UBC Social Ecological Economic Development Studies (SEEDS) Student Report

Fleets and Flights: A Greenhouse Gas Pilot Study of UBC Okanagan

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By

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Executive Summary

In an effort to mitigate greenhouse gas (GHG) emissions that contribute to global climate warming, the government of British Columbia has passed legislation that requires colleges, universities and other public sector organizations to be carbon neutral by 2010. To comply with this bill, the University of British Columbia must conduct a comprehensive internal GHG audit to quantify the carbon footprint of the institution.

A significant portion of this carbon footprint results from the use of fossil fuel for transportation by faculty and staff on behalf of the university for such activities as research, teaching and service. A study of the GHG emissions associated with institutional air and ground travel done on behalf of the University of British Columbia Okanagan (UBCO) is required to establish a GHG baseline for future audits. Institutional travel includes all travel done by UBCO-owned or leased fleet vehicles (Scope 1 emissions) and travel done in vehicles or airplanes not owned or controlled by UBCO (Scope 3 emissions).

Scope 1 and 3 data from UBCO were not available to the UBC Sustainability Office for the 2006 GHG audit. The absence of these data can be attributed to a lack in precedence of GHG recording and reporting protocol at UBCO. Since these data were not readily available, I conducted a pilot study to assess the carbon footprint associated with the use of fleet vehicles and a portion of the institutional travel of UBCO. This report summarizes the study results as well as recommendations for new GHG reporting protocols, which will serve to improve the response rate for campus-wide GHG audits in the future.

Data were collected by a voluntary survey distributed via internal email to a sample size of 157 faculty, staff and graduate students from academic units 1, 2 and 3 of the IK Barber School of Arts and Sciences. Data about their institutional ground and air-travel from April 1, 2007 to March 31, 2008 were collected. Data from Athletics travel, use of UBC-owned research vehicles, security vehicles, campus golf carts and maintenance equipment were collected directly from their respective department records. A survey response rate of 11% from staff, faculty and graduate students was obtained.

Based on the available information, the total mass of Scope 1 emissions for the one-year period was 41,537 kg CO_2 eq. Scope 1 emissions account for 44% of the total GHG emissions produced as a result of institutional travel reported by participants at UBCO. The total mass of Scope 3 emissions from these two areas was 53,387 kg CO_2 eq. Scope 3 emissions account for 56% of the total GHG emissions produced as a result of reported UBCO institutional travel.

1.0 Introduction

A study of the greenhouse gas (GHG) emissions associated with air and ground travel done on behalf of the University of British Columbia Okanagan (UBCO) is required to establish a GHG baseline for future audits. Ground and air travel done for the purposes of teaching, research or service to the university constitutes UBC institutional travel. This includes all travel done by UBCO-owned or leased fleet vehicles (Scope 1 emissions) and travel done in vehicles not owned or controlled by UBCO (Scope 3 emissions). These data were not available to the UBC Sustainability Office for the 2006 GHG audit. The absence of data can be attributed to a lack in precedence of GHG recording and reporting protocol at UBCO. Since these data are not readily available, I conducted a pilot study, in a joint effort with the Sustainability Office of UBC, to assess the carbon footprint associated with the use of fleet vehicles and the institutional travel of UBC Okanagan. This report summarizes the study results as well as recommendations for new GHG reporting protocols which may improve the response rate for campus-wide GHG audits in the future.

2.0 Global Warming and Climate Change

Measurements of ambient atmospheric temperatures have been recorded since 1850. Since 1906, a 100-year linear trend in surface temperature shows an increase of 0.74°C (IPPC 2007). During the past 50 years, this warming trend (global warming) increased in an exponential fashion to 0.13°C per decade. On a global scale, 11 of the

previous 12 years, from 1995 to 2006, ranked among the warmest years for mean surface temperature on record (Figure 1).

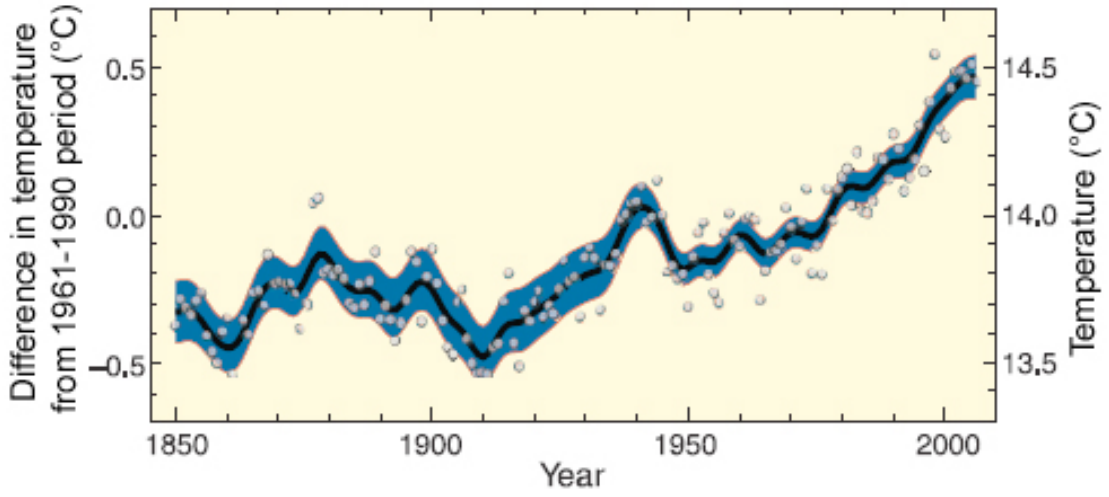

Figure 1. Measured changes in global mean surface temperature. All differences are relative to the mean for the period 1961-1990. The black smoothed curve shows the running decadal mean. White circles show yearly values. The blue-shaded area is the uncertainty interval estimated from a comprehensive analysis of known uncertainties (IPCC, 2007, Synthesis Report, p. 31).

A rising global mean surface temperature has negative implications for global climate stability. Prolonged periods of increased surface temperature slowly change the local climate (climate change). The primary mechanism of this climate change is through the alteration of the hydrosphere (IPCC 2007). The hydrological cycle is dependent upon ambient heat as the source of its energy. This heat energy is stored in and transported by the hydrological cycle throughout the atmosphere as latent heat in clouds and water vapour (IPCC 2007). As a result, local weather conditions are very sensitive to ambient temperature changes.

An increase in global mean surface temperature accelerates water evaporation from water reservoirs, rivers, lakes and oceans. This has a profound impact on the distribution of precipitation around the world and can lead to extreme drought and increased flooding. Global warming also causes an increase in the melting rate of glaciers and ice shelves. An increase in sea level is a consequence of this melting, which threatens to submerge many coastal cities around the world (IPCC 2007).

Changes in mean global temperatures, precipitation and snow cover affect the stability of ecosystems around the world. Degradation of ecosystems results in global habitat loss, modification and fragmentation, which has a negative impact on global species diversity (IPCC 2007). Specifically, changes in global precipitation and warmer regional temperatures affect the timing of organism reproduction, animal migration patterns, the length of growing season, species distributions, mortality and population sizes, and the frequency of pests and disease outbreaks (IPCC 2007). The ecosystems most vulnerable to climate change are Mediterranean-climate ecosystems, coral reefs, the sea-ice biome, and high-latitude ecosystems such as boreal forests and mountain ecosystems. Global warming and climate change result in the loss of biodiversity and ecosystems around the world, and consequently threaten the survival of all the species on Earth.

2.1 Causes of Global Warming

A consensus in the scientific community has emerged in last decade that attributes global warming to human (anthropogenic) activities. Since the industrial revolution in the

1800s, global surface temperatures have been increasing proportionally with Greenhouse Gas (GHG) emissions (Figures 1 and 2) (IPCC 2007). There is a strong correlation between GHG emissions and the warming trend between the years 1906 and 2006. The primary GHGs responsible for global warming are the by-products of fossil fuel burning. The three major GHGs produced during the burning of fossil fuels are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), in order of decreasing emissions (IPCC 2007).

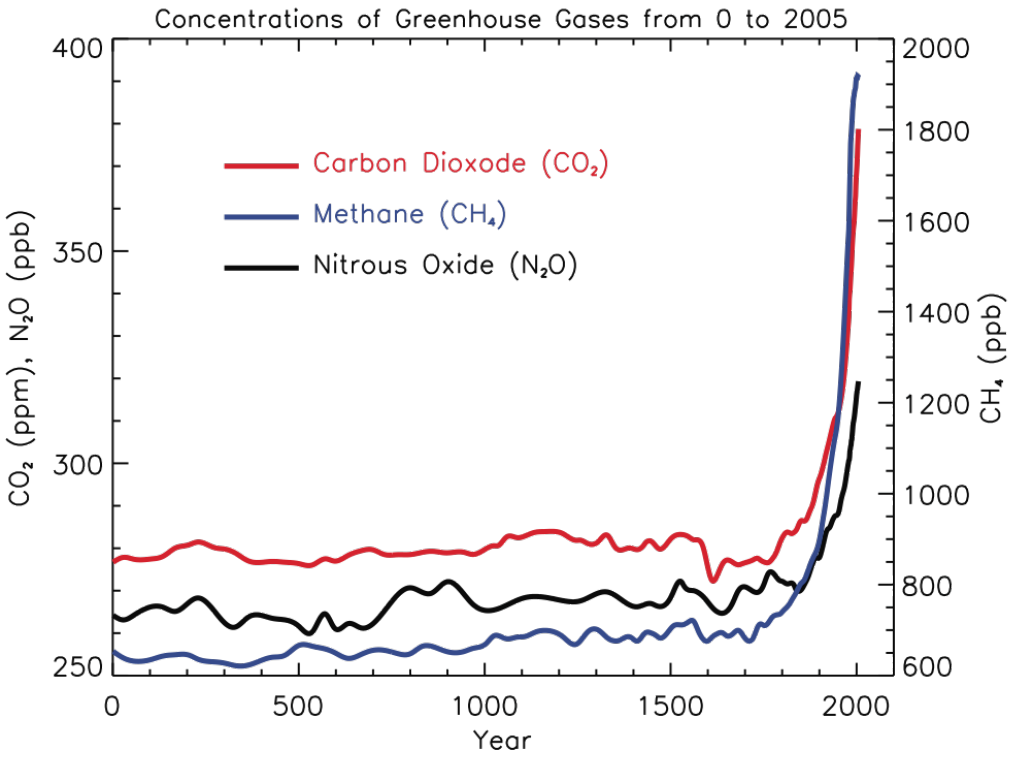

Figure 2. Atmospheric concentrations of the three major long-lived greenhouse gases over the last 2,000 years. Increases since approximately 1750 are attributed to human activities in the industrial era. Concentration units are parts per million (ppm) or parts per billion (ppb) and indicate the number of molecules of the greenhouse gas per million or billion air molecules, respectively, in a tropospheric air sample (IPCC 2005, Physical Science, Ch. 2, p. 135).

Pre-industrial atmospheric concentrations of relevant GHGs (CO_2, CH_4 and N_2O) have increased exponentially in the past 300 years (IPCC 2005). These anthropogenic GHG emissions are a direct result of industrial activity by humans around the world.

2.2 Greenhouse Gases and Radiative Forcing

A greenhouse gas is defined as any gaseous chemical species that absorbs radiation in the infrared (IR) range of the electromagnetic spectrum (wavelengths 700nm-1mm) (IPCC 2007). The three major GHGs in the Earth's atmosphere are H_2O, CO_2, and N_2O, in order of decreasing natural abundance. The molecular structure and bonding nature of these species dictates their relative IR absorption efficiencies; each GHG species has a unique chemical composition and therefore a unique IR absorption spectrum (Environment Canada 2009). Thus, each GHG exhibits different relative strengths of IR absorption. When IR radiation is absorbed, vibrational excitation of the GHG molecule occurs and is transferred to surrounding molecules (heat conduction) before the IR radiation is re-emitted by the GHG. The re-emitted radiation wavelength is longer than the incident radiation wavelength due to the loss in energy by heat conduction. This process is repeated until the radiation is too low in energy to be absorbed by the GHG (IPCC 2007). This characteristic heating effect of GHGs is known as radiative forcing (RF). The RF values of each GHG are reported in common units of radiation flux per unit area (W/m^2). The cumulative effect of these GHGs is a function of the identity of the GHG and is proportional to their concentration in the observed system (Figure 3).

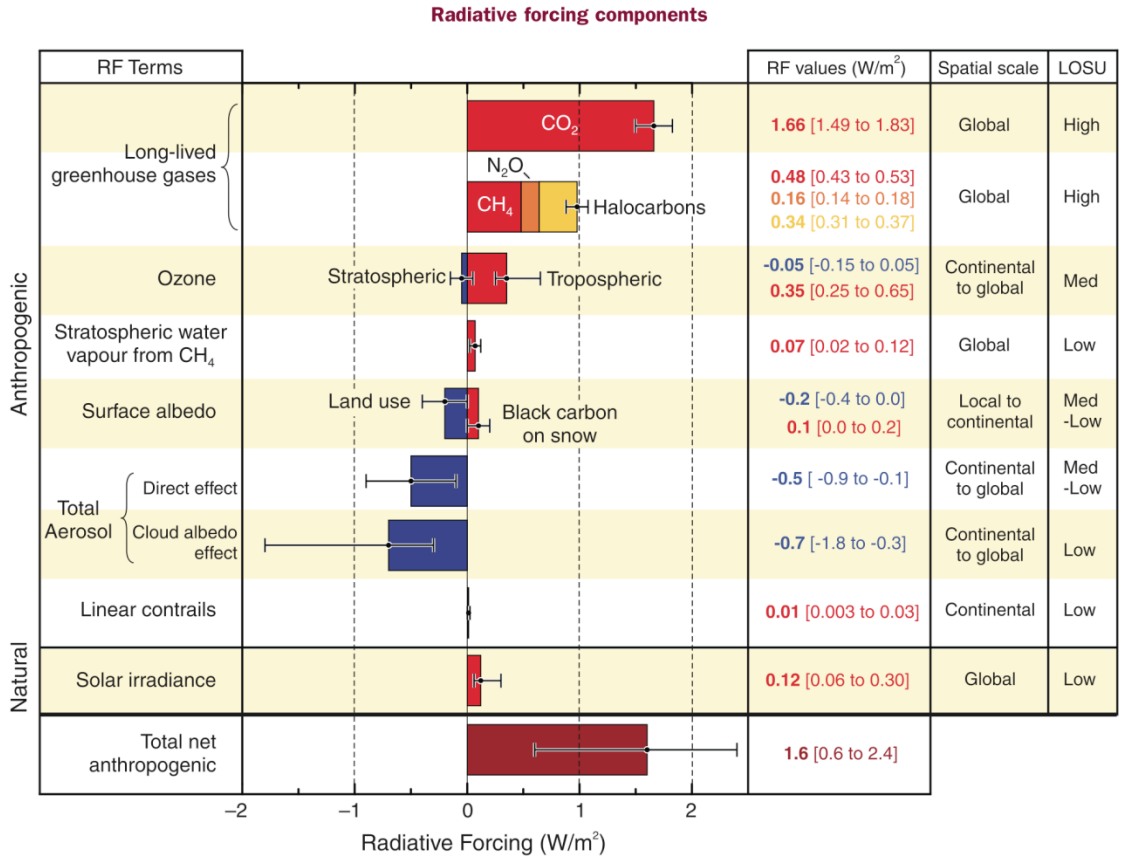

Figure 3. Global mean radiative forcing (RF) of GHGs in 2005 with respect to 1750 (pre-industrial levels considered to be a natural RF baseline) for CO_2, CH_4, N_2O and other important RF agents and mechanisms. The typical geographical extent (spatial scale) of the RF and the assessed level of scientific understanding (LOSU) are included. Aerosols from explosive volcanic eruptions contribute to a cooling effect for several years following an eruption. The horizontal black lines represent the range of uncertainty for the respective values (5 to 95% uncertainty ranges). Note that RF caused by natural water vapour (clouds) is not included as it is relatively constant (IPCC, 2007, Synthesis Report, p. 39).

To assess the total RF of a given GHG, the temporal and spatial distribution of each respective species must be taken into account. RF values cannot be used without integration over a given period of time relative to a given reference species mass. The magnitude of the time period over which the RF of the GHG is integrated is determined

by the atmospheric lifetimes of the individual GHGs. Atmospheric lifetimes (residency time in the atmosphere) of gas species vary according to chemical reactivity with atmospheric oxidizing agents (IPCC 2007). More reactive gas species have lower residency times within the atmosphere. A lower residency time for a given GHG will decrease the time period over which its cumulative RF is calculated. This integrated value for a GHG is known as its Global Warming Potential (GWP). Units of GWP were developed to assess the contribution towards global warming observed in the troposphere by each GHG (IPCC 2007). This unit of measurement incorporates the cumulative RF effect of each GHG species over a 100-year period (GWP_{100}). Each GWP_{100} value is calculated relative to a 1kg mass of gaseous CO_2 (Table 1).

Table 1. GWP_{100} of the three major anthropogenic GHG constituents (Environment Canada, 2009).

GHG Species	**GWP_{100}**
Carbon Dioxide (CO_2)	1
Methane (CH_4)	21
Nitrous Oxide (N_2O)	310

The GWP_{100} index is accepted internationally to compare the relative heating effects of each GHG in the atmosphere (IPCC 2007). As shown in Figures 2 and 3, CO_2 is by far the most abundant GHG in the Earth's atmosphere, while CH_4 and N_2O are three orders of magnitude less abundant. Despite its low CWP_{100} value, CO_2 is the principal contributor to global atmospheric RF due to its high atmospheric abundance. Therefore, CO_2 is the reference species as a standard unit for the comparisons of GHGs. The GWP_{100} was adopted by the 1990 Kyoto protocol to calculate all GHG emissions in the common units of CO_2 equivalents (CO_2 *eq*) (IPCC 2007).

2.3 The Carbon Cycle

The Carbon Cycle is the constant exchange of carbon between various reservoirs (carbon sinks) such as the atmosphere, hydrosphere, lithosphere and biosphere (Environment Canada 2009). On a global scale, the mass of carbon stored in a reservoir is measured in units of Gigatonnes of Carbon (GtC) (IPCC 2007). Throughout the carbon cycle, carbon exists in various chemical forms in a range of reduced and oxidized states. The hydrosphere is the largest carbon sink with a capacity to store approximately 39823 GtC, mainly as dissolved bicarbonate (H_2CO_3) in the oceans and rivers of the world (Figure 4) (NASA 2004). The lithosphere holds the second largest amount of carbon, approximately 1730 GtC, which is stored as various minerals in sediments and organic compounds in humus. Concrete products and fossil fuels derived from the lithosphere contained approximately 4000 GtC in 2004. The atmosphere is the third-largest carbon sink and held approximately 750 GtC in 2004, mainly in the form of gaseous CO_2. Finally, the biosphere, the smallest carbon sink, stored approximately 610 GtC, largely in the form of organic compounds such as cellulose in vegetation (NASA 2004).

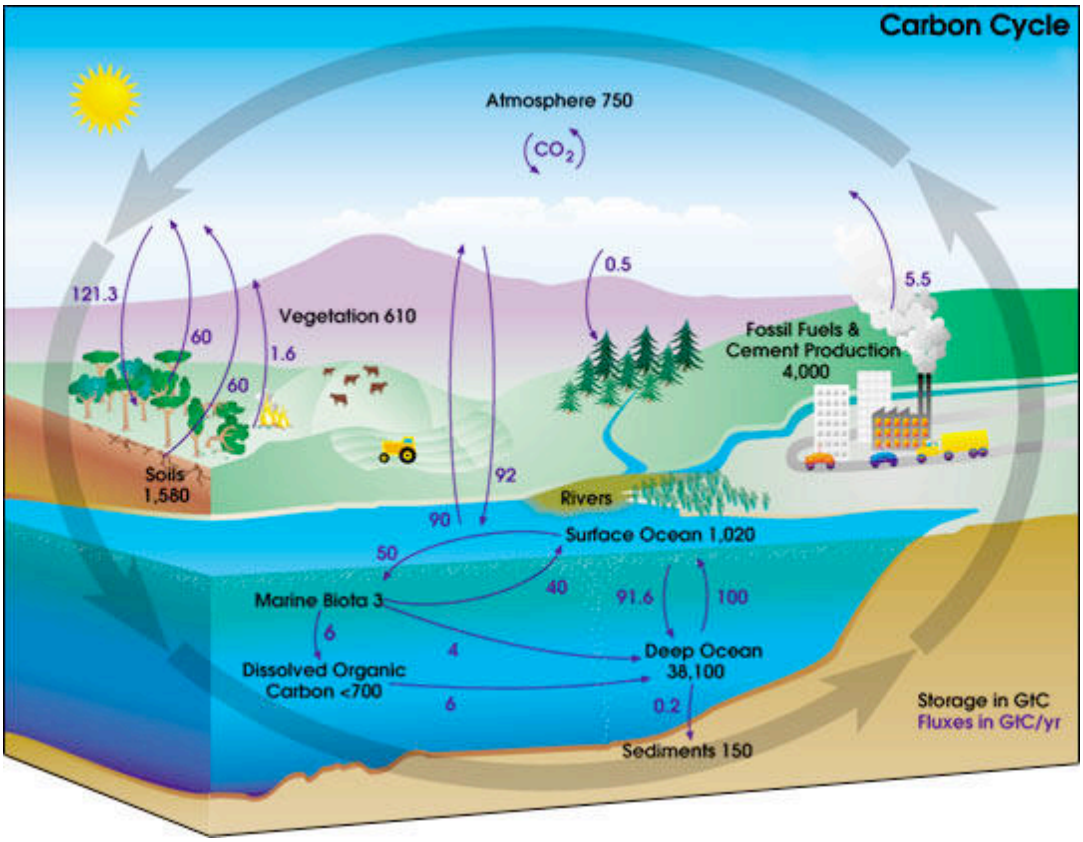

Figure 4. A simplified representation of the Carbon Cycle on Earth. Black values denote masses of carbon stored in reservoirs (units of Gigatonnes of carbon) (GtC). Purple values denote fluxes of carbon by various processes (units of Gigatonnes of carbon per year) (GtC/yr). Arrow directions indicate the net flow of carbon among reservoirs (NASA, 2004, The Human Role).

Within these reservoirs, various natural biotic and abiotic chemical processes transform the carbon-containing compounds and allow carbon transfer to occur among carbon reservoirs. Without these chemical processes, the carbon cycle would not occur and the carbon would remain within the different reservoirs in their respective chemical states. The natural rates of transfer (flux) of carbon between these reservoirs are determined by the speed of these biotic and abiotic chemical processes, which can range from nanoseconds to millions of years (IPCC 2007). On the global scale, carbon fluxes

are measured in units of Gigatonnes of carbon per year (GtC/yr) (Environment Canada 2009). Increases in CO_2 concentrations can occur in a given reservoir when the rates of CO_2 influx are greater than the natural rates of CO_2 efflux.

Carbon in the atmosphere exists primarily in its oxidized, gaseous CO_2 form (IPCC 2007). The global distribution of CO_2 remains relatively homogeneous because of the constant mixing of air masses throughout the troposphere. Due to the use of fossil fuels since the industrial revolution, the concentration of CO_2 in the atmosphere has been increasing exponentially (IPCC 2007) (Figure 2).

The rates of carbon flux between the atmosphere and the biosphere are the most rapid in the carbon cycle (IPCC 2007). The plants in the biosphere absorb CO_2 from the atmosphere via photosynthesis at rates of about 121.8 GtC/yr, which contributes to the short residency of CO_2 in the atmosphere (NASA 2004). CO_2 influx rates to the biosphere have been greatly modified in the past 100 years as a result of human activities. This influx rate to the biosphere is decreased by deforestation and soil degradation. Soils with poor nutrient levels or high levels of toxic contaminants will not support many trees or other plants. Without trees and plants, carbon influx of atmospheric CO_2 to the biosphere cannot occur through photosynthesis. CO_2 efflux from the biosphere is from plant cellular respiration, combustion (forest fires) and decomposition of vegetation (121.6 GtC/yr). The net result is a small natural positive carbon influx to the atmosphere by the biosphere of 0.2GtC/yr from the atmosphere (NASA 2004).

The second-fastest rate of carbon flux occurs between the atmosphere and the hydrosphere (IPCC 2007). These rates of carbon flux are dependent on the chemical processes of absorption and desorption of CO_2 in the Earth's waters. The processes of

absorption and desorption of a gas in a liquid is fast and result in global hydrospheric carbon influx and efflux values of 92and 90 GtC/yr respectively. The rate of CO_2 influx to the ocean is increasing due to human-caused increases of atmospheric CO_2 concentrations. The added CO_2 present in the atmosphere shifts the equilibrium (Equation 1) from reactants to products, which generates more carbonic acid and increases the acidity of the oceans as a by-product of the reaction. High acidity means the aqueous system will have a low pH value (high concentration of H^+). The consequences of changes in ocean pH on marine organisms are poorly understood and are therefore a cause for concern (IPPC 2007). The dissolved CO_2 reacts with water to create carbonic acid (H_2CO3), a weak acid, as shown in the following equation:

$$CO_{2(g)} + H_2O_{(l)} \rightarrow H_2CO_{3(aq)} + 17.9\ kJ$$

Equation 1. The hydration reaction of carbon dioxide with water creates carbonic acid at standard temperature and atmospheric pressure. The hydration equilibrium constant at 25°C, K_h is $1.70\times10^{-}3$. This means the majority of CO_2 is not converted into carbonic acid and stays as CO_2 molecules (CRC, 2009, p. 5-88).

The mean pH of surface waters varies naturally between 7.9 and 8.3 in the ocean. A decrease in mean ocean surface pH of 0.1 was calculated from the estimated uptake of anthropogenic CO_2 between 1750 and 1994 (IPCC 2007). Assuming that alkalinity and temperature remain constant, a 0.1 decrease in ocean pH corresponds to a 30% increase in the concentration of H^+ in the seawater (Aqueous Chemistry 2006). The observed anthropogenic impact on ocean acidity between 1982 and 2006 was a decrease in pH of 0.02 per decade (IPCC 2007).

Some types of marine biota absorb dissolved carbonate anions (CO_3^-) and calcium

cations (Ca^{+}) and then precipitate these as calcium carbonate ($CaCO_3$) in the formation of seashells. Upon the death of the organisms, their shells are deposited onto the ocean floor and then incorporated into the sediments over millions of years at a rate of 0.2 GtC/yr (NASA 2004). This is one way in which the CO_2 influx occurs, though indirectly, from the atmosphere to the lithosphere.

Natural carbon flux between the lithosphere and atmosphere is typically minor because heterogeneous chemical processes between a solid and gas are typically slow. Over millions of years, carbon accumulated in the biosphere as humic material, which was subsequently transformed under extreme temperatures and pressure into oil and natural gas deposits within the lithosphere. In the past 150 years, since the start of the industrial revolution, these fossil fuels have been extracted and combusted as a source of energy by humans (IPCC 2007). Burning fossil fuels accounts for the influx of carbon from the lithosphere into the atmosphere at a rate of 5.5 GtC/yr. The anthropogenic CO_2 influx into the atmosphere is also a full order of magnitude greater than the current rate of CO_2 influx by the biosphere (0.2 GtC/yr) (NASA 2004). As a result, a portion of the CO_2 emitted (5.3GtC/yr), which would otherwise have been sequestered in the lithosphere, accumulates in the atmosphere in an exponential fashion (see Figure 2).

2.4 The Greenhouse Effect

The greenhouse effect heats an atmosphere by trapping radiation within it. This process occurs in atmospheres that contain GHG species such as CO_2, CH_4 and N_2O. It is a naturally-occurring phenomenon observable on any planet meeting that criterion. On

Earth, the greenhouse effect is the mechanism by which the troposphere maintains thermal balance (Figure 5). Incoming solar radiation from the Sun (342 W/m^2) filters through the Ionosphere, Mesosphere, Stratosphere and Thermosphere (IPCC 2007). The full spectrum of radiation undergoes reflectance and scattering (77 W/m^2) by aerosols, gases and clouds. A portion of the radiation spectrum is absorbed by gases in the atmosphere (67 W/m^2). The fraction of the radiation spectrum that remains is either reflected (30 W/m^2) or absorbed (168 W/m^2) by the planetary surface. Radiation is then emitted by the surface to the surroundings as longwave IR radiation. The GHGs present in the troposphere absorb the outgoing longwave IR radiation, which is then re-emitted to its surroundings as back radiation (324 W/m^2) (IPCC 2007). The magnitude of the back radiation emitted by each GHG is proportional to their atmospheric concentrations and respective RF values as discussed in section 1.3.

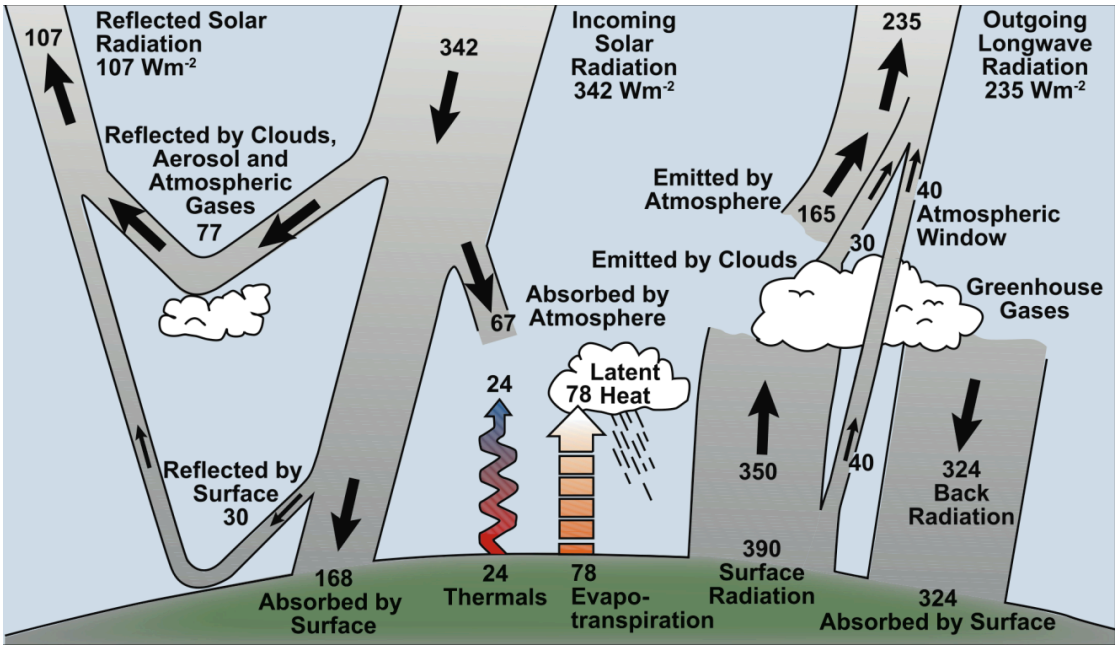

Figure 5. Estimates of the Earth's annual and global mean energy balance including the greenhouse effect. All values are displayed in units of radiation flux per unit area (W/m^2) (IPCC 2005, Physical Science, Ch. 2, p. 96).

The global energy balance is maintained by the greenhouse effect in which a portion of radiation normally emitted back into the vacuum of space is retained within the atmosphere. On Earth, the net result of the greenhouse effect warms the atmosphere to a global mean surface temperature of 14°C. In the absence of the greenhouse effect the global mean surface temperature would be -18°C (IPCC 2005).

2.5 Enhanced Greenhouse Effect

The enhanced greenhouse effect is an increase in global mean RF resulting in the perturbation of the global thermal equilibrium (global warming). The natural thermal equilibrium is maintained by the relative atmospheric concentrations of GHGs and their corresponding RF (IPCC 2007). The magnitude of the CO_2 RF is mainly a result of its naturally high atmospheric concentration (in the ppm range). Human activities, such as the burning of fossil fuels and other organic matter, increase the atmospheric concentration of CO_2 (IPPC 2007). As shown in Figure 3, CO_2 is the largest anthropogenic contributor of RF in the atmosphere, which enhances the greenhouse effect (IPCC 2007).

Other potent GHGs such as CH_4 and N_2O are also emitted by the burning of fossil fuels and other organic matter. Pre-industrial-revolution concentrations of CH_4 and N_2O in the atmosphere were approximately 610 and 255 ppb respectively (IPCC 2007), which is three orders of magnitude less than that of CO_2. However, the long atmospheric residencies of these two species make them important GHGs with GWP_{100} values larger than CO_2 (Table 1). Moreover, these increase the CO_2 eq concentrations and also

intensify the RF in a proportional manner (IPCC 2007).

3.0 Canadian Emission Sources and Trends

Modern human activities are dependent upon fossil fuels as energy sources. In 2006, 85% of the world's total energy generation and use resulted in the release of CO_2 and other GHGs (BP 2008). In Canada, energy from fossil fuels is used throughout many parts of the economy (Table 2). The energy sector is the largest source of GHG emissions in Canada (614 Mt CO_2 eq), which includes emissions of all GHGs associated with the production and combustion of fossil fuels. The sum of GHG emissions from all other contributing sectors in Canada is less than one third of the emissions generated by the energy sector (157.73 Mt CO_2 eq) (National Inventory 1990-2007).

Table 2. Annual GHG emissions in Canada by economic sector categories during 2007 shown in the Common Reference Format (CFR), United Nations Framework Convention on Climate Change (UNFCCC) (National Inventory Report, 1990–2007, p. 39-56).

Economic Sector	**Net GHG Emissions (Mt CO_2 eq)**
Energy	614
Agriculture	60
Industrial Processes	51.4
Land Use, Land-Use Change and Forestry	45
Waste	21
Solvent and Other Product Use	0.32
Total	**791.72**

Emissions from the Canadian energy sector are classified as either the result of fuel combustion or as fugitive emissions. Fuel combustion emissions are direct releases of GHGs from the burning of fossil fuels. Fugitive emissions are the intentional and unintentional releases of GHGs during the production, processing, transmission, storage,

and delivery of fossil fuels. In Canada, fuel combustion and fugitive emissions produced 549 and 64.8 Mt CO_2 eq respectively in 2007. Together these two categories represent the total GHG emissions from the energy sector and accounted for 82% of total Canadian GHG emissions (National Inventory Report 1990–2007).

Between 1990 and 2007, total energy sector GHG emissions rose by 31% in Canada. From 1990 to 2007, fuel combustion emissions increased 29%, while emissions from fugitive releases rose 52%, which is the fastest growth rate of any subsector (Figure 6). The rapid growth of fugitive emissions is due to a national increase in the use of oil and natural gas. Emissions for this subsector increased more rapidly than any other category in the energy sector (National Inventory Report 1990–2007).

GHG emissions from fuel combustion in Canada increased by 29% in 2007, from 427 Mt CO_2 eq in 1990 to 549 Mt CO_2 eq in 2007. During this period, transport GHG emissions grew by 38% (55 Mt CO_2 eq), which was the largest increase within the fuel combustion category. The transportation subsector also accounted for 35% of Canada's total emission growth from 1990 to 2007 (Figure 6). Transport includes emissions from fuel combustion for the transport of passengers and freight in five subcategories: road transportation, civil aviation (domestic aviation), navigation (domestic marine), railways, and other transportation (off-road and pipelines). Transport was also the second-largest emission-producing sector in Canada. Moreover, transport accounted for almost 27% (190 Mt CO_2 eq) of Canada's GHG emissions in 2007 (National Inventory Report 1990–2007).

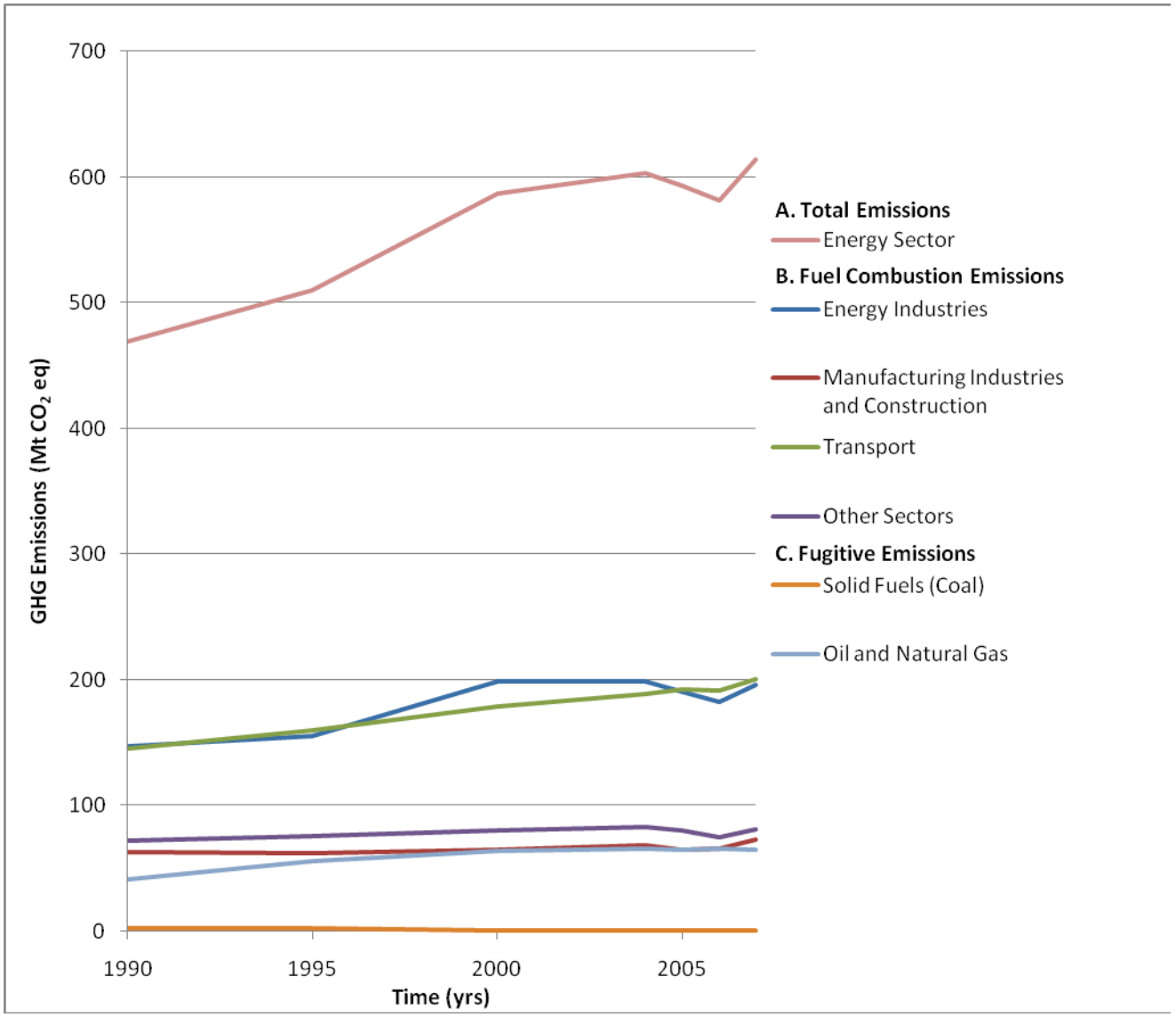

Figure 6. Annual GHG emissions in Canada, by energy sector, from 1990 to 2007 shown in UNFCCC CRF categories. (A) Total GHG emissions from the Energy Sector. (B) Fuel combustion emissions are divided into the following subsectors: Energy Industries, Manufacturing Industries and Construction, Transport, and Other Sectors. Other Sectors includes emissions from residential and commercial categories, as well as minor contributions of stationary fuel combustion emissions from the agriculture and forestry sectors. (C) Fugitive emissions are divided into the following subsectors: Solid Fuels such as coal and oil and natural gas (National Inventory Report, 1990–2007, p. 40).

3.1 Carbon Footprint, Carbon Neutrality and Carbon Credits

A carbon footprint is a measure of the negative impact human activities have on climate change. Specifically, it is the total mass of carbon CO_2 emitted by an individual, organization, event or product (Environment Canada 2009). The GHGs comprising a carbon footprint can be produced directly by the burning of fossil fuels for heat or transportation. They can also be produced indirectly by the consumption of electricity generated by fossil fuels elsewhere, the purchase of paper products, the construction of a building, the generation or disposal of waste, and the use of fertilizers or refrigerants (Environment Canada 2009). A larger carbon footprint means a greater contribution by the individual or organization to increasing GHG concentrations in the atmosphere.

Carbon neutrality is defined as the condition of an individual, organization, event or product having a net zero carbon footprint (IPCC 2007). This requires that the GHGs emitted into the atmosphere must be balanced with an equal amount of GHG sequestered or offset. Carbon neutrality cannot be achieved by simply reducing GHG emissions. Outsourcing of GHG emission reductions is required by any individual or institution that consumes energy, resources or products that are not generate by renewable energy such as wind, solar or hydroelectricity (IPCC 2007). This can be achieved by the use of carbon offsets in which shares are purchased of a company or project that reduce emissions of GHGs. Carbon offsets are traded and sold between individuals, institutions and governments through regulated international markets (e.g. the Chicago Climate Exchange).

3.2 Climate Change Mitigation Initiatives

Several international initiatives have been undertaken in the past decade to reduce anthropogenic GHG emissions. The Intergovernmental Panel on Climate Change (IPCC) has been at the forefront of climate change research. The panel is a diverse scientific body that publishes special reports which evaluate the science and impacts of global climate change. The panel includes representatives from most of the world's nations to work with the global community to reduce GHG emissions by way of international protocol agreements. Such a protocol began as an international agreement on the United Nations Framework Convention on Climate Change treaty during the 'Earth Summit' in Rio de Janeiro, Brazil. This treaty led to the creation of the Kyoto protocol and its subsequent adoption on December 11, 1997, during a conference in Kyoto, Japan. The protocol calls on all industrialized nations to reduce GHG emissions by 5.2% relative to 1990 levels by 2010. As of 2008, 179 nations, including Canada, have signed and ratified the Kyoto protocol.

International standards for GHG emissions reporting have been designed by the World Resources Institute (WRI) using the latest scientific knowledge about climate change. The emissions reporting protocol is separated into three scopes that reflect the carbon footprint of an institution:

> **Scope 1** refers to direct GHG emissions. Direct GHG emissions occur from sources that are owned or controlled by the institution, including but not limited to emissions from combustion in stationary sources (fuel, oil, and natural gas), fleet vehicles, emission from livestock, and refrigerants.

> **Scope 2** accounts for GHG emissions from the generation of purchased electricity consumed by the institution. Purchased electricity is defined as electricity that is purchased or otherwise brought into the organizational boundary of the company. These emissions physically occur at the facility where electricity is generated.
>
> **Scope 3** emissions are a consequence of the activities of the institution, but occur from sources not owned or controlled by the institution. These activities include: transportation and commuting (public transit and commuter traffic), institutional air travel, fertilizer application, waste generation and disposal, energy found in new construction and existing buildings and infrastructure, and use of purchased materials such as paper. (WRI GHG Protocol, 2004, p. 25)

3.3 Provincial GHG Reduction Initiatives

British Columbia is the second of two provinces in Canada (Quebec was first) to take action in reducing its carbon footprint to mitigate climate change. On November 20, 2007 the BC legislature passed the Greenhouse Gas Reduction Targets Act. This legislation ratifies reduction of GHG emissions by at least 33 % below 2007 levels by 2020. The bill also requires interim targets be set by 2008 by the BC Ministry of Environment for 2012, and 2016 and a GHG target of 80 % below 2007 levels by 2050. The bill requires schools, colleges, universities, hospitals, health authorities, Crown corporations and other public sector organizations to be carbon neutral by 2010 (BC Ministry of Environment 2007).

3.4 UBC Mitigation Initiatives

The University of British Columbia has taken action against climate change in accordance with the BC GHG Reductions Target Act. UBC has signed the Climate Change Statement of Action initiative, which invites university presidents from across British Columbia to commit to reducing institutional GHG emissions ahead of the legislated target dates. The main goal of this initiative is for these institutions to be deemed carbon neutral before 2010 by reducing their carbon footprints (UBC Climate Agenda 2008).

Several programs have been created by UBC to help to meet the goal of institutional carbon neutrality. The UBC ECOTrek program was created in 1997 to reduce GHGs produced by members of the UBC community when commuting to and from UBC-Vancouver. This $34 million program promotes sustainable modes of transportation such as transit, carpooling, walking and cycling. UBC ECOTrek also includes the U-Pass and Employer Pass, End of Trip facilities for cyclists, and Emergency Ride Home programs (UBC Climate Agenda 2008).

The Sustainability Office of UBC was created in 1998 to develop programs to reduce energy and resource consumption on campus, and to encourage the construction of green buildings. In 2006, the Sustainability Office commissioned a report to assess the GHG emissions baseline of the institution. This report included the emissions from all three emission scopes (Table 3). The report included GHG emissions for the UBC Vancouver campus from the use of: natural gas (building heat), oil, animals, electricity, paper, building construction, flights, commuting, waste and fertilizer.

Table 3. Total GHG emissions by the University of British Columbia Vancouver and Okanagan campuses in 2006. [a] Includes the energy used in building construction (UBC Climate Agenda, 2006, p. 12).

Scope	**Source**	**Total Emissions (tonnes CO_2 eq)**
Scope 1	Natural gas	66,000
	Oil	500
	Fleet	2,000
Scope 2	Electricity	22,000
Scope 3	Buildings [a]	12,000
	Air travel	15,000
	Commuting	26,000
	Waste	1,000
	Paper	1,000
	Fertilizer	100

The report also included UBC Okanagan baseline GHG emissions from natural gas use, paper use, building construction and waste; however, due to lack of available data, emissions associated with the purchase of electricity, fertilizer use, commuting to and from campus, and ground and air travel on behalf of the university were not included in the report. The absence of data can be attributed to a lack of precedence of GHG recording and reporting protocol at UBCO. Since a significant portion of the carbon footprint of UBC is from the use of fossil fuel for institutional travel, a thorough GHG audit of UBCO is necessary.

4.0 Methods for Combustion Emissions Quantification

Stoichiometric principals of physical chemistry can be used to quantify the mass of CO_2 eq emitted into the atmosphere from burning a known mass of fossil fuel. Burning fossil fuels activates the chemical bonds of the fuel molecules as well as oxygen from the

air to produce CO_2, H_2O and energy in finite proportions (combustion or oxidation). The following equation (Equation 2) represents the overall reaction during the oxidation of reduced organic matter (fossil fuels):

$$CH_{4(g)} + O_{2(g)} \rightarrow CO_{2(g)} + H_2O_{(l)} + 810\ kJ$$

Equation 2. The combustion reaction of methane at standard temperature and atmospheric pressure (CRC, 1995, p. 5-70).

This reaction is spontaneous and exothermic when the reactants are exposed to an ignition source such as a spark in an engine. Methane is used here as a simple example of fossil fuel combustion since it is a homogenous substance. If the combustion reaction goes to completion, the reactants can be considered consumed in a 1:1 molar ratio; however, this ratio cannot be applied to complex and often variable mixtures of gasoline or diesel fuels. With these assumptions, the mass of product species can be calculated from a known mass of pure reactant species; for example the volume of the methane in the example above can be converted into mass by multiplying the known density of methane to yield the mass of methane consumed. In this case, the precise mass of CO_2 emitted from a given volume of fossil fuel (methane) can be calculated as follows:

Volume fuel (L) x Density fuel (g/L) ÷ Molar Mass fuel (g/mol) x Moles CO_2 (mol) ÷ Moles fuel (mol) x Molar Mass CO_2 (g/mol)
= Mass Emitted CO_2 (g) ***(3)***

Emission factors are required when calculating the combustion products of other fossil fuels because fossil fuels are rarely pure substances with constant density and molar mass. The composition of fossil fuels varies according to government regulations and production facility standards. Emission factors used in these calculations take into

consideration the mean regional fuel composition and density (Table 4). For GHG emission reporting, emission factors are formulated regionally by individual governments (GVRD 2008).

Table 4. Environment Canada's carbon dioxide emission factors for different fuel types. (CSA, 2007, Annex 2, p. 252)

Fuel Type	**CSA Emission Factor (g CO_2/L fuel)**
Gasoline	2360
Diesel	2730
Natural Gas	1.89
Propane	1510
Aviation Gasoline	2330
Aviation Turbo Fuel	2550
Butanol	1490

The emission factors in Table 4 were generated by Environment Canada in accordance with the IPCC GHG reporting protocol (Environment Canada 2009). These factors incorporate the mean molar ratios of reactants and product species. Carbon dioxide emission factors are measured in units of grams of CO_2 per litre of fuel and can be directly substituted into the equation to calculate the mass of CO_2 emitted for a given volume of fuel:

Volume fuel (L) x Emission factor (g CO_2/L)
= Mass CO_2 emitted (g) ***(4)***

e.g. 10 litres of gasoline is combusted completely. i.e. all the carbon content is oxidized completely to CO_2 gas:

10 L gasoline x 2,360 g CO_2/L gasoline
= 23,600g CO_2 emitted

4.1 Quantifying Ground Transportation Emissions

Emissions reporting in the transportation sector is further complicated by the inherent inefficiencies of the internal combustion engine (ICE). The assumptions held in the previous example ignore the fact that the fuel combustion cycle in the ICE is neither perfectly efficient nor perfectly oxidizing. The fuel oxidation process never fully goes to completion, which results in a distribution of partially oxidized species such as CH_4, CO and other volatile organic compounds (VOCs). The emission distribution of partially oxidized species is heavily dependent on engine technology (analogous to vehicle category), age and fuel type (Table 5). CH_4 concentrations are of great concern because of its high GWP_{100} value.

The oxidation of fuel occurs at temperatures and pressures that are high enough to react with the nitrogen (N_2) in the injected air. As the oxygen from the air in the ICE is consumed during a combustion cycle, the normally inert nitrogen is oxidized in addition to the carbon in the fuel. This side reaction produces various amounts of the GHG nitrous oxide (N_2O) depending on engine technology, age and fuel type (Table 5).

Table 5. ICE carbon dioxide, methane and nitrous oxide emission factors for different vehicle category, age, and fuel type (Environment Canada, 2009, Annex 12, p. 252).

Vehicle Category/Year	**g CO_2/L**	**g CH_4/L**	**g N_2O/L**
Gasoline Vehicles			
Light-Duty Gasoline Vehicles (LDGVs)			
Tier 2 (2004-2009)	2360	**	**
Tier 1 (1994-2003)	2360	0.12	0.16
Tier 0 (1980-1993)	2360	0.32	0.66
Oxidation Catalyst (1975-1979)	2360	0.52	0.2
Non-Catalyst (1974 and older)	2360	0.46	0.028
Light-Duty Gasoline Trucks (LDGTs)			
Tier 2 (2004-2009)	2360	0.13	0.25
Tier 1 (1994-2003)	2360	0.21	0.66
Tier 0 (1980-1993)	2360	0.43	0.2
Oxidation Catalyst (1975-1979)	2360	0.56	0.028
Heavy-Duty Gasoline Vehicles (HDGVs)			
Three-Way Catalyst	2360	0.068	0.2
Non-Catalyst Controlled	2360	0.29	0.047
Uncontrolled	2360	0.49	0.084
Diesel Vehicles			
Light-Duty Diesel Vehicles (LDDVs)			
Advance Control	2730	0.051	0.22
Moderate Control	2730	0.068	0.21
Uncontrolled	2730	0.1	0.16
Light-Duty Diesel Trucks (LDDTs)			
Advance Control	2730	0.068	0.22
Moderate Control	2730	0.068	0.21
Uncontrolled	2730	0.085	0.16
Heavy-Duty Diesel Vehicles (HDDVs)			
Advance Control	2730	0.12	0.082
Moderate Control	2730	0.14	0.082
Uncontrolled	2730	0.15	0.075
Natural Gas Vehicles	1.89	9×10-3	6×10-5
Propane Vehicles	1510	0.64	0.028

The emission factors in Table 5 were determined experimentally in several studies of various engine technologies and fuel types (CSA 2007). Environment Canada considers these values to be a reliable source of emission factors for GHG emission calculations for complex fuel mixtures such as gasoline or diesel. Since speciation occurs

during complex fuel oxidation, the GWP_{100} values of CO_2, CH_4 and N_2O must also be incorporated into the equation:

Volume fuel (L) x Fuel/Vehicle Specific Emission Factor (g species/L) x Species Global Warming Potential (g CO_2 eq/g species) = Mass CO_2 eq (g) Emitted ***(5)***

e.g. 10 litres of gasoline is combusted in a 2005 sport utility vehicle ICE. The sum of g CO_2 eq from all three major GHG (CO_2 calculated in the previous example, CH_4 and N_2O) is quantified:

Carbon

10 L gasoline x 2360 g CO_2/L gasoline
= 23,600 g CO_2 emitted

Methane

10 L gasoline x 0.13 g CH_4/L gasoline x 21g CO_2 eq/g CH_4
= 27.3 g CO_2 eq emitted

Nitrous Oxide

10 L gasoline x 0.25 g N_2O /L gasoline x 310 g CO_2 eq/g N_2O
= 775 g CO_2 eq emitted

Total

=24,402.3 g CO_2 eq emitted

The assumptions held in the previous example ignore the fact that the ICE fuel combustion cycle is not perfectly efficient. An ICE has moving parts within it, which generate heat caused by friction. Internal friction in an ICE reduces the fuel efficiency because a portion of the energy in the fuel is diverted to overcome the force of friction rather than making the vehicle move. Fuel efficiencies also vary by ICE technology, vehicle size, type, year and make (Table 6). ICE fuel efficiencies are measured by the volume of fuel in litres consumed by driving a vehicle a distance of 100km. These fuel efficiencies can vary between identical vehicles; however, fuel efficiencies are grouped

into vehicle classes and years to simplify this variation for GHG reporting.

Table 6. ICE fuel efficiencies with respect to vehicle category, age, and fuel type (CSA 2007, Annex 2, p. 252).

Vehicle Category/Year	***L/100 km***
Gasoline Vehicles	
Light-Duty Gasoline Vehicles (LDGVs)	
Tier 1	10.0
Tier 0	10.1
Oxidation Catalyst	11.5
Non-Catalyst	12.3
Light-Duty Gasoline Trucks (LDGTs)	
Tier 1	14.2
Tier 0	14.1
Oxidation Catalyst	14.8
Non-Catalyst	14.8
Heavy-Duty Gasoline Vehicles (HDGVs)	
Three-Way Catalyst	43.5
Non-Catalyst Controlled	43.5
Uncontrolled	55.6
Diesel Vehicles	
Light-Duty Diesel Vehicles (LDDVs)	
Advance Control	10.0
Moderate Control	10.4
Uncontrolled	13.3
Light-Duty Diesel Trucks (LDDTs)	
Advance Control	13.9
Moderate Control	13.9
Uncontrolled	17.5
Heavy-Duty Diesel Vehicles (HDDVs)	
Advance Control	41.7
Moderate Control	41.7
Uncontrolled	45.5

Fuel efficiencies for different vehicle categories are defined by Transport Canada (Environment Canada 2009). These are mean values that take into account local driving conditions, climate, and mean vehicle performance in a given category. Using the fuel efficiencies in Table 6, the same three calculations for a given distance travelled by a

vehicle can be completed by substituting the following equation for volume of fuel:

Distance travelled (km) x Specific vehicle class fuel efficiency (L fuel consumed/ km)
= Volume fuel (L) ***(6)***

Equation 6 can then be substituted into Equation 5 to yield an equation that calculates the mass of CO_2 eq emitted fore a given distance travelled with an ICE vehicle. The emission masses of all three major GHGs, CO_2 CH_4 and N_2O are calculated separately using their respective emission factors, as shown in the previous example. The three equations calculate three CO_2 eq values, the sum of which is the total mass of CO_2 eq emitted for a given distance travelled with an ICE vehicle.

4.2 Quantifying Aviation Emissions

CO_2 emissions produced by aviation are calculated in a similar stoichiometric fashion to that of automobile emissions. Turbine technology used in jet engines makes fuel combustion more efficient than in an automobile ICE, and therefore leads to less partially oxidized speciation; however, separate CH_4 and N_2O emission factors for airplanes are not available from Environment Canada (GVRD 2007). Instead, they are reported in g CO_2 eq per passenger relative to the distance travelled and can be integrated into the following equation:

Distance travelled (km) x 135.9 (g CO_2 eq/passenger km)
= Mass Emitted CO_2 eq (g CO_2 eq /passenger) ***(7)***

e.g. A passenger flies 287 km from Kelowna to Vancouver. The sum of g CO_2 eq from all three major GHG (CO_2 calculated in the previous example, CH_4 and N_2O) is quantified:

287 km x 135.9 g CO_2/passenger km
= 39000 g CO_2 emitted

4.3 Summary of Quantifying Ground and Air Travel Emissions

Quantities of all three major GHGs produced in an internal combustion engine (ICE) can be calculated by using government approved emission factors. The quantities are then converted to CO_2 eq, using their respective GWP_{100} values, to measure all three emission species in common units. By accounting for different ICE fuel efficiencies, the total mass of CO_2 eq emitted can be calculated from a given distance travelled as opposed to a volume of fuel consumed. The CO_2 eq emission factor (135.9 g CO_2 eq/passenger km) used for air travel is a single value derived from the contributions by all three major GHGs and the average fuel efficiency of a commercial airplanes (GVRD 2007). This value is used to calculate the mass of GHGs emitted per passenger for a given distance.

Collecting travel data as a function of distance travelled rather than as a function of fuel consumed provides a more convenient method of calculating GHG emissions. Distances of driven trips are easy to calculate because instruments such as odometers are present in all vehicles. Likewise, the exact flight distances between airports are well documented by airline and travel agent software. However, for ground travel, using the proper emission factors and fuel efficiencies requires detailed information about the type, make, model, year and fuel type of a vehicle. Calculating GHG emissions from air travel requires only the departure, connection(s) and destination airport locations.

4.4 Summary of Report Intent

A study of the GHG emissions associated with air and ground travel done on behalf of the University of British Columbia Okanagan (UBCO) is required to establish a GHG baseline for future audits. Ground and air travel done for the purposes of teaching, research or service to the university constitutes UBC institutional travel. This includes all travel done by UBCO-owned or leased fleet vehicles (Scope 1 emissions) and travel done in vehicles not owned or controlled by UBCO (Scope 3 emissions). These data for UBCO were not available to the UBC Sustainability Office for the 2006 GHG audit. The absence of data can be attributed to a lack in precedence of GHG recording and reporting protocol at UBCO. Since these data are not readily available, I conducted a pilot study to assess the carbon footprint associated with the use of fleet vehicles and a portion of the institutional travel of UBC Okanagan (UBCO). This report summarizes the study results as well as recommendations for new GHG reporting protocols, which will serve to improve the response rate for campus-wide GHG audits in the future.

5.0 Methods

Data about institutional travel were collected in two main categories: Scope 1 (direct GHG emissions from institution-owned sources) and Scope 3 (GHG emissions from sources not owned or controlled by the institution). The nature of Scope 1 emission sources made the collection of data more direct, thorough and reliable. Since the vehicles in question are owned or leased by UBCO, it is essential that all researchers and departments provide travel data. Moreover, UBCO protocols were already in place for the

drivers of UBCO fleet vehicles to record travel distances. Scope 3 emission sources require individuals to keep track of institutional travel such as flights, car and bus trips. Methods of data collection were different for both Scope 1 and Scope 3 and are presented separately below.

5.1 Scope 1 (UBCO Fleet Use) Data Collection Methods

5.1.1 UBCO Fleet Vehicle Registry

The AVP Operations Office provided a copy of the UBCO Fleet Vehicle Registry, which includes the makes, models, years and licence plate numbers of each fleet vehicle. I contacted the department heads of UBCO Facilities and Security via email about the GHG survey, as well as the individual researchers who have a registered fleet vehicle. If I did not receive a response from a researcher or department heads, I met with them in person to solicit their participation.

5.1.2 UBCO Facilities and Security Fleet

UBCO Facilities Management data about the department fleet use was recorded on a spreadsheet. The spreadsheet was emailed as an attachment to Facilities Manager, Roger Bizzotto. Roger Bizzotto forwarded the email to the Security department for me. The emails contained instructions for completion of the spreadsheet data fields. The data fields included vehicle type, year, make, model, fuel type, distance of trip, and annual trip frequency. With these data and equations 5 and 6, I was able to calculate the annual mass

of CO_2 eq emitted from the total annual kilometres traveled by each fleet vehicle. Since the Facilities Management and Security departments used these vehicles exclusively for university duties, the purpose for the total annual distance driven in these fleet vehicles was assumed to be 'Service'. Instructions on the spreadsheet indicated that a return trip was to be entered as two separate one-way trips (Figure 7).

	A	B	C	D	E	F
1	**Institutional Automobile Travel (April 1, 2007 to March 31, 2008)**					
2	Please review the example data below and input your data			Please scroll to the right for Air Travel ---------->		
3						
4	PLEASE record return trips as two separate one-way trips					
5	**Vehicle Type (Car, SUV, Van, Light-duty truck, Heavy-duty truck**	**Vehicle Model Year**	**Fuel type (gasoline, deisel)**	**Trip route (Departure to destination)**	**Frequency of trip (per year)**	**Trip purpose (research, teaching or service)**
6	(Example) SUV	2003	gasoline	Kelowna to Vancouver	7	teaching
7	(Example) SUV	2003	gasoline	Vancouver to Kelowna	7	teaching
8						
9						
10						
11						
12						
13						
14						

Figure 7. Screen shot of a blank Excel spreadsheet to document institutional ground travel by staff, faculty and graduate students at UBCO.

5.1.3 UBCO Research Fleet

I contacted each researcher listed on the UBCO Fleet Vehicle Registry via email. I emailed a letter of introduction that outlined my research project and instructions on how to participate. I asked each researcher to forward me all electronic travel logs that included the studied time period April 1, 2007 to March 31, 2008. Researchers then forwarded me their most recent Excel spreadsheet file, which generally contained data for individual trips such as initial and final odometer readings in kilometres, amount of

money spent on fuel and any repairs or maintenance required. If these records were not available in digital format, I offered my assistance to sort through their logbooks. I made digital copies for later reference by scanning and saving each logbook page containing data within the studied time period. Specific vehicle information, such as fuel and vehicle type, was obtained through further correspondence with each researcher. With these data and equations 5 and 6, I was able to calculate the annual mass of CO_2 eq emitted from the total annual kilometres traveled by each research fleet vehicle.

5.1.4 UBCO Campus Golf Cart Fleet and Campus Maintenance Equipment

Data on the daily use of the campus golf cart fleet is not recorded by any department at UBCO; therefore, no data for past academic years could be found for the kilometres driven or the amount of fuel consumed. However, the fuel sources for all golf cart vehicles and all campus ground maintenance equipment is monitored by Facilities Management. Data about the refuelling rate, maximum storage volume, and type of fuel stored in the on-campus fuel tank were obtained via correspondence with Facilities Manager, Roger Bizzotto. With these data and equation 4, it was possible to calculate only the annual mass of CO_2 emitted from the use of the on-campus fuel tank. Since emissions factors are not available for all the different combustion technologies used in campus golf carts and miscellaneous ground maintenance equipment, quantification of CH_4 and N_2O speciation was not possible.

5.2 Scope 3 (Institutional Travel) Data Collection Methods

5.2.1 Institutional Ground Travel Data Collection

An email was sent to the heads of Units 1, 2 and 3 of the IK Barber School of Arts and Sciences, to be forwarded to their respective unit employees, which included a letter of introduction, an Excel spreadsheet and a letter of instructions for the survey respondents. This survey contained fields to be filled with data about ground travel (automobile) done in a vehicle not owned or leased by UBCO between April 1, 2007 and March 31, 2008. The data fields included vehicle type, year, make, model, fuel type, distance of trip, annual trip frequency, and the purpose of the trip (Research, Teaching and Service). Instructions stated that the surveys were to be completed by all employees of the unit, which included all travel done by the faculty, staff and graduate students. The letter also urged those who did not do any ground travel on behalf of UBCO during the stated time period to respond with a blank survey. Using these data and equations 4 and 5, the total mass of CO_2 eq emitted from the institutional ground travel was calculated from the total distance travelled by each vehicle.

5.2.2 Institutional Air Travel Data Collection

Data were collected about institutional air travel (civil aviation) done between April 1, 2007 and March 31, 2008 by the faculty, staff and graduate students of units 1, 2 and 3 in the IK Barber School of Arts and Sciences. These data were collected on a separate section of the emailed Excel spreadsheet survey (Figure 8). This survey contained fields to be filled with data about all air travel done during the above time period. The data fields included departure, connection(s) and destination locations and

the purpose of the trip (Research, Teaching, and Service). Instructions on the spreadsheet indicated that a return trip was to be entered as two separate one-way trips. Using these data and equation 7, the total flight distance was calculated then converted to mass of CO_2 eq emitted.

	H	I	J	K
1	**Institutional Air Travel (April 1, 2007 to March 31, 2008)**			
2	Please review the example data below and input your data.			
3				
4	Record return trips as two separate one way trips			
5	**Departure location**	**Connecting flight location(s)**	**Destination location**	**Trip purpose (research, teaching or service)**
6	(Example) Kelowna, Canada	Calgary, Canada to Frankfurt, Germany	Geneva, Switzerland	research
7	(Example) Geneva, Switzerland	London, England	Kelowna, Canada	research
8				
9				
10				
11				
12				
13				
14				

Figure 8. Screen shot of a blank Excel spreadsheet to document institutional air travel by staff, faculty and graduate students at UBCO.

5.2.3 Student Athletics Travel

Student athletic groups, including the basketball, volleyball and soccer teams at UBCO, travel the province and country to attend games not hosted at UBCO. Travel data from the 2007 and 2008 seasons for all UBCO sports teams were obtained from Rob Johnson, the UBCO Athletics & Recreation director. He provided a spreadsheet that included the destination cities of all trips taken by UBCO sports teams for the period of April 1, 2007 to March 31, 2008. The most common method of transportation was

chartered motor coach (bus). The sports teams traveled by air only to attend national championships at the end of the sports season. Using these data and equations 5 and 6, the drive distances were calculated and then converted to masses of CO_2 emissions only. A total of only CO_2 emissions rather than CO_2 eq emissions was calculated because there are no other emission factors for motor coaches available. Flight distances were totalled and converted to masses of CO_2 eq using equation 7.

5.2.4 Anonymity of Institutional Travel Data

UBCO employees were instructed in the survey emails to forward the completed institutional travel surveys to their respective unit assistants. The assistants for Units 1, 2 and 3 of the IK Barber School of Arts and Sciences removed any identifying information on the emailed Excel spreadsheet and then forwarded all Excel spreadsheets in a new email to me. In later email correspondence, the unit assistants provided me with the number of faculty, staff and graduate students who responded to the survey. The unit assistants also provided the total number of faculty, staff and graduate students currently working in their units. These numbers were used to calculate the survey response rate per academic unit. All data from Facilities and Athletics were not reported anonymously. This did not pose a problem for data collection since they are departments of the institution of UBCO and were thus obliged to cooperate with this internal GHG audit.

6.0 Scope 1 (UBCO Fleet Use) GHG Emissions

The mass of GHG emissions was calculated in kilograms of CO_2 eq and totalled in Table 9. The total mass of Scope 1 emissions from the Research, Facilities, Security and campus golf cart fleet vehicles was calculated to be 41,537 kg CO_2 eq. Scope 1 emissions account for 44% of the total GHG emissions produced as a result of reported UBCO institutional travel.

6.0.1 UBCO Facilities/Security and Research Fleets GHG Emissions

The total mass of GHG emissions from the Facilities and Security vehicle fleet use was determined to be 12,885 kg CO_2 eq. This mass represent 31% of Scope 1 emissions and 14% of total GHG emissions produced from reported UBCO institutional travel. The total mass of GHG emissions from the Research vehicle fleet use was determined to be 24,808 kg CO_2 eq. This mass accounts for 60% of Scope 1 emissions and 26% of total GHG emissions produced from reported UBCO institutional travel. The combined total emissions from both Facilities/Security and Research fleets are shown in table 7.

Table 7. UBCO Facilities/Security and Research Fleet vehicle data including reported distances driven between April 31, 2007 and March 1, 2008, the calculated fuel consumed, and the masses of CO_2, CH_4, N_2O and total CO_2 eq emitted by each fleet vehicle.

Make	Year	Model	Vehicle Class	Annual Distance Recorded (km)	Annual Fuel Use (L)	CO_2 (kg)	CH_4 (kg)→	CO_2 eq (kg)	N_2O (kg)→	CO_2 eq (kg)	Tota CO_2 e (kg)
Ford	1996	Aerostar 4DRSW	LDGT	3172	450	1,063.0	0.1	1.2	0.1	34.9	1,099.
Ford	1995	2WHDR Van	LDGT	10294	1462	3,449.7	0.2	4.0	0.4	113.3	3,567.
Ford	2001	Econo Van	LDGT	4611	655	1,545.2	0.1	1.8	0.2	50.7	1,597.
Ford	2001	Ranger	LDGT	8254	1172	2,766.1	0.2	3.2	0.3	90.8	2,860.
Toyota	2002	4Runner	LDGT	25529	3625	8,555.3	0.5	9.9	0.9	280.9	8,846.
Dodge	2003	Ram Charger PU	LDGT	24330	3455	8,153.5	0.4	9.4	0.9	267.8	8,430.
Subaru	2004	Forester 4DRSW	LDGT	5643	801	1,891.1	0.1	2.2	0.2	62.1	1,955.
Chevrolet	2005	Uplander Reg FWD	LDGT	5210	740	1,746.0	0.1	2.0	0.2	57.3	1,805.
Toyota	2007	4Runner	LDGT	19313	2742	6,472.2	0.4	7.5	0.7	212.5	6,692.
Ford	2001	F350 PU	LDDT	2157	300	818.5	0.0	0.4	0.1	20.4	839.4
						36,460.5	2.0	41.7	3.8	1,190.9	37,693

6.0.2 UBCO Campus Golf Cart Fleet and Campus Maintenance Equipment GHG Emissions

The total mass of GHG emissions from Facilities and Security vehicle fleet use was determined to be 3,843 kg CO_2 eq. This mass represents 9% of Scope 1 emissions and 4% of total GHG emissions produced from reported UBCO institutional travel.

6.1 Scope 3 (Institutional Travel) GHG Emissions

All GHG emissions as a result from institutional travel done by the faculty, staff and graduate students of the academic units 1, 2 and 3 of the I.K. Barber School of Arts and Sciences were calculated and totalled. The emissions as a result of institutional travel done by the Athletics Department were also included in the total. The total mass of Scope 3 emissions from these two areas was calculated to be 53,387 kg CO_2 eq. Scope 3

emissions account for 56% of the total GHG emissions produced as a result of reported UBCO institutional travel.

6.1.1 Response Rates to the Email Survey

The survey response-rates varied substantially among the three sampled academic units. Participation was highest in Unit 2 with 13 of 55 (24%) responding to the GHG survey (Table 8). Units 1 and 2 had very low response rates of only 2 and 3 respondents respectively. The mean response-rate was 11% for the entire sample group.

Table 8. Response rates for the emailed GHG survey within the sample group, academic units 1, 2 and 3 in the IK Barber School of Arts and Sciences. A response was defined as an Excel spreadsheet forwarded to me by a unit secretary. Blank and completed spreadsheets are included.

	Unit 1	**Unit 2**	**Unit 3**	**Total**
Faculty	23	32	20	75
Staff	0	4	5	9
Graduates	30	19	24	73
Total	53	55	49	157
Responded to Survey	2	13	3	18
% Response	4	24	6	**11**

6.1.2 Institutional Ground and Air Travel GHG Emissions

The total mass of GHG emissions from institutional ground and air travel reported by the sample group was determined to be 13,655 and 23,132 kg CO_2 eq respectively. However, it was not possible to calculate the distribution of GHG emission speciation for air travel because CSA aviation emission factors are only available in kg CO_2 eq, which already accounts for the speciation of GHGs as well as CO_2.

6.1.3 GHG Emissions From Student Athletics: Ground and Air Travel

The total mass of GHG emissions from ground and air travel reported by the Athletics Department was determined to be 14,858 and 1,741 kg CO_2 eq respectively. However, it was not possible to calculate the distribution of GHG emission speciation for air travel because CSA aviation emission factors are only available in kg CO_2 eq, which account for the speciation of GHGs as well as CO_2.

Table 9. Total calculated scope 1 and 3 GHG emissions (kg CO_2 eq) from ground and air travel by UBCO faculty, staff, graduate students and Athletics, April 1, 2007 to March 31, 2008. [a] No emission factors were available so only CO_2 emissions were calculated for on-campus fuel tank use (includes powers golf carts and campus maintenance equipment use). [b] GHG distribution is not available because CSA aviation emission factor is calculated as total kg CO_2 eq. Arrows indicate the conversion from mass of secondary GHG species to mass of CO_2 eq.

	CO_2 (kg)	**CH_4 (kg)→**	**CO_2 eq (kg)**	**N_2O (kg)→**	**CO_2 eq (kg)**	**Total CO_2 eq (kg)**
Scope 1 (UBCO Fleet Use)	40,304.0	2.0	41.7	3.8	1,190.9	**41,537**
Facilities and Security Fleets	12,461.1	0.7	14.4	1.3	409.2	12,885
Research Fleet	23,999.4	1.3	27.2	2.5	781.7	24,808
Campus Golf Cart Fleet [a]	3,843.4	-	-	-	-	3,843
Scope 3 (Institutional Travel)	52,891.8	1.3	28.1	1.5	466.7	**53,387**
Institutional Ground Travel	13,310.7	0.7	14.6	1.1	329.8	13,655
Institutional Air Travel [b]	23,132.1	-	-	-	-	23,132
Athletics Ground Travel	14,707.8	0.6	13.6	0.4	136.9	14,858
Athletics Air Travel [b]	1,741.2	-	-	-	-	1,741
Total	93,195.7	3.3	69.8	5.3	1,657.6	**94,923**

7.0 Discussion and Recommendations for Future Campus-Wide GHG Audits

During the study, I found that several licence plate numbers were either not on the proper vehicle or did not match any registered number on the list provided by the AVP Operations Office. This made it very difficult to account for all fleet vehicles in my records. Vehicles no longer in service must also be removed from the vehicle registry. The entire vehicle registry for UBCO fleet vehicles is out of date and needs to be re-inventoried by AVP Operations.

The pilot travel survey was sent to a small sample size of three UBCO academic units selected for data collection regarding an institutional ground and air travel survey. The sample groups selected were the academic units 1, 2 and 3 of the IK Barber School of Arts and Sciences. These units were selected because they included Physical Geography and Chemistry, both of which I am involved in academically. My involvement with these academic units made it possible to communicate, to each of the three academic unit heads, the importance of the having their respective unit employees complete the GHG survey. All UBCO faculty, staff and graduate students employed by these three academic units were the subjects of the voluntary GHG survey.

Despite a small survey sample size, the amount of flights taken by UBCO staff and faculty members on behalf of the institution is quite high. Although only 18 employees of academic units 1, 2 and 3 of the IK Barber School of Arts and Sciences participated in the pilot travel survey, 56 return-flights were reported for the time period of April 1, 2007 to March 31, 2008. The number of flights and ground trips taken by university employees varied significantly among academic units. It is unclear whether the

variation in the amount of institutional travel is a result of the variation in academic unit response rates, or whether it is due to the inherent "travel habits" of each respective unit. Larger sample sizes and response rates are needed to distinguish the quantitative distribution of intuitional travel (air as well as ground) by UBCO in the future. Once this broad and quantitative picture of the institutional travel done on behalf of UBCO is obtained, possible departmental GHG reductions by travel restrictions can be evaluated.

A system of tracking institutional air travel already exists within UBC. However, this system does not collect all the data required by accepted GHG auditing protocols and is not mandatory to use for all institutional travel. The travel department of Supply Management and the Accounts Payable department of UBC Finance tracks the annual amount of money spent on institutional air travel at UBC. Supply Management uses two main travel agencies, *North South Travel & Tours* and *Vision 2000 Travel Group*. At the UBC Vancouver campus, approximately 60% of these flights are booked through Supply Management; different departments and faculties book the remaining 40% of flights, which are then reimbursed by Accounts Payable. After several interviews with staff and faculty members, who travel regularly, it appeared that the percentage of staff and faculty who use the travel agencies is lower at the UBCO campus.

One procedure uses the Journal Voucher (JV) system for the UBC/Air Canada Corporate Pass Program. Traveling staff or faculty members submit a JV form to the Accounts Payable department of UBC Finance. The form contains fields for the trip expense as well as flight departure and destination locations. However, if JV forms are to be used in the future for tracking air travel at UBC, the addition of a field for connection location(s) is required. These fields must be completed in order for an accurate GHG

calculation to be performed. This would ensure that the entire flight path is accounted for in the GHG calculations rather than a shorter flight path.

The issue of campus-wide use of the JV form remains to be solved. Since more than 60% of travel by UBCO employees is reported through Supply Management, the JV data are not comprehensive enough for a quantitative GHG analysis of UBCO. Moreover, travel records from the department of Supply Management are discarded after a short time and thus cannot supplement the JV travel data.

UBC will likely have to make travel reporting mandatory to obtain a high response rate, but it should consider incentives and assistance as well. It is important that the university provides everyone not only with a means of tracking travel distances accurately, but also offers everyone incentives for their participation. With these minor changes, the existing Journal Voucher system can then be modified to serve as a comprehensive and user-friendly means for future GHG audits at UBCO.

References

Bernstein, L., P. Bosch, O. Canziani, Z. Chen, R. Christ, O. Davidson, W. Hare, S. Huq, D. Karoly, V. Kattsov, Z. Kundzewicz, J. Liu, U. Lohmann, M. Manning, T. Matsuno, B. Menne, B.Metz, M. Mirza, N. Nicholls, L. Nurse, R. Pachauri, J. Palutikof, M. Parry, D. Qin, N. Ravindranath, A. Reisinger, J. Ren, K. Riahi, C. Rosenzweig, M. Rusticucci, S. Schneider, Y. Sokona, S. Solomon, P. Stott, R. Stouffer, T. Sugiyama, R. Swart, D. Tirpak, C. Vogel and G. Yohe, 2007: *In: Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [A. Allali, R. Bojariu, S. Diaz, I. Elgizouli, D. Griggs, D. Hawkins, O. Hohmeyer, B. P. Jallow, L. Kajfez-Bogataj, N. Leary, H. Lee, D. Wratt (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Bhatia, P., J. Ranganathan, 2004: *The Greenhouse Gas Protocol: A Corporate Accounting and Reporting Standard (Revised Edition)*, World Resources Institute, Washington, DC, USA.

BP America Inc., 2008: *Statistical Review of World Energy 2008: Historical data*, http://www.bp.com/productlanding.do?categoryId=6929&contentId=7044622, Retrieved August 26, 2008.

Canadian Standards Agency, 2007: *Canadian GHG Challenge Registry: Emissions Estimation Resource Page Emission Factors and Global Warming Potentials*, http://www.ghgregistries.ca/challenge/emission_estimation_resources_e.cfm, Retrieved August 25, 2008.

Easton, C., L. Ferris, 2008: *Leadership and the Climate Agenda: Discussion Paper*, UBC Sustainability Office, Vancouver, BC, Canada.

Ergudenler, A. Senior Project Engineer, Policy and Planning Department, Greater Vancouver Regional District, E-mail correspondence September 2, 2008.

Forster, P., V. Ramaswamy, P. Artaxo, T. Berntsen, R. Betts, D.W. Fahey, J. Haywood, J. Lean, D.C. Lowe, G. Myhre, J. Nganga, R. Prinn, G. Raga, M. Schulz and R. Van Dorland, 2007: Changes in Atmospheric Constituents and in Radiative Forcing. *In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Le Treut, H., R. Somerville, U. Cubasch, Y. Ding, C. Mauritzen, A. Mokssit, T. Peterson and M. Prather, 2007: Historical Overview of Climate Change. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Lide, D. R., ed., 2009: *CRC Handbook of Chemistry and Physics, 89th Edition (Internet Version 2009),* CRC Press/Taylor and Francis, Boca Raton, FL, USA.

Lide, D. R., ed., 1995, *CRC Handbook of Chemistry and Physics, 75th Edition,* CRC Press/Taylor and Francis, Boca Raton, FL, USA.

Matin, A., F. Neitzert, S. Smyth, ed., 2009: *National Inventory Report 1990–2007: Greenhouse Gas Sources and Sinks in Canada*, Environment Canada.

National Space Agency, 2008: *National Observatory: The Carbon Cycle*, http://earthobservatory.nasa.gov/Features/CarbonCycle/carbon_cycle4.php, Retrieved October 12, 2008.

Penner, B., 2007: *Bill-44: Greenhouse Gas Reduction Targets Act*, BC Ministry of Environment.

Rogner, H. H., D. Zhou, R. Bradley. P. Crabbé, O. Edenhofer, B. Hare, L. Kuijpers, M. Yamaguchi, 2007: Introduction. *In: Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

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