity (B_0), which is expressed in terms of kg CH_4/kg BOD removed. The IPCC default value of 0.6 kg CH_4/kg BOD for B_0 was not used. The AECOM (2011) study commissioned by Environment Canada confirmed that its derivation from the 0.25 kg CH_4/kg COD

Table A6.7–1 **Emission Factors for CH_4 from Wastewater Treatment and Discharge**

Treatment	MCF	EF	Source
Aerobic Lagoon	0	0	IPCC 2006 Guidelines, Vol 5, Chapter 6, Table 6.3
Anaerobic Lagoon	0.8	0.288	IPCC 2006 Guidelines, Vol 5, Chapter 6, Table 6.3
Facultative Lagoon	0.2	0.072	IPCC 2006 Guidelines, Vol 5, Chapter 6, Table 6.3
Lagoon (Unspecified Lagoon)	0.2	0.072[a]	IPCC 2006 Guidelines, Vol 5, Chapter 6, Table 6.3
No Treatment	0.1	0.036[b]	IPCC 2006 Guidelines, Vol 5, Chapter 6, Table 6.3
Centralized Aerobic—Primary	0	0	IPCC 2006 Guidelines, Vol 5, Chapter 6, Table 6.3
Centralized Aerobic—Secondary	0	0	IPCC 2006 Guidelines, Vol 5, Chapter 6, Table 6.3
Centralized Anaerobic	0.8	0.288	IPCC 2006 Guidelines, Vol 5, Chapter 6, Table 6.3
Septic	0.5	0.18	IPCC 2006 Guidelines, Vol 5, Chapter 6, Table 6.3
Unknown/Other	0.15	0.054[c]	ECCC Best Judgement
Wetland	0.17	0.0612[d]	IPCC Suppmenent to 2006 Guidelines for Wetlands (2014)
Sequence Batch Reactor	0.05	0.018	Taşeli et al., 2018

Notes:

a. Unspecified Lagoon types were assumed to be facultative.
b. Discharge to sea, river or lake.
c. Assuming facilities of unknown or other treatment type are either facultative lagoon or untreated discharge to sea. The median value of the MCFs and EFs of these technologies used.
d. Mean value of three possible wetland treatment types used.

Table A6.7–2 **Emission Factors for N_2O from Wastewater Treatment and Discharge**

N_2O Emission Factor	Units	Source
0.005	kg N_2ON/kg N	IPCC 2006 Guidelines, Volume 5, Chapter 6

was erroneous, where COD is the chemical oxygen demand. A Canada specific value of 0.36 CH_4/kg BOD for B_0 was used (AECOM 2011).

The MCF values and emission factors for CH_4 emissions from wastewater treatment and discharge, by treatment technology are shown in Table A6.7–1.

A6.7.1.2. N_2O

N_2O emissions from wastewater are a function of the nitrogen entering the wastewater stream, which is, in turn a function of protein consumption per capita, population, nitrogen content in protein, and adjustment factors for input of non-consumed nitrogen (e.g. from washing) and industrial inputs. The emission factor used is the IPCC 2006 Guideline default value of 0.005 kg N_2O-N/kg N (IPCC 2006). The emission factor for N_2O from wastewater treatment and discharge is shown in Table A6.7–2.

A6.7.2. Waste Incineration

The emission factors for waste incineration are shown in Table A6.7–3.

A6.7.2.1. Sewage Sludge Incinerators

Emissions from sewage sludge incinerators are estimated from an emission factorobtained from the IPCC 2006 Guidelines.

A6.7.2.2. Municipal Solid Waste Incinerators

The emission estimates from municipal solid waste incineration are calculated based on bach or continuous operation, and based on stoker or fluidized bed combustion technology. The emission factors used are from the IPCC 2006 Guidelines (IPCC 2006). For CO_2 emisisons, only the non-biogenic (fossil) portion of the waste is included when calculating emissions.

A6.7.2.3. Hazardous Waste Incinerators

The emission factors for hazardous waste incinartion are taken from the IPCC 2006 Guidelines (IPCC 2006). The CO_2 emission factor is based on a carbon content of 50% and fossil carbon content of 90% of the carbon content.

A6.7.2.4. Clinical Waste Incinerators

The emission factors for clinical waste incineration are taken from the IPCC 2006 Guidelines (IPCC 2006). The CO_2 emission factor is based on a carbon content of 45%.

Table A6.7–3 **Emission Factors for Waste Incineration**					
Category	Emission Factor			Units	Source
	CO_2	CH_4	N_2O		
Municipal Solid Waste Incineration—Continuous—Fluidized Bed	3 666.67*	0.0002	0.00005	kg / tonne waste (for CH_4, N_2), *kg CO_2 / tonne fossil C in waste	IPCC (2006)
Municipal Solid Waste Incineration—Continuous—Stoker		0	0.00005		IPCC (2006)
Municipal Solid Waste Incineration—Semi-Continuous—Fluidize Bed		0.006	0.00005		IPCC (2006)
Municipal Solid Waste Incineration—Semi-Continuous—Stoker		0.188	0.00005		IPCC (2006)
Municipal Solid Waste Incineration—Batch—Fluidized Bed		0.06	0.00006		IPCC (2006)
Municipal Solid Waste Incineration—Batch—Stoker		0.237	0.00006		IPCC (2006)
Sewage Sludge Incineration	1 650.00	9.70	0.99	kg / tonne sewage sludge	IPCC (2006)
Hazardous Waste Incineration	1 650.00	0.20	0.10	kg / tonne waste	IPCC (2006)
Clinical Waste Incineration—Continuous	1 738.00	0.0002	0.05	kg / tonne wase	IPCC (2006)
Clinical Waste Incineration—Batch	1 738.00	0.06	0.06	kg / tonne waste	IPCC (2006)

A6.7.3. Biological Treatment of Solid Waste

The emission factors for the biological treatment of solid waste are shown in Table A6.7–4.

Table A6.7–4 **Emission Factors for the Biological Treatment of Solid Waste**					
Category	Emission Factor			Units	Source
	CO_2	CH_4	N_2O		
Anaerobic Digestion	-	-	-	-	Not Estimated
Composting	-	4	0.24	g / kg Waste	IPCC 2006 Guidelines, Vol5 Chapter 2 Table 4.1 Default for Canada

ANNEX 7

OZONE AND AEROSOL PRECURSORS

The Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC) (FCCC/CP/2013/10/Add.3—UNFCCC 2014) recommends that Parties provide information on indirect greenhouse gases (GHG) such as carbon monoxide (CO), nitrogen oxides (NO_x), non-methane volatile organic compounds (NMVOC) and sulphur oxides (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 GHG and quickly react to form GHG, as in the case of carbon monoxide (CO) reacting with a hydroxyl radical to form CO_2 in the atmosphere—hence the label "indirect greenhouse gases." Emissions from these precursors are produced by a number of sources, such as fossil fuel combustion in the energy and transportation sectors, industrial production and biomass combustion.

Information on ozone and aerosol precursor emissions in Canada, including CO, NO_x, NMVOC and SO_x is available on Canada.ca[1].

Canada also reports "indirect CO_2 emissions" that result from the atmospheric oxidation of CO emitted from biomass burned on site after forest harvest and from forest conversion activities. These emissions are reported in the Land Use, Land-use Change, and Forestry (LULUCF) sector within Table 6 of the Common Reporting Format (CRF)[2]. National totals are presented in CRF Tables 10 and Summary 2 with and without these "indirect CO_2 emissions" in accordance with paragraph 29 of the UNFCCC Annex I inventory reporting guidelines (UNFCCC 2014). Details on the source of these emissions can be found in Chapter 6 and Annex 3.5 of this report.

1 Canada's Air Pollutant Emissions Inventory data can be found at www.canada.ca/APEI.

2 Canada's 2020 Common Reporting Format Tables can be found at https://unfccc.int/ghg-inventories-annex-i-parties/2020.

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