Environment Canada

Environnement Canada

National Inventory Report

1990–2013

GREENHOUSE GAS SOURCES AND SINKS IN CANADA

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

Part 2

Canada

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List of Acronyms, Abbreviations and Units

AAC	Aluminum Association of Canada
AAFC	Agriculture and Agri-Food Canada
AC	air conditioning
AEDT	Aviation Environmental Design Tool
AER	Alberta Energy Regulator
AGEM	Aviation Greenhouse Gas Emission Model
AIA	Association de l'industrie d'aluminium du Québec
Al	aluminium
Al_2O_3	alumina
API	American Petroleum Institute
ASH	manure ash content
Asha	Ash content in baked anodes
Ashp	Ash content in pitch
ATV	all-terrain vehicle
AWMS	animal waste management system
BADA	Base of Aircraft Data
B_0	maximum methane production potential
BC	average binder content in paste
BOF	basic oxygen furnace
BOD_5	five-day biochemical oxygen demand
BSM	emissions of benzene-soluble matter
C	carbon
CAC	Criteria Air Contaminant (for Land Use, Land-use Change and Forestry Sector)
CAC	Cement Association of Canada (for Industrial Proccesses and Product Use Sector)
CaC_2	calcium carbide
$CaCO_3$	calcium carbonate; limestone
$CaMg(CO_3)_2$	dolomite (also $CaCO_3 \cdot MgCO_3$)
CanFI	Canada's National Forest Inventory
CANSIM	Statistics Canada's key socioeconomic database
CanSIS	Canadian Soil Information System
CanWEA	Canadian Wind Energy Association
CaO	lime; quicklime; calcined limestone
CAPP	Canadian Association of Petroleum Producers
CBM	Carbon Budget Model
CBM-CFS3	Carbon Budget Model for the Canadian Forest Sector, version 3
CC	baked anode consumption per tonne of aluminium
CEA	Canadian Electricity Association
CEPA 1999	*Canadian Environmental Protection Act, 1999*
CESI	Canadian Environmental Sustainability Indicators
CF_4	carbon tetrafluoride
C_2F_6	carbon hexafluoride
CFC	chlorofluorocarbon
CFS	Canadian Forest Service
CGA	Canadian Gas Association
CH_3OH	methanol
CH_4	methane
C_2H_6	ethane
C_3H_8	propane
C_4H_{10}	butane
C_2H_4	ethylene

C_6H_6	benzene
$CHCl_3$	chloroform
CIEEDAC	Canadian Industrial Energy End-Use Data Analysis Centre
CKD	cement kiln dust
CLRTAP	Convention on Long-range Transboundary Air Pollution
CO	carbon monoxide
CO_2	carbon dioxide
CO_2 eq	carbon dioxide equivalent
COD	chemical oxygen demand
CORINAIR	Core Inventory of Air Emissions in Europe
CPPI	Canadian Petroleum Products Institute
CRF	Common Reporting Format
CRW	crown cover area growth rate
CSPA	Canadian Steel Producers Association
CTS	crop and tillage system
CVS	Canadian Vehicle Survey
DE	digestible energy
DEF	diesel exhaust fluid
DM	dry matter
DMI	dry matter intake
DOC	dissolved organic carbon (for LULUCF Sector)
DOC	degradable organic carbon (for Waste Sector)
DOCF	degradable organic carbon dissimilated
DOM	dead organic matter
EAF	electric arc furnace
EC	Environment Canada
EDC	ethylene dichloride
EF	emission factor
EF_{BASE}	base emission factor
EMEP	European Monitoring and Evaluation Programme
EO	Earth Observation
EPA	Environmental Protection Agency (United States)
EPGTD	Electric Power Generation, Transmission and Distribution
eq	equivalent
ERCB	Energy Resources Conservation Board
ERS	Economic Research Service (USDA)
ERT	Expert Review Team
EU	European Union
FAA	Federal Aviation Administration (United States)
FAACS	Feasibility Assessment of Afforestation for Carbon Sequestration
FCR	fuel consumption ratio
FGD	flue gas desulphurization
FLCL	forest land converted to cropland
FLWL	forest land converted to wetland
FOCA	Federal Office of Civil Aviation
FOI	Swedish Defence Research Agency
F_{TILL}	tillage ratio factor
GCD	great-circle distance
GCV	gross calorific value
GDP	gross domestic product
GE	gross energy
GHG	greenhouse gas
GHGRP	Greenhouse Gas Reporting Program

GIS	geographic information system
GO	gross output
Gt	gigatonne
GRI	Gas Research Institute
GTIS	Global Trade Information Services
GVWR	gross vehicle weight rating
GWP	global warming potential
H_2	hydrogen
H_2O	water
H_2S	hydrogen sulphide
HCFC	hydrochlorofluorocarbon
HCl	hydrochloric acid
HDD	heating degree-day
HDDV	heavy-duty diesel vehicle
HDGV	heavy-duty gasoline vehicle
HE	harvest emissions
HF	hydrogen fluoride
HFC	hydrofluorocarbon
HHV	higher heating value
HNO_3	nitric acid
HQ	Hydro-Québec
HRAI	Heating, Refrigeration and Air Conditioning Institute of Canada
HSS	horizontal stud Søderberg
HWP	harvested wood products
HWP-C	carbon stored in harvested wood products
IAI	International Aluminium Institute
ICAO	International Civil Aviation Organization
IE	included elsewhere
IEA	International Energy Agency
IESO	Independent Electricity System Operator
I/M	inspection and maintenance
Impa	fluorine and other impurities
IPCC	Intergovernmental Panel on Climate Change
IPPU	Industrial Processes and Product Use
IT	intensive tillage
KAR	kilometre accumulation rate
K_2CO_3	potassium carbonate
kg	kilogram
kha	kilohectare
kt	kilotonne
kWh	kilowatt-hour
L_0	methane generation potential
LDDT	light-duty diesel truck
LDDV	light-duty diesel vehicle
LDGT	light-duty gasoline truck
LDGV	light-duty gasoline vehicle
LFG	landfill gas
LHV	lower heating value
LMC	land management change
LPG	liquefied petroleum gases
LTO	landing and takeoff
LULUCF	Land Use, Land-use Change and Forestry
m	metre

MARS	Monitoring, Accounting and Reporting System
MC	motorcycle
MCF	methane conversion factor (Agriculture)
MCF	methane correction factor (Waste)
Mg	magnesium; also megagram
$MgCO_3$	magnesite; magnesium carbonate
MGEM	Mobile Greenhouse Gas Emission Model
MgO	magnesia; dolomitic lime
Mha	megahectare, equivalent to a million hectares
MI	Manufactured Items
MMIC	Motorcycle & Moped Industry Council
MODTF	Modeling and Database Task Force
mol	mole
MP	total aluminum production
MS	manure system distribution factor
MSW	municipal solid waste
Mt	megatonne
MTOW	maximum takeoff weight
MW	megawatt
N	nitrogen
N_2	nitrogen gas
Na_2CO_3	sodium carbonate; soda ash
Na_3AlF_6	cryolite
NA	not applicable
N/A	not available
NAICS	North American Industry Classification System
NAP	National Action Plan
NCASI	National Council for Air and Stream Improvement
NCV	net calorific value
NE	not estimated
NEB	National Energy Board
NEU	non-energy use
NFI	National Forest Inventory
NFR	nomenclature for reporting
NGL	natural gas liquid
NH_3	ammonia
NH_4^+	ammonium
NH_4NO_3	ammonium nitrate
NIR	National Inventory Report
NMVOC	non-methane volatile organic compound
N_2O	nitrous oxide
NO	nitric oxide; also used for not occurring
NO_2	nitrogen dioxide
NO_3^-	nitrate
NO_x	nitrogen oxides
NOC	Nitrous Oxide of Canada
NPRI	National Pollutant Release Inventory
NRCan	Natural Resources Canada
NSCR	non-selective catalytic reduction
NT	no tillage
O_2	oxygen
ODS	ozone-depleting substance
OECD	Organisation for Economic Co-operation and Development

OEM	original equipment manufacturer
OS/HOU	oil sands and heavy oil upgrading
PC	paste consumption
PFC	perfluorocarbon
PIRD	Pollutant Inventories and Reporting Division
PJ	petajoule
POP	persistent organic pollutant
P/PE	precipitation/potential evapotranspiration
PTRC	Petroleum Technology Research Centre
QA	quality assurance
QC	quality control
RA	reference approach
RESD	*Report on Energy Supply and Demand in Canada*
RPP	refined petroleum product
RT	reduced tillage
RTI	Research Triangle Institute
SA	sectoral approach
Sa	sulphur content in baked anodes
SAGE	System for assessing Aviation's Global Emissions
SBR	styrene-butadiene
Sc	sulphur content in calcinated coke
SCR	selective catalytic reduction
SF_6	sulphur hexafluoride
SIC	Standard Industrial Classification
SiC	silicon carbide
SLC	Soil Landscapes of Canada
SMR	steam methane reforming
SO_2	sulphur dioxide
SO_x	sulphur oxides
SOC	soil organic carbon
Sp	sulphur content in pitch
SUV	sport utility vehicle
t	tonne
TWh	terrawatt-hour
UNECE	United Nations Economic Commission for Europe
UNFCCC	United Nations Framework Convention on Climate Change
UPCIS	Use Patterns and Controls Implementation Section
UOG	upstream oil and gas
UTC	urban tree crown
USDA	United States Department of Agriculture
VCM	vinyl chloride monomer
VKT	vehicle kilometres travelled
VSS	vertical stud Søderberg
VS	volatile solids
WMO	World Meteorological Organization

Table of Contents

List of Tables

List of Figures

Annex 1

Key Categories

A1.1.   Key Categories— Methodology

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

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

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

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

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

Level Assessment

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

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

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

where:

$L_{x,t}$	=	level assessment for source or sink x in latest inventory year (year t)
$|E_{x,t}|$	=	the absolute value of emission or removal estimate of source or sink category x in year t
$\sum_y |E_{y,t}|$	=	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 Equations A1-2and 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.

A1

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

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

where:

$T_{x,t}$	=	trend assessment of source or sink category x in year t as compared to the base year (year 0)
$L_{x,0}$	=	the level assessment for source or sink category x in year 0 (derived in Equation A1-1)
$E_{x,t}$ and $E_{x,o}$	=	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:

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

where:

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

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

A1.1.1.   Summary Assessment

Key categories were assessed for the 2013 inventory year using level and trend criteria and for the base year using the level criterion only.

There were 30 level key categories in 1990, while in 2013 there were 38 with all combined criteria. Results are shown in Table A1–1.

Table A1–1   Key Category Analysis Summary, 2013 Inventory Year

Source Table	IPCC Category	Direct GHG	Key Category (1990/2013)	Criteria (1990/2013) L: Level, T: Trend
1-A*	Stationary Fuel Combustion - Solid Fuels	CO_2	Yes / Yes	L / L , T
1-A*	Stationary Fuel Combustion - Solid Fuels	CH_4	No / No	
1-A*	Stationary Fuel Combustion - Solid Fuels	N_2O	No / No	
1-A*	Stationary Fuel Combustion - Liquid Fuels	CO_2	Yes / Yes	L / L , T
1-A*	Stationary Fuel Combustion - Liquid Fuels	CH_4	No / No	
1-A*	Stationary Fuel Combustion - Liquid Fuels	N_2O	No / No	
1-A*	Stationary Fuel Combustion - Gaseous Fuels	CO_2	Yes / Yes	L / L , T
1-A*	Stationary Fuel Combustion - Gaseous Fuels	CH_4	No / No	
1-A*	Stationary Fuel Combustion - Gaseous Fuels	N_2O	No / No	
1-A*	Stationary Fuel Combustion - Other Fuels	CO_2	No / No	
1-A*	Stationary Fuel Combustion - Other Fuels	CH_4	No / No	
1-A*	Stationary Fuel Combustion - Other Fuels	N_2O	No / No	
1-A*	Stationary Fuel Combustion - Fugitives	CO_2	No / No	
1-A*	Stationary Fuel Combustion - Fugitives	CH_4	No / No	

Table A1-1   Key Category Analysis Summary, 2013 Inventory Year   (cont'd)

Source Table	IPCC Category	Direct GHG	Key Category (1990/2013)	Criteria (1990/2013) L: Level, T: Trend
1-A*	Stationary Fuel Combustion - Fugitives	N_2O	No / No	
1-A*	Stationary Fuel Combustion - Biomass	CO_2	No / No	
1-A*	Stationary Fuel Combustion - Biomass	CH_4	Yes / Yes	L / L , T
1-A*	Stationary Fuel Combustion - Biomass	N_2O	No / No	
1-A-3-a	Fuel Combustion - Domestic Aviation	CO_2	Yes / Yes	L / L
1-A-3-a	Fuel Combustion - Domestic Aviation	CH_4	No / No	
1-A-3-a	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	Fuel Combustion - Other Transport (Off Road)	CO_2	Yes / Yes	L / L , T
1-A-3-e	Fuel Combustion - Other Transport (Off Road)	CH_4	No / No	
1-A-3-e	Fuel Combustion - Other Transport (Off Road)	N_2O	No / Yes	T
1-A-3-e-i	Fuel Combustion - Pipeline Transport	CO_2	Yes / Yes	L / L , T
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-B-1-a	Fugitive Emissions - Coal Mining and Handling	CH_4	No / Yes	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-4-b	IPPU - Other Uses of Soda Ash	CO_2	No / No	
2-A-4-c	IPPU - Other (Magnesite Use)	CO_2	No / No	
2-A-4-d	IPPU - Other (Limestone and Dolomite Use Other)	CO_2	No / No	
2-B-1	IPPU - Ammonia Production	CO_2	No / No	
2-B-2	IPPU - Nitric Acid Production	N_2O	No / No	
2-B-3	IPPU - Adipic Acid Production	N_2O	Yes / Yes	L / T
2-B-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
2-C-1	IPPU - Iron and Steel Production	CO_2	Yes / Yes	L / L , T
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	

A1

Table A1-1   Key Category Analysis Summary, 2013 Inventory Year   (cont'd)

Source Table	IPCC Category	Direct GHG	Key Category (1990/2013)	Criteria (1990/2013) L: Level, T: Trend
2-E-1	IPPU - Integrated Circuit or Semiconductor	SF_6	No / No	
2-E-1	IPPU - Integrated Circuit or Semiconductor	NF_3	No / No	
2-E-5	IPPU - Other	PFCs	No / No	
2-F	IPPU - Product Uses as Substitutes for Ozone Depleting Substances	HFCs	No / Yes	L , T
2-F	IPPU - Product Uses as Substitutes for Ozone Depleting Substances	PFCs	No / No	
2-G-1	IPPU - Electrical Equipment	SF_6	No / No	
2-G-2	IPPU - SF_6 and PFCs from Other Product Use	PFCs	No / No	
2-G-3-a	IPPU - Medical Applications of N_2O	N_2O	No / No	
2-G-3-b	IPPU - Use of N_2O for Propellant	N_2O	No / No	
2-G-4	IPPU - Other (Use of Urea in SCR vehicles)	CO_2	No / No	
3-A	Agriculture - Enteric Fermentation	CH_4	Yes / Yes	L / L , T
3-B	Agriculture - Manure Management	CH_4	Yes / No	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 , T
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 / Yes	T
3-I	Agriculture - Other Carbon-Containing Fertilizers	CO_2	No / No	
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 / Yes	L , T
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-2	LULUCF - Land converted to Wetlands	CO_2	Yes / Yes	L / T
4-D-2	LULUCF - Land converted to Wetlands	CH_4	No / No	
4-D-2	LULUCF - Land converted to Wetlands	N_2O	No / No	
4-E-2	LULUCF - Settlements remaining Settlements	CO_2	No / No	
4-E-2	LULUCF - Land converted to Settlements	CO_2	Yes / Yes	L / L
4-E-2	LULUCF - Land converted to Settlements	CH_4	No / No	
4-E-2	LULUCF - Land converted to Settlements	N_2O	No / No	
4-C	LULUCF - Grassland	CH_4	No / No	
4-C	LULUCF - Grassland	N_2O	No / No	
4-G	LULUCF - Harvested Wood Products (HWP)	CO_2	Yes / Yes	L / L , T
5-A-1	Waste - Solid Waste Disposal	CH_4	Yes / Yes	L / L , T
5-C-1	Waste - Incineration and Open Burning of Waste	CO_2	No / No	
5-C-1	Waste - Incineration and Open Burning of Waste	N_2O	No / No	
5-C-1	Waste - Incineration and Open Burning of Waste	CH_4	No / No	
5-D-1	Waste - Wastewater Treatment and Discharge	CH_4	No / No	
5-D-1	Waste - Wastewater Treatment and Discharge	N_2O	No / No	

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

A1.2. Key Category Tables

A1.2.1. Level Assessment With and Without LULUCF

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

Table A1–3 shows the 2013 key categories identified from level assessment with and without LULUCF.

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

Source Table	IPCC Category	Direct Greenhouse Gas	GHG Emission Estimates (kt CO_2 eq) Base Year 1990	GHG Emission Estimates (kt CO_2 eq) Current Year 2013	Level Assessment without LULUCF	Level Assessment with LULUCF	Cumulative Total without LULUCF	Cumulative Total with LULUCF
4-A-1	LULUCF - Forest Land remaining Forest Land	CO_2	-253 227	-169 258	NA	0.244	NA	0.24
4-G	LULUCF - Harvested Wood Products (HWP)	CO_2	140 365	145 225	NA	0.135	NA	0.38
1-A*	Stationary Fuel Combustion - Gaseous Fuels	CO_2	118 177	189 321	0.193	0.114	0.19	0.49
1-A-3-b	Fuel Combustion - Road Transportation	CO_2	94 263	133 880	0.154	0.091	0.35	0.58
1-A*	Stationary Fuel Combustion - Solid Fuels	CO_2	87 000	69 559	0.142	0.084	0.49	0.67
1-A*	Stationary Fuel Combustion - Liquid Fuels	CO_2	71 356	55 714	0.116	0.069	0.61	0.74
3-A	Agriculture - Enteric Fermentation	CH_4	22 838	25 234	0.037	0.022	0.64	0.76
5-A-1	Waste - Solid Waste Disposal	CH_4	22 332	23 743	0.036	0.021	0.68	0.78
1-A-3-e	Fuel Combustion - Other Transport (Off Road)	CO_2	21 991	36 946	0.036	0.021	0.71	0.80
1-B-2-(b+c)	Fugitive Emissions - Natural Gas	CH_4	17 600	19 810	0.029	0.017	0.74	0.82
1-B-2-(a+c)	Fugitive Emissions - Oil	CH_4	16 741	23 929	0.027	0.016	0.77	0.83
3-D-1	Agriculture - Direct N_2O Emissions from Managed Soils	N_2O	14 214	19 540	0.023	0.014	0.79	0.85
2-B-3	IPPU - Adipic Acid Production	N_2O	10 303	0	0.017	0.010	0.81	0.86
2-C-1	IPPU - Iron and Steel Production	CO_2	10 193	7 532	0.017	0.010	0.83	0.87
4-B-2	LULUCF - Land converted to Cropland	CO_2	9 364	3 511	NA	0.009	NA	0.88
2-C-3	IPPU - Aluminium Production	PFCs	7 558	1 594	0.012	0.007	0.84	0.88
2-D-1	IPPU - Non-Energy Products from Fuels and Solvent Use	CO_2	7 360	18 153	0.012	0.007	0.85	0.89
1-A-3-a	Fuel Combustion - Domestic Aviation	CO_2	7 093	7 435	0.012	0.007	0.86	0.90
1-A*	Stationary Fuel Combustion - Biomass	CH_4	6 727	5 047	0.011	0.006	0.87	0.90
1-A-3-e-i	Fuel Combustion - Pipeline Transport	CO_2	6 685	6 188	0.011	0.006	0.89	0.91
4-E-2	LULUCF - Land converted to Settlements	CO_2	6 591	6 750	NA	0.006	NA	0.92
1-A-3-c	Fuel Combustion - Railways	CO_2	6 222	6 542	0.010	0.006	0.90	0.92
1-B-2-(b+c)	Fugitive Emissions - Natural Gas	CO_2	6 129	5 445	0.010	0.006	0.91	0.93
2-A-1	IPPU - Cement Production	CO_2	5 760	5 986	0.009	0.006	0.91	0.93
1-B-2-(a+c)	Fugitive Emissions - Oil	CO_2	5 477	7 740	0.009	0.005	0.92	0.94
1-A-3-d	Fuel Combustion - Domestic Navigation	CO_2	4 741	5 048	0.008	0.005	0.93	0.94
4-D-2	LULUCF - Land converted to Wetlands	CO_2	4 648	1 273	NA	0.004	NA	0.95
3-B	Agriculture - Manure Management	CH_4	3 507	3 701	0.006	0.003	0.94	NA
3-B	Agriculture - Manure Management	N_2O	3 132	3 604	0.005	0.003	0.94	NA
1-A-3-b	Fuel Combustion - Road Transportation	N_2O	3 072	2 471	0.005	0.003	0.95	NA

Note: NA = Not Applicable

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Table A1–3   2013 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 2013	without LULUCF	with LULUCF	without LULUCF	with LULUCF
1-A*	Stationary Fuel Combustion - Gaseous Fuels	CO_2	118 177	189 321	0.261	0.176	0.26	0.18
4-A-1	LULUCF - Forest Land remaining Forest Land	CO_2	-253 227	-169 258	NA	0.157	NA	0.33
4-G	LULUCF - Harvested Wood Products (HWP)	CO_2	140 365	145 225	NA	0.135	NA	0.47
1-A-3-b	Fuel Combustion - Road Transportation	CO_2	94 263	133 880	0.184	0.124	0.45	0.59
1-A*	Stationary Fuel Combustion - Solid Fuels	CO_2	87 000	69 559	0.096	0.065	0.54	0.66
1-A*	Stationary Fuel Combustion - Liquid Fuels	CO_2	71 356	55 714	0.077	0.052	0.62	0.71
1-A-3-e	Fuel Combustion - Other Transport (Off Road)	CO_2	21 991	36 946	0.051	0.034	0.67	0.74
3-A	Agriculture - Enteric Fermentation	CH_4	22 838	25 234	0.035	0.023	0.70	0.77
1-B-2-(a+c)	Fugitive Emissions - Oil	CH_4	16 741	23 929	0.033	0.022	0.74	0.79
5-A-1	Waste - Solid Waste Disposal	CH_4	22 332	23 743	0.033	0.022	0.77	0.81
1-B-2-(b+c)	Fugitive Emissions - Natural Gas	CH_4	17 600	19 810	0.027	0.018	0.80	0.83
3-D-1	Agriculture - Direct N_2O Emissions from Managed Soils	N_2O	14 214	19 540	0.027	0.018	0.82	0.85
2-D-1	IPPU - Non-Energy Products from Fuels and Solvent Use	CO_2	7 360	18 153	0.025	0.017	0.85	0.86
4-B-1	LULUCF - Cropland remaining Cropland	CO_2	477	-11 109	NA	0.010	NA	0.87
1-B-2-(a+c)	Fugitive Emissions - Oil	CO_2	5 477	7 740	0.011	0.007	0.86	0.88
2-C-1	IPPU - Iron and Steel Production	CO_2	10 193	7 532	0.010	0.007	0.87	0.89
1-A-3-a	Fuel Combustion - Domestic Aviation	CO_2	7 093	7 435	0.010	0.007	0.88	0.89
4-E-2	LULUCF - Land converted to Settlements	CO_2	6 591	6 750	NA	0.006	NA	0.90
1-A-3-c	Fuel Combustion - Railways	CO_2	6 222	6 542	0.009	0.006	0.89	0.91
2-F	IPPU - Product Uses as Substitutes for Ozone Depleting Substances	HFCs	0	6 402	0.009	0.006	0.90	0.91
1-A-3-e-i	Fuel Combustion - Pipeline Transport	CO_2	6 685	6 188	0.009	0.006	0.91	0.92
2-A-1	IPPU - Cement Production	CO_2	5 760	5 986	0.008	0.006	0.91	0.92
4-A-1	LULUCF - Forest Land remaining Forest Land	CH_4	3 502	5 508	NA	0.005	NA	0.93
1-B-2-(b+c)	Fugitive Emissions - Natural Gas	CO_2	6 129	5 445	0.008	0.005	0.92	0.93
2-C-3	IPPU - Aluminium Production	CO_2	2 715	5 123	0.007	0.005	0.93	0.94
1-A-3-d	Fuel Combustion - Domestic Navigation	CO_2	4 741	5 048	0.007	0.005	0.94	0.94
1-A*	Stationary Fuel Combustion - Biomass	CH_4	6 727	5 047	0.007	0.005	0.94	0.95
3-D-2	Agriculture - Indirect N_2O Emissions from Managed Soils	N_2O	2 992	4 620	0.006	0.004	0.95	NA

Note: NA = Not Applicable

A1.2.2. Trend Assessment With and Without LULUCF

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

The integration of the LULUCF Sector introduces additional key categories and alters the categories' relative contributions and overall trends, which causes a rearrangement in the ranking of key categories. For example, a single LULUCF category, Forest Land Remaining Forest Land (CO_2), is ranked as the second highest contributor in both the 2013 level and trend assessments.

The trend assessment without LULUCF identifies 26 key categories (up from 20 in 2012), while the same analysis with LULUCF results in 29 key categories (up from 27 in 2012), including six categories from the LULUCF Sector.

Table A1–4   Key Categories by Trend Assessment with LULUCF

Source Table	IPCC Category	Direct Greenhouse Gas	GHG Emission Estimates (kt CO_2 eq)		Trend Assessment	Contribution to Trend	Cumulative Total
			Base Year 1990	Current Year 2013			
1-A*	Stationary Fuel Combustion - Gaseous Fuels	CO_2	118 177	189 321	0.048	0.160	0.16
4-A-1	LULUCF - Forest Land remaining Forest Land	CO_2	-253 227	-169 258	0.037	0.123	0.28
1-A*	Stationary Fuel Combustion - Solid Fuels	CO_2	87 000	69 559	0.032	0.105	0.39
1-A*	Stationary Fuel Combustion - Liquid Fuels	CO_2	71 356	55 714	0.027	0.091	0.48
1-A-3-b	Fuel Combustion - Road Transportation	CO_2	94 263	133 880	0.022	0.073	0.55
4-G	LULUCF - Harvested Wood Products (HWP)	CO_2	140 365	145 225	0.019	0.065	0.62
2-B-3	IPPU - Adipic Acid Production	N_2O	10 303	0	0.012	0.039	0.65
4-B-1	LULUCF - Cropland remaining Cropland	CO_2	477	-11 109	0.011	0.037	0.69
1-A-3-e	Fuel Combustion - Other Transport (Off Road)	CO_2	21 991	36 946	0.011	0.035	0.73
2-D-1	IPPU - Non-Energy Products from Fuels and Solvent Use	CO_2	7 360	18 153	0.009	0.030	0.76
4-B-2	LULUCF - Land converted to Cropland	CO_2	9 364	3 511	0.007	0.024	0.78
2-C-3	IPPU - Aluminium Production	PFCs	7 558	1 594	0.007	0.023	0.81
2-F	IPPU - Product Uses as Substitutes for Ozone Depleting Substances	HFCs	0	6 402	0.006	0.020	0.83
2-C-1	IPPU - Iron and Steel Production	CO_2	10 193	7 532	0.004	0.014	0.84
4-D-2	LULUCF - Land converted to Wetlands	CO_2	4 648	1 273	0.004	0.013	0.85
1-B-2-(a+c)	Fugitive Emissions - Oil	CH_4	16 741	23 929	0.004	0.013	0.87
2-C-4	IPPU - Magnesium Production	SF_6	2 738	0	0.003	0.010	0.88
1-A*	Stationary Fuel Combustion - Biomass	CH_4	6 727	5 047	0.003	0.009	0.89
3-D-1	Agriculture - Direct N_2O Emissions from Managed Soils	N_2O	14 214	19 540	0.003	0.009	0.89
5-A-1	Waste - Solid Waste Disposal	CH_4	22 332	23 743	0.002	0.008	0.90
2-C-3	IPPU - Aluminium Production	CO_2	2 715	5 123	0.002	0.006	0.91
1-B-2-(b+c)	Fugitive Emissions - Natural Gas	CO_2	6 129	5 445	0.002	0.006	0.92
1-A-3-e-i	Fuel Combustion - Pipeline Transport	CO_2	6 685	6 188	0.002	0.005	0.92
3-A	Agriculture - Enteric Fermentation	CH_4	22 838	25 234	0.002	0.005	0.93
1-B-1-a	Fugitive Emissions - Coal Mining and Handling	CH_4	2 824	1 728	0.002	0.005	0.93
1-A-3-e	Fuel Combustion - Other Transport (Off Road)	N_2O	1 798	3 639	0.001	0.005	0.94
4-A-1	LULUCF - Forest Land remaining Forest Land	CH_4	3 502	5 508	0.001	0.004	0.94
1-B-2-(a+c)	Fugitive Emissions - Oil	CO_2	5 477	7 740	0.001	0.004	0.94
1-A-3-b	Fuel Combustion - Road Transportation	N_2O	3 072	2 471	0.001	0.004	0.95

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Table A1–5   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 IPCC Category	Current Year 2013			
1-A*	Stationary Fuel Combustion - Gaseous Fuels	CO$_2$	118 177	189 321	0.020	0.060	0.22
1-A*	Stationary Fuel Combustion - Solid Fuels	CO$_2$	87 000	69 559	0.033	0.098	0.37
1-A*	Stationary Fuel Combustion - Liquid Fuels	CO$_2$	71 356	55 714	0.028	0.083	0.49
1-A-3-b	Fuel Combustion - Road Transportation	CO$_2$	94 263	133 880	0.004	0.013	0.59
2-B-3	IPPU - Adipic Acid Production	N$_2$O	10 303	0.00	0.000	0.000	0.65
1-A-3-e	Fuel Combustion - Other Transport (Off Road)	CO$_2$	21 991	36 946	0.005	0.015	0.69
2-D-1	IPPU - Non-Energy Products from Fuels and Solvent Use	CO$_2$	7 360	18 153	0.000	0.000	0.74
2-C-3	IPPU - Aluminium Production	PFCs	7 558	1 594	0.001	0.002	0.77
2-F	IPPU - Product Uses as Substitutes for Ozone Depleting Substances	HFCs	0	6 402	0.000	0.000	0.80
2-C-1	IPPU - Iron and Steel Production	CO$_2$	10 193	7 532	0.000	0.000	0.82
1-B-2-(a+c)	Fugitive Emissions - Oil	CH$_4$	16 741	23 929	0.001	0.003	0.83
2-C-4	IPPU - Magnesium Production	SF$_6$	2 738	0	0.000	0.001	0.85
1-A*	Stationary Fuel Combustion - Biomass	CH$_4$	6 727	5 047	0.003	0.008	0.86
3-D-1	Agriculture - Direct N$_2$O Emissions from Managed Soils	N$_2$O	14 214	19 540	0.000	0.000	0.87
2-C-3	IPPU - Aluminium Production	CO$_2$	2 715	5 123	0.004	0.012	0.88
3-A	Agriculture - Enteric Fermentation	CH$_4$	22 838	25 234	0.000	0.000	0.89
1-B-2-(b+c)	Fugitive Emissions - Natural Gas	CO$_2$	6 129	5 445	0.002	0.006	0.90
1-A-3-e-i	Fuel Combustion - Pipeline Transport	CO$_2$	6 685	6 188	0.002	0.006	0.91
1-B-1-a	Fugitive Emissions - Coal Mining and Handling	CH$_4$	2 824	1 728	0.001	0.004	0.91
1-A-3-e	Fuel Combustion - Other Transport (Off Road)	N$_2$O	1 798	3 639	0.001	0.002	0.92
1-B-2-(a+c)	Fugitive Emissions - Oil	CO$_2$	5 477	7 740	0.000	0.001	0.93
1-A-3-b	Fuel Combustion - Road Transportation	N$_2$O	3 072	2 471	0.001	0.003	0.93
2-B-9-a	IPPU - Fluorochemical Production	HFCs	971	0	0.000	0.001	0.94
3-H	Agriculture - Urea Application	CO$_2$	754	2 035	0.000	0.000	0.94
3-D-2	Agriculture - Indirect N$_2$O Emissions from Managed Soils	N$_2$O	2 992	4 620	0.000	0.000	0.95
1-B-2-(b+c)	Fugitive Emissions - Natural Gas	CH$_4$	17 600	19 810	0.003	0.008	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 2013. 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.   Uncertainty Assessment on 2013 Greenhouse Gas Emissions and Removals

Separate analyses were conducted for the inventory as a whole with and without LULUCF. The 2013 national emission estimate (not including the LULUCF Sector) of 726 Mt CO_2 eq lies within an uncertainty range of 703 Mt CO_2 eq to 749 Mt CO_2 eq (±3%) (Table A2–1). These results are consistent with those published in previous NIR submissions that ranged from -3% to +6%. The Energy Sector had the lowest uncertainty, at ±3%, while the Waste Sector had the highest uncertainty, at ±38%. The IPPU Sector and the Agriculture Sector had uncertainties of ±8, and ±15%, respectively. The emission source categories that made the largest contributions to uncertainty at the national level when LULUCF is not included were:

a)   Energy – Fuel Combustion – Other (off-road) Transportation, N_2O;

b)   Energy – Fuel Combustion – Public Electricity and Heat Production, CO_2;

c)   Waste – Solid Waste Disposal on Land, CH_4;

d)   Energy – Fuel Combustion – Manufacturing Industries and Construction, CO_2; and

e)   Agriculture – Indirect N_2O Emissions, N_2O.

The national emission estimate, including LULUCF emissions and removals of 711 Mt CO_2 eq, lies within an uncertainty range of 617 Mt CO_2 eq to 805 Mt CO_2 eq (±13%) Table A2–2. Typically, uncertainty is high for LULUCF estimates due to the fact that emissions are primarily driven by highly variable natural disturbance factors. 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)   Energy – Fuel Combustion – Other (off-road) Transportation, N_2O;

d)   Energy – Fuel Combustion – Public Electricity and Heat Production, CO_2; and

e)   Waste – Solid Waste Disposal on Land, CH_4.

The calculation of trend uncertainty was only performed without the LULUCF Sector. Given the high interannual variability in the LULUCF estimates and the fact that it is primarily driven by natural factors, such as wildfires in managed forests, this sector was not considered in the trend analysis of uncertainties in anthropogenic GHG emissions and removals. The trend uncertainty, excluding LULUCF, was found to be 0.56%. Therefore, the total increase in emissions since 1990 of 113 Mt CO_2 eq (+18.5%) falls within an uncertainty range of a minimum of +110 Mt CO_2 eq to a maximum of +117 Mt CO_2 eq (+17.9% to +19.1%).

A2.3.   Planned Improvements

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

Table A2–1   Uncertainty Assessment Level and Trend without LULUCF

	IPCC Source Category	Gas	Base Year Emissions	2013 Year Emissions	Activity Data Uncertainty[1]	Emission Factor Uncertainty[1]	Combined Uncertainty	Combined uncertainty as % of 2013 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		612 745	726 048	0.72	2.6	3.2	3.2	Assumption: Emission factors are fully correlated between years	Assumption: Activity data is fully correlated between years	0.56
1.A.1.a	Fuel Combustion - Public Electricity and Heat Production	CO$_2$	93 978	86 819	0.55	11	11	0.02	0.45	0.00	0.00
1.A.1.a	Fuel Combustion - Public Electricity and Heat Production	CH$_4$	45	148	0.89	34	34	0.00	0.01	0.00	0.00
1.A.1.a	Fuel Combustion - Public Electricity and Heat Production	N$_2$O	515	533	0.86	48	48	0.00	0.01	0.00	0.00
1.A.1.b	Fuel Combustion - Petroleum Refining	CO$_2$	17 021	18 315	1.1	9.6	9.7	0.00	0.03	0.00	0.00
1.A.1.b	Fuel Combustion - Petroleum Refining	CH$_4$	7	6	0.64	50	50	0.00	0.00	0.00	0.00
1.A.1.b	Fuel Combustion - Petroleum Refining	N$_2$O	52	43	0.51	45	45	0.00	0.00	0.00	0.00
1.A.1.c	Fuel Combustion - Manufacture of Solid Fuels and Other Energy Industries	CO$_2$	32 180	47 437	0.93	9.6	9.7	0.00	0.15	0.00	0.00
1.A.1.c	Fuel Combustion - Manufacture of Solid Fuels and Other Energy Industries	CH$_4$	1 854	2 096	1.4	54	54	0.00	0.01	0.00	0.00
1.A.1.c	Fuel Combustion - Manufacture of Solid Fuels and Other Energy Industries	N$_2$O	234	302	0.96	86	86	0.00	0.00	0.00	0.00
1.A.2	Fuel Combustion - Manufacturing Industries and Construction	CO$_2$	64 269	90 353	4.4	7.8	8.1	0.01	0.18	0.01	0.00
1.A.2	Fuel Combustion - Manufacturing Industries and Construction	CH$_4$	62	88	4.8	16	16	0.00	0.00	0.00	0.00
1.A.2	Fuel Combustion - Manufacturing Industries and Construction	N$_2$O	591	890	4.5	19	19	0.00	0.01	0.00	0.00
1.A.3.a	Fuel Combustion - Domestic Aviation	CO$_2$	7 093	7 435	-	0.6	0.6	0.00	0.00	-	-
1.A.3.a	Fuel Combustion - Domestic Aviation	CH$_4$	11	8	-	59	59	0.00	0.00	-	-
1.A.3.a	Fuel Combustion - Domestic Aviation	N$_2$O	66	65	-	540	540	0.00	0.01	-	-
1.A.3.b	Fuel Combustion - Road Transportation (Gas, Diesel, Natural Gas, Propane)	CO$_2$	94 263	133 880	-	0.5	0.5	0.00	0.02	-	-
1.A.3.b	Fuel Combustion - Road Transportation (Gas, Diesel, Natural Gas, Propane)	CH$_4$	362	245	-	72	72	0.00	0.02	-	-
1.A.3.b	Fuel Combustion - Road Transportation (Gas, Diesel, Natural Gas, Propane)	N$_2$O	3 072	2 471	-	29	29	0.00	0.06	-	-
1.A.3.c	Fuel Combustion - Railways	CO$_2$	6 222	6 542	-	1.7	1.7	0.00	0.00	-	-
1.A.3.c	Fuel Combustion - Railways	CH$_4$	8	9	-	65	65	0.00	0.00	-	-
1.A.3.c	Fuel Combustion - Railways	N$_2$O	760	814	-	270	270	0.00	0.04	-	-
1.A.3.d	Fuel Combustion - Domestic Navigation	CO$_2$	4 741	5 048	-	2.9	2.9	0.00	0.00	-	-
1.A.3.d	Fuel Combustion - Domestic Navigation	CH$_4$	8	10	-	180	180	0.00	0.00	-	-
1.A.3.d	Fuel Combustion - Domestic Navigation	N$_2$O	326	271	-	280	280	0.00	0.05	-	-
1.A.3.e	Fuel Combustion - Other Transportation (Off-Road)	CO$_2$	21 991	36 946	-	1	1	0.00	0.02	-	-
1.A.3.e	Fuel Combustion - Other Transportation (Off-Road)	CH$_4$	243	294	-	120	120	0.00	0.00	-	-

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

	IPCC Source Category	Gas	Base Year Emissions	2013 Year Emissions	Activity Data Uncertainty[1]	Emission Factor Uncertainty[1]	Combined Uncertainty	Combined uncertainty as % of 2013 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		**612 745**	**726 048**	**0.72**	**2.6**	**3.2**	**3.2**	*Assumption: Emission factors are fully correlated between years*	*Assumption: Activity data is fully correlated between years*	**0.56**
1.A.3.e	Fuel Combustion - Other Transportation (Off-Road)	N_2O	1 798	3 639	-	270	270	0.02	0.67	-	-
1.A.3.e	Fuel Combustion - Pipeline Transport	CO_2	6 685	6 188	0.99	3	3.1	0.00	0.01	0.00	0.00
1.A.3.e	Fuel Combustion - Pipeline Transport	CH_4	167	155	1	40	40	0.00	0.00	0.00	0.00
1.A.3.e	Fuel Combustion - Pipeline Transport	N_2O	54	50	0.98	88	88	0.00	0.00	0.00	0.00
1.A.4	Fuel Combustion - Other Sectors	CO_2	69 205	72 067	4.6	2.6	4.9	0.00	0.04	0.01	0.00
1.A.4	Fuel Combustion - Other Sectors	CH_4	6 743	5 043	5.8	12	12	0.00	0.06	0.00	0.00
1.A.4	Fuel Combustion - Other Sectors	N_2O	1 205	1 100	5.1	14	14	0.00	0.01	0.00	0.00
1.B.1.a	Fugitive Sources - Coal Mining and Handling	CH_4	2 824	1 728	-	57	57	0.00	0.15	0.00	0.00
1.B.2.(a+b)	Fugitive Sources - Oil & Gas	CO_2	121	286	-	15	15	0.00	0.00	0.00	0.00
1.B.2.(a+b)	Fugitive Sources - Oil & Gas	CH_4	17 940	19 391	-	22	22	0.00	0.07	0.00	0.00
1.B.2.(a+b)	Fugitive Sources - Oil & Gas	N_2O	30	30	-	49	49	0.00	0.00	0.00	0.00
1.B.2.c	Fugitive Sources - Venting	CO_2	6 995	8 050	-	42	42	0.00	0.02	0.00	0.00
1.B.2.c	Fugitive Sources - Flaring	CO_2	4 490	4 849	-	6.1	6.1	0.00	0.00	0.00	0.00
1.B.2.c	Fugitive Sources - Venting & Flaring	CH_4	16 401	24 349	-	14	14	0.00	0.11	0.00	0.00
1.B.2.c	Fugitive Sources - Venting & Flaring	N_2O	3	17	-	26	26	0.00	0.00	0.00	0.00
1.C	CO_2 Transport and Storage	CO_2	N/A	0.09	2	100	100	0.00	-	-	-
2.A.1	IPPU - Cement Production	CO_2	5 760	5 986	-	-	13	0.00	-	-	-
2.A.2	IPPU - Lime Production	CO_2	1 759	1 323	-	-	8.2	0.00	-	-	-
2.A.4.b	IPPU - Other Uses of Soda Ash	CO_2	246	114	-	-	10	0.00	-	-	-
2.A.4.c	IPPU - Other (Magnesite Use)	CO_2	147	91	7.8	2.1	8.1	0.00	0.00	0.00	0.00
2.A.4.d	IPPU - Other (Limestone and Dolomite Use)	CO_2	805	573	-	20	20	0.00	0.01	-	-
2.B.1	IPPU - Ammonia Production	CO_2	2 774	3 481	-	-	7	0.00	-	-	-
2.B.2	IPPU - Nitric Acid Production	N_2O	973	985	-	-	10	0.00	-	-	-
2.B.3	IPPU - Adipic Acid Production	N_2O	10 303	-	-	-	12	0.00	-	-	-
2.B.8	IPPU - Petrochemical and Carbon Black Production	CH_4	118	76	-	-	19	0.00	-	-	-
2.B.8	IPPU - Petrochemical and Carbon Black Production	N_2O	7	8	-	-	10	0.00	-	-	-
2.B.9.a	IPPU - Fluorochemical Production	HFCs	971	-	-	-	50	0.00	-	-	-
2.C.1	IPPU - Iron and Steel Production	CO_2	10 193	7 532	-	-	5.4	0.00	-	-	-
2.C.3	IPPU - Aluminium Production	CO_2	2 715	5 123	-	-	7.1	0.00	-	-	-
2.C.3	IPPU - Aluminium Production	PFCs	7 558	1 594	-	-	9.1	0.00	-	-	-
2.C.3	IPPU - Aluminium Production	SF_6	56	5	-	-	3.3	0.00	-	-	-
2.C.4	IPPU - Magnesium Production	SF_6	2 738	-	-	-	5.7	0.00	-	-	-
2.C.7	IPPU - Other (Magnesium Casting)	SF_6	225	213	-	-	4	0.00	-	-	-
2.D.1	IPPU - Non-Energy Products from Fuels and Solvent Use	CO_2	7 360	18 153	-	-	20	0.00	-	-	-

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

A2

IPCC Source Category	Gas	Base Year Emissions	2013 Year Emissions	Activity Data Uncertainty[1]	Emission Factor Uncertainty[1]	Combined Uncertainty	Combined uncertainty as % of 2013 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		**612 745**	**726 048**	**0.72**	**2.6**	**3.2**	**3.2**	*Assumption: Emission factors are fully correlated between years*	*Assumption: Activity data is fully correlated between years*	**0.56**
2.E.1	IPPU - Integrated Circuit or Semiconductor	PFCs	0	2	-	-	23	0.00	-	-	-
2.E.1	IPPU - Integrated Circuit or Semiconductor	SF_6	6	1	-	-	45	0.00	-	-	-
2.E.1	IPPU - Integrated Circuit or Semiconductor	NF_3	0.3	0.2	-	-	200	0.00	-	-	-
2.E.5	IPPU - Other	PFCs	-	-	-	-	23	0.00	-	-	-
2.F	IPPU - Product Uses as Substitutes for Ozone-Depleting Substances	HFCs	-	6 402	-	-	36	0.00	-	-	-
2.F	IPPU - Product Uses as Substitutes for Ozone-Depleting Substances	PFCs	-	2	-	-	23	0.00	-	-	-
2.G.1	IPPU - Electrical Equipment	SF_6	202	213	-	-	30	0.00	-	-	-
2.G.2	IPPU - SF_6 and PFCs from Other Product Use	PFCs	-	19	-	-	23	0.00	-	-	-
2.G.3.a	IPPU - Other (Medical Applications of N_2O)	N_2O	146	216	-	-	23	0.00	-	-	-
2.G.3.b	IPPU - Other (Uses of N_2O for Propellant)	N_2O	26	40	-	-	22	0.00	-	-	-
2.G.4	IPPU - Other (Use of Urea in SCR Vehicles)	CO_2	-	46	-	-	50	0.00	-	-	-
3.A	Agriculture - Enteric Fermentation	CH_4	22 838	25 234	1.4	21	21	0.01	0.06	0.00	0.00
3.B	Agriculture - Manure Management	N_2O	3 507	3 701	1.4	32	32	0.00	0.02	0.00	0.00
3.B	Agriculture - Manure Management	CH_4	4 121	4 732	-	-	51	0.00	-	-	-
3.D.1	Agriculture - Indirect N_2O Emissions	N_2O	14 214	19 540	-	-	28	0.01	-	-	-
3.D.2	Agriculture - Direct N_2O Emissions from Managed Soils	N_2O	2 992	4 620	-	-	76	0.00	-	-	-
3.F	Agriculture - Field Burning of Agricultural Residues	N_2O	177	40	50	40	64	0.00	0.01	0.00	0.00
3.F	Agriculture - Field Burning of Agricultural Residues	N_2O	55	12	50	48	69	0.00	0.00	0.00	0.00
3.G.1	Agriculture - Limestone $CaCO_3$	N_2O	378	329	30	50	58	0.00	0.01	0.00	0.00
3.H	Agriculture - Urea Application	N_2O	754	2 035	15	50	52	0.00	0.09	0.00	0.00
3.I	Agriculture - Other Carbon-Containing Fertilizers	N_2O	52	253	15	50	52	0.00	0.02	0.00	0.00
5.A	Waste - Solid Waste Disposal	CH_4	22 332	23 743	-	-	40	0.02	-	-	-
5.C	Waste - Incineration and Open Burning of Waste	CH_4	507	402	-	-	85	0.00	-	-	-
5.C	Waste - Incineration and Open Burning of Waste	N_2O	214	140	-	-	85	0.00	-	-	-
5.C	Waste - Incineration and Open Burning of Waste	CO_2	11	3	-	-	60	0.00	-	-	-
5.D	Waste - Wastewater Treatment and Discharge	CH_4	376	391	-	-	45	0.00	-	-	-
5.D	Waste - Wastewater Treatment and Discharge	N_2O	494	661	-	-	65	0.00	-	-	-

Note:

1. For categories where individual values are not given for emission factor and activity data uncertainty, combined uncertainty estimates are based on sectoral Monte Carlo analyses. For further information on sources of uncertainty data and calculation methods – as related to categories in the Energy, Industrial Processes and Product Use, Agriculture and Waste Sectors – the reader is referred to uncertainty sections in respective NIR chapters.

Table A2–2   Uncertainty Assessment with LULUCF

	IPCC Source Category	Gas	2013 Year Emissions	Combined Uncertainty
			kt CO_2 eq	%
	TOTALS		**710 974**	**13.27**
1.A.1.a	Fuel Combustion - Public Electricity and Heat Production	CO_2	86 819	11
1.A.1.a	Fuel Combustion - Public Electricity and Heat Production	CH_4	148	34
1.A.1.a	Fuel Combustion - Public Electricity and Heat Production	N_2O	533	48
1.A.1.b	Fuel Combustion - Petroleum Refining	CO_2	18 315	9.7
1.A.1.b	Fuel Combustion - Petroleum Refining	CH_4	6	50
1.A.1.b	Fuel Combustion - Petroleum Refining	N_2O	43	45
1.A.1.c	Fuel Combustion - Manufacture of Solid Fuels and Other Energy Industries	CO_2	47 437	9.7
1.A.1.c	Fuel Combustion - Manufacture of Solid Fuels and Other Energy Industries	CH_4	2 096	54
1.A.1.c	Fuel Combustion - Manufacture of Solid Fuels and Other Energy Industries	N_2O	302	86
1.A.2	Fuel Combustion - Manufacturing Industries and Construction	CO_2	90 353	8.1
1.A.2	Fuel Combustion - Manufacturing Industries and Construction	CH_4	88	16
1.A.2	Fuel Combustion - Manufacturing Industries and Construction	N_2O	890	19
1.A.3.a	Fuel Combustion - Domestic Aviation	CO_2	7 435	0.6
1.A.3.a	Fuel Combustion - Domestic Aviation	CH_4	8	59
1.A.3.a	Fuel Combustion - Domestic Aviation	N_2O	65	540
1.A.3.b	Fuel Combustion - Road Transportation (Gas, Diesel, Natural Gas, Propane)	CO_2	133 880	0.5
1.A.3.b	Fuel Combustion - Road Transportation (Gas, Diesel, Natural Gas, Propane)	CH_4	245	72
1.A.3.b	Fuel Combustion - Road Transportation (Gas, Diesel, Natural Gas, Propane)	N_2O	2 471	29
1.A.3.c	Fuel Combustion - Railways	CO_2	6 542	1.7
1.A.3.c	Fuel Combustion - Railways	CH_4	9	65
1.A.3.c	Fuel Combustion - Railways	N_2O	814	270
1.A.3.d	Fuel Combustion - Domestic Navigation	CO_2	5 048	2.9
1.A.3.d	Fuel Combustion - Domestic Navigation	CH_4	10	180
1.A.3.d	Fuel Combustion - Domestic Navigation	N_2O	271	280
1.A.3.e	Fuel Combustion - Other Transportation (Off-Road)	CO_2	36 946	1
1.A.3.e	Fuel Combustion - Other Transportation (Off-Road)	CH_4	294	120
1.A.3.e	Fuel Combustion - Other Transportation (Off-Road)	N_2O	3 639	270
1.A.3.e	Fuel Combustion - Pipeline Transport	CO_2	6 188	3.1
1.A.3.e	Fuel Combustion - Pipeline Transport	CH_4	155	40
1.A.3.e	Fuel Combustion - Pipeline Transport	N_2O	50	88
1.A.4	Fuel Combustion - Other Sectors	CO_2	72 067	4.9
1.A.4	Fuel Combustion - Other Sectors	CH_4	5 043	12
1.A.4	Fuel Combustion - Other Sectors	N_2O	1 100	14
1.B.1.a	Fugitive Sources - Coal Mining and Handling	CH_4	1 728	57
1.B.2.(a+b)	Fugitive Sources - Oil & Gas	CO_2	286	15
1.B.2.(a+b)	Fugitive Sources - Oil & Gas	CH_4	19 391	22
1.B.2.(a+b)	Fugitive Sources - Oil & Gas	N_2O	30	49
1.B.2.c	Fugitive Sources - Venting	CO_2	8 050	42
1.B.2.c	Fugitive Sources - Flaring	CO_2	4 849	6.1
1.B.2.c	Fugitive Sources - Venting & Flaring	CH_4	24 349	14
1.B.2.c	Fugitive Sources - Venting & Flaring	N_2O	17	26
1.C	CO_2 Transport and Storage	CO_2	0.09	100
2.A.1	IPPU - Cement Production	CO_2	5 986	13
2.A.2	IPPU - Lime Production	CO_2	1 323	8.2
2.A.4.b	IPPU - Other Uses of Soda Ash	CO_2	114	10
2.A.4.c	IPPU - Other (Magnesite Use)	CO_2	91	8.1
2.A.4.d	IPPU - Other (Limestone and Dolomite Use)	CO_2	573	20
2.B.1	IPPU - Ammonia Production	CO_2	3 481	7
2.B.2	IPPU - Nitric Acid Production	N_2O	985	10
2.B.3	IPPU - Adipic Acid Production	N_2O	-	12
2.B.8	IPPU - Petrochemical and Carbon Black Production	CH_4	76	19
2.B.8	IPPU - Petrochemical and Carbon Black Production	N_2O	8	10
2.B.9	IPPU - Fluorochemical Production	HFCs	-	50
2.C.1	IPPU - Iron and Steel Production	CO_2	7 532	5.4
2.C.3	IPPU - Aluminium Production	CO_2	5 123	7.1
2.C.3	IPPU - Aluminium Production	PFCs	1 594	9.1
2.C.3	IPPU - Aluminium Production	SF_6	5	3.3
2.C.4	IPPU - Magnesium Production	SF_6	-	5.7
2.C.7	IPPU - Other (Magnesium Casting)	SF_6	213	4
2.D.1	IPPU - Non-Energy Products from Fuels and Solvent Use	CO_2	18 153	20
2.E.1	IPPU - Integrated Circuit or Semiconductor	PFCs	2	23
2.E.1	IPPU - Integrated Circuit or Semiconductor	SF_6	1	45
2.E.1	IPPU - Integrated Circuit or Semiconductor	NF_3	0	200
2.E.5	IPPU - Other	PFCs	-	23
2.F	IPPU - Product Uses as Substitutes for Ozone-Depleting Substances	HFCs	6 402	36

A2

Table A2-2   Uncertainty Assessment with LULUCF   (cont'd)

A2

	IPCC Source Category	Gas	2013 Year Emissions	Combined Uncertainty
			kt CO_2 eq	%
	TOTALS		**710 974**	**13.27**
2.F	IPPU - Product Uses as Substitutes for Ozone-Depleting Substances	PFCs	2	23
2.G.1	IPPU - Electrical Equipment	SF_6	213	30
2.G.2	IPPU - SF_6 and PFCs from Other Product Use	PFCs	19	23
2.G.3.a	IPPU - Other (Medical Applications of N_2O)	N_2O	216	23
2.G.3.b	IPPU - Other (Uses of N_2O for Propellant)	N_2O	40	22
2.G.4	IPPU - Other (Use of Urea in SCR Vehicles)	CO_2	46	50
3.A	Agriculture - Enteric Fermentation	CH_4	25 234	21
3.B	Agriculture - Manure Management	N_2O	3 701	32
3.B	Agriculture - Manure Management	CH_4	4 732	33
3.D.1	Agriculture - Indirect N_2O Emissions	N_2O	19 540	28
3.D.2	Agriculture - Direct N_2O Emissions from Managed Soils	N_2O	4 620	76
3.F	Agriculture - Field Burning of Agricultural Residues	N_2O	40	64
3.F	Agriculture - Field Burning of Agricultural Residues	N_2O	12	69
3.G.1	Agriculture - Limestone $CaCO_3$	N_2O	329	58
3.H	Agriculture - Urea Application	N_2O	2 035	52
3.I	Agriculture - Other Carbon-Containing Fertilizers	N_2O	253	52
4.A	LULUCF - Forest Land Remaining Forest Land	CO_2	-169 258	41
4.A	LULUCF - Forest Land Remaining Forest Land	CH_4	5 508	31
4.A	LULUCF - Forest Land Remaining Forest Land	N_2O	2 753	29
4.A	LULUCF - Land Converted to Forest Land	CO_2	-593	200
4.B	LULUCF - Cropland	CO_2	-12 941	23
4.B	LULUCF - Cropland	N_2O	1	40
4.C	LULUCF - Grasslands	CH_4	520	64
4.C	LULUCF - Grasslands	N_2O	161	69
4.D	LULUCF - Wetlands	CO_2	2 399	0
4.E	LULUCF - Settlements	CO_2	-2 389	32
	LULUCF - Conversion of Forest Land	CO_2	13 137	17
	LULUCF - Conversion of Forest Land	CH_4	267	20
	LULUCF - Conversion of Forest Land	N_2O	136	20
4.G.	LULUCF - Harvested Wood Products (HWP)	CO_2	145 225	41
5.A	Waste - Solid Waste Disposal	CH_4	23 743	40
5.C	Waste - Incineration and Open Burning of Waste	CH_4	402	85
5.C	Waste - Incineration and Open Burning of Waste	N_2O	140	85
5.C	Waste - Incineration and Open Burning of Waste	CO_2	3	60
5.D	Waste - Wastewater Treatment and Discharge	CH_4	391	45
5.D	Waste - Wastewater Treatment and Discharge	N_2O	661	65

Annex 3

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

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

A3.1.1. Methodology

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

Equation A3–1: for general fuel combustion:

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

where:

$E_{Category,G}$ = GHG emissions by source category and by GHG (CO_2, CH_4 or N_2O)

$FC_{F,R}$ = Quantity of fuel consumed (in physical units, such as kg, L, or m^3) by fuel type (i.e. natural gas, sub-bituminous coal, kerosene, etc.) and by region

$EF_{G,F,R,T}$ = Country-specific emission factor (in physical units) by GHG, by fuel type, by region (where available) and by technology (for non-CO_2 factors)

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

A3.1.2. Activity Data from Statistics Canada

The principal source of fuel and energy data used to estimate combustion emissions is the annual Report on Energy Supply and Demand in Canada (RESD) (Statistics Canada 57-003-X). The RESD uses a mix of top down and bottom-up approaches to estimate the supply of, and demand for energy in Canada. The production of fuels in Canada is balanced with the use of fuels in broad categories such as import/export, producer consumption, residential and industry. Industrial energy-use data are divided into broad sectors based on the North American Industrial Classification System (NAICS). Currently, these sectoral industrial energy-use data do not include energy used to generate electricity or steam by industry (auto producers). This energy is captured in the RESD in two separate lines (one for electricity and one for steam); however, they are summary lines and are not divided by sector. Prior to 2003, these summary lines are fractionally allocated to the appropriate sector based on the quantities reported by sector in the Industrial Consumption of Energy Survey (ICE) (Statistics Canada 2013). After 2003, the electricity line (from auto producers) is reallocated directly to the appropriate sector based on the quantities reported by sector in the Electric Power Thermal Generating Station Fuel Consumption Survey (EPTGS) (Statistics Canada 2013). This change reflects a change in the Electricity by Industry line in the RESD, which from 2003 on was replaced directly with data from the EPTGS. This improvement was implemented by Statistics Canada to increase the transparency and accuracy of subsector information, since the fuel used to generate electricity is more complete and of higher quality. The steam line continues to be allocated using the fractional method and ICE data.

Figure A3–1   GHG Estimation Process Flow

A3
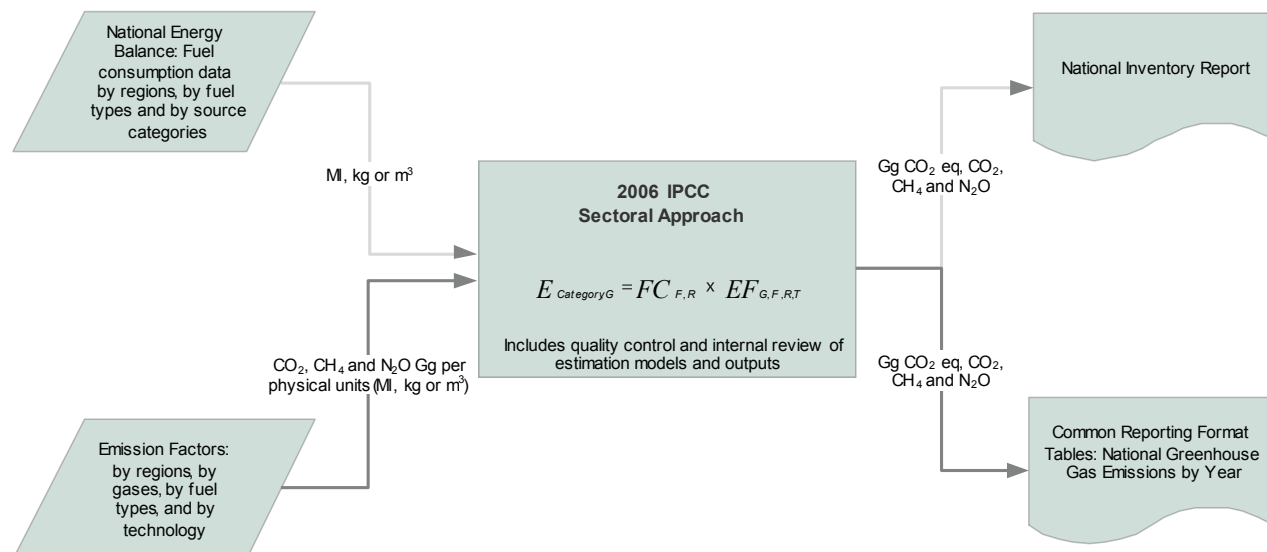
While the RESD provides fuel-use data at a provincial level, in general, the accuracy of these data is not as high as that of the national data. Statistics Canada generally collects the fuel data for the RESD through a number of specific surveys directed at suppliers of energy, provincial energy ministries and some users of energy. The accuracy of the sectoral end-use data is less than that of the total energy supply data. As a result, the total emission estimates for Canada are known with more certainty than the emissions from specific categories. Since 1995, Statistics Canada has been collecting energy-use statistics from end users through the annual *Industrial Consumption of Energy Survey* (ICE). This bottom-up approach to estimating fuel use by industry provides more accurate information at the sectoral level. Refer to Annex 4, National Energy Balance, for additional discussion on the development of the RESD and the ICE data set, including a discussion on Statistics Canada's quality assurance / quality control activities. Sector-specific surveys, like the EPTGS, are also used to verify sector trends and emission allocation.

The combustion and transport models apply the quantity of fossil fuel consumed in physical units rather than in energy units, since this is how the information is reported to Statistics Canada by reporting facilities under the *Statistics Act*. The quantities of fossil fuel consumed are also available in gross calorific units; however, this is assumed to be less accurate, since Statistics Canada applies, in most cases, constant energy conversion factors (a factor for 1990 to 1997 and another factor for 1998 onward) to each fuel type without taking into account year to year changes, especially for variable fuels such as coal and refinery fuel gas (still gas). One exception involves waste fuels, for which the data are only available in energy units from the Cement Association of Canada.

Additional non-Statistics Canada activity data sources used by the combustion and transport models, such as landfill gas quantities, waste fuel consumption and vehicle fleet information, are included in the specific methodological discussions (sections A3.1.4.1 and A3.1.4.2).

A3.1.3. Fuel Combustion Emission Factors

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

Natural Gas: The emission factors for CO_2 vary depending on the source of natural gas and whether or not the product is marketable or non-marketable (raw natural gas for on-site consumption by natural gas producers). Therefore, emission factors are assigned for different provinces based upon the origin and quality of the natural gas. The emission factors for CH_4 and N_2O vary with the combustion technology.

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

Coal: The emission factors for CO_2 vary with the properties of the coal. Therefore, emission factors are assigned for different provinces based upon the origin of the coal (domestic or foreign). The emission factors for CH_4 and N_2O vary with the combustion technology.

A3.1.3.1. CO$_2$ Emission Factors

CO$_2$ emissions from fuel combustion activities depend upon the amount of fuel consumed, the carbon content of the fuel and the IPCC default oxidation value. The basis of the CO$_2$ emission factor derivations are discussed in Annex 6, in the *Fossil Fuel and Derivative Factors* (McCann 2000) study and in previous inventory publications. The methods used to determine fuel properties such as carbon content, density and heating value are based on accepted industrial testing standards, such as the American Society for Testing and Materials (ASTM) and the Canadian General Standards Board (CGSB). Both the hydrocarbons and particulates formed during combustion are accounted for to some extent, but emissions of CO are included in the estimates of CO$_2$ emissions. It is assumed that CO in the atmosphere undergoes complete oxidation to CO$_2$ shortly after combustion (within 5 to 20 weeks of its release).

As stated above, the emission factors used in Canada's GHG inventory are based upon the physical quantity of fuel combusted rather than on the energy content of the fuel, with the exception of the emission factor for waste fuels. The waste fuel factor is based on energy content, as the data reported by the Cement Association of Canada (CAC) are in energy units. The emission factors employed to estimate emissions are subdivided by the type of fuel used and, in the case of N$_2$O and CH$_4$ emissions, the combustion technology employed.

A3.1.3.2. Non-CO$_2$ Emission Factors

Emission factors for all non-CO$_2$ GHGs from combustion activities vary to a lesser or greater degree with:

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

During the combustion of carbon-based fuels, a small portion of the fuel remains unoxidized as CH$_4$. Additional research is necessary to better establish CH$_4$ emission factors for many combustion processes. Overall factors are developed for sectors based on typical technology splits and available emission factors for the sector.

During combustion, some of the nitrogen in the fuel and air is converted to N$_2$O. The production of N$_2$O is dependent upon the combustion temperature and the emission control technology employed. Additional research is necessary to better establish N$_2$O emission factors for many combustion processes. Overall factors are developed for sectors based on typical technologies and available emission factors for the sector. Non-CO$_2$ emission factors in this inventory are listed in Annex 6.

A3.1.3.3. Biomass

For reporting under the United Nations Framework Convention on Climate Change (UNFCCC), CO$_2$ emissions from biomass fuels (including landfill gas) are not to be included in the Energy Sector total. CO$_2$ emissions from biomass fuel combustion are accounted for in the Land Use, Land-use Change and Forestry (LULUCF) Sector as a loss of biomass (forest) stocks. CO$_2$ from biomass combustion for energy purposes is reported as a memo item of the UNFCCC's Common Reporting Format (CRF) tables for information only. CH$_4$ and N$_2$O emissions from biomass fuel combustion are reported in the Energy Sector in the appropriate subcategories and included in inventory totals.

A3.1.4. Methodology for Stationary Combustion and Transport

A3.1.4.1. Stationary Combustion

The methodology used to estimate GHG emissions from stationary fuel combustion is consistent with the IPCC Tier 2 sectoral approach, along with country-specific emission factors as outlined in the *2006 IPCC Guidelines* (IPCC 2006). The methodology and emissions of SF$_6$ from the transmission of Electricity Generation (CRF Category 1.A.1.a) are included in the Industrial Processes Sector.

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

Table A3–1 presents a breakdown by source category of the application of activity data and emission factors. Discussions on assumptions of the estimation methodology for the following subcategories are also provided:

- Public Electricity and Heat Production;
- Petroleum Refining, Manufacture of Solid Fuels and Other Energy Industries;
- Manufacturing Industries and Construction;
- Other Sectors; and
- Pipeline Transport.

Details on specific source categories are included in the notes section of Table A3–1. 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. Emission estimates are calculated using Equation A3–1 exclusively and are consistent with the IPCC Tier 2 approach.

A3

Table A3–1 presents the methodology and emission factors according to fuel types as presented in Table A3–2. Most fossil fuels have been grouped based on their original production source.

A3

Table A3–1   Estimation Methodology for GHG Emissions from Stationary Combustion

CRF Source Category[1]	Fuels List (Table A3-2)	Activity Data Source[2]	Notes
1.A.1.a.i Electricity Generation	Solid Fuels	Table 1 – Primary and Secondary Energy Table F – Coal Details Line 10 – Transformed to Other Fuels: Electricity – By utilities Line 14 – Transformed to Other Fuels: Steam Generation	Provincial/territorial coal CO_2 emissions are calculated using regional emission factors and summed to a national total. Totals for petroleum coke and coke CO_2 emissions are based on the national total reported in the RESD. Canada totals for CH_4 and N_2O are based on the national total reported in the RESD. A portion of Line 14 is allocated to this source category prior to calculating emissions.
	Liquid Fuels	Table 3 – Refined Petroleum Products Line 10 – Transformed to Other Fuels: Electricity – By utilities Line 14 – Transformed to Other Fuels: Steam Generation	Canada totals for CO_2, CH_4 and N_2O are based on the national total reported in the RESD. A portion of Line 14 is allocated to this source category prior to calculating emissions.
	Gaseous Fuels	Table 1 – Primary and Secondary Energy Table 6 – Details of Natural Gas Liquids Line 10 – Transformed to Other Fuels: Electricity – By utilities Line 14 – Transformed to Other Fuels: Steam Generation	Canada total for natural gas CO_2 is the sum of all provinces'/territories' emissions due to regional emission factors being used. Totals for the remaining gaseous fuel CO_2 are based on the national total reported in the RESD. Canada totals for CH_4 and N_2O are based on the national total reported in the RESD. A portion of Line 14 is allocated to this source category prior to calculating emissions.
	Biomass	Table 10 – Solid Wood Waste and Spent Pulping Liquor, Total Consumption	Total biomass is the amount of solid wood waste and spent pulping liquors combusted. A portion of Table 10 is allocated to this source category. Canada totals for CO_2, CH_4 and N_2O are based on the national total reported in the RESD. Biomass CO_2 emissions are not included in the national totals, although CH_4 and N_2O emissions are. Instead, biomass CO_2 emissions are reported in the memo items section.
1.A.1.a.ii Combined Heat and Power Generation	Solid Fuels	Included elsewhere	Emissions for this subcategory are included in 1.A.1.a.i. – Electricity Generation.
	Liquid Fuels	Included elsewhere	Emissions for this subcategory are included in 1.A.1.a.i. – Electricity Generation.
	Gaseous Fuels	Included elsewhere	Emissions for this subcategory are included in 1.A.1.a.i. – Electricity Generation.
	Biomass	Included elsewhere	Emissions for this subcategory are included in 1.A.1.a.i. – Electricity Generation.
1.A.1.a.iii Heat Plants	Solid Fuels	Included elsewhere	Emissions for this subcategory are included in 1.A.1.a.i. – Electricity Generation.
	Liquid Fuels	Included elsewhere	Emissions for this subcategory are included in 1.A.1.a.i. – Electricity Generation.
	Gaseous Fuels	Included elsewhere	Emissions for this subcategory are included in 1.A.1.a.i. – Electricity Generation.
	Biomass	Included elsewhere	Emissions for this subcategory are included in 1.A.1.a.i. – Electricity Generation.

Table A3–1   Estimation Methodology for GHG Emissions from Stationary Combustion (cont'd)

A3

CRF Source Category[1]	Fuels List (Table A3-2)	Activity Data Source[2]	Notes
1.A.1.b. **Petroleum Refining**	*Solid Fuels*	NA	NA
	Liquid Fuels	Table 3 – Refined Petroleum Products Line 11 – Transformed to Other Fuels: Electricity – By industry Line 14 – Transformed to Other Fuels: Steam Generation Table 11 – Estimated Additions to Still Gas, Diesel, Petroleum Coke and Crude Oil	Canada totals for CO_2, CH_4 and N_2O are based on the national total reported in the RESD MINUS emissions related to flaring (which is included under category 1B Fugitive). The activity data reported in the RESD include the amount of fuel used to flare. CO_2, CH_4 and N_2O emissions from flaring activity are considered a fugitive source following the IPCC Guidelines; therefore, the fugitive emission and fuel value is subtracted from the estimated emissions and the RESD value to ensure that emissions are not double counted. Only flaring emissions from the petroleum refining fugitive model are subtracted. All other flaring emissions are subtracted from Manufacture of Solid Fuels and Other Energy Industries (1.A.1.c). Petroleum coke – Refineries & Others and Still Gas – Refineries & Others emissions are based on the national total MINUS that used by crude bitumen upgraders reported in the RESD (which is included in 1.A.1.c). A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions.
	Gaseous Fuels	Table 1 – Primary and Secondary Energy Table 6 – Details of Natural Gas Liquids Line 11 – Transformed to Other Fuels: Electricity – By industry Line 14 – Transformed to Other Fuels: Steam Generation Line 25 – Petroleum Refining	Canada total for natural gas CO_2 is the sum of all provinces'/territories' emissions due to regional emission factors being used. Canada totals for CH_4 and N_2O are based on the national total reported in the RESD. A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions.
	Biomass	NA	NA
1.A.1.c.i **Manufacture of Solid Fuels**	*Solid Fuels*	Table 1 – Primary and Secondary Energy Table F – Coal Details Line 16 – Producer-consumed	Canada total for CO_2 is the sum of all provinces'/territories' emissions due to regional emission factors being used. Canada totals for CH_4 and N_2O are based on the national total reported in the RESD.
	Liquid Fuels	NA	NA
	Gaseous Fuels	NA	NA
	Biomass	NA	NA
1.A.1.c.ii **Oil and Gas Extraction**	*Solid Fuels*	NA	NA
	Liquid Fuels	Table 3 – Refined Petroleum Products Table 6 – Details of Natural Gas Liquids Line 11 – Transformed to Other Fuels: Electricity – By industry Line 16 – Producer-consumed Table 11 – Estimated Additions to Still Gas, Diesel, Petroleum Coke and Crude Oil	Canada totals for CO_2, CH_4 and N_2O are based on the national total reported in the RESD. A portion of Line 11 is allocated to this source category prior to calculating emissions.
	Gaseous Fuels	Table 1 – Primary and Secondary Energy Line 11 – Transformed to Other Fuels: Electricity – By industry Line 16 – Producer-consumed	The activity data for natural gas reported in the RESD include the amount flared. Flared emissions are a fugitive source; therefore, the fugitive emissions and the quantity of fuel associated with flaring are subtracted, respectively, from estimated combustion emissions and RESD activity data to avoid double counting. Canada total for natural gas CO_2 is the sum of all provinces'/territories' emissions due to regional emission factors being used. Totals for remaining gaseous fuel CO_2 are based on the national total reported in the RESD. Canada totals for CH_4 and N_2O are based on the national total reported in the RESD. A portion of Line 11 is allocated to this source category prior to calculating emissions.
	Biomass	NA	NA

Table A3–1   Estimation Methodology for GHG Emissions from Stationary Combustion (cont'd)

A3

CRF Source Category[1]	Fuels List (Table A3-2)	Activity Data Source[2]	Notes
1.A.2.a. **Iron and Steel**	Solid Fuels	Table 1 – Primary and Secondary Energy	Canada total for CO_2 is the sum of all provinces'/territories' emissions due to regional emission factors being used EXCEPT for coke emissions, which are based on the national total reported in the RESD.
		Table F – Coal Details	
		Line 11 – Transformed to Other Fuels: Electricity – By industry	Canada totals for CH_4 and N_2O are based on the national total reported in the RESD.
		Line 14 – Transformed to Other Fuels: Steam Generation	CO_2 emissions from coke are reported under Industrial Processes. CH_4 and N_2O emissions are reported here. The CO_2 is considered to be a product of the process (the reduction of iron), while the CH_4 and N_2O are by products of combustion.
		Line 22 – Iron and steel	A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions.
	Liquid Fuels	Table 3 – Refined Petroleum Products	Canada totals for CO_2, CH_4 and N_2O are based on the national total reported in the RESD.
		Line 11 – Transformed to Other Fuels: Electricity – By industry	CO_2, CH_4 and N_2O associated with Transport fuels (i.e. gasoline and diesel) are included in the Transport subcategory.
		Line 14 – Transformed to Other Fuels: Steam Generation	A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions.
		Line 22 – Iron and steel	
	Gaseous Fuels	Table 1 – Primary and Secondary Energy	Canada total for natural gas CO_2 is the sum of all provinces'/territories' emissions due to regional emission factors being used. Totals for remaining gaseous fuel CO_2 are based on the national total reported in the RESD.
		Table 6 – Details of Natural Gas Liquids	
		Line 11 – Transformed to Other Fuels: Electricity – By industry	Canada totals for CH_4 and N_2O are based on the national total reported in the RESD.
		Line 14 – Transformed to Other Fuels: Steam Generation	A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions.
		Line 22 – Iron and steel	
	Biomass	Table 10 – Solid Wood Waste and Spent Pulping Liquor, Total Consumption	Canada totals for CO_2, CH_4 and N_2O are based on the national total reported in the RESD. Biomass CO_2 emissions are not included in the national totals, although CH_4 and N_2O emissions are. Instead, biomass CO_2 emissions are reported in the memo items section.
			A portion of Table 10 is allocated to this source category.
1.A.2.b. **Non-Ferrous Metals**	Solid Fuels	Table 1 – Primary and Secondary Energy	Canada total for CO_2 is the sum of all provinces'/territories' emissions due to regional emission factors being used EXCEPT for coke emissions, which are based on the national total reported in the RESD.
		Table F – Coal Details	
		Line 11 – Transformed to Other Fuels: Electricity – By industry	Canada totals for CH_4 and N_2O are based on the national total reported in the RESD.
		Line 14 – Transformed to Other Fuels: Steam Generation	A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions.
		Line 23 – Smelting and refining, non ferrous	
	Liquid Fuels	Table 3 – Refined Petroleum Products	Canada totals for CO_2, CH_4 and N_2O are based on the national total reported in the RESD.
		Line 11 – Transformed to Other Fuels: Electricity – By industry	CO_2, CH_4 and N_2O associated with Transport fuels (i.e. gasoline and diesel) are included in the Transport category.
		Line 14 – Transformed to Other Fuels: Steam Generation	A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions.
		Line 23 – Smelting and refining, non ferrous	
	Gaseous Fuels	Table 1 – Primary and Secondary Energy	Canada total for natural gas CO_2 is the sum of all provinces'/territories' emissions due to regional emission factors being used. Totals for remaining gaseous fuel CO_2 are based on the national total reported in the RESD.
		Table 6 – Details of Natural Gas Liquids	
		Line 11 – Transformed to Other Fuels: Electricity – By industry	Canada totals for CH_4 and N_2O are based on the national total reported in the RESD.
		Line 14 – Transformed to Other Fuels: Steam Generation	A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions.
		Line 23 – Smelting and refining, non ferrous	
	Biomass	Table 10 – Solid Wood Waste and Spent Pulping Liquor, Total Consumption	Canada totals for CO_2, CH_4 and N_2O are based on the national total reported in the RESD. Biomass CO_2 emissions are not included in the national totals, although CH_4 and N_2O emissions are. Instead, biomass CO_2 emissions are reported in the memo items section.
			A portion of Table 10 is allocated to this source category.

Table A3–1   Estimation Methodology for GHG Emissions from Stationary Combustion (cont'd)

CRF Source Category[1]	Fuels List (Table A3-2)	Activity Data Source[2]	Notes
1.A.2.c. **Chemicals**	*Solid Fuels*	Table 1 – Primary and Secondary Energy Table F – Coal Details Line 11 – Transformed to Other Fuels: Electricity – By industry Line 14 – Transformed to Other Fuels: Steam Generation Line 26 – Chemicals	Canada total for CO_2 is the sum of all provinces'/territories' emissions due to regional emission factors being used EXCEPT for coke emissions, which are based on the national total reported in the RESD. Canada totals for CH_4 and N_2O are based on the national total reported in the RESD. A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions.
	Liquid Fuels	Table 3 – Refined Petroleum Products Line 11 – Transformed to Other Fuels: Electricity – By industry Line 14 – Transformed to Other Fuels: Steam Generation Line 26 – Chemicals	Canada totals for CO_2, CH_4 and N_2O are based on the national total reported in the RESD. CO_2, CH_4 and N_2O associated with Transport fuels (i.e. gasoline and diesel) are included in the Transport subsector. A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions.
	Gaseous Fuels	Table 1 – Primary and Secondary Energy Table 6 – Details of Natural Gas Liquids Line 11 – Transformed to Other Fuels: Electricity – By industry Line 14 – Transformed to Other Fuels: Steam Generation Line 26 – Chemicals	Canada total for natural gas CO_2 is the sum of all provinces'/territories' emissions due to regional emission factors being used. Totals for remaining gaseous fuel CO_2 are based on the national total reported in the RESD. Canada totals for CH_4 and N_2O are based on the national total reported in the RESD. A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions.
	Biomass	Table 10 – Solid Wood Waste and Spent Pulping Liquor, Total Consumption	Canada totals for CO_2, CH_4 and N_2O are based on the national total reported in the RESD. Biomass CO_2 emissions are not included in the national totals, although CH_4 and N_2O emissions are. Instead, biomass CO_2 emissions are reported in the memo items section. A portion of Table 10 is allocated to this source category.
1.A.2.d. **Pulp, Paper and Print**	*Solid Fuels*	Table 1 – Primary and Secondary Energy Table F – Coal Details Line 11 – Transformed to Other Fuels: Electricity – By industry Line 14 – Transformed to Other Fuels: Steam Generation Line 21 – Pulp and paper	Canada total for CO_2 is the sum of all provinces'/territories' emissions due to regional emission factors being used EXCEPT for coke emissions, which are based on the national total reported in the RESD. Canada totals for CH_4 and N_2O are based on the national total reported in the RESD. A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions.
	Liquid Fuels	Table 3 – Refined Petroleum Products Line 11 – Transformed to Other Fuels: Electricity – By industry Line 14 – Transformed to Other Fuels: Steam Generation Line 21 – Pulp and paper	Canada totals for CO_2, CH_4 and N_2O are based on the national total reported in the RESD. CO_2, CH_4 and N_2O associated with Transport fuels (i.e. gasoline and diesel) are included in the Transport category. A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions.
	Gaseous Fuels	Table 1 – Primary and Secondary Energy Table 6 – Details of Natural Gas Liquids Line 11 – Transformed to Other Fuels: Electricity – By industry Line 14 – Transformed to Other Fuels: Steam Generation Line 21 – Pulp and paper	Canada total for natural gas CO_2 is the sum of all provinces'/territories' emissions due to regional emission factors being used. Totals for remaining gaseous fuel CO_2 are based on the national total reported in the RESD. Canada totals for CH_4 and N_2O are based on the national total reported in the RESD. A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions.
	Biomass	Table 10 – Solid Wood Waste and Spent Pulping Liquor, Total Consumption	Canada totals for CO_2, CH_4 and N_2O are based on the national total reported in the RESD. Biomass CO_2 emissions are not included in the national totals, although CH_4 and N_2O emissions are. Instead, biomass CO_2 emissions are reported in the memo items section. A portion of Table 10 is allocated to this source category.

A3

Table A3–1   Estimation Methodology for GHG Emissions from Stationary Combustion (cont'd)

A3

CRF Source Category[1]	Fuels List (Table A3-2)	Activity Data Source[2]	Notes
1.A.2.e. **Food Processing, Beverages and Tobacco**	*Solid Fuels*	Included elsewhere	Emissions for this subcategory are included in 1.A.2.f.iv. – Other Manufacturing.
	Liquid Fuels	Included elsewhere	Emissions for this subcategory are included in 1.A.2.f.iv. – Other Manufacturing.
	Gaseous Fuels	Included elsewhere	Emissions for this subcategory are included in 1.A.2.f.iv. – Other Manufacturing.
	Biomass	Included elsewhere	Emissions for this subcategory are included in 1.A.2.f.iv. – Other Manufacturing.
1.A.2.f. **Non-Metallic Minerals**	*Solid Fuels*	Table 1 – Primary and Secondary Energy Table F – Coal Details Line 11 – Transformed to Other Fuels: Electricity – By industry Line 14 – Transformed to Other Fuels: Steam Generation Line 24 – Cement Waste fuel data from the Canadian Industrial Energy End-use Data Analysis Centre (CIEEDAC).	Canada total for CO_2 is the sum of all provinces'/territories' emissions due to regional emission factors being used EXCEPT for coke and waste fuel emissions, which are based on the national total. Canada totals for CH_4 and N_2O are based on the national total reported in the RESD. A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions.
	Liquid Fuels	Table 3 – Refined Petroleum Products Line 11 – Transformed to Other Fuels: Electricity – By industry Line 14 – Transformed to Other Fuels: Steam Generation Line 24 – Cement	Canada totals for CO_2, CH_4 and N_2O are based on the national total reported in the RESD. CO_2, CH_4 and N_2O associated with Transport fuels (i.e. gasoline and diesel) are included in the Transport category. A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions.
	Gaseous Fuels	Table 1 – Primary and Secondary Energy Table 6 – Details of Natural Gas Liquids Line 11 – Transformed to Other Fuels: Electricity – By industry Line 14 – Transformed to Other Fuels: Steam Generation Line 24 – Cement	Canada total for natural gas CO_2 is the sum of all provinces'/territories' emissions due to regional emission factors being used. Totals for remaining gaseous fuel CO_2 are based on the national total reported in the RESD. Canada totals for CH_4 and N_2O are based on the national total reported in the RESD. A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions.
	Biomass	Table 10 – Solid Wood Waste and Spent Pulping Liquor, Total Consumption	Canada totals for CO_2, CH_4 and N_2O are based on the national total reported in the RESD. Biomass CO_2 emissions are not included in the national totals, although CH_4 and N_2O emissions are. Instead, biomass CO_2 emissions are reported in the memo items section. A portion of Table 10 is allocated to this source category.
1.A.2.g.iii **Mining**	Solid Fuels	Table 1 – Primary and Secondary Energy Table F – Coal Details Line 11 – Transformed to Other Fuels: Electricity – By industry Line 14 – Transformed to Other Fuels: Steam Generation Line 20 – Total mining & oil & gas extraction	Canada total for CO_2 is the sum of all provinces'/territories' emissions calculated using regional emission factors EXCEPT for coke emissions, which are based on the national total reported in the RESD. Mining, according to the RESD, includes fuel consumed for mining and extraction of oil and gas as well as upgrading of crude bitumen. Canada totals for CH_4 and N_2O are based on the national total reported in the RESD. A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions.
	Liquid Fuels	Table 3 – Refined Petroleum Products Line 11 – Transformed to Other Fuels: Electricity – By industry Line 14 – Transformed to Other Fuels: Steam Generation Line 20 – Total mining & oil & gas extraction	Canada totals for CO_2, CH_4 and N_2O are based on the national total reported in the RESD. CO_2, CH_4 and N_2O associated with Transport fuels (i.e. gasoline and diesel) are included in the Transport category. A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions.

Table A3–1   Estimation Methodology for GHG Emissions from Stationary Combustion (cont'd)

CRF Source Category[1]	Fuels List (Table A3-2)	Activity Data Source[2]	Notes
	Gaseous Fuels	Table 1 – Primary and Secondary Energy Table 6 – Details of Natural Gas Liquids	Canada total for natural gas CO_2 is the sum of all provinces'/territories' emissions due to regional emission factors being used. Totals for remaining gaseous fuel CO_2 are based on the national total reported in the RESD.
		Line 11 – Transformed to Other Fuels: Electricity – By industry Line 14 – Transformed to Other Fuels: Steam Generation Line 20 – Total mining & oil & gas extraction	Canada totals for CH_4 and N_2O are based on the national total reported in the RESD. A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions.
	Biomass	NA	NA
1.A.2.g.v **Construction**	Solid Fuels	Table 1 – Primary and Secondary Energy Table F – Coal Details	Canada total for CO_2 is the sum of all provinces'/territories' emissions due to regional emission factors being used EXCEPT for coke emissions, which are based on the national total reported in the RESD.
		Line 30 – Construction	Canada totals for CH_4 and N_2O are based on the national total reported in the RESD.
	Liquid Fuels	Table 3 – Refined Petroleum Products	Canada totals for CO_2, CH_4 and N_2O are based on the national total reported in the RESD.
		Line 30 – Construction	CO_2, CH_4 and N_2O associated with Transport fuels (i.e. gasoline and diesel) are included in the Transport category.
	Gaseous Fuels	Table 1 – Primary and Secondary Energy Table 6 – Details of Natural Gas Liquids	Canada total for natural gas CO_2 is the sum of all provinces'/territories' emissions due to regional emission factors being used. Totals for remaining gaseous fuel CO_2 are based on the national total reported in the RESD.
		Line 30 – Construction	Canada totals for CH_4 and N_2O are based on the national total reported in the RESD.
	Biomass	NA	NA
1.A.2.g.viii.1 **Other Manufacturing**	Solid Fuels	Table 1 – Primary and Secondary Energy Table F – Coal Details	A weighted emission factor is calculated for CH_4 and N_2O based on fuel consumption and applied on an annual basis.
		Line 11 – Transformed to Other Fuels: Electricity – By industry Line 14 – Transformed to Other Fuels: Steam Generation Line 27 – Other Manufacturing	A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions.
	Liquid Fuels	Table 3 – Refined Petroleum Products	A weighted emission factor is calculated for CH_4 and N_2O based on fuel consumption and applied on an annual basis.
		Line 11 – Transformed to Other Fuels: Electricity – By industry	CO_2, CH_4 and N_2O associated with Transport fuels (i.e. gasoline and diesel) are included in the Transport category.
		Line 14 – Transformed to Other Fuels: Steam Generation Line 27 – Other Manufacturing	A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions.
	Gaseous Fuels	Table 1 – Primary and Secondary Energy Table 6 – Details of Natural Gas Liquids	A weighted emission factor is calculated for CH_4 and N_2O based on fuel consumption and applied on an annual basis.
		Line 11 – Transformed to Other Fuels: Electricity – By industry	A weighted emission factor is calculated for CH_4 and N_2O and applied on an annual basis.
		Line 14 – Transformed to Other Fuels: Steam Generation Line 27 – Other Manufacturing	A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions.
	Biomass	Table 10 – Solid Wood Waste and Spent Pulping Liquor, Total Consumption	Canada totals for CO_2, CH_4 and N_2O are based on the national total reported in the RESD. Biomass CO_2 emissions are not included in the national totals, although CH_4 and N_2O emissions are. Instead, biomass CO_2 emissions are reported in the memo items section. A portion of Table 10 is allocated to this source category.

A3

Table A3–1   Estimation Methodology for GHG Emissions from Stationary Combustion (cont'd)

A3

CRF Source Category[1]	Fuels List (Table A3-2)	Activity Data Source[2]	Notes
1.A.3.e.i **Pipeline Transport**	*Solid Fuels* *Not Occurring (NO)*	NO	NO
	Liquid Fuels	Table 3 – Refined Petroleum Products Line 39 – Pipelines	Canada totals for CO_2, CH_4 and N_2O are based on the national total reported in the RESD.
	Gaseous Fuels	Table 1 – Primary and Secondary Energy Table 6 – Details of Natural Gas Liquids Line 39 – Pipelines	Canada total for natural gas CO_2 is the sum of all provinces'/territories' emissions due to regional emission factors being used. Totals for remaining gaseous fuel CO_2 are based on the national total reported in the RESD. Canada totals for CH_4 and N_2O are based on the national total reported in the RESD.
	Biomass	NA	NA
1.A.4.a.i **Commercial / Institutional – Stationary Combustion**	*Solid Fuels*	Table 1 – Primary and Secondary Energy Table F – Coal Details Line 11 – Transformed to Other Fuels: Electricity – By industry Line 46 – Commercial and Institutional Line 45 – Public Administration	Canada total for CO_2 is the sum of all provinces'/territories' emissions due to regional emission factors being used. Canada totals for CH_4 and N_2O are based on the national total reported in the RESD. A portion of Line 11 is allocated to this source category prior to calculating emissions.
	Liquid Fuels	Table 3 – Refined Petroleum Products Line 11 – Transformed to Other Fuels: Electricity – By industry Line 46 – Commercial and Institutional Line 45 – Public Administration	Canada totals for CO_2, CH_4 and N_2O are based on the national total reported in the RESD. CO_2, CH_4 and N_2O associated with Transport fuels (i.e. gasoline and diesel) are included in the Transport category. A portion of Line 11 is allocated to this source category prior to calculating emissions.
	Gaseous Fuels	Table 1 – Primary and Secondary Energy Table 6 – Details of Natural Gas Liquids Line 11 – Transformed to Other Fuels: Electricity – By industry Line 46 – Commercial and Institutional Line 45 – Public Administration	Canada total for natural gas CO_2 is the sum of all provinces'/territories' emissions due to regional emission factors being used. Totals for remaining gaseous fuel CO_2 are based on the national total reported in the RESD. Canada totals for CH_4 and N_2O are based on the national total reported in the RESD. A portion of Line 11 is allocated to this source category prior to calculating emissions.
	Biomass	Table 10 – Solid Wood Waste and Spent Pulping Liquor, Total Consumption	Canada totals for CO_2, CH_4 and N_2O are based on the national total reported in the RESD. Biomass CO_2 emissions are not included in the national totals, although CH_4 and N_2O emissions are. Instead, biomass CO_2 emissions are reported in the memo items section. A portion of Table 10 is allocated to this source category.
1.A.4.b.i **Residential – Stationary Combustion**	*Solid Fuels*	Table 1 – Primary and Secondary Energy Table F – Coal Details Line 44 – Residential	Canada total for CO_2 is the sum of all provinces'/territories' emissions due to regional emission factors being used. Canada totals for CH_4 and N_2O are based on the national total reported in the RESD.
	Liquid Fuels	Table 3 – Refined Petroleum Products Line 44 – Residential	Canada totals for CO_2, CH_4 and N_2O are based on the national total reported in the RESD.
	Gaseous Fuels	Table 1 – Primary and Secondary Energy Table 6 – Details of Natural Gas Liquids Line 44 – Residential	Canada total for natural gas CO_2 is the sum of all provinces'/territories' emissions due to regional emission factors being used. Totals for remaining gaseous fuel CO_2 are based on the national total reported in the RESD. Canada totals for CH_4 and N_2O are based on the national total reported in the RESD.
	Biomass	Firewood consumption estimated using Environment Canada residential fuelwood consumption model.	CO_2 emissions are not included in the national totals, but CH_4 and N_2O emissions are. CO_2 emissions from the use of biomass fuels are reported in the memo items section.

Table A3–1 Estimation Methodology for GHG Emissions from Stationary Combustion (cont'd)

CRF Source Category[1]	Fuels List (Table A3-2)	Activity Data Source[2]	Notes
1.A.4.c.i **Agriculture/ Forestry/ Fishing – Stationary Combustion**	*Solid Fuels*	Table 1 – Primary and Secondary Energy Table F – Coal Details Line 11 – Transformed to Other Fuels: Electricity – By industry Line 14 – Transformed to Other Fuels: Steam Generation Line 29 – Forestry Line 43 – Agriculture	Canada total for CO_2 is the sum of all provinces'/territories emissions due to regional emission factors being used. Canada totals for CH_4 and N_2O are based on the national total reported in the RESD. A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions.
	Liquid Fuels	Table 3 – Refined Petroleum Products Line 11 – Transformed to Other Fuels: Electricity – By industry Line 14 – Transformed to Other Fuels: Steam Generation Line 29 – Forestry Line 43 – Agriculture	Canada totals for CO_2, CH_4 and N_2O are based on the national total reported in the RESD. CO_2, CH_4 and N_2O associated with Transport fuels (i.e. gasoline and diesel) are included in the Transport category. A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions.
	Gaseous Fuels	Table 1 – Primary and Secondary Energy Table 6 – Details of Natural Gas Liquids Line 11 – Transformed to Other Fuels: Electricity – By industry Line 14 – Transformed to Other Fuels: Steam Generation Line 29 – Forestry Line 43 – Agriculture	Canada total for natural gas CO_2 is the sum of all provinces'/territories' emissions due to regional emission factors being used. Totals for remaining gaseous fuel CO_2 are based on the national total reported in the RESD. Canada totals for CH_4 and N_2O are based on the national total reported in the RESD. A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions.
	Biomass	Table 10 – Solid Wood Waste and Spent Pulping Liquor, Total Consumption	Canada totals for CO_2, CH_4 and N_2O are based on the national total reported in the RESD. Biomass CO_2 emissions are not included in the national totals, although CH_4 and N_2O emissions are. Instead, biomass CO_2 emissions are reported in the memo items section. A portion of Table 10 is allocated to this source category.
1.A.5.a. **Other (Not Specified) – Stationary Combustion**	*NA*	NA	Emissions from all other industrial sources are included in 1.A.2.f.iv. – Other Manufacturing.

Notes:

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

2. Activity data refer to the specific location of the data in the annual *Report on Energy Supply–Demand in Canada* (RESD) (Statistics Canada #57-003). Also refer to Table A3.1-3 for non-RESD data source references.

3. NA = Not applicable.

4. NO = Not occurring.

A3

Table A3–2   General Fuel Type Categories for Stationary Combustion Methodology

Fuel Types	Fuels
Liquid Fuels	Gasoline
	Kerosene and stove oil
	Diesel – Refineries & Others
	Diesel – Upgraders
	Ethane
	Propane
	Butane
	Light fuel oil
	Heavy fuel oil
	Aviation gasoline
	Aviation turbo fuel
	Refinery liquefied petroleum gases (LPGs)
	Still Gas – Refineries & Others
	Still Gas – Upgraders
	Petroleum Coke – Refineries & Others
	Petroleum Coke – Upgraders
Solid Fuels	Coke (coal)
	Coke oven gas
	Canadian bituminous
	Sub-bituminous (foreign & domestic)
	Lignite
	Anthracite
	Foreign bituminous
	Waste fuel
Gaseous Fuels	Natural gas
Biomass	Solid wood waste
	Spent pulping liquor
	Residential firewood
	Landfill gas

Activity data sources are presented in Table A3–3 for reference in the stationary combustion model methodology. The data are made available to Environment Canada in electronic format and may differ slightly when compared with Statistics Canada's rounded, published values.

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. CO_2, CH_4 and N_2O emissions are estimated by applying Equation A3–1 to activity data and emission factors for specific fuels on a national basis. Coal and natural gas emission factors for these subcategories have been developed on a regional basis. As previously discussed, in order to obtain

Table A3–3   Activity Data Model References

Statistics Canada – Manufacturing, Construction and Energy Division; annual Report on Energy Supply–Demand in Canada (RESD), #57-003-XPB.
Table 1 – Primary and Secondary Energy
Table 3 – Refined Petroleum Products
Table 5 – Non-energy Refined Petroleum Products
Table 6 – Details of Natural Gas Liquids
Table 10 – Solid Wood Waste and Spent Pulping Liquor
Table 11 – Estimated Additions to Still Gas, Diesel, Petroleum Coke and Crude Oil
Table F – Coal Details (as identified in the 1990 to 2001P RESD publications)
Waste fuel data - Based on CIEEDAC (2013). CIEEDAC Database on Energy, Production and Intensity Indicators for Canadian Industry. NAICS 327310 Cement Manufacturing. Canadian Industrial Energy End-use Data Analysis Centre. Also based on data collected by the Cement Assocation of Canada under WBCSD (2005). Cement Sustainability Initiative CO_2 Emissions Inventory Protocol. v.2.0.
Residential fuelwood consumption – Environment Canada. 2014. Residential Fuelwood Consumption in Canada. Unpublished report. Prepared by K. Tracey, Polllutant Inventories and Reporting Division, Environment Canada, October 2014.
Landfill Gas Utilization – See Annex 3, Additional Methodologies.

higher accuracy in GHG emissions, regional emission factors are applied to provincial/territorial data in this circumstance. For the remaining fuels, the emission factors are applied to the nationally reported data.

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 (Line 11 – Electricity by Industry and Line 14 – Steam Generation). In addition, activity data, in the form of solid wood waste and spent pulping liquor, are currently aggregated to a summary table in the RESD (Table 10 – Solid Wood Waste and Spent Pulping Liquor). The aggregated data needs to be reallocated to the appropriate industry (including the Public Electricity and Heat Production industry) where the fuel is used. This is completed using one of two methods.

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

- 1998 to present: the reallocation was completed using fractions developed based on the quantities reported by the Electricity Generation subcategory in the EPTGS survey. For each fuel and each province, the fuel use data reported 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.

- 1990 to 1997: the reallocation was completed using fractions developed based on the quantities reported by the Electricity Generation subcategory in the ICE survey, since EPTGS

data are not available prior to 1998. For each fuel and each province, the fuel use data reported by industry in ICE for electricity generation are used to develop each industry's fraction of the total fuel use. The fractions are then used with Line 11 from the RESD to determine what portion of that line should be reallocated to a particular industry. This portion is added to the activity data already reported for that industry. Since ICE data did not exist prior to 1995, for years between 1990 and 1995, the 1995 fractions were used.

Since the Heat and Steam Generation line (RESD Line 14) and the Solid Wood Waste and Spent Pulping Liquor table (RESD Table 10) is populated with ICE data:

- RESD Line 14: 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.

- RESD Table 10: 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.

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

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

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

To determine the activity data associated with the Petroleum Refining subcategory, some data reported in the RESD must be reallocated. All refined petroleum products that are reported as Producer-consumed are allocated to the Petroleum Refining subcategory

based on the assumption that they are consumed by the producers, except in provinces where no refinery exists. In such cases, the Producer-consumed RPPs are assigned to Oil and Gas Extraction. Physical quantities of producer–consumed liquefied petroleum gases (LPGs), as reported in the RESD, 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-consumed and applying Equation A3–1 to:

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

In addition, activity data, in the form of fuel used by industry to generate electricity or steam, are currently aggregated to two summary lines in the RESD (Line 11 – Electricity by Industry and Line 14 – Steam Generation). The aggregated data needs to be reallocated to the appropriate industry where the fuel is used. This is completed using one of two methods, which are discussed in detail in section A3.1.4.1.1.

To estimate emissions for the Petroleum Refining subcategory from the consumption of the transportation fuels listed below, the activity data reported under Producer-consumed are used in Equation A3–1 and the emissions are included under Petroleum Refining. Due to a lack of resolution in the RESD, the Manufacture of Solid Fuels and Other Energy Industries subcategory does not include emissions associated with the list of fuels presented below; instead their emissions are accounted for in the Petroleum Refining subcategory:

- gasoline; and
- diesel fuel.

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

To calculate GHG emissions from the Manufacture of Solid Fuels and Other Energy Industries subcategory, activity data for the

A3

following fuels reported as Producer-consumed in the RESD are used in Equation A3–1:

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

Petroleum coke, still gas and diesel are reported as Producer-consumed in the crude bitumen upgrading industry in a separate table in the RESD. The relevant quantities of petroleum coke and still gas are subtracted from the Petroleum Refining subcategory and included in the Oil and Gas Extraction sub-category. Diesel reported as Producer-consumed is used in oil sands mining trucks and reported under Off-road transport (see section A3.1.4.2.2).

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

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

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 lines (one for electricity and one for steam); however, they are summary lines and are not divided by industrial categories. In addition, activity data, in the form of solid wood waste and spent pulping liquor, are currently aggregated to a summary table in the RESD (Table 10 – Solid Wood Waste and Spent Pulping Liquor). The aggregated data needs to be reallocated to the appropriate industry where the fuel is used. This is completed using one of two methods, which are discussed in detail in section A3.1.4.1.1

Emissions are calculated for the following categories:

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

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

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

CO_2 emissions associated with the use of metallurgical coke in the iron and steel industry for the reduction of iron ore in blast furnaces have been allocated to the Industrial Processes Sector. CH_4 and N_2O emissions, however, are included, as they are by-products of the combustion process.

CO_2 emissions associated with biomass combustion are reported but not included in the national totals; however, CH_4 and N_2O emissions are included in the totals. Industrial consumption of biomass and spent pulping liquors is reported in the RESD; however, some of the data are limited. The RESD data for 1990 and 1991 were combined for the Atlantic provinces, as were the data for the Prairie provinces. Individual provincial data were delineated by employing a data comparison with the 1992 RESD data. For 1992, the data for Newfoundland and Nova Scotia were also combined, and there were no comparable data to allow separation of these provinces. Emissions are listed under Nova Scotia. In 2010, Environment Canada conducted a review of available wood waste moisture content data and concluded that for the purposes of the National Inventory Report (NIR), solid wood waste activity data are reported on a wet-weight basis and that the average moisture content is 50%.

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

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/Fisheries. GHG emissions associated with the Other Sectors category (with the exception of emissions from the combustion of residential firewood) are calculated by applying Equation A3–1 to activity data reported in the RESD and emission factors for specific fuels on a national basis.

The activity data used in the calculation of GHG emissions from the combustion of residential firewood are based on estimated

fuel use, as determined from Environment Canada's study Residential Fuelwood Consumption in Canada (Environment Canada 2014). Firewood consumption data were collected through a survey of residential wood use for the years 1996, 2006 and 2012 (Canadian Facts 1997, TNS 2006, TNS 2012). These data were collected by province and grouped into five major appliance-type categories:

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

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

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

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

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

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

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

the fuel is used. This is completed using one of two methods, which are discussed in detail in section A3.1.4.1.1.

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

A3.1.4.2. Transport (CRF Category 1.A.3)

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

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

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

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

Owing to the complexity of the Transport subsector, Canada's Mobile Greenhouse Gas Emission Model (MGEM) and the Aviation Greenhouse Gas Emission Model (AGEM) are used to calculate the emissions from Road Transportation, Railways, Navigation, Off-road and Aviation. The combustion emissions associated with pipeline transport are estimated separately.

A3.1.4.2.1. Road Transportation
(CRF Category 1.A.3.b.i-v)

The methodology used to estimate Road Transportation GHG emissions follows a detailed IPCC Tier 3 approach.

A3

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

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 were obtained from the *Canadian Vehicles in Operation Census*, which is maintained by DesRosiers Automotive Consultants Inc. Light-duty vehicle and truck populations for 2003–2013 were derived from Statistics Canada's *Canadian Vehicle Survey* (CVS). Heavy-duty vehicle populations were obtained from R.L. Polk & Co. for 1994–2002. Heavy-duty vehicle populations for 2003–2013 were derived from Statistics Canada's *Canadian Vehicle Survey*, while populations for 1990–1993 were estimated based on historical population trends. 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 heavyduty classes have a GVWR above 3900 kg.

Motorcycle populations for 2013 were extrapolated based upon data obtained from the Motorcycle & Moped Industry Council for the 2012 Submission (MMIC 2010).

Technology Penetration

To account for the effects that emission control technologies have on emissions 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. Figure A3–2 illustrates the varying penetration percentages of evolving technologies into new light-duty gasoline vehicles (LDGVs) and light-duty gasoline trucks (LDGTs) in successive model years. Technology penetration for heavy-duty gasoline vehicles (HDGVs), heavy-duty diesel vehicles (HDDVs), light-duty diesel vehicles (LDDVs), light-duty diesel trucks (LDDTs) and motorcycles (MCs) are detailed in Table A3–4 (U.S. EPA 2014).

Catalyst Survival Rate

With use, catalytic converters deteriorate, affecting tailpipe emission rates. Based on information from industry experts, a technology-specific deterioration rate is applied to LDGVs and LDGTs with catalyticcontrolled technologies. To model the deterioration effect, the vehicles with deteriorated catalysts are assigned to the noncatalytic 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.

Figure A3–2   Technology Penetration for Light-duty Gasoline Vehicles and Trucks
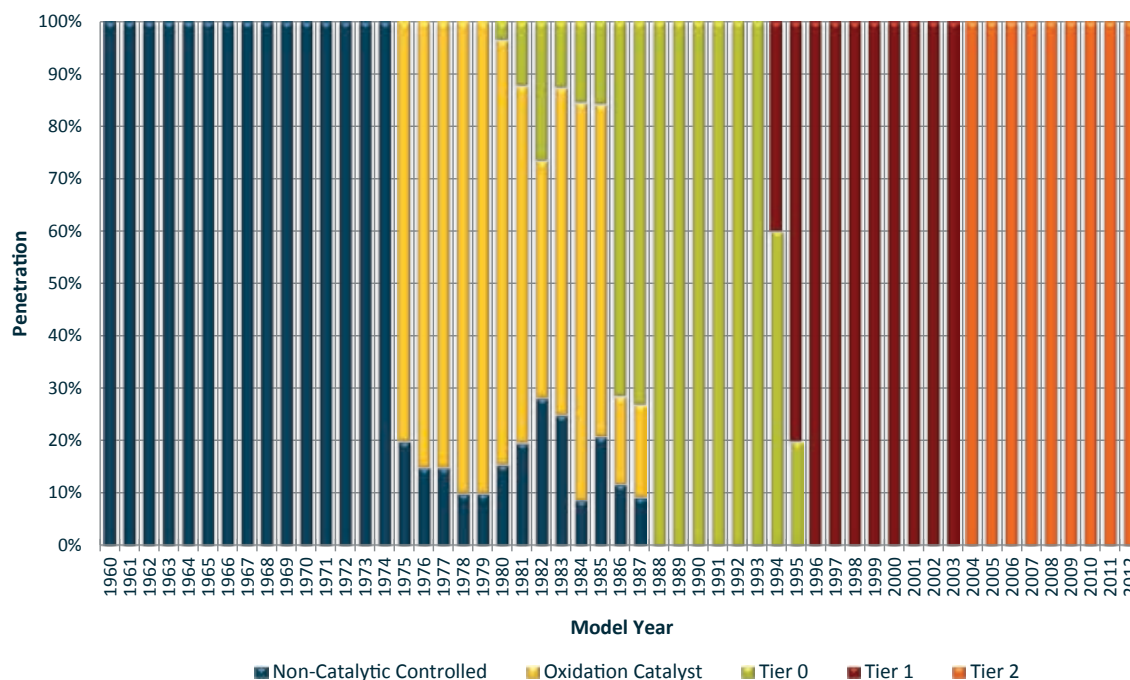
Table A3–4 Technology Penetration for HDGVs, HDDVs, LDDVs, LDDTs and MCs

Control Technology	Model Years
Heavy-duty Gasoline Vehicles (HDGVs)	
Uncontrolled	1960–1984
Non-catalytic Controlled	1985–1995
Three-way Catalyst	1996–2012
Heavy-duty Diesel Vehicles (HDDVs)	
Uncontrolled	1960–1982
Moderate Controls	1983–1995
Advanced Controls	1996–2012
Light-duty Diesel Vehicles and Trucks (LDDVs and LDDTs)	
Uncontrolled	1960–1982
Moderate Controls	1983–1995
Advanced Controls	1996–2003
Tier 2	2004–2012
Motorcycles (MCs)	
Uncontrolled	1960–1995
Non-catalytic Controlled	1996–2012

Fuel Consumption Ratios

Average provincial fuel consumption ratios (FCRs) by vehicle class and model year (based on provincial vehicle sales) are available for LDGVs, LDGTs, LDDVs and LDDTs (NRCan 2010). FCRs for HDGVs are based on a vehicle class and model year average (IPCC 2006). HDDV and motorcycle FCRs are based on a yearly fleet average (NRCan 2010). All class-specific FCRs representing the 2013 model year contribution to the Canadian fleet were extrapolated based upon the previously existing time series.

Laboratory FCRs are determined by standardized vehicle emission tests. However, research has shown that realworld fuel consumption is consistently higher than laboratory-generated data. Based on studies performed in the United States, on-road vehicle fuel consumption figures in MGEM have been adjusted to 25% above the laboratory FCR ratings (Maples 1993).

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 given vehicle class.. Light-duty car and truck KARs are estimated from the results of a report examining the differences in vehicle odometer readings recorded during successive inspection and maintenance (I/M) tests from Ontario and British Columbia (Stewart Brown Associates 2010). Due to the absence of I/M programs in other jurisdictions, the Ontario KAR estimates are adopted in all other provinces and territories excluding British Columbia, where the B.C. KAR estimates are directly applied.

Step 2: On-road Fuel Calculation

On-road gasoline and diesel fuel consumption is estimated using Equation A3–2; this calculation represents the initial "bottom-up" fuel calculation ("C") for consideration in the fuel normalization process described below.

Equation 3–2:

$$Fuel\ Consumption = Population * KAR * FCR$$

A3

For the most part, KARs and FCRs are different for each province, vehicle class, model year and inventory year. On-road vehicles are grouped into seven major vehicle classes, identical to those used by the U.S. Environmental Protection Agency (U.S. EPA) in its MOBILE emissions factor model. The U.S. EPA designations are as follows:

- LDGVs;
- LDGTs;
- HDGVs;
- MCs;
- LDDVs;
- LDDTs; and
- HDDVs.

It is assumed that all natural gas and propane fuel is consumed by light-duty vehicles. No breakdown by vehicle classification is utilized for natural gas and propane vehicles. The methodologies for propane and natural gas vehicles follow an IPCC Tier 2 method for CO_2 emissions and an IPCC Tier 1 method for CH_4, and N_2O emissions.

Step 3: Normalization

In an effort to improve the allocation of fuel between on- and off-road applications, a balancing algorithm has been incorporated into MGEM. It operates between two top-down fuel availability estimates and one bottom-up fuel consumption estimate. Below, the algorithm's logic is outlined.

There are two different sources of top-down fuel availability data to be considered against the bottom-up fuel consumption estimate calculated by MGEM:

- The RESD (Statistics Canada #57-003) compiles data from refineries, industry and import/export records to generate the national energy balance for gasoline and diesel fuel. The RESD is believed to provide an allencompassing picture of national fuel availability on a gross fuel-consumed level.
- Statistics Canada's Road Motor Vehicles, Fuel Sales, Annual (CANSIM, Table 405-0002) compiles reported provincial/territorial fuel sales data in the form of taxed and non-taxed fuel sales. This source is used for its ratio between taxed and non-taxed fuel consumption, where taxed fuel consumption represents on-road use and non-taxed use represents off-road use.

The RESD and Fuel Sales survey do not typically reconcile in terms of total fuel consumed. The balancing algorithm in MGEM ensures that total fuel consumed equals that reported in the RESD, and consults the Fuel Sales survey to help distinguish between on-road (taxed) and off-road (untaxed) use.

Given that Statistics Canada has stated that the volumes of gasoline reported in the RESD include ethanol, the estimates of ethanol are removed from the volumes of gasoline reported. Therefore, 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.

Gasoline

This section references Figure A3–3.

The preliminary gasoline on-road fuel consumption estimate is represented as C and is calculated in step 2 (above). It represents a bottom-up estimate based on vehicle population, FCRs and KARs.

The preliminary off-road estimate is represented by R and is the difference between the RESD total fuel consumed (represented by Q) and C.

The next process reconciles the two top-down reported fuel quantities at a total fuel level. The total sum (G) of taxed fuel (T) and non-taxed fuel (NT) is scaled to equal the RESD total fuel available (Q). This provides G_{max}, T_{max} and NT_{max} and a scaling factor A. These new values are illustrated in Phase 2 of Figure A3–3. The two top-down reported fuel quantities now equal each other, but the Fuel Sales survey has the additional information of a taxed versus non-taxed fuel use ratio, which will be used to help normalize MGEM's bottom-up on-road estimate.

Figure A3–3   On-Road Gasoline Normalization Procedure for MGEM
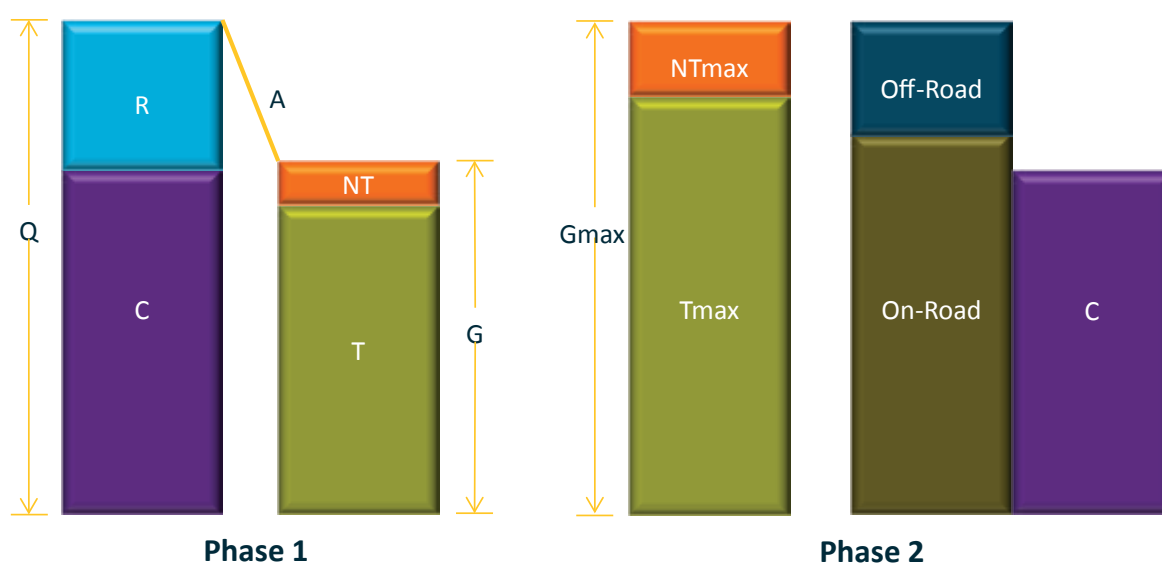
Q – Total gasoline fuel available in Canada from RESD
C – Preliminary bottom-up On-Road fuel consumption estimate (vehicle population x kilometre accumulation rate x fuel consumption rate)
R – First Off-Road estimate represented by Q-C
G – Gross gasoline fuel sales from Fuel Sales survey
T – Taxed gasoline fuel sales from Fuel Sales survey
NT – Non-Taxed gasoline fuel sales from Fuel Sales survey
A – Factor used to scale G to match Q: A = Q/G (range from 0.99 to 1.05)
Gmax – Scale G to match Q: Gmax = G x A = Q
Tmax – Scale T to preserve original gross to taxed fuel sales ratio from Fuel Sales survey: Tmax = T x A
NTmax – Scale NT to preserve original gross to taxed fuel sales ratio from Fuel Sales survey: NTmax = NT x A
On-Road – When C is less than or equal to Tmax then On-Road = (C + Tmax)/2; When C is greater than Tmax then On-Road = Tmax
Off-Road – The difference between Q (same as Gmax) and On-Road: Off-Road = Q - On-Road

Table A3–5   Gasoline Normalization Values, Selected Years

		1990	2000	2005	2009	2010	2011	2012	2013
Phase 1	C - Bottom-up On-Road Vehicle Calc. (ML)	30 238	32 729	35 636	37 702	38 182	38 377	38 587	38 805
	Q - RESD's Total Gasoline Fuel Available (ML)	33 943	38 268	40 810	42 217	43 347	42 905	43 011	44 198
	T - Taxed Gasoline Fuel Sales (ML)	31 842	36 375	38 484	39 708	40 101	40 412	40 444	41 450
	G - Gross Gasoline Fuel Sales (ML)	33 721	38 177	39 846	41 028	41 453	42 076	42 033	42 903
	A - Scaling Factor	1.01	1.00	1.02	1.03	1.05	1.02	1.02	1.03
Phase 2	T_{max} - Scaled Taxed Gasoline Fuel Sales (ML)	32 052	36 462	39 415	40 859	41 933	41 208	41 386	42 701
	On-Road - Final On-Road Gasoline Fuel Estimate (ML)	31 145	34 595	37 526	39 281	40 058	39 793	39 987	40 753
	Off-Road - Final Off-Road Gasoline Fuel Estimate (ML)	2 798	3 672	3 284	2 936	3 289	3 113	3 025	3 445
	On-Road + Off-Road (ML)	33 943	38 268	40 810	42 217	43 347	42 905	43 011	44 198
	On-Road Gasoline Normalization Factor	1.03	1.06	1.05	1.04	1.05	1.04	1.04	1.05

A3

To calculate the final normalized on-road estimate, represented by "On-Road" in Phase 2 of Figure A3–3, the following logic is applied:

- when C is less than T_{max}, "On-Road" is the average of C and T_{max} (midpoint between C and T_{max})
- when C is greater than T_{max}, "On-Road" is set to T_{max}

The final process is to scale C so that it equals "On-Road." This is accomplished by adjusting the initial KARs until the new bottom-up consumption equals the "On-Road" fuel volume.

"Off-Road" (as represented in Phase 2 of Figure A3–3) is now represented by the difference between G_{max} (which is equivalent to Q) and "On-Road."

Therefore, all fuel available in the RESD (Q) is accounted for, while the Fuel Sales survey aided in differentiating on-road from off-road fuel use.

At a provincial level, top-down and bottom-up gasoline consumption estimates differ slightly; however, at a national level, there is a high degree of correlation between the two estimates. Please refer to Table A3–5 for the national normalization factors for On-Road. The normalization factor is represented by the ratio of On-Road to C. Table A3–5 also includes the national values for the various coefficients found in Figure A3–3.

Diesel Fuel

This section references Figure A3–4.

The preliminary diesel on-road fuel consumption estimate is represented as C and is calculated in step 2 (above). It represents a bottom-up estimate based on vehicle population, FCRs and KARs.

The preliminary off-road estimate is represented by R and is the difference between the RESD total fuel consumed (represented by Q) and C.

The two top-down reported fuel quantities for diesel fuel differ from that of gasoline in that there is no gross fuel amount (Taxed + Non-Taxed) provided in the Fuel Sales survey for diesel fuel, only Taxed (T). Subsequently, the reconciling of the two top-down sources is quite different: if taxed fuel sales (represented by T) exceeds that of the total fuel consumed in the RESD (represented by Q), T is forced to equal Q; otherwise, T is not adjusted.

At the national level, T is always less than Q. The result of the above reconciliation is that, at a national level, Tmax equals T.

To calculate the final normalized on-road estimate, represented by On-Road in Figure A3–4, the following logic is used:

- When the average of C and Tmax is greater than Q, On-Road equals Q; otherwise,
- On-Road is equal to the average of C and Tmax.

The final process is to scale C so that it equals "On-Road." This is accomplished by adjusting the initial KARs until the new bottom-up consumption equals the "On-Road" fuel volume.

"Off-Road" (as represented in Phase 2 of Figure A3–4) is now represented by the difference between Q and "OnRoad."

Therefore, all fuel available in the RESD (Q) is accounted for while the Fuel Sales survey aided in differentiating on-road from off-road fuel use.

At a provincial level, top-down and bottom-up diesel fuel consumption estimates differ slightly; however, at a national level, there is a high degree of correlation between the two estimates. Please refer to Table A3–6 for the national normalization factors for On-Road. The normalization factor is represented by the ratio of On-Road to C. Table A3–6 also includes the national values for the various coefficients found in Figure A3–4.

Figure A3–4   On-Road Diesel Fuel Normalization Procedure for MGEM
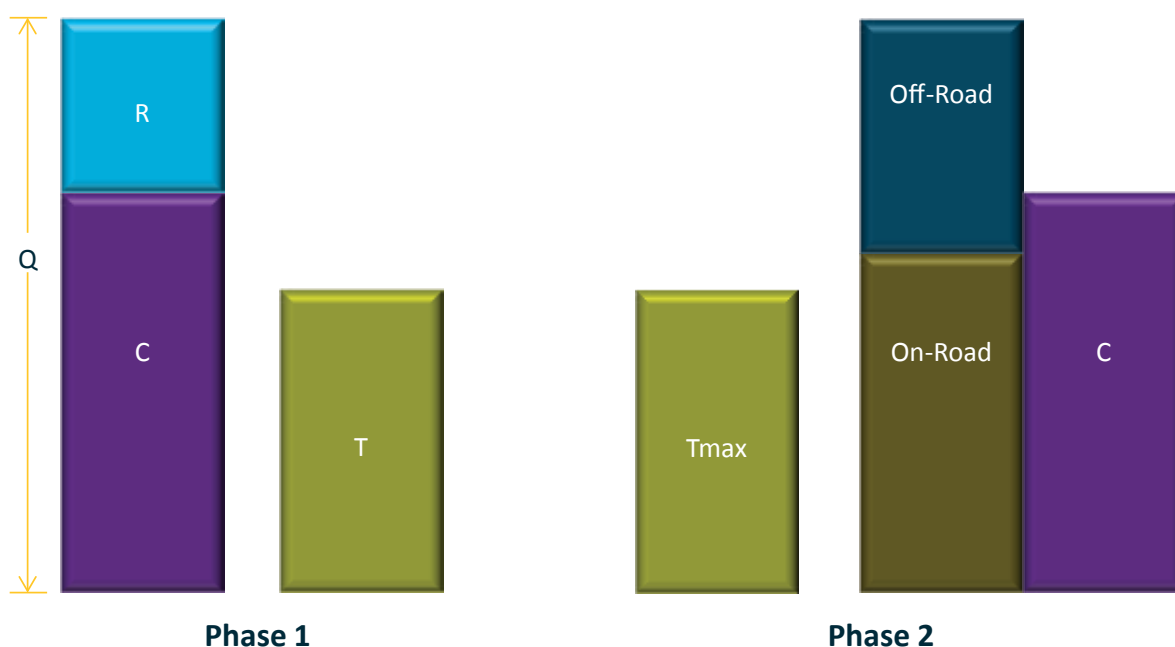
Q – Total diesel fuel available in Canada from RESD
C – Preliminary bottom-up On-Road fuel consumption estimate (vehicle population x kilometre accumulation rate x fuel consumption rate)
R – First Off-Road estimate represented by Q-C
T – Taxed diesel fuel sales from Fuel Sales survey
Tmax – When T is greater than or equal to Q then Tmax = Q; When T is less than Q then Tmax = T
On-Road – When (C + Tmax)/2 is greater than Q than On-Road = Q; Otherwise On-Road = (C + Tmax)/2
Off-Road – The difference between Q and On-Road: Off-Road = Q - On-Road

Table A3–6   Diesel Fuel Normalization Values, Selected Years

		1990	2000	2005	2009	2010	2011	2012	2013
Phase 1	C - Bottom-up On-Road Vehicle Calc. (ML)	7 181	11 116	13 405	14 644	14 974	15 216	15 461	15 698
	Q - RESD's Total Diesel Fuel Available (ML)	13 076	19 588	22 411	22 982	25 176	26 397	25 964	26 671
	T - Taxed Diesel Fuel Sales (ML)	8 543	13 275	16 216	16 188	16 779	17 798	17 456	17 898
Phase 2	Tmax - Scaled Taxed Diesel Fuel Sales (ML)	8 543	13 275	16 216	16 188	16 779	17 798	17 456	17 898
	On-Road - Final On-Road Diesel Fuel Estimate (ML)	7 862	12 196	14 811	15 416	15 876	16 507	16 458	16 798
	Off-Road - Final Off-Road Diesel Fuel Estimate (ML)	5 214	7 392	7 600	7 566	9 300	9 890	9 506	9 873
	On-Road + Off-Road (ML)	13 076	19 588	22 411	22 982	25 176	26 397	25 964	26 671
	On-Road Diesel Normalization Factor	1.10	1.10	1.11	1.05	1.06	1.09	1.07	1.07

Note: Values may not add up due to rounding.

Step 4: On-road Emission Calculation

Emission estimates are based on fuel type, the total fuel consumed and the appropriate emission factor.

Emissions are calculated using Equation A3–1.

A3.1.4.2.2. Off-road (CRF Category 1.A.3.e.ii)

The methodology used to estimate GHG emissions from off-road transportation follows an IPCC Tier 2 approach.

Step 1: Off-road Fuel Calculation

Off-road fuel is calculated using Equation A3–3.

Equation A3–3:

$$Off\text{-}road\ Fuel\ Consumption \\ = Fuel\ Available\ for\ Transportation \\ - On\text{-}Road\ Fuel\ Consumption$$

Step 2: Off-road Emission Calculation

Emission estimates are based on fuel type, the total fuel consumed and an emission factor.

Emissions are calculated using Equation A3–1.

A3.1.4.2.3. 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 (Off-road) and fuel used in stationary combustion applications at airports. Emissions from international flights are designated as "bunker" emissions and are not included in national totals but are estimated and reported separately under international bunkers.

Careful consideration should be paid when comparing emission estimates in this category against those reported to other institutions, such as the International Energy Agency (IEA). The IEA estimates are, in particular, quite different from those reported in the CRF when comparing domestic and international (bunker) emissions from aviation turbo fuel. The

Tier 3 method employed by AGEM in the NIR allows detailed flight-by-flight distinction between domestic and international movements based on a flight's origin and destination. The fuel consumption values (broken down 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 deemed 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.

Tier 3 Methodology

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 2014) 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 Transport Canada before November 1996. Both data streams are processed by Statistics Canada and redistributed to NAV Canada and Transport Canada. Environment Canada receives the information directly from Statistics Canada, including small airport movements that Statistics Canada collects directly and appends to the tower data from NAV Canada.

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

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

Flight Path Length

The flight path length is the true distance travelled between two airports. The movement data used for modelling are not radar data and thus do not track the exact path travelled by each individual movement. AGEM estimates the flight path length based on additional information obtained from the Federal Aviation Administration (FAA). The FAA operates an aviation model titled Aviation Environmental Design Tool (AEDT) (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 their model for calendar year 2005 involving Canadian airports and included the statistical measures (maximum, minimum, average, standard deviation)

for the radar distance travelled between any Canadian origin and final destination for a given aircraft type (Fleming 2008a). The average distance from these combinations was then used as the distance flown when the same combination appeared in AGEM's movement data (regardless of the calendar year of the movement). There are cases, however, when a combination in AGEM exists without a corresponding average distance. In these cases another method needed to be developed.

An adjusted great circle distance (GCD[1]) 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, elevation, etc. were compiled from various sources including Transport Canada (Cadieux 2006), the Canada Flight Supplement (NAV Canada 2009), SAGE (Fleming 2008b), the Modeling and Database Task Force (MODTF) (Fleming 2008c), the FAA (FAA 2009) and previous departmental work (Manning 2007). The main information required is the geographical coordinates so that a GCD can be calculated and used to determine the flight path length.

Aircraft Fuel Use Characteristics

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

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

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

Representative Aircraft Mapping

All possible aircraft type entries within the AGEM movement data were extracted and defined. Once defined, each aircraft was mapped to a representative aircraft with known fuel-use characteristics so that fuel consumption could be calculated for all aircraft in AGEM. The mapping was done using published mapping guides whenever possible (BADA 2009, IPCC 2006, ICAO 2008, EMEP/CORINAIR 2006) and matching aircraft characteristics (MTOW,[2] 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 (IPCC 2006), 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 onetoone adjustment of CH_4 emissions based on fuel ratio differences may not be entirely correct; however, lacking any additional information, this modification was made recognizing that the default values from table 3.6.9 do not truthfully reflect AGEM's methodology. For the cruise portion, CH_4 emissions are assumed to be zero (Wiesen et al. 1994). For ease of use by the general public, the published CH_4 emission factor will be a fleet average across the entire time series and based on total fuel consumed (LTO and cruise).

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

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

Step 2: Aircraft Fuel Calculation

Fuel consumed by each individual movement is estimated using Equation A3–4.

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1   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.

2   Maximum takeoff weight.

Equation A3–4:

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

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

The cruise phase of flight (above 3000 ft) is calculated based on the BADA fuel-use characteristics of the aircraft and the flight path length of the movement. The cruise phase is broken up into three parts, consisting of climb (3000 ft to cruise altitude), steady-state cruise (constant cruise altitude reached after completion of climb) and descent (from cruise altitude to 3000 ft). The distance it takes to reach and descend from the steady-state cruise altitude (including the LTO portions of climb out and approach) is subtracted from the flight path length when determining the distance travelled at the steady-state cruise altitude.

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

Step 3: Normalization

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

Step 4: Emission Calculation

Emission estimates are generated at the individual movement level based on the normalized total fuel consumed and the

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

A3.1.4.2.4. Domestic Navigation (CRF Category 1.A.3.d)

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

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

A3.1.4.2.5. Railways (CRF Category 1.A.3.c)

The methodology is considered to be an IPCC Tier 2 method. Railway fuel consumption reported in the RESD (Statistics Canada #57-003) is multiplied by fuel-specific emission factors (see Annex 6).

In Canada, locomotives are powered primarily by diesel fuel. Emissions associated with steam trains are assumed to be negligible, whereas electrically driven locomotives are accounted for under electricity production.

A3.1.4.2.6. Biomass (CRF Category 1.D.3.)

The methodology used to estimate emissions from the consumption of biogenic Transport fuels (ethanol and biodiesel) follows a modified IPCC Tier 1 method for gasoline and diesel fuel on-road transportation and an IPCC Tier 1 method for off-road transportation, railways and domestic marine. The volume of biofuels apparently consumed for Transportation is proportionally reallocated back into the respective diesel fuel and gasoline emission technology classes based on those classes' initial consumption volumes.

The volumes of biofuels used for transportation purposes for 1990–1996 were obtained from a 2011 report examining biofuel production and consumption in Canada (TFIS Inc. 2011). National consumption values for 1997–2010 were obtained from the Office of Energy Efficiency (OEE) within NRCan.[3] For

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3   Appleby J. 2011. Personal communications (emails sent to S. McKibbon July 22, 2011, and August 11, 2011). Pollution Inventories and Reporting Division.

A3

2013 biofuel data, provincial biofuel-use estimates (which also contained revised 2011 and 2012 estimates) were obtained from NRCan.[4]

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

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

A3.1.4.2.7. Pipeline Transport
(CRF Category 1.A.3.e.i)

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

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

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

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

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

All GHG emissions from fuel combustion activities associated with fossil fuel exploration, production, processing, transmission and distribution are reported under the Energy Industries

(Section 3.2.4) and Transport (Section 3.2.6) sections of Chapter 3 and their respective methodologies can be found in Annex 3.1 (sections A 3.1.4.1 and A 3.1.4.2).

A3.2.1. Solid Fuels

A3.2.1.1. Coal Mining

Fugitive emission estimates are based on two studies: *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. In the King study, emission factors (EFs) were calculated for all types of coal and coal mines.

There are two types of coal mines in Canada: underground mines and surface mines. The method used by King (1994) to estimate emission rates from coal was based on a modified procedure from the Coal Industry Advisory Board. The Cheminfo/Clearstone study updated the emission factors for seven surface mines in the provinces of British Columbia and Alberta, using a ground-based mobile plume transect system (MPTS) for area sources and tracer tests for volume and point sources. The emissions model is a hybrid of IPCC Tier 3 and Tier 2-type methodologies, depending on the availability of mine-specific data. Gross production, before cleaning and prep work, is used to calculate fugitive emissions for all mine types. The associated post-mining activity emissions are accounted for in the underground and surface mining emissions. The methodologies used to estimate the emissions from underground and surface mines are explained below.

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. Emissions from the mine shaft ventilation system were estimated (if measured data were not available) using Equation A3–5.

Equation A3–5:

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

where:

Y   =   emissions of CH_4 per gross tonne of coal mined, m³ CH_4/t coal

X   =   depth of mine, m

Table A3–7 Fugitive Emissions Factors for Coal Mining

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

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

A3

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. Emissions from post-mining activities are included in the coal production emission factors.

Surface Mines

For surface mines, it was assumed that the average CH_4 content of surface-mined bituminous or sub-bituminous coals was 0.4 m^3/t (based on U.S. measured data [King 1994]). Of this, it was assumed that 60% is released to the atmosphere before combustion. For lignite, gas content values determined previously for Canada were used (Hollingshead 1990).

A significant source of emissions from surface mines is the surrounding unmined strata. An attempt was made to account for this by applying a high-wall adjustment to account for the outgassing of the surrounding unmined strata to a depth of 50 m below the mining surface. It was estimated that base emission factors for surface mining should be increased by 50% (King 1994) to account for this. The emission factors as shown in Table A3–7, have been adjusted accordingly.

The emission factors for CH_4 determined in the King (1994) study are used to estimate the CH_4 fugitive emissions from 16 of Canada's 23 producing coal mines.

The Cheminfo/Clearstone study produced new emission factors for seven mines in Canada using field tests from two sub-bituminous coal mines in central Alberta, one bituminous coal mine in northeast BC and one bituminous coal mine in northwest Alberta. Results from the four tested mines were applied to an additional three mines nearby that mined the same coal seams and had similar geography. The MPTS method involves developing a two-dimensional y-z plot of the pollutant concentration and wind profile downwind of the target source(s). The measurement system was comprised of: (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 (SUV) equipped with a vertical sampling mast; and (6) a computer and software.

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

To obtain the emissions from coal mining, Equation A3–6 is used.

Equation A3–6:

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

where:

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

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

Activity Data

The activity data required are the gross mine output data for each type of coal mined in each province from Statistics Canada's *Coal and Coke Statistics* publication (#45-002, Table 2). However, the *Coal and Coke Statistics* publication was cancelled in 2002 by Statistics Canada and this information is now provided directly to Environment Canada through a memorandum of understanding.

Emission Factors

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

The weighted emission factors, by mine and coal type, developed using the King (1994) and Cheminfo/Clearstone (2014), are listed in Table A3–7.

A3.2.1.2. Abandoned Underground Coal Mines

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

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

Methodology

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

The IPCC Tier 2 equation for abandoned mines takes the general form:

Equation A3–7: IPCC Tier 2

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

where:

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

The IPCC Tier 3 equation for abandoned mines takes the general form:

Equation A3–8: IPCC Tier 3

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

where:

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

Detailed data on mine CH_4 emission rates during production years were only available for five mines in Nova Scotia (King 1994). This data allowed the use of Equation A3–8, IPCC Tier 3, for estimating abandoned mine emissions in this region. For all other regions of Canada, known production data for abandoned mines was averaged over the life of the mines, and the EFs in Table A3–7, were used to estimate emissions in the final year of production. On the basis of this estimate, Equation A3–7, IPCC Tier 2, was used to calculate emissions. Calculations were done using five time intervals, which can be seen in Table A3–10. Mines abandoned before 1900 are assumed to be non-emitting (IPCC 2006).

Following the end of mining activities, methane emissions have been shown empirically to drop off following a hyperbolic decline curve. This is modeled using the IPCC Tier 2/3 emission factor equation $(1+aT)^b$, where a and b are mine- or basin-specific constants and T is the time since abandonment (IPCC 2006). See Table A3–9 for a list of constants applied to Canadian data. This IPCC EF formula was used for all provincial estimates.

Table A3–8 Tier 2/3 – Emission Factor Coefficients

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

Methane emissions from flooding mines decrease dramatically once active pumping ceases. Water pressure inhibits methane from being emitted due to reduced relative permeability. U.S. EPA empirical studies (U.S. EPA 2004) based on US 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 confirmed that underground mines started flooding immediately after pumps were turned off. All mines were either already flooded or would be by the summer of 2013. In the absence of confirming data, emissions from the five most recently closed mines were assumed unflooded and emissions were modeled using an Equation A3–8, IPCC Tier 3, using active mine emission rates in 1990. For the St. Rose mine, which had no available emission rate data, a weighted average emission rate of other Nova Scotia mines was used. Firm data regarding the flooding state of these Nova Scotia mines may result in a significant drop in future emissions. Table A3–9 characterizes the condition of abandoned mines by flooded and non-flooded, for all regions of Canada that have underground coal mines.

The IPCC defaults in Table A3–10 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

Table A3–10   Tier 2 – IPCC Default - % Gassy Mines per Time Interval

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

A3

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. This may produce some overestimation of emissions in all regions.

Emissions

The results of emission calculations for all years can be seen in Figure A3–5. Abandoned mines in Nova Scotia contribute the largest proportion of emissions; the two emission peaks at years 1993 and 2000 correspond to closures of large mines in that province. There have been no recent mine abandonments and the effect of the models decline curves are visible after the year 2002.

A3.2.2.   Oil and Natural Gas

A3.2.2.1. Upstream Oil and Natural Gas Production

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

Table A3–9   Tier 2/3 - Abandoned Underground Coal Mines, 2013

Region	Number of Abandoned coal mines[a]	Number of abandoned mines flooded[b]
Nova Scotia[c]	282	277
Saskatchewan[d]	245	0
Alberta	854	13
British Columbia	50	0
CANADA	**1431**	**290**

a Only mines that produced more than 0.5 kilotonnes are included.

b When no data is available, mines are assumed to be non-flooded.

c Tier 2 & 3 estimates used for Nova Scotia.

d Saskatchewan lignite mine estimate uses IPCC Tier 2 sub-bituminous emissions factor calculated for each time band (see IPCC 2006 p 4.27, Equation 4.1.12).

Figure A3–5   Emissions From Abandoned Mines

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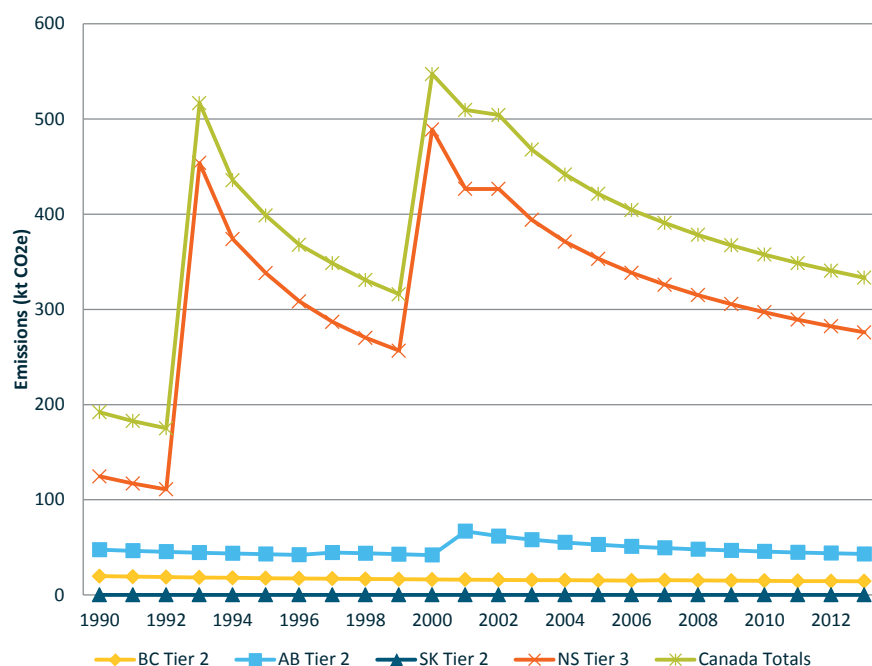
GHG emissions from the UOG sector, with the exclusion of oil sands mining, extraction and upgrading. The CAPP study provided a detailed emission inventory for the year 2000, while the UOG study produced inventories for the years 2005 and 2011.

Table A3–11 lists the sectors and sources that were estimated in the CAPP and UOG studies (CAPP 2005, 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 is presented below, along with the methodology used to estimate the emissions for 1990–1999, 2001–2004, 2006–2010 and from 2012 onwards.

Methodology for the 2000, 2005 and 2011 Estimates

The emission estimates contained in the CAPP and UOG studies were developed using a bottom-up approach, beginning at the individual facility and process unit level and aggregating the results to provide emission estimates by facility and geo-

graphic area. The Canadian UOG sector's assets and operations are vast: the 2011 inventory included over 300 000 capable oil and gas wells, 14 100 batteries producing gas into more than 5000 gathering systems delivering to almost 750 gas plants, and 24 000 oil batteries delivering to 150 tank terminals, all of which are interconnected by tens of thousands of kilometres of pipeline carrying hydrocarbons from wells to batteries to plants and finally to markets.

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

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

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

- measured volumes of natural gas taken from the process;
- vented and flared waste gas volumes;
- fuel purchases (propane, diesel fuel, etc.);
- fuel analyses;
- emission monitoring results;

Table A3–11 Allocation of UOG Inventory Emissions to CRF Fugitive Categories

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

- process operating conditions that may be used to infer the work being done by combustion devices (gas compositions, temperatures, pressures and flows, etc.); and
- spill and inspection reports.

Other required data included the following:

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

Refer to the CAPP study (CAPP 2005a) and UOG study (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.

Table A3–12   Required Activity Data and their Source

Publisher	Publication	Activity Data
Statistics Canada	CANSIM Table 131-0001 Supply and disposition of natural gas, monthly (Statistics Canada 2014a)	Less field flared and waste Field disposition and usage Gathering system disposal and use Plant uses Shrinkage
	CANSIM Table 126-0001 Supply and disposition of crude oil and equivalent, monthly (Statistics Canada 2013b)	Gross new production Heavy crude oil Light and medium crude oil Synthetic crude oil Crude bitumen
Saskatchewan Ministry of Energy and Resources	2013 Crude Oil Volume and Value Summary (Saskatchewan Ministry of Economy 2014a)	Light and medium crude oil production Heavy crude oil production
	2012–2013 Annual Report (Saskatchewan Ministry of Economy 2014b)	Total capable wells
Canadian Association of Petroleum Producers (CAPP)	*Statistical Handbook for Canada's Upstream Petroleum Industry* (CAPP 2014)	Total wells drilled (including dry and service)
Alberta Energy Regulator (AER)	ST-57 Field Surveillance and Operations Branch - Field Operations Provincial Summary 2012 (AER 2013)	Sum of blowouts (drilling, servicing and other), kicks and pipeline ruptures
	ST-59 Alberta Drilling Activity, Monthly Statistics, December 2012 (AER 2014a)	December capable oil and gas wells
British Columbia Ministry of Energy, Mines and Petroleum Resources	Oil and Gas Production and Activity in British Columbia 2013[1]	Sum of producing oil wells and producing gas wells
British Columbia Oil and Gas Commission	Drilling Kicks and Blowouts by Area	Sum of kicks and blowouts
Manitoba Innovation, Energy and Mines	Manitoba Petroleum Statistics (Manitoba Innovation, Energy and Mines 2014)	Wells capable of producing (Dec)
Canada–Newfoundland and Labrador Offshore Petroleum Board (CNLOPB)	Development Wells – Hibernia (CNLOPB 2014a)	Number of capable wells
	Development Wells – Terra Nova (CNLOPB 2014b)	Number of capable wells
	Development Wells – White Rose (CNLOPB 2014c)	Number of capable wells
	Development Wells – North Amethyst (CNLOPB 2014d)	Number of capable wells

1. Mou C. 2014. Personal communication (email from Mou C to Smyth S, Project Engineer, Pollutant Inventories and Reporting Division, dated 8 Sep 2014). British Columbia Ministry of Energy, Mines and Petroleum Resources.

Equation A3–9 is used to estimate emissions for non-inventoried years by multiplying base year emissions data for a given source and sector by the ratio of activity data for the non-inventoried year to that of the base year. Twelve activity parameters for each province/territory and year were used:

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

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

Table A3–13   Activity Data Used to Extrapolate Emission Sectors and Sources

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

Equation A3–9:

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

where:

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

Table A3–13 contains a list of the activity factors used to estimate emissions and the dependent source category.

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

Figure A3–6   Graphical Representation of the "Wedging" Method

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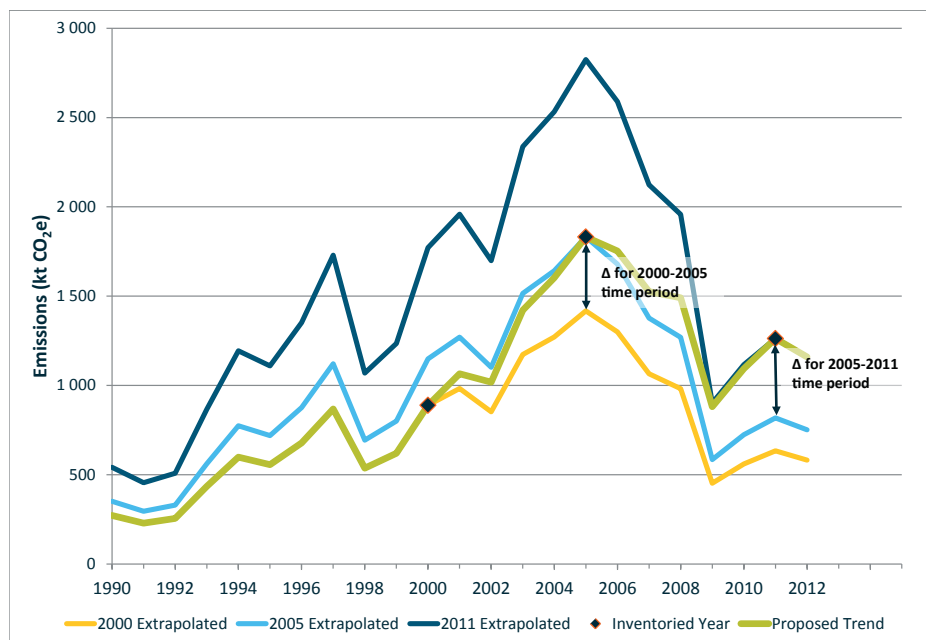
described above. This resulted in three curves which were used to interpolate the intermediate years by using either a "wedging" or "proportional adjustment" method, depending on the circumstance. The "wedging" method was used unless it resulted in negative emission estimates for any year in the time period. Less than 0.3% of cases required the use of the "proportional adjustment" method.

Wedging

The "wedging" method evenly distributes the difference in emissions for a given source and sector in a given province between an inventoried year and an extrapolated year to maintain the emissions trend using Equation A3–10.

Equation A3–10:

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

where:

$ER_{i,j}^{k}$	=	emission rate of compound i, source j, and year k
$ER_{i,j}^{k,k1\_exp}$	=	emission rate of compound i and source j from extrapolated year k1 data
$ER_{i,j}^{k2\_inv}$	=	emission rate of compound i and source j from inventoried year k2 data
$ER_{i\,j}^{k2,k1\_exp}$	=	emission rate of compound i, source j and year k2 from extrapolated year k1 data
k	=	year between k1 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 A3–8 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 A3–6 shows the results of the "wedging" method in graphical form. In general, the 2000 and 2005 inventory years are used to interpolate emissions by sector, source and province/territory for the 2001–2004 time period, while the 2005 and 2011 inventory years are used to interpolate emissions for the 2006–2010 time period. However, there are a few special cases where the 2000 and 2011 inventory years are used to interpolate emissions for the 2001–2010 time period. This occurs when data were missing or incomplete for the 2005 data year, and as a result specific sector, source and province/territory combinations were not able to be estimated for the 2005 inventory. In addition, on the basis of conversations with the contractor and the province of Saskatchewan, the Saskatchewan venting emissions for the cold production heavy crude oil sector in the 2005 inventory were determined to be unreliable. As a result, emissions for this source and sector were interpolated using the 2000 and 2011 data as end points with the 2005 data point being omitted.

Finally, if any specific source and sector in a given province/territory only existed in one of the inventoried years, then the inventoried data 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 A3–11.

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

Equation A3–11:

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

where:

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

A3.2.2.2. Natural Gas Transmission

Methodology

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

Fugitive emissions for natural gas transmission are based on several documents. The first, *CH₄ and VOC Emissions from the Canadian Upstream Oil and Gas Industry* (CAPP 1999), was prepared by Clearstone Engineering Ltd. for CAPP in July 1999. The second source is ancillary tables provided by Brian Ross of Clearstone Engineering Ltd. that describe the CO_2 emissions. There are no N_2O fugitive emissions from natural gas transmission. The CO_2 and CH_4 emissions for 1990–1996 are taken directly from the two sources. The CO_2 and CH_4 emissions for 1997–1999 were estimated based on province/territory natural gas transmission pipeline length and leakage rates, which were developed based on the 1996 emissions from CAPP (1999) and pipeline lengths from Statistics Canada.

For the years 2005 and 2011, emissions are taken from the UOG study (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 and 2006–2010 were provided directly by CEPEI, again following an IPCC Tier 3 approach. Emission estimates for 2012 onwards were extrapolated from 2011 data using the same extrapolation method as described for the UOG sector (see Equation A3–9), with the length of natural

A3

gas transmission pipeline multiplied by the amount of natural gas transported used as the activity factor.

The emissions are calculated per province/territory and then summed to get 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.ii Natural Gas—Production category of the CRF table.

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

Activity Data

The activity data required to estimate the fugitive emissions for 1997–1999 and 2012 onwards are the length of the natural gas pipeline used for natural gas transmission each year and the amount of natural gas transported. Transmission pipeline lengths were published annually in *Natural Gas Transportation and Distribution* (Statistics Canada 57-205-XIB). Statistics Canada has discontinued this publication but still collects the data and releases it to Environment Canada. However, pipeline length data were only available up to and including 2012; pipeline lengths for 2013 were therefore estimated. For Quebec, Ontario, Manitoba, Saskatchewan, Alberta, British Columbia and the Northwest Territories, the 2013 pipeline lengths were estimated based on the average annual change in length between 2000 and 2012. The 2013 values were assumed to be the same as 2012 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.

The volume of natural gas transported by the transmission pipelines is estimated by summing natural gas production, imports and inter-regional transfers by province/territory as contained in the *Report on Energy Supply and Demand in Canada* (Statistics Canada 57-003-XIB). Since the Trans-Canada natural gas pipeline is made up of several pipes running in parallel, which can be open or closed based on the required capacity, the inclusion of volume transported serves as a surrogate to modify emission estimates based on the assumed equipment being used to transport fuel.

A3.2.2.3. Petroleum Refining

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

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

Methodology

Fugitive Emissions

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

The fugitive emissions are generated using Equation A3–12.

Equation A3–12:

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

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–Demand in Canada* (Statistics Canada #57-003-XIB), including fuels listed under producer consumption from the refined petroleum product 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:

CO_2: 2.78 t CO_2/GJ

CH_4: 11.89 t CH_4/GJ

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

A3

Table A3–14   Required Refinery Activity Data and Their Source

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

A3

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

Flaring Emissions

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

Activity Data

The activity data required to estimate the fugitive emissions from refineries are listed in Table A3–14.

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 *Vented Emissions from Maintenance at Natural Gas Distribution Stations in Canada* (GRI 2000). The CGA study estimated emissions from the Canadian gas pipeline industry for the years 1990 and 1995 using an IPCC Tier 3 approach. Emissions were calculated based on emission factors from the U.S. EPA, other published sources and engineering estimates. The activity data were obtained from published sources and specialized surveys of gas distribution system companies. The surveys contained information on equipment schedules, operation 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 gas distribution pipeline distances by province provided by

Statistics Canada, which were then used to estimate emissions for the 1990–1999 time period.

For the year 2000 onwards, emissions are based on data from the UOG study (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 and 2006–2010 were provided directly by CEPEI, again following an IPCC Tier 3 approach. Emission estimates for 2012 onwards are estimated using length of natural gas distribution pipeline and amounts of natural gas distributed, using the approach governed by Equation A3–9.

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 activity data required are the length of natural gas distribution pipeline per province and amount of natural gas distributed. The pipeline length data were published annually in *Natural Gas Transportation and Distribution* (Statistics Canada 57-205-XIB) but have since been discontinued. Updated pipeline lengths for 2011 and 2012 were provided by Statistics Canada. Lengths for 2013 for all provinces were estimated based on the change in length between 2011 and 2012.

For New Brunswick and Nova Scotia, distribution lengths for 2000–2006 were provided by Enbridge Gas New Brunswick[5] and Heritage Gas,[6] respectively. In the Northwest Territories, the

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5   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 7 Dec 2010).

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

Ikhil Pipeline began providing Inuvik with natural gas in 1999 (Quenneville 2009). Distribution lengths for 1999–2006 were backcast based on the change in distribution length between 2007 and 2008.

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

Volumes of natural gas distributed were estimated using the "availability" line for natural gas from the *Report on Energy Supply and Demand in Canada* for each province/territory (Statistics Canada 57-003-XIB).

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), which in its natural state will not flow under reservoir conditions or on the surface. Bitumen occupies the lower end of the range of heavy crude oils and is sometimes referred to as ultra-heavy crude oil. "Oil sands" is a term applied by the Government of Alberta to a particular geographical area of the province of Alberta that contains concentrations of bituminous sands as well as deposits of other heavy crude oil. Bituminous sands are an unconsolidated mixture of sand, clay, water and bitumen.

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

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

For 2004 onwards, emissions are estimated using the Bitumen-Oil Sands Extrapolation Model – Rev 3, created by Clearstone Engineering Ltd. for Environment Canada in 2007 (Environment Canada 2007) (hereafter referred to as the bitumen model). The bitumen model uses results from the bitumen report (CAPP 2006) as its basis, along with annual production data as reported by the Alberta Energy Regulator (AER) and the National Energy Board (NEB). The methodology, model and data used are briefly dis-

cussed below. For more details, please refer to the bitumen report (CAPP 2006).

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

- process emissions from the steam reforming of natural gas to produce hydrogen for upgraders;
- 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 some tailings ponds;
- volatilization and decomposition of residual bitumen and diluent, which carry through to the tailings ponds;
- fugitive equipment leaks, venting, flaring and storage losses at ore preparation, extraction and upgrader plants and their associated utility and cogeneration plants;
- spills and accidental releases; and
- secondary sources, such as sewage treatment facilities, landfills, onsite construction and fabrication activities, motor vehicle fleets, corporate aircraft, and boats and dredges used on the tailings ponds.

These emissions have been grouped in the source categories and process areas listed in Table A3–15.

Bitumen Report: 1990–2003 Emission Estimates

The bitumen report (CAPP 2006) is a compilation of the individual Tier 3 inventories of facilities involved in the OS/HOU industry: Syncrude Canada Ltd. (Mildred Lake mining, extraction and upgrading facility and Aurora North mining and extraction facility); Suncor Energy (mining, extraction and upgrading facility); Husky Energy (Lloydminster upgrader); Consumers' Co-operative Refineries Limited (Regina upgrader); Albian Sands Energy (Muskeg River mining and extraction facility); and Shell

Table A3–15   Emission Source Categories and Process Areas in the Bitumen Report (CAPP 2006)

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

Canada Limited (Scotford upgrader). The facility boundaries were determined to ensure that all target emissions, including those from cogeneration facilities, were included.

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

The following sources were used to estimate emissions:

- facility operator information;
- energy statistics published by the AER;
- source emission monitoring results reported to Alberta Environment;
- data from company submissions to the Voluntary Challenge Registry;
- Environment Canada's National Pollutant Release Inventory (NPRI);
- environmental impact assessment files as part of recent energy development applications in the OS/HOU industry; and
- open literature.

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

Bitumen Model: 2004 Onwards

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

In 2006, the Petro-Canada Fort Hills oil sands operations started reporting to the AER. It has yet to produce any product. In 2008 the CNRL Horizon mining, extraction and upgrading operation and OPTI-Nexen upgrader came online. Emissions from the CNRL Horizon mining, extraction and upgrading operations were estimated using various emission factors from Suncor, Syncrude and Albian's Muskeg River operations. Emissions from the OPTI-Nexen upgrader were estimated using emission factors from the Shell Scotford upgrader, except for CO_2 flaring. These approximations are problematic in that each facility has different processes with different emissions, especially when comparing the Nexen and Scotford upgraders. The Nexen upgrader is the only facility to employ gasification technology that transforms waste product

(asphaltenes) into syngas used to create steam for *in-situ* extraction and hydrogen for upgrading (AER 2013c). For CO_2 emissions from flaring, the emission factor was estimated using data reported to the Greenhouse Gas Reporting Program by OPTI-Nexen and publicly available activity data from the AER. This was done because use of the Scotford flaring emission factor resulted in hugely overestimated flaring emissions. All of these approximations will be addressed when a new bitumen study is conducted in the future. Refer directly to the report on the bitumen model (Environment Canada 2007) for specific methodological discussions.

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

Estimation Methodology

The bitumen model provides emission estimates for the OS/HOU industry for 2004 onwards by applying facility-specific emission factors and pro-rating factors derived from the facility base inventories (1990–2003) to appropriate publicly available activity data for the specific year. It uses Equation A3–13 to estimate emissions.

Equation A3–13:

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

where:

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

Emission Factors

For the OS/HOU sector in Alberta and Saskatchewan, source-specific factors were developed for each facility by correlating the most recent three or four years of emission data for the facility, from the bitumen report (CAPP 2006), with available site-specific production accounting data. These emission factors can be found in the bitumen model (Environment Canada 2007)

Activity Data

Two activity data sources are used to extrapolate emissions. Alberta facilities data are extracted from ST-39: *Alberta Mineable Oil Sands Plant Statistics, Monthly Supplement December 2013* (AER 2014c). Data for Saskatchewan are taken from the NEB's *2013 Estimated Production of Canadian Crude Oil and Equivalent* (NEB 2014) table. The required data are listed in Table A3–16.

A3

Table A3–16   Activity Data Required for the Bitumen Model

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

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. Subsectors included in this sector are Mineral Industry, Chemical Industry, Metal Industry, Electronics Industry, Product Uses as Substitutes for ODS, Other Product Manufacture and Use, and Non-energy Products from Fuels and Solvent Use. Each of these can be further divided into various categories, such as CO_2 emissions from iron and steel production and SF_6 emissions from magnesium casting, as discussed in Chapter 4. This section of Annex 3 describes in detail the methodologies used to estimate the following:

- CO_2 from Cement Production;
- CO_2 from Ammonia Production;
- GHG from Aluminium Production;
- CO_2 from Non-energy Products from Fuels and Solvent Use;
- HFC emissions from Product Uses as Substitutes for Ozone Depleting Substances (ODS);
- SF_6 from Electrical Equipment; and
- CO_2 emissions from Iron and Steel Production.

A3.3.1. CO_2 Emissions from Cement Production

A3.3.1.1. Methodology

As part of Canada's continuous improvement and as recommended by the expert review team (ERT), Canada's submission on Cement Production uses a modified IPCC 2006 Tier 2 method (Volume 3, Equation 2.2) that includes emissions from carbon-bearing non-fuel materials (Volume 3, Equation 2.3). The method also incorporates country-specific emission factors (Equation A3–14). Plant-level data on the composition of carbonate raw materials are unavailable; a Tier 3 method is therefore not practical.

Equation A3–14:

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

where:

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

On behalf of Canada's cement industry, the Cement Association of Canada (CAC) provided Environment Canada with national aggregate data to support the clinker calcination emission factor (EF_{cl}), cement kiln dust correction factor (CF_{ckd}), and organic carbon emission factor (EF_{toc}) to estimate Cement Production emissions.

The data provided by the CAC were collected under the umbrella of the Cement Sustainability Initiative (CSI) of the World Business Council for Sustainable Development (WBCSD), which provides a CO_2 Emissions Inventory Protocol (the Protocol) for cement production. The Protocol contains two pathways for estimating process-related CO_2 emissions from the calcination of raw materials. The first is based on the amount and chemical composition of the products (clinker plus dust leaving the kiln system). The default emission factor for clinker is 0.525 tonnes of CO_2 per tonne of clinker. The second is based on the amount and composition of the raw materials entering the kiln.

The data collected by the CAC are representative of the years 1990, 2000, and 2002 through 2013. The calcination emission factor (EF_{cl}) varies from year to year and ranges from 0.522 tonnes of CO_2 per tonne of clinker to 0.533 tonnes of CO_2 per tonne of clinker. For the unknown data years (1991-1999, 2001), an average is taken from the known data years immediately before and after the unknown data point. The cement kiln dust correction factor (CF_{ckd}) and the organic carbon emission factor (EF_{toc}) are assumed to hold constant for all reporting years at 1.013 and 0.0115 tonnes of CO_2 per tonne of clinker, respectively.

Canadian Cement Kilns

In Canada, Portland cement accounts for more than 90% of cement production (Statistics Canada44-001-XIB and CANSIM tables 303-0060 and 3030061). There are 17 clinker facilities in Canada, located in British Columbia, Alberta, Ontario, Quebec and Nova Scotia[7]. Of these facilities, 16 are in operation and use dry kilns, and one is no longer in operation and has a wet kiln. There are a total of 24 operational kilns, six of which have a precalciner and another six of which have a preheater. The aggregate operational clinker production capacity is 15.8 Mt/year.

A3.3.2. CO_2 Emissions from Ammonia Production

A3.3.2.1. Methodology

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

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[7] Natural Resources Canada, Personal communication on Canada's Minerals subsector

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 the SMR process, and GHG emissions from fuels used in non-SMR ammonia production processes, are accounted for in the Energy Sector.

The facility-level data on the feedstock use of natural gas and the annual ammonia production were obtained as part of Environment Canada's voluntary data collection for the years 2005 through 2009. These data were then used to develop the facility-level ammonia-to-feed fuel (conversion) factors. Considering that these facility-level ammonia-to-feed fuel factors can be used to reveal the performance of a specific facility, they are not published and they are kept confidential. The ammonia-to-feed fuel factor for some facilities could not be determined either because they were not part of Environment Canada's voluntary data request or they did not respond to the data request. For these facilities the average ammonia-to-feed fuel factors, based on the average of the other known facilities, is used. The average ammonia-to-feed fuel factor is 671 m^3 of natural gas/tonne of NH_3 produced.

The facility-level annual ammonia production data are then multiplied by the facility-specific ammonia-to-feed fuel factor 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 of Canada in which these facilities are situated; see Equation A3-2.

Equation A3–15:

$$NG_{feedstock, p} = \sum_{i=1}^{n} P_{ammonia,i} \times FF_{ammonia,i}$$

where:

$NG_{feedstock,p}$	=	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 aggregates of the feedstock use natural gas for each province are then multiplied by the respective provincial natural gas carbon content found in Table A6-1 to determine the total carbon used. It is expected that all the 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 (see Equation A3–16).

Equation A3–16:

$$Generated\ CO_2 = \sum_{p=1}^{m} NG_{feedstock,p} \times CC_p \times COF$$

where:

p	=	a province of Canada containing one or more SMR ammonia producing facilities
Generated CO_2	=	clinker production data, kt
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 that are recovered for use in urea production are estimated using Equation A3–17, 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 A3–17:

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

where:

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

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

It should be noted that the quantity of feedstock natural gas used in the SMR process should be subtracted from 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. Please refer to the discussions in Section A3.3.4, CO_2 Emissions from Non-Energy Products from Fuels and Solvent Use, for details.

The annual facility-level ammonia production data for the years 1990 to 2011 were obtained from the following sources: 1990 to 2004 from the Cheminfo Services (2006) study; 2005 to 2009 from Environment Canada's voluntary data collection; and 2008 to 2013 from Statistics Canada's annual survey, *Industrial Chemicals and Synthetic Resins* (Statistics Canada 46-002-X).

Likewise, facility-level urea production data for the years 2008 through 2013 were retrieved from the same Statistics Canada's survey (46-002-X). Facility-level production values for earlier years (1990 through 2007) were estimated using the six-year average ratio of urea to ammonia production of the known data years (2008-2013).

A3.3.3. GHG Emissions from Aluminium Production

A3.3.3.1. Methodology

There are 11 aluminium facilities in Canada, 10 of which are located in Quebec and the other in British Columbia. In addition to the methodology description provided in Chapter 4, Section 4.10, information is provided here on aluminium production in Canada.

Canadian Aluminium Production

In 2006, Environment Canada and the Aluminum Association of Canada (AAC) signed a Memorandum of Understanding (MOU) to establish an arrangement for the annual transfer of GHG-related information from the AAC to Environment Canada. The information transfer covers process-related emissions data (CO_2, PFC, SF_6), plant-specific aluminium production data, a description of the methods used to estimate emissions, and copies of audit reports submitted to the province. The MOU was reconfirmed in 2013.

The emissions estimates for the reporting years 1990 through 2004 were submitted in the 2005 calendar year. The methods used by companies in earlier years of the time series were not consistent across all facilities or across all years. Since then, Environment Canada has received annual emissions submissions for the remaining years (2005-2013).

The industry has been subject to both voluntary and regulatory requirements that have streamlined the methods used to estimate emissions. As of 2013, Canadian facilities use a Tier 3

method to quantify process emissions of CO_2 and perfluoro-carbons PFCs (with the exception of one facility that uses Tier 2 EFs from IAI 2006).[8] Between 2002 and 2012, the AAC and the Government of Quebec committed to voluntary agreements where the companies were to re-assess their Tier 3 EFs for PFCs once every 36 months.[9] The methods used prior to 2002 have not been recorded.[10]

A3.3.4. CO_2 Emissions from Non-Energy Products from Fuels and Solvent Use

A3.3.4.1. Methodology

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. These emissions primarily relate to the petrochemical production process, although there are a number of other non-energy uses of fuel included, such as non-ferrous mining and processing, iron and steel, and other chemical industries. Within the petrochemical and carbon black industries, primary and secondary fossil fuels (e.g. natural gas and petroleum products) are used for non-fuel purposes in the production of products. The use of these fossil fuels may include the combustion of part of the hydrocarbon content to produce heat for the process (i.e. via the combustion of by-product fuel gases). Examples of non-energy use of fuels, included elsewhere in the inventory, are coke used in iron and steel production, and carbon anodes used to electrically reduce alumina to aluminium in the aluminium production process. The fossil fuels can be grouped into three types: gaseous, solid and liquid. Estimations of emissions coming from each type of fuel are discussed separately in the following subsections.

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. The CO_2 from ammonia production is estimated and reported in the source category 2.B.1 and explained in Section A3.3.2 above. The feedstock use of natural gas in ammonia manufacturing is included in the overall non-energy use of natural gas, as reported by Statistics Canada in the *Report on Energy Supply and Demand in Canada* (RESD) (Statistics Canada 57-003-XIB). To avoid double counting emissions, the

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8   Communication between Environment Canada and Rio Tinto Alcan dated 2014-10-03.

9   Communication between Environment Canada and Alcoa dated 2014-10-06.

10   Industrial representatives have commented that to characterize the methods used by each facility and for each year would be resource intensive.

A3

non-energy natural gas attributed to ammonia manufacturers—estimated in the calculation of CO_2 emissions from the source category 2.B.1 Ammonia Production—is subtracted from the RESD's overall non-energy natural gas. This will determine the remaining (residual) non-energy natural gas, which represents the use made by other industries (excluding the ammonia industry).

The Cheminfo Services (2005a) study determined the CO_2 emission factor for the overall non-energy use of natural gas. It used detailed natural gas consumption data for the fertilizer, methanol and carbon black industries to determine the overall non-energy natural gas emission factor of 1522 g CO_2 /m^3.

To determine CO_2 emissions from non-energy use of natural gas—excluding ammonia production—natural gas use data for non-ammonia production were used to develop a new non-energy (residual) natural gas emission factor of 38 g CO_2/m^3.

The residual non-energy natural gas values were then multiplied by the new non-energy emission factor to determine CO_2 emissions from the residual non-energy use of gaseous fuels. The non-energy gaseous fuel emissions are determined at the provincial level because the RESD data are available at the provincial level. The provincial level CO_2 emissions are then summed to obtain the national level CO_2 estimates. It should be noted 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 subsector are the non-energy use of:

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

To determine, by province, the CO_2 emissions coming from these solid fuels, the fuel-, province- and year-specific emission factors shown in Table A6-5, Table A6-7, and Table A6-17 of Annex 6 for petroleum coke, coal and metallurgical coke, respectively, are applied to the consumption quantities reported as non-energy use. The national emission estimate for non-energy use of solid fuels is the total of all provincial/territorial emissions.

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 99% of the carbon in these products will eventually be oxidized and emitted as CO_2.

The CO_2 emissions resulting from the consumption of electrodes in the aluminium industry are included in the source category of 2.C.3 Aluminium Production. A key fuel used to make electrodes for the aluminium industry is petroleum coke. The overall non-energy use of petroleum coke, found in the RESD, includes the petroleum coke used to make electrodes for the aluminium industry. To avoid double counting emissions, the non-energy petroleum coke is subtracted from the RESD's overall non-energy petroleum coke. The remaining (residual) non-energy petroleum coke quantities represent the other industries' (excluding the aluminium producers) use of non-energy petroleum coke. The residual petroleum coke non-energy CO_2 emissions are calculated by use of the factor provided in Table A6-5.

The non-energy fuels used to make electrodes to be used in electric arc furnaces (EAFs) in the iron and steel industry, for which emissions have been allocated to category 2.C.1 Iron and Steel Production, are expected to be included in the non-energy fuels reported in Statistics Canada's *Report on Energy Supply–Demand in Canada* (RESD; Statistics Canada #57-003). For this reason, and to avoid double counting, the CO_2 emissions resulting from electrode consumption in the EAF are removed from the provincial CO_2 estimates of the non-energy use of solid fuels.

Liquid Fuels

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

To estimate these emissions at provincial/territorial levels, the quantity of non-energy use of fuel is multiplied by the corresponding emission factor, as shown in Table A3–17 and Table A3–18 for liquid fuels. The summation of the provincial/territorial estimates gives the national emission estimate.

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 non-energy use of NGLs, the potential emission factors that occur when all the carbon is oxidized are provided in the McCann (2000) study. The *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/OECD/IEA 1997) show a default value for the fraction of carbon stored in products when propane, butane or ethane are used as feedstock. The McCann (2000) potential emission factors are then multiplied by (1 - IPCC default fraction of carbon stored of 0.8) to give the non-energy use emission factors of the three NGLs as shown in Table A3–17.

The non-energy use of petroleum products coming out of the oil refineries (i.e. petrochemical feedstocks, naphthas, lubricants,

Table A3–17   CO₂ Emission Factors for Natural Gas Liquids

	Fraction of Carbon Stored in Products	Emission Factors (g CO₂/L)	Sources
Propane	0.8	303	IPCC/OECD/IEA (1997); McCann (2000)
Butane	0.8	349	IPCC/OECD/IEA (1997); McCann (2000)
Ethane	0.8	197	IPCC/OECD/IEA (1997); McCann (2000)

Table A3–18   CO₂ Emission Factors for Non-Energy Petroleum Products

Non-Energy Products	Carbon Factor (g C/L)	Molecular Weight Ratio between CO₂ and Carbon	Fraction of Carbon Stored (IPCC Default)	Resulting CO₂ Emission Factor (g CO₂/L)
	A	B	C	D = A × B × (1 − C)
Petrochemical Feedstocks	680	44/12	0.8	500
Naphthas	680	44/12	0.75	625
Lubricating Oils and Greases	770	44/12	0.5	1410
Petroleum Used for Other Products	790	44/12	0.5	1450

A3

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 subsector. Their carbon factors (mass of carbon emitted per unit of fuel used) come from Jaques (1992). These factors are then multiplied by the molecular weight ratio of CO_2 to carbon, which is 44/12, and by (1 - fraction of carbon stored) to give the CO_2 emission factors used to estimate emissions. The default values of the fraction of carbon stored are also provided in the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/OECD/IEA 1997). Derivations of the non-energy use emission factors are shown in Table A3–18. To estimate emissions at national and provincial/territorial levels, the volume of non-energy product used is multiplied by its corresponding emission factor.

The CO_2 emissions resulting from the non-energy uses of gaseous, solid and liquid fuels are summed together, for each province and territory, to obtain the provincial and territorial CO_2 estimates for the Non-energy Products from Fuels and Solvent Use subsector. The sum of the provincial and territorial CO_2 estimates represent the national CO_2 estimates, and only the national level CO_2 estimates are published in order to satisfy the confidentiality requirements of the non-energy fuels data.

A3.3.4.2. Data Sources

RESD (Statistics Canada 57-003) and the micro data of Statistics Canada's *Industrial Consumption of Energy* Survey (Statistics Canada 57-505-XIE) are the activity data sources for the Non-energy Products from Fuels and Solvent Use subsector. The RESD presents data by fuel type and area of application (i.e. energy-use versus non-energy-use applications).

A3.3.5.   HFCs – Product Uses as Substitutes for Ozone Depleting Substances (ODS)

A3.3.5.1. Activity Data

HFC emission estimates for 1995 were based on data gathered from an initial HFC survey conducted by Environment Canada in 1996.[11] 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).[12] In some cases, one survey was done to collect data for two years. HFC sales data for 2001–2003 were also collected in 2005 from major HFC importers in Canada (Cheminfo Services 2005b). These data were provided by market segment, such that the total quantity used for each type of application could be determined.

HFC import and sales data for 2005–2010[13] were collected by Environment Canada through a voluntary data submission process, whereby requests for data were sent to the main importers

11   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.

12   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.

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

A3

of bulk HFCs and to companies that import/export HFC-containing products. For 2009, the distribution list for data collection was expanded, as Environment Canada became aware of other players 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).[14]

In 2014, Environment Canada performed a mandatory survey of bulk importers (Environment Canada 2014) for the data years 2008 to 2012, and the results of the survey 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 requirements.

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

Once the emission estimates at the national level were obtained, they were distributed by province/territory based on proxy variables, such as gross output of accommodation and food services for commercial refrigeration and number of households for residential refrigeration. The details of the proxy variables used and assumptions made can be made available upon request.

A3.3.5.2. Methodology

Preparation of Data for the Inventory

Canada uses a relatively detailed sector use of HFC subcategory listing Table A3–19, requiring that the HFC use data be broken down at this level annually. To meet this requirement, missing data had to be filled in and aggregated data had to be broken down by subcategory.

To fill in the data gaps from reporters to the voluntary surveys, a variety of techniques were used. When a company did not report in subsequent years, the data was held constant. Where

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14   It should be noted that HFC data from the CBSA cannot be used for GHG inventory purposes, as these HFC data 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 expanding the distribution list for the HFC data collection conducted by the GHG Division and for cross-checking the data submitted to the Division.

Table A3–19   Canadian HFC Use Categories and Sub-Categories

USE_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)

data years were missing due to no surveys being performed (e.g. imports/exports of manufactured items 1999 to 2003), linear interpolation was used to estimate the missing data.

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

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

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

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

The least squares method was also used to linearly extrapolate HFCs in MI imports and exports to 2013, based on data submitted for 2008 to 2010. The resultant extrapolated data were then checked for extreme values brought about by an outlier in the 2008 to 2010 data and, where found, the 2010 data were used for the time period.

To estimate the 2013 imported bulk HFC, the resultant 2008 to 2012 HFC bulk import data, including voluntary survey data, were used as the basis. The least squares method was used to extrapolate the 2008 to 2012 data to the 2013 data year. The resultant extrapolated data was then checked for extreme values brought about by an outlier in the 2008 to 2012 data and, where found, the 2012 data were used for the 2013 data.

A3.3.5.3. Report on Emission Factors for HFCs in Canada

Emission Factors

In 2013, Environment Canada had a survey of the air-conditioning and refrigeration categories conducted (EHS 2013).

The information on emission factors was reviewed (EHS 2013, Environment Canada 2014), taking into account the IPCC Good Practice Guidance (IPCC 2000), specifically its chapter on quality control measures (IPCC 2000). The emission factors were also compared to and most were found to be within the range of the emission factors set out in the IPCC 2006 Guidelines. Several emission factors did not meet the IPCC Good Practice Guidance for expert elicitation (generally the decommissioning); a value was therefore chosen within the range of emission factors established by the IPCC 2006 GL, guided by information received and taking the changing regulatory environment in Canada into account.

The expected HFC lifetimes were chosen based on the survey results and the information provided in the IPCC 2006 Guidelines; this provided emission factors for the air-conditioning and refrigeration categories for 2012. As the same regulatory environment existed in its mature form from 2010 to 2013, these country-specific emission factors were assumed to be applicable for the period 2010 to 2013.

The National Action Plan for the Environmental Control of Ozone-Depleting Substances (ODS) and their Halocarbon Alternatives (NAP) was published in 1992 and updated in 1998 to include HFCs. Following the update of the NAP, the provincial and territorial governments began implementing regulations for HFC recovery/recycling and emissions control, and by 2005 all provinces except Nova Scotia had regulations in place. The original IPCC 1996 emission factors used by Canada were kept for the period 1995 to 1998.

Between 1998 and 2010, the regulatory environment was continually evolving, with more provinces adopting the regulations. In addition, the Federal Halocarbon Regulations, 2003, were introduced for federal properties and equipment. Because no surveys of the practices used by the air-conditioning and refrigeration categories were performed during that period of increasingly stringent HFC-release regulations, a linear change in the emission factors from the 1998 to 2010 was assumed.

The HFC emission factors and lifetimes for the remaining categories were chosen from the IPCC 2006 Guidelines.

Table A3–20 and Table A3–21 present the emission factors used to estimate the HFC emissions from 1995 through 2013.

A3

Table A3–20   HFC Assembly Emission Factors (%)

Subcategory	1995 - 1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010 - 2013
Aerosols[1]	0	0	0	0	0	0	0	0	0	0	0	0	0
Blowing agent in foams[1]													
Open-cell foam	100	100	100	100	100	100	100	100	100	100	100	100	100
Closed-cell foam	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Air conditioning (Original Equipment Manufacture)[2]													
Air-conditioner units in motor vehicles	4.5	4.2	3.8	3.5	3.2	2.8	2.5	2.2	1.8	1.5	1.2	0.8	0.5
Chillers (specify centrifugal or reciprocating)	3.5	3.3	3.1	2.9	2.7	2.5	2.3	2.0	1.8	1.6	1.4	1.2	1
Residential (air conditioners, dehumidifiers, etc.)	3.5	3.3	3.1	2.9	2.7	2.5	2.3	2.0	1.8	1.6	1.4	1.2	1
Air conditioning (Service/Maintenance)[2]													
Air-conditioner units in motor vehicles	4.5	4.2	3.8	3.5	3.2	2.8	2.5	2.2	1.8	1.5	1.2	0.8	0.5
Chillers (specify centrifugal or reciprocating)	3.5	3.3	3.1	2.9	2.7	2.5	2.3	2.0	1.8	1.6	1.4	1.2	1
Residential (air conditioners, dehumidifiers, etc.)	3.5	3.3	3.1	2.9	2.7	2.5	2.3	2.0	1.8	1.6	1.4	1.2	1
Refrigeration (Original Equipment Manufacture)[2]													
Commercial transport	3.5	3.3	3.1	2.9	2.7	2.5	2.3	2.0	1.8	1.6	1.4	1.2	1
Commercial and institutional (retail foods, vending machines, etc.)	3.5	3.3	3.1	2.9	2.7	2.5	2.3	2.0	1.8	1.6	1.4	1.2	1
Industrial (warehouses, process equipment, etc.)	3.5	3.3	3.1	2.9	2.7	2.5	2.3	2.0	1.8	1.6	1.4	1.2	1
Residential (freezers, refrigerators)	2	1.9	1.8	1.7	1.5	1.4	1.3	1.2	1.1	1.0	0.8	0.7	0.6
Other equipment (specify)	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration (Service/Maintenance)[2]													
Commercial transport	3.5	3.3	3.1	2.9	2.7	2.5	2.3	2.0	1.8	1.6	1.4	1.2	1
Commercial and institutional (retail foods, vending machines, etc.)	3.5	3.3	3.1	2.9	2.7	2.5	2.3	2.0	1.8	1.6	1.4	1.2	1
Industrial (warehouses, processes, etc.)	3.5	3.3	3.1	2.9	2.7	2.5	2.3	2.0	1.8	1.6	1.4	1.2	1
Residential (refrigerators, freezers, etc.)	2	1.9	1.8	1.7	1.5	1.4	1.3	1.2	1.1	1.0	0.8	0.7	0.6
Other equipment (specify)	-	-	-	-	-	-	-	-	-	-	-	-	-
Solvent[1]	0	0	0	0	0	0	0	0	0	0	0	0	0
Fire suppression/extinguishing systems (Original Equipment Manufacture)[1]													
Portable (mobile) systems	0	0	0	0	0	0	0	0	0	0	0	0	0
Total flooding (fixed) systems	0	0	0	0	0	0	0	0	0	0	0	0	0
Fire suppression/extinguishing systems (Service/Maintenance)[1]													
Portable (mobile) systems	0	0	0	0	0	0	0	0	0	0	0	0	0
Total flooding (fixed) systems	0	0	0	0	0	0	0	0	0	0	0	0	0
Miscellaneous[1]	0	0	0	0	0	0	0	0	0	0	0	0	0
Other (specify)[1]	0	0	0	0	0	0	0	0	0	0	0	0	0

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

Table A3–21   HFC In-Service Emission Factors ([%])

Subcategory	1995 to 1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010 - 2013	Life Time
Aerosols [1]	50	50	50	50	50	50	50	50	50	50	50	50	50	2
Blowing agent in foams [1]														
Open-cell foam	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Closed-cell foam	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	23
Air conditioning (Original Equipment Manufacture) [2]														
Air conditioner units in motor vehicles	15	14.6	14.2	13.8	13.3	12.9	12.5	12.1	11.7	11.3	10.8	10.4	10	13
Chillers (specify centrifugal or reciprocating)	17	16.0	15.0	13.9	12.9	11.9	10.9	9.8	8.8	7.8	6.8	5.7	4.7	17
Residential (air conditioners, dehumidifiers, etc.)	17	15.9	14.8	13.8	12.7	11.6	10.5	9.4	8.3	7.3	6.2	5.1	4	17
Air conditioning (Service/ Maintenance)) [2]														
Air-conditioner units in motor vehicles	15	14.6	14.2	13.8	13.3	12.9	12.5	12.1	11.7	11.3	10.8	10.4	10	13
Chillers (specify centrifugal or reciprocating))	17	16.0	15.0	13.9	12.9	11.9	10.9	9.8	8.8	7.8	6.8	5.7	4.7	17
Residential (air conditioners, dehumidifiers, etc.)	17	15.9	14.8	13.8	12.7	11.6	10.5	9.4	8.3	7.3	6.2	5.1	4	17
Refrigeration (Original Equipment Manufacture) [2]														
Commercial transport	17	16.8	16.7	16.5	16.3	16.2	16.0	15.8	15.7	15.5	15.3	15.2	15	13
Commercial and institutional (retail foods, vending machines, etc.)	17	16.4	15.8	15.3	14.7	14.1	13.5	12.9	12.3	11.8	11.2	10.6	10	17
Industrial (warehouses, process equipment, etc.)	17	16.4	15.8	15.3	14.7	14.1	13.5	12.9	12.3	11.8	11.2	10.6	10	17
Residential (freezers, refrigerators)	1	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.6	0.6	0.5	0.5	15
Other equipment (specify)	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration (Service/ Maintenance)) [2]														
Commercial transport	17	16.8	16.7	16.5	16.3	16.2	16.0	15.8	15.7	15.5	15.3	15.2	15	13
Commercial and institutional (retail foods, vending machines, etc.)	17	16.4	15.8	15.3	14.7	14.1	13.5	12.9	12.3	11.8	11.2	10.6	10	17
Industrial (warehouses, processes, etc.)	17	16.4	15.8	15.3	14.7	14.1	13.5	12.9	12.3	11.8	11.2	10.6	10	17
Residential (refrigerators, freezers, etc.)	1	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.6	0.6	0.5	0.5	15
Other equipment (specify)	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Solvent [1]	50	50	50	50	50	50	50	50	50	50	50	50	50	1
Fire suppression/extinguishing systems (Original Equipment Manufacture) [1]														
Portable (mobile) systems	60	60	60	60	60	60	60	60	60	60	60	60	60	18
Total flooding (fixed) systems	35	35	35	35	35	35	35	35	35	35	35	35	35	18
Fire suppression/extinguishing systems (Service/Maintenance) [1]														
Portable (mobile) systems	60	60	60	60	60	60	60	60	60	60	60	60	60	18
Total flooding (fixed) systems	35	35	35	35	35	35	35	35	35	35	35	35	35	18
Miscellaneous [1]	50	50	50	50	50	50	50	50	50	50	50	50	50	2
Other (specify) [1]	50	50	50	50	50	50	50	50	50	50	50	50	50	2

1 IPCC 2006

2 Environment Canada 2015

A3

Table A3–22 HFC End-of-Life Emission Factors (%)

Subcategory	1995 to 1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010 - 2013	Life Time
Aerosols [1]	100	100	100	100	100	100	100	100	100	100	100	100	100	2
Blowing agent in foams [1]														
Open-cell foam	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Closed-cell foam	100	100	100	100	100	100	100	100	100	100	100	100	100	23
Air conditioning (Original Equipment Manufacture) [2]														
Air-conditioner units in motor vehicles	100	97.9	95.8	93.8	91.7	89.6	87.5	85.4	83.3	81.3	79.2	77.1	75	13
Chillers (specify centrifugal or reciprocating)	100	92.1	84.2	76.3	68.3	60.4	52.5	44.6	36.7	28.8	20.8	12.9	5	17
Residential (air conditioners, dehumidifiers, etc.)	100	93.3	86.7	80.0	73.3	66.7	60.0	53.3	46.7	40.0	33.3	26.7	20	17
Air conditioning (Service/ Maintenance)) [2]														
Air-conditioner units in motor vehicles	100	97.9	95.8	93.8	91.7	89.6	87.5	85.4	83.3	81.3	79.2	77.1	75	13
Chillers (specify centrifugal or reciprocating))	100	92.1	84.2	76.3	68.3	60.4	52.5	44.6	36.7	28.8	20.8	12.9	5	17
Residential (air conditioners, dehumidifiers, etc.)	100	93.3	86.7	80.0	73.3	66.7	60.0	53.3	46.7	40.0	33.3	26.7	20	17
Refrigeration (Original Equipment Manufacture) [2]														
Commercial transport	100	94.2	88.3	82.5	76.7	70.8	65.0	59.2	53.3	47.5	41.7	35.8	30	13
Commercial and institutional (retail foods, vending machines, etc.)	100	94.2	88.3	82.5	76.7	70.8	65.0	59.2	53.3	47.5	41.7	35.8	30	17
Industrial (warehouses, process equipment, etc.)	100	94.2	88.3	82.5	76.7	70.8	65.0	59.2	53.3	47.5	41.7	35.8	30	17
Residential (freezers, refrigerators)	100	94.2	88.3	82.5	76.7	70.8	65.0	59.2	53.3	47.5	41.7	35.8	30	15
Other equipment (specify)	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration (Service/ Maintenance)) [2]														
Commercial transport	100	94.2	88.3	82.5	76.7	70.8	65.0	59.2	53.3	47.5	41.7	35.8	30	13
Commercial and institutional (retail foods, vending machines, etc.)	100	94.2	88.3	82.5	76.7	70.8	65.0	59.2	53.3	47.5	41.7	35.8	30	17
Industrial (warehouses, processes, etc.)	100	94.2	88.3	82.5	76.7	70.8	65.0	59.2	53.3	47.5	41.7	35.8	30	17
Residential (refrigerators, freezers, etc.)	100	94.2	88.3	82.5	76.7	70.8	65.0	59.2	53.3	47.5	41.7	35.8	30	15
Other equipment (specify)	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Solvent [1]	100	100	100	100	100	100	100	100	100	100	100	100	100	1
Fire suppression/extinguishing systems (Original Equipment Manufacture) [1]														
Portable (mobile) systems	0	0	0	0	0	0	0	0	0	0	0	0	0	18
Total flooding (fixed) systems	0	0	0	0	0	0	0	0	0	0	0	0	0	18
Fire suppression/extinguishing systems (Service/Maintenance) [1]														
Portable (mobile) systems	0	0	0	0	0	0	0	0	0	0	0	0	0	18
Total flooding (fixed) systems	0	0	0	0	0	0	0	0	0	0	0	0	0	18
Miscellaneous [1]	100	100	100	100	100	100	100	100	100	100	100	100	100	2
Other (specify) [1]	100	100	100	100	100	100	100	100	100	100	100	100	100	2

1 IPCC 2006

2 Environment Canada 2015

A3

A3.3.6. SF$_6$ Emissions from Electrical Equipment

A3.3.6.1. Methodology – Derivation of the Country-Specific Quantification Method

To quantify SF$_6$ emissions (for 2006–2013), the Canadian electricity industry uses a method derived from the basic Tier 3 IPCC life-cycle Equation 8.3, Volume 3, as explained below.

A3.3.6.1.1. Equipment Manufacturing Emissions

Since Canadian electric utilities do not manufacture their transmission and distribution equipment, it is assumed that SF$_6$ emissions released during the manufacturing stage are negligible.

A3.3.6.1.2. Equipment Installation Emissions

SF$_6$ equipment is delivered to utilities pre-charged with some SF$_6$, and it is charged to full capacity at 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.

A3.3.6.1.3. 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.

A3.3.6.1.4. 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 from 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$_6$ is leaked out of the equipment. Hence, equipment damages are a potential source of emissions.

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

A3.3.6.1.5. 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 U.S. 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 A3–18.

Equation A3–18:

$$
\begin{aligned}
\textit{Total Utility SF}_6 \ \textit{Emissions} \\
= \sum \textit{Equipment Use Emissions} \\
+ \sum \textit{Equipment Decommissioning and Failure Emissions}
\end{aligned}
$$

A3.3.6.2. 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 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 again. 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.

A3.3.6.2.1. 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 (please see also A3.3.6.1.2, 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 performed 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 inven-

tory 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.

A3.3.6.3. 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 A3–19:

$$\text{Equipment decommisioning emissions} \\ = \text{Nameplate capacity of retired equipment} \\ - SF_6 \text{ amount recovered from retired equipment}$$

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

The information provided in this section (A3.3.6) is extracted from the *SF_6 Emission Estimation and Reporting Protocol for Electric Utilities* (Environment Canada and Canadian Electricity Association 2008), available upon request at http://www.publications.gc.ca/site/eng/454401/publication.html. For further details on data uncertainty, data quality control, data verification by third party, transfer of information and data to Environment Canada, documentation and archiving, new information or data updates, and protocol reviews and amendments, please refer to the Protocol.

Table A3–23 Canadian Iron and Steel Manufacturing Facilities and Processes

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

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

A3.3.6.4. Data Sources

The SF_6 emissions by province for 2006-2013 were provided by the Canadian Electricity Association and Hydro Quebec.

A3.3.7. CO$_2$ Emissions from Iron and Steel Production

A3.3.7.1. Methodology

In addition to the methodology description provided in Chapter 4, Section 4.9, information is provided here on production plants in Canada and their process technologies.

Canadian Iron and Steel Manufacturing Facilities

As of 1998, the Canadian steel sector consisted of 17 facilities, namely five integrated mills and 12 non-integrated mills (10 mini-mills and two specialty steel mills). Of the 17 facilities, nine are located in Ontario (including four integrated mills), four in Quebec and one in each of Alberta, Saskatchewan, Manitoba and Nova Scotia. All 17 are listed in Table A3–19, which also indicates the manufacturing processes involved (Environment Canada 1998).

Canadian Iron and Steel Process Technologies

Steel is produced in Canada by two main steelmaking processes (see Figure A3–7): basic oxygen furnaces (58.5% in 1998) and electric arc furnaces (41.5% in 1998) (Environment Canada 1998).

Figure A3–7 Canadian Steelmaking Processes
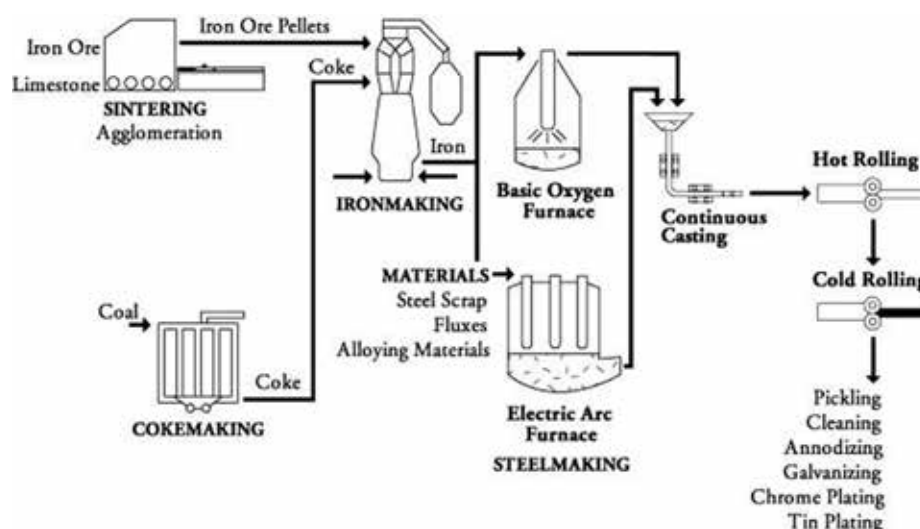
The basic oxygen furnace is used in integrated mills in conjunction with cokemaking, sintering, and blast furnace ironmaking operations. The integrated mills, which smelt iron ore and melt scrap, produce the greatest diversity of products, including bars, rods, structural shapes, plates, sheets, pipes and tubes, and wire rods. Although electric arc furnace 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. Dofasco Inc. operates the only integrated steel plant in Canada that produces part of its steel by the electric arc furnace process. Ispat Sidbec Inc. operates the only Canadian steel mill that produces and uses DRI as part 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.

A3.4.   Methodology for the Agriculture Sector

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

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

The sources of animal population data required to calculate agricultural emissions of CH_4 and N_2O are presented first 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).

Table A3–24   Animal Categories and Sources of Population Data

Category	Sources/Notes
Cattle	Statistics Canada. Table 003-0032 - Number of cattle, by class and farm type, annual (head), CANSIM (database). http://www5.statcan.gc.ca/cansim/a05?lang=eng&id=0030032&pattern=0030032&searchTypeByValue=1&p2=35 (accessed September 24, 2014)
—Dairy Cattle	All cattle used in the production of milk and milk products
—Non-dairy Cattle	All other cattle
Bison, Goats, Horses, Llamas and Alpacas, Deers and Elk, Mink, Foxes, Wild Boars	Statistics Canada. 2008. Alternative Livestock on Canadian Farms: Census years 1981, 1986, 1991, 1996, 2001, and 2006 (Catalogue # 23-502-X), 2011 Census: Statistics Canada. Table 95-640-XWE - 2011 Farm and farm operator data (database). http://www29.statcan.gc.ca/ceag-web/eng/data-type-selection-type-donnees?geold=0- linear interpolation between census years, remains constant after last census
Rabbits	Agriculture and Agri-Food Canada, Red Meat Market Information, Alternative Livestock. http://www.agr.gc.ca/redmeat/rpt/tbl38a eng.htp
Sheep and Lambs	Statistics Canada. Table 003-0031 - Number of sheep and lambs on farms, annual (head), CANSIM (database). http://www5.statcan.gc.ca/cansim/a05?lang=eng&id=0030031&pattern=0030031&searchTypeByValue=1&p2=35 (accessed September 24, 2014)
Swine	Statistics Canada. Table 003-0004 - Number of hogs on farms at end of quarter, quarterly (head), CANSIM (database). http://www5.statcan.gc.ca/cansim/a26;jsessionid=59B3777642DC730198B7D13BA6029B86?lang=eng&retrLang=eng&id=0030004&tabMode=dataTable&srchLan=-1&p1=-1&p2=35 (accessed September 24, 2014)

Subcategories: Boars, Sows, Growers under 20 kg, 20 to 60 kg, and over 60 kg |
| **Poultry** | Farm data and farm operator data tables (section 6.5 of publication #95-629) (Statistics Canada [2007a])

Selected historical data from the Census of Agriculture, Canada and provinces: census years 1976 to 2006 (Table 2.16 and section 4.6 of Statistics Canada catalogue #95-632). (Statistics Canada [2007b]) 2011 Census: Statistics Canada. Table 95-640-XWE - 2011 Farm and farm operator data (database). http://www29.statcan.gc.ca/ceag-web/eng/data-type-selection-type-donnees?geold=0 (Aaccessed December 20, 2012) - linear interpolation between census years, remains constant after last census |

Table A3–25 Cattle Production Stage Model

Subcategory	Production Environment	Period of Year1	Province
Beef cows	Pregnant, confined	Jan-Apr/Oct-Dec	NF./P.E./N.S./N.B./QC./ON./MB./SK./AB./B.C.
Beef cows	Lactating, pasture	May-Oct	NF./P.E./N.S./N.B./QC./ON./MB./SK./AB./B.C.
Beef cows	Pregnant, confined	Feb-Mar	MB.
Beef cows	Lactating, pasture	Jan/Mar-Dec	MB.
Breeding bulls	Mature, confined	Jan-Apr/Nov-Dec	P.E./N.S./QC./ON./MB./SK./AB./B.C.
Breeding bulls	Mature pasture	May-Oct	P.E./N.S./QC./ON./MB./SK./AB./B.C.
Breeding bulls	Young confined	Mar-Apr	NF./P.E./N.S./N.B./QC./ON./MB./SK./AB./B.C.
Breeding bulls	Young pasture	May-Oct	NF./P.E./N.S./N.B./QC./ON./MB./SK./AB./B.C.
Breeding bulls	Young confined	Nov-Dec/Jan-Feb	NF./P.E./N.S./N.B./QC./ON./MB./SK./AB./B.C.
Beef calves	Birth to pasture	Mar	NF./P.E./N.S./N.B./QC./ON./MB./SK./AB./B.C.
Beef calves	Pasture	Apr-Sep	NF./P.E.I/N.S./N.B./QC./ON./MB./SK./AB./B.C.
Beef calves	Heifer replacement	Oct-Dec/Jan-Mar	P.E./N.S./QC./ON./MB./SK./AB./B.C.
Beef calves	Background heifers	Oct-Dec/Jan-Mar	P.E./N.S./QC./ON./MB./SK./AB./B.C.
Beef calves	Background steers	Oct-Dec/Jan-Mar	NF./P.E./N.S./N.B./ON./MB./SK./AB./B.C.
Beef calves	Finisher heifers	Oct-Dec/Jan-Mar	NF./P.E./N.S./N.B./ON./MB./SK./AB./B.C.
Beef calves	Finisher steers	Oct-Dec/Jan-Mar	P.E./N.S./N.B./ON./MB./SK./AB./B.C.
Heifer replacement	Young, not pregant	Apr-May	NF./P.E./N.S./N.B./QC./ON./MB./SK./AB./B.C.
Heifer replacement	Early gestation	Jun-Sep	NF./P.E./N.S./N.B./QC./ON./MB./SK./AB./B.C.
Heifer replacement	Late gestation	Oct-Dec/Jan-Mar	NF./P.E./N.S./N.B./QC./ON./MB./SK./AB./B.C.
Finisher heifers	Feedlot, short-keeps	Apr-Jun	P.E./N.S./N.B./ON./MB./SK./AB./B.C.
Finisher steers	Feedlot, short-keeps	Apr-Jun	P.E./N.S./N.B./ON./MB./SK./AB./B.C.
Finisher heifers	Feedlot short-keep long-finish	April-Jul	N.S./ON./MB.
Finisher steers	Feedlot short-keep long-finish	April-Jul	N.S./ON./MB.
Background heifers	Confined	Mar-May	NF./N.S./ON./MB./SK./AB./B.C.
Background steers	Confined	Mar-May	NF./N.S./ON./MB./SK./AB./B.C.
Background heifers	Pasture	Jun-Sep	NF./N.S./ON./MB./AB./B.C.
Background steers	Pasture	Jun-Sep	NF./N.S./ON./MB./AB./B.C.
Finisher heifers	Feedlot, long-keeps	Oct-Dec	P.E./N.S./N.B./QC./ON./MB./SK./AB./B.C.
Finisher steers	Feedlot, long-keeps	Oct-Dec	P.E./N.S./N.B./QC./ON./MB./SK./AB./B.C.
Dairy cows	Lactating, confined	var2	NF./P.E./N.S./N.B./QC./ON./MB./SK./AB./B.C.
Dairy cows	Lactating, pasture	var	NF./P.E./N.B.
Dairy cows	Lactating, confined (after pasture)	var	P.E.
Dairy cows	Dry, low-quality feed	var	NF./P.E./N.S./N.B./QC./ON./MB./SK./B.C.
Dairy cows	Dry, high-quality feed	var	MB./SK./AB./B.C.
Dairy cows	Dry, pasture	var	NF./ON.
Dairy heifers	Confined (243 days year)	Jan-Apr/Oct-Dec	NF./P.E./N.S./N.B./QC./ON./MB./SK./AB./B.C.
Dairy heifers	Pasture	May-Oct	NF./P.E./N.B./ON./SK.
Dairy heifers	Confined (365 days year)	Jan-Dec	N.B./ON./SK.

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

Table A3–26   Typical Characteristics of Dairy Production in 2001 in Canada

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

Notes:

1. Values represent typical values observed in Canada but not population-weighted averages quantitatively representing Canadian dairy production, as reported in the CRF.

2. The numbers in parentheses are the standard deviation.

3. Values with no reference were obtained from expert consultations (see Boadi et al. 2004b).

4. "Calf crop" is the percentage of the overwintering cows that produced a live calf.

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 (Table A3–24).

Annual animal populations of cattle, sheep and swine are presented as the simple mean of semiannual or quarterly surveys. Surveys are corrected by Statistics Canada to the *Census of Agriculture*, conducted every 5 years. The populations of horses, goats, buffalo,[15] llamas and alpacas, deer and elk, wild boars, mink, foxes, rabbits and poultry are taken from the *Census of Agriculture* exclusively. Annual populations are developed by linear interpolation in order to avoid large changes in census years. Buffalo populations were not collected in 1986; thus, the buffalo population was set constant for 1990 at the 1991 level.

For beef and dairy cattle, the IPCC Tier 2 approach (IPCC 2006) was adopted to estimate CH_4 emission factors from enteric fermentation and manure management. The subcategories of provincial cattle populations collected by Statistics Canada were further disaggregated into subannual production stages to isolate and quantify the effect of specific production practices on gross energy intake and as a consequence, CH_4 emission. Data to describe the production environment and associated performance of classes of animals were collected from a combination of production and management practices published in scientific journals, a survey of dairy and beef production practices conducted and administered to regional and provincial beef and dairy cattle specialists across the country, and consultation with scientists at universities and federal research institutions, as well as from provincial/national associations and provincial/regional performance-recording organizations (Boadi et al. 2004b).

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 nondairy cattle and 9 for dairy cattle, observed throughout the different

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15   The IPCC animal category buffalo is used; however, in Canada, it refers to North American bison (*Bison bison) that are raised for meat.*

Table A3–27   Average Milk Production from 1990 to 2013 at a Provincial Level

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

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

provinces of Canada (Table A3–25). The model characterizes cattle by physiological status, diet, age, sex, weight, growth rate, activity level and production environment.

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

A3.4.1.1. Dairy Cattle

Production and Performance

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

Table A3–26 provides an example of production performance data collected for Canadian dairy cattle, originally used as a quality assurance (QA) verification of the data incorporated in the Tier 2 model.

Currently, it is assumed that all production characteristics of the Canadian dairy herd have remained constant over the 1990–2013

period, including the live weight of dairy cows, as data from Holstein Ontario do not indicate increases in weight over this period. As a result, dairy cows' and dairy heifers' live weights are set constant to the 2001 weight, estimated in Boadi et al. (2004b).

Milk Yield and Fat Data

Milk productivity has increased in all Canadian provinces (Table A3–27), as documented by the CanWest Dairy Herd Improvement (DHI) Services, representing more than two thirds of the Canadian dairy cow population for the period of 1999–2013. 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

Table A3–28   Typical Characteristics of Beef Production in Canada in 2001[1] from Various Sources

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

Notes:

1. Values represent typical values observed in Canada but not population-weighted averages quantitatively representing Canadian beef production, as reported in the CRF.

2. The numbers in parentheses are the standard deviations.

3. Values with no reference were obtained from expert consultations compiled in Boadi et al. (2004b).

to 2007. A 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 animals that were dry during the summer months were on pasture; animals that were dry during the remainder of the year were in confinement. Replacement heifers were assumed to calve at 24 months.

Percentage of Cows Pregnant

An estimate of the percentage of cows pregnant in the herd at any given time was calculated in Boadi et al. (2004b) 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.

Figure A3–8 Non-Dairy Cattle Carcass Weight, Based on Data Collected by CBGA and Published by Agriculture and Agri-Food Canada
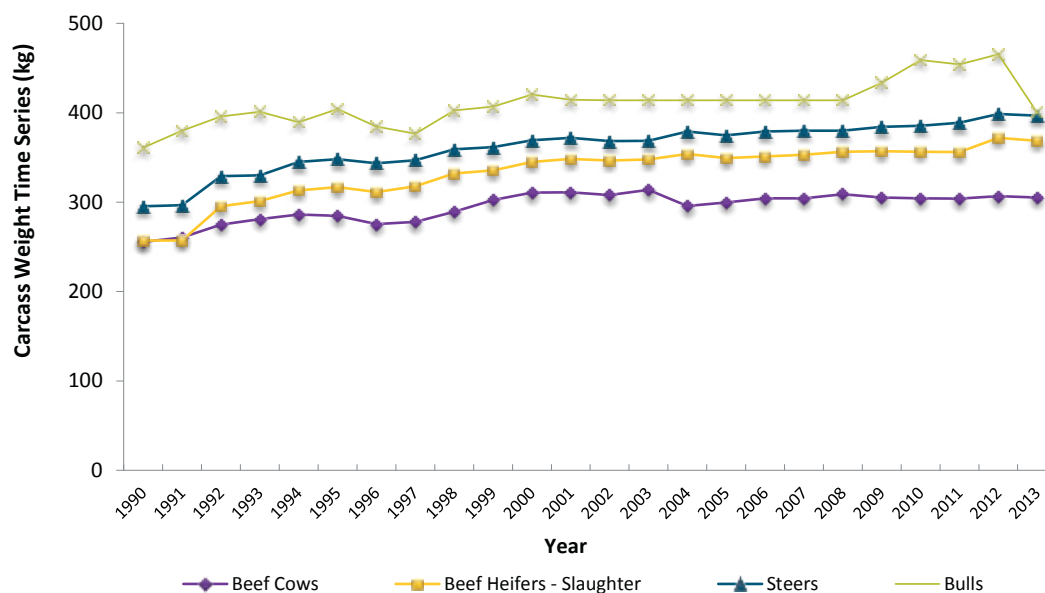
Table A3–29 Carcass Weights Used as an Indicator of Live Body Weight Change Over Time for Non-dairy Cattle

Cattle Subcategory	Trend in Live Weight Applied
Beef cows	Trends in beef cow carcass weight used as an indicator of live weight.
Heifers for slaughter	Trends in heifer carcass weight used as an indicator of live weight.
Beef heifers	Trends in beef cow carcass weight used as an indicator of live weight.
Steers	Trends in steer carcass weight used as an indicator of live weight.
Bulls	Trends in bull carcass weight used as an indicator of live weight from 1990 to 2002; 2003 to 2008 live weights are set constant to the 2002 live weight; 2009–2011 uses carcass weight trend again; 2012 values were kept constant.
Calves	No change
Dairy heifers[1]	No change

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

Ration Digestible Energy

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

A3.4.1.2. Non-Dairy Cattle

Production Practices and Performance

Production practices for non-dairy cattle also vary across the country due to climate, land prices and differences in traditional farming practices. The study conducted by Boadi et al. (2004b) 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 A3–28 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.

A3

Trends in carcass weights are used as an indicator of changes in mature weight from the 2001 benchmark values established by Boadi et al. (2004b) for the specific animal subcategories presented in Table A3–29. Carcass weight data are collected by the Canadian Beef Grading Agency (CBGA) and published by Agriculture and Agri-Food Canada (AAFC 1990–2013). Carcass weights increased from 1990 to 2003 for beef cows, heifers for slaughter, steers and bulls (Figure A3–8). Since 2003, beef cow carcass weights have remained more or less stable, but slaughter animal weights have continued to increase. As discussed in the 2014 NIR submission, small errors were observed on the AAFC website. As a result, the entire carcass weight time series was reevaluated and small changes were made to animal weights from 1990 to 2012. Bull weights were observed to decrease considerably in 2013. This observation was verified and the low carcass weight was demonstrated to be correct, but was associated with a low number of bulls being slaughtered in that year.

In 2003, the Canadian cattle meat 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 was retained at their 2002 value. From 2009 to 2013, the slaughter weight of bulls was, once again, used in the time series.

Duration of Time in a Production Environment

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

Ration Digestible Energy (DE)

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

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

A3.4.2. CH_4 Emissions from Enteric Fermentation

The release of CH_4 from enteric fermentation from all categories of livestock in Canada is calculated using Equation A3–20. CH_4 emissions from enteric fermentation for cattle are estimated using the country-specific emission factors derived from IPCC (2006) Tier 2 equations (Table A3–30). For the other animal categories, the IPCC Tier 1 methodology and default emission factors are applied (see Annex 6).

Equation A3–20:

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

where:

CH_{4EF}	=	CH_4 emissions from enteric fermentation for all animal categories
N_T	=	animal population for the Tth animal category or subcategory in each province
$EF_{(EF)T}$	=	emission factor for the Tth animal category or subcategory (Table A3–30 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 (2000) 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 A3–21.

Table A3–30   CH4 Emission Factors for Enteric Fermentation for Cattle from 1990 to 2013

	EF(EF)T - (kg CH4/head/year)[1]							
Year	Dairy Cows	Dairy Heifers	Bulls	Beef Cows	Beef Heifers	Heifers for Slaughter[2]	Steers[2]	Calves
1990	129.6	78.2	108.1	106.0	82.5	44.7	41.4	43.9
1991	130.3	78.2	112.0	107.0	83.2	44.8	41.8	43.8
1992	133.2	78.3	115.3	110.0	84.7	47.2	43.6	43.7
1993	134.4	78.2	116.3	111.3	85.3	48.5	43.1	43.8
1994	134.7	78.2	114.1	112.5	86.1	49.0	44.3	43.8
1995	134.9	78.1	117.2	112.1	85.9	48.8	43.6	43.8
1996	137.7	78.1	113.4	110.0	84.6	49.3	43.9	43.7
1997	137.5	78.1	111.9	110.6	85.5	50.3	44.8	43.7
1998	139.4	78.2	117.2	113.0	86.9	51.5	46.2	43.9
1999	141.7	78.2	118.3	115.9	88.8	52.5	47.2	43.7
2000	143.3	78.3	121.0	117.5	89.4	53.0	47.8	43.8
2001	143.7	78.4	120.0	117.5	89.4	53.4	47.6	43.9
2002	145.2	78.4	119.9	116.7	89.1	53.3	47.2	43.8
2003	144.7	78.5	119.8	117.7	89.7	52.4	46.5	43.6
2004	144.2	78.4	119.8	113.7	86.9	52.7	46.1	43.6
2005	144.8	78.4	119.9	114.4	87.1	52.8	46.0	43.6
2006	146.1	78.3	119.8	115.3	87.6	53.0	46.7	43.6
2007	146.5	78.4	120.0	115.3	87.6	53.0	47.0	43.6
2008	147.0	78.4	119.9	116.3	88.4	53.1	46.7	43.6
2009	147.4	78.4	123.6	115.5	87.9	52.9	47.1	43.7
2010	148.9	78.4	128.5	115.3	87.8	52.8	47.0	43.7
2011	149.4	78.4	127.6	115.1	87.5	52.7	47.4	43.7
2012	150.0	78.4	129.8	115.6	87.7	53.5	47.9	43.7
2013	155.1	78.4	117.1	115.4	87.3	53.6	48.1	43.7

Notes:

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

Equation A3–21:

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

where:

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

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 calculated. Criteria used in the weighting included duration of time spent in the production category 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 A3–22. 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 A3–30).

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Equation A3–22:

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

where:

$EF_{(EF)T}$	=	annual emission factor for defined animal population T, kg/head/year
GE_T	=	gross energy, MJ/day within the defined population T, kg/day
TP_T	=	time (days/year) of a stage of production with defined population T
Y_{mT}	=	methane conversion rate at which the fraction of gross energy is converted to methane by an animal within defined population T, m³/kg

A3.4.2.1.1. Changes in Enteric Fermentation Emission Factors, IPCC 2006 Guidelines

The implementation of the 2006 IPCC Guidelines consisted of five changes to the Tier 2 methodology for cattle.

The equation used to calculate the net energy of growth Equation A3–23) was changed from:

Equation A3–23:

$$NE_g = 4.18 \times \left\{ 0.0635 \times \left[0.891 \times (BW \times 0.96) \times \left(\frac{478}{(C \times MW)} \right) \right]^{0.75} \times (WG \times 0.92)^{1.097} \right\}$$

where:

NE_g	=	net energy needed for growth, MJ/day
BW	=	live body weight of the animal, kg
C	=	coefficient with a value of 0.8 for females, 1.0 for steers and 1.2 for bulls
MW	=	the mature body weight of an adult animal, (kg)
WG	=	the daily weight gain, kg/day

to the 2006 IPCC Guidelines equation (Equation A3–24)

Equation A3–24:

$$NE_g = 22.02 \times \left(\frac{BW}{C \times MW} \right) \times (WG)^{1.097}$$

where:

NE_g	=	net energy needed for growth, MJ/day
BW	=	live body weight of the animal, kg
C	=	coefficient with a value of 0.8 for females, 1.0 for steers and 1.2 for bulls
MW	=	the mature body weight of an adult animal, (kg)
WG	=	the daily weight gain, kg/day

This simplification of the original equation had a very minor impact on the final emission factor (see Chapter 5 for the quantitative breakdown of recalculations with changes in equations).

The Equation 4.4a, net energy due to weight loss, from the Good Practice Guidance (IPCC 2000) was removed from the gross energy intake (GEI) summation.

The methane conversion rate (Ym) was changed from 4 to 3% of GEI for slaughter cattle in feedlots (only during the time that they are receiving finishing rations) and from 6 to 6.5% of GEI for all other cattle.

Updated Cfi factors taken from Table 10.4 of the 2006 IPCC Guidelines were integrated into the calculation of net energy of maintenance (NEm) for lactating cattle and bulls.

Implementation of Equation 10.2 (Equation A3–25) for Non-Dairy cattle:

Equation A3–25:

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

where:

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

The cold-adjusted Cfi was derived by using the average temperature for the period October to April for each Canadian province, weighted based on the geographic location of Non-Dairy cattle (distributed at the ecodistrict scale) in the province. The cold adjusted Cfi was then corrected based on the percentage of animals kept in barns for different provinces, taken from Sheppard

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

A3.4.2.2. Verification of Parameter Selection Against Canadian Research

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

Research measuring enteric fermentation in Canada indicates that the average measured methane conversion rates (Y_m), are 6.6% (±2.4) of gross energy (GE) for non-dairy cattle outside of feedlots, 3.2% (±1.9) GE on feedlots and 6.2% (±2.4) for dairy cattle (McCaughey et al. 1997, 1999; Boadi and Wittenberg 2002; Boadi et al. 2002, 2004a; McGinn et al. 2004, 2008, 2009; Beauchemin and McGinn 2005, 2006; Chaves et al. 2006; Kebreab et al. 2006; Ominski et al. 2006; Odongo et al. 2007; Eugène et al. 2008; Van Haarlem et al. 2008; Beauchemin et al. 2009; Ellis et al. 2010). These values tend to agree with the values published in *the 2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2006). From the same compilation of research, the emission factor for non-dairy cattle is observed to be 57 (±22) kg CH_4/head/yr outside of feedlots and 56 (±24) kg CH_4/head/yr in feedlots, and the average measured dairy cattle emission factors are 130 (±34) kg CH_4/head/yr.

Caution must be used in interpreting these values, as the majority of studies focus on yearling heifers and steers, and the average value does not take into account the relative importance of different cattle subcategories on 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 65 kg CH_4/head/year. However, dairy emission factors calculated using the 2006 IPCC Guidelines tend to be higher,

ranging from 130 to 155 kg CH_4/head/yr. A recent publication by Jayasundara and Wagner-Riddle (2014) suggests that Ym factors for Canadian Dairy cattle may be as low as 5.6% and vary over time. In the current Canadian cattle model, a fixed Y_m of 6.5% GE for Non-Dairy cattle outside of feedlots and dairy cattle and 3% GE for non-dairy cattle in feedlots is used.

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

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

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

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

For non-cattle animal categories, IPCC Tier 1 emission factors are used to calculate emissions (see Annex 6).

A3.4.2.4. Uncertainty

A comprehensive uncertainty analysis was carried out on all methodology used in the calculation of methane from livestock for 2010. For this submission, the uncertainty ranges (percentages) of means were rerun for 2013. 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 upon a recent study (Karimi-Zindashty et al. 2012); however, the Environment Canada stochastic model (ECSM) built in Mathematica© (i) used the exact parameters and equations used in the Canadian inventory methodology based on the Good Practice Guidance (IPCC 2000), but also (ii) included uncertainty associated with populations and duration of production stages that impacts

subcategory emission factors (Table A3–31), and (iii) used the provincial distribution of manure management systems with improved estimates of probability distributions (Table A3–31). The ECSM was run for the years 1990, 2005, 2010 and 2012. A new trend analysis was carried out to establish the uncertainty in the estimate of the differences in emissions from 1990 to 2012. For 2013, the relative uncertainties from the 2014 analysis were applied to the 2013 values.

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

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

All other animal population estimates are renewed only through the *Census of Agriculture*. To account for the increase in uncertainty due to the time that has elapsed since the census, a function was developed that increased uncertainty as a function of time from the census. A linear regression was run through census year population estimates from 1991, 1996, 2001, 2006 and 2011. The uncertainties for populations in 2012 were estimated as the agricultural census uncertainty at the provincial level, plus the 95% confidence interval for the linear regression times 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 in the 2010/2011 uncertainties, similar to those animals from which populations are taken from biannual and quarterly surveys, though this had little impact on total uncertainty. The national population uncertainties for these 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 are 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 nonsymmetrical 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 Valacta Dairy Services after the published 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. Therefore, a uniform distribution was incorporated in the ECSM analysis to account for the impact of incorporating an estimate of net energy mobilized through weight loss during lactation (NE_{mob}) that varied according to duration of weight loss between 0 and 20% of the lactation period. As this parameter has been removed from the 2006 IPCC Guidelines, this approach was an effective way to evaluate the overall impact of this parameter.

A trend analysis was carried out using the ECSM in which the uncertainty in the magnitude of the change in emissions over time was calculated. For the long-term trend, emissions for 1990 and 2012 were calculated simultaneously, allowing only timedependent parameters to vary independently in the estimates. These parameters represent the elements of the calculation model that change over time, and therefore an estimate is available for a value in 1990 and in 2012 (noted by a superscript 7 in

Table A3–31 Uncertainties in Inputs, Sources of Uncertainty and the Spatial and Animal Category at which Uncertainty is Assigned, for Parameters Used for Estimating Methane Emissions from Enteric Fermentationn

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

Table A3–31   Uncertainties in Inputs, Sources of Uncertainty and the Spatial and Animal Category at which Uncertainty is Assigned, for Parameters Used for Estimating Methane Emissions from Enteric Fermentation (cont`d)

Parameter Category	Coefficient/ Parameter Source	Distribution Type	Uncertainty Range[1]	Uncertainty Distribution Estimate Source and Notes	Spatial Allocation/ Animal Category Allocation
Gross Energy for Cattle Calculation IPCC Tier 2 Equation A3–2 (cont'd)					
Net Energy for Cattle Tier 2 Equations 4.1 to 4.10, IPCC Good Practice Guidance (2000)					
Animal activity coefficient (Ca)	IPCC (2000)	normal	±30%	Karimi-Zandashty et al. (2012) – Monni et al. (2007)	National/cattle
Gender coefficient (C)	IPCC (2000)	normal	±30%	Karimi-Zandashty et al. (2012) – Monni et al. (2007)	National/cattle
Maintenance coefficient Cfi	IPCC (2000)		±30%	Karimi-Zandashty et al. (2012) – Monni et al. (2007)	National/cattle
Lactation coefficient	IPCC (2000)		±30%	Karimi-Zandashty et al. (2012) – Monni et al. (2007)	National/cattle
Weight loss rate	IPCC (2000)	normal	5%	Karimi-Zindashty et al. (2012) – from expert opinion	Provincial/subcategory
Weight loss duration	IPCC (2000)	normal	LB: 0 UB: 20% of lactation period.	Interpretation of differences between 2000 and 2006 IPCC Guidelines.	Provincial/subcategory
Non-cattle Emission Factors					
Swine	IPCC (2000)	normal	±37%	Karimi-Zandashty et al. (2012) – Monni et al. (2007)	National/category
Other animals	IPCC (2000)	normal	±50%	Karimi-Zandashty et al. (2012) – Monni et al. (2007)	National/category

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

Table A3–31). The parameters in 1990 and 2012 are considered to be entirely independent and, as a consequence, for each calculation in the Monte Carlo simulation, a value was selected from the probability distribution for 1990 and 2012 independently. In contrast, other parameters used a value selected once from their probability distribution for the calculation of emissions in both 1990 and 2012. The parameters that were allowed to vary independently for the enteric fermentation analysis were animal populations, milk production and fat content in dairy cattle, and body weights in cattle. The relative uncertainty values for the trend analysis were applied to the 2013 results.

The summary results of the uncertainty analysis for emissions from enteric fermentation are reported in Chapter 5, Section 6.2.3. Briefly, the uncertainty range for enteric fermentation emissions is 39% (-17% to +22% of the mean) (Table 63). Most uncertainty in the estimate is associated with the Tier 2 emission factors for cattle that 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 also 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 used as activity data has changed very 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 between 9–19%, 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 11–22% with an MLV of 16%. To estimate the trend uncertainty reported in Table 6-3, the percentage difference between confidence intervals and the MLV was applied to the mean change in emissions between 1990 and 2012, resulting in a range of +8% to +16% around the mean calculated change in emissions of +12%.

In general, this uncertainty analysis was consistent with other agricultural estimates of uncertainty. The paper by Monni et al. (2007) is, to our knowledge, currently the only one detailing agricultural CH_4 emission uncertainty with the use of IPCC Tier 2 methodology. The use of comparable probability distributions for IPCC Tier 2 default parameters provides comparability among the two different national emission estimation methodologies. Monni et al. (2007) estimated the national-scale uncertainty for Finnish agriculture enteric fermentation of different

cattle subcategories ranging from -22 to +29% of the mean to -29 to +39% of the mean. Rypdal and Winiwarter (2001) reported uncertainty for some European countries from ±20% of the mean in the United Kingdom to ±50% of the mean in Austria, but these were mainly Tier 1 estimation methodologies. We did not find comparable publications for trend uncertainty analyses within the domain of Agriculture.

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

Uncertainty analyses will be completely updated only when changes are made to the emission model or source of activity data.

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 A3–26 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, and Fur-bearing Animals, which were calculated based on IPCC defaults. Wild Boar emission factors were calculated based on average swine Tier 2 parameters, but assuming only solid manure. Sources of animal population data are the same as those used in the enteric fermentation estimates and are listed in Table A3–24.

Equation A3–26:

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

where:

CH$_{4MM}$	=	emissions for all animal categories
N$_T$	=	animal population for the Tth animal category or subcategory in each province
EF$_{(MM)T}$	=	emission factor for the Tth animal category or subcategory calculated according to Equation A3–27

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 A3–27. The following equation represents an IPCC Tier 2 estimate of CH$_4$ emission factors from manure management systems:

Equation A3–27:

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

where:

EF$_{(MM)T}$	=	annual emission factor for defined animal population T, kg CH$_4$/head-year
VS$_T$	=	daily volatile solids excreted for an animal within the defined population T, kg/day
Bo$_T$	=	maximum CH4 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)

The following sections outline the sources of input values for VS, DE, ASH, B$_0$, MCF and AWMS.

A3

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. 2004b), as shown in Equation A3–21. Estimates of VS were derived for each cattle subcategory at the provincial level based on regional and seasonal stages of production (Equation A3–28). 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.

Non-Cattle (VS)

Volatile solids for animal categories other than cattle were calculated by Marinier et al. (2004) a stochastic approach, 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 A3–28). A Monte Carlo simulation was performed using Crystal Ball® (Decisioneering 2000), resulting in a mean value of VS and a probability distribution based on the variance in expert opinion and scientific literature (Table A3–32).

Table A3–32   **Mean Volatile Solids in Manure of Non-Cattle Animal Categories and Associated 95% Confidence Interval, Expressed as a Percentage of the Mean**

Animal Category	Mean Volatile Solids (kg/head/day)	95% Confidence Interval (%)
Sheep and Lambs[1]	0.6	31
Mature Horses	3.6	16
Swine	0.23	50
Goats	0.72	41
Bison	3.1	16
Wild Boars[2]	0.23	50
Poultry	0.023	20

Note:

1. Llamas and alpacas are given the same values as sheep and lambs.

2. Wild Bboars, equal to swine.

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

where:

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

The following sections outline the data sources 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 Sections A3.4.1.1 and A3.4.1.2, respectively.

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

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 A3–33). This method does not, however, account for additives that may increase or decrease digestibility. The DMI for non-cattle was determined through consultation with experts and published values (Table A3–34).

Manure Ash Content (ASH)

The ash content in the manure is the inorganic portion of the manure. Table A3–35 contains the values used in this inventory for ash content in volatile solid calculations and their sources.

A3.4.3.2. Maximum CH_4 Producing Potential (B_0)

The B_0 is defined as the maximum volume of CH_4 that can be produced from 1 kg of VS loaded into a manure management system and is expressed in m^3/kg VS loaded. The values published in the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2006) were used for all animals. For bison, non-dairy cattle values were used.

Table A3–33　Approximate Digestible Energy (DE) for Selected Livestock Subcategories and Data Sources

Animal Category	DE (%)	Data Sources[1]
Goat	65	W. Whitmore, Manitoba Agriculture and Food
Laying Hen	80	S. Leeson, University of Guelph; D. Korver, University of Alberta
Chicken	80	S. Leeson, University of Guelph; D. Korver, University of Alberta
Turkey	78	S. Leeson, University of Guelph
Swine	87	C.F. deLange, University of Guelph
Feeding on Grain Diet		
Sheep	74	Weston (2002)
Horse	70	L. Warren, Colorado State University
Feeding on Roughage Diet		
Sheep	65	W. Whitmore, Manitoba Agriculture and Food
Horse	60	L. Warren, Colorado State University

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

Table A3–34　Dry Matter Intake for Selected Livestock

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

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

Table A3–35   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

A3.4.3.3. Methane Conversion Factor (MCF)

The MCF describes the proportion of B_0 that is attained, depending on the storage system and climate region. The values published in the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* were used for all animals.

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

The AWMS factor is the proportional distribution of AWMS of a livestock category within a given area. There is little reliable information published on the distribution of manure management systems in Canada. A survey of experts in manure management and animal production was conducted in 2003–2004 as

part of the Tier 2 study by Marinier et al. (2004); national averages of results are summarized in Table A3–36. Briefly, among the dominant animal production categories across the country, swine manure is mainly handled as liquid manure, while poultry manure is stored as solid manure. On average, dairy cattle manure storage is evenly distributed among solid and liquid forms, with roughly 20% being deposited on pastures; however in certain provinces, the proportion of dairy manure handled as liquid can be as high as 89% (British Columbia) or as low as 20% (Manitoba and Prince Edward Island). Beef cattle manure is equally distributed between solid storage and deposition on pastures, with the exception of British Columbia and Manitoba, where the majority of manure is deposited in pastures.

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

A3.4.3.5. Cattle Manure Management CH$_4$ Emission Factors

Cattle emission factors developed to calculate CH$_4$ emissions from manure management vary by animal subcategory and over time (Table A3–37). As VS was calculated based on the GE derived from the enteric fermentation cattle production model, an emission factor time series was derived for cattle to reflect i) the increase in milk productivity of dairy cows, and ii) the change in live weight of non-dairy cattle as explained in sections A3.4.1.1 and A3.4.1.2, respectively. Emission factors are highest from dairy cattle, reflecting their high rates of confinement, high proportions of liquid manure management systems and high dietary intake for sustained milk production. Beef cattle emission factors

Table A3–36   Percentage of Manure Handled by Animal Waste Management Systems (AWMS) for Canada (per Animal Category, Based on the Distribution of Animal Populations in 2013)[1]

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

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

Table A3–37   Emission Factors to Estimate CH4 Emissions from Manure Management for Cattle Subcategories from 1990 to 2013

	$EF_{(MM)T}$ (kg CH_4/head/year)							
Year	Dairy Cows	Dairy Heifers[1]	Bulls	Beef	Beef Heifers	Heifers for Slaughter[2]	Steers[2]	Calves
1990	29	20	4.4	4.1	3.2	1.9	1.8	1.8
1991	29	20	4.6	4.1	3.2	1.9	1.8	1.8
1992	30	20	4.7	4.2	3.2	2.0	1.8	1.8
1993	30	20	4.7	4.3	3.2	2.0	1.8	1.8
1994	30	20	4.6	4.3	3.1	2.0	1.9	1.8
1995	30	20	4.7	4.3	3.1	2.0	1.9	1.8
1996	31	20	4.5	4.2	3.1	2.0	1.9	1.8
1997	31	20	4.5	4.2	3.2	2.0	1.9	1.8
1998	31	20	4.6	4.3	3.2	2.0	1.9	1.8
1999	31	21	4.7	4.4	3.2	2.1	1.9	1.8
2000	32	21	4.7	4.4	3.2	2.1	1.9	1.8
2001	32	21	4.6	4.5	3.3	2.1	1.9	1.8
2002	33	21	4.6	4.5	3.3	2.1	1.9	1.8
2003	33	21	4.6	4.5	3.3	2.1	1.9	1.8
2004	33	21	4.6	4.3	3.2	2.1	1.9	1.8
2005	33	21	4.6	4.3	3.1	2.1	1.9	1.8
2006	33	21	4.6	4.3	3.1	2.1	1.9	1.8
2007	33	21	4.6	4.3	3.1	2.1	2.0	1.8
2008	33	21	4.6	4.3	3.1	2.1	2.0	1.8
2009	33	21	4.7	4.3	3.1	2.1	2.0	1.8
2010	34	21	4.9	4.3	3.1	2.1	2.0	1.8
2011	34	21	4.9	4.3	3.1	2.1	2.0	1.8
2012	34	21	5.0	4.3	3.0	2.1	2.0	1.8
2013	35	21	4.5	4.3	3.1	2.1	2.0	1.8

Note:

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

are lower, reflecting their lower rates of confinement, lower GE and the fact that the majority of manure is managed in a solid form with a low MCF.

A3.4.3.6. Non-Cattle Manure Management CH₄ Emission Factors

Manure management emission factors for non-cattle animals vary by animal subcategory but are constant over time (Table A3–37). For the largest non-cattle animal categories—swine, sheep and poultry—growth stages for animals are taken into account. The emission factor calculations use VS derived from Marinier et al. (2004). However, emission factors were recalculated to incorporate the latest scientific information available on B_0 and MCF taken from the *2006 IPCC Guidelines* (IPCC 2006). The largest emission factors are from swine, varying between 1.8 and 7.9 kg CH₄/head/year depending on growth stage, due to the high percentage of manure that is stored in liquid form. Emission factors for other minor categories tend to be low due to the large portion of manure that is either deposited on pasture, range or paddock or in solid form in pens and holding yards. Bison manure management emission factors are equal to the non-dairy emission factors for each individual province.

A3.4.3.7. Verification of Parameter Selection Against Canadian Research

The Manure Management source category was a part of a Tier 2 QA/QC for the Agriculture Sector for the 2011 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 varies from greater than 100% (suggesting that B_0 is also underestimated) to as low as 14% in the case of swine and from 4% to 62% for dairy with no mitigation measures in place (Kaharabata et al. 1998; Massé et al. 2003, 2008; Wagner-Riddle et al. 2006; Laguë et al. 2005; Park et al. 2006, 2010; VanderZaag et al. 2009, 2010). Some studies exist in Canada on emissions from solid manures and other

A3

Table A3–38 CH_4 Emission Factors for Manure Management for Non-Cattle

Non-Cattle Animal Categories	Manure Management Emission Factors $EF_{(MM)}$ (kg CH_4/head/year)
Swine	
Boars	7
Sows	7.0-7.3
Pigs < 20 kg	2.1-2.2
Pigs 20–60 kg	4.4-4.5
Pigs > 60 kg	8.4-8.6
Other Livestock	
Sheep	0.33
Lambs	0.22
Goats	0.32
Horses	2.6
Bison	2.2–2.4
Elk and Deer	0.22
Wild Boars1	0.56
Foxes	0.68
Mink	0.68
Rabbits	0.08
Poultry	
Chickens	0.03
Hens	0.12
Turkeys	0.1

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

storage methods (composting) (Pattey et al. 2005; Xu et al. 2007; Hao 2007; Hao et al. 2001b, 2008, 2009, 2010a, 2010b). As was the case with liquid manure systems, variability in emissions and methodology make comparisons to IPCC parameters difficult.

A recent article with a small sample from eastern Canadian farms suggested that the B_0 values for swine, beef and dairy cattle were 0.47–0.42, 0.21–0.19 and 0.35–0.30, respectively (Godbout et al. 2010). The values for beef cattle and swine are consistent with IPCC default values, though dairy manure is the exception and observed B_0 was 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; therefore, the variability observed in studies is likely linked to a combination of differences in measurement methodology, variability in manure characteristics (B_0) and 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 to evaluate whether IPCC parameters are appropriate for estimating emissions from manure management systems.

A3.4.3.8. Uncertainty in Manure Management CH_4 Emissions

Methane emissions from manure management were included in the comprehensive uncertainty analysis discussed in Section A3.4.3.8. As was the case with enteric fermentation, the analysis built on the recent study by Karimi-Zindashty et al. (2012) and has applied a precautionary principle such that for parameters with very little information, probability distributions were intentionally conservative (Table A3–39). 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 2013 numbers.

Population uncertainty for major animal categories was identical to that discussed in Section A3.4.2.3, and the distributions used to define uncertainties can be found in Table A3–31.

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

The probability distributions for coefficients used in IPCC Tier 2 equations used to calculate the emission factors were taken, for the most part, directly from Karimi-Zindashty et al. (2012), who derived the distributions, either from expert opinion within the Marinier et al. (2004) report or directly from the 2006 IPCC Guidelines. The uncertainty for B_0 was taken from Marinier et al. (2004),

but no reliable source was available for the estimate of uncertainty around the MCF. In the current study, a large uncertainty range was used (±45% of the mean) based on expert opinions; however, the choice of this value simply indicates that our confidence in the MCF value is low. Therefore, the actual value of the total uncertainty estimate for manure management must be taken within the context that it is highly dependent on a value and a probability distribution function that is highly uncertain.

In contrast with the Karimi-Zindashty (2012) study, the current analysis was based on a provincial distribution of manure management systems, and uncertainty ranges were estimated from values observed in different provincial and national reports (Koroluk and Bourque 2003; BPR-Infrastructure 2008) and surveys (Sheppard et al. 2009, 2010, 2011; Sheppard and Bittman 2011). In the case of dairy cattle, the lower bound for liquid manure management systems was based on a comparison between reports that suggested that manure treated by liquid systems could vary by as much as 10% above or below the Marinier et al. (2005) estimate. Furthermore, it was reported that there has been a continual movement towards liquid manure systems over time. Therefore, the upper bound was set as 25% based on the rate of adoption of liquid systems from BPR-Infrastructure (2008) and the number of years that have passed since the Marinier et al. survey (2005). In the case of swine, liquid manure management systems upper bounds were fixed at 100%. Other manure management systems' lower bounds for all animal types were 0, also tending to skew probability distributions. This approach resulted in non-symmetrical distributions for all manure management systems. While this approach increased the uncertainty of each individual manure management system, relative to the Karimi-Zindashty study, it likely reduced its impact on the national emission uncertainty because the manure systems were disaggregated to the provincial level, and the total manure management systems were held to 100% of total manure management systems.

The trend analysis carried out using the ECSM quantified the uncertainty in the magnitude of the change in emissions over time for manure management. As was the case for enteric fermentation, for the long-term trend, emissions for 1990 and 2013 were calculated simultaneously, allowing only time-dependent parameters to vary independently in the estimates. More detailed description of the trend analysis is found in Section A3.4.2.4. The parameters allowed to vary independently for the manure management trend analysis were animal populations, milk production and fat content in dairy cattle, body weights in cattle, and AWMS (noted by a superscript 7 in Table A3–31 and superscript 5 in Table A3–39). 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 nonsymmetrical distributions for all manure management systems, and for the trend analysis it also modified the symmetry of prob-

ability distributions around liquid systems between the base year and the current year. Trend uncertainty for the year 2013 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 6, Section 6.3.1.3. Briefly, the uncertainty range for manure management CH_4 emissions 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: 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 8% increase, though it is most likely that there has been an increase in emissions of roughly 5.5%. The assumption that liquid manure storage and other manure storages have increased over time affects the trend. For example, for dairy cattle in Ontario in 1990, the triangular distribution used around the percentage of manure treated in liquid manure management systems had a lower boundary of 16%, a most likely value of 40% and an upper boundary of 42%; in 2010, the lower boundary was 37%, the most likely value, also 40%, and the upper boundary, 59%. The use of a skewed distribution indicating a higher probability that fewer animals were raised on liquid manure management systems in the past balances the increase in animal populations; as a result, it is improbable overall that there is an increase in manure management emissions over time, particularly from cattle.

A3

Table A3–39   Uncertainties in Inputs, Sources of Uncertainty and the Spatial and Animal Category at which Uncertainty is Assigned, for Parameters Used for Estimating Methane Emissions from Manure Management.

A3

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

Table A3-39: **Uncertainties in Inputs, Sources of Uncertainty and the Spatial and Animal Category at which Uncertainty is Assigned, for Parameters Used for Estimating Methane Emissions from Manure Management   (cont'd)**

Parameter Category	Parameter/Animal Category or Subcategory	Distribution Type	Uncertainty Range[1]		Spatial Allocation/ Animal Category Allocation	Uncertainty Distribution Estimate Source and Notes
			Range	Most Likely Value[1]		
Emission Factor Calculation (Equation A3–23) (cont'd)						
Maximum Methane Producing Potential (B_0) (cont'd)		Triangular				
Poultry			0.24–0.39	0.32	National/Category	Karimi-Zindashty et al. (2012) – IPCC (2006)/Marinier et al. (2004)
Sheep and lambs			0.19–0.36	0.19	National/Category	Karimi-Zindashty et al. (2012) – IPCC (2006)/Marinier et al. (2004)
Goats			0.15–0.19	0.18	National/Category	Karimi-Zindashty et al. (2012) – IPCC (2006)/Marinier et al. (2004)
Horses			0.30–0.36	0.3	National/Category	Karimi-Zindashty et al. (2012) – IPCC (2006)/Marinier et al. (2004)
Buffalo			0.19–0.33	0.19	National/Category	Karimi-Zindashty et al. (2012) – IPCC (2006)/Marinier et al. (2004)
Manure Management System (MS)[5]						
Dairy cattle		Triangular	LB: MLV-10% UB: MLV+25%	MLV[4] from Marinier et al. (2005)	Provincial/Category	Expert opinion, bounds based on interpretation of multiple data sources Internally correlated variable[3] Liquid systems allowed to vary to non-symmetric triangular distributions
Swine		Triangular	LB: MLV-10% UB: 100%	MLV from Marinier et al. (2005)	Provincial/Category	Expert opinion, bounds based on interpretation of multiple data sources Internally correlated variable[3] Liquid systems allowed to vary to non-symmetric triangular distributions
Non-dairy cattle		Normal	±17%		Provincial/Category	Marinier et al. (2005). Internally correlated variable[3]
Poultry		Normal	±17%		Provincial/Category	Marinier et al. (2005). Internally correlated variable[3]
Sheep and lambs		Normal	±17%		Provincial/Category	Marinier et al. (2005). Internally correlated variable[3]
Goats		Normal	±17%		Provincial/Category	Marinier et al. (2005). Internally correlated variable[3]
Horses		Normal	±17%		Provincial/Category	Marinier et al. (2005). Internally correlated variable[3]
Buffalo		Normal	±17%		Provincial/Category	Marinier et al. (2005). Internally correlated variable[3]

Notes:

1. Most likely value when triangular distribution, normal distributions given as simple ±%.

2. Ash for swine varies among some provinces.

3. Internal correlation indicates values that vary in terms of a fraction of the whole, i.e., a fraction of a total equalling 100%.

4. MLV = most likely value; LB = lower bound; UB = upper bound

5. Values that vary independently during trend analysis.

The uncertainty range for 2013 was slightly smaller than for 2010 (2%), likely due to a combination of lower uncertainty for census animal populations, and due to the modifications in the uncertainty bounds around AWMS systems with the addition of two years from the time of the original survey. Overall, the uncertainty range around manure management emissions produced by this analysis is slightly smaller than those reported by Karimi-Zindashty et al. (2012), as the proportions of manure treated by different manure management systems were distributed to the provincial level in this analysis, whereas a national average was used in the 2012 publication. Monni et al. (2007) estimated CH_4 manure management emission factor uncertainty to be roughly ±30% based strictly on expert opinion. As was the case with enteric fermentation, Karimi-Zindashty et al. (2012) demonstrated that most uncertainty in the manure management model is associated with the use of default IPCC model parameters that are applied at the national level, specifically the MCF. By deriving MCF factors for different regions and different storage structures, uncertainty would be significantly reduced. Further work on uncertainty will focus on the development of trend uncertainty and the refinement of probability distributions around country-specific parameters already existing in the model.

A3.4.4. N_2O Emissions from Manure Management

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

A3

Table A3–40   Time Series of Manure N Excretion Rates for Cattle (kg N/head/year)[1]

	(kg N/head/year)							
Year	Dairy Cows	Dairy Heifers	Bulls	Beef Cows	Beef Heifers	Heifers for Slaughter[2]	Steers[2]	Calves
1990	102	54	88	58	45	45	48	27
1991	102	54	93	59	46	45	49	27
1992	102	54	97	62	48	52	54	27
1993	102	54	98	64	49	53	54	27
1994	102	54	95	65	50	55	57	27
1995	102	54	99	65	50	55	57	27
1996	102	54	94	62	48	54	56	27
1997	102	54	92	63	49	55	57	27
1998	102	54	99	66	51	58	59	27
1999	102	54	100	69	53	59	59	27
2000	102	54	103	70	54	60	61	27
2001	102	54	102	70	54	61	61	27
2002	102	54	102	70	54	61	60	27
2003	102	54	102	71	55	61	60	26
2004	102	54	102	67	51	62	62	26
2005	102	54	102	68	52	61	61	26
2006	102	54	102	69	53	61	62	26
2007	102	54	102	69	53	62	62	27
2008	102	54	102	70	53	62	62	27
2009	102	54	107	69	53	62	63	27
2010	102	54	113	69	53	62	63	27
2011	102	54	112	69	53	62	64	27
2012	102	54	114	69	53	65	65	27
2013	102	54	99	69	53	64	65	27

Note:
1. N excretion rate for dairy cattle is 0.44 kg N-1000 kg -1-day -1 (IPCC 2006 Table 10.10); N excretion rate for other cattle is 0.31 kg N-1000 kg -1-day -1 (IPCC 2006 Table 10.10). Data source: IPCC (2006), Volume 4, Agriculture, Forestry and Other Land Use.

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

A3.4.4.1. Direct N$_2$O Emissions from Manure Management

Three factors are required to estimate N$_2$O 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.

Nitrogen Excretion Rates for Various Domestic Animals

Manure N excretion from cattle varies by animal subcategory and also over the time series, due to the increase in animal weight. Annual live weights (see Section A3.4.1.2) were multiplied by the IPCC default N excretion rate (IPCC 2006) to produce a time series of manure N excretion rates (Table A3–40). Annual manure N excretion rates from non-cattle domestic animals, according to IPCC Tier 1 default values (IPCC 2006), vary by livestock category. Poultry have high excretion rates (Table A3–41), while horses and bison have the lowest excretion rates. However, on a per-head basis, bison is the largest N excretor in the noncattle category. In

the case of cattle, dairy cows have very high excretion factors due to the protein requirements of sustained milk production. Fur-bearing animals have exceptionally high excretion rates relative to their size (Table A3–41).

Emission Factors Associated with AWMS

The type of AWMS has a significant impact on N$_2$O emissions. Less-aerated systems, such as liquid systems, generate little N$_2$O, whereas drylots or manure on pasture and paddock produce more. However, there is little scientific information in Canada specifying amounts of N$_2$O emissions associated with manure management systems. Therefore, IPCC default emission factors, as listed in Annex 6, were used to estimate emissions.

Table A3–36 summarizes the distribution of manure management systems in Canada by animal category. Emissions of N$_2$O 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 A3.4.5.2. Animal population data are detailed in SectionA3.4.11.

Table A3–41   Manure N Excretion Rates for Non-Cattle

Animal Categories	N Excretion Rate[1] (kg N/1000 kg/day)	Average Body Weight[2] (kg)	Annual Manure N (kg N/head/year)
Swine	0.5	61	11.1
Sheep	0.42	27	4.1
Lambs	0.42	27	4.1
Goats	0.45	64	10.5
Horses	0.3	450	49.3
Llamas and Alpacas	0.42	112	17.2
Bison	0.32	578.5	67.6
Hens	0.83	1.8	0.5
Broilers	1.1	0.9	0.4
Turkeys	0.74	6.8	1.8
Elk and Deer	-	-	14.0
Wild Boars[3]	-	-	11.1
Foxes	-	-	12.1
Mink	-	-	4.6
Rabbits	-	-	8.1

Notes:

1. Data source: IPCC (2006).

2. For Buffalo, average live weight was taken from the US NIR.

3. Equivalent to swine.

Direct N_2O emissions from manure management are estimated using the IPCC Tier-1 method (Equation A3–29) as follows:

Equation A3–29:

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

where:

$N_2O_{D(mm)}$	=	emissions for all AWMS and livestock categories, excluding emissions from urine and dung deposited on pasture, range and paddock, kg N_2O/yr
$N_{i,T}$	=	population for the Tth animal category or subcategory in province i
$N_{i,AWMS}$	=	percentage of manure N handled by each AWMS in province i, fraction (see Table A3–36)
$N_{EX,T}$	=	N excretion rate for the Tth animal category or subcategory (see Table A3–41 for non cattle and Table A3–40 for cattle), kg N/head/year
EF_{AWMS}	=	N_2O emission factors from manure management for each specific AWMS (see Annex 6), kg N_2O N/kg N
44/28	=	coefficient converting N_2O-N to N_2O

A3.4.4.2. Indirect N_2O Emissions from Manure Management

During animal manure storage and handling losses of N occur through indirect pathways i) volatilization of manure N as NH_3 and NO_x and subsequent re-deposition; and ii) leaching and runoff of N. These losses of manure N can result in N_2O emissions (Equation A3–30 and Equation A3–31).

Equation A3–30:

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

where:

$N_2O_{G(mm)}$	=	indirect N_2O emissions due to NH_3 volatilization for Manure Management, excluding emissions from urine and dung deposited on pasture, range and paddock, kg N_2O/yr
$N_{i,T}$	=	population for livestock category or subcategory, T in province i
$N_{i,AWMS}$	=	percentage of manure N handled by each AWMS in province i, fraction (see Table A3–36)
$N_{EX,T}$	=	N excretion rate for the Tth animal category or subcategory (see Table A3–41 for non cattle and Table A3–40 for cattle), 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 A3–42)
EF_4	=	emission factor for N_2O emissions from atmospheric deposition of N on soils and water surfaces, 0.01 kg N_2O N/(kg NH_3-N + NO_x-N volatilized)$^{-1}$ (IPCC 2006)
44/28		coefficient converting N_2O-N to N_2O

Equation A3–31:

$$N_2O_{L(mm)} =$$

$$\sum_i \sum_{AWMS} \left(N_T \times N_{i,\,AWMS} \times N_{EX,T} \times FRAC_{LeachMS(T,AWMS)} \right) \times EF_5 \times \frac{44}{28}$$

where:

$N_2O_{L(mm)}$	=	indirect N_2O emissions due to leaching and runoff from Manure Management, excluding emissions from urine and dung deposited on pasture, range and paddock, kg N_2O/yr
$N_{i,T}$	=	population for livestock category or subcategory, T in province i
$N_{i,AWMS}$	=	percentage of manure N handled by each AWMS in province i, fraction (see Table A3–36)
$N_{EX,T}$	=	N excretion rate for the Tth animal category or subcategory (see Table A3–41 for non cattle and Table A3–40 for cattle), kg N/head/year
$FRAC_{LeachMS(T,AWMS)}$	=	fraction of managed manure N losses for livestock category T due to leaching and runoff during solid and liquid storage of manure, AWMS (see Table A3–42)
EF_5	=	emission factor for N_2O emissions from N leaching and runoff, 0.0075 kg N_2O N/(kg N leaching/runoff)$^{-1}$ (IPCC 2006)
44/28		coefficient converting N_2O-N to N_2O

A3.4.5. N_2O Emissions from Agricultural Soils

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

A3.4.5.1. Direct N_2O Emissions from Agricultural Soils

Direct sources of emissions from agricultural soils include inorganic N fertilizers, organic N fertilizers, urine and dung deposited on pasture by grazing animals, crop residues, mineralization associated with loss of soil organic matter, cultivation of organic soil as well as soil organic matter decay as affected by

conservation tillage practices, summerfallow and irrigation. The N_2O emission factors for most of the direct emission sources are country-specific, and incorporate the influence of moisture regimes, landscape position and soil texture on rates of N_2O production and emissions (Rochette et al. 2008).

The approach involves determining base emission factors "EF_{BASE}" for each of 444 ecodistrict,[16] using long-term precipitation and potential evapotranspiration. The EF_{BASE} is subsequently modified to reflect site-specific practices and conditions. Data on long-term climate normals and topographic characteristics are used to develop an EF_{BASE} (Equation A3–32).

Equation A3–32:

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

where:

EF_{BASE}	=	a weighted average of emission factors for ecodistrict i, taking into account moisture regimes and topographic conditions, kg N_2O-N/kg N/year
EF_{CT}	=	emission factor, estimated at actual P/PE accounting for moisture regime and topography in an ecodistrict, kg N_2O-N/kg N (see Figure A3–9)
$EF_{CT,\,P/PE=1}$	=	emission factor of 0.017 estimated at P/PE = 1, kg N_2O-N/kg N
F_{TOPO}	=	fraction of the ecodistrict area in the lower section of the toposequence See Rochette et al. (2008)
P	=	long-term mean growing season precipitation from May to October in an ecodistrict, mm
PE	=	long-term mean potential evapotranspiration from May to October, mm

Base N_2O Emission Factor (EF_{BASE})

Nitrous oxide is produced mainly during denitrification and, therefore, is 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 A3–9). The EF_{BASE} factors were determined using the same approach as for

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

A3

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 upon 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 soils are imperfectly and poorly drained with mottles[17] within 50 cm of the land surface. MacMillan and Pettapiece (2000) used digital elevation models to characterize the areal extent of upper, mid, lower and depressional portions of the landscape and their associated characteristics (slope and length). Their results were used to determine 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)

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

Figure A3–9 EF_{CT} as a Function of Long-Term Ratio of Precipitation Over Potential Evapotranspiration (P/PE) from 1971 to 2000

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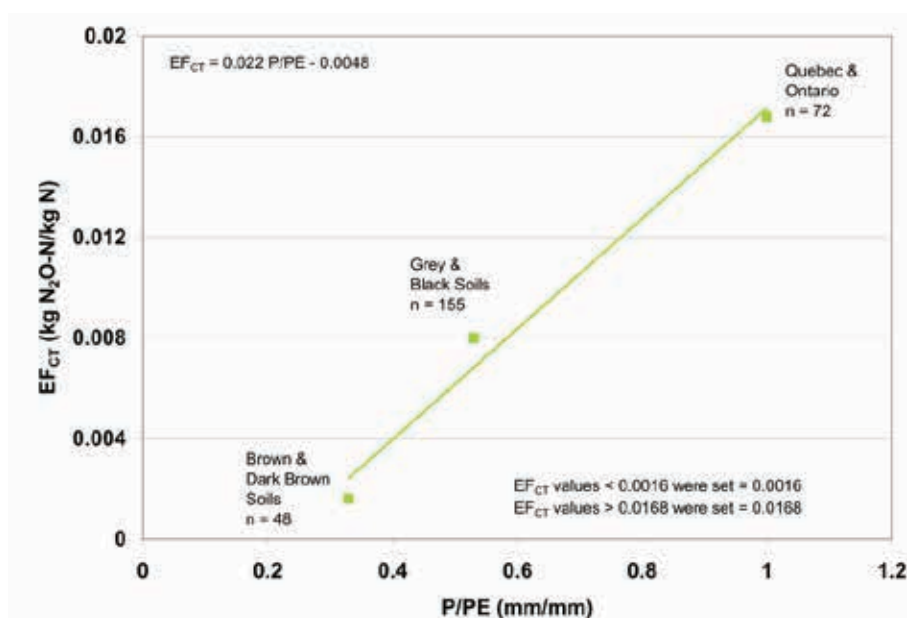
reported mean N_2O emissions during the winter and spring thaws in southern Ontario to be 1.2 kg N_2O-N ha^{-1} (Wagner-Riddle et al. 2007; Wagner-Riddle and Thurtell 1998); these emissions were included in the relationship between EF_{CT} and P/PE shown in Figure A3–9.

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

There are 958 weather stations in the AAFC-archived weather database.[18] These stations (80º00'N–41º55'N, 139º08'W–52º40'W) across Canada (758 stations) and the United States (200 stations) were used to interpolate precipitation and potential evapotranspiration from May to October from 1971 to 2000 to the ecodistrict centroids. Canadian weather data were provided by the Meteorological Service of Canada, Environment Canada.

Soil Texture and N_2O Emissions

Soil texture does not directly influence N_2O production in soils. However, it correlates with several physical and chemical parameters that control N_2O production and transport in the soil profile (Arrouays et al. 2006; da Sylva and Kay 1997; Minasny et al. 1999). Consequently, soil texture-related variables often correlate with N_2O emissions from agricultural soils (Hénault et al. 1998; Corre et al. 1999; Chadwick et al. 1999; Bouwman et al. 2002; 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. A value of 0.8 was assigned to the $RF_{TEXTURE-COARSE}$ 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. Assuming 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 A3–33:

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

where:

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

Organic Nitrogen Fertilizers

Emissions of N_2O from manure N applied as fertilizers include N_2O produced from the application of manure from drylot and solid storage, liquid and other waste management systems on agricultural soils. A country-specific Tier 2 methodology is used for estimating N_2O emissions from organic N fertilizers. The methodology is based on the quantity of manure N produced by domestic animals (see Section A3.4.3.8) and country-specific EF_{BASE} taking into account moisture regime and topographic conditions at the ecodistrict level. Estimates of N_2O emissions from this source are calculated using Equation A3–34.

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

Table A3–42 Total N, NH₃- and NOx-N Losses Associated with Various Livestock and Manure Management Systems

Animal Categories	Manure Management Systems	FRAC$_{(LossMS)}$ (%)[1]	Leaching Loss (%)[3] (FRAC$_{LeachMS}$)	NH₃-N and NOₓ-N Loss (%)[1,2,4] (FRAC$_{GasMS}$)
Dairy Cows	Liquid	40 (15–45)	0	40 (15–45)
	Solid Storage	35 (10–55)	10	25 (10–40)
	Pasture and Range	-	-	20 (5–50)
Non-dairy Cattle	Liquid	40 (15–45)	0	40 (15–45)
	Solid Storage	40 (20–50)	10	30 (20–50)
	Pasture and Range	-	-	20 (5–50)
Swine	Liquid	48 (15–60)	-	48 (15–60)
	Solid Storage	50 (20–70)	5	45 (10–65)
Sheep, Lamb, Llamas and Alpacas	Solid Storage	15 (5–20)	-	12 (5–20)
	Pasture and Range	-	-	20 (5–50)
Goat and Horse	Solid Storage	15 (5–20)	3	12 (5–20)
	Pasture and Range	-		20 (5–50)
Elk and Deer	Solid Storage	15 (5–20)	3	12 (5–20)
Wild Boars	Solid Storage	15 (5–20)	3	12 (5–20)
Foxes	Solid Storage	15 (5–20)	3	12 (5–20)
Mink	Solid Storage	15 (5–20)	3	12 (5–20)
Rabbits	Solid Storage	15 (5–20)	3	12 (5–20)
Poultry	Liquid	50	0	50
	Solid Storage	53 (20–80)	5	48 (10–60)
	Pasture and Range	-	-	20 (5–50)

Notes:

1. Numbers in parentheses indicate a range.
2. Data sources: Hutchings et al. (2001); U.S. EPA (2004); Rotz (2004).
3. Leaching loss is the difference between total loss and volatilized loss.
4. Leaching loss from pasture, range and paddock is reported under indirect N₂O emissions from agricultural soils, and is calculated using the same parameters as manure N spread to agricultural soils.

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Equation A3–34:

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

where:

N₂O$_{MAN}$	=	emissions from manure N applied to cropland as fertilizers, kg N₂O/year
N$_{MAN-CROPS,i}$	=	animal manure applied as N fertilizers on cropland in ecodistrict i, kg N/year
EF$_{BASE,i}$	=	a weighted average emission factor for ecodistrict i, taking into account moisture regimes and topographic conditions, kg N₂O-N/kg N-year
RF$_{TEXTURE,i}$	=	soil texture N₂O ratio factor for ecodistrict i
44/28	=	coefficient converting N₂O-N to N₂O

The amount of animal manure applied as fertilizer at an ecodistrict level was calculated using Equation A3–35. It was assumed that all manure, excluding that deposited on pasture, range and paddock, is applied to cropland soils.

Equation A3–35:

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

where:

N$_{MAN-CROPS,i}$	=	animal manure applied as N fertilizers on cropland in ecodistrict i, kg N/year
N$_T$	=	population for animal category or subcategory T, heads
N$_{EX,T}$	=	N excretion rate for animal category or subcategory (Table A3–40 and Table A3–41), kg N/head/year
N$_{PRP,T}$	=	fraction of manure N on pasture, range and paddock for each animal category or subcategory T in ecodistrict i (see Table A3–36)
FRAC$_{(LossMS,T)}$	=	fraction of manure N losses (volatilization, leaching, etc.) for each animal category or subcategory T excluding pasture, range and paddock in ecodistrict i (Table A3–42)

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Animal population data sources and population accounts 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 at the ecodistrict level is interpolated.

Inorganic Nitrogen Fertilizers

The method for estimating N_2O emissions from inorganic N fertilizer application on agricultural soils takes into account moisture regimes and topographic conditions. Equation A3–36 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 A3–36:

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

where:

N_2O_{SFN}	=	emissions from inorganic N fertilizers, kg N_2O/year
$N_{FERT,i}$	=	inorganic N fertilizer consumption in ecodistrict i, kg N/year; N_{FERT} at an ecodistrict level is estimated using Equation A3–40
$EF_{BASE,i}$	=	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 A3–37) 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 ($N_{MAN-AV,CROPS}$).

Equation A3–37:

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

where:

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

Based on the work of Yang et al. (2007), N_{RCMD} was estimated as the sum of the products of each crop type and the recommended fertilizer application rate for that crop in an ecodistrict (Equation A3–38):

Equation A3–38:

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

where:

$N_{RCMD,i}$	=	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

$N_{MAN-AV,CROPS}$ was calculated as the sum of all manure N from all farm animals (Equation A3–39) in the ecodistrict as follows:

Equation A3–39:

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

where:

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

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

Equation A3–40:

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

where:

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

For years between census years (census years are 1991, 1996, 2001, 2006 and 2011), N_{RCMD} was linearly interpolated to successively estimate annual values of N_{APPLD} and N_{FERT} at the ecodistrict level. The consumption of synthetic N fertilizers in Canada has significantly increased, from 1.2 Mt to 2.5 Mt N, since 1990 mainly because of the intensification of cropping systems (Figure A3–10).

From 1990 to 2002, Agriculture and Agri-Food Canada collected annual fertilizer N consumption data at the provincial level and published *Canadian Fertilizer Consumption, Shipments and Trade*. From 2003 to 2006, fertilizer N data were collected and published by the Canadian Fertilizer Institute.[19] Since 2007, Statistics Canada has collected and published fertilizer sales data annually (Statistics Canada 2014b).

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

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

Canada uses a country-specific method for estimating N_2O emissions from urine and dung deposited on pasture, range and paddock by grazing animals. The N_2O emission factors for all livestock types were determined on the basis of a research project carried out between 2009 and 2011 for dairy cows in eastern Canada and for beef cattle in western Canada. Results from dairy manure in eastern Canada are available in Rochette et al. (2014). Results from beef manure in western Canada are summarized in Table A3–43 (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 ratio of precipitation over 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 A3–33, 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 A3–43). Emissions of N_2O are calculated using a basic fixed emission factor approach (Equation A3–42).

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Figure A3–10   Synthetic Nitrogen Fertilizer Sales in Canada from 1990 to 2013
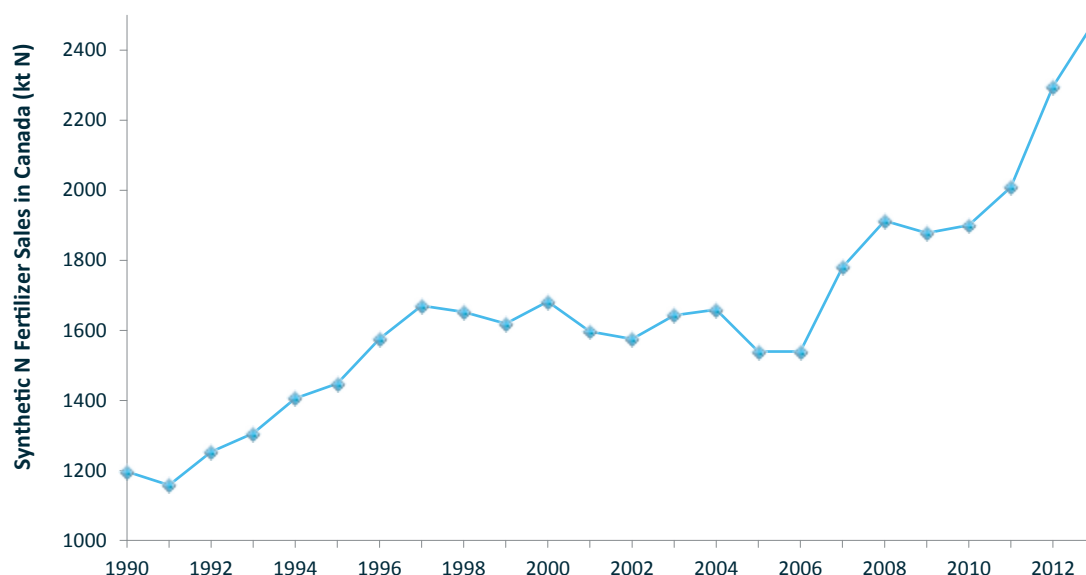
Table A3–43   Emissions of Nitrous Oxide from Beef Urine and Dung on Pasture in Western Canada[1]

Site	Treatment	Flux	Target N Rate	Standard Deviation	Emission Factor
			kg N ha^{-1}		kg N$_2$O-N kg^{-1}N
Swift Current, Saskatchewan	Control	0.07		0.04	
	Dung	0.07	500	0.05	0.000002 ± 0.00003
	Urine	0.79	750	1.56	0.001 ± 0.002
Lacombe, Alberta	Control	0.59		0.33	
	Dung	0.50	500	0.41	0 ± 0.0002
	Urine	0.72	750	0.58	0.0002 ± 0.0003
Overall Mean					
	Dung				0 ± 0.0001
	Urine				0.0006 ± 0.0012

1. Unpublished data (Lemke et al. 2012); urine and dung applied in spring, summer and fall, and repeated one more time along with three replicates, and N$_2$O 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.

Equation A3–41:

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

where:

N$_2$O$_{PRP}$	=	emissions from urine and dung deposited on pasture, range and paddock from grazing animals, kg N$_2$O/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 A3–40 and Table A3–41)
N$_{PRP,T}$	=	fraction of manure N excreted on pasture, range and paddock by animal category or subcategory T (Table A3–36)
EF$_{PRP,i}$	=	emission factor for manure N deposited by animals on pasture, range and paddock in ecodistrict i
44/28	=	coefficient converting N$_2$O-N to N$_2$O

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

Crop Residue Decomposition

The transformation (nitrification and denitrification) of the N released during the decomposition of crop residues result in N$_2$O emissions into the atmosphere. A country-specific Tier 2 methodology similar to that for inorganic and organic N fertilizers is used to estimate N$_2$O emissions from crop residues, based on Equation A3–42, Equation A3–43, and Equation A3–44. The amount of N contained in the above-ground crop residues

subjected to field burning at the provincial level is removed from the emission estimate to avoid double counting (see Section A3.4.7).

Equation A3–42:

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

where:

N$_2$O$_{RES}$	=	emissions from crop residue decomposition, kg N$_2$O/year
N$_{RES,i}$	=	total amount of crop residue N that is returned to the cropland for ecodistrict i, excluding N losses due to residue burning, kg N/year (see Equation A3–43)
EF$_{BASE,i}$	=	a weighted average of emission factors for ecodistrict i, taking into account moisture regimes and topographic conditions, kg N$_2$O-N/ kg N/year
RF$_{TEXTURE,i}$	=	soil texture N$_2$O ratio factor for ecodistrict, i
44/28	=	coefficient converting N$_2$O-N to N$_2$O

Equation A3–43:

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

where:

$N_{RES,i}$	=	total amount of crop residue N that is returned to the cropland for ecodistrict i, excluding N losses due to residue burning, kg N/year
$P_{T,i}$	=	total production of the Tth crop type that is renewed annually in ecodistrict i, kg DM/year (see Equation A3–45)
$FRAC_{RENEW,T,i}$	=	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 A3–44:

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

where:

$P_{T,i}$	=	total production of the Tth 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
$P_{T,p}$	=	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 2014; CANSIM, Table 001-0010). Crops include wheat, barley, corn/maize, oats, rye, mixed grains, flax seed, canola, buckwheat, mustard seed, sunflower seed, canary seeds, fodder corn, sugar beets, tame hay, dry peas, soybean, dry white beans, coloured beans, chick peas and lentils. The area seeded and the yield of each crop are reported at the census agricultural region and provincial levels, and yields have been allocated to Soil Landscapes of Canada (SLC) polygons through area overlays by Agriculture and Agri-Food Canada. Specific parameters for each crop type are listed in Janzen et al. (2003).

Mineralization Associated with Loss of Soil Organic Matter

The amount of nitrogen in mineral soils that is mineralized in association with loss of soil organic matter as a result of changes to land management practices can result in additional N_2O emissions from the Cropland remaining Cropland category. A database containing soil organic carbon and N for all major soils in Saskatchewan (a data set of about 600) was used to derive an average C:N ratio of 11 with a standard deviation of 1.9. No such comprehensive data on C:N ratios for other provinces exist, and the C:N ratio of agricultural soils is considered to be consistent among regions. The 2006 IPCC Guidelines propose a range of C:N ratios from 8 to 15. A country-specific method is used for emission estimates (see Equation A3–45 and Equation A3–46).

Equation A3–45:

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

where:

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

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Equation A3–46:

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

where:

N_2O_{FSOM}	=	emissions associated with loss of soil organic matter due to changes in land management practices, kg N_2O/year
$EF_{BASE,i}$	=	a weighted average of emission factors for ecodistrict i, taking into account moisture regimes and topographic conditions, kg N_2O-N/kg N/year
$RF_{TEXTURE,i}$	=	soil texture N_2O ratio factor for ecodistrict, i
44/28	=	coefficient converting N_2O-N to N_2O

Activity data on soil organic carbon loss at an ecodistrict level from 1990 to 2013 are transferred from the data reported in the LULUCF Cropland remaining Cropland category.

Cultivation of Organic Soils (Histosols)

Cultivation of organic soil (histosols) for annual crop production produces N_2O. The IPCC Tier 1 methodology is used to estimate N_2O emissions from cultivated organic soils (Equation A3–47).

Equation A3–47:

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

where:

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

Areas of cultivated histosols at a provincial level are not collected as part of the *Census of Agriculture*. Consultations with numerous soil and crop specialists across Canada indicate that the total area of cultivated organic soils from 1990 to 2013 in Canada was 16 kha (Liang et al. 2004).

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

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

Field studies in Quebec and Ontario showed that NT practices increased N_2O emissions, whereas on the Prairies the opposite was observed (Gregorich et al. 2005). To quantify the impact of tillage practices on N_2O, a tillage ratio factor (F_{TILL}) defined as the ratio of mean N_2O fluxes on NT or RT to mean N_2O fluxes on IT (N_2O_{NT}/N_2O_{IT}), (Equation A3–49) (Rochette et al. 2008):

Equation A3–48:

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

where:

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

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

N$_2$O 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$_2$O emissions relative to a cropped situation, such as higher soil water content, temperature and available carbon and N. Field studies have shown that N$_2$O 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$_2$O emissions. During a crop year, direct N$_2$O emissions from a given field are summarized as follows:

Equation A3–49:

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

where:

N_2O_{CROP}	=	emissions from a cropped rotation, kg N$_2$O/year
N_2O_{BACK}		the background soil N$_2$O emissions that are not due to crop residue-N, fertilizer-N or manure-N additions
N_2O_{SFN}	=	emissions from inorganic N fertilizers, kg N$_2$O/year
N_2O_{MAN}	=	emissions from organic N fertilizers, kg N$_2$O/year
N_2O_{RES}	=	emissions from crop residue decomposition, kg N$_2$O/year

In the absence of external N inputs, N$_2$O 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 A3–50:

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

where:

N_2O_{FALLOW}	=	emissions due to the effect of summerfallow, kg N$_2$O/year
N_2O_{BACK}	=	background emissions, kg N$_2$O/year

Since N$_2$O emissions are estimated to be equal during fallow and cropped years ($N_2O_{CROP} = N_2O_{FALLOW}$) and assuming that N_2O_{BACK} is the same in cropped and fallow situations, $N_2O_{FALLOW-EFFECT}$ can be empirically estimated as follows:

Equation A3–51:

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

where:

$N_2O_{FALLOW-EFFECT}$	=	Emissions occurring under fallow land.

The N$_2$O emissions due to the practice of summerfallow are therefore calculated for each ecodistrict by applying emissions from N inputs to annual crops (crop residues, fertilizers and manure) to the area of that ecodistrict under summerfallow:

Equation A3–52:

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

where:

$N_2O_{SFN,i}$	=	emissions from inorganic N fertilizers in ecodistrict i, kg N$_2$O
$N_2O_{RES,i}$	=	emissions from crop residue decomposition in ecodistrict i, kg N$_2$O
$N_2O_{MAN,i}$	=	emissions from organic N fertilizers to cropland in ecodistrict i, kg N$_2$O
$FRAC_{FALLOW,i}$	=	fraction of cropland in ecodistrict i that is under summerfallow

A3

Estimates of N_2O_{SFN}, N_2O_{RES} and N_2O_{MAN} at an ecodistrict level are those derived from synthetic N fertilizers, manure N applied as fertilizers and crop residue N. The fraction, $FRAC_{FALLOW}$, is derived from the *Census of Agriculture* for each ecodistrict and is identical to that used in the LULUCF Cropland remaining Cropland category for the summerfallow practice (see Section 3 – Cropland in Annex 3.5). Annual $FRAC_{FALLOW}$ between two consecutive census years is adjusted through interpolation.

N$_2$O Emissions from Irrigation

Higher soil water content under irrigation increases N$_2$O emissions by increasing biological activity and reducing soil aeration (Jambert et al. 1997). Accordingly, highest N$_2$O 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$_2$O 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$_2$O 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$_2$O emissions is in addition to those of the non-irrigated area within an ecodistrict. Consequently, the effect of irrigation on N$_2$O emissions from agricultural soils was accounted for using an EF_{BASE} estimated at a P/PE = 1 (EF_{BASE} = 0.017 N$_2$O-N/kg N) for the irrigated areas of an ecodistrict:

Equation A3–53:

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

where:

N_2O_{IRRI}	=	emissions from irrigation, kg N$_2$O/year
$N_{FERT,i}$	=	inorganic N fertilizer consumption in ecodistrict i, kg N/year
$N_{MAN,CROPS,i}$	=	amount of organic N fertilizers to cropland in ecodistrict i, kg N/year
$N_{RES,i}$	=	amount of crop residue N that is returned to the cropland in ecodistrict i, kg N/year
$EF_{BASE,i}$	=	a weighted average emission factor for ecodistrict i, taking into account moisture regimes and topographic conditions, kg N$_2$O-N/kg N-year for ecodistrict i
$FRAC_{IRRI,i}$	=	fraction of irrigated cropland in ecodistrict i
44/28	=	coefficient converting N$_2$O-N to N$_2$O

The fraction, $FRAC_{IRRI}$, is derived from the *Census of Agriculture* for each ecodistrict (see Section 3 – Cropland in Annex 3.5). Annual $FRAC_{IRRI}$ between two consecutive census years is adjusted through interpolation.

A3.4.5.2. Indirect N$_2$O Emissions from Agricultural Soils

Volatilization and Redeposition of Nitrogen

The IPCC Tier 1 methodology is used to estimate indirect N$_2$O emissions from volatilization and redeposition of fertilizer and manure N. The emission calculation is shown in Equation A3–55.

Equation A3–54:

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

where:

N_2O_{VD}	=	emissions from volatilization and redeposition of N, kg N$_2$O/year
$N_{FERT,i}$	=	inorganic N fertilizer consumption in ecodistrict i, kg N/year
$FRAC_{GASF}$	=	fraction of inorganic fertilizer N applied to soils that volatilizes as NH$_3$- and NO$_x$-N: 0.1 kg (NH$_3$-N + NO$_x$-N)/kg N (IPCC 2006)
$MAN_{PRP,iT}$	=	the amount of manure N excreted on pasture, range and paddock by animal category or subcategory T in an ecodistrict i, kg N/year
$FRAC_{GasMS-PRP,T}$	=	fraction of volatilized manure N deposited on pasture, range and paddock by animal category or subcategory T: 0.2 kg (NH$_3$-N + NOx-N)/kg N (IPCC 2006)
$N_{MAN-CROPS,i}$	=	organic N fertilizers on cropland in ecodistrict i, kg N/year (see Equation A3–35)
$FRAC_{GASM}$	=	fraction of volatilized organic N fertilizers in ecodistrict i: 0.2 kg (NH$_3$-N + NO$_x$-N)/kg N (IPCC 2006)
EF_4	=	emission factor due to volatilization and redeposition: 0.01 kg N$_2$O-N/kg N (IPCC 2006)
44/28	=	coefficient converting N$_2$O-N to N$_2$O

Data sources for estimating N_{FERT} and $N_{MAN-CROPS}$ at an ecodistrict level are provided in the previous sections (Section A3.4.5.1 and Equation A3–39).

Leaching and Runoff

A modified IPCC Tier 1 methodology is used to estimate N_2O emissions from leaching and runoff of inorganic N, organic N and crop residue N from agricultural soils:

Equation A3–55:

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

where:

N_2O_L	=	emissions from leaching and runoff of N, kg N_2O/year
$N_{FERT,i}$	=	inorganic N fertilizers applied for ecodistrict i, kg N
$N_{MAN-CROPS,i}$	=	organic N fertilizers for ecodistrict i, kg N
$MAN_{PRP,i}$	=	urine and dung deposited on pasture, range and paddock for ecodistrict i, kg N
$N_{RES,i}$	=	crop residue N for ecodistrict i, kg N
$FRAC_{LEACH,i}$	=	fraction of N that is lost through leaching and runoff for ecodistrict i, as defined below
EF_5	=	leaching/runoff emission factor: 0.0075 kg N_2O-N/kg N (IPCC 2006)
44/28	=	coefficient converting N_2O-N to N_2O

Determining the Fraction of Nitrogen that is Leached ($FRAC_{LEACH}$) at the Ecodistrict Level in Canada

In Canada, leaching losses of N vary widely among regions. High N inputs in humid conditions may lead to losses greater than 100 kg N/ha-year in some farming systems of southern British Columbia (Paul and Zebarth 1997; Zebarth et al. 1998). Those farming systems, however, represent only a small fraction of Canadian agroecosystems. In Ontario, Goss and Goorahoo (1995) predicted leaching losses of 0~37 kg N ha^{-1}, representing between 0 and 20% of N inputs. Leaching losses in most of the Prairie region may be smaller due to lower precipitation and lower N inputs on an areal basis. Based on a long-term experiment in central Alberta, Nyborg et al. (1995) suggested that leaching losses were minimal,

and Chang and Janzen (1996) found no evidence of N leaching in non-irrigated, heavily manured plots, despite large accumulations of soil nitrate in the soil profile.

The default value for $FRAC_{LEACH}$ in the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/OECD/IEA 1997) was 0.3. The values for $FRAC_{LEACH}$ can be as low as 0.05 in regions where rainfall is much lower than potential evapotranspiration (IPCC 2006), such as in the Prairie region of Canada. Accordingly, it was assumed that $FRAC_{LEACH}$, depending on the ecodistrict, would vary from 0.05 to 0.3.

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 recommended by the Revised 1996 IPCC Guidelines (IPCC/OECD/IEA 1997) of 0.3 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 between 0.23 and 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 A3–11).

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

Long-term normals of monthly precipitation and potential evapotranspiration from May to October, 1971–2000 (AAFC-archived database) were used to calculate $FRAC_{LEACH}$ at an ecodistrict level.

A3.4.6. Uncertainty Estimates of N_2O Emissions

A comprehensive uncertainty analysis was completed for all methodology 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 in a refereed journal, 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 principle emission source categories. For this submission, the uncertainty ranges (percentages) developed for 2010 means were applied to means for 2013. In the analysis, a stochastic reproduction of the complete N_2O emission model was built in Analytica© at the scale of ecodistricts, 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 the greatest amount to different emission source categories.

The parameters used in the calculation of N_2O emissions can be divided into three categories: those associated with information at the ecodistrict scale; provincial-scale data; and IPCC / national-scale parameters (Table A3–44). The majority of national-scale

A3

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), either derived 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 Section A3.4.2.4 and Section A3.4.3.8; the distributions used to define uncertainties can be found in Table A3–31 and Table A3–39. 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 include the analysis of emissions considering the 2006 IPCC Guidelines leaching factor.

The summary of results of the uncertainty analysis on emissions of N_2O is reported in Chapter 5. The uncertainty range for N_2O emissions from agricultural sources is 56% (-27% to +29% of the mean). Most uncertainty is associated with indirect emissions and specifically with the indirect emission factors for volatilized and leached N, with the estimate of indirect emissions uncertainty of 126% (-58% to +68% of the mean). The emissions are skewed to the lower end of the emission probability distribution, because emission factor uncertainty is bounded by zero and emission factor variability is expressed as a factor on the lower scale; a change from 1% to 0.2% has a lower impact on total emissions than a change from 1% to 5% at the upper end of the probability distribution. The uncertainty range of direct N_2O emissions from agricultural soils is 69% (31% to +38% of the mean). There have been few complete studies of uncertainty from emissions of N_2O in the literature. In a study directly comparable to this particular uncertainty analysis, Monni et al. (2007) estimated that total N_2O emissions in Finland ranged between -50% and +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 (UK), 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.

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.

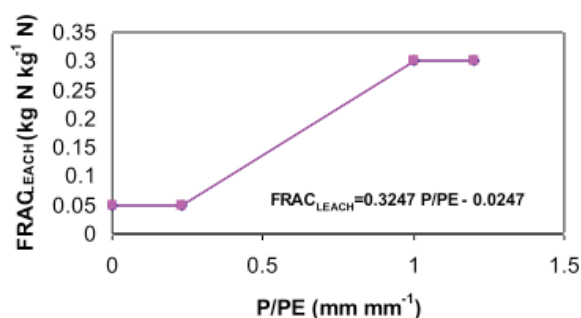**Figure A3–11   Determination of the Ecodistrict FRAC$_{LEACH}$ Values**

Table A3–44   Uncertainty Parameters Used in the Calculation of Agricultural N_2O Emissions

Parameter	Coefficient/ Parameter Source	Distribution Type	Uncertainty Range	Most Likely Value[2]	Uncertainty Distribution Estimate Source and Notes
IPCC and National Scale Parameters					
Animal populations and characterization data[1]					Karimi-Zindashty et al. (2012) from Statistics Canada, personal communication[4]
N excretion	IPCC, 2006 Guidelines	Normal	±50%	IPCC default	
FRAC$_{GAS}$/ FRAC$_{LOSSMS}$	IPCC, 2006 Guidelines	Triangular	IPCC default	IPCC default	See Table 10.22/10.23 IPCC, 2006 Guidelines
AWMS emission factor	IPCC, 2006 Guidelines	Triangular	Liquid 0.0005–0.002 PRP -0.007–0.06	Minimum liquid 0.001 Maximum PRP -0.02	IPCC, 2006 Guidelines,[4] variable depending on the manure storage type
Crop characteristics					
H_2O content	Rochette et al. 2008, factors are drawn from common usage in AAFC[2] literature and modelling studies.	Normal	±15%		Expert Opinion
Relative DM allocation of residue (product, above ground and below ground)	Rochette et al. 2008, factors are drawn from common usage in AAFC[2] literature and modelling studies.	Normal	±15%		Expert Opinion
FRAC$_{Renew}$ (duration)	Rochette et al. 2008, factors are drawn from common usage in AAFC[2] literature and modelling studies.	Normal	±15%		Expert Opinion
N concentration in residue (aboveground and below-ground)	Rochette et al. 2008, factors are drawn from common usage in AAFC[2] literature and modelling studies.	Normal	±15%		Expert Opinion
Direct and indirect emission factors/modifiers					
P/PE regression parameters	Rochette et al. 2008	Normal	Intercept +/- 54% Slope +/- 21%		Analysis of raw research data, consultation with study authors
FRAC$_{LEACH}$ calculation parameters	Rochette et al. 2008	Normal	Intercept +/- 54% Slope +/- 21%		Analysis of raw research data, consultation with study authors
F$_{TILL}$	Rochette et al. 2008	Normal	±100%		Analysis of raw research data, consultation with study authors
RF$_{TEXTURE}$	Rochette et al. 2008	Normal	±30%		Analysis of raw research data, consultation with study authors
EF$_{LEACH}$	IPCC, 2006 Guidelines	Triangular	0.002–0.12	0.025	IPCC, 2006 Guidelines
EF$_{VD}$	IPCC, 2006 Guidelines	Triangular	0.002–0.05	0.01	IPCC, 2006 Guidelines
EF$_{HIST}$	IPCC, 2006 Guidelines	Triangular	2–24	8	IPCC, 2006 Guidelines
Provincial–Scale Parameters					
Fertilizer application rate (kg/ha)	Factors are drawn from common usage in AAFC[3] literature and modelling studies.	Normal	±15%		Expert Opinion
Provincial fertilizer sales	Statistics Canada	Normal	±15%		Interpretation of data quality evaluation in Statistic Canada Report
Ecodistrict–Scale Parameters					
P and PE	Weather Station Data	Normal	5–15%		Based on individual weather station data, 30-year average
Total ecodistrict area	AAFC[3], Geographically referenced soil landscape agricultural database, derived from Census of Agriculture, 1991-2011	Normal		Function of Relative Ecodistrict Size: Maximum uncertainty of 30% for small ecodistricts, decreases to minimum of 3% for largest ecodistricts, maximums and minimums vary depending on the parameter.	Based on the uncertainty methodology used in the carbon quantification methodology for croplands.
Crop areas	AAFC[3], Geographically referenced soil landscape agricultural database, derived from Census of Agriculture, 1991-2011	Normal		Function of Relative Ecodistrict Size: Maximum uncertainty of 30% for small ecodistricts, decreases to minimum of 3% for largest ecodistricts, maximums and minimums vary depending on the parameter.	Based on the uncertainty methodology used in the carbon quantification methodology for croplands.
Animal population distribution to ecodistrict	AAFC[3], Geographically referenced soil landscape agricultural database, derived from Census of Agriculture, 1991-2011	Normal		Function of Relative Ecodistrict Size: Maximum uncertainty of 30% for small ecodistricts, decreases to minimum of 3% for largest ecodistricts, maximums and minimums vary depending on the parameter.	Based on the uncertainty methodology used in the carbon quantification methodology for croplands.
F$_{TOPO}$ (proportion of lowland soils in ecodistrict)	AAFC[3], Geographically referenced soil landscape agricultural database, derived from Census of Agriculture, 1991-2011	Normal		Function of Relative Ecodistrict Size: Maximum uncertainty of 30% for small ecodistricts, decreases to minimum of 3% for largest ecodistricts, maximums and minimums vary depending on the parameter.	Based on the uncertainty methodology used in the carbon quantification methodology for croplands.

A3

Table A3–44   Uncertainty Parameters Used in the Calculation of Agricultural N$_2$O Emissions (cont'd)

Parameter	Coefficient/ Parameter Source	Distribution Type	Uncertainty Range	Most Likely Value[1]	Uncertainty Distribution Estimate Source and Notes
Extent of organic soils	AAFC[3], Geographically referenced soil landscape agricultural database, derived from Census of Agriculture, 1991-2011	Normal		Function of Relative Ecodistrict Size: Maximum uncertainty of 30% for small ecodistricts, decreases to minimum of 3% for largest ecodistricts, maximums and minimums vary depending on the parameter.	Based on the uncertainty methodology used in the carbon quantification methodology for croplands.
Irrigated soil area	AAFC[3], Geographically referenced soil landscape agricultural database, derived from Census of Agriculture, 1991-2011	Normal		Function of Relative Ecodistrict Size: Maximum uncertainty of 30% for small ecodistricts, decreases to minimum of 3% for largest ecodistricts, maximums and minimums vary depending on the parameter.	Based on the uncertainty methodology used in the carbon quantification methodology for croplands.
Soil texture	AAFC[3], Geographically referenced soil landscape agricultural database, derived from Census of Agriculture, 1991-2011	Normal		Function of Relative Ecodistrict Size: Maximum uncertainty of 30% for small ecodistricts, decreases to minimum of 3% for largest ecodistricts, maximums and minimums vary depending on the parameter.	Based on the uncertainty methodology used in the carbon quantification methodology for croplands.

1 Uncertainty associated with most livestock parameters can be found in Section A3.3.3.3 and Section A3.3.4.8, and the distributions used to define uncertainties can be found in Table A3-8 and Table A3-16.

2 Reported where applicable when using a triangular distribution.

3 Agriculture and Agri-Food Canada.

A3.4.7.   CH$_4$ and N$_2$O Emissions from Field Burning of Agricultural Residues

Crop residues are sometimes burned in Canada, as a matter of convenience and disease control through residue removals, even though 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$_2$O. The quantity of crop residue burning in Canada can be estimated as follows:

Equation A3–56:

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

where:

Q_{BURN}	=	quantity of crop residue burned from crop T for each province, Mg dry matter/year
$PRODUCTION_T$	=	total production of crop T, Mg/year
$MOISTURE_T$	=	moisture content of the product from crop T, fraction
$RatioAR/P_T$	=	ratio of above-ground crop residue to the crop product for crop T, unitless
PCB_T	=	percent of crop residue that is subject to field burning for crop T, fraction
$RATIO_{SCALE}$	=	a scaling factor or an intensity factor adjusted for burning in 2006, unitless

Data in 2001 and 2006 by Statistics Canada collected through its Farm Environmental Management Survey (FEMS)[20] include crop residue burning. The type of crop and the extent of crop residue burning for each province were only available for 2006; these data were collected in FEMS and are summarized in Table A3–45. To establish a complete time series of activity data, additional information on crop residue burning for 1991 and 1996 has been gathered through expert consultations (Coote et al. 2008). Thus, the crop that was subject to field burning in 2006 was also assumed for the entire time series.

The intensity of the crop residue burning in each province for 1991, 1996, and 2001 was adjusted as a ratio based on the average burning for 2006. Basic characteristics of crops, such as moisture content of crop product and ratio of above-ground crop residue to crop product, are reported by Janzen et al. (2003). Annual production of each crop subject to residue burning is available (Statistics Canada 2011; Catalogue No. 22-002). Other parameters, such as fraction of biomass actually burned, and emission factors required for emission estimates were obtained from the 2006 IPCC Guidelines.

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

Table A3–45   Burning of Crop Residues by Crop Types in 2006 (FEMS 2006)

	Spring wheat	Winter wheat	Oats	Barley	Mixed grains	Flaxseed	Canola
	% Crop Residue Burned (by Weight)						
Newfoundland and Labrador	0	0	0	0	0	0	0
Prince Edward Island	3	0	0	1	0	0	0
Nova Scotia	33	0	0	0	0	0	0
New Brunswick	0	0	1	0	0	0	0
Quebec	0	0	1	0	0	0	0
Ontario	0	0	0	1	2	0	0
Manitoba	2	3	3	1	0	17	1
Saskatchewan	0	0	0	0	0	15	1
Alberta	0	0	0	0	0	8	0
British Columbia	0	0	0	0	0	0	0

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

Equation A3–57:

$$EMISSION_{BURN} = \sum_{Province,i} \left(Q_{BURN,i} \times C_F \times G_{EF} \right) /1000$$

where:

$EMISSION_{BURN}$	=	emissions of N_2O or CH_4 from the burning of crop residues for Canada (kt N_2O or CH_4)
Q_{BURNi}	=	quantity of crop residue burned from province i, Mg, dry matter/year
C_F	=	fuel efficiency (IPCC 2006), unitless
G_{EF}	=	emission factor (IPCC 2006), g N_2O or CH_4 kg^{-1} of dry matter burned
1000	=	converting Mg to kt

Table A3–46   Crop Residue Burning by Province in Canada for 1991, 1996, 2001 and 2006

	1991	1996	2001	2006
	% of Crop Residue Burned (by Weight)			
Newfoundland and Labrador	0	0	0	0
Prince Edward Island	0.4	0.4	0.4	0.4
Nova Scotia	0.5	0.5	0.5	0.5
New Brunswick	0.5	0.5	0.5	0.5
Quebec	0.4	0.4	0.4	0.3
Ontario	0.7	0.7	0.7	0.3
Manitoba	12.6	10.1	8.9	2.3
Saskatchewan	8.1	5.8	3.9	1.5
Alberta	0.8	0.7	0.2	0.2
British Columbia	0	0	0	0

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

A3.4.8. CO$_2$ Emissions from Liming and Urea Fertilization

A3.4.8.1. CO$_2$ Emissions from Liming

With the implementation of the 2006 IPCC Guidelines, the reporting of limestone emissions has been transferred from the Cropland remaining Cropland category of LULUCF to the Agriculture Sector. Limestone ($CaCO_3$) is often used to neutralize acidic soils, increase the availability of soil nutrients, in particular phosphorus, reduce the toxicity of heavy metals, and improve the crop growth 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 the 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 A3–58:

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

where:

CO_2-C Emission	=	annual C emissions from lime application, Mg C/year
$M_{Limestone,i}$	=	annual amount of limestone consumption in province i, Mg/year
$EF_{Limestone}$	=	0.12, emission factor (IPCC 2006)

The quantity of lime used for agricultural purposes is not collected through the Census of Agriculture by Statistics Canada, but rather through Natural Resources Canada's Canadian Minerals Yearbook (1990 to 2006). For more recent years, this information is only available on request[21]. This new data source provides a more consistent and complete time series of activity data on agricultural lime consumption in Canada. The previous data were obtained through consultations with the Canadian Fertilizer Institute.

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, uncertainty of when lime sold is actually applied, and 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 fertilizers are applied to a soil to augment crop production, CO_2 is released upon the hydrolysis as follows:

$$(NH_2)_2CO + H_2O \rightarrow NH_4^+ + OH^- + CO_2$$
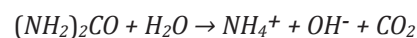
In addition to urea, Canadian farmers also use significant amounts of urea ammonium nitrate (28-0-0) with a mixture of 30% $CO(NH_2)_2$. CO_2 emissions from urea fertilization can be estimated using Equation A3–60:

Equation A3–59:

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

where:

CO_2-C Emission	=	annual C emissions from urea application, Mg C/year
$M_{Urea,i}$	=	annual amount of urea fertilization, Mg/year
EF_{Urea}	=	0.20, emission factor (IPCC 2006)

Statistics Canada collects and publishes fertilizer sales data including urea and urea ammonium nitrate annually (Statistics Canada 2014b).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.

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21   D. Panagapko, Natural Resources Canada, personal communication

A3.5. Methodology for the Land Use, Land-use Change and Forestry Sector

The Land Use, Land-use Change and Forestry (LULUCF) Sector of the inventory includes estimates of greenhouse gas (GHG) emissions and removals associated with managed lands and with the conversion of land from one category to another.

As in Chapter 6, the structure of this annex attempts to maintain the land-based reporting categories, while grouping related data collection and estimate development methodologies. Section A3.5.1 summarizes the spatial framework for estimate development and area reconciliation. The general approach for estimating carbon stock changes, emissions and removals in all forest-related categories, including Forest Land, Forest Land converted to Other Lands and Lands converted to Forest Land, is briefly described in Section A3.5.2; this description is not repeated under the Forest Land converted to Cropland, Grassland, Wetlands and Settlements categories. Section A3.5.3 describes methods to quantify the effect of management practices on agricultural land for the Cropland category. Likewise, the sections on Grassland (A3.5.4), Wetlands (A3.5.5) and Settlements (A3.5.6) focus on category-specific estimation methodologies. Finally, the approach to estimate the emissions associated with the use and disposal of Harvested Wood Products (HWP) from wood harvested in Canada is described in Section A3.5.7.

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. Important differences exist in the spatial framework specific to each land category, with the risk that activity data and estimates become 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 the GHG inventory.

At the finest level of spatial resolution are analysis units, which 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 634 analysis units across 12 provinces and territories (Table A3–47). Changes in the number of spatial analy-

Table A3–47 Spatial Analysis Units of Managed Forests

Province/Territory	Number of Analysis Units
Alberta	181
British Columbia	92
Manitoba	70
New Brunswick	1
Newfoundland and Labrador	24
Northwest Territories	30
Nova Scotia	1
Nunavut	0
Ontario	52
Prince Edward Island	1
Quebec	129
Saskatchewan	40
Yukon	13
Canada	**634**

sis units may occur from one submission to the next and reflect refinements in the integration of multiple spatial layers. For example, the modifications 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 agricultural lands (Cropland category) is the National Soil Database of the Canadian Soil Information System[22] and its underlying Soil Landscapes of Canada (SLC). The full array of attributes that describe a distinct type of soil and its associated landscapes, such as surface form, slope, typical soil carbon content under native and dominant agricultural land use, and water table depth, is called a soil landscape. Soil landscapes are spatially associated with SLC polygons (the analysis units), that may contain one or more distinct soil landscape components. The SLC polygons are in the order of 1000 to 1 000 000 hectares (ha) in area and are appropriate for mapping at the scale of 1:1 million.

SLC polygons are also the basic units of Canada's National Ecological Framework, a hierarchical, spatially consistent national context within which ecosystems at various levels of generalization can be described, monitored and reported on (Marshall and Schut 1999). The 12 353 SLC polygons are nested in the next level of generalization (1021 ecodistricts), which are further grouped into 218 ecoregions and 15 ecozones.

Analysis units for estimating the areas of forest converted to other uses are the result of the spatial intersection of forest conversion strata (see Figure A3–16) with ecological and administrative boundaries. Forest conversion strata were developed on the basis

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

Table A3–48   Estimates of Land, Water, Managed Forest and Cropland Areas in 2013

Reporting Zone Number and Name		Areas (Kha)[1]				
		Total	Total Land	Total Fresh Water	Managed Forest	Cropland
1	Arctic Cordillera	24 300	24 000	286		
2	Northern Arctic	151 000	142 000	8 610		
3	Southern Arctic	84 600	74 600	10 000		
4	Taiga Shield East	74 800	65 700	9 170	1 100	
5	Boreal Shield East	111 000	99 100	11 900	55 600	722
6	Atlantic Maritime	20 900	19 700	1 200	15 400	1 180
7	Mixedwood Plains	16 800	11 000	5 770	2 670	5 910
8	Hudson Plains	37 400	36 400	977	302	
9	Boreal Shield West	84 000	71 100	12 800	28 800	194
10	Boreal Plains	73 600	67 200	6 430	37 800	9 490
11	Subhumid Prairies	22 300	21 600	742	1 790	17 200
12	Semiarid Prairies	24 000	23 500	473	40	14 900
13	Taiga Plains	65 800	58 200	7 590	20 500	7
14	Montane Cordillera	48 500	47 200	1 240	35 500	528
15	Pacific Maritime	20 800	20 500	322	13 200	84
16	Boreal Cordillera	46 800	45 800	944	16 600	C[2]
17	Taiga Cordillera	26 500	26 400	157	412	
18	Taiga Shield West	63 200	52 200	11 000	1 830	

Notes:

1. Totals may not add up due to rounding. Annex 8 describes the rounding protocol.

2. Small area associated with forest conversion to cropland considered confidential due to Statistics Canada confidentiality restrictions under the Statistics Act. Therefore this area has been added to the neighbour RZ14 (Montane Cordillera).

C = Confidential

of expected conversion rates and characteristics. The sampling approach used to monitor forest conversion requires that analysis units 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 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, with three exceptions: the Boreal Shield and Taiga Shield ecozones are split into their east and west components to form four reporting zones; and the Prairies ecozone is divided into a semi-arid and a subhumid component. These subdivisions do not alter the hierarchical nature of the spatial framework. Table A3–48 provides the land and water areas of each reporting zone, as well as the estimated area of managed forest and cropland for the 2013 inventory year. Methods and data sources used for developing this information are described in McGovern (2014).

The analysis units of different land-use categories often overlap. Furthermore, the exact location of events, stands or activities 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 levels of analysis units during estimate development and of RUs during estimate compilation.

A3.5.2.   Forest Land and Forest-related Land-use Change

A3.5.2.1.   Carbon Modelling

The estimation of carbon stock changes, emissions from and removals by managed forests, forest conversion to other land uses, and land converted to forests was 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 (forest age, area and species composition), libraries of merchantable volume over age curves, equations to convert stand merchantable volume into total biomass, data on natural and anthropogenic disturbances, and simulations of carbon transfers between pools and with the atmosphere that are associated with ecosystem processes and various events.

Table A3–49   Forest Carbon Pools in IPCC and CBM-CFS3

IPCC Carbon Pools		Pool Names in CBM-CFS3
Living Biomass	Above-ground biomass	Merchantable stemwood Other (submerchantable stemwood, tops, branches, stumps, non-merchantable trees) Foliage
	Below-ground biomass	Fine roots
		Coarse roots
Dead Organic Matter (DOM)	Dead wood	Above-ground fast
		Below-ground fast
		Medium
		Softwood stem snag
		Softwood branch snag
		Hardwood stem snag
		Hardwood branch snag
	Litter	Above-ground very fast
		Above-ground slow
Soils	Soil organic matter	Below-ground very fast[1]
		Below-ground slow
		Black carbon[2]
		Peat[2]

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

The ecosystem processes (or "annual processes") modelled by the CBM-CFS3 to generate the estimates submitted in this report are growth, litter fall, 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 commercial thinning, clear-cutting, partial cutting, salvage cutting[23] and the burning of harvest residues during site preparation or for fire risk management. Different practices of forest conversion are also simulated, including controlled burning.

The forest carbon pools represented in the CBM-CFS3 can be matched to the Intergovernmental Panel on Climate Change (IPCC) forest carbon pools (Table A3–49). Although not shown here, living biomass pools are further subdivided into two sets, for each of hardwood and softwood tree species.

Annual processes and events trigger arrays of carbon transfers between pools as shown in Figure A3–12.

Annual ecosystem processes comprise growth, litter fall, mortality and decomposition and are simulated as carbon transfers executed at each time step (annually) in every inventory record. During annual processes, carbon is taken up in the biomass pool and some biomass carbon is transferred to dead organic matter (DOM) pools. The decay of DOM carbon results in its transfer to

another DOM pool (e.g. stem snags to medium deadwood pool), to a slow soil pool or to the atmosphere. More information on pool structure and decay rates is provided in Kurz et al. (2009). Rates of carbon transfer are defined for each pool, based on pool-specific turnover rates (for biomass pools) or decay rates (DOM and soil pools). Turnover rates can be 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 Q10 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. Every record in the forest inventory used in each of the 634 analysis units is associated with a yield curve that defines the dynamics of merchantable volume over time. Assignment of an inventory record to the appropriate curve is based on a classifier set that includes province, ecological stratum, leading species, site productivity class and several other classifiers that differ between provinces and territories. Curve libraries for each province and territory in Canada are derived from permanent or temporary sample plots or from forest inventory information.

Conversion of merchantable volume curves to above-ground biomass curves is performed with a set of equations developed for Canada's National Forest Inventory (Boudewyn et al. 2007). These equations derive the above-ground biomass of each stand component from merchantable stemwood volume (per ha), for

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23   Salvage cutting (or "salvage logging") is the removal of merchantable timber left after a natural disturbance. Whenever possible, salvage logging is distinguished from conventional harvesting operations.

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.

Disturbances trigger different combinations of carbon transfers, 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 defined in a disturbance matrix, which specifies for one or more disturbance types the proportion of carbon in each ecosystem pool that is transferred to other pools, released to the atmosphere (in different GHGs) or transferred to Harvested Wood Products. Figure A3–13 illustrates one such matrix, simulating clear-cut harvesting and salvage logging, which is applicable in all ecozones except those in Alberta and Quebec. In the 2015 submission, the simulation uses a total of 119 disturbance matrices to simulate the impact of disturbances. The number of different disturbance matrices is dependent on the availability of activity data (e.g. the spatial and temporal resolution of data sources used to document disturbances) and on the knowledge required to parameterize the matrices for more distinct regions or intensities of disturbance in place of more generically developed parameter sets.

The proportion of CO_2-C emitted from each pool, 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 distur-

bances of a given type, such as fires. With a few exceptions, the proportion of total carbon emitted in each carboncontaining GHG (CO_2, CO, and CH_4) due to fire is constant: 90% of carbon is emitted as CO_2, 9% as CO and 1% as CH_4 (Cofer et al. 1998; Kasischke and Bruhwiler 2003).

While the CBM-CFS3 can model carbon fluxes at various spatial scales, generating national estimates involves harmonizing, integrating and ingesting vast quantities of data from a great diversity of sources. The next section documents the key data sources used for this submission.

A3.5.2.2. Data Sources

Managed Forest Land

The Canadian provincial and territorial governments, whose jurisdiction includes natural resource management, provided essential information—notably detailed forest inventory data and, when available, details on forest management activities and practices, disturbances and disturbance prevention or control, regional yield tables (volume/age curve) for dominant tree species, and site indices—as well as regional expertise (Table A3–50). 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. Considerable efforts were necessary to harmonize, format

Figure A3–12   Carbon Pools and Transfers Simulated by the CBM-CFS3
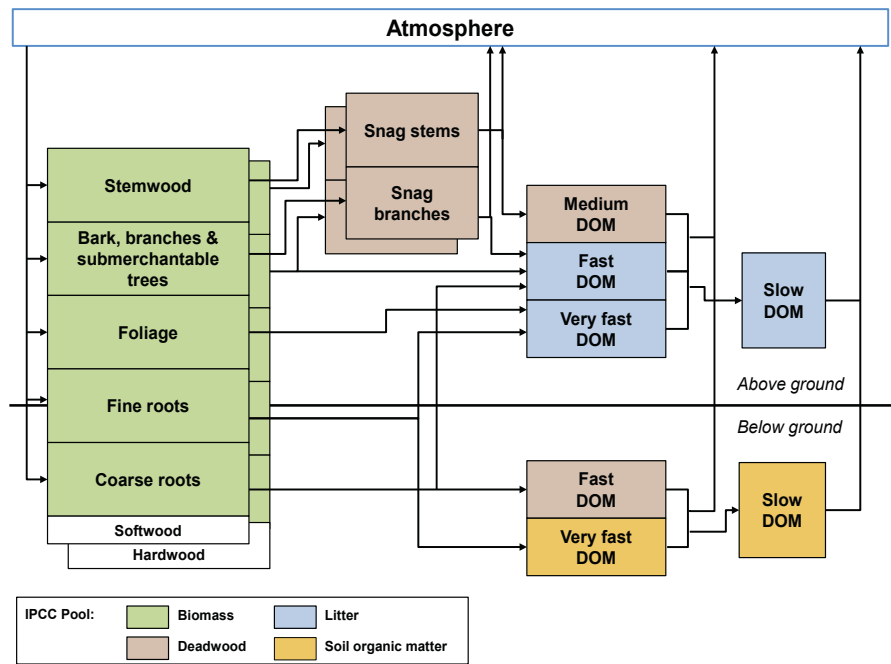
Source: White et al. (2008), updated

Figure A3–13   Disturbance Matrix Simulating the Carbon Transfers Associated with Clearcut Harvesting and Salvage Logging

	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	

Figure A3–14   Decision Tree for the Determination of Managed Forest Area

Is the forest area managed for timber or non-timber forest resources?

No → Is the forest area under intensive protection against natural disturbances?

Yes → Classify the forest area as "managed forest"

Yes → Classify the forest area as "managed forest"
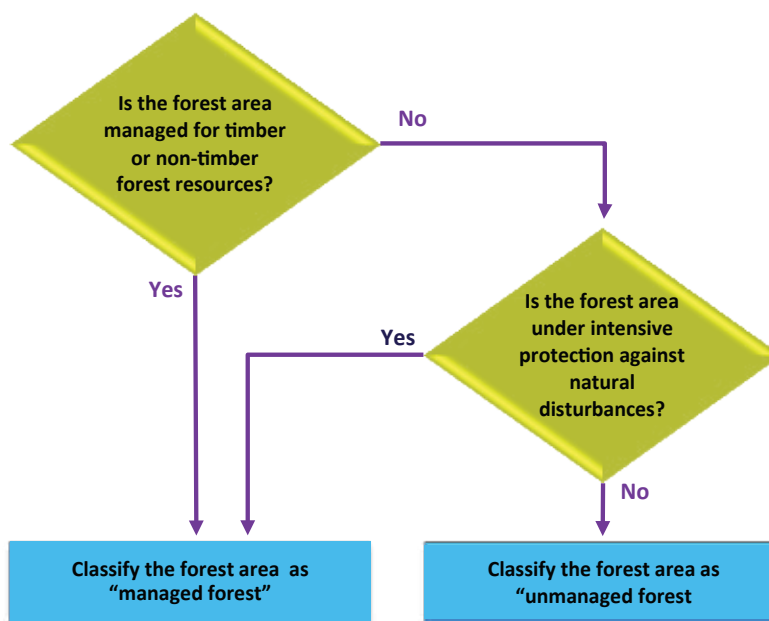
No → Classify the forest area as "unmanaged forest"

Table A3–50   Main Sources of Information and Data, Managed Forests

Description	Source	Spatial Resolution	Temporal Coverage	Reference
Fire data	National Burned Area Composite	Spatially explicit	2004–2013	http://www.nrcan.gc.ca/node/13159
	Canadian National Fire Database	Spatially referenced	1959–2003	http://www.nrcan.gc.ca/node/13159
Forest inventories & merchantable volume data[1]	Canada's National Forest Inventory (CanFI)	CanFI grid cell	1949–2004	https://nfi.nfis.org/index.php
	Alberta[2]	Analysis units	1949–1999	Provincial experts
	British Columbia	Analysis units	1995–2000	Provincial experts
	Newfoundland	Analysis units	1991–2006	Provincial experts
	Nova Scotia	Analysis units	2006	Provincial experts
	Ontario	Analysis units	2000	Provincial experts
	Prince Edward Island	Analysis units	2000	Provincial experts
	Quebec	Analysis units	2000	Provincial experts
Harvest data[3]	National Forestry Database	Provincial boundaries	1990–2013	http://nfdp.ccfm.org/
	National Forestry Database	Analysis units	1990–2013	http://nfdp.ccfm.org/
Insect data	Forest Insect and Disease Survey	Spatially explicit	1990–2009	Atlantic Forestry Centre and Pacific Forestry Centre
	Alberta	Spatially explicit	1990–2012	Provincial experts
	British Columbia	Spatially explicit	1990–2013	Provincial experts
	Saskatchewan	Spatially explicit	1998–2001	Provincial experts
	Manitoba	Spatially explicit	1990–1998	Provincial experts
	Newfoundland	Spatially explicit	2000–2003	Provincial experts
	Yukon	Spatially explicit	1994–2005	Provincial experts
Climate data	CFS	Analysis units	1961–1990 normals	McKenney (2005)

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

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

3. Given the absence of complete harvest data for the most recent reporting year for all provinces and territories besides Quebec, 2013 harvest data are estimated by assuming them to be equal to 2012 values.

and compile the detailed inventory information into input data for the CBM-CFS3. A series of "methods papers" describe the compilation process for each provincial and territorial forest inventory. Since forest inventory data were not collected in the same years, additional steps were necessary to synchronize the inventory data to the year 1990 (Stinson et al. 2006a).

Conceptually, 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 A3–14). The estimation of the managed forest area required the spatial delineation and combination of boundaries of many different forest areas, including all operational forest management units, timber supply areas, tree farm licences, industrial freehold timberland, private woodlots and any other land in the Forest category where there is active management for timber or non-timber resources, as well as forest areas where there is intensive protection against natural disturbances. All these layers are aggregated and intersected with underlying forest inventory data. The procedures are documented in Stinson et al. (2006b). Figure A3–15 illustrates the location of lands with managed and unmanaged forests in Canada, for the purpose of GHG estimation and reporting. In 2013, the total area of managed forests was 232 Mha, of which 68% lie in four reporting zones: Boreal Shield East, Montane Cordillera, Boreal Plains and Boreal Shield West (see Table A3–48). The managed forest area represents 67% of the total forest area in Canada.

Forest management activities are documented in the National Forestry Database;[24] additional information on specific activities is obtained directly from provincial and territorial forest management agencies.

Historical data on 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) product for the years

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

2004 to 2013 (Table A3–50). The NBAC is a composite of low- and medium-resolution remote sensing data and fire mapping data, provided by resource management agencies from across Canada, that provides complete mapping of wildfires using the best available data sources. Medium-resolution remote sensing data are used where these are available; data from resource management agencies are given second priority; and lowresolution remote sensing data are only used where no other fire mapping data are available.

Insect disturbances are monitored by aerial surveys (Table A3–50), 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 the severity of the impact is reflected in the parameters of the disturbance matrix applied (Kurz et al. 2009).

Forest Conversion

In order to account for the long residual effects of forest conversion, conversion rates were estimated starting in 1970. The approach for estimating forest areas converted to other uses is based on three main information sources: systematic or representative sampling of remote sensing imagery, records and expert judgement/opinion. The basic methods have been tested in several pilot projects (Leckie 2006a), and the methodology has now been implemented across the country.

The core method involves remote sensing mapping of forest conversion on samples from Landsat images dated circa 1975, 1990, 2000 and 2008. 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 if the land cover of the candidate event was forest initially (at Time 1) and actual land-use change at Time 2 (Leckie et al. 2002, 2010a). This forest conversion interpretation process is strongly supported by additional spatial data, including digitized aerial photographs; snow-covered, leaf-off, winter Landsat imagery; secondary Landsat images from other dates and years; ancillary data, such as maps of road networks, settlements, wetlands, woodland coverage and mine and gravel pit locations; and specialized databases giving locations of oil and gas pipelines and well pads (Leckie et al. 2006). 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 broad forest type prior to forest conversion is interpreted,[25] and the post-deforestation land use recorded ("post-class"). Confidence ratings on the land use at the initial time and a later time period are used in subsequent quality control and field validation procedures.

Monitoring of forest conversion activity covers all forest areas of Canada, and is not limited to the managed forest. The entire forested area of Canada is broadly stratified into regions of expected forest conversion level and dominant cause, which dictate the target sampling intensity. Depending on the expected spatial patterns and rates of forest conversion, sampling approaches range

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

Figure A3–15   Lands with Managed and Unmanaged Forests in Canada
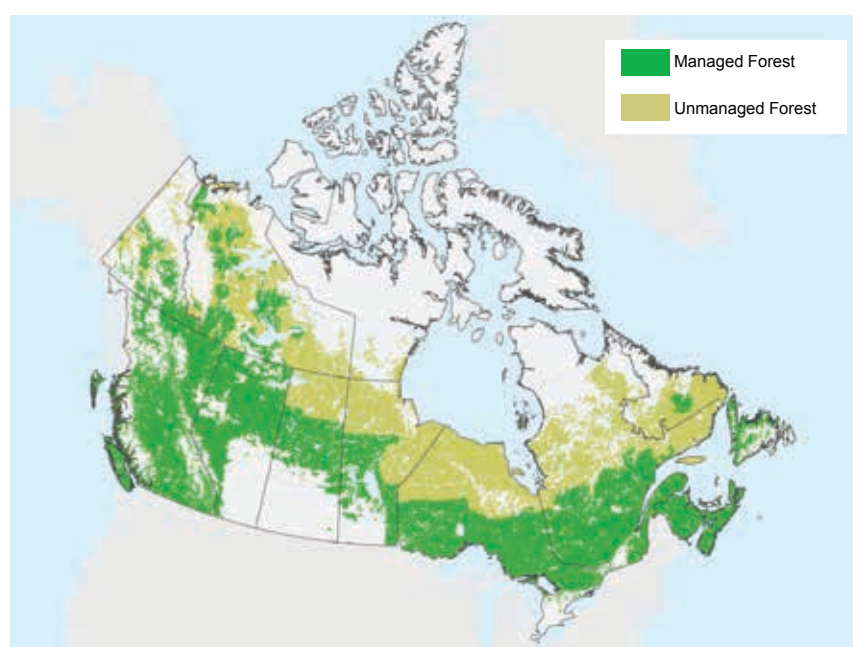
from complete mapping, to systematic sampling over the entire analysis unit of interest, to a representative selection of sample cells within a systematic grid. For example, in populated areas of southern Quebec and in the Prairie fringe, a 12% sampling rate was generally achieved, with 3.5 × 3.5-km sample cells at the nodes of a 10 x 10-km grid (Figure A3–17). 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 A3–16) approximately 346 million hectares (Mha), of which over 17 Mha were mapped for 1975–1990, 41 Mha were mapped for 1990–2000, and 22 Mha were mapped for 2000–2008.

Representative samples are used in areas of moderate expected rates of forest conversion (e.g. eastern woodlots in the Maritimes, the Eastern Townships in Quebec, the Lower Mainland of British Columbia, and the south agricultural zone of the Prairies). The forest activity region comprises a large area of Canada with a low population density; the main economic activities consist of forestry and other resource extraction. Again, a representative sampling approach is used, augmented with additional samples (e.g. pilot studies) in Quebec, Ontario and British Columbia. Special cases of known, localized and large forest conversion activities were 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 A3–16), with spatially complete mapping.

Records were gathered when available. They consist mostly of information on forest roads, power lines, oil and gas infra-

structure, and hydroelectric reservoirs (Leckie et al. 2006). The temporal coverage, availability and applicability of these records are assessed to determine the most appropriate information sources (records or imagery). Records data are sometimes used to aid in the validation of estimates made through image interpretation. In particular for British Columbia, records data are used to provide estimates of conversion activity for power lines and oil and gas activity. In northern Quebec, a mix of remote sensing image interpretation and records data are used to assess the areas of forest converted as a result of hydroelectric development. If the extent of forests affected by land submersion cannot be determined through official records or image interpretation, it is estimated by multiplying the area of land flooded by the proportion of forest cover in the region surrounding the reservoir, as determined by a Landsat image classification forest cover map (Wulder et al. 2004).

Work with high-resolution imagery has revealed that, although records information may indicate that pipeline right-of-ways are less than 20 metres (m) wide, they are often adjacent to co-disturbance events such as access roads. The resulting total disturbance width is greater than 20 m. As a result of this analysis, pipeline records are used in combination with high-resolution sampling to determine the actual impact of pipelines.

Expert opinion is only called upon when remote sensing sampling is insufficient and records data are unavailable or of poor quality. Expert judgement is also used to reconcile differences between records and remote sensing information and to resolve large discrepancies in the 1975–1990, 1990–2000 and 2000–2008 area estimates. In such cases, available expert opinion and data sources are brought together, remote sensing and records data are reviewed, and decisions are made (Leckie 2006b; Leckie et al.

**Figure A3–16   Forest Conversion Strata and Areas Sampled**
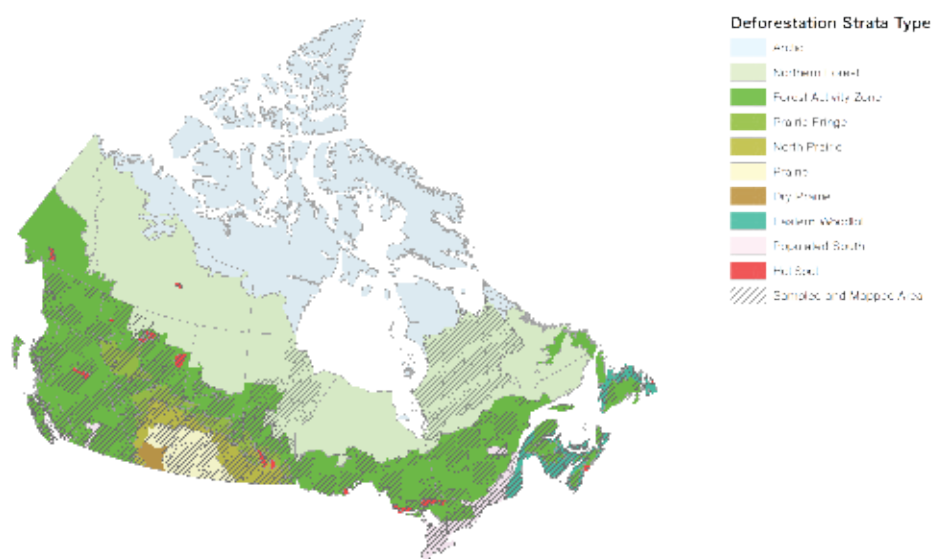
2010b; Dyk et al 2014). For most estimates, certainly those where the land-use change categories had the largest impacts, estimates are derived directly from remote sensing samples.

The activity data are compiled and summarized initially by analysis unit. All conversion events are assembled into a database. A compilation is made to summarize events for detailed post-conversion classes for each reconciliation unit. This compilation process also involves insertion of records data and expert judgement. In the course of these procedures, each event is compiled to yield a local forest conversion rate (ha/year) based on the time interval between the images. Since the available imagery was not necessarily dated 1975, 1990, 2000 or 2008, the rates cover different time periods. At the data compilation phase, forest conversion events are assigned to one of three time periods (1975–1990, 1990–2000, 2000–2008), 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

Figure A3–17   Sampling Grids Over Satellite Imagery for Forest Conversion Mapping.
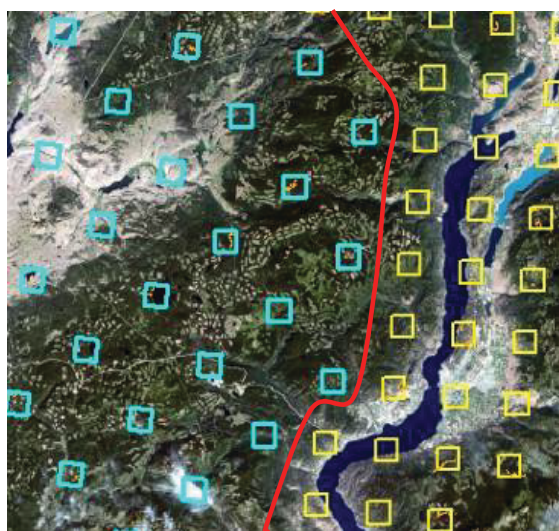
Background Imagery: Area Near Kelowna, British Columbia, Landsat TM, Summer 2000. Denser grid cells at right represent a 12% sampling density; lighter grid on the left is 6% intensity

Figure A3–18   Procedure for Developing a Consistent Time Series of Rates of Forest Conversion
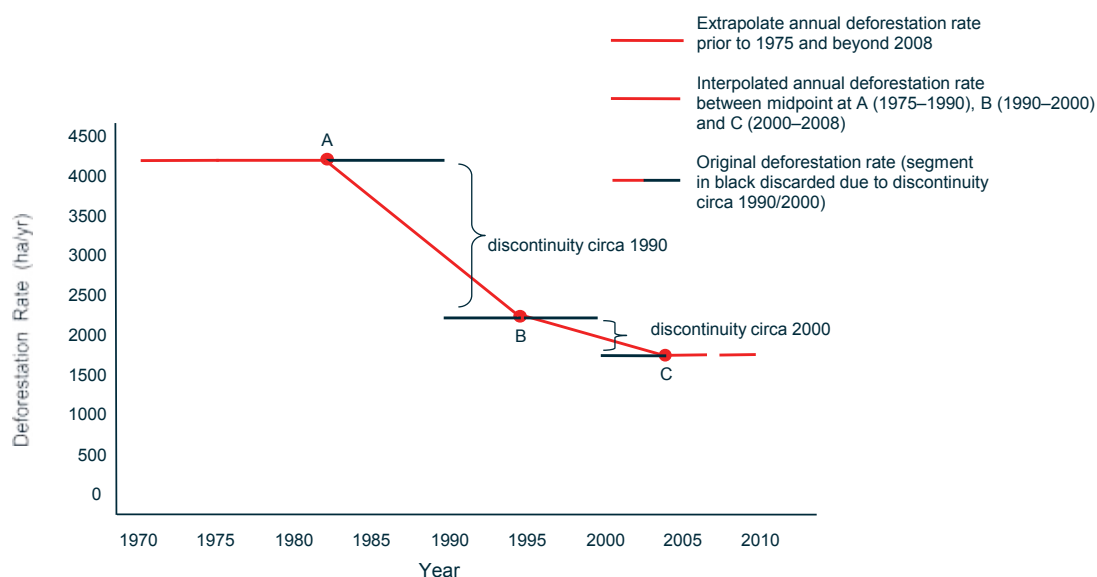
all events of the same type. Relative rates are scaled up for each analysis unit. Data are finally grouped by end use (e.g. the change rate for agricultural crop or rural residential) and in turn, are summarized by broader categories when recompiled by reconciliation unit.

The remote sensing data are derived using the imagery from circa 1975, 1990, 2000 and 2008, whereas records data are annual or summarized over time periods. As explained above, the remote sensing core method provides three distinct average rates of forest conversion for 1975–1990, 1990–2000 and 2000–2008 but no annual estimates of these rates. The preparation of annual forest conversion rates for 1970–2013 requires the simultaneous application of two procedures: 1) extrapolation of annual rates prior to 1975 and beyond 2008; and 2) interpolation between the 1975–1990, 1990–2000 and 2000–2008 data (Figure A3–18). In the absence of documented and tested procedures, the simplest approach is to assign the 1975–1990 rate to each year from 1970 to 1983, the 1990–2000 rate to each year from 1983 to 1995, and the 2000–2008 rate to each year from 1995 to 2004. A constant forest conversion rate is assumed to provide extrapolated data for the post-2004 period. Information for an additional period will be used to update the process.

A linear interpolation is applied between the three temporal anchor points (1983, 1995 and 2004), which results in an estimate of the annual rate of forest conversion for each intervening year. The procedure is illustrated in Figure A3–18. Noted exceptions to this procedure do occur, and reflect individual large events for which actual disturbance information is known either from records information or detailed mapping activity. One example of this would be the case of hydroelectric reservoirs.

Figure A3–19 displays the annual rates of forest conversion by selected end uses: forest land to cropland (FLCL) and forest land to wetlands (FLWL [reservoir flooding]). The figure helps illustrate the different approaches implemented in developing annual estimates. The conversion to cropland estimate is based on the approach illustrated in Figure A3–18. The estimate of forest conversion to wetlands (reservoir flooding) reflects the use of records and detailed mapping information to account for large unique events. Note that these figures differ from the ones reported in the common reporting format (CRF) tables, which are cumulative areas in the "Land converted to" categories.

Quality Assurance/Quality Control of Forest Conversion Data

Great care was taken in understanding the records data, their suitability and their limitations. Documentation of the records data was examined, personnel involved in managing and implementing the data collection and storage were interviewed and, where available, numbers were checked against independent data sources, sampling of high resolution imagery and the knowledge of experts.

The remote sensing interpretation follows defined procedures (Leckie et al. 2010a; Dyk et al. 2014), although it is conducted by a variety of organizations, including provincial government forestry or geomatics groups, remote sensing or mapping companies, research and development organizations and in-house government staff. The basic image analysis quality control (QC) process includes internal checks within the mapping agency or company by a senior person; real-time quality assurance (QA) by Canadian Forest Service specialists during interpretation, with feedback

Figure A3–19   Annual Rates of Forest Conversion to Cropland (FLCL) and Forest Conversion to Wetland (FLWL [Reservoir Flooding])
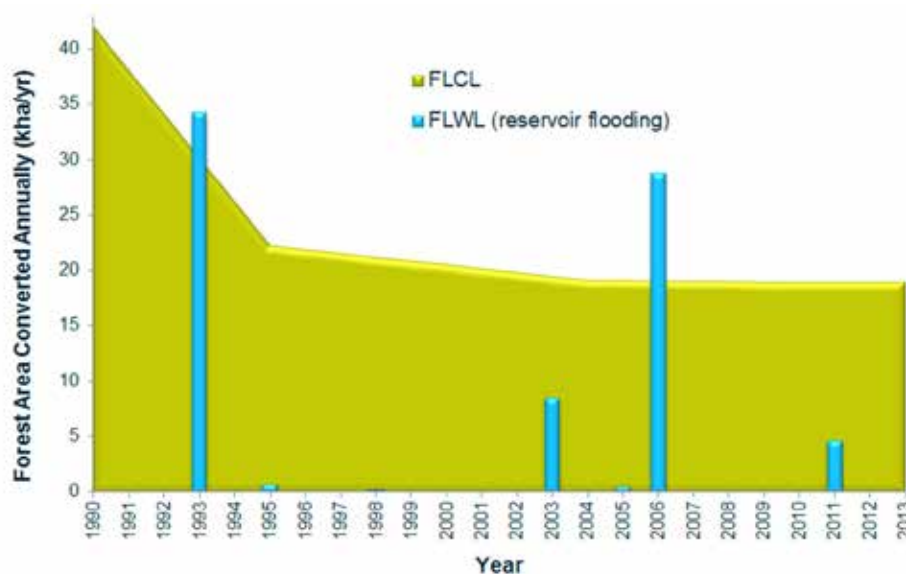
provided within days of interpretation of an area; and a final QA and vetting of the interpretation by the Canadian Forest Service. Field validation is conducted on an ongoing basis as resources permit. Each QC point and revision is documented within the Geographic Information System (GIS) database of conversion events (Dyk et al. 2011).

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. 2012, 2014). 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. 2014). Specific improvements in the last three years include:

1. Expanded data sets with additional Earth Observation (EO) data, Landsat (MSSS/TM/ETM/Winter), SPOT-5, aerial photography, and high resolution satellite imagery.
2. Expansion of the sampled area for targeted and other areas.
3. Analysis and validation of records data with high-resolution imagery (for example, co-disturbance of pipelines and access roads).
4. Extending the temporal coverage to the 2000–2008 period, which provides a longer time period to confirm the nature of historical events. This results in greater confidence and the reduction of commission and omission[26] errors.
5. Greater knowledge resulting from increased experience and expertise gained through QC review and validation activity.

These improvements result in enhanced detection, delineation and determination of event size and cause, as well as a more accurate estimate of timing of conversion events.

Two approaches were considered to estimate uncertainties: an empirical approach and an analytical approach. The resulting estimate is based on consideration of these approaches and provides an estimate of uncertainty associated with activity area estimates. The additional sources of uncertainty related to forest type being removed, post-conversion land category and event timing are not considered.

The empirical approach is an attempt to estimate an overall uncertainty in the forest conversion area estimate. This approach provides an estimate that considers all of its varied components and their potential interactions.

The empirical estimate was developed by making estimates of extreme low, low, high and extreme high forest conversion rates for each reconciliation unit and end-use class. These estimates were based on expert knowledge of activity and practices at a regional scale. All of these estimates were then compiled on a national basis. Comparisons between extreme and non extreme estimates provided some insight into the possible range for which conversion activity could occur. Based on this exercise, an estimate for overall uncertainty for forest conversion was determined to be in the range of ± 20% to ± 30%.

The analytical approach breaks the uncertainty down into subcomponents and then combines these 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 2000–2008 time period, commission errors are likely to be greater than omission errors, particularly because of insufficient time lapse to enable post-disturbance conditions to be confirmed.

Uncertainty associated with boundary delineation errors considers the errors resulting from the displacement of the event boundary from the actual or true boundary of the event. Both underestimation and overestimation of area can result. This source of uncertainty is greatly influenced by the quality and resolution of imagery used in the delineation process; improvements made in resolution and image quality reduce this source of uncertainty.

Estimates of sampling uncertainty take into account the uncertainty associated with the sampling process and the scaling of estimates to large regions (strata/reconciliation units). The sampling process is a mixture of wall-to-wall mapping and systematic sampling. In some areas, the sample coverage and design differed between 1975–1990, 1990–2000 and 2000–2008. 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 (Paradine et al. 2004). 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.

A3

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26   Omission errors are the result of missing true conversion events, and commission errors are the result of including nonconversion disturbances (e.g. forest harvest, burns, beaver flooding).

Table A3–51   GHG Fluxes To and From Managed Forests, 2013

Process/Event	GHG Balance (Gg CO$_2$ eq)[1]				
	Biomass	**DOM**	**Soil**	**N$_2$O[3]**	**Ecosystem Net Balance**
Annual processes	-2 951 017	2 105 378	616 598	0	- 229 042
Slash burning	8	8 009	0	337	8 355
Wildfires	10 561	46 714	0	2 416	59 691
Insects[2]	0	0	0	0	0
Total	**-2 940 448**	**2 160 100**	**616 598**	**2 753**	**- 160 996**
Harvesting (memo item)[4]	**134 250**	**8 012**	**0**	**0**	**142 262**

Notes:
1. On a C pool basis, exchanges of GHG with the atmosphere are not equal to C stock changes.
2. "0" emissions indicate that events do not cause emissions to, or removals from, the atmosphere. Rather, they kill biomass that is transferred to DOM.
3. Carbon in CH$_4$ and CO emissions is included in each pool's assessment, but N$_2$O emissions are computed separately from total CO$_2$ emissions (see Annex 8).
4. The transfer of C from forest biomass and DOM pools from managed forests to the forest products sector is represented in the Harvested Wood Products category. These transfers between LULUCF categories are presented here for information purposes.

This ± 30% uncertainty about the estimate of the total forest area converted annually in Canada places, with 95% confidence, the true value of this area for 2013 as being between 32 and 60 kha. This 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).

Planned Improvements in Forest Conversion

Planned improvements will be incremental, with an emphasis on reducing uncertainties and improving specific estimates. Improvement strategies combine a greater sample coverage, expanded records compilation, improved information processing and system documentation, and additional field verification. Initial image collection and compilation as well as record gathering are underway, to enable extending of estimates for the post-2008 period.

Land Converted to Forest Land

Records of land conversion to forest land in Canada were available for 1990–2002 from the Feasibility of Afforestation for Carbon Sequestration (FAACS) initiative (White and Kurz 2005). Conversion activities for 1970–1989 and 2003–2008 were estimated based on activity rates observed in the FAACS data. Additional information from the Forest 2020 Plantation Demonstration Assessment was included for 2004 and 2005, and an environmental scan was performed to identify additional sources of information on afforestation rates during 2000–2008. Each event, regardless of date, source, type or location, was converted to an inventory record for the purposes of carbon modelling. All events were compiled in a single data set of afforestation activity in Canada from 1970 to 2008. No new afforestation activity data

were identified for the 2009–2013 inventory years. Renewed efforts are underway to obtain additional data on recent afforestation activities in Canada.

For 1990–2008, the area planted was stratified by ecozone, province and species. Total area planted by province and ecozone, in conjunction with the proportion of species planted for each province, was used to calculate area planted by species, resulting in estimates of the area converted to forest, by species, for each reconciliation unit.

Yield curves are not always available for some plantation species or growing conditions (stocking level or site history); those used to estimate growth increments were taken from a variety of sources, most often directly from provincial experts. Where species do not have their own yield curve, they are given the yield curve of another species with similar growth characteristics or the species most likely to have been present in that area. Changes in soil carbon stocks are highly uncertain because of difficulties in locating data about the carbon stocks prior to plantation. It was assumed that the ecosystem would generally accumulate soil carbon at a slow rate; the limited time frame of this analysis and the scale of the activity relative to other land-use and land-use change activities suggest that the impact of this uncertainty, if any, is minimal.

A3.5.2.3. 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 applies the sets of carbon transfers associated with annual processes to all records (managed forest, land converted to forest and land converted from forest), including both stocked and non-stocked stands. As explained above, annual processes combine growth, turnover and decay processes, applied to the entire area of managed forests. The outputs consist of the net GHG balance of managed forests, including growth; immediate emissions due to disturbances (carbon stock changes, carbon losses to the atmosphere and to forest products); and decay of both DOM and soil organic matter, including on stands affected by disturbances. During this stage, inventory records that have been in a "Land converted to" category for 20 years are converted into the "Land remaining" category and the simulation of C dynamics—usually decay—continues in this new category.

The same data output is available on converted forest lands (except tree growth), but is reported in the new land category—e.g., the Land converted to Cropland (CRF Table 4.B Row 2), Land converted to Wetlands (CRF Table 4.D Row 2), and Land converted to Settlements (CRF Table 4.E Row 2) categories. Exceptions consist of estimates of soil organic matter emissions on forest land converted to cropland and peat extraction fields, which are developed separately; methods are described in sections A3.5.3.3 and A3.5.5.1. Likewise, estimation methods for emissions (as opposed to carbon stock changes) from forest land converted to flooded lands are described in Section A3.5.5.2.

Note that the immediate effect of disturbances in managed forests is identifiable in the output data sets for the year of the disturbance. In subsequent years, post-disturbance emissions and removals in forests are simulated as annual processes. The CBM-CFS3 does not distinguish post-disturbance processes from other processes affecting forest ecosystem C; hence, the long-term impact of disturbances in the managed forests cannot be fully identified.

The broad components of the GHG emissions and removals in managed forests simulated by the CBM-CFS3 include annual (ecosystem) processes, immediate emissions from slash burning and natural disturbances and carbon transfers to the forest products sector from harvesting (Table A3–51). The largest fluxes are carbon uptake by biomass and its release by DOM decay (from heterotrophic respiration). The first is largely influenced by the age-class distribution of the managed forests; organic matter decay is controlled by input from litter fall, mortality and post-disturbance decay. The majority of immediate emissions due to slash burning and wildfires are from the DOM pool. Insect disturbances cause very limited immediate emissions; however,

depending on the severity of infestations and insect damage, they may result in 1) decreases in C uptake through growth reductions, 2) large carbon transfers from biomass to DOM and 3) alterations in the long-term trend of organic matter decay (Kurz et al. 2008a). Although harvesting results in a loss of carbon from both the biomass and DOM pools, these losses are represented as carbon transfers to the Harvested Wood Products category (Section A3.5.7).

A3.5.2.4. 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; computational requirements can quickly become a limiting factor. Not all model parameters or input data have equal influence on model outputs; careful consideration must therefore be given to balance available computing capacity and the inclusion in the uncertainty assessment of input data, parameters and other functions with a large influence on model outputs.

The general approach to uncertainty assessment emphasizes model inputs and parameters as the main sources of uncertainty. The specific uncertainty sources are forest inventory data, influential model parameters and the initialization of soil and dead organic matter C stocks prior to model runs. Additional randomization steps are also fed into the development of confidence intervals, by randomly selecting 10 000 bootstrap samples of the Monte Carlo run outputs. 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 the forest carbon dynamics as a whole. Disturbances affect emissions and removals of C in the short term, and in the long term through residual decay and age-class distribution. Uncertainties of 10% and 25% are assumed on the areas of managed forests subject annually to wildfires and insect infestations, respectively.

A3

A3

The uncertainties about the carbon removed in harvested material are regionally specific, and incorporate error ranges in harvested volume (± 1%), and standard deviations about round-wood specific gravity and bark adjustment factor (Table A3–52). No error was assumed for the carbon proportion of biomass. The annual coefficient of variation was multiplied by 2 to approximate a normal distribution with a triangular one.

The assessment also provides uncertainties about emissions due to forest conversion; here a 30% uncertainty about areas converted annually is used. The "Forest Conversion" section of this annex describes the derivation of this value.

Soil and other slow-decaying DOM pools contain a considerable amount of carbon. Previous work had shown that the initial DOM C stocks, at the beginning of a complete run, are sensitive to historical disturbance rates. In this assessment, initial C stocks in the soil and DOM pools were allowed to vary by modifying the historical (pre-1990) fire return intervals. Even though the rates of soil organic matter decay modelled by the annual processes are very low, they do, by virtue of the pool size and forest areas, strongly influence emissions from annual processes. A sensitivity analysis of carbon emissions from the dead organic matter and soil pools revealed that the most influential model parameters included decay rates for soil organic matter, and the decay and release to the atmosphere of carbon from very-fast cycling pools, such as dead fine roots and litter (White et al. 2008).

For the purpose of this analysis, 28 model parameters are allowed to vary in the Monte Carlo runs:

- Base decay rates for DOM pools (11 parameters)
- Proportion of decayed material that is oxidized, versus that which is transferred to another DOM pool (5 parameters)
- Turnover rates for biomass pools (12 parameters)

In the absence of evidence to support more complex functions, all input probability distribution functions for biomass increments, activity data on human and natural disturbances and decay parameters are triangular. A gamma probability distribution function is used for fire intervals (Metsaranta et al. 2014).

Significant uncertainty in the modelling framework results 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

Table A3–52   Uncertainty Ranges for Harvested Carbon, by Canadian Province and Territory

Province/Territory	Minimum Multiplier	Maximum Multiplier
Alberta	0.9	1.1
British Columbia	0.92	1.08
Newfoundland	0.96	1.04
Manitoba	0.86	1.14
New Brunswick	0.92	1.08
Northwest Territories	0.74	1.26
Nova Scotia	0.88	1.12
Ontario	0.92	1.08
Prince Edward Island	0.88	1.12
Quebec	0.86	1.14
Saskatchewan	0.92	1.08
Yukon	0.84	1.16

Source: Metsaranta et al. (2014)

category along those curves. Emissions due to disturbances—including the conversion of forests to other land categories—are driven not only by the areas affected, but also the pre-conversion standing carbon stocks, the parameters of the disturbance matrices that re-allocate carbon among pools or "release" it to the atmosphere, and the post-conversion decay rates. Hence, uncertainties about estimates cannot be obtained from a simple combination of "activity data" and "emission factor" uncertainties.

Not all uncertainty sources have been captured: importantly, the analysis did not consider the impact of processes that are currently not simulated. Hence, the results should not be used to assess potential bias (or accuracy) of estimates. Additional considerations may be warranted to identify the direct human-induced effects, and their uncertainties, on forest carbon dynamics. Improvements are expected to occur over coming years, due to better knowledge, refined procedures and access to more computing capacity.

A3.5.3.   Cropland

The methodologies described in this section apply to carbon stock changes in mineral soils subject to cropland management and to the conversion of land in the Forest and Grassland categories to the Cropland category; CO_2 emissions from the cultivation of histosols; changes in the biomass of woody perennial crops; and N_2O emissions from soil disturbance upon conversion to cropland. The estimation methodologies for carbon stock changes and GHG emissions from the biomass and DOM pools upon conversion of forest land to cropland are provided in Section A3.5.2.3.

A3.5.3.1. Cropland Remaining Cropland

A detailed description of the methodologies used for this category can be found in McConkey et al. (2007a).

Change in Carbon Stocks in Mineral Soils

Changing Management Practices

The amount of organic carbon retained in soil represents the balance between the rates of input from crop residues and losses through soil organic carbon (SOC) decomposition. How the soil is managed determines whether the amount of SOC stored in a soil is increasing or decreasing. The development of the CO_2 estimate methodology is based on the premise that, on long-existing cropland, changes in soil C stocks over time occur following changes in soil management that influence the rates of either C additions to, or C losses from, the soil. If no change in management practices occurs, the C stocks are assumed to be at equilibrium, and hence the change in C stocks is deemed zero.

A number of management practices are generally known to increase SOC in cultivated cropland, such as reduction in tillage intensity, intensification of cropping systems, adoption of yield-promoting practices and re-establishment of perennial vegetation (Janzen et al. 1997; Bruce et al. 1999). Adoption of reduced tillage (RT) or no-till (NT) can result in significant accumulation of SOC compared with intensive tillage (IT) (Campbell et al. 1995, 1996a, 1996b; Janzen et al. 1998; McConkey et al. 2003). Many cropping systems can be intensified by increasing the duration of photosynthetic activity through a reduction of summerfallow (Campbell et al. 2000, 2005; McConkey et al. 2003) and greater use of perennial forage (Biederbeck et al. 1984; Bremer et al. 1994; Campbell et al. 1998). Intensification of cropping systems not only increases the amount of C entering the soil, but may also reduce decomposition rates by cooling the soil through shading and by drying the soil. Conversely, switching from conservative to conventional tillage or from intensive to extensive cropping systems will generally reduce C input and increase organic matter decomposition, thereby reducing SOC.

VandenBygaart et al. (2003) compiled published data from long-term studies in Canada to assess the effect of agricultural management practices on SOC. This compendium, as well as the availability of activity data from the *Census of Agriculture*, provided the basis for identifying key management practices and management changes used to estimate changes in soil C stocks. Emissions and removals of CO_2 from mineral soils are estimated for the following land management changes (LMCs):

1. Change in mixture of crop type
   a) Increase in perennial crops
   b) Increase in annual crops

2. Change in tillage practices
   a) IT to RT
   b) IT to NT
   c) RT to IT
   d) RT to NT
   e) NT to IT
   f) NT to RT

3. Change in area of summerfallow
   a) Increase in area of summerfallow
   b) Decrease in area of summerfallow

Where nutrients are greatly limiting, proper fertilization can increase SOC; in such conditions, however, fertilizer or other nutrient-enhancing practices are generally applied. Irrigation in semi-arid areas can affect SOC, but the impact is unclear, and the area of irrigated land has been relatively constant in Canada. Therefore, it is assumed that the selected LMCs represent the most important and consistent influences on SOC in mineral soils.

Carbon Stock Change Factor

To estimate C emissions or removals, an SOC stock change factor specific to each combination of SLC polygon and management change is multiplied by the area of change. The factor is the average rate of SOC change per year and per unit of area of LMC.

Equation A3–60:

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

where:

ΔC	=	change in SOC stock for inventory year, Mg C
F	=	average annual change in SOC subject to LMC, Mg C/ha/year
A	=	LMC area, ha

Areas of LMC such as changes in tillage, crop type and fallow are obtained from the *Census of Agriculture*. Census data provide information on the net change in area over five-year census periods. In practice, land probably both enters and leaves a land management practice, and combinations of management changes occur. However, because only net change data are available, two assumptions are made: additivity and reversibility of SOC factors. Reversibility assumes that the factor associated with an LMC from A to B is the opposite of that associated with the LMC from B to A. Additivity assumes that the C changes from each individual LMC occurring on the same piece of land are independent and therefore additive. This assumption is supported by the findings

A3

of McConkey et al. (2003), who reported that the impact of tillage and crop rotations on SOC is generally additive.

There is a relatively large set of Canadian observations of long-term changes in SOC for LMCs such as adoption of NT and reduced frequency of summerfallow (VandenBygaart et al. 2003; Campbell et al. 2005). However, even this large data set does not cover the whole geographical extent of Canadian agriculture. In addition, there are difficulties in comparing measurements among research sites, in determining the duration of an effect, in estimating full uncertainty from a range of initial soil conditions, and in determining the variability of soil C stocks without management change.

Because of these limitations, a well-calibrated and validated model of SOC dynamics, the Century model (Parton et al. 1987, 1988), is used to derive individual SOC factors for changes between NT and IT, RT and IT, RT and NT, annual and perennial crops, and area of summerfallow. The Century model has been widely used to simulate SOC change for Canadian conditions (Voroney and Angers 1995; Liang et al. 1996; Monreal et al. 1997;

Campbell et al. 2000, 2005; Pennock and Frick 2001; Carter et al. 2003; Bolinder 2004).

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 general method for developing C factors is outlined in Figure A3–20 and Figure A3–21. The starting points were the SOC values in the SLC polygon attribute database (CanSIS). These database SOC values were derived from measurements made for soil surveys and land resource studies (Tarnocai 1997) and were

Figure A3–20   Method for Deriving Carbon Factors for a Land Management Change of Interest
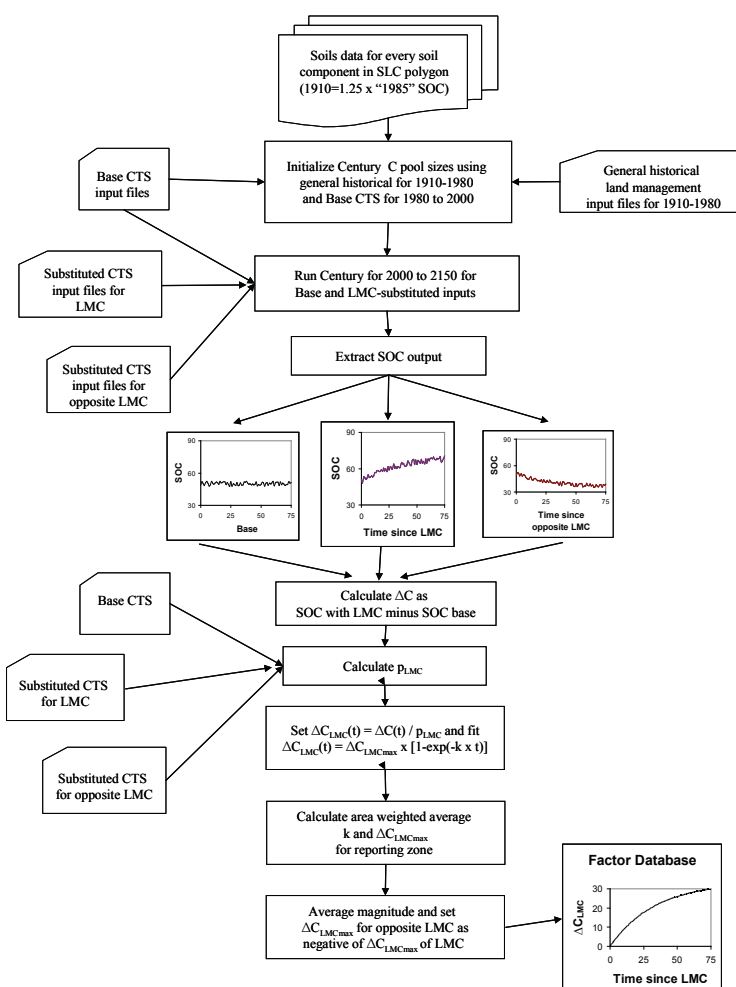
assumed to represent average SOC on cropland in 1985. Initial SOC in 1910 was estimated as 1.25 times the SOC in the SLC polygon. Changes in SOC factors were estimated using the difference in SOC stocks over time between simulation of a generalized land use and management scenario with and without the 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.

Equation A3–61:

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

where:

$\Delta C_{LMC(t)}$	=	the difference in SOC between land management systems from year to year (Mg SOC/ha)
P_{LMC}	=	the proportion of the land area under a given land management system subject to the LMC

This proportion (P_{LMC}) can be derived as the proportion of the particular LM in the base system less the amount of the LM in the new system after the LMC. That is,

Figure A3–21   Method for Deriving Land Management Input Files to Use with Century Model to Estimate the Carbon Factor for a Land Management Change of Interest
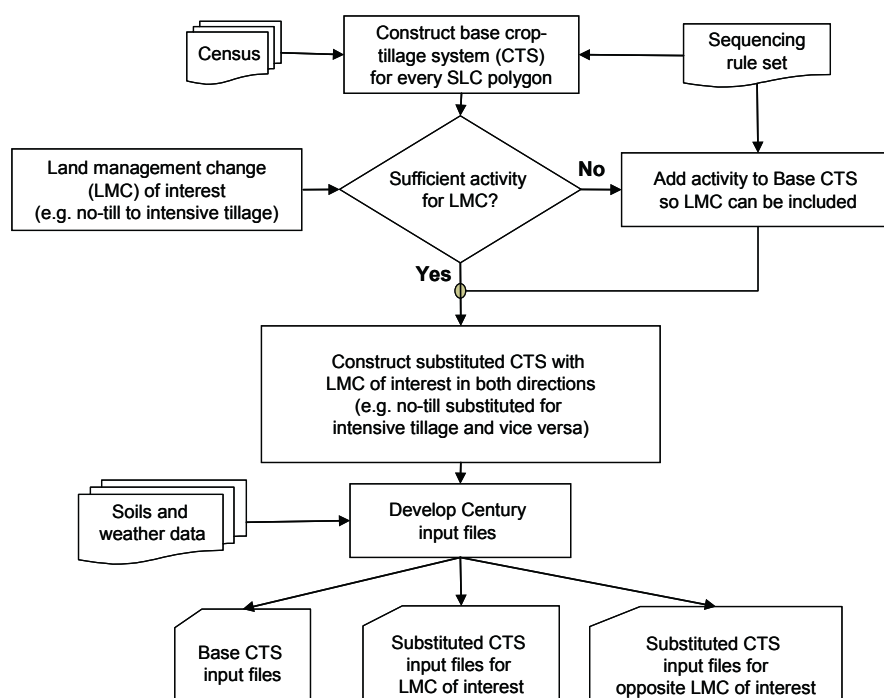
Equation A3–62:

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

where:

P$_{LMbase}$	=	the fraction of land management of interest in the base land management system
P$_{LMnew}$	=	the fraction of land management of interest in the new land management system

The following provides an example of Century runs for a Lethbridge loam (Orthic Dark Brown Chernozem) in the Semi-arid Prairies reporting zone. A base model run was made using a 10-year base mix of crops based on the *1996 Census of Agriculture* and weather data covering the years 1951–2000. Century simulations of SOC were made by substituting perennial crops for the seven annual crops out of ten in the base mixture. As a separate exercise, NT was substituted for IT four years out of ten in the base mixture (Figure A3–22). The next step was to calculate the ΔC$_{LMC}$(t) function by subtracting the simulated SOC values for the base mix values from those imposed by the LMC of interest (Equation A3–61). Finally, the ΔC$_{LMC}$(t) was calculated as the proportion of area of farming system divided by the P$_{LMC}$ (Equation A3–62). Figure A3–23 illustrates the time series of ΔC$_{LMC}$. In this particular case 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.

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

Equation A3–63:

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

where:

ΔC$_{LMCmax}$	=	the maximum SOC change induced by the LMC
k	=	the rate constant
t	=	year

In practice, the exponential equations are fit statistically using methods of least squares. The slope of the 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 A3–64:

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

Figure A3–22 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
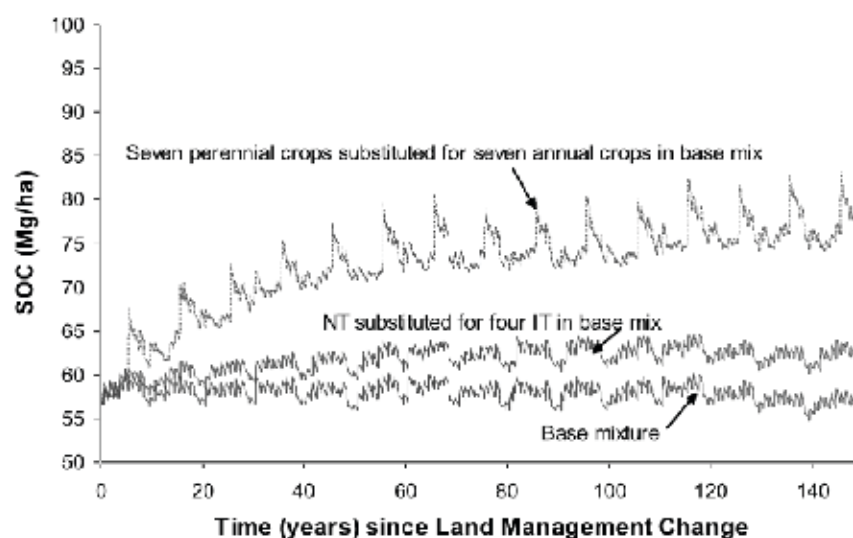
Since perfect steady-state conditions are never reached, the exponential equation should theoretically apply forever. In practice, however, the exponential equation was truncated when the $F_{LMC}(t)$ dropped to 25 kg C/ha per year. This rate was below a practical measurement limit (Figure A3–24).

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 A3–53). 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 or greater than 0.15 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 P_{LMC} of 0.5 (for example a change from 50% fallow to no use of fallow). The k value was derived from the Century simulations as described above.

Generally, rates of SOC losses may be expected to be greater upon an LMC than rates of SOC gain upon the reverse LMC. However, this effect depends greatly on the relative SOC amount at the time of the LMC. Documenting SOC at the time of all LMCs is currently impossible; hence for transparency and simplicity the reversibility assumption was imposed, which requires that the SOC effect of an LMC in one direction is exactly the negative of the SOC effect of the practice change in the opposite direction.

Soil Carbon Factor Validation

SOC change factors for LMCs used in the inventory were compared with empirical coefficients in VandenBygaart et al. (2008). They showed that empirical data comparing SOC change between IT and NT were highly variable, particularly for eastern Canada. Nonetheless, the modelled factors were still within the range derived from the empirical data. The mean IT-NT factor for experiments in the Subhumid Prairies reporting zone was over four times that of the Semi-arid Prairies reporting zone. The mean Century model–derived factor for the Semi-arid Prairies reporting zone was similar to the factor derived from the field experiments. However, the Century-derived IT-NT factor for the Subhumid Prairies reporting zone was about 30% lower than the factor derived from the field experiments.

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Figure A3–23   Change in SOC for Simulations with Substitutions Relative to Simulations with Base Crop Mix
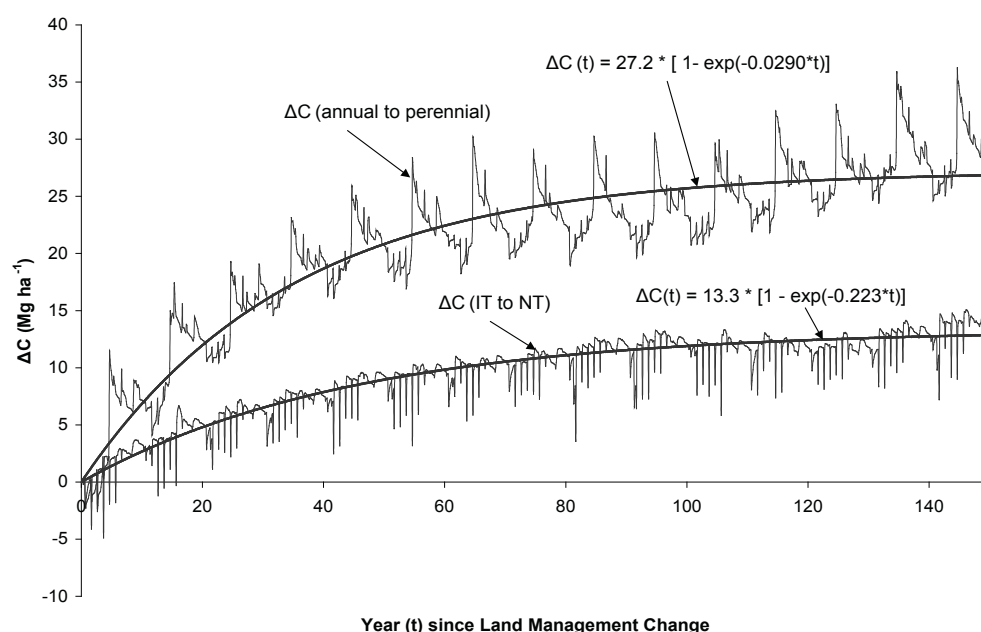
When considering the switch from annual to perennial cropping, the mean empirical factor was 0.59 Mg C/ha per year, and this compared favourably with the range of 0.46–0.56 Mg SOC/ha per year in the modelled factors in the Parkland, Semi-arid Prairies and West reporting zones (Table A3–53). In eastern Canada, only two empirical change factors were available in the East Central reporting zone, but they appeared to be in line with the modelled values (0.60–1.07 Mg SOC/ha per year empirical versus 0.74–0.77 Mg C/ha per year modelled).

For conversion of crop fallow to continuous cropping, the rate of C storage was more than double the average rate of 0.15 ± 0.06 Mg/ha per year derived from two independent assessments of the literature. This difference led to the decision to use empirically based factors for changes in summerfallow in the inventory.

Estimates of Change in Soil Carbon Stocks

SOC changes as a result of LMC were reported for 1990–2013. 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, with accounting using an IPCC Tier 2 approach as follows:

Equation A3–65:

$$\Delta C_{LMC} = \sum_{1951-2013} \sum_{ALLSLC} (\Delta C_{TILL} + \Delta C_{SF} + \Delta C_{CROPPING})$$

where:

ΔC_{LMC}	=	change in SOC stocks due to LMC for a specific year since 1951
ΔC_{TILL}	=	change in SOC stocks due to change in tillage practices from each SLC, since each particular tillage change
ΔC_{SF}	=	change in SOC stocks due to the change in summerfallow in each SLC
$\Delta C_{CROPPING}$	=	change in soil C stocks due to the change in annual and perennial crops in each SLC

Figure A3–25 provides a schematic of the method for C estimation.

Data Sources

Carbon stock change estimates rely on C factors and a time series of land management data in the *Census of Agriculture*. There are two types of data used for either deriving C factors (modelling) or computing the actual estimates of C stock change. The data mainly used for modelling C factors include SLC, crop-tillage systems derived from the *Census of Agriculture*, and crop yields, climate data and activity data from other surveys and databases. The land management practices from the *Census of Agriculture* are mainly used for estimating annual C stock changes.

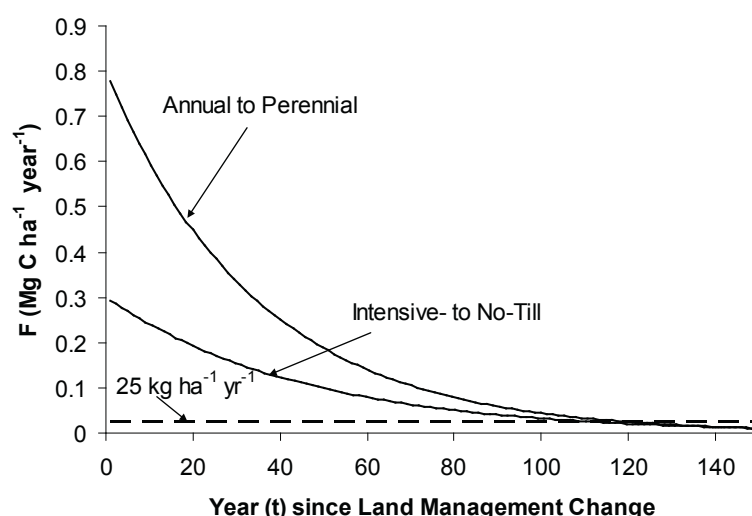**Figure A3–24   Carbon Factors as a Function of Time**

Table A3–53 Generalized Values of Parameters for $F_{LMC}(t) = \Delta C_{LMCmax} \times [1 - exp^{(-k \times t)}]$ to Predict Change from Land Management Change (LMC) and Effective Linear Coefficients of SOC Change

Zone[1]	LMC[2]	k/year	ΔC_{LMCmax} (Mg/ha)	Final Year of Effect after LMC[3]	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:

1. 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.
2. For LMCs in the opposite direction to that listed, the FLMCmax will be the negative of the value listed.
3. No further C change once the absolute value of the rate of change is less than 25 kg C/ha per year.

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.[27] The SLC Version 3.11 was chosen for the LULUCF inventory because of its national scope and standardized structure that ensure that all areas of the country are treated in a consistent manner with regard to inventory assessment procedures. In addition, all SLC polygons are "nested" within the 1995 National Ecological Framework, making it possible to scale up or scale down data and estimates, as required.

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

soil texture, pH, bulk density and soil hydraulic properties for modelling C factors with Century. The SLC polygon provides the spatial basis for allocating land management practices such as tillage practices and cropping systems from the *Census of Agriculture* and Cropland converted from Forest and Grassland to modelled C factors. The estimated areas of cropland and other land-use practices on an SLC polygon basis were derived from EO-based maps for 1990, 2000 and 2010.

Analysis Units

There are 3404 SLC polygons that have agricultural activities. Since the SLC polygons have several soil landscape components, the finest spatial resolution for analysis of agricultural activities is 13 771 unique combinations of soil landscape components within SLC polygons. These unique combinations represent the basic analysis units. The location of land management and soil components is not spatially explicit but rather spatially referenced to SLC polygons.

27 Available online at http://sis.agr.gc.ca/cansis/nsdb/slc/v1/intro.html.

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 them more or less likely to have different 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. Annual crop production is linked to those components with a high rating. If there was insufficient area with high likelihood of being under annual cropland for area of annual crops, the remaining annual crop production was linked to components with moderate likelihood of being under annual crop production and, if required, to low-ranked components. After linking the annual crop production area, 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. Eight publications are released at strategic points in the crop year; the first area report contains the planting intentions of producers, whereas the June estimates are made after most of the seeding has been completed. 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 for accounting included 1975–2004 yield data for wheat, barley, oats, corn, soybeans, potatoes and canola. These yields were used to calibrate the Century crop growth submodel.

Climatic Data

There are 958 weather stations in the weather database archived by Agriculture and Agri-Food Canada (AAFC). Long-term normals of monthly maximum and minimum temperatures (^{o}C) and precipitation (mm) from 1951 to 2000 for all ecodistricts were used for modelling C factors. AAFC-archived weather data were provided by the Meteorological Service of Canada, Environment Canada.

Earth Observation and the Census of Agriculture (CoA)

Activity data for C estimation in Cropland remaining Cropland rely mainly on a combination of data from the Census of Agriculture and area estimates based on EO analyses. In comparison with the previous submissions, a significant improvement was

Figure A3–25   Method of Using Factors for Land Management Change to Estimate Carbon Change over Large Areas
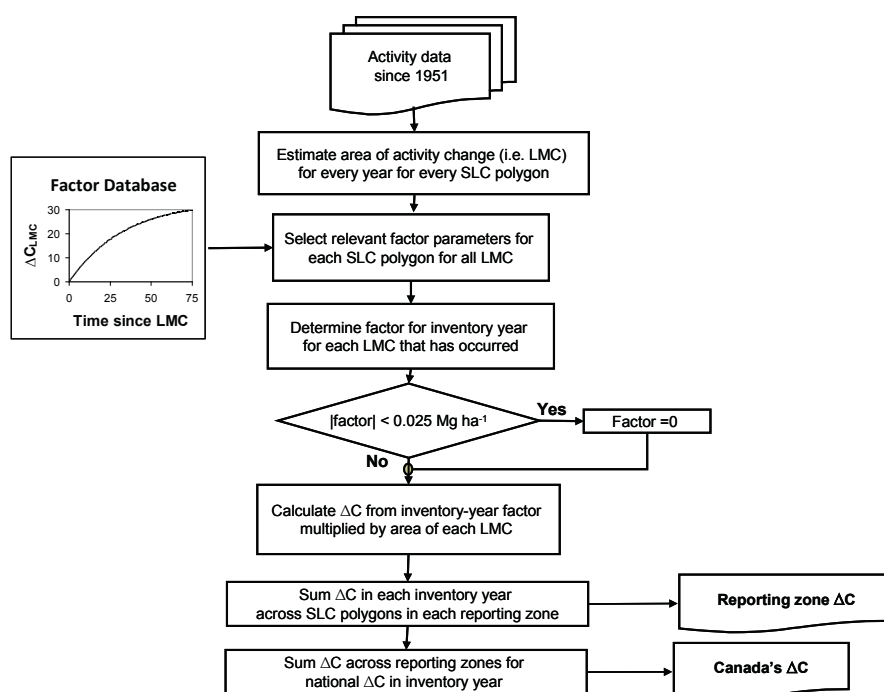
made through the incorporation of EO- based mapping data to provide area estimates of all land use practices within each of the agricultural SLCs in Canada. The EO approach eliminated the need to reconcile land areas that were previously reported in the CoA. The CoA was not intended for longitudinal analysis and hence activity estimates based on it were difficult to reconcile through the reporting time series.

Land-use maps based on EO information were generated for 1990, 2000 and 2010. From 1990 to 2013, annual estimates of land-use areas were generated by interpolating between EO years and extrapolating beyond 2010. For area estimates prior to 1990, the Census of Agriculture was used to calculate the percent change in cropland and grassland area, starting with the change from 1981 to 1990 and applying this to the 1990 EO data areas, and then moving progressively back through census years to 1951. To minimize spatial variability associated with a problem from reporting land-use areas based on farm headquarters, the percent change was calculated at the spatial scale of the ecodistrict and applied to all SLC polygons nested within.

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. The EO-based cropland attributes were estimated using the Census of Agriculture, which provided ratios of cropland area attributes to the total cropland area.

The smallest area for which Statistics Canada will externally release data from the CoA, for confidentiality reasons, is the Dissemination/Enumeration Area level (approximately 52 000 in Canada). Data at this level was attributed to the SLC polygons (McConkey et al. 2007a). Data on tillage practices were taken from the CoA 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. There are two limitations of the census data pertaining to tillage practices that resulted in uncertainties: 1) Statistics Canada and expert opinion indicate that conservation tillage tends to be underestimated, and 2) tillage distributions as reported for a region must be applied equally to all crops within that region.

A comparison of land areas within different cropping systems from the previous submission showed that, while there are variations, the general trends within agricultural land-use categories were similar. Of note is a decrease in annual crops in favour of perennial crops in the mid 1980s through 2006, followed by a reversal whereby the proportion of land in annual crops has

been steadily increasing since 2007. More technical details on the methodological approach used to create the EO-based agricultural activity data is provided (Cerkowniak 2014).

Uncertainty

The derivation of uncertainties about estimates of CO_2 emissions or removals requires estimates of uncertainties for LMC areas and C factors of management changes for fallow, tillage and annual/perennial crops (McConkey et al. 2007b). The current uncertainty described in this report is based on the 2014 submission methodology and has not yet been updated for the new Earth Observation methodology.

The uncertainty of area of change was determined for ecodistricts (one level of spatial aggregation above SLC). 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 activity is not occurring within the ecodistrict. Therefore, area uncertainty can be more reliable 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.[28]

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

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

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 the 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 are provided in Chapter 6.

CO$_2$ Emissions and Removals from Woody Biomass

Vineyards, fruit orchards and Christmas tree farms are intensively managed for sustained yields. Vineyards are pruned each year, leaving only the trunk and one-year-old stems. Similarly, fruit trees are pruned annually to maintain the desired canopy shape and size. Old plants are replaced on a rotating basis for disease prevention, stock improvement or introduction of new varieties. Typically, Christmas trees are harvested at about 10 years of age. For all three crops, it was assumed that, because of these rotating practices and the requirements for sustained yield, a uniform age-class distribution is generally found on production farms. Hence, there would be no net increase or decrease in biomass C within existing farms, as C lost from harvest or replacement would be balanced by gains due to new plant growth. The approach was therefore limited to detecting changes in areas under vineyards, fruit orchards and Christmas tree plantations and estimating the corresponding C stock changes in total biomass.

There are no Canadian studies on the above-ground or below-ground C dynamics of vineyards or fruit trees. However, results from other studies are considered valid inasmuch as varieties, field production techniques and even root stocks are often the same. Canadian literature on Christmas tree plantations is used whenever suitable.

On average, vines are replaced at 28 years of age; the average vine is therefore 14 years old (Mailvaganam 2002). Because of intensive pruning, the biomass of shoots and leaves is set at the constant value of 4 Mg/ha, whereas linear rates of aboveground and below-ground biomass accumulation in trunks and roots were 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 6.9 Mg C/ha is assumed, equal to the average standing biomass for 14-year-old vines (McConkey et al. 2007a).

Because of different standard planting densities, the range of standing biomass per area for apple and peach trees varied narrowly between 36 and 40 Mg/ha (McConkey et al. 2007a). This similarity is expected, since, regardless of tree size and planting density, the tree shapes and canopies are manipulated to maximize net photosynthesis per area. An annual rate of C sequestration was calculated over a 12-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. It was assumed that, on new orchard areas, trees accumulate biomass at a linear rate for 10 years (the average tree age on a plantation). 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). Wood accounts for approximately 70% of Christmas tree biomass, and fresh wood has a moisture content of 60~80%. With typical spacing and an expected market mass of 10 kg per tree, a plantation of marketable trees is estimated to have an above-ground biomass density of 17.1 Mg/ha. With a root: shoot ratio of 0.3 (Bartelink 1998; Litton et al. 2003; Xiao and Ceulemans 2004), the total C biomass of a marketable tree plantation is estimated at 11.1 Mg C/ha. Carbon sequestration in biomass of new Christmas tree plantations is calculated for five years at rates of 0.85 and 0.26 Mg C/ha for above-ground and below-ground biomass, respectively. A decrease of plantation area would result in the immediate loss of 5.6 Mg C/ha.

Uncertainty

Poorly growing plants are regularly removed and replaced. Frequently, fruit trees and vineyards are irrigated to maintain desired growth during dry periods. Consequently, the variability in C stock changes should be less than that for other agricultural activities.

For loss of area, all C in woody biomass is assumed to be immediately released. There are no Canadian-specific data on this uncertainty. Therefore, the default uncertainty of ±75% for woody biomass on Cropland from the 2006 IPCC *Guidelines* was used. If the loss in area of fruit trees, vineyards or Christmas trees is estimated to have gone to annual crops, there is also a deemed perennial to annual crop conversion with associated C change uncertainty that contributes to C change uncertainty for a reporting zone.

Cultivation of Organic Soils

Cultivation of histosols for annual crop production usually involves drainage, tillage and fertilization. All these practices increase decomposition of SOC and, thus, release of CO_2 to the atmosphere.

Methodology

The IPCC Tier 1 methodology is based on the rate of C released per unit land area:

Equation A3–66:

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

where:

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%.

A3.5.3.2. Grassland Converted to Cropland

Conversion of native grassland to cropland generally results in losses of SOC and soil organic nitrogen (SON) and in turn leads to emissions of CO_2 and N_2O to the atmosphere. Carbon changes from the above-ground or below-ground biomass or dead organic matter upon conversion are generally insignificant based on findings from a recent work by Bailey and Liang (2013) on burning of managed grassland in Canada: they 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, 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 breaking.

The SOC dynamics from breaking of grassland to cropland for the Brown and Dark Brown Chernozemic soils (Figure A3–26) can be estimated with the Century model (Version 4.0). Shortly after breaking, there is an increase in soil organic matter, as below-ground biomass of the grass becomes part of SOC. After a few years, SOC declines below the amount of SOC that existed under grassland. The rate of SOC decline gradually decreases with time. Neglecting the initial SOC increase due to C added from roots, simulated SOC dynamics can be described by the following equation:

A3

Equation A3–67:

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

where:

$\Delta C(t)$	=	change in SOC for the tth year after conversion, Mg C/ha
ΔC_{Bmax}	=	ultimate change in SOC from grassland to cropland, Mg C/ha
k	=	rate constant for describing the decomposition
t	=	time since breaking of grassland, years
t_{lag}	=	time lag before ΔC becomes negative, years

Assuming that the 22% loss at about 50–60 years after initial breaking represents the total loss, the ΔSOC_{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 A3–68:

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

where:

$\Delta C(t)$	=	change in SOC for the tth 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 A3–69:

$$\Delta C_{GLCL} = \sum_{1951-2013} \sum_{ALLSLC} \sum_{t} (\Delta C_t \times AREA_{GLCL})$$

where:

ΔC_{GLCL}	=	losses of SOC in 2013 due to conversion of grassland to cropland since 1951, Mg C
ALL SLC	=	all soil polygons that contain grassland
t	=	time after grassland conversion, years
ΔC_t	=	change in SOC for the tth 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 A3–70:

$$N_2O_{GLCL} = \sum_{1951-2013} \sum_{ALLSLC} \sum_{t} (\Delta C_{GLCL} \times AREA_{GLCL}) \times 0.06 \times EF_{BASE} \times \frac{44}{28}$$

where:

N_2O_{GLCL}	=	emissions of N_2O in 2013 due to the conversion of grassland to cropland since 1951, kt
ALL SLC	=	all soil polygons that contain grassland
t	=	time after grassland conversion, years
ΔC_{GLCL}	=	change in SOC for the tth year after conversion, Mg C/ha
$AREA_{GLCL}$	=	area of grassland converted to cropland annually since 1951, ha
EF_{BASE}	=	N_2O emission factor, defined as a function of long-term climate normals (precipitation divided by potential evapotranspiration from May to October; P/PE) at an ecodistrict level (See A3.4.6)
0.06	=	ratio of ON to OC losses
44/28	=	coefficient converting N_2O-N to N_2O

Table A3–54 Soil Organic C for Forested and Agricultural Land in Eastern and Western Canada from the Canadian Soil Information System Database (0- to 30-cm soil depth)

Soil Texture	Soil Organic Carbon (Mg C/ha)		Difference (%)
	Forested Land[1]	Cropland[1]	
Eastern Canada			
Coarse	85 (26)	68 (42)	-20
Medium	99 (38)	77 (35)	-22
Fine	99 (58)	78 (36)	-21
Western Canada			
Coarse	73 (39)	74 (38)	0
Medium	66 (30)	73 (30)	4
Fine	74 (38)	77 (25)	1

Note:
1. Standard deviation in parentheses.

Data Sources

The area of Grassland remaining Grassland (GLGL) was estimated using a combination of data from the Census of Agriculture and EO data. Grassland areas for the entire time series were reconciled with area estimates of Grassland converted to Cropland (GLCL) back to 1990 and onward.

Within an SLC, GLGL was allocated to soil components identified as "low" for "likelihood of being cropped." Once allocated to SLC polygons, area totals for GLGL were aggregated to an ecodistrict as required in each year from 1990.

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).

Figure A3–26 Century-Simulated SOC Dynamics after Breaking of Grassland to Cropland for the Brown and Dark Brown Chernozemic Soils
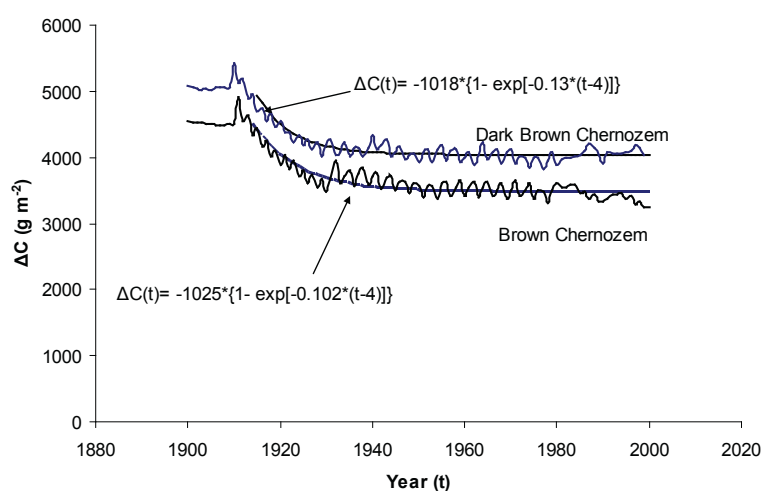
A3.5.3.3. Forest Converted to Cropland

Emissions of CO_2 and N_2O from Soils

Clearing forest to increase agricultural land is a declining but still significant practice in Canada. This section describes the methodology for estimating CO_2 and N_2O emissions associated with the soil disturbance. The method for estimating emissions from biomass upon conversion is presented in Section A3.5.2.3. 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 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 A3–54), indicating that, on average, SOC for the uppermost 30 cm of soil under agriculture was 20.5% less than under forest.

Although the SOC for forested land in Table A3–54 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, and Figure A3–27 shows an example of such dynamics. In the first years after the conversion, there is an increase in soil organic matter, as litter and aboveground and below-ground DOM become part of SOC. After a few years, SOC declines below the amount of SOC 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 A3–27, neglecting the initial SOC increase:

Equation A3–71:

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

where:

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

For the example shown in Figure A3–27, 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 A3–27) 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 about 100 years after forest conversion; the ΔC_{Dmax} is therefore 1/0.927 times this value, or 22.1% of SOC under long-term forest. As the CanSIS soil database has more data on SOC for conditions under longterm cropland than on SOC

Figure A3–27 Century-Simulated Soil Organic Carbon Following Conversion of Deciduous Forest to Cropland
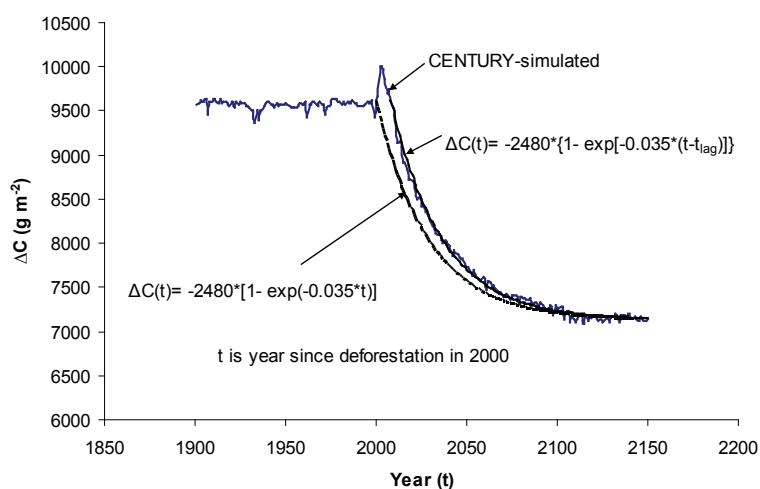
under long-term forest in areas where cropland exists, the maximal SOC losses were calculated relative to stabilized cropland SOC (i.e. loss = 0.221/(1−0.221) × SOC or loss = 0.284 × SOC under agriculture). Therefore, the final equation for estimating SOC loss for forest conversion to cropland in eastern Canada is:

Equation A3–72:

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

where:

ΔC(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 A3–73:

$$\Delta C_{FLCL} = \sum_{1970-2013} \sum_{ALLSLC} \sum_{t} (\Delta C_t \times AREA_{FLCL})$$

where:

ΔC_{FLCL}	=	total SOC loss in 2013 from the conversion of forest land to cropland since 1970, Mg C/ha
t	=	time after the conversion, year
ALL SLC	=	all soil polygons that contain forest land converted to cropland
ΔC_t	=	change in SOC for the tth year after conversion, Mg C/ha (See Equation A3–33)
$AREA_{FLCL}$	=	area of forest land converted to cropland annually since 1970, ha

Note that the SOC loss predicted by Equation A3–34 is in addition to C stock changes in tree biomass and woody DOM that existed in the forest at the time of forest conversion.

Based on the field observations, average N change in eastern Canada was -5.2%, representing 0.4 Mg N/ha (McConkey et al. 2007a). For those comparisons where both N and C losses were determined, the corresponding C loss was 19.9 Mg C/ha, and carbon loss was 50 times N loss. For simplicity, it was assumed

that N loss was a constant 2% of C loss. Thus, N_2O emissions from forest land converted to cropland are estimated using the following equation:

Equation A3–74:

$$N_2O_{FLCL} = \sum_{1970-2013} \sum_{ALLSLC} \sum_{t} (\Delta C_t \times AREA_{FLCL}) \times 0.02 \times EF_{BASE} \times \frac{44}{28}$$

where:

N_2O_{FLCL}	=	emissions of N_2O subject to conversion of forest to cropland since 1970, kt
ALL SLC	=	all soil polygons that contain forest land conversion
ΔC_t	=	change in SOC for the 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 A3.4.6)
44/28	=	coefficient converting N_2O-N to N_2O

Western Canada

Much of the current agricultural soil in western Canada was grassland prior to cultivation. Hence, forest conversion has been primarily of forest that adjoins grassland areas. There is also limited conversion of secondary forest that has grown on former grassland since the suppression of wildfires with agricultural development. Historically, forest conversion has been less important in western Canada than in eastern Canada, and fewer comparisons of SOC under forest and agriculture are available in the literature. Ellert and Bettany (1995) reported that there was no difference in SOC between native aspen forest and longterm 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 A3–54). 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- and below-ground tree biomass and coarse woody DOM that existed in the forest at the time of conversion. Similarly, average organic nitrogen change in western Canada for sites at least 50 years from breaking was +52% (McConkey et al. 2007a), reflecting substantial added N in agricultural systems compared with forests. However, recognizing the uncertainty about actual soil C–N dynamics upon conversion, forest land converted to cropland was assumed not to be a source of N_2O from the soil pool. N_2O emissions are reported wherever biomass burning occurs during conversion (see Section A3.5.2.1).

Data Sources

The approach used to estimate the area of forest land converted to cropland is described in Section A3.5.2.2. The annual forest conversion by reconciliation unit was disaggregated to SLC polygons on the basis of concurrent changes in the area of cropland within SLC polygons. Only polygons that showed an increase in cropland area for the appropriate time period were allocated to forest conversion, and the amount allocated was equivalent to that polygon's proportion of the total cropland increase within the reconciliation unit.

Uncertainty

The uncertainty of C change in each reporting zone was estimated differently for eastern and western Canada because of differences in C change estimation methods (McConkey et al. 2007b). For western Canada, an uncertainty of C change was estimated, although the mean value of SOC change factor was 0. The assumption was that the uncertainty of SOC change after forest land to cropland conversion in western Canada would follow a similar pattern as that for eastern Canada.

A3.5.4.   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: 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, "agricultural Grassland" is 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 CH_4 and N_2O emissions from natural or prescribed fires on agricultural grassland in Canada, are presented in the following section.

A3.5.4.1. 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 A3–75:

$$SOC = SOC_{REF} \bullet F_{MG} \bullet F_I$$

where:

SOC	=	soil organic carbon stock at any particular time since management and input change, Mg C ha^{-1}
SOC_{REF}	=	the reference soil organic carbon stock, Mg C ha^{-1}
F_{MG}	=	carbon stock change factor for management regime, dimensionless
F_I	=	carbon stock change factor for input of organic matter, dimensionless

The total area of managed grassland is calculated as follows:

Equation A3–76:

$$A_{2013} = GLGL_{1990} - \sum_{1990}^{2013} GLCL$$

where:

A_{2013}	=	the total area of grassland remaining grassland in 2013, 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 A3–77:

$$\Delta C_{GGMineral} = [(SOC_0 - SOC_{0-T}) \times A]/T$$

where:

$\Delta C_{GGMineral}$	=	the net change in SOC due to management and input from grassland remaining grassland, Mg C ha^{-1}yr^{-1}
SOC_0	=	soil organic carbon stock in the inventory year, Mg C ha^{-1}
SOC_{0-T}	=	soil organic carbon stock T years prior to the inventory year, Mg C ha^{-1}
A	=	area of change in management and input from grassland remaining grassland, ha
T	=	inventory time period, yr (default 20 yr)

If no change in management practices or input occurs, the C stocks are assumed to be at equilibrium, and hence the change in C stocks is deemed 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- and below-ground plant growth (Schuman et al. 2002; Liebig et al. 2005). An additional influence of grazing regime is the increased return of C in fecal matter as stocking rate increases (Baron et al. 2002). Bruce et al. (1999) estimated that there was no opportunity to increase SOC from grazing management improvements on extensively managed rangeland in North America.

The addition of organic amendments and inorganic fertilizer will increase the productivity of native grassland (Smoliak 1965), suggesting that these practices could increase SOC through greater C inputs. However, such practices are basically of academic interest, as the only economically practical management options for semi-arid grasslands are altering grazing regime, burning and introducing new plant species (Liebig et al. 2005).

Grasslands managed for grazing in western Canada in the Brown and Dark Brown soil zones of Alberta, Saskatchewan and British Columbia are occasionally burned by wildfire, and by prescribed burning for purposes such as brush management, habitat management, the removal of decadent vegetation and military training exercises. Burning from managed grassland is a net source of CH_4, CO, NO_x and N_2O.

Equation A3–78:

$$EMISSION_{BURN} = \sum (AREA_i \times FUELLOAD_i \times C_{F,i} \times G_{EF}) /1000$$

where:

$EMISSION_{BURN}$	=	emissions of CH_4 or N_2O from prescribed and non-prescribed burning of managed agricultural grassland, kt CH_4 or N_2O
$AREA_i$	=	area of the ith managed agricultural grassland subject to burning, ha
$FUELLOAD_i$	=	average fuel load for the ith managed agricultural grassland subject to burning, Mg DM ha^{-1}
$C_{F,i}$	=	combustion efficiency for the ith managed agricultural grassland subject to burning, fraction, unitless
G_{EF}	=	emission factor of CH_4 (2.7 g CH_4 kg^{-1} dry matter burnt) or N_2O (0.07 g N_2O kg^{-1} dry matter burnt) (IPCC 2006)
1000	=	conversion of mg to kt

Data Sources

Data sources for Grassland remaining Grassland are the same as A3.5.3.2 – Grassland converted to Cropland. There are no detailed comprehensive activity data over time on management change for Canadian agricultural grassland, except for wild and prescribed fires. Activity data on area, fuel load, and combustion efficiency for each burning event for managed agricultural grassland were collected through consultations (Bailey and Liang 2013).

A3.5.5. Wetlands

A3.5.5.1. Peat Extraction

Approximately 15 kha of peatlands are currently managed in Canada for the production of horticultural peat. The cumulative area of peatlands ever managed for this purpose amounts to 27 kha, the difference being peat extraction fields that are no longer under production. The production consists of horticultural peat only; Canada does not produce peat for use as fuel.

Virtually all peat extraction in Canada relies on vacuum harvest technology. However, many abandoned peat extraction fields were once exploited with the cut-block method; this influences the post-abandonment dynamics of vegetation regrowth.

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Owing to the extraction technology and desired properties of sphagnum peat, at the time of site selection, preference is given, among other factors, to open bog peatlands, which are classified as "Other Land" under Canada's land categorization framework for the LULUCF Sector. On average, 5% of pre-conversion area meets the definition of "Forest Land."

General Approach and Methods

Only CO_2 emissions from land converted to peat extraction and peat extraction lands remaining peat extraction lands were estimated. The estimation included the following sources: vegetation clearing and subsequent decomposition, decay of soil organic matter on sites drained during the inventory year and from fields under production, peat stockpiles, decay of peat transported off-site, abandoned peat fields, and restored peatlands. In any inventory year, emissions from land converted for peat extraction are expressed by Equation A3–80.

Equation A3–79:

$$CO_2\text{-}C_{L\_Peat} = CO_2\text{-}C_{BIOMASS} + CO_2\text{-}C_{DOMresidual} + CO_2\text{-}C_{SOILSextraction} + CO_2\text{-}C_{SOILS\,stockpiled} + CO_2\text{-}C_{SOILS\,off\text{-}site}$$

where:

$CO_2\text{-}C_{L\_Peat}$	=	total carbon emissions as CO_2 from land converted to wetlands (for peat extraction)
$CO_2\text{-}C_{BIOMASS}$	=	carbon emissions as CO_2 from the loss of carbon to forest products upon forest clearing
$CO_2\text{-}C_{DOM\,residual}$	=	carbon emissions as CO_2 from the decay of vegetation cleared no more than 20 years prior to the inventory year
$CO_2\text{-}C_{SOILS\,drained}$	=	carbon emissions as CO_2 from the oxidation of soil organic matter on peatlands drained during the inventory year
$CO_2\text{-}C_{SOILS\,extraction}$	=	carbon emissions as CO_2 from the oxidation of soil organic matter on productive peat extraction fields converted for no more than 20 years
$CO_2\text{-}C_{SOILS\,stockpiles}$	=	carbon emissions as CO_2 from the oxidation of stockpiled peat on productive peat extraction fields converted for no more than 20 years
$CO_2\text{-}C_{SOILS\,off\text{-}site}$	=	carbon emissions as CO_2 from the decay of peat transported off-site from productive peat extraction fields converted for no more than 20 years

Preconversion biomass (or biomass cleared) is estimated at an average of 20 t C/ha and 2.8 t C/ha for forest land and other land, respectively. Upon clearing, all forest biomass carbon is transferred to forest products (estimated at 63% of biomass, which is considered emitted to the atmosphere as CO_2 in the year of harvest) or DOM; the latter begins to decay in the same year, following an exponential decay curve as expressed in Equation A3–81.

Equation A3–80:

$$C_{DOM(t)} = C_{DOM(0)}\,e^{-kt}$$

where:

$C_{DOM(t)}$	=	amount of C in DOM for the tth year after conversion, Mg C/ha
$C_{DOM(0)}$	=	initial amount of C in DOM from land conversion to peat extraction, Mg C/ha
k	=	rate constant for describing the decomposition, year^{-1}
t	=	time since land conversion, years

On Wetlands remaining Wetlands (peat extraction), emissions are expressed as in Equation A3–82.

Equation A3–81:

$$CO_2 - C_{Peat} = CO_2 - C_{DOMresidual} + CO_2 - C_{SOILSextraction} + CO_2 - C_{SOILS\ off\text{-}site} + CO_2 - C_{SOILSabandoned} + CO_2 - C_{SOILSrestored}$$

where:

CO_2-C_{Peat}	=	total carbon emissions as CO_2 from wetlands remaining wetlands (peat extraction fields)
CO_2-$C_{DOM\ residual}$	=	carbon emissions as CO_2 from the decay of biomass cleared more than 20 years ago
CO_2-$C_{SOILS\ extraction}$	=	carbon emissions as CO_2 from the oxidation of soil organic matter on peat extraction fields converted for more than 20 years
CO_2-$C_{SOILS\ stockpiles}$	=	carbon emissions as CO_2 from the oxidation of stockpiled peat on peat extraction fields converted for more than 20 years
CO_2-$C_{SOILS\ off\text{-}site}$	=	carbon emissions as CO_2 from the decay of peat transported off-site from productive peat extraction fields converted for more than 20 years
CO_2-$C_{SOILS\ abandoned}$	=	carbon emissions/removals as CO_2 resulting from the net ecosystem production on abandoned (decommissioned) peat extraction fields
CO_2-$C_{SOILS\ restored}$	=	carbon emissions/removals as CO_2 resulting from the net ecosystem exchange on peatlands restored after peat extraction

Soil emissions from a productive peat field, "CO_2-$C_{SOILS\ extraction}$," are estimated with a single emission factor reflecting peat oxidation rates. Emissions from peat stockpiles are calculated as an exponential decay for half a year.

Canadian peat is transported off-site, largely to the United States, for non-energy uses such as horticulture, where it is assumed to decay in an aerobic environment. Due to the lack of information on decay rates by end use, it is assumed that all peat is emitted in the extraction year. Emissions of CO_2 are calculated based on an estimate of total organic carbon in the peat using a country-specific carbon fraction parameter (Table A3–55) derived from laboratory analysis of pure peat products with moisture contents ranging from 27 to 64%

Abandoned peat fields remain a persistent source of atmospheric CO_2 (Waddington and McNeil 2002) until carbon uptake by regrowing vegetation exceeds soil and residual DOM decay. In the current model, the emission factor on abandoned fields is reduced by a fixed annual amount to reflect the effect of gradual vegetation establishment and the slow decrease of emissions over several decades.

Current restoration practices consist of blocking drainage ditches, sowing the field with fresh moss spores and spreading a layer of straw on abandoned peat fields (to prevent desiccation). In the initial years of restoration, straw decomposition may further increase CO_2 emissions until vegetation re-establishes. Net carbon sequestration on restored peat fields is assumed to occur after five years, and its rate is subsequently maintained constant.

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Table A3–55 Parameters and Emission Factors for Estimating CO_2-C Emissions from Peat Extraction

Emission Factor/Parameter	Unit	Value
Forest land biomass cleared	t C/ha	20
Other land biomass cleared	t C/ha	2.8
Exponential decay constant, DOM		0.05
Emission factor on newly drained fields	g CO_2-C/m^2 per year	350
Emission factor on productive fields		
Vacuum-harvested	g CO_2-C/m^2 per year	1000
Block-cut	g CO_2-C/m^2 per year	1400
Emission factor on abandoned fields		
Exponential decay constant, stockpiles		0.05
Peat carbon fraction	t C/t air-dry peat	0.26
Annual decreas in emission factor, abandoned fields		
Vacuum-harvested	g CO_2-C/m^2 per year	15
Block-cut	g CO_2-C/m^2 per year	35
Emission factor, restored peatlands		
First year	g CO_2-C/m^2 per year	1800
> Five years	g CO_2-C/m^2 per year	-84

It is assumed that the non-growing season is six months long. In that period, emissions represent 15% of the annual total ecosystem CO_2 respiration, and gross primary production is zero.

Data Sources

Comprehensive information on the areas managed for peat extraction in Canada is not available. The Canadian Sphagnum Peat Moss Association confirmed that 14 kha were under production in 2004 (derived from Cleary 2003).[29] From this starting point, areas under production were modelled to fit the general trends in total domestic peat production (NRCan 2014). The annual area drained for peat extraction was assumed to be equal to the difference in total production areas between successive years, minus abandoned fields and restored peatlands. Areas of restored peatlands were obtained from restoration consultants and the Canadian Sphagnum Peat Moss Association. With the vacuum harvest technology, the average lifetime of a productive peat field is approximately 35 years (Cleary 2003). By default, land converted for more than 20 years is reported in the category Wetlands remaining Wetlands. National peat production statistics were used to represent the annual amount of extracted peat transported off-site.

Uncertainties

Emission factors were derived from flux measurements made mostly over abandoned peat extraction fields, which introduces significant uncertainty when applied to actively managed peat extraction fields, and peat stockpiles. All measurements were conducted in eastern Canada, adding uncertainties to estimates in western Canada. The large variation in moisture content among peat products may contribute substantially to the uncertainty of off-site peat CO_2 emission estimates.

A3.5.5.2. Flooded Lands

General Approach and Methods

Following the 2006 *IPCC Guidelines*, emissions from Land converted to Wetlands (creation of flooded lands, namely reservoirs) are estimated for all known reservoirs flooded for 10 years or less. Only CO_2 emissions are reported. An IPCC Tier 2 method was used, whereby country-specific CO_2 emission factors were developed based on measurements, as described below. Details can be found in Blain et al. (2013). It is believed that the default approach, assuming that all biomass carbon would be emitted upon flooding, would overestimate immediate forest conversion emissions from reservoir creation, because the majority of submerged forest biomass does not decay for an extended period of time.

Two complementary estimation methodologies are used to account for GHG fluxes from flooded lands, depending on land conversion practices. When there is evidence of forest clearing and/or burning prior to flooding, immediate and residual emissions from all forest carbon pools are estimated as in all forest conversion events since 1970, 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 A3.5.7).

In the absence of evidence of forest clearing, it was assumed that all vegetation was simply flooded, leading to the emission—as CO_2—of a fraction of the submerged carbon from the surface of the reservoir. The proportion of the area flooded that was previously forested was used to attribute these emissions to either the Forest Land converted to Wetlands category or the Other Land converted to Wetlands category.

Since 1993, measurements of CO_2 fluxes have been made above some 57 hydroelectric reservoirs in four different 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 33 measurements (Figure A3–28). It is important to note that each of these measurements (data points in Figure A3–28) 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.

29   Hood G, President, Canadian Sphagnum Peat Association. 2006. Personal communication dated December 15, 2006, to Dominique Blain, Environment Canada.

Equation A3–82:

$$CO_{2\,rate\,L\_reservoir} = b_0 + b_1 \times In(t)$$

where:

$CO_{2\,rate\,L\_reservoir}$	=	rate of CO_2 emissions from land converted to wetlands (reservoirs), mg/m2 per day
b_0, b_1	=	curve parameters, unitless
t	=	time since flooding, years

Total CO_2 emissions from the surface of reservoirs were estimated as the sum of all emissions from reservoirs flooded for 10 years or less:

Equation A3–83:

$$CO_{2\,L\_reservoirs} = \sum \left(CO_{2\,rate\,L\_reservoir} \times A_{reservoir} \times Days_{ice\,free} \times 10^{-8} \right)$$

where:

$CO_{2\,L\_reservoirs}$	=	emissions from lands converted to flooded lands (reservoirs), Gg CO_2/year
$CO_{2\,rate\,L\_reservoir}$	=	rate of CO_2 emissions for each reservoir, mg/m2 per day
$A_{reservoir}$	=	reservoir area, ha
$Days_{ice\,free}$	=	number of days without ice, days

$A_{reservoir}$ was used as the best available estimate of the area converted to managed wetlands (reservoirs), although in reality reservoirs may contain islands, i.e., emergent land areas. "Ice-free period" was defined as the average number of days between the observed freeze date and the breakup date of ice cover on a body of water (Magnuson et al. 2000). In the case of hydroelectric reservoirs, locations were mapped and estimates of the ice-free period were generated from the lakes–ice-free period isoline map of Canada (NRCan 1974).

Emissions were calculated starting on the year of flooding completion. Reservoirs take a minimum of one year to fill following dam completion, unless otherwise confirmed.

Data Sources

The three main data sources used to develop area estimates were 1) information on forest conversion due to reservoir impoundment in reporting zones 4 and 5 (see Section A3.5.2.2, Forest Conversion); 2) the Canadian Reservoir Database (Duchemin 2002); and 3) official industry numbers, derived from industry correspondence (Eichel 2006; Tremblay[30]).

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 but no changes occurred to the reservoir area.

As CO_2 emissions from the surface of reservoirs are reported only for the 10 years following impoundment, all flooding

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30   Tremblay A, Hydro-Québec. 2010. Personal communication dated November 19, 2010, to Dominique Blain, Environment Canada.

Figure A3–28   Logarithmic Curve Fit for National Reservoir Emission Factors

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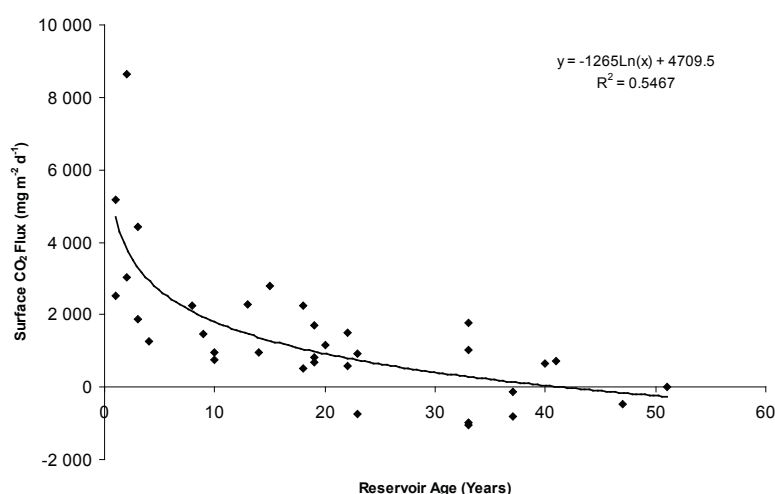
events since 1980 were used. The trend in area flooded is characterized by two distinct periods (Figure A3–29). The first, prior to 1994, was marked by large-scale flooding, which occurred in the early 1980s and still appeared under the Land converted to Wetlands category in the 1990–1993 inventory years. After 10 years, these reservoirs were removed from the accounting, and there was a corresponding decrease in the area to a low in 1994. Four reservoirs (Toulnustouc, Peribonka, Eastmain-1 and Rupert Diversion) have been recently created; flooding for Toulnustouc and Eastmain-1 reservoirs was completed in 2005 and 2006, respectively. Accounting of reservoir emissions for Peribonka and the Rupert Diversion started in 2008 and 2011, respectively; the 2015 submission includes emissions from both the forest clearing and associated flooding for these four sites.

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 the 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).

Planned Improvements

Planned improvements include developing improved estimates of the preconversion standing biomass, better understanding of conversion practices for both peat extraction and reservoir flooding, and integrating new emission measurements to the curve as they become available.

A3.5.6.   Settlements

This category comprises estimates of removals of CO_2 from land classified as Settlements remaining Settlements (carbon sinks in urban trees) and emissions from land conversion to settlements (conversion of forest land and of unmanaged grassland to settlements). The following two sections describe the approaches developed to estimate carbon sequestration by urban trees and emissions from the conversion of non-forest land (unmanaged grassland or tundra) to settlements in the Canadian Arctic and sub-Arctic. Approaches, methods and data sources for estimating emissions from the conversion of forest land to settlements are covered in Section A3.5.2.2.

Figure A3–29   Cumulative Areas in the Lands Converted to Wetlands (Flooded Lands) Category
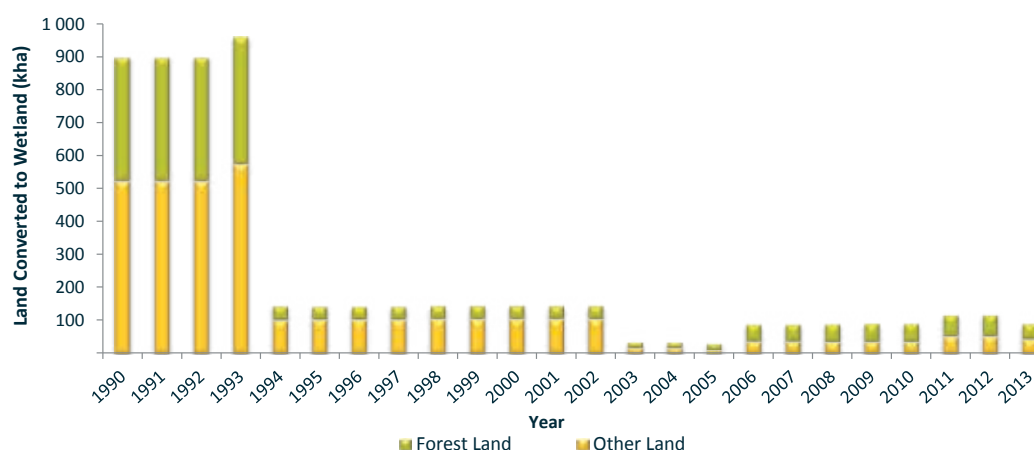
A3.5.6.1. Settlements Remaining Settlements

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 A3–84:

$$\Delta C_G = \sum AT \times CRW$$

where:

ΔC_G	=	annual carbon accumulation attributed to biomass increment of urban trees in Settlements remaining Settlements, tonnes C yr^{-1}
AT	=	total crown cover area of urban trees, ha
CRW	=	crown cover area-based growth rate for urban trees, tonnes C (ha crown cover)$^{-1}$ yr^{-1}

The total urban area of Canada in 2012 was estimated using the boundaries of Statistics Canada's 2011 populated place digital boundary layer,[31] as it was the most nationally consistent delineation of urban areas available. Of the 947 population centres (2.42 Mha) in Canada, 86 (1.63 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 67% of the total urban area in which approximately 76% of Canada's population lives (Statistics Canada 2011). While

31 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.

Figure A3–30 Sampling Grids and Point Sampling Over Georeferenced Air Photo
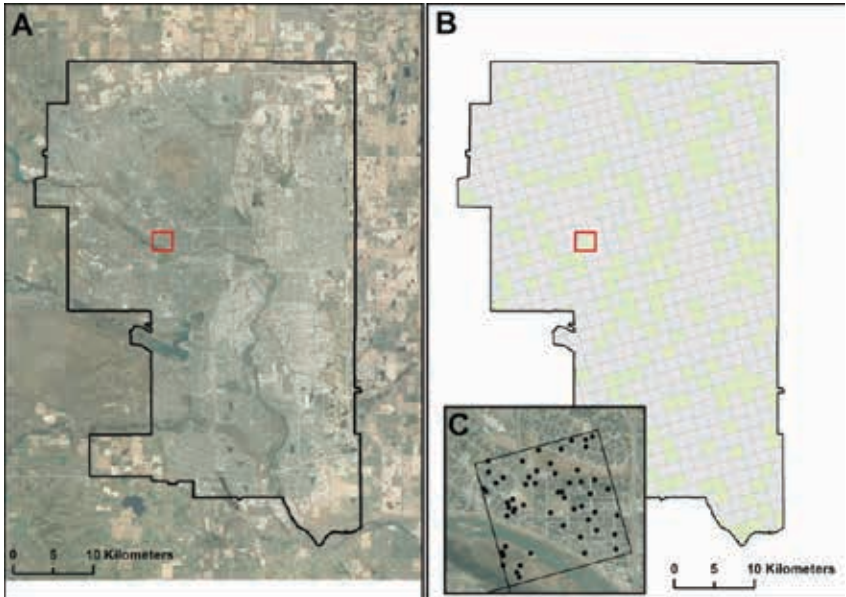
Background Imagery: (A) Calgary, Alberta urban area boundary, (B) 1 km × 1 km grid cells representing a 25% sampling rate with randomly selected grid cells shown in green, and (C) close-up of a single grid cell (20 pts/km2 sampling).Orthophoto courtesy of City of Calgary.

the population centres selected did not completely represent all populated places in Canada, many of the smaller communities filtered out are parts of an overall matrix of forest or agricultural land which may be captured under other land categories. The total urban area in 1990 was estimated using the boundaries of the 2012 estimates to identify the extent and location of urban area in the 1991 metropolitan layer (Statistics Canada 1992). The 1991 boundaries were then adjusted by manual editing using the 1990 GeoCover (MDA 2004[32]) land cover raster data set. The resulting 1990 urban layer represented a smaller total area (1.53 Mha) than the total urban area identified for 2012.

The 86 population centres were spatially allocated to 18 of the 60 reconciliation units (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 A3–30). Random points at a density of 55 points/km2 on digital air photos or high-resolution satellite imagery were interpreted manually and classed into broad categories of tree crown or non-tree crown.

The same sampling point locations were used for both the 1990 and 2012 UTC assessments, although sampling cells and points which fell outside the 1990 urban boundary were not included to ensure that sampling was restricted to representative 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 urban area has increased by 6% from 1990 to 2012, the national-scale estimate of crown cover changed little, with regional variation in trends. Gains in crown cover area (e.g. tree growth and planting) tended to balance with losses (e.g. tree removal, mortality and urban land-use change).

A Canadian specific crown cover area-based growth rate for woody perennials (CRW) based on field data did not exist. Therefore, a domestic CRW value (2.12 t C/ha) was derived from data sets for the United States (Nowak et al. 2013), adjusting for Canada's shorter average growing season (on average 133 days). Net carbon sequestration was estimated as 74% of gross sequestration, accounting for urban tree growth characteristics and tree mortality and decomposition (Nowak et al. 2013). These growth and sequestration factors are applied consistently to all regions of the country and, as a result, estimates of urban tree

crown cover area are the main driver of overall removal estimates. Interpolation and extrapolation techniques were used to develop a consistent time series for the 1990–2013 period.

Uncertainty

The uncertainties associated with the estimates of urban area, UTC and carbon sequestration rate all contribute to the overall uncertainty of the estimates of CO_2 removals by urban trees. The result of these combined uncertainties using a Tier 1 error propagation approach was estimated as an estimated total uncertainty of 30% for 1990 and 27% for 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 (US EPA, 2013). The error associated with the 1990 urban area estimate was assumed to be slightly higher at 15% than for 2012, based on expert judgement. This approach is similar to the uncertainty estimate for boundary delineation (15%) used for developing forest conversion estimates (Leckie 2011).

The uncertainty associated with UTC estimates was based on the standard error of the sampling approach calculated for each sampling period (1990/2012). Standard errors for the UTC estimates were low (0.2% for the national UTC estimate) given the very high number of sampling points used.

The uncertainty estimate for the national gross carbon sequestration rate (16%) was developed from sampling error associated with urban tree field data collected in the United States. This uncertainty estimate does not include the estimation error related to using biomass equations, conversion factors and measurement error (Nowak et al. 2013).

A3.5.6.2. Non-Forest Land Converted to Settlements

General Approach and Methods

The Canadian northern regions (Arctic and sub-Arctic) cover nearly half of Canada's land mass and include five land categories (IPCC 2006), except Cropland. This assessment covered an area of about 359 million ha and included reporting zones 1, 2, 3 and 17, some small northern areas of reporting zones 4, 8 and 10, as well as reporting zones 13 and 18 north of 60°N latitude. The challenge was to capture land-use change and estimate associated emissions in this vast and remote landscape. An approach was developed specifically for this task and included the following components:

1. Map non-forest land-use change in Canada's Arctic/sub-Arctic prior to and including 1990 and between 1990 and 2000.
2. Estimate annual GHG emissions (above-ground biomass only) from non-forest land-use change in Canada's Arctic/sub-Arctic for the 1990–2000 period.

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32   Info on MDA GeoCoveravailable at: http://www.mdafederal.com/geocover/geocoverlc/gclcoverview/.

A comprehensive, wall-to-wall analysis over this area was clearly impractical, as this would require on the order of 100 Landsat satellite scenes for each date. Similarly, random sampling would likely not capture enough land-use change events to allow a reliable assessment. Instead, GIS data sets denoting the occurrence of cultural, mining and other human development were used to reduce and optimize the domain of investigation, by flagging areas with high probability of occurrence of landuse change. These areas of concentrated land-use change potential were targeted for change detection analysis (change vector analysis – Johnson and Kasischke 1998) using 23 Worldwide Reference System Landsat frames from circa 1985, 1990 and 2000. The scenes cover more than 8.7 million ha, 56% of the potential land-use change area identified using the GIS data sets, or 70% of potential land-use change area if seismic survey lines are not included.[33] All 23 frames were located in the western Arctic and sub-Arctic regions.

The Land Use Change Mapping System for Canada's North (Butson and Fraser 2005), can be described as a hybrid change detection method based on two separate techniques: change vector analysis for identifying changed areas and constrained signature extension for labelling those changes (Olthof et al. 2005). A detailed description of how the Land Use Change Mapping System for Canada's North was used for the purpose of capturing non-forest land-use change in Canada's north is available in Fraser et al. (2005). The average rate of land-use change between 1985 and 2000 over the assessed area was 666 ha/year, and 60% of land-use change areas occurred in reporting zone 13. Lack of

33   Recent, low-impact seismic lines have a narrow swath of approximately 2 m in width, as opposed to conventional ones, which were much larger (~8 m). Low-impact seismic lines were widely adopted over the past decade and considerably reduce the environmental impact of seismic exploration.

available imagery prevented the implementation of the system beyond 2000; therefore, the same annual rate of land-use change was applied for the years 2001–2013.

A series of above-ground biomass maps in 2000 were developed for the main land-use change areas, using relationships between above-ground biomass and remote sensing data constructed from and calibrated with ground measurements (Figure A3–31). These maps were used to determine CO_2 emissions from the clearing of above-ground biomass.

The dominant land cover types in the two study areas are rock, lichen, low to high shrub, grass and sparse woodland.

Multiple regressions were conducted between natural logarithm (ln) (above-ground biomass) and a combination of image signals for all vegetation covers combined (grass, shrub, sparse woodland). The best least square approximation had an $r^2 = 0.72$–0.78, dependent on approaches used, a relative mean square error of 75–80%, and a median value of the absolute percentage error of 33–53%. Biomass regressions were applied to the preconversion imagery for all land-use change areas to yield an estimate of the biomass cleared. All land-use change activities involved conversion of tundra vegetation to settlements, and all preconversion biomass carbon was deemed emitted upon clearing.

Since the 2007 submission, additional imagery was analyzed with the change detection method used for forest conversion area estimation. Reporting zone 4 and part of reporting zone 8 were fully mapped for both forest and non-forest conversion to settlements, adding 55 Mha to the area already mapped. The above-ground biomass of non-forest vegetation was derived from a literature search and estimated at 6 kt/ha (or 3 kt C/ha). For this

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Figure A3–31   Study Areas for the Determination of Above-Ground Biomass in Canada's Arctic and Sub-Arctic Region
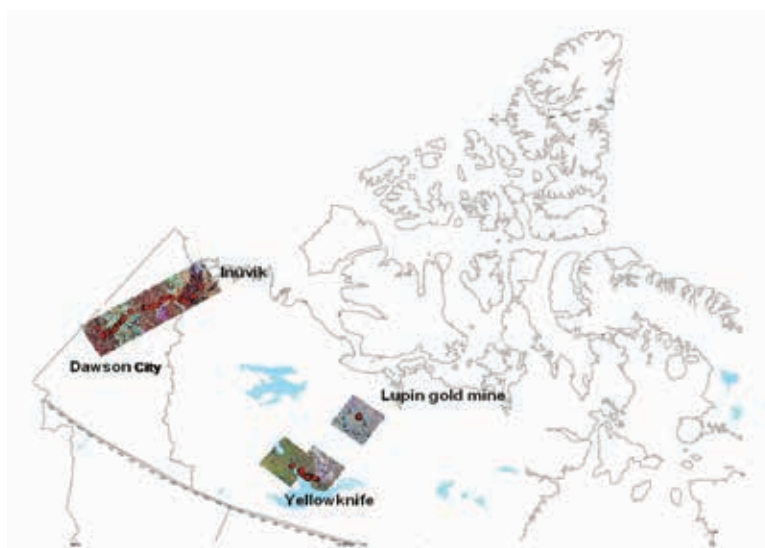
region, there was an average rate of non-forest land-use change of 133 ha/year for the 1990–2006 period.

When only the above-ground biomass component is considered, land-use change activities for the non-forested regions of Canada's north released on average an estimated 153 kt CO_2 eq per year in the 1990–2013 period.

Uncertainty

The uncertainty in land-use change area covered by the 23 Landsat scenes is estimated to be within 20% (Fraser et al. 2005). The biomass equations developed from field measurements in the Dawson City study area were validated on the other study areas of Yellowknife and the Lupin mine. The median values of the absolute percentage error in above-ground biomass estimation for both study areas are 33–53%.

A Monte Carlo simulation method was used to quantify the overall error in carbon emissions caused by uncertainties in landuse change area and biomass estimation. At the 95% confidence level, the percentage error varies from 218% if there is only one land-use change site within a reporting zone to 15% if a reporting zone has 75 or more land-use change sites. The error in the total above-ground biomass carbon stock change estimate, if considered as one reporting area, is about 15%. A full discussion of uncertainty can be found in Chen et al. (2005, 2009).

A3.5.7. Harvested Wood Products

There is broad scientific agreement on the inaccuracy introduced by the assumption used in previous GHG inventory submissions that all carbon transferred out of managed forests from harvesting is immediately oxidized and released to the atmosphere.

Instead, a large proportion of the carbon removed from forests is stored in wood products, and eventually released over the product lifetime and at the point of disposal.

Starting with this submission, the LULUCF Sector of the inventory includes an estimate of the CO_2 emissions associated with the use and disposal of Harvested Wood Products manufactured from wood coming from forest harvest and forest conversion activities in Canada, and consumed either in Canada or elsewhere in the world, in accordance with the general framework of the Production Approach described in the Annex to Volume 4, Chapter 12 of the 2006 IPCC Guidelines (IPCC 2006). The approach tracks the fate of C in all woody biomass harvested domestically and taken off-site. Emissions of CO_2 from HWP use and disposal are estimated and reported by the LULUCF Sector, while CH_4 and N_2O emissions from HWP combustion or domestic decomposition are estimated and reported by the Waste and Energy sectors.

General Approach and Methods

A new country-specific model has been developed to estimate and report on the fate of C harvested in Canada's forests: the National Forest Carbon Monitoring, Accounting and Reporting System for Harvested Wood Products (NFCMARS-HWP). This new model has been built as an upgrade of the Carbon Budget Model Framework for Harvest Wood Products (CBM-FHWP) that was used to prepare preliminary estimates for HWP reported in Table 7.6 of the 2014 National Inventory Report (NIR).

Model Inputs and Data Sources

Input to the model includes the annual mass of C transferred to forest products that result from harvesting in forest lands and from forest conversion activities since 1990; it is spatially distrib-

Figure A3–32   A Simplified Schematic of Carbon Flows in Harvested Wood Products
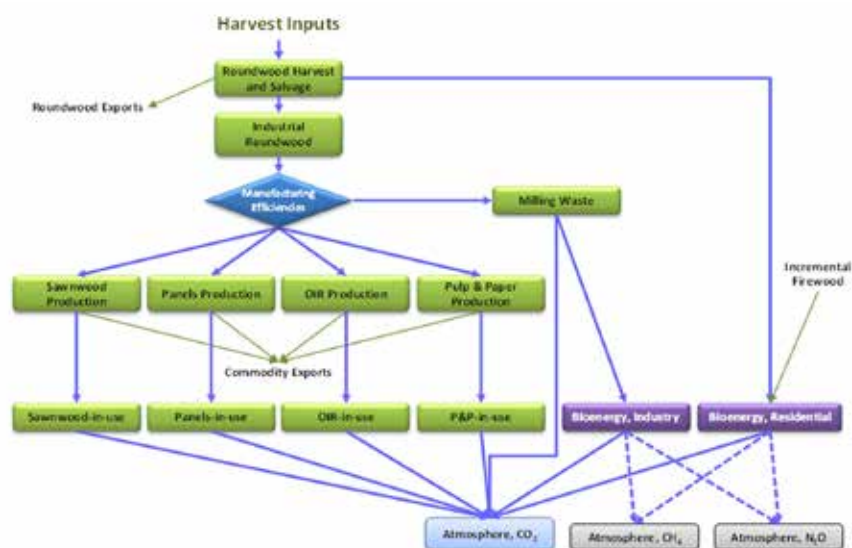
Table A3–56   Default Parameter Values Used in HWP Analysis

Description	Units	Value	Source
Bark expansion factor, Softwoods	dimensionless	1.11	IPCC 2006 (Vol. 4, Table 12.5)
Bark expansion factor, Hardwoods	dimensionless	1.15	IPCC 2006 (Vol. 4, Table 12.5)
Bark expansion factor, Mixedwoods	dimensionless	1.13	IPCC 2006 (Vol. 4, Table 12.5)
C content of wood	tonnes C/od tonne[1]	0.5	IPCC 2006 (Vol. 4, Table 12.4)

1. Tonnes carbon per oven dry tonne of wood material

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uted 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. Additional input includes the C associated with the annual volume of residential firewood provided by the Energy Sector, in excess[34] of firewood statistics already contained in the National Forestry Database Program (NFDP). For historical harvest, the C input comes from commodity production from Statistics Canada, at a national level of spatial resolution and covering the period 1941-1989.

Model Flow and Parameters

The model uses a conceptual flow network describing the movement and transformation of harvested wood once it leaves the forest (Figure A3–32). 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 bioenergy pools. The complete model consists of 15 such networks—one for each province and territory (except Nunavut), plus one for each of the United States, Japan, and 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 Forest Land.

The FAO database of forestry trade flows was used to determine the proportion of Canadian roundwood and commodity production exported to the three main destinations. For example, in any given year around 75% of industrial roundwood from domestic harvest remains in Canada for further transformation. Likewise, over the entire time series, around 30% of sawnwood, between 40% and 75% of wood-based panels and less than 10% of pulp and paper are used domestically. The longevity of HWP in-use 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 carbon content were used for all countries (Table A3–56). Default parameters were used to convert product volume to units of carbon for countries other than Canada and the U.S., and where country-specific parameters are not available for Canada or the U.S. (Table A3–57). 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 U.S. Default values were used for domestic and imported quantities for Japan and elsewhere. It is assumed that all wood fibre feedstock produced in a given year is processed by the forest products manufacturing sector in the same year.

The model starts the pool in 1941 and applies product in-use half-life parameters to wood product types based on geographic location. Half-life parameters are sourced directly from Table 3a.1.3 of IPCC (2003), or derived from that table using production-weighted averages to fit the wood product categories of the NFCMARS-HWP (Table A3–56).

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 and N_2O in amounts that are dependent on the combustion technology used. Data come from a survey of residential wood use in

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34   Difference between NFDP statistics and the annual volume provided by the Energy Sector.

Table A3–57   Wood Densities of Commodities

Country/ Countries	Description	Units[1]	Value	Source
Canada	Species-weighted average density, Roundwood	od tonne/m³	0.386	Derived
Canada	Species-weighted average density, Sawnwood	od tonne/m³	0.481	Derived
Canada	Species-weighted average density, Other Industrial Roundwood	od tonne/m³	0.583	Derived
Canada	Species-weighted average density, Panels	od tonne/m³	0.643	Environment Canada
Canada	Species-weighted average density, Bioenergy	od tonne/m³	0.523	Derived
U.S.	Coniferous (C) roundwood	od tonne/green m³	0.455	FAO 2010
U.S.	Nonconiferous (NC) roundwood	od tonne/green m³	0.527	FAO 2010
U.S.	C+NC roundwood	od tonne/green m³	0.465	FAO 2010
U.S.	Hardwood (HW) plywood & veneer	tonnes C/m³	0.28	Skog 2008
U.S.	Softwood (SW) lumber	tonnes C/m³	0.22	Skog 2008
U.S.	HW lumber	tonnes C/m³	0.26	Skog 2008
U.S.	Particle board	tonnes C/m³	0.29	Skog 2008
U.S.	Hardboard	tonnes C/m³	0.42	Skog 2008
U.S.	Medium Density Fibreboard	tonnes C/m³	0.32	Skog 2008
U.S.	Fibreboard, compressed	tonnes C/m³	0.37	Derived
U.S.	Pulp, paper & board	tonnes C/ad tonne	0.42	Skog 2008
U.S.	Insulating board	tonnes C/m³	0.45	Skog 2008
All	Sawnwood - C	od tonne/m³	0.45	IPCC 2006 (Vol. 4, Table 12.4)
All	Sawnwood - NC	od tonne/m³	0.45	IPCC 2006 (Vol. 4, Table 12.4)
All	Panels, structural	od tonne/m³	0.628	IPCC 2006 (Vol. 4, Table 12.4)
All	Panels, non-structural	od tonne/m³	0.628	IPCC 2006 (Vol. 4, Table 12.4)
All	Paper	od tonne/ad tonne	0.9	IPCC 2006 (Vol. 4, Table 12.4)
All	Wood Pulp	od tonne/ad tonne	0.9	IPCC 2006 (Vol. 4, Table 12.4)

Note:
1. od tonne = oven dry tonne of wood material, ad tonne = air dry tonne of product

Table A3–58   Half-Life Parameters (Years) of Harvested Wood Products In-use

Country/ Countries	Description[1]	Value	Source
Canada	Sawnwood	35	IPCC 2003 (Appendix 3a.1, Table 3a.1.3)
Canada	Wood panels	25	Derived from IPCC 2003 (Appendix 3a.1, Table 3a.1.3)
Canada	Pulp and paper	2	IPCC 2003 (Appendix 3a.1, Table 3a.1.3)
Canada	Other industrial roundwood	35	IPCC 2003 (Appendix 3a.1, Table 3a.1.3)
U.S.	Sawnwood	40	IPCC 2003 (Appendix 3a.1, Table 3a.1.3)
U.S.	Wood panels	27	Derived from IPCC 2003 (Appendix 3a.1, Table 3a.1.3)
U.S.	Pulp and paper	3	Derived from IPCC 2003 (Appendix 3a.1, Table 3a.1.3)
U.S.	Other industrial roundwood	40	IPCC 2003 (Appendix 3a.1, Table 3a.1.3)
Rest of world	Sawnwood	35	IPCC 2003 (Appendix 3a.1, Table 3a.1.3)
Rest of world	Wood panels	25	Derived from IPCC 2003 (Appendix 3a.1, Table 3a.1.3)
Rest of world	Pulp and paper	2	IPCC 2003 (Appendix 3a.1, Table 3a.1.3)
Rest of world	Other industrial roundwood	35	IPCC 2003 (Appendix 3a.1, Table 3a.1.3)

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

1995 and extrapolated for other years based on 1995 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. Emissions are derived by multiplying the amount of wood burned in each appliance type by the emission factor for that appliance type. The relevant emission factors are given in Table A6-31, 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. Data on industrial consumption of biomass and spent pulp liquors are reported in the annual Report on Energy Supply and Demand in Canada (RESD). 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 A6-31. 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 current approach introduces certain methodological inconsistencies and requires improvement in future submissions. First, some of the wood used as domestic firewood is removed from harvest slash that will be considered as decomposing in the forest ecosystem model. There is therefore a possibility of some double-counting of emissions. Second, another part of domestic firewood may be extracted from areas outside of the managed forest, such as private woodlots, shelterbelts or agricultural land, for which the growth of the trees is not included in the CBM-CFS3 model. The emissions are therefore not off-set by the sink associated with tree growth.

Uncertainty

Uncertainty associated with this category is greatly influenced by the uncertainty of the carbon inputs, namely: i) the carbon estimated as forest products from forest harvest and forest conversion in the CBM-CFS3 model; ii) the incremental volume of residential firewood provided by the Energy Sector; and iii) available statistics of pre-1990 harvest. Efforts are being made to produce uncertainty estimates, and a formal assessment is planned to be conducted for the next inventory submission.

A3.6. Methodology for Waste Sector

The Waste Sector consists of three sources of emissions: solid waste disposal on land (landfills), wastewater treatment, and waste incineration. This section of Annex 3 details the accounting methodologies that are used to describe the greenhouse gas (GHG) emission estimates for the following categories from the Waste Sector:

- CH_4 emissions from solid waste disposal on land;
- CH_4 and N_2O emissions from wastewater treatment; and
- CO_2, CH_4, and N_2O emissions from waste incineration.

A3.6.1. CH_4 Emissions from Solid Waste Disposal on Land

A3.6.1.1. Methodology

Emissions are estimated from two types of landfills in Canada:

- municipal solid waste (MSW) landfills; and
- wood waste landfills.

The Scholl Canyon model is used to estimate CH_4 generation from landfills using the following first-order decay equation (IPCC 2000):

Equation A3–85:

$$Q_{T,x} = kAM_xL_0e^{-k(T-x)}$$

where:

$Q_{T,x}$	=	the amount of CH_4 generated in the current year (T) by the waste Mx, kt CH_4/year
X	=	the year of waste input
M_x	=	the amount of waste disposed of in year x, Mt
k	=	CH_4 generation rate constant, yr^{-1}
A	=	Normalization Factor $((1/e^{-k})-1)/k)$
L_0	=	CH_4 generation potential, kg CH_4/t waste

Equation A3–86:

$$Q_T = \sum Q_{T,x}$$

where:

Q_T	=	The amount of CH_4 generated in the current year (T), kt CH_4/year

Figure A3–33   Scholl Canyon Model Representation of Landfill Degradation
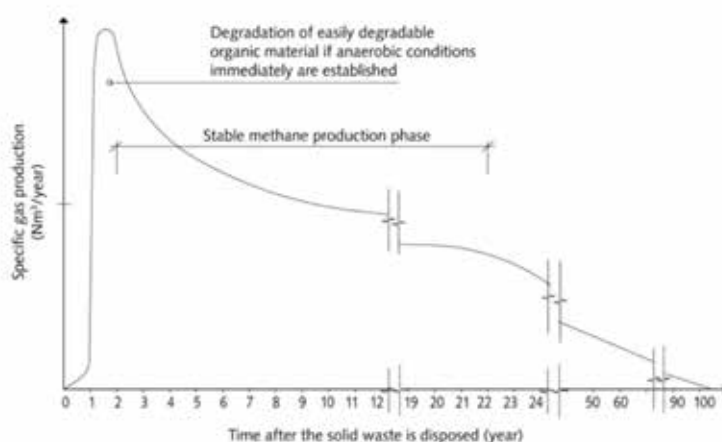
Note:
Figure is from Jensen and Pipatti (2003) and is shown as published without modification.

A3

The normalization factor, presented in Equation A3–85, is in its corrected form as provided in the IPCC 2006 Guidelines (IPCC 2006).

Figure A3–33 provides the typical landfill gas production rate variation over a time series after the waste has been deposited. The Canadian landfill emission estimation is based on the Scholl Canyon model and assumes that CH_4 production is highest in the early phase, followed by a slow steady decline in annual production rates. It also assumes that the initial lag time where anaerobic conditions are established is negligible, as shown in Figure A3–33.

In order to estimate CH_4 emissions from landfills, information on several of the factors described above is needed. To calculate the net emissions for a specific year and province/territory, the total captured gas quantities (to be flared and or utilized) are subtracted from the generated CH_4 quantities (the sum of $Q_{T,x}$ for every portion of waste landfilled in past "x" years), then to this result the CH_4 emitted from the incomplete combustion of the flared portion of captured gas is added. A computerized model has been developed to estimate aggregate emissions on a regional basis in Canada.

Waste Disposed of Each Year (M_x)

MSW Landfills

For the purposes of the inventory, MSW includes residential; institutional, commercial and industrial (ICI); and construction and demolition (C&D) wastes. Two primary sources are used in obtaining landfill data for the GHG inventory. The amount of MSW landfilled in the years 1941 through 1990 was estimated by Levelton (1991). Starting from 1998 and biennially for

subsequent years to 2010 inclusively, MSW disposal data were obtained from the *Waste Management Industry Survey*, which is conducted by Statistics Canada on a biennial basis (Statistics Canada, 2000, 2003, 2004, 2007a, 2008a, 2010a, 2013a). MSW disposal values for the subsequent odd years (1999, 2001, 2003, 2005, 2007 and 2009) are obtained by taking an average of the adjacent even years. Disposal, with respect to the Statistics Canada data, refers to the combination of waste incinerated, exported and waste landfilled. Therefore, in order to obtain the amount of waste landfilled, incinerated waste and exported waste quantities are subtracted from the Statistics Canada disposal values for 1998 to 2013. The amount of waste exported is included in the waste disposal values for the Statistics Canada 2000 survey year and subsequent years.[35,36] Waste disposal data compiled by Statistics Canada in the Waste Management Industry Survey are the most complete data available, as the coverage of respondents includes the collection and transportation of non-hazardous and hazardous waste disposal facilities, the operation of transfer stations and the treatment and disposal of waste deemed to be hazardous for activities undertaken by companies, local governments and other public waste management bodies. A methodology is used to account for those populations that do not meet the population threshold as detailed in the following extract from the survey text: "…a survey coverage population was developed using information provided by survey respondents as well as from other sources about the municipalities that were served by disposal and recycling facili-

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35   Marshall J. 2006. Personal communication (February 2006). Manager of the Waste Management Industry Survey: Business and Government Sectors, 2002 Report. Statistics Canada.

36   Marshall J. 2007. Personal communication (email dated February 21, 2006). Manager of the Waste Management Industry Survey: Business and Government Sectors, 2004 Report. Statistics Canada.

Table A3–59   Multiple Linear Regression Polynomial Coefficients Used in Estimating the Amount of MSW Landfilled for 1991–1997

	N.L.	N.S.	N.B.	Que.	Ont.	Man.	Sask.	Alta.	B.C.
C	6.87E+09	8.60E+09	−1.87E+10	2.18E+11	−2.91E+10	−8.47E+09	3.96E+10	−4.35E+11	1.70E+12
C_1	−1.97E+06	−3.22E+06	4.22E+06	−4.70E+08	−2.37E+07	3.28E+06	6.20E+06	4.13E+08	−1.17E+09
C_2	3.14E+03	−1.02E+04	−7.88E+02	8.18E+05	2.49E+04	5.10E+03	−1.39E+04	−4.96E+04	2.53E+04
C_3	1.62E+00	2.65E+00	2.26E+00	−3.18E+02	1.50E+01	−5.77E−01	−1.75E+01	−3.04E+01	−1.65E+02
C_4	8.20E−06	−1.59E−03	1.30E−03	−2.15E−01	−5.96E−03	−1.51E−03	3.28E−03	−4.42E−03	8.23E−02
C_5	−9.81E−08	2.46E−06	−5.70E−07	4.76E−05	−1.68E−06	−2.78E−07	3.72E−06	2.21E−05	1.52E−06
C_6	−1.63E−10	8.20E−10	3.21E−10	4.16E−08	1.13E−09	1.51E−10	7.74E−10	−1.55E−08	3.39E−08
C_7	−8.88E−14	−2.11E−13	−2.43E−14	5.93E−12	−3.00E−14	2.72E−13	−4.58E−13	−1.02E−12	−5.11E−12
C_8	−6.34E−17	−1.50E−16	−1.09E−16	6.56E−15	−8.94E−16	−7.69E−17	8.21E−17	4.03E−15	−2.76E−15
C_9	5.40E−20	−2.03E−19	−2.03E−20	−5.89E−18	−2.33E−19	−5.56E−20	7.12E−20	−1.61E−18	−2.24E−19
C_{10}	−1.48E−24	3.34E−24	−1.30E−23	−1.91E−21	2.36E−22	1.74E−23	−1.54E−22	4.04E−22	3.44E−22
C_{11}	−6.62E−28	2.48E−26	9.41E−27	1.61E−25	1.08E−25	8.89E−27	6.66E−26	8.76E−26	−9.63E−25
C_{12}	3.03E−30	2.21E−29	2.63E−30	5.53E−28	−2.26E−29	−3.09E−30	−2.86E−29	−9.54E−29	3.59E−28
C_{13}	−1.32E−33	−7.77E−33	−3.92E−34	−1.00E−31	−1.03E−32	−6.66E−35	7.64E−33	1.57E−32	−6.11E−33

Notes:
Coefficients have been rounded and may not result in the correct totals for MSW landfilled.

ties. Total populations were calculated for these municipalities using Statistics Canada data. The difference between the total population and the covered population was calculated. A provincial per capita disposal figure was applied to this undercovered population, and this total was added to the survey total to arrive at an adjusted disposal figure. The undercovered portion of the population is small and has been decreasing with each iteration of the survey."

Over the period 1991–1997, with the exception of Prince Edward Island, the Northwest Territories, Nunavut and Yukon, MSW landfill values were estimated by fitting a polynomial to the Levelton (1991) and Statistics Canada (2000, 2003, 2004) MSW landfill values. Data for 2011, 2012 and 2013 were trended from earlier waste quantity values. To estimate the coefficients in the polynomial, a multiple linear regression application (Microsoft Excel LINEST statistical tool for an array) is used. The choice of how many coefficients to use for the polynomial function depended on how well the data fit the lowerorder polynomials. Generally, the polynomial fit was improved with increasing number of coefficients. A polynomial of the order 13 is used in the inventory MSW estimates. This multiple linear regression method of estimation is consistent with the Intergovernmental Panel on Climate Change (IPCC) interpolation method (IPCC 2000). Table A3–59 shows the polynomial coefficients generated by the multiple linear regression method for each of the provinces.

The amounts of MSW landfilled for the years 1991–1997 are calculated according to the following equation:

Table A3–60   Canadian Exports of Non-Hazardous Wastes

	Non-Hazardous Waste Exported to U.S. (t)			
Year	Ontario	Quebec	B.C.	Total
1989	100 000	7 000	20 283	127 283
1990	100 000	7 000	20 283	127 283
1991	100 000	7 000	20 283	127 283
1992	1 300 000	90 720	262 867	1 653 587
1993	1 300 000	90 720	262 867	1 653 587
1994	1 000 000	58 735	170 189	1 228 924
1995	1 046 398	26 750	77 511	1 150 660
1996	776 652	20 380	66 269	863 302
1997	770 822	17 195	55 027	843 044
1998	817 071	14 010	32 542	863 623
1999	782 286	73 826	35 235	891 347
2000	1 366 382	91 205	37 928	1 495 516
2001	1 792 287	9 718	46 318	1 848 323
2002	2 083 654	85 438	54 708	2 223 800
2003	2 940 903	85 354	71 487	3 097 743
2004	3 629 172	133 761	88 266	3 851 199
2005	3 728 170	136 236	96 656	3 961 062
2006	3 879 461	224 923	105 046	4 209 429
2007	3 988 280	667 026	118 168	4 773 475
2008	3 644 997	402 614	103 951	4 151 562
2009	3 127 662	389 620	115 428	3 632 711
2010	2 836 269	188 148	150 156	3 174 572
2011	3 374 223	88 153	227 554	3 689 930
2012	2 558 031	499 585	238 705	3 296 321
2013	2 747 859	411 624	234 720	3 394 204

A3

Equation A3–87:

$$M_x = (C_{13} \times X^{13}) + (C_{12} \times X^{12}) + (C_{11} \times X^{11}) + (C_{10} \times X^{10}) + (C_9 \times X^9) + (C_8 \times X^8) + (C_7 \times X^7) + (C_6 \times X^6) + (C_5 \times X^5) + (C_4 \times X^4) + (C_3 \times X^3) + (C_2 \times X^2) + (C_1 \times X) + C$$

where:

M_X	=	MSW landfilled in year X, t
C_i	=	coefficient of the ith order (see Table A3–59)
x	=	year of interest

Statistics Canada MSW disposal data are unavailable for Prince Edward Island, the Northwest Territories, Nunavut and Yukon. Thus, MSW landfill values for this province and these territories for the period 1991–2013 are obtained by trending historical landfill data with the provincial populations for 1971–2013 (Statistics Canada 2006, 2014). Three sources of landfill data are used to estimate the MSW landfill amounts for 1991–2013. The first set of data was provided by Levelton (1991) for 1971–1990. The second set of landfill data was provided by the Hazardous Waste Branch of Environment Canada for 1992 (Environment Canada 1996b). The third set of landfill data involves multiplying the 1992 percentage of waste landfilled for Prince Edward Island, the Northwest Territories, Nunavut and Yukon (Environment Canada 1996b) by the surplus of waste landfilled provided by Statistics Canada for 1998, 2000, 2002, 2004 and 2006 (Statistics Canada 2000, 2003, 2004, 2007a, 2008a). The surplus of waste landfilled for 1998, 2000, 2002, 2004 and 2006 is calculated by subtracting the sum of the provided provincial landfill values from the total Canadian landfill value.

The estimates of exported solid waste were developed from information solicited by Canada directly from the individual states in the United States where the waste was accepted for disposal (Environment Canada 2013a and 2014a). It was found that the exporting provinces do not track the quantities of non-hazardous wastes leaving the province to the U.S. However, from information obtained from the U.S. CRS[37] Reports for Congress (CRS 1990, 1993, 1995–1998, 2000–2002, 2004 and 2007), the Michigan DEQ[38] Solid Waste Reports for 1996–2011 (Michigan 1996–2011) and from communications with state officials and with representatives of individual landfill facilities in pertinent waste receiving states—Michigan, Washington, New York, Ohio, Montana, Indiana, Pennsylvania and North Dakota—a more complete and accurate data set was compiled to replace the previous set that was based mostly on Ontario exports. A summary of the exported waste quantities is provided in Table A3–60.

Table A3–61 shows the amount of MSW landfilled for the period 1990–2013.

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37   Congressional Research Service.

38   Department of Environment Quality.

Wood Waste Landfills

The amount of wood waste landfilled in the years 1970 through 1992 is estimated at a national level based on the National Wood Residue Data Base (NRCan 1997). Data for the years 1998 and 2004 are provided in subsequent publications (NRCan 1999, 2005). A linear regression trend analysis is conducted to interpolate the amount of wood residue landfilled in the years 1993–1997 and 1999–2003. An exponential growth function was used to extrapolate wood residue quantities landfilled for the years 2005–2013 so as to reflect the expected exponential reduction in landfilled quantities. These interpolation methods were selected because they are most suitable for the data distribution.

The breakdown in the amount of wood residue disposed of (defined as residue that is not further used in a product, used as a source of fuel, or converted into a chemical) for the solid wood operations and the pulp and paper industries is estimated based on information from a study of pulp and paper mill waste (MWA Consultants Paprican 1998). The proportion of wood waste disposal is estimated at 80% for solid wood operations and 20% for pulp and paper mills.

The breakdown of the portion of the wood residue directed to landfills from the solid wood and pulp and paper industry operations is estimated based on the National Wood Residue Data Base (NRCan 1997). The allocation of wood waste landfilled in private landfills is estimated at 15% for solid wood operations and 86% for pulp and paper mills. To avoid double counting, since emissions from public landfills are already accounted for in the emissions from MSW landfills, the ratio of wood waste landfilled in private versus public landfills, obtained from NRCan (1997), is used to isolate the quantity landfilled in dedicated private wood waste landfills. This portion is assumed to be also true for the years 1970–2013. Table A3–62 shows the amount of wood waste disposed of and landfilled for the period 1990–2013.

CH$_4$ Generation Rate Constant (k)

The CH$_4$ generation rate constant k represents the first-order rate at which CH$_4$ is generated after waste has been landfilled. The value of k is affected by four factors: moisture content, availability of nutrients, pH and temperature. In calculating provincial decay rates, however, the ambient temperature should not be considered, as the landfill temperature is independent of the ambient temperature at depths exceeding 2 m. The moisture content should be the sole parameter considered (Maurice and Lagerkvist 2003; Thompson and Tanapat 2005).

MSW Landfills

The k values used to estimate emissions from MSW landfills were obtained from a study conducted by Environment Canada's Greenhouse Gas Division that employed provincial precipitation data from 1941 to 2007 (Environment Canada 1941-2007). The provincial locations at which the average

Table A3–61   MSW Landfilled for 1990–2013[4]

Year	N.L.	P.E.I.	N.S.	N.B.	Que.[3]	Ont.[3]	Man.	Sask.	Alta.	B.C.[3]	Yk.	N.W.T. & Nvt.	Canada
							tonnes						
1990[1]	366 004	51 293	493 010	462 391	3 699 833	5 957 104	696 174	638 942	1 577 585	1 760 621	16 608	34 493	15 754 058
1991	400 159	63 047	540 341	489 539	4 073 027	6 287 557	741 706	720 035	1 790 701	1 990 162	16 904	34 897	17 148 074
1992	402 670	74 800	533 426	488 826	4 152 266	6 390 940	755 034	729 362	1 837 539	2 012 191	17 200	35 300	17 429 552
1993	403 918	72 786	523 456	485 805	4 230 976	6 479 872	767 869	736 993	1 881 860	2 028 235	19 629	40 929	17 672 327
1994	403 775	74 911	510 179	480 262	4 309 123	6 552 824	780 167	742 752	1 923 350	2 037 746	20 505	42 899	17 878 493
1995	402 110	77 036	493 335	471 972	4 386 673	6 608 214	791 881	746 453	1 961 687	2 040 161	21 381	44 869	18 045 772
1996	398 783	79 161	472 655	460 706	4 463 598	6 644 405	802 966	747 906	1 996 538	2 034 895	22 257	46 839	18 170 708
1997	393 651	81 286	447 861	446 225	4 539 872	6 659 708	813 373	746 914	2 027 558	2 021 350	23 133	48 809	18 249 740
1998[2]	366 280	91 555	455 192	468 571	5 134 572	5 915 749	964 726	848 408	2 527 817	2 166 237	27 770	59 073	19 025 951
1999	382 549	86 211	402 202	441 815	5 299 103	6 919 164	939 619	835 177	2 638 911	2 229 875	26 149	55 625	20 256 397
2000[2]	398 818	80 866	349 827	415 058	5 411 108	7 294 407	914 511	821 946	2 750 004	2 287 008	24 528	52 176	20 800 256
2001	387 706	76 365	348 511	414 332	5 512 702	7 214 659	905 534	808 535	2 820 149	2 341 591	23 162	49 272	20 902 517
2002[2]	376 594	71 864	347 456	413 606	5 453 306	7 396 919	896 556	795 124	2 890 294	2 387 620	21 797	46 368	21 097 503
2003	388 321	75 268	355 772	427 890	5 754 175	6 607 799	912 337	795 029	2 983 803	2 413 758	22 830	48 564	20 785 544
2004[2]	400 048	78 672	363 389	442 173	6 006 198	5 987 923	928 117	794 933	3 077 311	2 440 967	23 862	50 761	20 594 354
2005	414 429	71 031	341 260	476 940	5 932 353	5 827 045	916 195	814 343	3 448 592	2 512 496	21 544	45 830	20 822 055
2006[2]	428 809	63 389	320 744	511 706	5 772 031	5 614 308	904 272	833 753	3 819 872	2 584 435	19 226	40 900	20 913 445
2007	404 493	59 462	314 996	495 584	5 240 331	5 456 751	924 857	868 348	3 983 715	2 524 725	18 035	38 366	20 329 661
2008[2]	380 176	55 535	313 498	479 461	5 414 619	5 749 868	945 441	902 943	4 147 558	2 493 496	16 844	35 832	20 935 271
2009	387 206	63 444	322 762	477 363	5 246 840	6 064 719	948 527	920 106	4 032 525	2 413 035	19 243	40 935	20 936 704
2010[2]	394 235	71 354	333 859	475 265	5 267 279	6 151 608	951 612	937 268	3 917 492	2 308 571	21 642	46 039	20 876 224
2011	401 265	63 821	343 202	473 167	5 186 745	5 409 955	954 698	954 431	3 802 459	2 158 681	19 358	41 179	19 808 959
2012	408 294	63 760	350 142	471 069	4 594 866	6 020 815	957 783	971 593	3 687 426	2 076 307	19 339	41 139	19 662 533
2013	415 324	63 699	305 705	494 330	4 781 545	6 049 436	969 071	1 019 039	4 635 887	2 240 813	19 320	41 100	21 035 267

Notes:
1. 1990 data obtained from Levelton (1991).
2. 1998, 2000, 2002, 2004, 2006, 2008 and 2010 data obtained from Statistics Canada disposal data (Statistics Canada 2000, 2003, 2004, 2007a, 2008a, 2010a, 2013a).
3. Exported MSW subtracted from the Statistics Canada disposal data (Environment Canada 2013a).
4. The data represented above were chosen from selected years. MSW landfill data from 1941 to 1990 (Levelton 1991) were used in the multiple linear regression method for estimation of MSW landfilled for 1991–1997.

annual precipitations calculated were those indicated in the Levelton study where major landfills were located over the 1941 to 1990 period (Levelton 1991), with additional data for British Columbia from a study performed by Golder Associates Ltd. (2008). From these precipitation values, k values were determined using a relationship prepared by the Research Triangle Institute (RTI) for the U.S. Environmental Protection Agency (RTI 2004). RTI assigns default decay values of less than 0.02/year, 0.038/year and 0.057 /year to areas with an annual precipitation of less than 20 inch/year (< 500 mm), between 20 and 40 inch/year (500 to 1000 [average 750] mm) and greater than 40 inch/year (> 1000 mm), respectively. The plot of these decay values and precipitation data showed a linear relationship: k (yr[1]) = 7 x 105 x precipitation (mm)-0.0172. Using this relationship and Environment Canada's average provincial precipitation data for 1941–1975, 1976–1989 and 1990–2007, average provincial landfill decay rates were calculated (Environment Canada 1941-2007). The U.S. k values are related to precipitation, assuming that the moisture content of a landfill is a direct function of the annual precipitation. Based on both the U.S. k

values and precipitation data and the average annual precipitation at Canadian landfills surveyed by Levelton (1991), k values were assigned to each of the provinces for the three respective time series: 1941–1975, 1976–1989 and 1990–2007. These three time intervals were selected to match those used to derive the provincial L_0 values in order to better represent the changing conditions over the 1941–2013 time series. It is assumed that the conditions for which the 1990–2007 k values were derived were also valid from 2008 to 2013.

The applicability of the RTI relationship to Canadian landfills was supported by an in-house study that compared Canadian municipal solid waste composition to those observed in the United States (Environment Canada 2015). The Canadian composition was obtained from the latest composition study (NRCan 2006) based on 2002 data, and the American compositions were obtained from the 2014 National Inventory Report as submitted to the UNFCCC (US EPA 2014), 2002 EPA data tables (US EPA 2003) and the 1998 data tables (US EPA 2014). The comparison showed good agreement between Canadian and American municipal solid waste compositions.

Table A3–62   Wood Waste Generated and Landfilled in Canada for 1990–2013

Year	Wood Waste Disposed of (bone dry tonnes)		Wood Waste Landfilled (bone dry tonnes)		
	Pulp & Paper	Solid Wood Industry	Pulp & Paper	Solid Wood Industry	Total
1990	1 811 062	7 244 248	1 557 513	1 086 637	2 644 151
1991	1 811 062	7 244 248	1 557 513	1 086 637	2 644 151
1992	1 811 062	7 244 248	1 557 513	1 086 637	2 644 151
1993	1 537 557	6 150 226	1 322 299	922 534	2 244 833
1994	1 447 245	5 788 981	1 244 631	868 347	2 112 978
1995	1 356 934	5 427 736	1 166 963	814 160	1 981 124
1996	1 266 623	5 066 491	1 089 296	759 974	1 849 269
1997	1 176 311	4 705 246	1 011 628	705 787	1 717 415
1998	1 080 000	4 320 000	928 800	648 000	1 576 800
1999	995 689	3 982 755	856 292	597 413	1 453 706
2000	905 378	3 621 510	778 625	543 227	1 321 851
2001	815 066	3 260 265	700 957	489 040	1 189 997
2002	724 755	2 899 020	623 289	434 853	1 058 142
2003	634 444	2 537 775	545 622	380 666	926 288
2004	547 561	2 190 244	470 902	328 537	799 439
2005	536 030	2 144 120	460 986	321 618	782 604
2006	492 687	1 970 746	423 710	295 612	719 322
2007	452 848	1 811 392	389 449	271 709	661 158
2008	416 231	1 664 922	357 958	249 738	607 697
2009	382 574	1 530 297	329 014	229 544	558 558
2010	351 639	1 406 557	302 410	210 984	513 393
2011	323 206	1 292 822	277 957	193 923	471 880
2012	297 071	1 188 285	255 481	178 243	433 724
2013	273 050	1 092 200	234 823	163 830	398 653

Table A3–63 shows the mean annual precipitation and decay values assigned for each of the provincial landfill sites selected by Levelton (1991) and Golder Associates Ltd. (2008).

The k values used to estimate emissions from MSW landfills at a provincial level are derived from taking the average of k value estimates for each province for each of the three time series. These values are provided in Table A3–64.

Wood Waste Landfills

Based upon the default value for estimating wood products industry landfill CH_4 emissions recommended by the National Council for Air and Stream Improvement Inc., a k value of 0.03/year was assumed to represent the CH_4 generation rate constant for all of the wood waste landfills in Canada (NCASI 2003).

CH_4 Generation Potential (L_0)

MSW Landfills

The CH_4 generation potential (L_0) represents the amount of CH_4 that could be theoretically produced per tonne of waste landfilled. The following equation, as presented in the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*, is used to calculate the CH_4 generation potential for MSW landfills (IPCC/OECD/IEA 1997):

Equation A3–88:

$$L_0 = MCF \times DOC \times DOC_F \times F \times \frac{16}{12} \times 1000 \frac{kgCH_4}{tCH_4}$$

where:

L_0	=	CH_4 generation potential, kg CH_4/t waste
MCF	=	CH_4 correction factor, fraction
DOC	=	degradable organic carbon, t C/t waste
DOC_F	=	fraction of DOC dissimilated
F	=	fraction of CH_4 in landfill gas
16/12	=	stoichiometric factor to convert CH_4 to carbon

The methane correction factor (MCF) accounts for the proportion of managed to unmanaged solid waste disposal sites. Unmanaged solid waste disposal sites produce less CH_4, since a larger fraction of waste decomposes aerobically in the top layers of the site. The IPCC default value for MCF for managed landfill sites is chosen to represent the MCF for MSW landfills, since it is assumed that all landfills covered by the data collected are engineered

A3

Table A3–63   Mean Annual Precipitation and MSW Landfill k Value Estimates for Provincial Landfill Sites

Region	Annual Precipitation (mm) from Environment Canada's Historical Climate Data			Rate constant k (yr-1)		
	1941–1975	1976–1989	1990–2007	1941–1975	1976–1989	1990–2007
British Columbia						
Campbell River	1 521.4	1 370.2	1 507.0	0.089	0.079	0.088
Chilliwack	1 674.4	1 736.9	1 678.0	0.100	0.104	0.100
Courtney	1 465.7	1 387.9	1 441.3	0.085	0.080	0.084
Kamloops	270.1	273.9	296.5	0.002	0.002	0.004
Matsqui	1 537.1	1 480.1	1 571.6	0.090	0.086	0.093
Port Alberni	1 954.2	1 870.8	2 050.1	0.120	0.114	0.126
Prince Rupert	2 636.2	3 082.7	2 538.7	0.167	0.199	0.161
Vancouver	1 846.0	1 599.8	1 564.5	0.112	0.095	0.092
Vernon	393.2	415.3	429.7	0.010	0.012	0.013
Victoria	864.6	978.6	1 197.7	0.043	0.051	0.067
Average	**1 416.3**	**1 419.6**	**1 427.5**	**0.082**	**0.082**	**0.083**
Alberta						
Calgary	429.9	406.8	426.5	0.013	0.011	0.013
Edmonton	451.9	480.2	446.8	0.014	0.016	0.014
Fort McMurray	441.1	445.8	417.9	0.014	0.014	0.012
Lethbridge	427.5	396.4	385.8	0.013	0.011	0.010
Medicine Hat	344.1	332.5	338.9	0.007	0.006	0.007
Red Deer	450.9	463.5	487.4	0.014	0.015	0.017
Average	**424.2**	**420.9**	**417.2**	**0.012**	**0.012**	**0.012**
Saskatchewan						
Moose Jaw	388.9	329.7	468.4	0.010	0.006	0.016
Prince Albert	333.2	425.9	458.7	0.006	0.013	0.015
Regina	390.2	359.9	404.2	0.010	0.008	0.011
Saskatoon	360.0	332.9	356.3	0.008	0.006	0.008
Swift Current	385.1	359.8	409.1	0.010	0.008	0.011
Yorkton	440.7	440.1	435.1	0.014	0.014	0.013
Average	**383.0**	**374.7**	**422.0**	**0.010**	**0.009**	**0.012**
Manitoba						
Brandon	464.8	434.7	480.8	0.015	0.013	0.016
Portage la Prairie	540.4	533.8	562.4	0.021	0.020	0.022
Thompson	566.8	517.5	500.7	0.022	0.019	0.018
Winnipeg	534.1	487.7	540.9	0.020	0.017	0.021
Average	**526.5**	**493.4**	**521.2**	**0.020**	**0.017**	**0.019**
Ontario						
Barrie	894.6	952.3	927.6	0.045	0.049	0.048
Belleville	868.3	898.7	920.6	0.044	0.046	0.047
Brantford	741.3	815.8	857.1	0.035	0.040	0.043
Brockville	961.2	977.2	1 013.0	0.050	0.051	0.054
Cornwall	934.7	969.0	1 044.9	0.048	0.051	0.056
Guelph	839.6	915.3	900.5	0.042	0.047	0.046
Hamilton	750.2	945.3	889.1	0.035	0.049	0.045
Kingston	810.3	975.2	964.2	0.040	0.051	0.050
Kitchener	885.9	985.5	844.0	0.045	0.052	0.042
London	921.5	997.8	993.3	0.047	0.053	0.052
North Bay	979.2	1 015.2	1 050.3	0.051	0.054	0.056
Oshawa	843.5	941.3	866.4	0.042	0.049	0.043
Ottawa-Hull	868.4	939.2	937.7	0.044	0.049	0.048
Peterborough	749.4	862.8	856.5	0.035	0.043	0.043
St. Catharines	806.7	860.2	866.5	0.039	0.043	0.043
Sarnia	752.4	842.6	972.8	0.035	0.042	0.051
Sudbury	760.6	907.7	911.6	0.036	0.046	0.047
Thunder Bay	734.8	696.1	578.4	0.034	0.032	0.023
Timmins	780.4	864.6	809.7	0.037	0.043	0.039
Toronto	794.4	843.2	808.1	0.038	0.042	0.039
Windsor	839.8	921.8	927.0	0.042	0.047	0.048
Average	**834.2**	**910.8**	**901.9**	**0.041**	**0.047**	**0.046**
Quebec						
Montréal	952.8	935.2	1 018.8	0.049	0.048	0.054
Québec	1 137.9	1 174.9	1 148.6	0.062	0.065	0.063
Rimouski	773.0	955.7	961.3	0.037	0.050	0.050
Saint-Étienne	1 021.0	994.2	981.4	0.054	0.052	0.051
Saint-Tite-des-Caps	1 009.1	1 102.4	1 178.3	0.053	0.060	0.065
Ste-Cécile	1 113.5	1 218.6	1 245.1	0.061	0.068	0.070
Ste-Sophie	1 047.3	1 031.2	1 063.4	0.056	0.055	0.057
Average	**1 007.9**	**1 058.9**	**1 085.3**	**0.053**	**0.057**	**0.059**
New Brunswick						
Bathurst	958.1	1 067.5	1 123.4	0.050	0.058	0.061
Campbellton	1 002.6	1 002.6	1 002.6	0.053	0.053	0.053
Edmundston	1 078.3	1 053.3	992.1	0.058	0.057	0.052
Fredericton	1 077.4	1 182.5	995.7	0.058	0.066	0.053
Moncton	1 159.4	1 116.7	1 172.1	0.064	0.061	0.065
Saint John	1 339.3	1 477.4	1 245.5	0.077	0.086	0.070
Average	**1 102.5**	**1 150.0**	**1 088.6**	**0.060**	**0.063**	**0.059**
Prince Edward Island						
Charlottetown	1 116.0	1 218.3	1 096.2	0.061	0.068	0.060
Summerside	987.6	1 052.7	1 149.1	0.052	0.056	0.063
Average	**1 051.8**	**1 135.5**	**1 122.6**	**0.056**	**0.062**	**0.061**

A3

Table A63:   Mean Annual Precipitation and MSW Landfill k Value Estimates for Provincial Landfill Sites   (cont'd)

Region	Annual Precipitation (mm) from Environment Canada's Historical Climate Data			Rate constant k (yr-1)		
	1941–1975	1976–1989	1990–2007	1941–1975	1976–1989	1990–2007
Nova Scotia						
Dartmouth	1 492.8	1 449.5	1 349.6	0.087	0.084	0.077
Halifax	1 492.8	1 449.5	1 349.6	0.087	0.084	0.077
Lunenburg	1 456.2	1 475.2	1 559.5	0.085	0.086	0.092
New Glasgow	1 076.8	1 120.5	1 106.7	0.058	0.061	0.060
Sydney	1 359.1	1 514.9	1 413.0	0.078	0.089	0.082
Truro	1 087.7	1 226.1	1 110.8	0.059	0.069	0.061
Average	**1 327.6**	**1 372.6**	**1 314.9**	**0.076**	**0.079**	**0.075**
Newfoundland						
Carbonear	N/A	N/A	N/A	N/A	N/A	N/A
Corner Brook	1 127.1	1 255.9	1 196.1	0.062	0.071	0.067
St. John's	1 502.4	1 525.2	1 515.3	0.088	0.090	0.089
Average	**1 314.8**	**1 390.5**	**1 355.7**	**0.075**	**0.080**	**0.078**
Yukon						
Whitehorse	264.2	261.7	271.8	0.001	0.001	0.002
Average	**264.2**	**261.7**	**271.8**	**0.001**	**0.001**	**0.002**
Northwest Territories						
Yellowknife	261.2	273.0	287.0	0.001	0.002	0.003
Average	**261.2**	**273.0**	**287.0**	**0.001**	**0.002**	**0.003**
Nunavut						
Iqaluit	420.1	448.9	372.1	0.012	0.014	0.009
Average	**420.1**	**448.9**	**372.1**	**0.012**	**0.014**	**0.009**
Average (N.W.T. and Nvt.)	**340.6**	**360.9**	**329.5**	**0.007**	**0.008**	**0.006**

Note: N/A = not available.

Table A3–64   Provincial and Territorial MSW Landfill k (yr^{-1})Value Estimates

	Provinces and Territories											
Year	N.L.	P.E.I.	N.S.	N.B.	Que.	Ont.	Man.	Sask.	Alta.	B.C.	Yk.	N.W.T. & Nvt.
1941–1975	0.075	0.056	0.076	0.06	0.053	0.041	0.020	0.01	0.012	0.082	0.001	0.001
1976–1989	0.080	0.062	0.079	0.063	0.057	0.047	0.017	0.009	0.012	0.082	0.001	0.002
1990–2013	0.078	0.061	0.075	0.059	0.059	0.046	0.019	0.012	0.012	0.083	0.002	0.003

landfills. The IPCC default values for MCF are shown in Table A3–65 (IPCC 2006).

The IPCC (2006) default value for the fraction of CH_4 in landfill gas (F) is 0.5. It can vary based on certain factors, including waste age and composition and potential air dilution effects that can lower the actual concentration of CH_4 in the landfill gas. The default value 0.5 is chosen for the fraction of CH_4 in landfill gas.

DOC_F represents the amount of organic carbon that is ultimately degraded and released from the solid waste disposal site. It accounts for the fact that some of the organic carbon does not degrade or degrades very slowly. A value of 0.6 was selected from the IPCC (2000) DOC_F default range of 0.5 to 0.6 for waste that includes lignin (IPCC 2000). This value, from the upper end of the range, i.e., more easily degraded, was selected rather than the IPCC (2006) default value as it best represents the situation in Canada, where the majority of the wood wastes from saw mills and the pulp and paper industry—which, by definition, have high lignin concentrations—are disposed of in dedicated private landfills.

Table A3–65   Solid Waste Disposal Site CH_4 Correction Factors

Type of Site	MCF Default Values
Managed - anaerobic	1.0
Managed - semi-aerobic	0.5
Unmanaged: deep (≥ 5 m waste)	0.8
Unmanaged: shallow (< 5 m waste)	0.4
Uncategorized solid waste disposal sites	0.6

DOC represents the amount of organic carbon that is accessible to biochemical decomposition and is based on the composition of the waste. Waste composition percentages from across Canada are used to calculate the provincial DOC values according to the following equation (IPCC 2006) using the default DOC values for paper, garden, food and wood wastes as provided in Table 2.4 Volume 5 (IPCC 2006).

Table A3–66   Provincial and Territorial CH$_4$ Generation Potential (L$_0$) Values

Province/Territory	2002 Organic Waste Diversion[1] (%)	1941 to 1975		1976 to 1989		1990 to Present	
		DOC	L$_0$ (kg CH$_4$/t waste)	DOC	L$_0$ (kg CH$_4$/t waste)	DOC	L$_0$ (kg CH$_4$/t waste)
Newfoundland	N/A	0.31	122.50	0.19	75.07	0.19	74.94
Prince Edward Island	N/A	0.28	112.86	0.17	67.37	0.16	63.77
Nova Scotia	29.7	0.27	107.30	0.16	63.28	0.16	63.84
New Brunswick	19.8	0.25	99.35	0.17	67.29	0.16	64.11
Quebec	13.7	0.39	154.54	0.21	82.91	0.20	81.62
Ontario	16.4	0.37	149.72	0.21	83.48	0.21	83.51
Manitoba	4.9	0.35	139.26	0.19	77.74	0.19	77.65
Saskatchewan	4.3	0.38	151.65	0.22	86.32	0.22	86.55
Alberta	16.7	0.29	114.23	0.19	74.63	0.19	74.18
British Columbia	23.3	0.28	112.39	0.18	71.74	0.17	66.91
Territories (Yk., N.W.T. & Nvt.)	N/A	0.23	93.26	0.15	60.11	0.17	66.14

Notes:
Sources: Derived from data obtained from NRCan (2006), Statistics Canada (2007a) and CRC Press (1973).
1. Thompson et al. (2006).
N/A = Not available.

Equation A3–89:

$$\%DOC(by\ net\ weight) = (0.4 \times A) + (0.17 \times B) + (0.15 \times C) + (0.3 \times D)$$

where:

A	=	% of MSW that is paper and textiles
B	=	% of MSW that is garden or park waste
C	=	% of MSW that is food waste
D	=	% of MSW that is wood or straw

The provincial and territorial DOCs were calculated from waste disposal composition values for three distinct time periods: 1941–1975, 1976–1989 and 1990–2006. Using waste composition data obtained from a Natural Resources Canada (NRCan) study, which were based on the 2002 data year (NRCan 2006), DOC values were derived and assumed to be constant over the period 1990 to 2013. The DOCs were developed from residential, ICI and C&D waste type compositions. Since the waste diversion programs were not significant prior to 1990, a second set of DOCs was developed to represent the waste composition at disposal from 1976 to 1989 by adding the NRCan landfill data to the 2004 Statistics Canada recycled waste composition data (Statistics Canada 2007a). A third set of DOCs was developed from a 1967 national study to cover the period from 1941 to 1975 (CRC Press 1973). Provincial and territorial DOCs and L$_0$s are summarized in Table A3–66.

From the NRCan (2006) document, the quantities for each standard category of waste from residential, ICI and C&D origins were added together to reflect the true composition at disposal at the MSW landfill sites. Therefore, by this methodology, the biodegradability of all three waste types is accounted for in the MSW waste composition. The NRCan report uses a consistent methodology to estimate the MSW waste composition at disposal for all provinces and territories.

Since significant results from waste diversion projects only began to be made manifest in the early 1990s in Canada, as supported by this document and expert opinion in the field, the "1990 to present" provincial/territorial DOCs given in Table A3–66 are used in the estimation of L$_0$s and ultimately in the provincial/territorial specific methane emission generation for the period 1990–2013, inclusively.

For the period 1976–1989, DOC values were calculated based on the assumption that the waste composition at disposal could be represented by the generation waste composition for the year 2002. This was accomplished by summing the MSW (residential and ICI) waste quantities (NRCan 2006) at disposal for each waste category with the recycled quantities for the corresponding category for each province and territory. The latter data were obtained from Statistics Canada report *Waste Management Industry Survey: Business and Government Sectors 2004* (Statistics Canada 2007a). Where gaps were identified in the Statistics Canada report, due to confidentiality issues, regional factors (western, central and maritime provinces and northern territories) were used to populate the missing data.

The years 1941 to 1975 are covered by an L$_0$ developed by a third set of DOC values, based on national waste compositions provided in Table 1.1-9 of CRC Press (1973) The data from this table are derived from the article "World Survey Finds Less Organic Matter" (Anon. 1967a). Waste audit data for the time series 1976 to 1998 were obtained from Table 1: Waste Composition Data for Ontario,

A3

Table A3–67   Estimated MSW CH₄ Captured, Flared, and Emitted for 1990–2013

Year	CH₄ Generated (kt)	CH₄ Captured (kt)	CH₄ Flared (kt)	CH₄ Emitted from Flare (kt)	CH₄ Emitted (kt)
1990	963.63	192.59	23.54	0.07	771.04
1991	981.33	195.56	27.09	0.08	785.77
1992	999.14	204.68	35.18	0.11	794.46
1993	1 016.86	209.26	44.33	0.13	807.60
1994	1 034.38	223.19	56.56	0.17	811.19
1995	1 051.57	243.23	69.15	0.21	808.34
1996	1 068.27	264.31	78.44	0.24	803.96
1997	1 084.34	267.56	80.76	0.24	816.78
1998	1 101.26	271.54	90.52	0.27	829.72
1999	1 122.20	275.53	100.29	0.30	846.67
2000	1 144.21	293.93	117.55	0.35	850.28
2001	1 165.58	312.34	134.81	0.41	853.24
2002	1 186.51	312.15	136.65	0.41	874.36
2003	1 205.24	311.96	138.92	0.42	893.28
2004	1 222.27	312.51	146.48	0.44	909.76
2005	1 238.26	313.06	154.03	0.46	925.20
2006	1 252.65	304.31	130.41	0.39	948.34
2007	1 262.67	329.47	164.41	0.49	933.20
2008	1 274.04	347.38	162.06	0.49	926.67
2009	1 284.89	348.72	170.95	0.51	936.16
2010	1 295.16	419.88	219.67	0.66	875.27
2011	1 298.92	431.83	228.00	0.69	867.09
2012	1 299.10	463.31	238.82	0.72	835.79
2013	1 302.41	468.92	238.66	0.72	833.49

of the report *Residential Waste Composition Study*, Ontario Waste composition Study – Vol. 1 (Ontario Ministry of the Environment 1991). The waste audit studies were conducted in 1976, 1978 and 1980 and gave paper, wood, food wastes, textile and yard waste average percentages of 40%, 2.6%, 22%, 3.4% and 13%, respectively. These are comparable to those from the 2002 generated estimates used for the 1976 to 1989 period. The 1967 article data (Anon. 1967a) gave paper and organic matter compositions of 70% and 10%, respectively. Therefore, 1975–1976 was judged to be an appropriate transition point to use to allow for a realistic change between the significantly different 1967 data set and the data derived from the 2002 waste composition without waste diversion employed to represent the waste composition for the late 1970s and 1980s. The breakdown of organic matter percentage (10%), obtained from Table 1.1-9: Summary of International Refuse Composition, into food and yard waste was based upon the waste composition (10.2% and 8.6%, respectively) given for Montréal, Quebec, from the same CRC Press (1973) text, Table 1.1-10: Composition of Household Garbage, where the data were obtained from a separate 1967 article (Anon. 1967b). The information on percentage of wood (2.4%) came from an article by

the American Public Works Association (1964), and was presented in Table 1.1-2.8: Composition and Analysis of Average Municipal Refuse (CRC Press 1973).

A provincial profile was developed from the 1967 national average by pro-rating each of its DOC waste categories to match the same provincial profile as for the 1976 to 1989 period.

Wood Waste Landfills

Equation A3–88, as presented in the Revised *1996 IPCC Guidelines for National Greenhouse Gas Inventories*, is used to calculate the CH₄ generation potential for wood waste landfills (IPCC/OECD/IEA 1997). The IPCC default value for MCF for unmanaged deep landfill sites (0.8) is chosen to represent the MCF, as it best represents industry practices.

The value 0.5 is chosen for the fraction of CH₄ in landfill gas (F), being the IPCC default value (2006).

DOC$_F$ represents the amount of organic carbon that is ultimately degraded and released from the solid waste disposal sites. It

accounts for the fact that some of the organic carbon does not degrade or degrades very slowly. The *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (IPCC 2000) provides default values in the order of 0.5–0.6 for waste sites that include lignin. The lower end of this range, 0.5, is used in the calculation for the CH_4 generation potential to better represent the high lignin content in wood waste (IPCC/OECD/IEA 1997).

DOC represents the amount of organic carbon that is accessible to biochemical decomposition. Equation A3–89 is used to calculate the national wood waste DOC value, assuming a 100% wood composition (IPCC 2006).

Based on these considerations, an L_0 of 115 kg CH_4/t of wood waste is calculated from Equation A3–88.

Captured Landfill Gas

At many large MSW landfill facilities, landfill gas is captured to be flared or utilized, or both. Owing to the relatively high concentration of CH_4 in the landfill gas, the gas can be combusted for electricity or heat generation. To a lesser extent, in recent years, the captured gas is simply collected and vented. If not utilized, the captured landfill gas is flared. For the purposes of the inventory, captured gas includes only the gas that is flared or utilized. In order to calculate the net CH_4 emissions from landfills, the amount of captured CH_4 is subtracted from the CH_4 generated as estimated by the Scholl Canyon model, and then this value is added to the portion of CH_4 emitted from the flaring operation. GHG emissions affiliated with the use of landfill gas for energy recovery are accounted for in the Energy Sector. The calculation of net CH_4 emissions is shown in the following equation:

Equation A3–90:

$$CH_{4(NET)} = CH_{4(generated)} - CH_{4(captured)} + CH_{4(emitted-F)}$$

where:

$CH_{4(NET)}$ = net CH_4 emissions from MSW landfills, t

$CH_{4(generated)}$ = CH_4 emissions generated from MSW landfills, t

$CH_{4(captured)}$ = CH_4 emissions captured from MSW landfills, t

$CH_{4(emitted-F)}$ = CH_4 emissions emitted from flaring of captured MSW landfill gas, t

A flaring emission control efficiency of 99.7% is used to determine the amount of CH_4 emitted. This value is obtained from Table 2.4-3 of Chapter 2.4 of EPA AP 42 (US EPA 1995). The amount of CH_4 emitted from flaring of landfill gas is calculated as follows:

Equation A3–91:

$$CH_{4(emitted-F)} = CH_{4(flared)} \times (1 - Eff_{(flare-control)})$$

where:

$CH_{4(emitted-F)}$ = CH_4 emissions emitted from flaring of MSW CH_4 gas, t/year

$CH_{4(flared)}$ = CH_4 gas flared, t/year

$Eff_{(flare-control)}$ = flare emission control efficiency, fraction

The quantities of CH_4 gas collected from 1983 to 1996 were obtained from ad hoc surveys conducted by Environment Canada,[39] while quantities for the years 1997–2003 were collected directly from individual landfill operators biennially by Environment Canada's National Office of Pollution Prevention (Environment Canada 2003a). CH_4 gas capture data for 2005 were obtained through a study prepared for Environment Canada (Environment Canada 2007). CH_4 gas capture and utilization data for 2006/2007, 2008/2009, 2010/2011 and 2012/2013 were obtained through survey studies conducted by the Greenhouse Gas Division of Environment Canada in 2008, 2010, 2012 and 2014, respectively (Environment Canada 2009, 2011, 2013b, 2014b). Prior to the 2008 data collection survey, the landfill gas capture data were collected every odd year, and therefore, for the purposes of the national GHG inventory, the landfill gas capture data for the subsequent even years were averaged from the odd years starting from 1997. However, the subsequent biennial surveys collected data for two data years from the facilities; these data were first employed in the 2007 National Inventory Report (NIR) submission estimates. Table A3–67 shows the amount of CH_4 captured and flared from 1990 to 2013.[40]

A3.6.1.2. Data Sources

Waste disposal data are collected from a Statistics Canada biennial waste survey (Statistics Canada 2000, 2003, 2004, 2007a, 2008a, 2010a, 2013a). The Statistics Canada data for 1998, 2000, 2002, 2004, 2006, 2008 and 2010 waste disposal are used in developing its MSW estimates for the national GHG inventory.

Landfill gas capture and flare data for 1997–2003 were collected directly from individual landfill operators biennially by Environment Canada's National Office of Pollution Prevention (Environment Canada 2003a). CH_4 gas capture data for 2005 were obtained through the study entitled "An Inventory of Landfill Gas Recovery and Utilization in Canada," prepared for Environment Canada (Environment Canada 2007). CH_4 gas capture data for 2006/2007, 2008/2009, 2010/2011 and 2012/2013 were collected through the subsequent studies conducted by the Greenhouse Gas Division (Environment Canada 2009, 2011, 2013b, 2014b).

39 Perkin. Personal communication (letter dated July 1998). National Office of Pollution Prevention, Environment Canada.

40 Where data were not made available from the landfill gas capture facilities, data from previous surveys were employed.

A3.6.2. CH$_4$ Emissions from Wastewater Treatment

A3.6.2.1. Methodology

Municipal Wastewater Treatment

The IPCC (2006) default method for calculating CH$_4$ emissions from domestic wastewater handling is not used, because the required data (i.e. volumes of wastewater treated) are not available. Instead, a method similar to the IPCC methodology, developed for Environment Canada (AECOM Canada 2011), is used to calculate an emission factor. A new maximum methane producing capacity (B$_o$) was derived. In past submissions, a methane emission factor developed by ORTECH (1994), 0.22 kg CH$_4$/kg five-day biological oxygen demand (BOD$_5$), was used. Following the 2009 centralized review, this value was questioned, because the default 2006 IPCC greenhouse gas emission factor (GHG EF) is given as 0.6 kg CH$_4$/kg BOD$_5$. Further to the expert review team (ERT) report, and having identified a problem with the derivation of the IPCC default B$_o$ value, AECOM was commissioned to review the current data and confirm the emission factor (EF) to be used. The B$_o$ recommended by AECOM is 0.36 kg CH$_4$ per kg BOD$_5$. It was also recommended that the methane conversion factor (MCF) be changed from a percent of population served by anaerobic treatment to the product of a combined MCF (septic systems, facultative lagoons, anaerobic lagoons and direct discharge) and the provincial population served by these systems, i.e., not served by a centralized treatment system. An MCF of 0.3 was recommended, as it best reflected the reality of the distribution of the Canadian municipal wastewater treatment units for the best data available.

Therefore, an emission factor of 0.108 was derived from the product of a B$_o$ of 0.36 kg CH$_4$ per kg BOD$_5$ and an MCF of 0.3. To provide the EF in units of kg CH$_4$/capita/yr, the following relation was used, given an organic loading rate of 0.050 kg BOD$_5$/person/day:

Equation A3–92:

$$EF_{CH_4}(kg\ CH_4\ /capita\ per\ year\ ) = (per\ capita\ BOD_5\ loading\ rate) \times (CH_4\ generation\ rate)$$
$$= \left(0.05 \frac{kgBOD_5}{capita \times day}\right) \times \left(365 \frac{days}{years}\right) \times \left(0.108 \frac{kgCH_4}{kgBOD_5}\right) = \left(1.971 \frac{kgCH_4}{capita \times year}\right)$$

The percentage of wastewater that is treated aerobically for each province is derived from the product of the percentage of rural population (AECOM Canada 2011) and the population of the province or territory. It is assumed that anaerobic primary and secondary wastewater treatment, septic tanks and out-falls where the effluent is discharged without treatment, where CH$_4$ emissions are not captured, are present in rural areas. Canadian urban municipalities can be assumed to be serviced by aerobic

treatment systems and/or anaerobic systems that have full capture of the biogases where they are utilized or flared with near complete combustion. Using the Statistics Canada definition of an urban area[41] and the 2006 census data, which give the provincial populations, the percentage of rural population is obtained.

Emissions are calculated by multiplying the emission factor by the population of the respective province (Statistics Canada 2006, 2014) and the fraction of wastewater that is anaerobically treated.

Equation A3–93:

$$CH_{4(x)} = EF_{CH_4} \times P_x \times FRAC_{AN(x)}$$

where:

CH$_{4(x)}$	=	CH$_4$ emissions from wastewater treatment for province x, t/year
EF$_{CH4}$	=	CH$_4$ emission factor for wastewater treatment, t/capita per year
P$_x$	=	population of province x
FRAC$_{AN(x)}$	=	fraction of wastewater treated anaerobically for province x

Table A3–68 shows the percentage of wastewater treated anaerobically, including untreated wastewater for 1990–2019. The remaining percentage of wastewater is treated aerobically (primary and secondary wastewater treatment).

Industrial Wastewater Treatment – CH$_4$ & N$_2$O

Data were collected through in-house surveys of industrial facilities either known or likely to be employing anaerobic units to treat their effluent on-site (Environment Canada 2014d, 2014e). The information gained allowed for the estimation of CH$_4$ emissions for each site. The fraction of co-discharge of industrial wastewater is taken as 1.0 until further studies can confirm the industrial contribution. The IPCC (2006) default value of 1.25 may be an overestimation for Canada. Therefore, only the human contribution is accounted for. N$_2$O emissions from this source are not expected to be significant, in view of the relatively few units in operation, and given that that wastewater from pulp and paper and the effluent from potato processing (the two largest industry sectors involved) do not contain large quantities of nitrogenous matter.

Emissions from industrial wastewater handling at a plant-site level are typically difficult to quantify, due to confidentiality issues and the variety of biological treatment units available that focus on biodegradable organics or nitrogen removal, or that can serve both functions.

41　Statistics Canada definition of urban area: "An urban area has a minimum population concentration of 1000 persons and a population density of at least 400 persons per square kilometre, based on the current census population count. All territory outside urban areas is classified as rural. Taken together, urban and rural areas cover all of Canada."

Based on the responses to inquiries submitted to industrial associations and provincial ministries of the environment for the first survey in 2006, which indicated that anaerobic industrial wastewater units were relatively few in Canada, it was decided to implement a Tier 3 approach to collect information from the individual facilities directly. To use the default data and methodology—without knowledge regarding those industry sectors using anaerobic treatment, the existence of biogas recovery systems, and the quantities actually recovered, would invite an unacceptable overestimation of methane emissions.

As recommended by the IPCC *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (IPCC 2000), the Decision Tree for CH$_4$ Emissions from Industrial Wastewater Handling was followed as a framework for the Tier 3 approach. Using the information gathered for previous NIRs, detailed in Annex 3.5 of Canada's original 2010 submission, for industries with large volumes of wastewater produced, industry sectors were prioritized for the plant-specific data to be collected through surveys in order of importance: pulp and paper, chemicals and chemical products, food, beverages, petroleum and coal products, rubber products, plastic products, and total textiles.

The following industrial sectors were ruled out based on confirmations from industry representatives that anaerobic treatment was not taking place at facilities in their sectors: chemicals and chemical products,[42] beverages,[43] petroleum and coal products,[44] rubber products,[45] plastic products,[46,47] and total textiles.[48] Requests were submitted to the Canadian Chemical Producers' Association (CCPA), Canadian Soft Drink Association (CSDA), Canadian Association of Petroleum Producers (CAPP) and Rubber Association of Canada (RAC) in 2006 to obtain a confirmation for recent years, and 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,

fifteen in the food industry and two in the beverage industry. Lecture notes from a seminar in 2004 show the existence of 13 sites (Crolla et al. 2004), so it may be assumed that the coverage for this sector is complete. Of all the subject industry sectors, the two pulp and paper facilities treat by far the largest portion of process water.

From Internet searches and direct communications with the facilities, we identified only two pulp and paper facilities in Canada using anaerobic treatment. This was confirmed by the industry sector association, i.e., the Forest Products Association of Canada (FPAC).[49] These facilities directly provided the methane production in volumetric units. These quantities were converted to mass units using the density of methane at 25°C and 1 atm. Fugitive losses from the digesters and the piping system were estimated to be 0.5%, which was an average of the 0.6% for losses in pipelines and leakage at the end user for processing, transmission and distribution of natural gas, and 0.4% for leakage from residential and commercial sectors as given in the IPCC Reference Manual, Table 1.6, page 1.29 (IPCC/OECD/IEA 1997). However, a representative from the engineering design firm for one of the systems confirmed that there should not be any leaks, because the system was under negative pressure and oxygen sensors were provided in the system to alert the operators of a breach. Therefore, these emissions should be non-existent if the other facility used a similar system. Methane emissions from the inefficiencies of the flare and utilization devices were also accounted for. These methane destruction efficiencies were 0.995 for an enclosed flare and 0.98 for a boiler (Climate Action Reserve 2009). Therefore, the total emissions were the sum of the piping losses and the quantities of methane circumventing combustion in the flare and boiler.

Similarly, the emissions for the food industry were calculated. However, where no production data were made available (i.e. from a cheese manufacturer, potato processor and candy bar manufacturer), design parameters (process wastewater volumes, chemical oxygen demand [COD]) were used from the engineering firm that supplied the units to these facilities in conjunction with the default IPCC EF (IPCC/OECD/IEA 1997), to generate gas quantities. As it is known that the gas is collected, it was assumed that the losses, i.e., emissions, would consist of piping losses and utilization by a boiler.

Table A3–69 shows the industry sectors included within the Environment Canada surveys (Environment Canada 1986, 1991, 1996a) and the corresponding IPCC default COD values that are chosen to represent the industry sectors (IPCC 2000).

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42   CCPA. Personal communication (email dated December 4, 2006). Bruce Caswell, Canadian Chemical Producers' Association, to Paula Critchley, Waste Sector, Greenhouse Gas Division.

43   CSDA. Personal communication (telephone conversation dated December 2006). Canadian Soft Drink Association and Paula Critchley, Waste Sector, Greenhouse Gas Division.

44   CAPP. Personal communication (email dated October 24, 2006). Sonia Simard, Canadian Association of Petroleum Producers, to Paula Critchley, Waste Sector, Greenhouse Gas Division

45   RAC. Personal communication (telephone conversation dated December 2006). Rubber Association of Canada and Paula Critchley, Waste Sector, Greenhouse Gas Division.

46   CPIA. Personal communication (email dated December 4, 2006). Ray Kelsey, Canadian Plastics Industry Association, to Paula Critchley, Waste Sector, Greenhouse Gas Division.

47   CPIA. Personal communication (email dated October 6, 2010). Fred Edgecombe, Canadian Plastics Industry Association, to Shanta Chakrovortty, Waste Sector, Greenhouse Gas Division.

48   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.

49   FPAC. Personal communication (email dated October 4, 2010). Roger Cook, Forest Products Association of Canada, to Shanta Chakrovortty, Waste Sector, Greenhouse Gas Division.

A3

Table A3–68   Percentage of Wastewater Treated Anaerobically by Province for the 1990–2012 Time Series

	Fraction of Wastewater Treated Anaerobically (%)												
Year	NL	PE	NS	NB	QC	ON	MB	SK	AB	BC	NU	NT	YT
1990	92	56	76	40	43	9	30	44	18	23	100	97	57
1991	92	56	76	40	43	9	30	44	18	23	100	97	57
1992	92	56	76	40	43	9	30	44	18	23	100	97	57
1993	92	56	76	40	43	9	30	44	18	23	100	97	57
1994	92	56	76	40	43	9	30	44	18	23	100	97	57
1995	92	56	76	40	43	9	30	44	18	23	100	97	57
1996	92	56	76	40	43	9	30	44	18	23	100	97	57
1997	92	56	76	40	41	9	30	44	18	23	100	97	57
1998	92	56	76	40	37	9	30	44	18	23	100	97	57
1999	92	56	76	40	32	9	30	44	18	23	100	97	57
2000	92	56	76	40	27	9	30	44	18	23	100	97	57
2001	92	56	76	40	25	9	30	44	18	23	100	97	57
2002	92	56	76	40	25	9	30	44	18	23	100	97	57
2003	92	56	76	40	25	9	30	44	18	23	100	97	57
2004	92	56	76	40	25	9	30	44	18	23	100	97	57
2005	92	56	76	40	25	9	30	44	18	23	100	97	57
2006	92	56	76	40	25	9	30	44	18	23	100	97	57
2007	92	56	76	40	25	9	30	44	18	23	100	97	57
2008	92	56	76	40	25	9	30	44	18	23	100	97	57
2009	92	56	76	40	25	9	30	44	18	23	100	97	57
2010	92	56	76	40	25	9	30	44	18	23	100	97	57
2011	92	56	76	40	25	9	30	44	18	23	100	97	57
2012	92	56	76	40	25	9	30	44	18	23	100	97	57
2013	92	56	76	40	25	9	30	44	18	23	100	97	57

Source: 1996–2006 data obtained from AECOM (2011). Subsequent and prior years were assumed constant.

Table A3–69   COD Values Used in CH_4 Emission Estimates per Industry Type

Industry Group	IPCC Industry Type	IPCC Degradable Organic Component—COD (g/L)
Food	Vegetables, Fruits & Juices	5
Beverages	Soft Drinks	2
Rubber Products	Organic Chemicals	3
Plastic Products	Plastics and Resins	3.7
Primary Textiles & Textile Products	Textiles (Natural)	0.9
Wood Products	N/A	N/A
Paper & Allied Products	Pulp & Paper (Combined)	9
Primary Metals	N/A	N/A
Fabricated Metals	N/A	N/A
Transportation Equipment	N/A	N/A
Non-Metallic Mineral Products	N/A	N/A
Petroleum & Coal Products	Petroleum Refineries	1
Chemicals & Chemical Products	Organic Chemicals	3

Notes:
Sources: IPCC (2000), except for Industry Group, which is from Environment Canada (1986, 1991, 1996a).

A3.6.2.2. Data Sources

Volumes of biogas collected, the fraction of CH_4 in the biogas, and information on the combustion of the collected biogas (utilization and/or flaring) were provided directly from the industrial facility. Where the information was not available, design specifications obtained from the engineering firms that designed the specific systems or that were made available from the facility were used to derive the emissions, which would be conservative estimations.

A3.6.3. N₂O Emissions from Wastewater Treatment

A3.6.3.1. Methodology

The N_2O emissions from municipal wastewater treatment facilities are calculated using the IPCC default method (IPCC/OECD/IEA 1997). This method estimates emissions based on the amount of nitrogen in sewage and the assumption that 0.01 kg N_2O-N/kg sewage nitrogen will be generated.

To estimate the amount of nitrogen in sewage, it is assumed that protein is 16% nitrogen (IPCC/OECD/IEA 1997). The Canadian protein consumption is obtained from the annual food statistics publication (Statistics Canada 2007b, 2008b, 2010b), as shown in Table A3–70. The protein consumption data also account for retail, household, cooking and plate losses. Data are provided for the years 1991, 1996 and 2001–2009. Protein consumption data for missing years are estimated by applying a multiple linear regression application to the Statistics Canada data. In the absence of protein consumption data for 2010 - 2013, a growth function was used to extrapolate protein consumption.

Protein consumption (accounting for food wastage at the retail, household cooking and plate level) is employed in this case rather than protein availability because it provides a more realistic and accurate estimate of N_2O emissions. In order to assess the appropriateness of its accounting of food wastage, Canada launched a study carried out through a contract with AECOM.

The AECOM (2012) study highlighted the problems in following the IPCC (2006) methodologies for wastewater, which is why the methodologies adopted by Canada are country-specific. The conclusions of this report are as follows:

1. Canada is compliant with the requirements of the Revised 1996 IPCC Guidelines and IPCC Good Practice Guidance.

2. 1996 IPCC Guidelines estimates N_2O emissions from "human sewage" based on "annual per capita protein intake". The use of annual per capita protein available for consumption results in an overestimate of emissions.

Table A3–70 Canadian Protein Consumption

Year	Protein Consumption (g/capita per day)
1990	65.26
1991[a]	66.19
1992	66.55
1993	67.20
1994	67.86
1995	68.52
1996[a]	68.59
1997	69.87
1998	70.56
1999	71.25
2000	71.95
2001[a]	72.97
2002	72.79
2003[a]	71.76
2004[a]	72.18
2005[b]	71.12
2006[b]	71.03
2007[b]	71.79
2008[b]	70.25
2009[b]	69.85
2010[b]	69.77
2011[b]	69.43
2012[b]	69.09
2013[b]	68.75

Sources :
a. Statistics Canada (2008b), Food Statistics, Catalogue No. 21-020-X: the data have been adjusted for retail, household cooking and plate loss.

b. Statistics Canada (2010b), Food Statistics, Catalogue No. 21-020-X: the data have been adjusted for retail, household cooking and plate loss.

3. Canada adjusts the protein available using USDA[50] Food Loss statistics to obtain an estimate of the protein consumed. FAO datasets provide annual per capita protein available for consumption; use of this data overestimates annual per capita protein consumption.

    Consumer and retail level losses should be considered when developing protein consumption estimates; particularly in developed countries, such as Canada, where most of the loss occurs at the retail and consumer levels. In developing countries, 40% of the losses occur post-harvest and processing. Therefore, FAO[51] data does not adequately account for major losses in developed countries.

    Canada does not have country-specific information required to estimate these food losses, and therefore uses USDA ERS[52] loss estimates.

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50 United States Department of Agriculture

51 Food and Agriculture Organization of the United Nations

52 Economic Research Service of the United States Department of Agriculture

A3

Although Canada and U.S. have demonstrably different food consumption patterns, the categories of food consumed are almost identical and food processing and food intake style are comparable for a given food. Therefore, the U.S. food loss estimates, which are available by food item, are applicable to Canadian food consumption estimates.

4. The approach used in the 2011 Canadian National Inventory Submission should not be compared to that used by the U.S., without taking into account the differences in the methodologies used. The U.S. follows the IPCC 2006 Guidelines, which applies factors to account for non-consumed nitrogen and industrial/commercial inputs of nitrogen. Although it may appear that the use of these factors provides a more conservative estimate of N_2O emissions from wastewater, it must be recognized that the emission factor used in the IPCC 2006 Guidelines is half that of the Revised IPCC 1996 Guidelines (IPCC/OECD/IEA,1997). The net result is that the U.S. reports lower N_2O emissions per capita than Canada.

5. The IPCC 2006 Guidelines default FNON-CON[53] value of 1.4 is not appropriate for Canada. The IPCC 2006 Guidelines suggest the use of a default value for FNON-CON of 1.4 for developed countries using FWDs.[54] Fewer than 10% and 50% of households in Canada and the U.S., respectively, use FWD units. Food waste in Canada is typically managed through the solid waste management or on-site composting streams. Therefore, if Canada was to adopt the IPCC 2006 Guidelines, it would not be appropriate to use the FNON-CON value of 1.4.

6. Per capita nitrogen loading rates based on individual sewage contributions to the sewer system reflect the nitrogen loading basis of the Revised 1996 IPCC Guidelines. A typical wastewater industry value for nitrogen produced by an individual when FWD units are not used is 13 g N/capita/day. As discussed in Section 7.1, Canadian nitrogen loading based on 2009 per capita protein consumption and protein available data is 11.2 g N/capita/day and 16.5 g N/capita/day, respectively. The former value is a more accurate estimate of the nitrogen produced by an individual at the household and is aligned with the Revised IPCC 1996 Guidelines intent to account for proteins from human sewage, and not include industrial and non-consumed proteins.

7. The use of the Revised IPCC 1996 Guidelines with available protein data provides a higher per capita N_2O-N generation estimate than the use of IPCC 2006 Guidelines with all combinations of available and consumed protein and FNON-COM default values.

The Revised IPCC 1996 Methodology is based on consumed protein; using available Canadian consumed protein data, N_2O generation of 0.1118 g N_2O-N/capita/day is calculated. However, the ERT argues that Canada should use available protein in this calculation, which would result in an N_2O generation of 0.1644 g N_2O-N/capita/day. This value does not appear to be reasonable when compared to equivalent calculations using the IPCC 2006 Guidelines. Using all combinations of available or consumed protein and FNON-CON values of

1.1 or 1.4, the Canadian per-capita N_2O-N emissions calculated by the IPCC 2006 approach are lower than that calculated using the Revised IPCC 1996 approach with available protein data. Therefore, there appears to be little justification that Canada should use the ultraconservative approach recommended by the ERT."

The N_2O emission factor is calculated as follows:

Equation A3–94:

$$EF_{N_2O} = PC \times EF_{N_2O-N} \times FRAC_{NPR} \times \frac{44}{28}$$

where:

EF_{N2O}	=	emission factor: kg N_2O/capita per year
PC	=	annual per capita protein consumption, kg/capita per year (Statistics Canada 2007b, 2008b, 2010b)
EF_{N2O-N}	=	emission factor: default 0.01 (0.002–0.12) kg N_2O-N/kg sewage nitrogen produced
$FRAC_{NPR}$	=	fraction of nitrogen in protein: default = 0.16 kg N/kg protein
44/28	=	stoichiometric factor to convert nitrogen to N_2O

Emissions are calculated by multiplying the emission factor by the population of the respective provinces (Statistics Canada 2006, 2014):

Equation A3–95:

$$N_2O_S = EF_{N_2O} \times NR_{PEOPLE}$$

where:

N_2O_s	=	N_2O emissions from human sewage, kg N_2O/year
EF_{N2O}	=	emission factor: kg N_2O/capita per year (Equation A3–94).
NR_{PEOPLE}	=	number of people in country

A3.6.3.2. Data Sources

The Canadian protein consumption data are obtained from the annual food statistics publication (Statistics Canada 2008b, 2010b).

The provincial populations are obtained from Statistics Canada (Statistics Canada 2006, 2014).

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[53] Fraction of non-consumed protein

[54] Food waste disposal

Table A3–71   Estimated MSW Incinerated by Province for 1990–2013

Year	MSW Incinerated (t)					
	N.L.	P.E.I.	N.S.	Que.	Ont.	B.C.
1990	0	32 000	76 500	619 522	258 700	239 752
1991	0	32 000	53 458	564 219	266 361	252 214
1992	35 500	29 800	56 700	541 100	277 000	257 500
1993	0	32 000	57 953	530 107	255 272	262 964
1994	0	32 000	57 564	508 308	251 779	265 179
1995	0	32 000	55 924	483 314	249 873	265 668
1996	0	32 000	53 421	455 098	249 719	264 723
1997	0	32 000	50 443	423 631	251 484	262 637
1998	0	32 000	47 385	388 882	255 337	259 705
1999	0	32 212	45 000	298 904	258 429	254 800
2000	0	33 000	42 000	303 887	270 811	256 400
2001	0	32 224	42 000	303 910	281 671	246 700
2002	0	32 703	41 738	307 715	165 060	245 555
2003	0	32 914	38 809	310 700	178 747	242 525
2004	0	33 192	36 578	314 041	192 169	238 424
2005	0	33 426	38 276	317 108	204 647	233 217
2006	0	33 310	38 361	320 440	216 690	227 599
2007	0	33 221	41 672	324 499	225 977	221 431
2008	0	33 861	40 733	329 085	236 694	214 121
2009	0	34 564	37 977	334 552	247 106	206 456
2010	0	35 650	33 387	340 281	259 538	199 544
2011	0	37 098	30 552	345 502	271 165	195 388
2012	0	37 847	30 119	350 644	284 425	189 962
2013	0	37 999	32 373	355 260	297 171	184 943

Note: Ontario incineration plant closed as of 2001 year-end.

A3.6.4.   CH$_4$ and N$_2$O Emissions from Municipal Wastewater and Industrial Sludge Handling

Methane emissions from these two sources are assumed as not occurring. The sludge from municipal wastewater treatment is typically either placed in landfills or applied to soils, and therefore they are accounted for within the emissions from MSW landfills, or, when land-applied, the application is on the surface, meaning that the degradation is aerobic with no significant CH$_4$ emissions.

Methodologies for the estimation of N$_2$O emissions from industrial sludge treatment are not provided in either the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/OECD/IEA 1997) or the IPCC *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (IPCC 2000) and, therefore, this category was not estimated.

A3.6.5.   CO$_2$ Emissions from Waste Incineration

A3.6.5.1. Methodology

Municipal Solid Waste Incineration

The IPCC decision tree in Figure 5.5 of IPCC (2000) for CO$_2$ emissions from waste incineration defines good practice in adapting the methods in the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/OECD/IEA 1997). Country-specific carbon contents are not available; thus, Box 2 of the decision tree in Figure 5.5 (IPCC 2000) is the chosen methodology for calculation of CO$_2$ emissions.

The following steps detail the methodology for the estimation of CO$_2$ emissions from waste incineration:

Calculating the Amount of Waste Incinerated: The amount of waste incinerated each year is based on two primary sources. The amount

Table A3–72   Quantities of Waste Incinerated in 1992

Waste Types	Waste Quantities Incinerated in 1992											
	N.L.	P.E.I.	N.S.	N.B.	Que.	Ont.	Man.	Sask.	Alta.	B.C.	N.W.T. & Nvt.	Yk.
Paper	13 600	10 100	19 940	n.l.	171 610	96 200	n.l.	n.l.	n.l.	92 170	n.l.	n.l.
Plastic	2 650	2 800	5 250	n.l.	42 490	23 200	n.l.	n.l.	n.l.	23 700	n.l.	n.l.
Organics	9 820	9 670	17 710	n.l.	190 480	102 000	n.l.	n.l.	n.l.	65 580	n.l.	n.l.

Source: Environment Canada (1996b), tables 2.3-2.26.
Note: n.l. means that no incineration occurs in that province.

A3

of MSW incinerated in the year 1992 was estimated based on a study performed by the Hazardous Waste Branch of Environment Canada (Environment Canada 1996b). The amount of MSW incinerated for the years 1999, 2000 and 2001 was estimated based on the study "Municipal Solid Waste Incineration in Canada: An Update on Operations 1999–2001, performed by A.J. Chandler & Associates Ltd. for Environment Canada (Environment Canada 2003b). A polynomial curve-fitting equation is employed to estimate the amount of MSW incinerated over the period 1991–1998 based on the values provided by A.J. Chandler & Associates Ltd. and Environment Canada. To estimate the coefficients in the polynomial, a multiple linear regression application (Microsoft Excel LINEST statistical tool for an array) is used. A polynomial of the order 13 provides the best fit. This multiple linear regression method of estimation is consistent with the IPCC interpolation method (IPCC 2000). To estimate the amount of MSW incinerated for 2002–2013, a trend extrapolation was performed with the A.J. Chandler & Associates Ltd. and Environment Canada MSW incineration values for all relevant provinces except Quebec and Ontario, for which only the former MSW incineration values were used. In the province of Ontario, one of the incineration plants closed at the end of 2001. Therefore, the amount of waste incinerated in Ontario for the period 2002–2013 is estimated by trending the A.J. Chandler & Associates Ltd. incineration values for 1999–2001 with population (Statistics Canada 2006, 2014), assuming that the Ontario incineration plant was closed for this period.

MSW incineration estimates for the period 1990–2013 are shown in Table A3–71.

Developing Emission Factors: Provincial CO_2 emission factors are developed based on a study performed by the Hazardous Waste Branch of Environment Canada (Environment Canada 1996b). The CO_2 emission factors are founded on the assumption that carbon contained in waste undergoes complete oxidation to CO_2.

The provincial breakdown in the type of waste incinerated for 1992 was estimated by the Hazardous Waste Branch of Environment Canada (Environment Canada 1996b). The quantity of waste incinerated was divided into three categories: paper, plastics and organics. Table A3–72 summarizes these waste quantities.

In accordance with the IPCC Guidelines (2006), only CO_2 emissions resulting from the incineration of carbon in waste of fossil origin (e.g. plastics, certain textiles, rubber, liquid solvents and waste oil) are included in emission estimates. Therefore, it is necessary to estimate the fossil origin portion of the waste in order to develop an emission factor that excludes emissions due to the incineration of biomass. The breakdown in organic composition is estimated by averaging waste composition data from three published documents (Environment Canada 1994a, 1995a, 1995b). Table A3–73 shows the averaged breakdown in organic composition as well as the moisture and carbon content employed to develop the MSW incineration emission estimates.

The amount of fossil fuel-based carbon available in the waste incinerated is determined using typical percent weight carbon content values. Carbon and moisture content values were provided by Tchobanoglous et al. (1993) and Peavy et al. (1985). The carbon content for plastic is 80%, an average of the 75–85% range provided by the Good Practice Guidance (IPCC 2000), based upon a recommendation from a 2011 ERT centralized review. The amount of carbon per tonne of waste is estimated by subtracting the moisture content from the mass of fossil origin waste and multiplying by the carbon content value of the waste type. The fossil origin portion of the organic waste is determined by multiplying the organic waste by the percent fossil origin composition as follows:

Equation A3–96:

$$Waste\ Type_{Fossil-Origin} = M_{Total} \times \left(1 - \%\ Organic_{Comp}\right)$$

where:

WasteType_{Fossil-Origin} = amount of fossil fuel–based waste incinerated, t

M_{Total} = amount of waste incinerated, t (1992 data provided by Environment Canada [1996b])

%Organic_{Comp} = % organic composition per waste type (Environment Canada 1994a, 1995a, 1995b)

Table A3–73   Estimated MSW Organic Composition and Moisture and Carbon Content

Component	Composition of Total Organics (%)	Moisture Content (%)	Carbon Content (%)
Yard/Garden Waste	41	60.0	47.8
Food Waste	31	70.0	48.0
Wood Waste	16	20.0	49.5
Textiles	10	10.0	55.0
Rubber	2	2.0	69.7
Total Organics	100	50.5	49.3

Sources:
Tchobanoglous et al. (1993), pages 70, 80.

Carbon constants for Textiles and Yard Waste from Peavy et al. (1985).

A3

The amount of fossil fuel-based carbon is converted to tonnes of CO_2 per tonne of waste by multiplying by the ratio of the molecular mass of CO_2 to that of carbon. The derivation of the CO_2 emission factor is shown in the following equations:

Equation A3–97:

$$C_{Avail(y)} = \left(Waste\,Type_{\,Fossil-Origin}\right) \times (1 - \%\,Moisture) \times \%\,C_{Waste\,Type}$$

where:

$C_{Avail(y)}$ = available carbon per waste type for province y, t

$WasteType_{Fossil-Origin}$ = amount of fossil fuel-based waste incinerated, t (1992 data provided by Environment Canada [1996b])

% Moisture = % moisture content per waste type (Tchobanoglous et al. 1993)

% $C_{WasteType}$ = % carbon content per waste type (dry basis) (Tchobanoglous et al. 1993)

Equation A3–98:

$$EF_{CO_2-1992(y)} = \left(\frac{\sum C_{Avail(y)}}{M_{Inc(y)}}\right) \times \frac{44}{12}$$

where:

$EF_{CO2-1992(y)}$ = 1992 CO_2 emission factor for incineration for province y, t CO_2/t waste incinerated

$C_{Avail(y)}$ = available carbon per waste type for province y, t (See Equation A3–97)

$M_{Inc\,(y)}$ = total mass waste incinerated in 1992 for province y, t

44/12 = stoichimetric factor to convert carbon to CO_2

Calculating CO_2 Emissions: Emissions were calculated on a provincial level by multiplying the amount of waste incinerated by the appropriate emission factors.

Equation A3–99:

$$CO_{2(x)} = EF_{CO_2-1992} \times \left(M_{Inc(x)/province}\right)$$

where:

$CO_{2(x)}$ = CO_2 emissions from waste incineration in year x, t/province per year

$EF_{CO2-1992}$ = 1992 provincial CO_2 emission factor for incineration, t CO_2/t incinerated

$M_{Inc(x)/province}$ = mass waste incinerated per province in year x, t/year

Hazardous Waste Incineration

CO_2 emissions were estimated from activity data provided directly by facilities engaged in hazardous waste incineration in Canada through successive surveys conducted in 2006, 2008 and 2010 (Environment Canada 2010). The waste quantities and emissions are presented at a national level in Table A3–74.

These amounts incinerated include contaminated substrates such as soils, wood, metal and other material, and therefore are conservative. The hazardous waste quantities also include inorganic wastes such as aqueous solutions containing heavy metals, or that have relatively low fossil carbon origin wastes such as water-based urethanes, as opposed to solvent-based urethane wastes.

The good practice guidance IPCC defaults were used for the CO_2 estimation: carbon content (50%), and fossil carbon as % of total carbon (90%). In the absence of IPCC default values for N_2O and CH_4 emission factors, EFs were derived from one hazardous waste incineration facility that had provided total emissions based on direct measurements of N_2O and CH_4 emissions for the year 2007.

The site burned 177 tons of hazardous waste (HW) and emitted 0.03 tons CH_4 and 0.56 tons N_2O in 2007. The emission factors were then calculated as 0.0001695 t CH_4/t HW and 0.003164 t N_2O/t HW.

A3.6.5.2. Data Sources

The amount of MSW incinerated in the year 1992 was estimated by the Hazardous Waste Branch of Environment Canada (Environment Canada 1996b). The amount of MSW incinerated for the years 1999, 2000, and 2001 was estimated by A.J. Chandler & Associates Ltd. for Environment Canada (Environment Canada 2003b).

The amount of fossil fuel-based carbon available in the waste incinerated is determined using typical percent weight carbon constants. Carbon constants and moisture contents were provided by Tchobanoglous et al. (1993) and Peavy et al. (1985).

Hazardous incineration activity data were obtained directly from facilities. Surveys were conducted by Environment Canada in 2006, 2008, 2010 (Environment Canada 2010), 2012 (Environment Canada 2013c) and 2014 (Environment Canada 2014c).

A3.6.6. N_2O Emissions from Waste Incineration

A3.6.6.1. Methodology

Municipal Solid Waste Incineration

Emissions of N_2O from MSW incineration are estimated using the assumption that the IPCC five-stoker facility factors are most representative. The average N_2O emission factor over the range given as IPCC default values for MSW five-stoker facilities is 0.148 kg/t waste incinerated (IPCC/OECD/IEA 1997). To estimate emissions, the calculated factor is multiplied by the amount of waste incinerated by each province. The national emission values are then determined as the summation of these emissions for all provinces.

Equation A3–100:

$$N_2O_{MSW} = M_{MSW} \times EF_{N_2O-MSW}$$

where:

N_2O_{MSW}	=	N_2O emissions from municipal solid waste incineration, t/year
M_{MSW}	=	mass of municipal solid waste incinerated, t/year
$EF_{N2O-MSW}$	=	MSW N_2O emission factor (0.148 kg N_2O/t MSW incinerated / 1000 kg/t)

Table A3–74 Activity Data and Emissions from Hazardous Waste Incineration for 1990–2013

Year	Quantitiy of Hazardous Waste Incinerated	Estimated GHG Emissions		
	tonnes	kt CO_2	kt N_2O	kt CH_4
1990	100 762	166.3	0.319	0.017
1991	109 111	180.0	0.345	0.019
1992	117 879	194.5	0.373	0.020
1993	125 109	206.4	0.396	0.021
1994	142 050	234.4	0.449	0.024
1995	164 727	271.8	0.521	0.028
1996	146 125	241.1	0.462	0.025
1997	132 348	218.4	0.419	0.022
1998	155 511	256.6	0.492	0.026
1999	140 820	232.4	0.446	0.024
2000	168 379	277.8	0.533	0.029
2001	179 525	296.2	0.568	0.030
2002	184 845	305.0	0.585	0.031
2003	144 036	237.7	0.456	0.024
2004	161 891	267.1	0.512	0.027
2005	157 788	260.4	0.499	0.027
2006	147 775	243.8	0.468	0.025
2007	134 878	222.6	0.427	0.023
2008	147 494	243.4	0.467	0.025
2009	134 122	221.3	0.424	0.023
2010	138 031	227.8	0.437	0.023
2011	130 503	215.3	0.413	0.022
2012	85 153	253.4	0.486	0.026
2013	89 604	147.9	0.284	0.015

Sewage Sludge Incineration

Emissions of N_2O from sewage sludge incineration are estimated using the IPCC default emission factor for fluidized beds, 0.8 kg/t of dried sewage sludge incinerated (IPCC 2000). 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 A3–101:

$$N_2O_{ss} = M_{ss} \times EF_{N_2O-SS}$$

where:

N_2O_{SS}	=	N_2O emissions from sewage sludge incineration, t/year
M_{SS}	=	mass of dried sewage sludge incinerated, t/year
EF_{N2O-SS}	=	sewage sludge N_2O emission factor (0.8 kg N_2O/t dried sludge incinerated / 1000 kg/t)

Table A3–75   Estimated Sewage Sludge Incinerated for 1990–2013

	Sewage Sludge Incinerated (t, dry basis)				
Year	Que.	Ont.	Sask.	B.C.	National Total
1990	49 200	222 795	1 840	0	273 835
1991	59 400	222 795	1 840	0	284 035
1992	79 800	222 795	1 840	0	304 435
1993	64 833	129 125	71	0	194 029
1994	100 181	93 072	59	0	193 311
1995	101 356	113 985	152	0	215 493
1996	93 276	112 697	70	0	206 043
1997	15 424	0	0	4 885	20 310
1998	18 341	0	0	4 951	23 292
1999	22 032	0	0	0	22 032
2000	24 651	0	0	0	24 651
2001	27 960	0	0	0	27 960
2002	31 096	0	0	0	31 096
2003	34 234	0	0	0	34 234
2004	37 373	0	0	0	37 373
2005	40 511	0	0	0	40 511
2006	43 649	0	0	0	43 649
2007	46 787	0	0	0	46 787
2008	49 925	0	0	0	49 925
2009	53 064	0	0	0	53 064
2010	56 202	0	0	0	56 202
2011	59 340	0	0	0	59 340
2012	62 478	0	0	0	62 478
2013	65 616	0	0	0	65 616

Note:
A large step change is observed in the quantities of sewage sludge incinerated in Ontario for the period 1996–1997. This is as a result of two pilot projects that were approved in the mid-1990s for the non-incineration waste disposal of sewage sludge. The first project involved the spreading of treated sewage sludge on farmers' fields outside of Toronto, and the second project involved the transportation of sewage sludge to be spread on mine tailings. Both projects proved to have difficulties, owing to odour problems and the large quantities of waste that were to be spread on farmers' fields. From 1996 to 2000, Toronto sludge was stored during periods when excess quantities of waste were unable to be applied on land. In 2001, a new contract commenced that involved the spread of biosolids on Ontario farmers' fields, with excess biosolids being shipped to U.S. landfill sites.

Hazardous Waste Incineration

Refer to Section A3.6.5.1.

A3.6.6.2. Data Sources

Data sources for MSW incineration are described in Section A3.6.5.2.

Estimates of the amount of dried solids in the sewage sludge incinerated in the years 1990–1992 are based on a study completed in 1994. Data for the years 1993–1996 were acquired through telephone surveys of facilities that incinerate sewage sludge (Environment Canada 1997). Data for the years 1997 and 1998 are based on a study prepared by Compass Environmental Inc. for Environment Canada (Environment Canada 1999). Activity data for the years 1999, 2000 and 2001 are taken from a study prepared by A.J. Chandler & Associates Ltd. for Environment Canada (Environment Canada 2003b).

Hazardous incineration activity data were obtained directly from facilities. Surveys were conducted by Environment Canada in 2006, 2008, 2010 (Environment Canada 2010), 2012 (Environment Canada 2013c) and 2014 (Environment Canada 2014c).

A3.6.7. CH$_4$ Emissions from Waste Incineration

A3.6.7.1. Methodology

MSW Incineration

CH$_4$ emissions from the incineration of MSW are assumed to be negligible, as supported by the findings of a recent study commissioned by Environment Canada (CRA 2011). However, waste incineration of the biosolids resulting from municipal wastewater treatment does produce CH$_4$ emissions. The IPCC does not provide a methodology for CH$_4$ emissions from waste incineration, but recommends that national experts use existing published methods (IPCC 2000).

A3

Emissions of CH_4 are estimated based on emission factors obtained from the U.S. Environmental Protection Agency (US EPA 1995). The emission factors are 1.6 t/kt of total dried solids for fluidized bed sewage incinerators and 3.2 t/kt of dried solids for multiple hearth incinerators, both equipped with venturi scrubbers. It is assumed that all incinerators are of the fluidized bed type.

CH_4 emissions from sewage sludge incineration are dependent on the amount of dried solids incinerated. To calculate the CH_4 emissions, the amount of dried solids incinerated is multiplied by an appropriate emission factor. Estimates of the amount of dried solids in the sewage sludge incinerated in the years 1990–1992 are based on a study completed in 1994 (Environment Canada 1994b). Data for the years 1993–1996 were acquired through telephone surveys of facilities that incinerate sewage sludge (Environment Canada 1997). Data for the years 1997 and 1998 are based on a study prepared by Compass Environmental Inc. for Environment Canada (Environment Canada 1999). Activity data for the years 1999, 2000 and 2001 are taken from a study prepared by A.J. Chandler & Associates Ltd. for Environment Canada (Environment Canada 2003b). To estimate the amount of sewage sludge incinerated in the years 2002–2013, a linear regression analysis was completed using the A.J. Chandler & Associates Ltd. and Compass Environmental Inc. MSW incineration values.

In view of the relatively small number of facilities that incinerate sewage sludge in Canada, we believe that all relevant facilities were contacted, and we expect that the activity data collected from all three sources of information are complete. As such, our approach in estimating the amount of sewage sludge incinerated over the time series years is consistent.

Sewage sludge incineration estimates for the period 1990–2013 are shown in Table A3–75.

CH_4 emissions are calculated as follows:

Equation A3–102:

$$CH_{4(s)} = S_{Inc} \times EF_{CH_4-FB}$$

where:

$CH_{4(s)}$	=	CH_4 emissions from waste incineration, t/year
S_{Inc}	=	sewage sludge incinerated, dry t/year
EF_{CH4-FB}	=	CH_4 emission factor for fluidized bed incinerators: 1.6 t CH_4/kt sewage sludge incinerated / 1000 kg/t

Hazardous Waste Incineration

Refer to Section A3.6.5.1.

A3.6.7.2. Data Sources

Estimates of the amount of dried solids in the sewage sludge incinerated in the years 1990–1992 are based on a study completed in 1994. Data for the years 1993–1996 were acquired through telephone surveys of facilities that incinerate sewage sludge (Environment Canada 1997). Data for the years 1997 and 1998 are based on a study prepared by Compass Environmental Inc. for Environment Canada (Environment Canada 1999). Activity data for the years 1999, 2000 and 2001 are taken from a study prepared by A.J. Chandler & Associates Ltd. for Environment Canada (Environment Canada 2003b).

Hazardous incineration activity data were obtained directly from facilities. Surveys were conducted by Environment Canada in 2006, 2008, 2010 (Environment Canada 2010), 2012 (Environment Canada 2013c) and 2014 (Environment Canada 2014c).

Annex 4

National Energy Balance

This annex covers the energy and the CO_2 emission results from the reference approach (RA), a comparison of the results from the RA with those estimated by the sectoral approach (SA), and a summary of the national energy balance, which is the main energy data source for both the RA and the SA.

A4.1. Comparison of Reference Approach with Sectoral Approach

Results from the RA were compared with the SA as a check of energy consumed and CO_2 emissions from the combustion of fossil fuels. The check was performed for all years from 1990 to 2013 and is an integral part of reporting to the United Nations Framework Convention on Climate Change (UNFCCC).

Direct comparison of energy results in the RA and SA shows significant discrepancies, since the SA total does not include some of the non-energy use of fossil fuels and feedstocks. Comparison of the RA and SA shows a 5.8 to 10.5% variation in energy. This is corrected by excluding the non-combustion energy of certain feedstocks and fossil fuels to ensure that the RA and the SA are comparing similar sources. When the RA energy amounts include adjustments for non-energy use of feedstocks and fossil fuels, the difference between the SA and adjusted RA varies from -1.98 to 0.26%. Table A4-1 shows a comparison of the original and adjusted RA and SA.

Table A4–1   Comparison of Adjusted Reference Approach and Sectoral Approach for Canada (1990–2000)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Overall Energy Comparison											
Reference Approach (PJ)	6 975	6 827	7 039	7 086	7 331	7 535	7 754	7 963	8 092	8 331	8 668
Sectoral Approach (PJ)	6 474	6 314	6 556	6 566	6 789	6 950	7 164	7 317	7 423	7 733	8 084
Percent Difference without Adjustment (%)	7.7	8.1	7.4	7.9	8.0	8.4	8.2	8.8	9.0	7.7	7.2
Reference Approach with Non-Energy Use of Fossil Fuels and Feedstock Adjustment (PJ)	6 467	6 311	6 520	6 544	6 779	6 962	7 103	7 276	7 420	7 621	7 987
Percent Difference with Adjustment - 100% x (RA-SA)/SA	**-0.11**	**-0.05**	**-0.54**	**-0.33**	**-0.15**	**0.17**	**-0.86**	**-0.56**	**-0.04**	**-1.45**	**-1.19**
Adjusted Non-Energy Fossil Fuels and Feedstocks											
Non-Energy Use of Gaseous Fuels (PJ)	157	176	167	187	194	193	235	253	247	258	234
Non-Energy Use of Liquid Fuels (PJ)	399	398	418	410	405	431	485	496	494	510	469
Non-Energy Use of Solid Fuels (PJ)	3	3	3	4	4	4	5	5	5	4	5
Overall Emission Comparison											
Reference Approach (Gg CO_2)	421 854	413 128	423 982	422 962	437 010	450 212	454 687	468 391	479 102	489 443	516 992
Sectoral Approach (Gg CO_2)	417 649	407 710	421 422	418 552	431 334	442 313	455 265	468 280	475 567	491 829	514 254
Percentage Difference (%)	**1.01**	**1.33**	**0.61**	**1.05**	**1.32**	**1.79**	**-0.13**	**0.02**	**0.74**	**-0.49**	**0.53**
Liquid Fuels											
Reference Approach (Gg CO_2)	211 822	199 210	200 233	202 331	208 388	211 532	208 542	216 839	222 503	221 145	228 491
Sectoral Approach (Gg CO_2)	205 624	193 800	197 205	198 101	202 789	205 545	210 764	218 161	222 112	223 843	226 273
Percentage Difference (%)	**3.01**	**2.79**	**1.54**	**2.14**	**2.76**	**2.91**	**-1.05**	**-0.61**	**0.18**	**-1.21**	**0.98**
Solid Fuels											
Reference Approach (Gg CO_2)	84 134	89 184	91 319	83 818	87 364	90 812	91 777	98 308	104 953	105 153	114 806
Sectoral Approach (Gg CO_2)	87 000	90 216	92 681	84 977	89 428	90 856	92 785	99 833	105 467	105 622	114 736
Percentage Difference (%)	**-3.29**	**-1.14**	**-1.47**	**-1.36**	**-2.31**	**-0.05**	**-1.09**	**-1.53**	**-0.49**	**-0.44**	**0.06**
Gaseous Fuels											
Reference Approach (Gg CO_2)	125 775	124 676	132 337	136 640	140 908	147 583	154 077	153 101	151 429	162 933	173 447
Sectoral Approach (Gg CO_2)	124 903	123 636	131 444	135 302	138 767	145 630	151 429	150 146	147 774	162 156	173 000
Percentage Difference (%)	**0.70**	**0.84**	**0.68**	**0.99**	**1.54**	**1.34**	**1.75**	**1.97**	**2.47**	**0.48**	**0.26**

Table A4-1   Comparison of Adjusted Reference Approach and Sectoral Approach for Canada (2001–2013)

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Overall Energy Comparison													
Reference Approach (PJ)	8 466	8 586	8 875	8 847	8 653	8 572	8 937	8 762	8 325	8 640	8 817	9 061	9 144
Sectoral Approach (PJ)	7 983	8 095	8 320	8 257	8 170	8 056	8 444	8 227	7 860	8 039	8 181	8 203	8 396
Percentage Difference without Adjustment (%)	6.1	6.1	6.7	7.1	5.9	6.4	5.8	6.5	5.9	7.5	7.8	10.5	8.9
Reference Approach with Non-Energy Use of Fossil Fuels and Feedstock Adjustment (PJ)	7 836	7 975	8 208	8 120	8 030	7 914	8 277	8 129	7 720	7 930	8 100	8 224	8 366
Percentage Difference with Adjustement - 100% x (RA-SA)/SA	-1.84	-1.49	-1.35	-1.66	-1.71	-1.77	-1.98	-1.19	-1.78	-1.35	-0.99	0.26	-0.36
Adjusted Non-Energy Fossil Fuels and Feedstocks													
Non-Energy Use of Gaseous Fuels (PJ)	198	147	153	165	154	157	156	125	138	139	158	162	166
Non-Energy Use of Liquid Fuels (PJ)	548	574	615	674	544	601	612	600	555	647	654	773	691
Non-Energy Use of Solid Fuels (PJ)	4	4	4	4	11	8	8	11	7	4	4	3	4
Overall Emission Comparison													
Overall - Reference Approach (Gg CO$_2$)	504 282	510 273	524 818	518 888	510 285	500 248	524 293	514 279	482 747	497 470	499 037	508 859	513 865
Overall - Sectoral Approach (Gg CO$_2$)	509 189	512 953	528 189	524 787	519 288	510 363	534 531	517 956	490 198	499 716	501 825	500 886	511 031
Overall - Percentage Difference (%)	-0.96	-0.52	-0.64	-1.12	-1.73	-1.98	-1.92	-0.71	-1.52	-0.45	-0.56	1.59	0.55
Liquid Fuels													
Reference Approach (Gg CO$_2$)	226 201	227 269	241 597	246 358	239 520	233 692	241 587	238 432	231 534	239 801	237 197	248 732	245 763
Sectoral Approach (Gg CO$_2$)	230 118	229 268	244 055	252 479	249 415	246 033	253 596	245 117	239 642	244 253	243 419	244 652	245 524
Percentage Difference (%)	-1.70	-0.87	-1.01	-2.42	-3.97	-5.02	-4.74	-2.73	-3.38	-1.82	-2.56	1.67	0.10
Solid Fuels													
Reference Approach (Gg CO$_2$)	112 396	110 267	108 602	101 910	103 539	100 542	105 903	100 995	82 519	84 589	76 244	70 803	70 004
Sectoral Approach (Gg CO$_2$)	113 075	110 599	109 672	102 168	103 453	99 765	104 708	98 887	83 064	84 125	74 961	69 088	69 559
Percentage Difference (%)	-0.60	-0.30	-0.98	-0.25	0.08	0.78	1.14	2.13	-0.66	0.55	1.71	2.48	0.64
Gaseous Fuels													
Reference Approach (Gg CO$_2$)	165 449	172 366	174 256	170 222	166 944	165 728	176 411	174 493	168 386	172 750	185 297	188 927	197 700
Sectoral Approach (Gg CO$_2$)	165 760	172 716	174 099	169 742	166 137	164 279	175 834	173 562	167 184	171 008	183 146	186 749	195 550
Percentage Difference (%)	-0.19	-0.20	0.09	0.28	0.49	0.88	0.33	0.54	0.72	1.02	1.17	1.17	1.10

A4

No adjustments were necessary for the emissions estimate in the RA since online CRF Reporting software, supplied by the UNFCCC, correctly removes non-energy and feedstock associated emissions and allocates them to industrial processes. Comparison of the RA and SA emission estimates, as seen in Table A4–1, shows an overall -1.98 to 1.59% variation.

A4.1.1.   Reference Approach Methodology

The RA follows the Revised 1996 Intergovernmental Panel on Climate Change (IPCC) Guideline's designated method with the use of country-specific energy conversion factors (in higher heating value [HHV]/gross calorific value [GCV]) and emission factors. In Canada, as in the United States, HHV is used to record the energy content of fuels. Fuel quantities from the most recent Report on Energy Supply–Demand in Canada (RESD; Statistics Canada catalogue no. 57-003) and the Energy Statistics Handbook (Statistics Canada 2010) are entered in their physical units, with the exception of international bunkers. A discussion of the data for international bunkers is presented in the following sections: 3.4.1, International Bunker Fuels; A2.4.2.3, Civil Aviation; and A2.4.2.4, Navigation. For primary fuels (crude oil, coal and natural gas), the stock change data have been adjusted to account for inter-product transfers, stock variation and other adjustments, and are then transformed to other fuels to determine the apparent consumption values. The stock change data for secondary fuels take into consideration imports, exports, international bunkers, stock variations, non-energy use and other adjustments.

Once the apparent consumption is determined, country-specific energy conversion factors and carbon emission factors are used to calculate the carbon content and emissions. These factors are taken from the following sources: Statistics Canada's annual Report on Energy Supply–Demand in Canada (RESD, 57-003); Canada's Greenhouse Gas Emissions: Estimates for 1990 (Jaques 1992); the 1998 Fossil Fuel and Derivative Factors (McCann 2000); and Measurement Canada, an Industry Canada agency. For the majority of fossil fuels, the applied emission factors and oxidation factors are from McCann (2000), Jaques (1992) and from IPCC/OECD/IEA (1997).

Table A4–2 presents the applied emission factor, energy conversion factor and oxidation value in the RA. Energy conversion factors are taken directly from the RESD, with the exception of crude oil, natural gas, petroleum coke and still gas, where weighted factors have been developed to account for the quantity and variation of energy content at the point of consumption such as commercial usage or self-generated usage. For example, for provinces with natural gas production, there are two emission factors for natural gas: marketable natural gas, which is sold to consumers, and non-marketable natural gas, which is consumed directly by the producers of natural gas.

To adjust the RA for comparison with the SA, non-energy use of fossil fuels and feedstocks and the corresponding carbon dioxide emitted must be calculated using the storage and emission factors for industrial processes presented in Annex 6 of the NIR.

A4.2. The National Energy Balance

The objective of this annex is to provide a general background on the national energy balance and its data quality framework. In Canada, the Environment, Energy and Transportation Statistics Division (EETSD) of Statistics Canada is responsible for the collection, compilation and dissemination of energy data under the authority of the *Statistics Act*.[1] The national energy balance is known as the annual Report on Energy Supply and Demand in

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1 Statistics Canada. Statistics Act. http://laws-lois.justice.gc.ca/eng/acts/S-19/.

A4

Table A4–2 Reference Approach Energy Conversion and Emission Factors for Canada

Fuel Types			Energy Conversion Factor, GCV			Carbon Emission Factor – 2013 Value (t C/TJ GCV)	Reference	Oxidation Factors (IPCC Default)	Comments
			2013 Value	Unit	Reference				
Liquid	**Primary Fuels**	Crude Oil	39.13	TJ/ML	See Comments	19.26	Refer to Comments	1.0	Weighted energy conversion and emission factor are based on country-specific data.
		Ethane	17.22	TJ/ML	4	15.46	2	1.0	Total available ethane is consumed as a feedstock in industrial processes.
		Orimulsion	NA	–	–	NA	–	1.0	
		Natural Gas Liquids	27.26	TJ/ML	–		–	1.0	Propane and butane from natural gas liquids.
	Secondary Fuels	Bitumen	44.46	TJ/ML	4	21.11	3	1.0	Use of asphalt.
		Gas/Diesel Oil	38.3	TJ/ML	4	18.86	2	1.0	Use of diesel fuel oil.
		Gasoline	35	TJ/ML	4	17.84	2	1.0	
		Jet Kerosene	37.4	TJ/ML	4	18.67	2	1.0	Use of aviation turbo fuel.
		Liquefied Petroleum Gases (LPG)	25.31	TJ/GL	4	16.35	2	1.0	Propane and butane from petroleum refineries.
		Lubricants	39.16	TJ/ML	4	19.66	3	1.0	
		Naphtha	35.17	TJ/ML	4	19.33	3	1.0	
		Other Kerosene	37.68	TJ/ML	4	18.53	2	1.0	
		Other Oil	38.8	TJ/ML	4	19.15	2	1.0	Use of light fuel oil.
		Petroleum Coke – Refinery and Upgrader	44.31	TJ/ML	4	22.78	4	1.0	Reallocated to the Liquid Fossil fuel category for 2013 submission. 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	20.07	2	1.0	Use of heavy fuel oil.
		Shale Oil	NA	–	–	NA	–	–	
		Still Gas – Refinery and Upgrader Fuel Gas	39.29	TJ/ML	4	13.87	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.

Table A4-2   Reference Approach Energy Conversion and Emission Factors for Canada   (cont'd)

Fuel Types			Energy Conversion Factor, GCV			Carbon Emission Factor – 2013 Value (t C/TJ GCV)	Reference	Oxidation Factors (IPCC Default)	Comments
			2013 Value	Unit	Reference				
	Other Liquid Fuels	Aviation Gasoline	33.52	TJ/ML	4	19.25	3	1.0	
		Other Product Feedstocks	39.82	TJ/ML	4	19.84	3	1.0	
Solid	Primary Fuels	Anthracite	27.7	TJ/kt	4	23.50	3	1.0	
		Other Bituminous Coal	26.9	TJ/kt	4	22.20	5	1.0	Use of Canadian bituminous coal
		Sub-bituminous Coal	19.15	TJ/kt	4	24.84	5	1.0	
		Lignite	15	TJ/kt	4	26.36	5	1.0	
		Oil Shale	NA	–	–	NA	–	–	
		Peat	NA	–	–	NA	–	–	
	Secondary Fuels	Coke	28.83	TJ/kt	4	23.69	2	1.0	Previously reported as Coking Coal.
		BKB & Patent Fuel	NA	–	–	NA	–	–	
		Coke Oven Gas	19.14	TJ/GL	4	12.52	2	–	Previously reported in Gaseous fuel category.
	Other Solid Fuels	Foreign Bituminous Coal	29.82	TJ/kt	4	23.43	5	1.0	
Gaseous	Primary Fuels	Natural Gas	39.64	TJ/GL	4	13.60	2	1.0	Country-specific weighted emission factor based on proportion of marketable and non-marketable natural gas.
Biomass		Solid Biomass	18	TJ/kt	4	28.41	3	1.0	1) Consists of industrial and residential biomass consumption. 2) Assumed 99% oxidation.
		Liquid Biomass	16.19	TJ/kt	4	18.82	3	1.0	1) Consists of spent pulping liquor, ethanol and biodiesel. 2) Weighted oxidation factor.
		Gas Biomass	39.82	TJ/Gl	1	13.54	1	1.0	1) Consists of methane from landfill gas. 2) Assumed a 100% oxidation factor.

References: (1) IPCC/OECD/IEA (1997); (2) McCann (2000); (3) Jaques (1992); (4) Statistics Canada, #57-003 (2013 data); (5) EC Coal Study.

NA = Not applicable; BKB = Charcoal briquettes; NGL = natural gas liquids; LPG = liquified petroleum gas.

Canada (RESD) and can be found on Statistics Canada's website.[2] The RESD is the key underlying activity data used to estimate greenhouse gas (GHG) emissions for the Energy Sector. The non-energy and feedstock information from the RESD is also used by the Industrial Processes and Product Use Sector. The RESD is an accounting of energy forms in Canada from import and export activities through to production and domestic consumption (refer to Figure A4–1 for a sample of an energy flow diagram). It consists of information on crude oil, natural gas, coal, refined petroleum product (RPPs), electricity, steam, non-energy use of fossil fuels, feedstock and other secondary energy forms for all Canadian industrial sectors and other energy use, such as the transportation, residential and commercial sectors.

Energy and fossil fuel data are collected by various methods, such as a mix of annual and monthly surveys, along with census data from industry, federal agencies (such as the National Energy Board [NEB]), provincial energy departments and agencies (such as the Alberta Energy Regulator [AER] and the Alberta Utilities Commissions [AUC]), and the Canadian Industrial Energy End-Use Data and Analysis Centre (CIEEDAC). Refer to Figure A4–2, Canadian Energy Flow, for a sample of the energy and fossil fuel data input. The oil and gas information as provided by the AER is highly accurate, since it is tied to oil and gas exploitation permits and to federal and provincial royalty schemes.

The RESD is used by various federal departments for energy efficiency programs, policy development, reporting to the International Energy Agency, energy and emission forecasting, and reporting to the UNFCCC. As such, EETSD's quality management system for the RESD includes an internal and external stakeholder review process. Its quality assurance framework and methodological reports are documented and made available through Statistics

the quantity of crude oil shipped as reported by the producer is verified against report receipts from pipeline companies, and the information as reported by pipelines is verified against refinery receipts. EETSD also applies both a top-down approach through the supply and disposition surveys and a bottom-up approach through the Industrial Consumption of Energy (ICE) survey to verify the quality of the data for manufacturing industries. The ICE survey collects fuel consumption data directly from manufacturing industries following the North American Industry Classification System. In addition, an annual Survey of Secondary Distributors of Refined Petroleum Products (SSD) was implemented to collect data on sale volumes for use in reallocating volumes of heavy fuel oil, light fuel oil, diesel and gasoline to the appropriate consuming sectors due to the deregulation of the sale of these products from primary producers (refineries) to include secondary resellers/distributers. Prior to this improvement, the volume of fuel sold by refineries to secondary distributors were all misallocated to the commercial sector. The deregulation of the sale of these four fuels started around the year 2000. A consistent approach was applied to the historical dataset to address the misallocated fuel volumes between 2000 and 2008 since the SSD only started collecting sale volumes in from 2009 onward.

Also, as part of EETSD's quality framework, an annual "work-in-progress" review has been established with Environment Canada and Natural Resources Canada to review the ICE estimates and the RESD prior to their official release. Industrial stakeholders also participate in the review of ICE data through the Canadian Industry Program for Energy Conservation group. CIEEDAC also participates in the review of refinery data and the industrial energy statistics.

A4

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. The Common Reporting Format (CRF) tables also indicate source and sink categories that are NE or IE as well as ones that are not occurring (NO) in Canada.

Table A5–1   Summary of GHG Sources and Sinks Not Estimated (NE) or Included Elsewhere (IE)

Source/Sink Category	GHG	NE / IE	Explanation
1.A. Fuel Combustion 1. Energy Industries c. Manufacture of Solid Fuels and Other Energy Industries i. Manufacture of Solid fuels; Liquid Fuels; Gaseous Fuels	CO_2 CH_4 N_2O	IE	Only aggregated activity data available.
1.A. Fuel Combustion 2. Manufacturing Industries and Construction e. Food Processing, Beverages and Tobacco Liquid Fuels; Solid Fuels; Gaseous Fuels	CO_2 CH_4 N_2O	IE	Only aggregated data available.
1.A. Fuel Combustion 3. Transport b. Road Transportation i-iv. Cars/Light duty trucks/Heavy duty trucks and buses/Motor-cycles – Liquefied Petroleum Gases (LPG); Gaseous Fuels	CO_2 CH_4 N_2O	IE	Canada is not currently able to disaggregate propane and gaseous guel (natural gas) emissions into the various vehicle subcategories under Road Transportation and is thus including all on-road propane and gaseous fuel emissions under 1.A.3.b.v Other/Propane and Natural Gas Vehicles.
1.A. Fuel Combustion 4. Other Sectors c. Agriculture/Forestry/Fishing ii. Off-road vehicles and other machinery – Gasoline; Diesel Oil; Other Liquid Fuels; Biomass	CO_2 CH_4 N_2O	IE	Canada is not currently able to disaggregate off-road emissions into the various 1.A.4 CRF categories and is thus including all off-road emissions under 1.A.3.e Other Transportation.
1.A. Fuel Combustion 4. Other Sectors c. Agriculture/Forestry/Fishing iii. Fishing – Residual Fuel Oil; Gas/Diesel Oil; Gasoline; Other Liquid Fuels; Biomass	CO_2 CH_4 N_2O	IE	Canada is not currently able to disaggregate fishing from domestic navigation. Fishing emissions are thus included under 1.A.3.d Domestic Navigation.
Fuel Type – Ethane	CO_2	IE	Non-energy use of ethane from natural gas liquids removed manually.
1.B. Fugitive Emissions from Fuels 1. Solid Fuels a. Coal Mining and Handling i. Underground Mines – Post Mining Activities	CH_4	IE	Emissions from post-mining activities are included in the coal production emission factors.
1.B. Fugitive Emissions from Fuels 1. Solid Fuels a. Coal Mining and Handling ii. Surface Mines – Post Mining Activities	CH_4	IE	Emissions from post-mining activities are included in the coal production emission factors.
1.B. Fugitive Emissions from Fuels 1. Solid Fuels a. Coal Mining and Handling i. Underground Mines – Mining Activities	CO_2	NE	Unknown emissions rates and activity data.
1.B. Fugitive Emissions from Fuels 1. Solid Fuels a. Coal Mining and Handling ii. Surface Mines – Mining Activities	CO_2	NE	Unknown emissions rates and activity data.

Table A5-1 Summary of GHG Sources and Sinks Not Estimated (NE) or Included Elsewhere (IE) (cont'd)

Source/Sink Category	GHG	NE / IE	Explanation
1.B. Fugitive Emissions from Fuels 1. Solid Fuels a. Coal Mining and Handling i. Underground Mines – Post Mining Activities	CO_2	NE	Unknown emissions rates and activity data.
1.B. Fugitive Emissions from Fuels 1. Solid Fuels a. Coal Mining and Handling ii. Surface Mines – Post Mining Activities	CO_2	NE	Unknown emissions rates and activity data.
1.B. Fugitive Emissions from Fuels 1. Solid Fuels b. Solid Fuel Transformations	CO_2 CH_4	NE	Fugitive emissions from solid fuel transformation are not estimated owing to a lack of data. Other sources of solid fuel transformation emissions are not known. These sources are thought to be insignificant.
1.B. Fugitive Emissions from Fuels 2. Oil, Natural Gas and Other Sources a. Oil i. Exploration	CO_2 CH_4	IE	Only aggregated data available.
1.B. Fugitive Emissions from Fuels 2. Oil, Natural Gas and Other Sources a. Oil v. Distribution of Oil Products	CO_2 CH_4	IE	Only aggregated data available.
1.B. Fugitive Emissions from Fuels 2. Oil, Natural Gas and Other Sources b. Natural Gas i. Exploration	CO_2 CH_4	IE	Only aggregated data available.
1.C CO_2 Transport and Storage 1. Injection and Storage a. Injection	CO_2	IE	Included under 1.B.2.a.2 Oil Production.
1.D. Memo Items 3. Multilateral Operations	CO_2 CH_4 N_2O	IE	Canada is not currently able 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.
2.A. Mineral Products 3. Glass Production	CO_2	IE	Emissions coming from the use of limestone and soda ash in glass manufacturing are reported under 2.A.4 Production and Other Process Uses of Carbonates.
2.B. Chemical Industry 1. Ammonia Production	CH_4	NE	CH_4 emissions from industrial processes associated with the production of ammonia are small and are not estimated in the current NIR submission. However, this category will be reported in the next NIR submission.
2.B. Chemical Industry 1. Ammonia Production	N_2O	NE	N_2O emissions associated with the production of chemicals other than nitric acid, adipic acid and ethylene are reported as NE. According to a recent study (Cheminfo Services 2010), production of chemicals, such as ammonia and methanol, is not a large source of N_2O emissions.
2.B. Chemical Industry 3. Adipic Acid Production	CO_2	NE	IPCC 2006 Guidelines (IPCC 2006) does not provide methodology for estimating of CO_2 from industrial processes associated with adipic acid production and therefore emissions are not estimated. Note that the Canadian plant became indefinitely idled as of spring 2009, and hence both N_2O and CO_2 are indicated as "not occurring" (NO) in the CRF tables.
2.B. Chemical Industry 8. Petrochemical and Carbon Black Production b. Ethylene	CO_2	IE	Only aggregated activity data available; reported under 2.D Non-Energy Products from Fuels and Solvent Use.
2.B. Chemical Industry 8. Petrochemical and Carbon Black Production g. Other – Styrene	CH_4	IE	Included under 2.B.8 Petrochemical and Carbon Black Production due to confidentiality of data.
2.C. Metal Production 1. Iron and Steel Production	CH_4	IE	Included under the relevant Energy Sector category 1.A.2.a. Iron and Steel.
2.C. Metal Production 1. Iron and Steel Production d. Sinter	CO_2	IE	Included under the relevant Energy Sector category 1.A.2.g.iii. Mining.
2.C. Metal Production 1. Iron and Steel Production d. Sinter	CH_4	IE	Included under the relevant Energy Sector category 1.A.2.g.iii. Mining.
2.C. Metal Production 1. Iron and Steel Production g. Other – Coke	CO_2	IE	Included under the relevant Energy Sector category 1.A.2.a. Iron and Steel.
2.C. Metal Production 1. Iron and Steel Production g. Other – Coke	CH_4	IE	Included under the relevant Energy Sector category 1.A.2.a. Iron and Steel.
2.C. Metal Production 2. Ferralloys Production	CO_2	IE	Only aggregated activity data available; reported under 2.C.1.b. Pig iron.
2.C. Metal Production 2. Ferralloys Production	CH_4	IE	Included under the relevant Energy Sector category 1.A.2.a. Iron and Steel.

A5

Table A5-1   Summary of GHG Sources and Sinks Not Estimated (NE) or Included Elsewhere (IE) (cont'd)

Source/Sink Category	GHG	NE / IE	Explanation
2.D. Non-Energy Products from Fuels and Solvent Use	CH_4	IE	Included under 2.B.8 Petrochemical and Carbon Black production.
2.D. Non-Energy Products from Fuels and Solvent Use 3. Other – Road Paving with Asphalt	CO_2	NE	CO_2 emissions from asphalt roofing are not estimated. Currently, there are no country-specific information on this. Based on the 2006 IPCC Guidelines (Volume 3, Chapter 5), CO_2 emissions from this category are thought to be negligible.
2.D. Non-Energy Products from Fuels and Solvent Use 3. Other – Asphalt Roofing	CO_2	NE	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 5), CO_2 emissions from this category are thought to be negligible.
2.F. Product Uses as Substitutes for Ozone Depleting Substances 4.Aerosols	PFCs	NE	Data on PFCs used in aerosols are currently unavailable.
3.A. Enteric Fermentation 4. Other Livestock – Mules, Asses and Camels	CH_4 N_2O	NE	Minor livestock categories and no activity data.
3.B. Manure Management 4. Other Livestock – Mules, Asses and Camels	CH_4 N_2O	NE	Minor livestock categories and no activity data.
3.B. Manure Management - Animal Waste Management Systems from Anaerobic Lagoons, and Daily Spread	CH_4 N_2O	NE	These manure management systems are considered minor by Canadian experts when compared with liquid/slurry and solid and dry lot storage.
3.D. Agricultural Soils a. Direct N_2O Emissions from Manages Soils 2. Organic N Fertilizers b. Sewage Sludge Applied to Soils	N_2O	NE	This practice does not occur on a large scale in Canada and no activity data is currently available to estimate emissions.
4.B. Cropland 2. Land converted to Cropland 2.3 Wetlands converted to Cropland	CO_2	NE	Activity data not available.
4.B. Cropland 2. Land converted to Cropland 2.4 Settlements converted to Cropland"	CO_2	NE	Activity data not available.
4.C. Grassland 1. Grassland remaining Grassland Carbon stock changes in all pools	CO_2	NE	If no change in management practices or input occurs, the C stocks are assumed to be at equilibrium, and hence the change in C stocks is deemed zero. AD on management practice change are not available
4.D. Total Wetlands 2. Land converted to Wetlands	CO_2	IE	All non-forest land conversion to Wetlands is reported under Other Land converted to Wetlands.
4.E. Total Settlements 1. Settlements remaining Settlements, Carbon stock change in DOM	CO_2	IE	The net increase in biomass C accounts for urban tree growth characteristics and tree mortality and decomposition.
4.E. Total Settlements 1. Settlements remaining Settlements, Carbon stock change in soils	CO_2	NE	Activity data not available.
4.E. Total Settlements 2. Land Converted to Settlements 2.2 Cropland converted to Settlements	CO_3	NE	Activity data not available.
4.E. Total Settlements 2. Land Converted to Settlements 2.4 Wetlands converted to Settlements	CO_2	NE	Activity data not available.
4.G. Harvested Wood Products – Information Item: HWP in SWDS	CO_2	NE	Methods under development.
5.A. Solid Waste Disposal	CO_2	NE	CO_2 emissions from MSW landfills are not reported in the total since they are of biogenic origin.
5.A. Solid Waste Disposal 2. Unmanaged Waste Disposal Sites	CH_4	IE	In Canada, most waste disposal on land occurs in managed municipal or privately owned landfills. Very few, if any, unmanaged waste disposal sites exist. Therefore, it has been assumed that all waste is disposed of in managed facilities.
5.C. Incineration and Open Burning of Waste (Non-Biogenic) – Municipal Solid Waste	CH_4	NE	According to the IPCC Guidelines methane emissions from incineration are very uncertain and more research is required in this area. It is also accepted that the methane emissions from incineration are considered as negligible and therefore have not been estimated.
5.D. Wastewaster Treatment and Discharge 2. Industrial Waste Water	N_2O	NE	No methodology is provided in the IPCC 2006 Guidelines.

A5

Annex 6

Emission Factors

This annex summarizes the development and selection of emission factors for use in estimating greenhouse gas (GHG) emissions. Additional details on sector-specific methodologies for the use of these factors are presented in Annex 3.

A6.1.   Fuel Combustion

A6.1.1.   Natural Gas and Natural Gas Liquids

A6.1.1.1. Carbon Dioxide (CO_2)

CO_2 emission factors for fossil fuel combustion depend primarily on fuel properties such as carbon content, density and heating value and, to a lesser extent, on the combustion technology.

For natural gas, there are two principal fuel types combusted in Canada: marketable fuel (processed for commercial sale) and non-marketable fuel (unprocessed, for internal use). There are regional variations in marketable and non-marketable natural gas use, with nine regions consuming marketable fuel and seven regions consuming non-marketable fuel. Provincial and territorial emission factors (Table A6–1) have been developed based on data from chemical analysis of representative natural gas samples (McCann 2000). Both imported and domestic natural gas were included, where applicable, in the mix of gas samples used for chemical analysis. Nonmarketable natural gas emission factors are higher than those of marketable fuels as a result of their raw nature; in addition to methane, non-marketable natural gas may include ethane, propane and butane in the fuel mix.

CO_2 emission factors (Table A6–3) for natural gas liquids (NGL), such as ethane, propane and butane, were developed based on chemical analysis data for marketable fuels (McCann 2000).

A6.1.1.2. Methane (CH_4)

Emissions of CH_4 from fuel combustion are technology-dependent. Sectoral emission factors (Table A6–2 and Table A6–3) have been developed based on technologies typically used in Canada. The factors were developed based on a broad review of emission factors for combustion technologies (SGA Energy 2000). The emission

factor for producer consumption of natural gas was developed based on a technology split for the upstream oil and gas industry (CAPP 1999) and technology-specific emission factors from the U.S. EPA report AP 42 (U.S. EPA 1996a).

Table A6–1 CO_2 Emission Factors for Natural Gas

Province	Emission Factor[1] (g/m³)	
	Marketable[2]	Non-marketable[3]
Newfoundland and Labrador	1 901	2 494
Nova Scotia	1 901	2 494
New Brunswick	1 901	NO
Quebec	1 887	NO
Ontario	1 888	NO
Manitoba	1 886	NO
Saskatchewan	1 829	2 441
Alberta	1 928	2 392
British Columbia	1 926	2 162
Yukon	1 901	2 401
Northwest Territories	2 466	2 466

Notes:

NO = Not occurring

1. McCann (2000)

2. The term "marketable" applies to fuel consumed by the Electric Utilities, Manufacturing Industries, Residential/Commercial and Transport subsectors.

3. The term "non-marketable" applies to raw gas consumption, mainly by natural gas producers.

Table A6–2 CH_4 and N_2O Emission Factors for Natural Gas

Source	Emission Factor (g/m³)[1]	
	CH_4	N_2O
Electric Utilities	0.490	0.049
Industrial	0.037	0.033
Producer Consumption (Non-marketable)	6.4[2]	0.060
Pipelines	1.900	0.050
Cement	0.037	0.034
Manufacturing Industries	0.037	0.033
Residential, Construction, Commercial/Institutional, Agriculture	0.037	0.035

Notes:

1. SGA Energy (2000)

2. Adapted from U.S. EPA (1996b) and CAPP (1999)

Table A6–3   Emission Factors for Natural Gas Liquids

Source	Emission Factor (g/L)		
	CO_2	CH_4	N_2O
Propane			
Residential	1 515[1]	0.027[2]	0.108[2]
All Other Uses	1 515[1]	0.024[2]	0.108[2]
Ethane	986[1]	0.024[2]	0.108[2]
Butane	1 747[1]	0.024[2]	0.108[2]

Notes:

1. McCann (2000)

2. SGA Energy (2000)

A6.1.1.3. Nitrous Oxide (N₂O)

Emissions of N_2O from fuel combustion are technology-dependent. Emission factors (Table A6–2 and Table A6–3) have been developed based on technologies typically used in Canada. The factors were developed from an analysis of combustion technologies and a review of their emission factors (SGA Energy 2000).

A6.1.2. Refined Petroleum Products

A6.1.2.1. CO₂

CO_2 emission factors for fossil fuel combustion are dependent primarily on fuel properties and, to a lesser extent, on the combustion technology.

Emission factors have been developed for each major class of refined petroleum products (RPP) based on their heating value,

carbon content and destiny (McCann 2000), to ensure consistency with the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2006).

The composition of petroleum coke is process-specific. Factors have been developed for both refinery (catalytic cracker) derived cokes and coke used in upgrading facilities. These factors (Table A6–5) have been developed using data provided by industry to the Canadian Industrial Energy End-Use Data Analysis Centre (CIEEDAC) in their Review of Energy Consumption reports on the refining and upgrading industry (CIEEDAC 2003, 2010). The bulk of the coke consumed by refineries is catalytic cracker-derived, and the emission factor is an average of petroleum coke and catalytic cracker coke emission factors.

Emission factors for still gas (Table A6–5) from refining operations and upgrading facilities were also derived from data provided by industry and reported by CIEEDAC (2003, 2010).

Table A6–4   Emission Factors for Refined Petroleum Products

Source	Emission Factor (g/L)		
	CO₂[1]	CH₄[2]	N₂O[2]
Light Fuel Oil			
Electric Utilities	2 753	0.18	0.031
Industrial	2 753	0.006	0.031
Producer Consumption	2 670	0.006	0.031
Residential	2 753	0.026	0.006
Forestry, Construction, Public Administration and Commercial/Institutional	2 753	0.026	0.031
Heavy Fuel Oil			
Electric Utilities	3 156	0.034	0.064
Industrial	3 156	0.12	0.064
Producer Consumption	3 190	0.12	0.064
Residential, Forestry, Construction, Public Administration and Commercial/Institutional	3 156	0.057	0.064
Kerosene			
Electric Utilities	2 560[3]	0.006	0.031
Industrial	2 560[3]	0.006	0.031
Producer Consumption	2 560[3]	0.006	0.031
Residential	2 560[3]	0.026	0.006
Forestry, Construction, Public Administration and Commercial/Institutional	2 560[3]	0.026	0.031
Diesel - Refineries and Others	2 690	0.133	0.4
Diesel - Upgraders[4]	2 690	0.147	1.10
Petroleum Coke	(see Table A6–5)	0.12	(see Table A6–5)
Still Gas	(see Table A6–5)	N/A	0.00002
Motor Gasoline	2 316	N/A	0.02[5]

Notes:
1. Adapted from McCann (2000)
2. SGA Energy (2000); except Diesel - Upgraders and Motor Gasoline
3. Assumed McCann (2000) aviation turbo-fuel emission factor
4. Assumed Off-road Diesel emission factors (see Table A6–11) since fuel is consumed in oil sands mining trucks.
5. Adapted from IPCC/OECD/IEA (1997)

N/A = Not available

Table A6–5 CO_2 Emission Factors for Petroleum Coke and Still Gas

						Emission Factor						
	1990	1995	2000	2005	2006	2007	2008	2009	2010	2011-2012	2013
Petroleum Coke						g/L						
Upgrading Facilities[1]	3 556	3 551	3 481	3 494	3 494	3 494	3 494	3 494	3 494	3 494	3 494
Refineries & Others[2]	3 766	3 787	3 711	3 814	3 817	3 820	3 817	3 816	3 826	3 814	3 814
Still Gas						g/m³						
Upgrading Facilities[1]	2 310	2 090	2 120	2 140	2 140	2 140	2 140	2 140	2 140	2 140	2 140
Refineries & Others[2]	1 678	1 748	1 683	1 719	1 753	1 760	1 705	1 723	1 700	1 600	1 883

Notes:
1. CIEEDAC (2003)
2. CIEEDAC (2014)

Table A6–6 N_2O Emission Factors for Petroleum Coke

						Emission Factor						
	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001–2013
Petroleum Coke						g/m³						
Upgrading Facilities[1,2]	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[1,2]	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:
1. Adapted from IPCC (2006)
2. Energy content from Statistics Canada Cat. No. 57-003 (2013)

A6

A6.1.2.2. CH_4

Emissions of CH_4 from fuel combustion are technology-dependent. Emission factors were developed (Table A6–4) based on technologies typically used in Canada. The factors were developed from an analysis of combustion technologies and a review of their emission factors (SGA Energy 2000).

The emission factor for petroleum coke was assumed to be the same for both catalytic cracker-derived cokes and coke used in upgrading facilities. An emission factor for still gas is not available, according to the 2000 SGA Energy study.

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 A6–4) 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 A6–6) were based on 2006 IPCC default emission factors and were calculated on an annual basis using energy conversion factors provided by Statistics Canada (2013).

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 A6–7) 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.

Factors presented in Table A6–7 were developed based on the statistical analysis 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. Factors for coal 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).

Table A6–7 CO_2 Emission Factors for Coal

Province	Coal Type	Source	Emission Factor (kg CO_2/tonne)[1,2,3]			
			Mean	Uncertainty (95% Confidence Interval)		Moisture (wt %)
				Low	High	
Newfoundland & Labrador, P.E.I., Quebec, Nova Scotia (prior to 2000)	Canadian Bituminous (Eastern)	Nova Scotia	2 344	-33%	22%	3.2
Newfoundland & Labrador, P.E.I., Quebec, Nova Scotia (2000 onward)	Canadian Bituminous (Western)	Alberta	2 212	-26%	26%	7.7
New Brunswick	Canadian Bituminous (Eastern)	New Brunswick	2 333	-14%	14%	3.2
Atlantic[4]	Foreign Bituminous	Non-U.S.	2 571	-7%	7%	8.3
Ontario	Canadian Bituminous (Western)	Alberta	2 212	-26%	26%	7.6
Ontario, Quebec	Foreign Bituminous	U.S. (Pennsylvania)	2 626	-17%	12%	N/A
Ontario, Manitoba	Foreign Sub-bituminous	U.S. (Wyoming)	1 743	-18%	18%	N/A
Saskatchewan	Lignite	Saskatchewan	1 465	-13%	13%	36
Alberta, Saskatchewan, B.C.	Canadian Sub-bituminous (Western)	Alberta	1 763	-23%	18%	19
Alberta, Saskatchewan, B.C.	Canadian Bituminous (Western)	Alberta	2 212	-26%	26%	7.7
All Provinces & Territories	Anthracite	--	2 411	N/A	N/A	N/A

Notes:

1. Factors presented on a "wet basis." Moisture content shown is that for the "weighted average" emission factor.
2. Radovan et al. (2012)
3. 95% confidence intervals, which were determined through statistical analysis of Canadian coal data
4. Atlantic refers to the Maritime provinces and Newfoundland & Labrador

N/A = not available

Coke and coke oven gas emission factors are presented in Table A6–8. 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 A6–9) have been developed based on technologies typically used in Canada. The factors were developed from an analysis of combustion technologies and a review of their emission factors (SGA Energy 2000).

A6.1.3.3. N_2O

Emissions of N_2O from fuel combustion are technology-dependent. Emission factors for sectors (Table A6–9) have been developed based on technologies typically used in Canada. The emission factors were developed from an analysis of combustion technologies and a review of their emission factors (SGA Energy 2000).

Table A6–8 CO_2 Emission Factors for Coal Products

Coal Product - Fuel Type	Emission Factor
Coke Oven Gas[1]	687 g/m³
Coke[2]	3 173 g/kg

Notes:
1. McCann (2000)
2. CRA (2014)

Table A6–9 CH_4 and N_2O Emission Factors for Coals [1]

Source	Emission Factor	
	CH_4	N_2O
	g/kg	
Coal		
Electric Utilities	0.02	0.03
Industry and Heat & Steam Plants	0.03	0.02
Residential, Public Administration	4.00	0.02
Coke	0.03	0.02
	g/m³	
Coke Oven Gas	0.04	0.04

Note:
1. SGA Energy (2000)

A6.1.4. Other Fuels

A6.1.4.1. CO_2

Alternative fuels such as tires, refuse, and waste oil and solvents are used in the cement industry to offset combustion of purchased fuels like coal, oil or natural gas. CO_2 emissions associated with the stationary combustion of waste fuels are included in the National Inventory Report where data are available. Fuel use data reported by the cement industry, using CO_2 accounting and reporting standards developed by the World Business Council for Sustainable Development (WBSCD 2005), were used to generate the emission factors in Table A6–10.

A6.1.4.2. CH_4

CH_4 emission factors for alternative fuels were adapted from the 2006 IPCC Guidelines (IPCC 2006).

A6.1.4.3. N_2O

N_2O emission factors for alternative fuels were adapted from the 2006 IPCC Guidelines (IPCC 2006).

A6.1.5. Mobile Combustion

A6.1.5.1. CO_2

CO_2 emission factors for mobile combustion are dependent on fuel properties and are generally the same as those used for stationary combustion fuels.

A6.1.5.2. CH_4

Emissions of CH_4 from fuel combustion are technology-dependent. Mode-specific CH_4 emission factors have been developed based on technologies typically used in Canada, and are summarized in Table A6–11. The factors were initially adopted from a review of available knowledge and an analysis of combustion technologies (SGA Energy 2000). A number of on-road CH_4 emission factors were

subsequently refined with updated Canadian and U.S. emissions test results (Environment Canada 2006, 2009; Graham et al. 2008).

Over 50 aircraft-specific aviation turbo fuel CH_4 emission factors from the 2006 IPCC Guidelines (IPCC 2006) are used in the Tier 3 civil aviation model (Aviation Greenhouse Gas Emission Model - AGEM). Table A6–11 displays a national overall average implied emission factor, for conciseness (refer to Section A3.4.2.3 for more information on AGEM).

A6.1.5.3. N_2O

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 (SGA Energy 2000). Similar to the CH_4 emission factors of Section A6.1.5.2, a number of on-road N_2O emission factors were subsequently refined with updated Canadian and U.S. emissions test results (Environment Canada 2006, 2009; Graham et al. 2008, 2009).

In particular, the updated test data highlighted the effect of high-sulphur gasoline on N_2O emission factors. Vehicles fuelled with high-sulphur gasoline for the majority of their useful lives generally emitted higher levels of N_2O than those run on lowsulphur 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 A6–12.

A6.2.2. Chemical Industry

Tables A6–13, A6–14, A6–15 and A6–16 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 A6–10   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 - 2013
Cement Industry Waste Fuel	CO_2[1]	78.8	77.6	78.6	80.6	82.6	81.5	81.2	83.8	87.7	86.3	79.2	80.1
	CH_4[2]	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
	N_2O[2]	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004

Notes:
1. Adapted from WBSCD (2005)
2. Adapted from IPCC (2006)

Table A6–11   Emission Factors for Energy Mobile Combustion Sources

Mode[†]	Emission Factor (g/L fuel)		
	CO_2	CH_4	N_2O
Road Transport			
Gasoline Vehicles			
Light-duty Gasoline Vehicles (LDGVs)			
Tier 2	2 316[1]	0.14[3]	0.022[4]
Tier 1	2 316[1]	0.23[5]	0.47[5]
Tier 0	2 316[1]	0.32[6]	0.66[7]
Oxidation Catalyst	2 316[1]	0.52[8]	0.20[6]
Non-catalytic Controlled	2 316[1]	0.46[8]	0.028[6]
Light-duty Gasoline Trucks (LDGTs)			
Tier 2	2 316[1]	0.14[3]	0.022[4]
Tier 1	2 316[1]	0.24[5]	0.58[5]
Tier 0	2 316[1]	0.21[8]	0.66[7]
Oxidation Catalyst	2 316[1]	0.43[8]	0.20[6]
Non-catalytic Controlled	2 316[1]	0.56[6]	0.028[6]
Heavy-duty Gasoline Vehicles (HDGVs)			
Three-way Catalyst	2 316[1]	0.068[8]	0.20[8]
Non-catalytic Controlled	2 316[1]	0.29[6]	0.047[6]
Uncontrolled	2 316[1]	0.49[6]	0.084[6]
Motorcycles			
Non-catalytic Controlled	2 316[1]	0.77[3]	0.041[3]
Uncontrolled	2 316[1]	2.3[6]	0.048[6]
Diesel Vehicles			
Light-duty Diesel Vehicles (LDDVs)			
Advanced Control*	2 690[2]	0.051[6]	0.22[6]
Moderate Control	2 690[2]	0.068[6]	0.21[6]
Uncontrolled	2 690[2]	0.10[6]	0.16[6]
Light-duty Diesel Trucks (LDDTs)			
Advanced Control*	2 690[2]	0.068[6]	0.22[6]
Moderate Control	2 690[2]	0.068[6]	0.21[6]
Uncontrolled	2 690[2]	0.085[6]	0.16[6]
Heavy-duty Diesel Vehicles (HDDVs)			
Advanced Control	2 690[2]	0.11[9]	0.151[9]
Moderate Control	2 690[2]	0.14[6]	0.082[6]
Uncontrolled	2 690[2]	0.15[6]	0.075[6]
Natural Gas Vehicles	1.9[2]	9E-03[6]	6E-05[6]
Propane Vehicles	1 515[2]	0.64[6]	0.028[6]
Off-road			
Off-road Gasoline	2 316[1]	2.7[6]	0.050[6]
Off-road Diesel	2 690[2]	0.15[6]	1.1[6]
Railways			
Diesel Train	2 690[2]	0.15[6]	1.1[6]
Marine			
Gasoline Boats	2 316[1]	1.3[6]	0.066[6]
Diesel Ships	2 690[2]	0.15[6]	1.1[6]
Light Fuel Oil Ships	2 753[2]	0.26[6]	0.073[6]
Heavy Fuel Oil Ships	3 156[2]	0.28[6]	0.079[6]
Aviation			
Aviation Gasoline	2 365[10]	2.2[10]	0.23[10]
Aviation Turbo Fuel	2 560[2]	0.029[11]	0.071[12]
Renewable Fuels			
Ethanol	1 509[13]	**	**
Biodiesel	2 474[13, 14]	***	***

Notes:

† In the context of Transportation Modes, Tiers 0–2 refer to increasingly stringent U.S. EPA emission standards, enabled through advancements in emission control technologies. It should not be confused with IPCC GHG estimation methodologies. EPA Tiers apply to on-road vehicles under the following model year breakdown, with some overlap due to technology penetration (refer to Figure A3-2 of Annex 3 for more details): Tier 0: 1980-1995; Tier 1: 1994-2003; Tier 2: 2004-2013.

1. Adapted from McCann (2000)
2. McCann (2000)
3. Adapted from Environment Canada ERMD Report 04-44 (2006)
4. Adapted from Environment Canada ERMD Report 04-44 (2006) and Graham et al. (2009)
5. Adapted from Environment Canada ERMS Report 07-14A (2009)

6. SGA Energy (2000)
7. Adapted from Barton & Simpson (1994)
8. ICF Consulting (2004)
9. Graham et al. (2008)
10. Jaques (1992)
11. National overall average emission factor based on 2006 IPCC Guidelines (IPCC 2006). Refer to Section A3.4.2.3 of Annex 3.1 for further information.
12. IPCC (2006)
13. Refer to Section 3.5.3 and 3.5.4 of Chapter 3 for further information.
14. BioMer (2005)

* 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.

Table A6–12   Carbon Dioxide (CO$_2$) Emission Factors for Mineral Products

Category	Mineral Product	Emission Factor (g CO$_2$/kg of mineral product)
Cement Production	Clinker	534[1]
Lime Production	TOC	11.5[2]
	High-Calcium Lime	751[3]
Limestone and Dolomite Use	Dolomitic lime	889[3]
	Limestone	418[4]
Soda Ash Use	Dolomite	468[4]
Magnesite Use	Soda Ash	415[4]
	Magnesite	506[4]

Notes:

1. Cement Association of Canada (2014). 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, 1.013 to account for clinker that is lost or removed from the process. Excluding the correction factor, the 2013 EF is 527 g CO$_2$/kg clinker.
2. Cement Association of Canada (2014).
3. Developed based on information provided by Kenefick (2008). Personal communication (email to Shen A, Environment Canada, dated October 7, 2008). Canadian Lime Institute (CLI).
4. AMEC (2006).

Table A6–13   Emission Factors for Ammonia Production

	Activity Data	Fuel Factor m^{3}natural gas/tonne of NH$_3$	Emission Factor CO$_2$/ m^3 of natural gas	Emission Recovery Factor g CO$_2$ / kg of urea
Ammonia Production	Feedstock use of natural gas to manufacture ammonia	Facility-specific fuel factors are used and these are confidential. See Annex 3.3 for details.	Marketable natural gas emission factors found in Table A6–1 are used.	728

Table A6–14   N$_2$O Emission Factors for Nitric Acid and Adipic Acid Production

Category	Process Description	N$_2$O Emission Factor (kg/t)
Nitric Acid Production	Dual-pressure plants with extended absorption "Type 1"	9.4[1]
	Dual-pressure plants with extended absorption "Type 2"	12[1]
	High-pressure plants with non-selective catalytic reduction	0.66[1]
	High-pressure plants with selective catalytic reduction	8.5[2]
Adipic Acid Production	Oxidation reaction of cyclohexanone and cyclohexanol mixture without N$_2$O abatement	0.3[2]

Notes:
1. Collis G. 1992. Personal communication (letter from Collis G to Jaques A., Greenhouse Gas Division, dated March 23, 1992). Canadian Fertilizer Institute
2. IPCC (2000)

A6.2.3.   Metal Production

The emission factors for metallurgical coke use are year-specific, and were obtained from Cheminfo Services (2010) for 1990-2009, with the 2009 emission factor used for 2010-2013. The range of the metallurgical coke emission factors and other parameters used for estimating emissions from iron and steel production are found in Table A6–17.

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 A6–18. The parameter values of other tier types, which were also used in the estimation of emissions from aluminium production, are found in Section 4.9.2 of Chapter 4 and Annex 3.3.

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 A6–19

A6

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 A6–5. The 2011 emission-factor value for Upgrading Facilities in Table A6–5 has been used for Ontario across the time series. For the other provinces, the 2011 emission-factor value for Refineries and Others is used across the time series. The emission factors associated with NEU of coal are referenced in Table A6–7.

Table A6–15   Emission Factors for Petrochemical Products

Petrochemical Product	Emission Factor	Type
Silicon Carbide	11.6 kg CH_4 / t (tonne) product	IPCC default[1]
Calcium Carbide	4.8 kg CH_4 / t product	Derived from IPCC data[2]
Carbon Black	1.29 kg CH_4 / t product	Sector-wide weighted average[3]
	0.032 kg N_2O / t product	Sector-wide weighted average[3]
Ethylene	0.013 kg CH_4 / t product	Sector-wide weighted average[3]
	0.0055 kg N_2O / t product	Sector-wide weighted average[3]
Ethylene Dichloride	0.4 kg CH_4 / t product	IPCC default[1]
Styrene	4 kg CH_4 / t product	IPCC default[1]
Methanol	0.031 kg CH_4 / t product	Sector-wide weighted average[3]
	0.010 kg N_2O / t product	Sector-wide weighted average[3]

Notes:
1. Default value from IPCC (2006)
2. Derived from IPCC (2006) data. See section 4.8.2 for details
3. Cheminfo Services (2010)

Table A6–16   Emission Factor for By-Product Emissions from Fluorochemical Production

Process	Emission Factor
HCFC-22 production	0.04 t HFC-23 emitted / t HCFC-22 produced[1]

Note:
1. IPCC (2000)

Table A6–17 CO_2 Emission Factors for Iron and Steel Industry

Parameter	Emission Factor	Unit
Iron ore reduction with coke	3.2–3.3[1]	t CO_2/t (tonne) coke used
Electrode consumption in electric arc furnaces	4.53[2]	kg CO_2/ t steel
Electrode consumption in basic oxide furnaces	0.23[2]	kg CO_2/ t steel

Notes:
1. Year-specific emission factors provided in Cheminfo Services (2010)
2. Provided by the Canadian Steel Producers Association. Chan K. 2009. Personal communication (email from Chan K to Pagé M, Environment Canada, dated July 21, 2009). Canadian Steel Producers Association.

Table A6–18   Tier 1 Emission Factors for Aluminium Production

Cell Technology Type	Emission Factor[1]		
	CO_2	Carbon Tetrafluoride (CF₄)	Carbon Hexafluoride (C₂F₆)
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

Notes:
1. IAI (2006)

A6

Table A6–19 CO_2 Emission Factors for Non-energy Use of Natural Gas Liquids and Petroleum Products

Product	Fraction of Carbon Stored in Product	CO_2 Emission Factor (g CO_2/L)
Natural Gas Liquids		
Propane	0.8[1]	303[2]
Butane	0.8[1]	349[2]
Ethane	0.8[1]	197[2]
Petroleum Products		
Petrochemical Feedstocks[3]	0.8[1]	500[7]
Naphthas[4]	0.75[1]	625[7]
Lubricating Oils and Greases[5]	0.5[1]	1 410[7]
Petroleum Used for Other Products[6]	0.5[1]	1 450[7]

Notes:

1. IPCC/OECD/IEA (1997)
2. McCann (2000)
3. Carbon factor for Petrochemical Feedstocks is 680 g of carbon per litre (C/L) (Jaques 1992)
4. Carbon factor for Napthas is 680 g C/L (Jaques 1992)
5. Carbon factor for Lubricating Oils and Greases is 770 g C/L (Jaques 1992)
6. Carbon factor for Petroleum Used in Other Products is 790 g C/L (Jaques 1992)
7. The resulting CO_2 emission factor is calculated by multiplying the carbon factor for each product by the molecular weight ratio between CO_2 and Carbon (44/12) and by (1-fraction of carbon stored in product).

Table A6–20   Emission Factors for the use of PFCs, SF_6 and NF_3 in the Electronics Industry

Application	GHG Source	IPCC Tier	Emission Rate (%)	By-Product Emission Rate
Integrated Circuit or Semiconductor Manufacturing	CF_4	T2B - CVD	80[1]	N/A[1]
	CF_4	T2B - Etching	70[1]	N/A[1]
	C_2F_6	T2B - CVD	70[1]	0.1 kg CF_4 / kg C_2F_6[1]
	C_2F_6	T2B - Etching	40[1]	0.1 kg CF_4 / kg C_2F_6[1]
	c-C_4F_8	T2B - Etching	30[1]	N/A[1]
	SF_6	T2A	20[2]	N/A[2]
	NF_3	T2A	20[2]	0.09 kg CF_4 / kg NF_3[2]
	NF_3	T2B - Etching	20[3]	N/A[2]
Other Emissive Applications	PFCs	T2	50% first year / 50% second year[1]	N/A

Notes:

1. IPCC/OECD/IEA (1997)
2. IPCC (2006)
3. Cheminfo Services (2014)

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 A6–20.

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 A6–21 and Table A6–22 summarize emission rates used to estimate 1995–2013 HFC and PFC emissions.

A6

Table A6–21   2013 HFC as ODS Substitute – Assembly, In-Service and End-of-Life Emission Factors (%)

Subcategory	Assembly (%)	In-Service (%)	End-of-Life (%)	Life Time (years)
Aerosols[1]	0	50	100	2
Blowing agent in foams[1]				
Open cell foam	100	0	0	1
Closed cell foam	0.1	4.5	100	23
Air conditioning (Original Equipment Manufacture)[2]				
Air conditioner units in motor vehicles	0.5	10	75	13
Chillers (specify centrifugal or reciprocating)	1	4.7	5	17
Residential (air conditioners, dehumidifiers, etc.)	1	4	20	17
Air conditioning (Service / Maintenance)[2]				
Air conditioner units in motor vehicles	0.5	10	75	13
Chillers (specify centrifugal or reciprocating)	1	4.7	5	17
Residential (air conditioners, dehumidifiers, etc.)	1	4	20	17
Refrigeration (Original Equipment Manufacture)[2]				
Commercial transport	1	15	30	13
Commercial and institutional (retail foods, vending machines, etc.)	1	10	30	17
Industrial (warehouses, process equipment, etc.)	1	10	30	17
Residential (freezers, refrigerators)	0.6	0.5	30	15
Other equipment (specify)	-	-		-
Refrigeration (Service / Maintenance)[2]				
Commercial transport	1	15	30	13
Commercial and institutional (retail foods, vending machines, etc.)	1	10	30	17
Industrial (warehouses, processes, etc.)	1	10	30	17
Residential (refrigerators, freezers, etc.)	0.6	0.5	30	15
Other equipment (specify)	-	-		-
Solvent[1]	0	50	100	1
Fire suppression / Extinguishing systems (Manufacture)[1]				
Portable (mobile) systems	0	60	0	18
Total Fflooding (fixed) systems	0	35	0	18
Fire suppression / Extinguishing systems (Service /Maintenance)[1]				
Portable (mobile) systems	0	60	0	18
Total flooding (fixed) systems	0	35	0	18
Miscellaneous[1]	0	50	100	2
Other (specify)[1]	0	50	100	2

Notes:
1. IPCC (2006)
2. Environment Canada (2015)

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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 A6–23 below. The development of these emission factors is explained in Section 4.15.1 in Chapter 4.

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 A6–24.

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 A6–25.

A6.4. Agriculture

The sources of agricultural GHGs are Enteric Fermentation, Manure Management, Field Burning of Crop Residues, Agricultural Soils, and Agricultural Use of Lime, Urea and Other-Carbon Containing Fertilizers. As a result of the implementation of the 2006 IPCC Guidelines, several new emission sources have been included in the Agriculture Sector. Nitrous oxide emissions from mineralization/immobilization associated with loss/gain of soil organic matter are now included, calculated using country-specific emission factors as derived in Annex 3.4 for direct emissions from agricultural soils. Carbon dioxide emissions from Lime, Urea

Table A6–22   2013 PFC as ODS Substitute – Assembly, In-Service and End-of-Life Emission Factors (%)

Application	PFC Emission Rate (%)
Assembly	
Residential Refrigeration Equipment	3.5% (of charge)[1]
Commercial Refrigeration Equipment	
Stationary AC Equipment	3.5% (of charge)[1]
Mobile AC Equipment	4.5% (of charge)[2]
Operation	
Residential Refrigeration Equipment	17% (of stock in existing systems)
Commercial Refrigeration Equipment	17% (of stock in existing systems)
Stationary AC Equipment	17% (of stock in existing systems)
Mobile AC Equipment	30% (of stock in existing systems)
Other Applications	
Foam Blowing – open cell	100% (of use)
Foam Blowing – closed cell	10% of charge released during manufacturing and 4.5% of the original quantity charge released per year over the product's lifetime
Solvents	50% (of use) in the first year and the other 50% (of use) in the second year

Notes:

1. The *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* provide two ranges for values: 2–3% and 4–5%. The mid-point of the two ranges was used. (IPCC/OECD/IEA 1997).

2. The *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* provide a range of 4–5% as values. The average value was used. (IPCC/OECD/IEA 1997).

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Table A6–23   Emission Factors for N_2O Usage (Medical & Propellant)

Product	Application	N_2O Emission Rate (%)
N_2O Use	Anaesthetic Usage	100
	Propellant Usage	100

Source: IPCC (2006)

Table A6–24   Emission Factors for PFC Emissions from Other Contained Product Uses

Process	PFC Emissions from Other Contained Sources
Assembly	1% (of charge)
Annual Leakage Rate	2% (of stock)
Disposal	98% (of remaining stock)

Note:
Source: IPCC (2000)

Table A6–25   Emission Factors for Use of Urea in SCR Vehicles

Product	DEF Purity	Dosing Rate
Urea use in SCR Vehicles	32.50%	2% of diesel consumption

Note:
Source: IPCC (2000)

Table A6–26   Methane Emission Factors for Enteric Fermentation for Non-Cattle Animals

Non-cattle Animal Category	Enteric Fermentation Emission Factor[1] (kg CH_4/head/year)
Pigs	
Boars	1.5
Sows	1.5
Pigs < 20 kg	1.5
Pigs 20–60 kg	1.5
Pigs > 60 kg	1.5
Other Livestock	
Sheep	8
Lambs	8
Goats	5
Horses	18
Bison	55
Llamas & Alpacas	8
Elk & Deer	20
Wild Boars	1.5
Fox	N/A
Mink	N/A
Rabbits	N/A
Poultry	
Chickens	N/A
Hens	N/A
Turkeys	N/A

Notes:

1.   IPCC Tier 1 default emission factors (IPCC/OECD/IEA 1997)

N/A = Not available

Table A6–27   Methane Emission Factors for Manure Management for Elk and Deer, Rabbits, Fox and Mink[1]

Livestock	CH_4 Emission Factor (kg CH_4 head^{-1} yr^{-1})
Elk and Deer	0.22
Rabbits	0.08
Fox	0.68
Mink	0.68

Notes:

1.   Data source: IPCC (2006), Volume 4: Agriculture, Forestry and Other Land Uses, Table 10.16

Table A6–28   Maximum Methane-Producing Potential (B_0) by Animal Category[1]

Animal Category	Maximum CH_4-Producing Potential (B_0) (m³/kg VS)[4]
Dairy Cattle[2]	0.24
Non-dairy Cattle[3]	0.19
Sheep	0.19
Goats	0.18
Horses	0.3
Swine	0.48
Hens	0.39
Broilers	0.36
Turkeys	0.36

Notes:

1.   Data source: IPCC (2006), Volume 4: Agriculture, Forestry and Other Land Uses, Tables 10A-5 to 10A-9

2.   Dairy cattle include dairy cows and dairy heifers.

3.   The non-dairy cattle value is also used for bison.

4.   VS = volatile solids

Table A6–29   Methane Conversion Factors (MCFs) by Animal Category and Manure Management System[1]

Animal Categories	Liquid Systems (MCF$_L$)	Solid Storage and Drylot (MCF$_{SSD}$)	Pasture, Range and Paddock (MCF$_{PRP}$)	Other Systems (MCF$_O$)
Dairy Cattle	0.2	0.02	0.01	0.01
Non-dairy Cattle[2]	0.2	0.02	0.01	0.01
Swine	0.2	0.02	NA	0.01
Poultry	0.2	0.015	0.015	NA
Horses	NA	0.01	0.01	NA
Goats	NA	0.01	0.01	NA
Sheep	NA	0.01	0.01	NA
Lambs	NA	0.01	0.01	NA

Notes:

1.   Data source: IPCC (2006), Volume 4: Agriculture, Forestry and Other Land Uses, Tables 10A-5 to 10A-9 (cool climate, average annual temperature 12°C)

2.   Non-dairy cattle values are also used for bison.

NA = Not applicable

Table A6–30   Emission Factors (EFs) for Manure Nitrogen (N) Lost as N$_2$O-N by Animal Category and Animal Waste Management Systems[1]

	Liquid Systems (EF$_L$)	Solid Storage and Drylot (EF$_{SSD}$)	Other Systems (EF$_O$)
Non-dairy Cattle	0.001	0.02	0.005
Dairy Cattle	0.001	0.02	0.005
Poultry	0.001	0.02	0.005
Sheep and Lambs	0.001	0.02	0.005
Swine	0.001	0.02	0.005
Goats	0.001	0.02	0.005
Horses	0.001	0.02	0.005
Buffalo	0.001	0.02	0.005

Notes:
1.   Source: IPCC (2006), Volume 4, Agriculture, Forestry and Other Land Uses, Table 11.1

and Other Carbon Containing Fertilizers are calculated based on the total quantity of C contained in these products, Finally, indirect emissions of N leaching from stored manure are calculated based on the IPCC default emission factor for leached N (0.0075 kg N$_2$O/kg-N).

Methodologies for generating country-specific emission factors for enteric fermentation (cattle only), manure management, and agricultural soil emission estimates are detailed in Section A3.4. Furthermore, new country-specific N$_2$O emission factors for urine and dung deposited on pasture, range and paddock by grazing animals have been implemented in this submission. A detailed description of the methodology used to derive these emission factors as well as other agricultural methodologies, emission factors and parameters used for estimating emissions from agricultural source categories are provided in Annex 3.4. Certain default parameters used in Tier 2 calculations and Tier 1 emission factors are provided in Table A6–26 to Table A6–29.

A6.5.   Land Use, Land-Use Change and Forestry

The IPCC Tier 2 and Tier 3 methods and country-specific parameters are used for generating estimates for most of the LULUCF Sector. The CBM-CFS3 model is used for estimating growth, litter fall, tree mortality and decomposition, as well as the effects of natural disturbances for Forest Land. For Cropland, a process model (CENTURY) is used for estimating CO$_2$ emissions and removals as influenced by management activities, based on the National Soil Database of the Canadian Soil Information System. More detail on methods, emission factors and parameters for Forest Land and Cropland is provided in Annex 3.5.

As a result of the implementation of the 2006 IPCC Guidelines, new emission sources have been included in the LULUCF Sector. Notably, emissions from the use and disposal of Harvested Wood Products (HWP) were estimated and reported under the new LULUCF subsector (Harvested Wood Products, Chapter 6, Section 6.9). In addition, CO$_2$ emission estimates from the off-site decay of extracted peat are now reported in the Wetlands category and CO$_2$ removal estimates were revised for the Settlements category due to the implementation of a country-specific methodology.

A6

A6.6. Biomass Combustion

A6.6.1. CO$_2$

Emissions of CO$_2$ from the combustion of biomass (whether for energy use, from prescribed burning or from wildfires) are not included in National Inventory totals. These emissions are estimated and recorded as a loss of biomass stock in the Land Use, Land-use Change and Forestry (LULUCF) Sector.

The emissions related to energy use are reported as memo items in the common reporting format (CRF) tables as required by the United Nations Framework Convention on Climate Change (UNFCCC). Emission factors for residential combustion (Table A6–31) are technology-dependent.

Emissions from industrial combustion of biomass are dependent primarily on the characteristics of the fuel being combusted. The CO$_2$ emission factor (Table A6–31) for industrial wood waste has been developed from facility source sampling data collected by the U.S. EPA in units of lb/MMBTU (one million British thermal units; U.S. EPA 2003). The U.S. EPA data were converted to kg/tonne at 50% moisture content (m.c.) using a higher heating value (HHV) of 10.47 MJ/kg at 50% m.c., which was developed from an internal review of available moisture content and heating value data. The emission factor for spent pulping liquor is calculated from data collected by the National Council for Air and Stream Improvement (NCASI), based on carbon content assuming a 1% correction for unoxidized carbon (NCASI 2010). The NCASI emission factors were reported in units of kg/GJ HHV, which was converted to kg/tonne at 50% m.c. based on the same HHV vs. moisture content relationship used to convert wood waste.

CO$_2$ 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 A3.4.2).

A6.6.2. CH$_4$

Emissions of CH$_4$ from residential combustion of firewood are technology-dependent. The emission factors are taken or adapted from the U.S. EPA AP 42 Supplement B (U.S. EPA 1996b).

Emissions from industrial combustion of biomass are dependent primarily on the characteristics of the fuel being combusted. The emission factor (Table A6–31) for CH$_4$ from industrial wood waste has been developed from facility source sampling data collected by the U.S. EPA in units of lb/MMBTU (U.S. EPA 2003) and converted to kg/tonne at 50% m.c. as discussed in Section A6.6.1 above.

A6

Table A6–31 Emission Factors for Biomass

Source [1]	Description	Emission Factor (g/kg fuel)		
		CO$_2$	CH$_4$	N$_2$O
Wood Fuel / Wood Waste	Industrial Combustion	840[4]	0.09[4]	0.06[4]
Forest Wildfires	Open Combustion	NA	NA[2]	NA[3]
Controlled Burning	Open Combustion	NA	NA[2]	NA[3]
Spent Pulping Liquor	Industrial Combustion	891[5]	0.02[6]	0.02[6]
Stoves and Fireplaces	Residential Combustion			
Conventional Stoves		1 696[7]	15[7]	0.16[9]
Conventional Fireplaces and Inserts		1 696[7]	15[7]	0.16[9]
Stoves/Fireplaces with Advanced Technology or Catalytic Control		1 696[7]	6.9[8]	0.16[9]
Other Wood-burning Equipment		1 696[7]	15[7]	0.16[9]

Notes:

1. CO$_2$ emissions from biomass combusted for energy or agricultural purposes are not included in inventory totals, whereas CH$_4$ and N$_2$O emissions from these sources are inventoried under the Energy Sector. All greenhouse gas (GHG) emissions, including CO$_2$ emissions from biomass burned in managed forests (wildfires and controlled burning), are reported under Land-Use, Land-use Change and Forestry (LULUCF) and excluded from national inventory totals.

2. Emission ratio for CH$_4$ is 1/90th CO$_2$. See Section A3.4 in Annex 3.

3. Emission ratio for N$_2$O is 0.017% CO$_2$. See Section A3.4 in Annex 3.

4. Adapted from U.S. EPA (2003)

5. Adapted from NCASI (2010)

6. Adapted from IPCC (2006)

7. U.S. EPA (1996b)

8. Adapted from U.S. EPA (1996b). Average of the Non-Catalyst Stove and Catalyst Stove Emission factors

9. Jacques (1992)

NA = not applicable

Table A6–32   Emission Factors for Landfill Gas Combustion

Source	Description	Emission Factor (kg /t)		
		CO_2	CH_4	N_2O
Landfill Gas	Industrial Combustion	2 752	0.05	0.005

Source: Adapted from IPCC (2006), Volume 2, Energy, Table 2.2

The emission factor for CH_4 from spent pulping liquor is adapted from the IPCC (2006). It is converted from the units reported in the IPCC (kg/TJ lower heating value [LHV]) to kg/tonne at 50% m.c. based on the assumption that the LHV is 20% lower than the HHV along with the same HHV vs. moisture content relationship discussed in Section A6.6.1.

Emission factors from landfill gas (Table A6–32) 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 emission factors (Table A6–31) were chosen based on a review of emission factors for combustion technologies and an analysis of combustion technologies typically used in Canada (Jacques 1992).

Emissions from industrial combustion of biomass are dependent primarily on the characteristics of the fuel being combusted. Emission factors (Table A6–31) for industrial wood waste have been developed from facility source sampling data collected by the U.S. EPA in units of lb/MMBTU (U.S. EPA 2003) and converted to kg/tonne at 50% m.c. as discussed in Section A6.6.1 above. The emission factor for CH_4 from spent pulping liquor is adapted from the IPCC (2006). It is converted from the units reported in the IPCC (kg/TJ LHV) to kg/tonne at 50% m.c. based on the assumption that the LHV is 20% lower than the HHV along with the same HHV vs. moisture content relationship discussed in A6.6.1.

Emission factors for landfill gas (Table A6–32) 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 A3.4.2).

A6.7.   Waste

A6.7.1.   Municipal Wastewater Handling – Wastewater

A6.7.1.1. CH_4

Emissions from municipal wastewater handling are dependent upon the organic loading of the effluent stream, population and the type of wastewater treatment provided. The emission factor in this case is the product of the methane correction factor (MCF), which is an estimate of the fraction of biological oxygen demand (BOD) that will ultimately degrade anaerobically (MCF) and the maximum methane producing capacity (B_0), which is expressed in terms of kg CH_4/kg BOD removed. On the basis of a recent study by AECOM Canada (2010), commissioned by Environment Canada, it is recommended that the following country-specific values be used: an MCF of 0.3, which is a blended category that represents the Canadian proportion of septic tanks, anaerobic lagoons and untreated effluents as well as the degree of degradation of the organics expected of the treatment or discharge; and a B_0 of 0.36 kg CH_4/kg BOD_5. Therefore, the emission factor is 0.108 kg CH_4/kg BOD_5.

The IPCC default emission factor of 0.6 kg CH_4/kg BOD was not used, as the AECOM study confirmed that its derivation from the 0.25 kg CH_4/kg COD was erroneous, where COD is the chemical oxygen demand.

A6.7.2.   Municipal Wastewater Handling – Human Sewage

A6.7.2.1. N_2O

N_2O emissions from human sewage are a function of protein consumption per capita, population and the nitrogen content in protein. The emission factor used is the IPCC default value of 0.01 kg N_2O-N/kg sewage-N (IPCC/OECD/IEA 1997).

A6.7.3.   Waste Incineration

A6.7.3.1. CH$_4$ from Sewage Sludge Incinerators

CH$_4$ emissions from sewage sludge incinerators are estimated from an emission factor of 1.6 kg CH$_4$/tonne of dry sludge, which is obtained from the U.S. EPA (1995).

A6.7.3.2. N$_2$O from MSW Incinerators

The emission estimates from municipal solid waste (MSW) incineration are calculated from an average IPCC default emission factor for MSW five-stoker facilities of 0.148 kg N$_2$O/tonne of waste (IPCC/OECD/IEA 1997). For wastewater sludge incineration, the emission factor is taken from the IPCC Good Practice Guidance and has the value of 0.8 kg N$_2$O/tonne of dry sludge.

A6.7.3.3. CH$_4$ from Hazardous Waste Incinerators

In the absence of an IPCC default value, the emission factor used for the estimation of CH$_4$ from hazardous waste incinerators is based on country-specific measured emissions from data obtained from a facility in Canada that responded to a biennial survey conducted by Environment Canada on waste incineration (Environment Canada 2010). On the basis of the CH$_4$ emitted and the hazardous waste quantities incinerated in 2009, an emission factor of 1.695 x 10-4 kt CH$_4$/kt of hazardous waste was estimated.

A6.7.3.4. N$_2$O from Hazardous Waste Incinerators

In the absence of an IPCC default value, similarly to the description in Section A6.7.3.3 regarding the calculation of CH$_4$ from this source, the N$_2$O emission factor is based on the set of data from the same facility (Environment Canada 2010). On the basis of the N$_2$O emitted and the hazardous waste quantities incinerated in 2009, an emission factor of 3.164x 10-4 kt CH$_4$/kt of hazardous waste was estimated.

A6.7.3.5. CO$_2$ from Hazardous Waste Incinerators

For the estimation of the emission factor for CO$_2$ emissions from hazardous waste incineration, the IPCC default values (IPCC 2000) are used for the carbon content of 50% and percent fossil carbon content over total carbon of 90% for hazardous waste. The emission factor is then 1.65 kt CO$_2$/kt hazardous waste.

A6

Annex 7

Ozone and Aerosol Precursors

Information on Canada's ozone and aerosol precursors, including carbon monoxide (CO), nitrogen oxides (NO_x), non-methane volatile organic compounds (NMVOC) and sulphur oxides (SO_x) is available on Environment Canada's website.[1] As recommended by the Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC) (FCCC/CP/2013/10/Add.3 – UNFCCC 2013), Annex I Parties should provide information on indirect greenhouse gases (GHGs) such as CO, NO_x, NMVOC and SO_x in the National Inventory Report.

While these gases do not have a direct global warming effect, they either influence the creation and destruction of tropospheric and stratospheric ozone or affect terrestrial radiation absorption, as in the case of SO_x. These gases can impact the climate by acting as short-lived GHGs, alter atmospheric lifetimes of other GHGs and form GHGs, as in the case of CO reacting with a hydroxyl radical to form CO_2 in the atmosphere. These emissions are produced by a number of sources, such as fossil fuel combustion in the energy and transportation sectors, industrial production and biomass combustion.

National emission summaries for key air pollutants, along with historical national emission trends, are also available on Environment Canada's website.

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1   Canada's Air Pollutant Emission Data can be found at http://www.ec.gc.ca/inrp-npri/donnees-data/ap/index.cfm?process=true&sector=&lang=en&year=1990-2013&substance=all&location=CA&submit=Submit.

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