2017 – 2018 GREENHOUSE GAS INVENTORY

UNIVERSITY OF CALGARY

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List of Abbreviations and Units

AESO	Alberta Electric System Operator
CH_4	Methane
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
$DDOC_m$	Mass of decomposable Carbon
DOC_f	Fraction of degradable organic carbon
DT	Distance travelled
EF	Emission factor
F	Fraction of methane in landfill gas
FTE	Full time equivalent
GHG	Greenhouse gas
GJ	Gigajoule
GSM	Gross square meter
GWP	Global warming potential
HFC	Hydrofluorocarbon
IPCC	Intergovernmental Panel on Climate Change
kg	Kilogram
kWh	Kilowatt hour
L	Litre
LDDT	Light duty diesel truck
LDDV	Light duty diesel vehicle
LDGT	Light duty gasoline truck
LDGV	Light duty gasoline vehicle
M^3	Cubic meter
MCF	Methane correction factor
N_2O	Nitrous oxide
NIR	National Inventory Report
PFC	Perfluorocarbon
SF_6	Sulphur hexafluoride
SOV	Single occupant vehicle
T&D	Transmission and distribution
U of C	University of Calgary
U of L	University of Lethbridge
UCPCCSA	University and College Presidents' Climate Change Statement of Action
UTEC	Urban Transportation Emission Calculator
W	Mass of waste deposited
WBCSD	World Business Council for Sustainable Development
WRI	World Resources Institute

Executive Summary

The 2017/18 University of Calgary Greenhouse Gas Inventory is an institutional report on the U of C's greenhouse gas (GHG) emissions. It is a periodic update which fulfills the agreement made in the University and College Presidents' Climate Change Statement of Action for Canada (UCPCCSA), which the University of Calgary (U of C) became a signatory in October 2008. This report uses fiscal year 2008/09 GHG data as the baseline for benchmarking.

The inventory is a Scope 1, Scope 2, and partial Scope 3 quantification of the U of C's GHG emissions for fiscal year 2017/18. Each scope is defined below:

Scope 1: Direct GHG emissions from sources that are owned or controlled by the U of C, including stationary/mobile combustion of fossil fuels and animal husbandry.

Scope 2: Indirect GHG emissions from sources that the U of C does not own or control, but are a direct result of its operation. These include emissions associated with electricity and steam that the University purchases.

Scope 3: Other indirect GHG emissions from sources that the U of C does not own or control, including emissions related to commuting, transmission and distribution losses, waste, financed travel, paper, and wastewater.

Using organizational and operational boundaries established by the World Resources Institute Greenhouse Gas Protocol (WRI/WBCSD, 2004), the operational control approach was taken to define GHG emission boundaries. This means that only Scope 1, 2, and 3 GHG emissions from sources which the U of C has direct operational control over are included in the inventory.

In fiscal year 2017/18, the U of C was responsible for GHG emissions of 182,112 metric tonnes of carbon dioxide equivalent (CO_2e). Carbon dioxide equivalent is a single measure of amount of GHGs, including Carbon dioxide, Methane, and Nitrous oxide. The following table provides a comparison of 2008/09 and 2017/18 GHG emissions:

Table 1 - Total Greenhouse Gas Emissions

	2008/09	2017/18	Change
	metric tonnes CO_2e		%
Scope 1	50,133	86,931	73%
Scope 2	189,822	95,181	-50%
Total Scope 1 & 2	239,955	182,112	-24%
Scope 3	88,621	42,453	

An increase in Scope 1 emissions is due to the increased consumption of natural gas at the cogeneration plant. Combustion of natural gas was the largest contributor to the U of C's 2017/2018 GHG emissions, releasing 86,782 metric tonnes of CO_2e (46% of total Scope 1 & 2 emissions). The decrease in Scope 2 emissions is due to the lowered purchase of grid electricity, as electricity produced from cogeneration provides a significant portion of the university's requirements. It is important to note that the decrease in Scope 3 emissions is due to a less complete inventory of Scope 3 GHG sources, as well as improvements in commuting emissions calculations as a result of more accurate data from the 2013 Transportation Survey.

Growth in GHG emissions can be attributed to institutional growth, both in campus population and building area. By comparing the GHG intensity of the U of C's emissions, 2008/09 and 2017/18 emissions can be compared on a more equivalent basis. Table 2 summarizes GHG intensity with respect to full time equivalents (FTE – the measure for students, staff, and faculty) and gross square meters (GSM – the measure for building area).

Table 2 - Greenhouse Gas Intensities

	2008/09	2017/18	Change (%)
Total Scope 1 & 2 Emissions (metric tonnes CO_2e)	239,955	182,112	-24%
Campus Population (FTE)	30,249	33,558	11%
Building Area (GSM)	829,938	1,010,933	22%
GHG Intensity (metric tonnes CO_2e / FTE)	7.93	5.43	-32%
GHG Intensity (metric tonnes CO_2e / GSM)	0.29	0.18	-38%

It is evident that the U of C has decreased its GHG emissions per person and per square meter. The U of C's Climate Action Plan[1] has made projections in regard to a number of institutional metrics. Comparing these projections to actual changes in students, staff, faculty, building area, and total GHG emissions provides a measure of progress toward goals, as well as an evaluation of the accuracy of the projections made.

Table 3 - Climate Action Plan and Actual Data Comparison

	Climate Action Plan (Projection)	2017/18 (Actual)	Difference (%)
Campus Population (FTE)	33,118	33,558	1%
Building Area (GSM)	945,839	1,010,933	7%
Total Scope 1 & 2 Emissions (metric tonnes CO_2e)	130,000	182,112	40%

The estimated growth rates used to project changes in campus population and building area provided a reasonably accurate estimate of actual values (within 10% of actual). The estimated growth rates used to project changes in total scope 1 & 2 emissions overestimated reductions.

The U of C will continue to produce annual GHG inventories to measure progress toward reducing institutional emissions as outlined in the Climate Action Plan. Similar to the 2008/09 Inventory, certain sources of GHG emissions are not included because data was either unavailable or too difficult to retrieve due to a lack of tracking mechanisms.[2] As more tracking mechanisms are put in place, this information will be included in future inventories, meaning data will be more accurate. Establishing pilot projects and tracking and recording programs to consistently capture the U of C's GHG emissions will create a transparent and precise on-going inventory.

[1] Climate Action Plan available at https://www.ucalgary.ca/sustainability/climate-energy

[2] For a list of omissions, see Appendix C

1. Introduction

The 2017/18 University of Calgary Greenhouse Gas Inventory quantifies the total greenhouse gas (GHG) emissions that U of C was responsible for in fiscal year 2017/18. This is the 10th report produced by Office of Sustainability reporting U of C's GHG emissions, following the 2015/2016 GHG inventory. These reports have been completed as part of U of C's commitment to UCPCCSA, signed in October 2008 by the former President Dr. Harvey Weingarten, and endorsed by the current President Dr. Elizabeth Cannon. U of C will continue to provide an annual inventory in order to measure progress, provide direction for institutional and operational planning, and to communicate transparent information in regard to U of C's GHG emissions.

2. Methodology

2.1 Temporal Boundary

The 2017/18 GHG Inventory accounts for GHG emissions occurring during the fiscal year of April 1, 2017 to March 31, 2018.

2.2 Organizational Boundaries

U of C's GHG emissions are quantified under the operational control approach. This means that emissions from all operations are reported if the U of C has the authority to introduce and implement policies at those operations. In fiscal year 2017/18, U of C had operational control over the following owned or leased assets[3]:

- Main Campus
- Foothills Campus
- Spy Hill Campus
- Downtown Campus
- Bookstore Storage Facility
- Bow River Pump Station
- Barrier Lake Field Station
- R.B. Miller Field Station
- Rothney Astrophysical Observatory
- Petro-Canada (Mechanical Engineering) Building
- University Research Center

A full list of buildings and sites under U of C's operational control can be found in Appendix A. The following table summarizes the changes to organizational boundaries from fiscal year 2015/16 to fiscal year 2017/18:

Table 4 - Changes in Organizational Boundaries

Site	Changes
Main Campus	Engineering Complex Renovations (net increase of 12 m^2) Professional Faculties Renovations (net decrease of 29 m^2 due to correction of recorded values)
Foothills Campus	No significant changes at the Foothills Campus.
Other Satellite Campuses	Construction of the Weather Research Centre (net increase of 306 m^2) Removal of space from Downtown Campus Lease (net decrease of 306 m^2)

[3] For a list of exclusions, see Appendix B

2.3 Operational Boundaries

Operational boundaries are set by categorizing direct or indirect emissions from the operations within organizational boundary.

Operational boundaries are divided into three scopes. These scopes are defined to avoid GHG emissions being accounted by multiple parties, and provide a division of GHG emissions into groupings that warrant different operational considerations when defining opportunities to reduce GHG emissions. These scopes are categorized as follows:

Scope 1: Direct GHG emissions from sources that are owned or controlled by the U of C. Scope 1 emissions include stationary and mobile combustion of fossil fuels, and animal husbandry.

Scope 2: Indirect GHG emissions from sources that the U of C does not own or control, but are a direct result of its operation. These include emissions associated with electricity and steam that the University purchases.

Scope 3: Other indirect GHG emissions from sources that the U of C does not own or control, including emissions related to commuting, transmission and distribution losses, waste, financed travel, paper, and wastewater.

2.4 Global Warming Potential

This GHG Inventory reports emissions of carbon dioxide (CO2), methane (CH4), and nitrous oxide (N2O) - three of the six GHGs specified by the Kyoto Protocol. Data for Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs), and Sulphur hexafluoride (SF6) was not available for the U of C in 2017/18, and thus was not included in this inventory.

Global warming potential the relative measure of heat trapped by a greenhouse gas in the atmosphere. Emissions are presented in terms of carbon dioxide equivalent (CO_2e), a weighted sum of all GHGs that use the most abundant GHG (CO_2) as the reference gas. GHGs are measured to have a Global Warming Potential (GWP) in comparison to CO_2, and are a measure of the relative contribution of a gas to the greenhouse effect. Table 5 summarizes the GWP of the three GHGs included in this report:

Table 5 - Global Warming Potentials of Greenhouse Gases[4]

Greenhouse Gas	Global Warming Potential
Carbon Dioxide (CO_2)	1
Methane (CH_4)	25
Nitrous Oxide (N_2O)	298

[4] Environment Canada, *National Inventory Report 1990-2016: Greenhouse Gas Sources and Sinks in Canada – Part 1, Table 1-1*

2.5 Emission Factors

Emissions factor (EF) is a representative value that attempts to relate the quantity of a pollutant released to the atmosphere with an activity associated with the release of that pollutant. These were primarily formulated using information provided in Environment Canada's National Inventory Report (NIR). In addition to NIR, the Intergovernmental Panel on Climate Change (IPCC), and Transport Canada were also used. Appendix D covers the details of the calculation for each factor. Table 6 below summarizes these EFs:

Table 6 - Greenhouse Gas Emission Factors

Greenhouse Gas Source	Emission Factor	Unit
Natural Gas	0.00194	kg CO_2e / L
Propane	1.548	kg CO_2e / L
Diesel	2.804	kg CO_2e / L
Fleet Gasoline	2.337	kg CO_2e / L
Fleet Diesel	2.748	kg CO_2e / L
Sheep	208.3	kg CO_2e / head
Cattle	2599.3	kg CO_2e / head
Calves	1165.0	kg CO_2e / head
Muskox	1443.8	kg CO_2e / head
Horses	515.0	kg CO_2e / head
Llama, goats, reindeer, etc.	133.0	kg CO_2e / head
Swine	182.0	kg CO_2e / head
Electricity	0.764	kg CO_2e / kWh
Commuting - Vehicle	0.289	kg CO_2e / km
Commuting - Bus	0.230	kg CO_2e / pass km
Transmission and Distribution Losses	0.1400	kg CO_2e / kWh
Solid Waste	1.467	kg CO_2e / kg waste

2.6 Measure of Confidence

The quality of data that was collected for the inventory is rated on a qualitative scale in order to provide insight into the accuracy of the information provided. These measures of confidence are summarized as follows:

Table 7 - Measures of Confidence

Confidence Level	Definition
High	- Accurately measured/tracked data - Government-published figures used in emission factor derivations - Alberta/Canadian emission factors
Medium	- Some measurement with minimal interpolation - North American emission factors
Low	- Minimal or no measurement - Data based on linear interpolation is used

3. Greenhouse Gas Footprint

U of C's fiscal year 2017/18 Scope 1 & 2 GHG emissions are 182,112 metric tonnes of CO_2e, showing a 25% decrease compared to 239,955 metric tonnes of CO_2e in fiscal year 2008/09. This decrease is largely due to the lowered consumption of grid electricity related to the cogeneration system. Table 8 provides a comparison of GHG emissions for the 2008/09 and 2017/18 fiscal years, and Table 9 shows the breakdown of each scope.

Table 8 - Total Greenhouse Gas Emissions

	2008/09	2017/18	Change
	metric tonnes CO_2e		%
Scope 1	50,133	86,931	65%
Scope 2	189,822	95,181	-51%
Total Scope 1 & 2	239,955	182,112	-26%
Scope 3	88,621	42,453	

Table 9 - Scope Breakdown

	2008/09	2017/18
	metric tonnes CO_2e	
Scope 1		
Natural Gas	49,468	85,920
Propane	227	424
Diesel[5]	-	51
Fleet Gasoline	323	129
Fleet Diesel	82	302
Animals[6]	-	105
Scope 2		
Electricity	158,777	69,692
Steam	31,045	25,489
Scope 3		
Commuting Vehicle	43,949	9,773
Commuting Bus	12,647	8,328
T&D Losses	15,842	2,188
Solid Waste	1,991	22,165
Financed Travel[7]	13,491	-
Paper[7]	551	-
Wastewater[7]	149	-

[5] Diesel fuel consumption in emergency generators was not available for the 2008/09 inventory

[6] Animal husbandry information was not available from the Department of Veterinary Medicine for the 2008/09 inventory

[7] The noted Scope 3 emissions sources were not reported on for the 2017/18 GHG inventory

3.1 Scope 1 GHG Emissions

In fiscal year 2017/18, the U of C emitted 86,931 metric tonnes CO_2e of Scope 1 GHGs. These emissions were attributed to the stationary combustion of natural gas and propane; the mobile combustion of fleet fuels including gasoline and diesel; and animal husbandry.

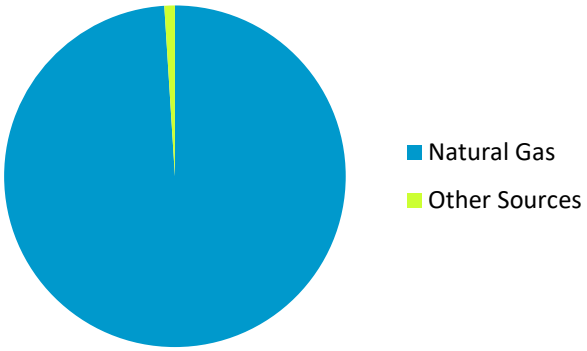

Figure 1 - Scope 1 GHG Emissions

Natural Gas

The U of C combusts natural gas for the production of electric power and thermal energy via cogeneration at the Central Heating and Cooling Plant. Natural gas is also used for heating at satellite facilities and leased space.

Methodology: Data for natural gas consumption was collected in units of gigajoules (GJ). Using conversion factors of 26.8 m^3/GJ and 1000 L/m^3, the total quantity of natural gas consumed was calculated in liters (L). Using regional GHG emission factors and known GWPs, an emission factor for natural gas per liter was derived, and the total quantity of CO_2e emissions related to natural gas combustion was calculated.

Source: Consolidated utility data spreadsheet
Confidence Level: High – metered data

Propane

Propane is consumed on the main campus and satellite campuses for heating.

Methodology: Data for propane consumption was collected in units of liters. Using GHG emission factors and known GWPs, an emission factor for propane per liter was derived, and the total quantity of CO_2e emissions related to propane combustion was calculated.

Source: Consolidated utility data spreadsheet
Confidence Level: High – recorded data

Diesel

Diesel is consumed on the main campus and satellite campuses for running emergency generators.

Methodology: Data for diesel consumption was collected in units of liters. Using GHG emission factors and known GWPs, an emission factor for diesel per liter was derived, and the total quantity of CO_2e emissions related to stationary diesel combustion was calculated.

Source: Consolidated utility data spreadsheet
Confidence Level: High – recorded data

Fleet Gasoline

The U of C operates a number of gasoline-fueled vehicles.

Methodology: Data for gasoline consumption was collected in units of liters as well as the model and year for each vehicle. Using Canadian GHG emission factors for mobile combustion and known GWPs, an emission factor for gasoline per liter was derived, and the total quantity of CO_2e emissions related to gasoline fleet vehicles was calculated.

Source: Consolidated fuel logs and university fleet inventory
Confidence Level: Medium – methodology is based on general estimates from the NIR and tracked fuel usage.

Fleet Diesel

The U of C fleet operates a number of diesel-fueled vehicles.

Methodology: Data for diesel consumption was collected in units of liters as well as the model and year for each vehicle. Using Canadian GHG emission factors and known GWPs, an emission factor for diesel per liter was derived, and the total quantity of CO_2e emissions related to diesel fuel combustion was calculated.

Source: Consolidated fuel logs and university fleet inventory
Confidence Level: Medium – methodology is based on general estimates from the NIR and tracked fuel usage.

Animal Husbandry

The U of C owns a number of animals at the Spy Hill Campus under the Faculty of Veterinary Medicine. These animals, which include calves, cattle, goats, horses, muskox, sheep, and swine, emit methane gas.

Methodology: An inventory of animals at the Spy Hill campus was obtained from the Faculty of Veterinary Medicine. Emission factors corresponding to each animal type were applied in order to calculate total CO_2e emissions during fiscal year 2017/18.

Source: Spy Hill Campus animal inventory
Confidence Level: Medium – methodology is based on general estimates from the NIR

3.2 Scope 2 GHG Emissions

In fiscal year 2017/18, the U of C was responsible for indirect emissions of 95,181 metric tonnes CO_2e of Scope 2 GHGs. These Scope 2 emissions are generated on behalf of the U of C through off-campus electricity generation and steam production at the Foothills campus. The assets that produce these GHG emissions are not owned by the U of C, but since the consumption of electricity and steam is under direct control of the U of C, these emissions fall under Scope 2.

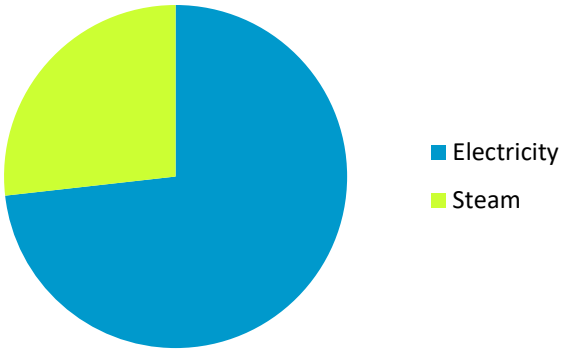

Figure 2 - Scope 2 GHG Emissions

Electricity

All electric power for the U of C is purchased from the Alberta electricity grid though the energy retailer, TransCanada and the wires service provider, ENMAX.

Methodology: Total electricity consumption data was collected in units of kilowatt hours (kWh). Using provincial GHG emission factors and known GWPs, an emission factor for electricity from the Alberta grid per kWh was derived, and the total quantity of CO_2e emissions related to purchased electricity was calculated.

Source: Consolidated utility data spreadsheet
Confidence Level: High – metered data

Steam

Steam is generated by the Alberta Health Services Central Plant and then sold to the U of C foothills campus buildings.

Methodology: The University of Calgary's portion of natural gas burned for steam production at the Alberta Health Services Central Plant is calculated in units of gigajoules. Using conversion factors of 26.8 m^3/GJ and 1000 L/m^3, the total quantity of natural gas consumed for steam was calculated in liters (L). The scope 1 emission factor for steam was then applied to the natural gas burned for purchased steam.

Source: Consolidated utility data spreadsheet
Measure of Confidence: High – metered data

3.3 Scope 3 GHG Emissions

In fiscal year 2017/18, the U of C was responsible for indirect GHG emissions of 42,453 metric tonnes CO_2e of Scope 3 GHGs. The U of C does not have direct control over these Scope 3 GHG emissions, but they are the direct result of its operation.

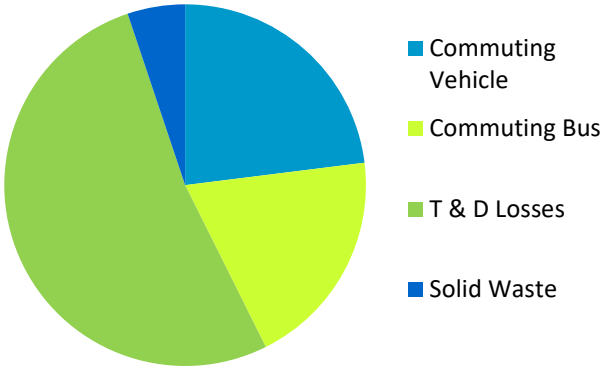

Figure 3 - Scope 3 GHG Emissions

Commuting - Vehicle

With the majority of students living off campus, the U of C is largely a commuter campus. The Office of Sustainability conducted a campus-wide online 2013 Transportation Survey to record the commuting behavior of staff, faculty, and students. A number of assumptions were made regarding travel distance and frequency.

Methodology: Using data from the 2013 Transportation Survey, a modal[8] distribution was estimated, and the number of commuters by each mode was determined by extrapolating survey results onto the entire U of C population. Conservative estimates of frequency were made in order to determine the total number of vehicles. The number of vehicles commuting was multiplied by the respective emission factors to obtain CO_2e emissions.

Source: 2013 Transportation Survey
Confidence Level: Low – estimates for vehicle numbers and frequency used

[8] Modes of transportation are forms of travel (e.g. single occupant vehicle (SOV), carpool, bus, CTrain, bike, and walk).

Transmission and Distribution Losses

The delivery of electricity to the U of C has associated energy losses. These losses are the direct result of the U of C's operation, but do not occur in University owned assets, and thus fall under Scope 3 GHG emissions.

Methodology: The portion of electric power lost through transmission and distribution varies by year. The emissions factor for the grid losses is based on the difference between the Consumption and Generation values provided in the NIR, Table A13–10.

Source: Consolidated utility data spreadsheet
Confidence Level: High – metered data and NIR factors used

Solid Waste

The U of C generates a significant quantity of waste every year, much of which is disposed of in landfills. Emissions account only for the methane generated as a result of the decomposition of the waste, and not the transport and disposal of it.

Methodology: Data for annual waste totals was gathered in kilograms (kg). A GHG emission factor was calculated based on IPCC methodology. The resulting factor was used to estimate the CO_2e emissions associated with the U of C's waste generation.

Source: Solid waste tracking spreadsheet
Confidence Level: High – tracked data

Appendix A – Building and Site List

Table 10 - Buildings and Sites under the U of C's Operational Control

	Gross Square Meters (m^2)
Main Campus	760,952
Foothills Campus	173,642
Spy Hill Campus	16,464
Downtown Campus	13,319
Bookstore Storage Facility	178
Bow River Pump Station	190
Barrier Lake Field Station	3,847
R.B. Miller Field Station	116
Rothney Astrophysical Observatory	717
Olympic Volunteer Center	4,529
Petro-Canada (Mechanical Engineering) Building	6,202
Total	1,010,933

Appendix B – Exclusions

The exclusions listed below are ongoing or long-term exclusions in accordance to the organizational boundaries defined by the WRI's Greenhouse Gas Protocol. Since the U of C does not have operational or financial control at/of these sites, GHG emissions resulting from these locations will not be included in future inventories.

- **Agricultural Land (Priddis and Spy Hill Campus):** Two lots of agricultural land are owned by the U of C and leased out to a local farmer for each lot. The U of C does not manage this land and has no operational control.
- **Alastair Ross Technology Center:** Considered to be a "de minimus" greenhouse gas emission source.
- **Bamfield Marine Science Center (BMSC):** BMSC is owned and operated by the non-profit Western Canadian Universities Marine Sciences Society (WCUMSS), comprised of Simon Fraser University, the University of Alberta, the University of British Columbia, the University of Calgary, and the University of Victoria.
- **Clark-Milone Telescope:** Considered to be a "de minimus" greenhouse gas emission source.
- **Electrical Substations:** Considered to be a "de minimus" greenhouse gas emission source.
- **Garneau Professional Building, Edmonton:** Space rented from the NorthWest Health Centre in Edmonton for the social work degree program. This building is owned and operated by Garneau.
- **Kluane Lake Research Station:** The Kluane Lake Research Station is housed on land leased from the Yukon Territory. It is leased by the Arctic Institute of North America, an affiliate institute at the University. The U of C does not have the ability to direct the financial policies of the research station, neither does it have authority to introduce and implement its operating policies.
- **Macleod Institute:** This building is operated by an independent research group.
- **McMahon Stadium:** The U of C does not have operational control of McMahon Stadium. It is a stand-alone operation, operated by McMahon Stadium Society on behalf of the U of C.
- **Parking Kiosks:** Considered to be a "de minimus" greenhouse gas emission source.
- **Spray Lakes Sawmills Family Sports Center:** This space is owned and operated by the Cochrane Gymnastics Center. The Kinesiology department rents this space and has no operational control over it.
- **University of Calgary Medical Clinics (North Hill and Sunridge)**: Ownership assigned to Alberta Health Services.
- **University of Lethbridge Social Work:** Space leased from the University of Lethbridge for the social work degree program. This space is owned and operated by the U of L.
- **Waste Water Treatment Plan**: Space is owned by the City of Calgary and is under operational control of Urban Alliance, a partnership between the City of Calgary, and the University of Calgary

Appendix C – Omissions

Following are the omissions when conducting the 2017/18 GHG Inventory. Information was not reported if it did not fall under the temporal, organizational, and operational boundaries established for the report, or if information was unavailable for the reporting period.

- **Buildings under construction (not operational) in fiscal year 2017/18**
    - Mechanical Engineering Building, and the MacKimmie Library Tower were under construction as major renovations in 2017/2018
    - The High Density Library and Clinical Skills Building Expansion was not operational in 2017/18

- **Hazardous waste (solid, liquid, and biohazard):** Bio hazardous and hazardous waste generated in fiscal year 2017/18 was not included in total U of C solid waste since they are not sent to the landfill.

- **Olympic Oval Zambonis:** The propane consumption from the Olympic Oval Zambonis have been omitted from this report as U of C does not have operational control of the ice maintenance in the building.

- **Fugitive emissions (GHG emissions due to equipment leaks and evaporative processes):** Fugitive emissions are calculated by reporting quantities of refrigerants refilled over the reporting period. Below is a list of sources of U of C refrigerants and chemicals that have the potential to produce fugitive emissions:
    - Air conditioning units
    - Chemical lab processes
    - Chiller units at the Central Heating & Cooling Plant
    - Fire extinguishers
    - Freezers/refrigerators
    - HALON Fire Suppression System

  Refrigerants are reclaimed and/or refilled by Sub Zero Technical Ltd., the contracted company for U of C refrigeration equipment. Chartwells and Calgary Health Region also use refrigeration equipment that Sub Zero Ltd. is not the contractor for. Fugitive emissions have been omitted as there has been no report which quantifies fiscal year 2017/2018 fugitive emissions.

  Moving forward, Facilities Management and Environmental Health and Safety will capture data pertaining to fugitive emissions.

Appendix D – Emission Factors

Natural Gas

Using emission factors from the National Inventory Report:[9]

$$EF_{Natural\ Gas} = (EF_{CO_2} * GWP_{CO_2}) + (EF_{CH_4} * GWP_{CH_4}) + (EF_{N_2O} * GWP_{N_2O})$$

$$EF_{Natural\ Gas} = \left(1.928 \frac{kg\ CO_2}{m^3} * \frac{1}{1000} \frac{m^3}{L} * 1 \frac{kg\ CO_2e}{kg\ CO_2}\right) + \left(0.000037 \frac{kg\ CH_4}{m^3} * \frac{1}{1000} \frac{m^3}{L} * 25 \frac{kg\ CO_2e}{kg\ CH_4}\right) + \left(0.000035 \frac{kg\ N_2O}{m^3} * \frac{1}{1000} \frac{m^3}{L} * 298 \frac{kg\ CO_2e}{kg\ N_2O}\right)$$

$$\boldsymbol{EF_{Natural\ Gas} = 0.00194 \frac{kg\ CO_2e}{L}}$$

Propane

Using emission factors from the National Inventory Report:[10]

$$EF_{Propane} = (EF_{CO_2} * GWP_{CO_2}) + (EF_{CH_4} * GWP_{CH_4}) + (EF_{N_2O} * GWP_{N_2O})$$

$$EF_{Propane} = \left(1.515 \frac{kg\ CO_2}{L} * 1 \frac{kg\ CO_2e}{kg\ CO_2}\right) + \left(0.000024 \frac{kg\ CH_4}{L} * 25 \frac{kg\ CO_2e}{kg\ CH_4}\right) + \left(0.000108 \frac{kg\ N_2O}{L} * 298 \frac{kg\ CO_2e}{kg\ N_2O}\right)$$

$$\boldsymbol{EF_{Propane} = 1.548 \frac{kg\ CO_2e}{L}}$$

Diesel

Using emission factors from the National Inventory Report:[11]

$$EF_{Diesel} = (EF_{CO_2} * GWP_{CO_2}) + (EF_{CH_4} * GWP_{CH_4}) + (EF_{N_2O} * GWP_{N_2O})$$

$$EF_{Diesel} = \left(2.681 \frac{kg\ CO_2}{L} * 1 \frac{kg\ CO_2e}{kg\ CO_2}\right) + \left(0.000133 \frac{kg\ CH_4}{L} * 25 \frac{kg\ CO_2e}{kg\ CH_4}\right) + \left(0.0004 \frac{kg\ N_2O}{L} * 298 \frac{kg\ CO_2e}{kg\ N_2O}\right)$$

$$\boldsymbol{EF_{Diesel} = 2.804 \frac{kg\ CO_2e}{L}}$$

Fleet Gasoline

All gasoline-burning vehicles in the U of C fleet are assumed to be either a LDGV or LDGT. These two categories can be further separated into Tier 0, Tier 1, and Tier 2 vehicles as defined by the National Inventory Report[12]. Each tier represents the range of years of manufacturing standards with respect to the stringency of emission standards applied. The proportion of each vehicle type was based on the number of Tier 0, Tier 1, and Tier 2 vehicles in the University of Calgary's fleet. Note that the university does not currently operate any Tier 0 LDGV. Emission factors were taken from the National Inventory Report.[13]

$$\%LDGV_{tier\ 1} = \frac{LDGV_{tier\ 1}}{(LDGV_{tier\ 1} + LDGV_{tier\ 2} + LDGT_{tier\ 0} + LDGT_{tier\ 1} + LDGT_{tier\ 2})} = \frac{2}{(2 + 10 + 1 + 16 + 126)} = 1.29\%$$

$$\%LDGV_{tier\ 2} = \frac{LDGV_{tier\ 2}}{(LDGV_{tier\ 1} + LDGV_{tier\ 2} + LDGT_{tier\ 0} + LDGT_{tier\ 1} + LDGT_{tier\ 2})} = \frac{10}{(2 + 10 + 1 + 16 + 126)} = 6.54\%$$

[9] Environment Canada, *National Inventory Report 1990-2016: Greenhouse Gas Sources and Sinks in Canada – Part 2*, Table A6-1/A6-2

[10] Environment Canada, *National Inventory Report 1990-2016: Greenhouse Gas Sources and Sinks in Canada – Part 2*, Table A6-3

[11] Environment Canada, *National Inventory Report 1990-2016: Greenhouse Gas Sources and Sinks in Canada – Part 2*, Table A6-4

[12] Environment Canada, *National Inventory Report 1990-2016: Greenhouse Gas Sources and Sinks in Canada – Part 2*, Table A6-12 (footnote)

[13] Environment Canada, *National Inventory Report 1990-2016: Greenhouse Gas Sources and Sinks in Canada – Part 2*, Table A6-12

$$\%LDGT_{tier\ 0} = \frac{LDGT_{tier\ 0}}{(LDGV_{tier\ 1} + LDGV_{tier\ 2} + LDGT_{tier\ 0} + LDGT_{tier\ 1} + LDGT_{tier\ 2})} = \frac{1}{(2 + 10 + 1 + 16 + 1267)} = 0.65\%$$

$$\%LDGT_{tier\ 1} = \frac{LDGT_{tier\ 1}}{(LDGV_{tier\ 1} + LDGV_{tier\ 2} + LDGT_{tier\ 0} + LDGT_{tier\ 1} + LDGT_{tier\ 2})} = \frac{16}{(2 + 10 + 1 + 16 + 126)} = 1032\%$$

$$\%LDGT_{tier\ 2} = \frac{LDGT_{tier\ 2}}{(LDGV_{tier\ 1} + LDGV_{tier\ 2} + LDGT_{tier\ 0} + LDGT_{tier\ 1} + LDGT_{tier\ 2})} = \frac{126}{(2 + 10 + 1 + 16 + 1267)} = 81.29\%$$

$$EF_{Vehicle\ Type} = \left(EF_{CO_2} * GWP_{CO_2}\right) + \left(EF_{CH_4} * GWP_{CH_4}\right) + \left(EF_{N_2O} * GWP_{N_2O}\right)$$

$$EF_{LDGV_{tier\ 1}} = \left(2.307\frac{kg\ CO_2}{L} * 1\frac{kg\ CO_2e}{kg\ CO_2}\right) + \left(0.00023\frac{kg\ CH_4}{L} * 25\frac{kg\ CO_2e}{kg\ CH_4}\right) + \left(0.00047\frac{kg\ N_2O}{L} * 298\frac{kg\ CO_2e}{kg\ N_2O}\right) = 2.462$$

$$EF_{LDGV_{tier\ 2}} = \left(2.307\frac{kg\ CO_2}{L} * 1\frac{kg\ CO_2e}{kg\ CO_2}\right) + \left(0.00014\frac{kg\ CH_4}{L} * 25\frac{kg\ CO_2e}{kg\ CH_4}\right) + \left(0.000022\frac{kg\ N_2O}{L} * 298\frac{kg\ CO_2e}{kg\ N_2O}\right) = 2.453$$

$$EF_{LDGT_{tier\ 0}} = \left(2.307\frac{kg\ CO_2}{L} * 1\frac{kg\ CO_2e}{kg\ CO_2}\right) + \left(0.00021\frac{kg\ CH_4}{L} * 25\frac{kg\ CO_2e}{kg\ CH_4}\right) + \left(0.00066\frac{kg\ N_2O}{L} * 298\frac{kg\ CO_2e}{kg\ N_2O}\right) = 2.509$$

$$EF_{LDGT_{tier\ 1}} = \left(2.307\frac{kg\ CO_2}{L} * 1\frac{kg\ CO_2e}{kg\ CO_2}\right) + \left(0.00024\frac{kg\ CH_4}{L} * 25\frac{kg\ CO_2e}{kg\ CH_4}\right) + \left(0.00058\frac{kg\ N_2O}{L} * 298\frac{kg\ CO_2e}{kg\ N_2O}\right) = 2.486$$

$$EF_{LDGT_{tier\ 2}} = \left(2.307\frac{kg\ CO_2}{L} * 1\frac{kg\ CO_2e}{kg\ CO_2}\right) + \left(0.00014\frac{kg\ CH_4}{L} * 25\frac{kg\ CO_2e}{kg\ CH_4}\right) + \left(0.000022\frac{kg\ N_2O}{L} * 298\frac{kg\ CO_2e}{kg\ N_2O}\right) = 2.317$$

$$EF_{Fleet\ Gasoline} = \left(\%\ LDGV_{tier\ 1} * EF_{LDGV_{tier\ 1}}\right) + \left(\%\ LDGV_{tier\ 2} * EF_{LDGV_{tier\ 2}}\right) + \left(\%\ LDGT_{tier\ 0} * EF_{LDGT_{tier\ 0}}\right) + \left(\%\ LDGT_{tier\ 1} * EF_{LDGT_{tier\ 1}}\right) + \left(\%\ LDGT_{tier\ 2} * EF_{LDGT_{tier\ 2}}\right)$$

$$\boldsymbol{EF_{Fleet\ Gasoline} = 2.337\frac{kg\ CO_2e}{L}}$$

Fleet Diesel

All diesel-burning vehicles in the U of C fleet are either a LDDT with moderate control, or a LDDT with advanced control. The proportion of each vehicle type was calculated based on the number of moderate control and advanced control LDDTs on the university's fleet. Emission factors were taken from the National Inventory Report.[14]

$$\%LDDT_{Moderate\ Control} = \frac{LDDT_{Moderate\ Control}}{(LDDT_{Moderate\ Control} + LDDT_{Advanced\ Control})} = \frac{0}{(0 + 9)} = 0.00\%$$

$$\%LDDT_{Advanced\ Control} = \frac{LDDT_{Advanced\ Control}}{(LDDT_{Moderate\ Control} + LDDT_{Advanced\ Control})} = \frac{9}{(0 + 9)} = 100.00\%$$

$$EF_{Vehicle\ Type} = \left(EF_{CO_2} * GWP_{CO_2}\right) + \left(EF_{CH_4} * GWP_{CH_4}\right) + \left(EF_{N_2O} * GWP_{N_2O}\right)$$

$$EF_{LDDT_{Moderate\ Control}} = \left(2.681\frac{kg\ CO_2}{L} * 1\frac{kg\ CO_2e}{kg\ CO_2}\right) + \left(0.000068\frac{kg\ CH_4}{L} * 25\frac{kg\ CO_2e}{kg\ CH_4}\right) + \left(0.00021\frac{kg\ N_2O}{L} * 298\frac{kg\ CO_2e}{kg\ N_2O}\right) = 2.745$$

$$EF_{LDDT_{Advanced\ Control}} = \left(2.681\frac{kg\ CO_2}{L} * 1\frac{kg\ CO_2e}{kg\ CO_2}\right) + \left(0.000068\frac{kg\ CH_4}{L} * 25\frac{kg\ CO_2e}{kg\ CH_4}\right) + \left(0.00022\frac{kg\ N_2O}{L} * 298\frac{kg\ CO_2e}{kg\ N_2O}\right) = 2.748$$

$$EF_{Fleet\ Diesel} = \left(\%\ LDDT_{Moderate\ Control} * EF_{LDDT_{Moderate\ Control}}\right) + \left(\%\ LDDT_{Advanced\ Control} * EF_{LDDT_{Advanced\ Control}}\right)$$

$$\boldsymbol{EF_{Fleet\ Diesel} = 2.748\frac{kg\ CO_2e}{L}}$$

[14] Environment Canada, *National Inventory Report 1990-2016: Greenhouse Gas Sources and Sinks in Canada – Part 2*, Table A6-12

Animal Husbandry

Enteric fermentation[15] and manure management[16] factors for animal husbandry were taken from the National Inventory Report. As an example, the EF for horses is calculated as follows:

$$EF_{Animal\ Type} = \left({}^{Animal\ Type}_{EF_{Enteric\ Fermentation}} + {}^{Animal\ Type}_{EF_{Manure\ Management}} \right) * GWP_{CH_4}$$

$$EF_{Horses} = \left(18\ \frac{kg\ CH_4}{head \cdot year} + 2.6 \frac{kg\ CH_4}{head \cdot year}\right) * 25 \frac{kg\ CO_2e}{kg\ CH_4}$$

$$\boldsymbol{EF_{Horses} = 515.0\ \frac{kg\ CO_2e}{head \cdot year}}$$

Cattle are the only exception to the previous methodology. The emission factor was calculated based on the average enteric fermentation and manure management from dairy cows, diary heifers, bulls, beef cows, beef heifers, heifers for slaughter, and steers.

Electricity

Using emission factor data from the National Inventory Report:[17]

$$EF_{Electricity} = \left({}^{Alberta}_{EF_{CO_2}} * GWP_{CO_2} \right) + \left({}^{Alberta}_{EF_{CH_4}} * GWP_{CH_4} \right) + \left({}^{Alberta}_{EF_{N_2O}} * GWP_{N_2O} \right)$$

$$EF_{Electricity} = \left(0.76\ \frac{kg\ CO_2}{kWh} * 1 \frac{kg\ CO_2e}{kg\ CO_2}\right) + \left(0.00004\ \frac{kg\ CH_4}{kWh} * 25\ \frac{kg\ CO_2e}{kg\ CH_4}\right) + \left(0.00001 \frac{kg\ N_2O}{kWh} * 298 \frac{kg\ CO_2e}{kg\ N_2O}\right)$$

$$\boldsymbol{EF_{Electricity} = 0.764 \frac{kg\ CO_2e}{kWh}}$$

Commuting – Vehicle

The average commuter vehicle emission factor was calculated based on the total population of light duty vehicle types from the National Inventory Report[18] and typical distance-based emission factors from the WRI Greenhouse Gas Protocol[19]. The analysis considered light duty gas cars (LDGV), light duty gas trucks (LDGT, which includes most pickups, minivans, and sport utility vehicles). The vehicle breakdown used by students, staff and faculty are assumed to be the same as the national average of light duty vehicles.

$$\%\ LDGV_{Canada} = \frac{LDGV_{Canada}}{LDGV_{Canada} + LDGT_{Canada}} = \frac{12{,}381{,}000}{23{,}619{,}000} = 52.42\%$$

$$\%\ LDGT_{Canada} = \frac{LDGT_{Canada}}{LDGV_{Canada} + LDGT_{Canada}} = \frac{11{,}238{,}000}{23{,}619{,}000} = 47.58\%$$

Using distance-based emission factor data for different vehicle types from the Greenhouse Gas Protocol Mobile Combustion GHG Emissions Calculation Tool (version 2.6), emission factors for each of the two light duty gas vehicle

[15] Environment Canada, *National Inventory Report 1990-2016: Greenhouse Gas Sources and Sinks in Canada – Part 2*, Table A6-27

[16] Environment Canada, *National Inventory Report 1990-2016: Greenhouse Gas Sources and Sinks in Canada – Part 2*, Table A3-39

[17] Environment Canada, *National Inventory Report 1990-2016: Greenhouse Gas Sources and Sinks in Canada – Part 3*, Table A13-10

[18] Environment Canada, *National Inventory Report 1990-2016: Greenhouse Gas Sources and Sinks in Canada – Part 1,* Table 2-6

[19] Greenhouse Gas Protocol Mobile Combustion GHG Emissions Calculation Tool (version 2.6), Emissions Factors for US by Vehicle Distance

categories were determined. As overall average emission factors for vehicle populations were not available, emission factors based on modern vehicle technology (2005 – present) were used.

$$EF_{CO_2e} = \left(EF_{CO_2} * GWP_{CO_2} + EF_{CH_4} * GWP_{CH_4} + EF_{N_2O} * GWPF_{N_2O}\right)$$

$$EF_{CO_2e-LDGV} = \left(243.3\frac{g\ CO_2}{km} * 1\frac{g\ CO_2e}{g\ CO_2} + 0.0091\frac{g\ CH_4}{km} * 25\frac{g\ CO_2e}{g\ CH_4} + 0.0049\frac{g\ N_2O}{km} * 298\frac{g\ CO_2e}{g\ N_2O}\right) = 245.0\frac{gC\ O_2e}{km}$$

$$EF_{CO_2e-LDGT} = \left(337.8\frac{g\ CO_2}{km} * 1\frac{g\ CO_2e}{g\ CO_2} + 0.0098\frac{g\ CH_4}{km} * 25\frac{g\ CO_2e}{g\ CH_4} + 0.0063\frac{g\ N_2O}{km} * 298\frac{g\ CO_2e}{g\ N_2O}\right) = 340.0\frac{g\ CO_2e}{km}$$

Lastly, using the vehicle specific emission factors and the Canadian vehicle breakdowns, an average distance-based commuter vehicle emission factor was determined:

$$EF_{commuter} = \left(EF_{CO_2e-LDGV} * \%\ LDGV_{Canada} + EF_{CO_2e-LDGT} * \%\ LDGT_{Canada}\right)$$

$$EF_{commuter} = \left(0.245\frac{kg}{km} * 53.33\% + 0.340\frac{kg}{km} * 46.67\%\right)$$

$$\boldsymbol{EF_{commuter} = 0.289\frac{kg\ CO_2e}{km}}$$

Commuting – Bus

The distance-based bus commuting emission factor was determined based on information on the latest annual GHG emissions and distance traveled information from Calgary Transit[20] and information on average bus loading for transit serving the university collected during a study by Urban Systems[21].

$$EF_{CommutingBus} = \frac{\begin{matrix}Calgary\ Transit\\ Bus\ Emissions\end{matrix}}{\begin{matrix}Passengers\\ per\ Bus\end{matrix} * \begin{matrix}Calgary\ Transit\\ Total\ Distance\ Travelled\end{matrix}}$$

$$EF_{CommutingBus} = \frac{72{,}972{,}000\ kg\ CO_2e}{6\ passengers * 52{,}923{,}000\ km}$$

$$\boldsymbol{EF_{CommutingBus} = 0.230\frac{kg\ CO_2e}{passenger \cdot km}}$$

Transmission and Distribution Losses

[20] Calgary Transit, e-mail message to the Office of Sustainability, February 20, 2014

[21] Urban Systems Ltd., *Benchmark Transportation Modal Survey Report* (Calgary, 2011)

Using 2016 NIR emission factors for electricity, the difference between the Generation and Consumption emission factors is used.[22]

$$EF_{T\&D} = EF\ Generation - EF\ Consumption = Los * \left(0.900 \frac{kg\ CO_2e}{kWh} - \left(0.760 \frac{kg\ CO_2e}{kWh}\right)\right)$$

$$\boldsymbol{EF_{T\&D} = 0.140 \frac{kg\ CO_2e}{kWh}}$$

Solid Waste

Using factors from the National Inventory Report:[23]

$$EF_{Solid\ Waste} = \frac{DDOCm}{W} * F * \frac{M_r\ CH_4}{M_r\ C} * 25\ \frac{kgCO_2e}{kg\ CH_4}$$

$$EF_{Solid\ Waste} = \frac{decomposable\ DOC\ mass}{masss\ of\ weight\ deposited} * fraction\ of\ CH_4 in\ landfill\ gas * \frac{Molecular\ weight\ of\ CH_4}{Molecular\ weight\ of\ C}$$

$$EF_{Solid\ Waste} = 0.22 * 0.6 * 0.5 * \frac{(12\ +\ 4 * 1)\frac{g}{mol}}{12\frac{g}{mol}} * 25 \frac{kg\ CO_2e}{kg\ CH_4}$$

$$\boldsymbol{EF_{Solid\ Waste} = 2.2 \frac{kg\ CO_2e}{kg\ waste}}$$

[22] Environment Canada, *National Inventory Report 1990-2016: Greenhouse Gas Sources and Sinks in Canada – Part 3*, Table A13-10.

[23] Environment Canada, *National Inventory Report 1990-2016: Greenhouse Gas Sources and Sinks in Canada – Part 2*, Table A3-68

Appendix E – Acknowledgements

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