Guidelines for College-Level Greenhouse Gas Emissions Inventories

Version 1

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This resource is considered a work in progress. As such, your suggestions and comments are appreciated. Please direct your feedback to Julian Dautremont-Smith:
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Introduction

As the science behind global warming becomes clearer and clearer, colleges and universities across the country are engaging in efforts to reduce their greenhouse gas (GHG) emissions. For example, the 2020 Project at Oberlin College is currently working with the Rocky Mountain Institute to produce a plan able to bring Oberlin to "climate neutrality" by the year 2020. The presidents of all 56 New Jersey colleges and universities have committed to reducing their campus greenhouse gas emissions to 3.5% below 1990 levels by 2005. At Tufts University, President John DiBiaggio has committed to reduce Tufts' GHG emissions to meet or beat the emission reductions set forth in the Kyoto Protocol of 7% below 1990 levels by the year 2012. Likewise, in April 2001 Harold D. Craft Jr., vice president for administration and chief financial officer at Cornell, committed Cornell University to "do everything within its ability, consistent with the university's obligations for teaching, research, service and extension, to implement the Kyoto Protocol standards." And in the spring of 2002, students at Lewis & Clark College overwhelmingly approved a proposal to increase student fees by $10 per student per year to purchase sufficient GHG "offsets"[a] to bring the college into compliance with the Kyoto Protocol.

Each of these efforts require campus-wide GHG emissions inventories that can establish baselines from which to measure progress as well as provide a foundation for setting and meeting targets. These inventories can also help evaluate cost-effective GHG reduction opportunities. This guide is the product of a summer research project performing a GHG emissions inventory for Lewis & Clark College and a full school year refining the method. It flows from a desire to develop a uniform inventory methodology so as to facilitate comparison between different colleges. In devising it, I reviewed and attempted to improve upon the methods used and suggested by other colleges, businesses, and organizations. It is designed to be comprehensive yet easy to use.

For ease of presentation, this guide is broken down into sections. In the first section, I introduce some general concepts that will be helpful in carrying out your inventory and provide some useful suggestions for you to consider. Then, there is one section explaining how to calculate the emissions from each of the following sectors: Energy, Transportation, Solid Waste, Wastewater and Other Emissions Sources. For each emissions source, I have provided a sample calculation to demonstrate the procedure. Next, I discuss some additional emissions sources that can not be evaluated at this time. Finally, I end with a list of helpful resources.

Performing an emissions inventory is a rewarding learning opportunity with global implications that can provide important insight into your school's environmental practices. I hope you find this guide useful in your work. Please don't hesitate to contact me with any questions that arise.

Towards Climate Neutrality,

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[a] Purchasing offsets is essentially providing funding for activities that reduce GHG emissions like renewable energy of reforestation projects. They are sold at a price per unit of gas reduced (ex: $5/ton CO_2 reduced).

I Advice and Key Concepts

Advice

I have only a couple words of advice to offer. First, you will find that not all of the information needed to complete you inventory is readily available so be prepared to wait for the relevant departments to gather the information and don't be surprised if you end up having to go through some files yourself. You will make your job significantly easier if you focus on evaluating the emissions from an academic year rather than a calendar year. This is because colleges keep their records by academic year. Also, be prepared to make some assumptions. There will be some numbers that are simply unattainable or unreliable; use your best judgment in deciding how to account for them. The four largest sources of GHGs from your school are likely to be: electricity consumption, on-campus combustion of fossil fuels for heat and cooling, commuters coming to campus, and air travel paid for by the college. Thus, although this guide shows how to estimate emissions from many additional sources, if you are pressed for time, you should focus on these four sources. Finally, don't let the math that is involved discourage you; it is really not very difficult once you familiarize yourself with it.

Key Concepts

Emissions Coefficient: An emissions coefficient, also referred to as an emissions factor, is a measure of the amount of a gas released from a particular process. For example, combusting one gallon of gasoline releases about 19.56 pounds of carbon dioxide (CO_2) on average. Thus, the CO_2 emissions coefficient for gasoline is 19.56 lbs. CO_2/gal. Emissions coefficients are the most important concept to understand in performing a GHG inventory so it is important to familiarize yourself with their use. There is often a range of estimates for different emissions coefficients and in this guide I recommend specific emissions coefficients for each emissions source. Since many emissions targets use the year 1990 as a baseline, where possible, I have provided emissions coefficients for 1990 as well as 2001. For the most part, the emissions coefficients provided in this guide apply only to the United States and thus students from other countries who wish to do a GHG emissions inventory for their college are encouraged to find alternate emissions coefficients that are applicable to their country. Lastly, since emissions coefficients may not always be provided in the appropriate units, Appendix 1 provides a number of common conversion factors. Also included in Appendix 1 are density conversions and heat equivalents for commonly used fuels.

Global Warming Potential: In addition to CO_2, this guide shows how to estimate emissions of methane (CH_4) and nitrous oxide (N_2O).[b] To calculate the total greenhouse gas impact, we must

[b] Although water vapor is a GHG and is released from the combustion of hydrocarbons, according to the Energy Information Agency (EIA), "[w]ater vapor is so plentiful in the atmosphere already that additional emissions are unlikely to absorb any significant amount of infrared radiation" and it is "[a]lso likely that the amount of water vapor held in the atmosphere is generally in equilibrium, and that increasing emissions of water vapor would not increase atmospheric concentrations" thus, "anthropogenic water vapor emissions at the Earth's surface are unlikely to be an important element in either causing or ameliorating climate change" [EIA, *Emissions of Greenhouse Gases in the United States 1995* DOE/EIA-0573(95) (Washington, D.C., 1996) http://www.eia.doe.gov/oiaf/1605/gg96rpt/chap1.html#head1]. As a result, "anthropogenic emissions of water vapor are not factored into national greenhouse gas emission inventories for the purposes of meeting the requirements of the United Nations Framework Convention on Climate Change (UNFCCC) or the Kyoto Protocol" and will also not be counted here [EIA, *Emissions of Greenhouse Gases in the United States 2000* DOE/EIA-0573(2000) (Washington, D.C., November 2001) at 1; http://www.eia.doe.gov/oiaf/1605/ggrpt/index.html].

convert the emissions of these three gases into common units so they can be added together. We can do by using the concept of global warming potential (GWP). As explained by the U.S. Environmental Protection Agency (EPA), GWP "is intended as a quantified measure of the globally averaged relative radiative forcing impacts of a particular greenhouse gas" and "is defined as the cumulative radiative forcing - both direct and indirect effects - over a specified time horizon resulting from the emission of a unit mass of gas relative to some reference gas."[1] The most commonly used reference gas is CO_2 and thus GWP weighted emissions are measured in units of CO_2 equivalent (CO_2 Eq or CO_2e). For example, the 100 year time horizon GWP for N_2O is 296. This means that in terms of global warming impact over 100 years, one lb. of N_2O is equal to 296 lbs. of CO_2. The 100 year time horizon GWP of CH_4 is 23. The GWPs used in this guide are all based on a 100 year time horizon as suggested for the parties to the United Nations Framework Convention on Climate Change (UNFCCC) and as used by the EPA in their annual GHG emissions inventory of the United States.[c2] A table of GWPs for various gases at different time horizons is included in Appendix 2. Note that although refrigerants such as CFCs and HFCs have very high GWPs, for reasons I explain later, I do not provide a methodology to estimate such emissions.

Example

Question: Say we have established that in 2001 your school released 40,000,000 lbs. of CO_2, 15,000 lbs. of N_2O, and 75,000 lbs. of CH_4. What were your school's total 2001 GHG emissions in CO_2e?

Answer:
40,000,000 lbs. CO_2 * 1 CO_2e / 1 CO_2 = 40,000,000 lbs. CO_2e
15,000 lbs. N_2O * 296 CO_2e / 1 N_2O = 4,440,000 lbs. CO_2e
75,000 lbs. CH_4 * 23 CO_2e / 1 CH_4 = 1,700,000 lbs. CO_2e

40,000,000 lbs. CO_2e + 4,440,000 lbs. CO_2e + 1,700,000 lbs. CO_2e = 46,140,000 lbs. CO_2e

Abbreviations used in this report

CNN - Climate Neutral Network
DOC - Degradable Organic Component
DOE - U.S. Department of Energy
BTU - British Thermal Unit
EIA - Energy Information Administration
EIIP - Emission Inventory Improvement Program
EPA - U.S. Environmental Protection Agency
GHG - Greenhouse Gas
GWP - Global Warming Potential
IPCC - Intergovernmental Panel on Climate Change
IRN - International Rivers Network
MBTU - Million British Thermal Units
MMTC - Million Metric Tons of Carbon
MSW - Municipal Solid Waste
MTCE - Metric Tons Carbon Equivalent
SWDS - Solid Waste Disposal Site

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[c] However, I use the latest GWPs set out in the IPCC's Third Assessment Report. The EPA inventory as well as some others still use the GWPs from the IPCC's Second Assessment Report in accordance the UNFCCC's reporting guidelines (which were developed before the Third Assessment Report).

UNFCCC - United Nations Framework Convention on Climate Change
VRGGP - Voluntary Reporting of Greenhouse Gases Program
WCD - World Commission on Dams
WTE - Waste-to-Energy

II Calculating GHG Emissions from Energy

The facilities manager (or equivalent) at your school should be able to provide annual consumption data for each of the categories in this section:

- Natural Gas
- Electricity
- Distillate Fuel
- Residual Fuel
- Propane / Liquified Petroleum Gas

The chart below provides the emissions coefficients recommended in this section. Calculating emissions from electricity generation requires more than simple emissions coefficients and is thus not included in the chart.

	CO_2	N_2O	CH_4
Natural Gas (lbs. / MBTU)	117.080	0.000233	0.000287
Distillate Fuel (lbs. / gal.)	22.384	0.00019	0.000226
Residual Fuel (lbs. / gal.)	26.033	0.00019	0.000226
Propane (lbs. / gal.)	12.669	0	0.00024
Liquified Petroleum Gas (lbs. / gal.)	12.805	0	0.00024

Natural Gas

Natural gas is used mostly for space and water heating, as well as in some kitchens and science laboratories. For CO_2 emissions from natural gas combustion, I suggest an emissions coefficient of 117.080 lbs. CO_2 / MBTU (120.593 lbs. CO_2 / 1000 ft^3) as provided by the U.S. Department of Energy (DOE)'s Voluntary Reporting of Greenhouse Gases Program (VRGGP).[3] These emissions coefficients are appropriate for both 1990 and 2001 because the carbon content of natural gas has remained constant from at least 1990 through 2000 according to Energy Information Administration (EIA) figures.[4] For N_2O and CH_4, I advocate EIA-provided emissions coefficients of 0.000233 lbs. N_2O / MBTU and 0.000287 lbs. CH_4 / MBTU for both 1990 and 2001.[5] Gas consumption is often measured in therms. A therm is equal to 100,000 BTU; thus 10 therms = 1 MBTU.[d]

Example

Q: If your school consumed 3,000,000 therms of natural gas in 2001, how much CO_2, N_2O, and CH_4 did it produce?

A: 3,000,000 therms * 10 therms / MBTU * 117.080 lbs. CO_2 / MBTU = 3,512,400,000 lbs. CO_2
3,000,000 therms * 10 therms / MBTU * 0.000233 lbs. N_2O / MBTU = 6990 lbs. N_2O
3,000,000 therms * 10 therms / MBTU * 0.000287 lbs. CH_4 / MBTU = 8610 lbs. CH_4

[d] To my knowledge, there is no standard way of accounting for CH_4 emissions that come from the leakage of natural gas during transmission. I recommend calling your natural gas supplier and asking if they have any suggestions. Since natural gas is almost completely CH_4, natural gas leakage should be counted as emissions of CH_4. Gas leakage is likely to be a tiny portion of your total emissions so don't worry if you are unable to include this source.

Electricity

The combustion of fossil fuels to produce electricity is a major source of GHGs. Although emissions from electricity consumption are generated remotely and are therefore indirect, a report prepared for the Pew Center on Global Climate Change concludes that "[a] consensus is … growing to account for electricity usage because of its ubiquity and the degree of control possessed by organizations to modify their electricity consumption."[6] Rather than using a single emissions coefficient for electricity based on statewide or national statistics, I advocate estimating these emissions based upon the fuel mix used by your school's electricity supplier since this number will be more accurate than any broader average. You will need to contact your school's electricity supplier to obtain this information for both 1990 and 2001. The fuel mix should be presented in the form of percentages from each fuel. For instance, in 1990, 18% of the electricity provided to Portland General Electric (PGE) customers was produced with coal, 5% was produced with natural gas, 24% came from nuclear, 13% was generated with hydropower, and 40% was purchased by PGE from other electricity suppliers in what is known as "net purchasing."

Each electricity production method has its own emissions coefficient. The emissions coefficient for coal and natural gas is derived using information on total CO_2 production and total electricity generation from the EIA's *Annual Energy Review*:[7]

	Emissions coefficient
Coal (utility)	(lbs. CO_2 / kwh)
1990	2.1228
1999*	2.1476
Natural Gas (utility)	
1990	1.198
1999*	1.342
*1999 is the latest year for which data is available.	

No such emissions coefficients for CH_4 and N_2O from electricity produced with coal or gas exist yet.

There is some debate on how best to account for nuclear and hydro power. For nuclear power, the VRGGP suggests zero CO_2 emissions.[8] Arguing against this idea, Rob Edwards, writing in the British journal *New Scientist*, points out that:

> Although no one could argue that nuclear plants emit as much carbon as fossil fuel plants, many processes in the nuclear fuel cycle do use energy which results in carbon emissions. Fossil fuels are burnt to mine uranium, to enrich it and to fabricate it into fuel. A study published last year by German power companies concluded that 38 300 tonnes of CO_2 are released every year to provide the fuel for one 1300 megawatt nuclear generating station[9]

Another article in *The Ecologist* concludes similarly that "nuclear power does, in fact, cause CO_2 emissions, albeit indirectly."[10] For our purposes however, since our emissions coefficients for gas, coal and oil relate to only those emissions released at combustion and do not include emissions from the extraction and transportation of these fuels, it is not appropriate to adopt a different standard with nuclear power. I thus recommend an emissions coefficient of zero for nuclear power while at the same time recognizing that the nuclear power industry itself is not climate neutral. Similarly, I recommend and emissions coefficient of zero for solar and wind power even though GHGs are produced in the manufacture of wind turbines and photovoltaic solar panels

The VRGGP also suggests zero CO_2 emissions from hydropower.[11] However, according to a recent report from the World Commission on Dams (WCD), "[t]he emission of greenhouse gases (GHG) from reservoirs due to rotting vegetation and carbon inflows from the catchment is a recently identified ecosystem impact (on climate) of storage dams,"[12] and indeed, a recent study found that "globally, these emissions may be equivalent to 7% of the global warming potential of other documented anthropogenic emissions."[13] The International Rivers Network (IRN) cites new research suggesting that "average gross emissions from hydro plants in boreal and temperate regions of Canada are equivalent to between 10 and 200 grams [.02 - .4 lbs.] of carbon dioxide per kilowatt-hour generated."[14] Usage of such an emissions coefficient is complicated however by the large range and the fact that the calculations are based on gross rather than net emissions. As the WCD cautions, "[e]stablishing that a reservoir emits GHGs is not enough to assess the impact of a dam on climate change. Natural habitats (undisturbed by dams) may also emit GHGs."[15] IRN points out however that, because forests and other ecosystems flooded by dams are often carbon sinks, net emissions may actually be higher than gross emissions.[16] More important though, is that gross emissions do not take into account the fact that the decaying organic material responsible for the emissions is biogenic and would likely decompose and release CO_2 at some point. Accounting for this is likely to significantly reduce the estimated emissions coefficient.[e] This, combined with the wide variations in emissions based upon "the area and type of ecosystems flooded, reservoir depth and shape, the local climate, the way in which the dam is operated and the ecological, physical and socio-economic characteristics of the dammed river basin"[17] and the fact that dams are often multi-purpose and do not only produce electricity, precludes the development of any valid standardized emissions coefficient on a per kwh basis. However, as with nuclear power, it is important to recognize that hydropower is not climate neutral. As IRN points out, beyond the emissions from rotting organic material, there are "[e]missions of greenhouse gases during dam construction due to the use of fossil fuels and the production of materials such as cement," as well as secondary emissions such as "deforestation caused by displaced farmers clearing new land, and new access roads built for construction which open areas previously inaccessible to development."[18]

The last source of electricity is "net purchasing." Net purchasing refers to the net amount of electricity purchased off the grid by one electric utility from other utilities. The purchasing utility then distributes this electricity to its customers as normal. Since it is impossible to determine the source of net purchased electricity, there are two sets of regional emissions coefficients that can be used. One set, developed by the EIA, is a statewide average based upon the fuel mix of all electricity produced within the state.[19] The latest statewide averages as well as statewide averages developed by the DOE in 1992, the earliest year available, are provided in Appendix 3. As the latest estimates are based on the combined emissions from both utility and non-utility generators, please make sure to use the "combined" figures from 1992 as well. Additionally, you may notice substantial changes between the current CH_4 and N_2O emissions coefficients and those from 1992. Since the EIA has previously noted that "[t]hese differences

[e] This only applies to dams in boreal and temperate regions where "most of the global warming impact of dams … is from the diffusion of carbon dioxide into the atmosphere from the surfaces of their reservoirs" [McCully, *Flooding the Land*, 8-9]. Tropical dams often release CH_4 that would not be produced in absence of the dam and should thus be treated differently.

are due to use of more accurate fuel emission factors,"[20] I think it makes sense to throw out the 1992 coefficients for CH_4 and N_2O and just use the current ones in all cases.

A different and much higher set of electricity emissions coefficients also included in Appendix 3 was developed for the EPA by the Cadmus Group in 1998 and applies to EPA regions rather than individual states.[21] Rather than being based upon the averages as the EIA figures are, the Cadmus Group figures are based on *marginal* averages and thus reflect the actual change in emissions based on a change in electricity consumption. In some areas, the marginal and average coefficients do not differ greatly. However, in places like the Pacific Northwest where the hydro power is running all of the time, any change in electricity consumption during peak hours actually only affects fossil fuel generators and thus the two coefficients differ substantially.

It is difficult to know which set of coefficients to use. The Cadmus Group figures provide a better estimate of the actual change in emissions that would result from changes in electricity consumption. At the same time however, it is not really fair to account for *all* of your school's electricity consumption at the marginal level. Additionally, the Cadmus Group figures do not provide emissions coefficients for CH_4 and N_2O and only apply to one year making it impossible to take into account changes in electricity production between 1990 and 2000. In contrast, the EIA's statewide figures are for all three primary GHGs and change over time. Given the advantages and drawbacks of each side, I recommend evaluating half of the net purchased electricity using the marginal coefficient and the other half using the average coefficient.

Before we can begin to calculate total emissions from electricity consumption, we must first adjust for line loss, i.e. electricity lost during transmission of electricity from the production facility. Although line loss obviously differs based on one's location in relation to the various production facilities, Terry Morlan, manager of economic analysis at the Northwest Power Planning Council, suggests an average loss factor of 10.5 percent for investor-owned utilities.[22] It may be worth calling your own utility for their own estimate but I think 10.5% is a reasonable default value. Therefore, to get the total kWh consumption for which your school is responsible, you should divide its electric consumption by .895.

Lastly, if your school pays a surcharge to buy green power, you must take this into account. First make sure the green power is actually produced without GHG emissions - wind, solar, hydro, or geothermal all count. If this green power purchase was not reflected in the original fuel mix provided by your electric supplier, you will have to subtract the total kWh of green power purchased from the line loss adjusted electricity consumption before applying the emissions coefficients.

Example

Q: According to your electric supplier, the fuel mix used to produce your school's electricity in 2001 is as follows: 33% - coal; 21% - natural gas; 8% - nuclear; 7 - hydro; 31% net purchasing. In 2001, your school purchased 100,000 kWh of carbon-free greenpower. If you live in New York and your school consumed 21,649,372 kWh in 2001, how much CO_2, N_2O, and CH_4 did this produce?

A: First adjust for line loss: 21,649,372 kWh / .895 = 24,189,242 kWh
Then subtract kWh of carbon-free greenpower: 24,189,242 kWh - 100,000 kWh = 24,089,242 kWh

Next calculate the emissions from each fuel source:
Coal - 24,089,242 kWh * 33% * 2.1476 lbs. CO_2 / kWh = 17,072,000 lbs. CO_2
Natural Gas - 24,089,242 kWh * 21% * 1.342 lbs. CO_2 / kWh = 6,788,000 lbs. CO_2

Nuclear - 24,089,242 kWh * 8% * 0 lbs. CO_2 / kWh = 0 lbs. CO_2
Hydro - 24,089,242 kWh * 7% * 0 lbs. CO_2 / kWh = 0 lbs. CO_2
Net Purchasing (average) - 24,089,242 kWh * 15.5% * 0.86 lbs. CO_2 / kWh = 3,200,000 lbs. CO_2
24,089,242 kWh * 15.5% * 0.0089 lbs. N_2O/MWh * 1MWh/1000 kWh = 33 lbs. N_2O
24,089,242 kWh * 15.5% * 0.0081 lbs. CH_4/MWh * 1MWh/1000 kWh = 30 lbs. CH_4
Net Purchasing (marginal) - 24,089,242 kWh * 15.5% * 1.679 lbs. CO_2 / kWh = 6,269,000 lbs. CO_2

Total emissions from electricity = 33,329,000 lbs. CO_2; 33 lbs. N_2O; 30 lbs. CH_4;

Distillate Fuel

The VRGGP classifies No. 1, No. 2, No. 4 fuel oil and diesel as distillate fuels.[23] For CO_2 emissions from distillate fuel consumption, I recommend the VRGGP's emissions coefficient of 22.384 lbs. CO_2 / gal.[24] This figure can be used for both 1990 and 2000 because, according to EIA estimates, the carbon content of distillate fuels has remained constant since at least 1990.[25] For N_2O and CH_4 emissions from distillate oil, I suggest EIA-provided emissions coefficients of 0.0014 lbs. N_2O / MBTU and 0.00163 lbs. CH_4 / MBTU.[26] I used an EPA-supplied energy factor for distillate fuel of 5.825 MBTU / barrel[27] to get these coefficients into more useful units: 0.00019 lbs. N_2O / gal.[f] and 0.000226 lbs. CH_4 / gal.[g] These coefficients should be okay for 1990 as well as 2001.

Example
Q: If your school consumed 8,000 gallons of distillate fuel in 2001, how much CO_2, N_2O, and CH_4 did it produce?

A: 8,000 gal. * 22.384 lbs. CO_2 / gal. = 179,070 lbs. CO_2
8,000 gal. * 0.00019 lbs. N_2O / gal. = 1.5 lbs. N_2O
8,000 gal. * 0.000226 lbs. CH_4 / gal. = 1.81 lbs. CH_4

Residual Fuel

The VRGGP classifies No. 5 and No. 6 fuel oil as residual fuels.[28] For CO_2 emissions from residual fuel consumption, I recommend the VRGGP's emissions coefficient of 26.033 lbs. CO_2 / gal.[29] This figure can be used for both 1990 and 2000 because, according to EIA estimates, the carbon content of distillate fuels has constant since at least 1990.[30] The EIA provides the same N_2O and CH_4 emissions coefficient for residual oil as it does for distillate oil so I therefore recommend using the emissions coefficients as calculated above for both 1990 and 2001: 0.00019 lbs. N_2O / gal. and 0.000226 lbs. CH_4 / gal.

Example
Q: If your school consumed 500 gallons of residual fuel in 2001, how much CO_2, N_2O, and CH_4 did it produce?

A: 500 gal. * 26.033 lbs. CO_2 / gal. = 13,017 lbs. CO_2
500 gal. * .00019 lbs. N_2O / gal. = .095 lbs. N_2O
500 gal. * .000226 lbs. CH_4 / gal. = .113 lbs. CH_4

[f] .0014 lbs. N_2O / MBTU * 5.825 MBTU / barrel * barrel / 42 gal. = .00019 lbs. N_2O / gal.
[g] .00163 lbs. CH_4 / MBTU * 5.825 MBTU / barrel * barrel / 42 gal. = .000226 lbs. CH_4 / gal.

Propane / Liquified petroleum gas

For CO_2 emissions from propane or liquified petroleum gas (LPG) consumption, I recommend the VRGGP's emissions coefficients of 12.669 lbs. CO_2 / gal. for propane and 12.805 lbs. CO_2 / gal. for LPG.[31] According to Paul F. McArdle, the program manager of the Greenhouse Gases Program at the DOE, "[n]either the EIA, the Environmental Protection Agency (EPA), nor the Intergovernmental Panel on Climate Change (IPCC) have developed an emission factor for nitrous oxides (N_2O) from LPG [or propane] combustion" and "N_2O emissions from LPG [and propane] combustion are, therefore, assumed to be zero."[32] For CH_4, McArdle suggested an emissions coefficient of 1,216 Metric Tons of CH_4 per quadrillion Btu of propane combusted for residential/commercial use of propane/LPG. Following his advice, I recommend emissions coefficients of 0 lbs. N_2O / gal. and 0.00024 lbs. CH_4 / gal.[h] for both propane and LPG.

Example

Q: If your school consumed 350 gallons of propane in 2001, how much CO_2, N_2O, and CH_4 did it produce?

A: 350 gal. * 12.669 lbs. CO_2 / gal. = 4434 lbs. CO_2
350 gal. * 0 lbs. N_2O / gal. = 0 lbs. N_2O
350 gal. * 0.00024 lbs. CH_4 / gal. = .084 lbs. CH_4

[h] 1,216 tonnes CH_4 / 10^{15} BTU * 1,000kg/tonne * 2.205lbs/kg * 1,000,000 BTU/MBTU * (139.178 lbs. CO_2/MBTU / 12.669 lbs. CO_2/gal.) = .00024 lbs. CH_4 /gal.

III Calculating GHG Emissions from Transportation

This section will show how to estimate GHG emissions from:

- College gasoline consumption
- College mileage and gasoline purchase reimbursements
- Student, faculty and staff commuting to campus
- Air travel by college staff, faculty, athletic programs, and overseas programs

Because the derivations and explanations for the emissions coefficients presented below are rather technical, for simplicity I present them in Appendix 4.

Automobile Travel

Emissions coefficients for automobile travel exist on a per mile or per gallon basis. You will probably end up using both types of coefficients in your inventory. As explained in Appendix 4, I have derived the following emissions coefficients with data from U.S. government agencies and the IPCC:

	1990	Latest year available
CO_2		
Lbs. CO_2 / mile (car)	1.06	1.01
Lbs. CO_2 / mile (light truck / SUV)	1.767	1.405
Lbs. CO_2 / mile (weighted average)	1.26	1.15
Lbs. CO_2 / gal. motor gasoline (all automobiles)	19.62	19.56
N_2O		
Lbs. N_2O / mile (car)	0.000180	0.000102
Lbs. N_2O / mile (light truck / SUV)	0.000300	0.000142
Lbs. N_2O / mile (weighted average)	.000215	.000116
Lbs. N_2O / gal. motor gasoline (all automobiles)	.0034	.0020
CH_4		
Lbs. CH_4 / mile (car)	0.000142	0.000106
Lbs. CH_4 / mile (light truck / SUV)	0.000248	0.000124
Lbs. CH_4 / mile (weighted average)	.000173	.000112
Lbs. CH_4 / gal. motor gasoline (car)	.0026	.0021
Lbs. CH_4 / gal. motor gasoline (light truck / SUV)	.0034	.0016
Lbs. CH_4 / gal. motor gasoline (weighted average)	.0029	.0019

The facilities manager (or equivalent) at your school should be able to provide annual gasoline consumption data by college-owned vehicles. Your school's business office should be able to provide you with information about gasoline or mileage reimbursements. For data on commuting by students, faculty, and staff, your transportation manager may be able to provide some estimates. If not, you may end up having to do your own transportation survey or just make some assumptions about people's traveling habits. Information on the commuting populations - students living off-campus, faculty, and staff - can be obtained from your school's Residence director, Registrar, and Personnel Department.

Example 1

Q: In 2001, campus-owned vehicles, all of which are light trucks, consumed 4,578 gallons of gasoline. How much CO_2, N_2O, and CH_4 did this produce?

A: 4,578 gal. * 19.56 lbs. CO_2 / gal. = 89,550 lbs. CO_2

4,578 gal. * .0020 lbs. N_2O / gal. = 9.2 lbs. N_2O
4,578 gal. * .0016 lbs. CH_4 / gal. = 7.3 lbs. CH_4

Example 2

Q: In the 2001/2002 school year, there were 1,000 on-campus students and 2,000 off-campus students at your school. In addition, there were 300 faculty members and 400 staff. 66% of off-campus students drove alone to campus, 10% carpooled with one other person, 6% carpooled with 2 other people, 4% carpooled with 3 or more other people, and the remaining 14% walked or biked. 88% of faculty and staff drove alone to campus, 7% carpooled with one other person, 2% carpooled with 2 other people, 1% carpooled with 3 or more other people, and the remaining 2% walked or biked. The average distance to campus for off-campus students, faculty and staff was 12.5 miles making for a round-trip of 25 miles. There were 150 work days during the entire school year. How much CO_2, N_2O, and CH_4 was produced by commuters to campus during the school year?

A: First calculate the total number of automobile trips taken in one work day:
Students - (2,000 * .66) + [(2,000 * .1) / 2] + [(2,000 * .06) / 3] + [(2,000 * .04) / 4] = 1,480
Faculty/Staff - (700 * .88) + [(700 * .07) / 2] + [(700 * .02) / 3] + [(700 * .01) / 4] = 648

Next calculate the total number of trips in the school year:
(1480 + 648) trips / work day * 150 work days / year = 319,200 trips / year

Then calculate the total miles traveled by commuters in the school year:
319,200 trips / yr. * 25 mi. / trip = 7,980,000 mi. / yr.

Finally, use this figure to calculate total emissions:
7,980,000 mi. * 1.15 lbs. CO_2 / mi. = 9,177,000 lbs. CO_2
7,980,000 mi. * .000116 lbs. N_2O / mi. = 926 lbs. N_2O
7,980,000 mi. * .000112 lbs. CH_4 / mi. = 958 lbs. CH_4

Bus Travel

To account for emissions from members of the college community who take the bus to campus, I suggest the following emissions coefficients:

	1990			Latest year available		
	CO_2	N_2O	CH_4	CO_2	N_2O	CH_4
lbs. / passenger mi.	.3642	0.0000090	0.000018	0.389	0.0000090	.000016

Appendix 4 shows how these coefficients were derived.

Example

Q: In the 2001/2002 school year, there were 1,000 on-campus students and 2,000 off-campus students at your school. In addition, there were 300 faculty members and 400 staff. 12% of off-campus students and 3% of faculty and staff took the bus to campus. The average distance to campus for off-campus students, faculty and staff was 12.5 miles making for a round-trip of 25 miles. There were 150 work days during the entire school year. How much CO_2, N_2O, and CH_4 was produced by commuters riding the bus to campus during the school year?

A: [(2000 * .12) + (700 * .03)] trips/day * 150 days * 25 miles = 978,750 passenger miles
978,750 pass. mi. * 0.389 lbs. CO_2 / pass. mi. = 381,000 lbs. CO_2
978,750 pass. mi. * 0.0000090 lbs. N_2O / pass. mi. = 8.8 lbs. N_2O
978,750 pass. mi. * .000016 lbs. CH_4 / pass. mi. = 16 lbs. CH_4

Air travel

To take into account emissions from air travel paid for by the college (faculty and staff travel reimbursements, overseas trips, athletic trips)[i], I suggest the following emissions coefficients:

	1990	Latest year available
lbs. CO_2 /passenger-mile (Domestic operations)	.7707	.6333
lbs. CO_2 /passenger-mile (International operations)	.7103	.6443
lbs. N_2O/passenger-mile (all operations)	.00002	.00002
lbs. CH_4/passenger-mile (all operations)	0	0

Appendix 4 shows how these coefficients were derived. Information on air travel paid for by the college can be obtained from your school's business office, the overseas department and the athletic department. To establish the mileage between cities, I recommend using http://www.ityt.com/mileagecalculator/.

Example

Q: In 2001, you and a friend flew from Portland, OR to Johannesburg, South Africa with a connection at London's Heathrow airport. How much CO_2, N_2O, and CH_4 did you and your friend release?

A: First calculate the round trip mileage. According to http://www.ityt.com/mileagecalculator/, Heathrow airport is 4,929 mi. from Portland while Johannesburg is 5,628 mi. from Heathrow. Round trip is therefore:

(4,929 mi. / trip + 5,628 mi. / trip) * 2 trips * 2 passengers / trip = 42,228 passenger miles

Then apply the emissions coefficients above, keeping in mind that this is an international flight:

42,228 pass. mi. * .6443 lbs. CO_2 / pass. mi. = 27,210 lbs. CO_2
42,228 pass. mi. * .00002 lbs. N_2O / pass. mi. = 0.8 lbs. N_2O
42,228 pass. mi. * 0 lbs. CH_4/ pass. mi. = 0 lbs. CH_4

[i] I recommend not including student flights to and from campus because you have to draw the line somewhere, and the school has very little influence over how students first arrive in the campus vicinity. In contrast, a school can affect how people commute to campus through parking passes, designated carpool parking spaces, provision of a shuttle service, etc.

IV Calculating GHG Emissions from Solid Waste

This section shows how to estimate GHG emissions from:

- Solid Waste Decomposition
- Solid Waste Combustion

CH_4 from Solid Waste Decomposition

The decomposition of municipal solid waste (MSW) in solid waste disposal sites (SWDS) releases both CO_2 and CH_4. However, following IPCC guidelines, I recommend estimating only CH_4 emissions. The EPA explains:

> Neither the CO_2 emitted directly as biogas nor the CO_2 emitted from oxidation of methane at flares is counted as an anthropogenic greenhouse gas emission. The source of the CO_2 is primarily the decomposition of organic materials derived from biomass sources (e.g., crops, forests), and in the U.S. these sources are grown and harvested on a sustainable basis. Sustainable harvests imply that photosynthesis (which removes CO_2 from the atmosphere) is equal to decomposition (which adds CO_2 to the atmosphere), and thus CO_2 emissions from biogas or CH_4 oxidation are not counted in GHG inventories.[33]

The general equation to calculate your school's CH_4 emissions from solid waste decomposition is:

Lbs. CH_4 = .9 * lbs. solid waste from college * (.0715 - total CH_4 lbs. recovered / total lbs. incoming solid waste)

An explanation of how this equation was derived is provided in Appendix 5. Your school's waste collector should be able to provide you with information about how much waste your school produces as well as to what SWDS the waste goes. The SWDS operator should be able to tell you how much CH_4, if any, is collected and flared per year as well as how much waste by weight comes in every year.

In addition, the EPA provides an average estimate of the emissions from the transport of waste to the SWDS as 0.01 MTCE of anthropogenic CO_2e emissions per short ton of material landfilled.[34] Converted into more useful units, this comes to 0.04 lbs. of CO_2e per lbs. of MSW.[j] It seems reasonable to include this emissions source in your inventory.

Example

Q: In 2001, your school sent about 1,100,000 lbs. of MSW to a SWDS. The SWDS operator received 300,000,000 lbs. of MSW in 2001. The operator also captured and flared 500,000 lbs. of CH_4 in 2001. How much CH_4 and CO_2e was released in the transport and decomposition of your school's waste?

A:
.9 * 1,100,000 lbs. MSW * (.0715 lbs. CH_4/lbs. MSW - 500,000 lbs. CH_4/300,000,000 lbs. MSW) = 69,000 lbs.CH_4
1,100,000 lbs. MSW * 0.04 lbs. CO_2e / lbs. MSW = 44,000 lbs. CO_2e

Solid Waste Combustion

Waste incineration releases CO_2, CH_4, and N_2O, however, according to the IPCC "[e]missions of CH_4 are not likely to be significant because of the combustion conditions in incinerators."[35]

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[j] .01MTCE / 2000 lbs. waste * 1000kg/MT * 2.205 lbs./kg * 44 lbs. CO_2e / 12 lbs. CE = 0.04 lbs. CO_2e / lbs. waste

An EPA document using IPCC data on ranges of N_2O emissions from six classifications of MSW combustors, "averaged the midpoints of each range and converted the units to MTCE of N_2O per short ton of MSW" to develop an estimate of 0.01 MTCE N_2O / ton combusted MSW [.0001 lbs. N_2O / lbs. combusted MSW[k]].[36] Likewise, a report prepared for the Emission Inventory Improvement Program (EIIP) suggests an emissions coefficient of .0001 lbs. N_2O / lbs. MSW combusted.[37] Therefore, I too recommend this emissions coefficient.

Calculating CO_2 emissions from waste combustion is slightly more complex because, as the EIIP notes, "[a]s with CO_2 from biogas and oxidation of CH_4, CO_2 emissions from biogenic sources (e.g., paper and food scraps) are not counted as a greenhouse gas, because they simply return CO_2 that plants recently absorbed through photosynthesis to the atmosphere."[38] The IPCC[39] and the EPA[40] also included only emissions from non-biogenic sources.

To estimate CO_2 emissions the EPA assumed that "(1) all carbon in textiles was non-biomass carbon, i.e., petrochemical-based plastic fibers such as polyester (this is a worst-case assumption), and (2) the category of 'rubber and leather' in EPA's MSW characterization report was composed almost entirely of rubber" to estimate that there are 0.11 pounds of non-biogenic carbon per pound of mixed MSW.[41] They then assumed that "98 percent of this carbon would be converted to CO_2 when the waste was combusted, with the balance going to the ash."[42] They used these figures to calculate an emissions coefficient of 0.10 MTCE / ton combusted MSW [0.4 lbs. / lbs. combusted MSW[l]]. Since the EIIP supplies the same emissions coefficient,[43] I also recommend an emissions coefficient of 0.4 lbs. CO_2 / lbs. combusted MSW.

In addition, I again recommend accounting for "transporting waste to the WTE [waste to energy] plant, and ash from the WTE plant to a landfill" using an EPA emissions coefficient of 0.01 MTCE / ton combusted MSW [0.04 lbs. CO_2 e / lbs. combusted MSW[m]][n].[44]

Example

Q: In 2001, your school sent about 50,000 lbs. of MSW to an incinerator. How much CO_2, N_2O, and CO_2e was released in the transport and incineration of your school's waste?

A:
50,000 lbs. MSW * 0.0001 lbs. N_2O / lbs. MSW = 5 lbs. N_2O
50,000 lbs. MSW * 0.4 lbs. CO_2 / lbs. MSW = 20,000 lbs. CO_2
50,000 lbs. MSW * 0.04 lbs. CO_2e/ lbs. MSW = 2,000 lbs. CO_2e

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[k] .01 MTCE/ton MSW * 1000 kg/MT * 2.205lbs./kg * ton/2000lbs. * 44 CO_2/12 CE * N_2O/310 CO_2 = .0001 lbs. N_2O / lbs. MSW

[l] .10 MTCE / 2000 lbs. waste * 1000kg/MT * 2.205 lbs./kg * 44 lbs. CO_2e / 12 lbs. CE = 0.4 lbs. CO_2e / lbs. waste

[m] .01MTCE / 2000 lbs. waste * 1000kg/MT * 2.205 lbs./kg * 44 lbs. CO_2e / 12 lbs. CE = 0.04 lbs. CO_2e / lbs. waste

[n] The same EPA report also estimated the "avoided CO_2 emissions from increased steel recycling made possible by steel recovery from WTE plants," and encouraged deducting these avoided emissions from the total. The EPA estimated that 0.02 tons of steel are recovered per ton of mixed MSW combusted and calculated the avoided CO_2 emissions as a result of this recovery to be and 0.01 MTCE per ton for mixed MSW [EPA, *GHG from MSW*, 89]. I recommend against awarding credit for these reductions. The CO_2 emissions avoided occurred because of the implementation of a steel recovery program by the WTE plant and therefore the WTE plant, not the college, should get the credit for these avoided emissions.

V Calculating GHG Emissions from Wastewater

This section shows how to estimate N_2O and CH_4 emissions from wastewater treatment. These emissions are likely to make a relatively minor contribution to your school's total emissions.

N_2O from wastewater

N_2O is produced during nitrification and denitrification of sewage nitrogen during wastewater treatment and disposal. To calculate these emissions, I recommend the following the equation:[45]

lbs. N_2O released/yr. = person-days / yr. * .0006 lbs. N_2O / person-day

To account for the fact that only a portion of the population actually lives and produces all of their waste on-campus while other segments of the population are not on-campus all year and/or only spend a portion of their days here, I recommend breaking down the equation and calculating the person-days on-campus for each different sector of the campus population separately based on how many days of the year and for how long each sector is on-campus. Then sum and apply the emissions coefficient of .0006 lbs. N_2O / person-day. Appendix 6 shows how this equation was derived.

Example

Q: In the 2001/2002 school year, there were 1,000 on-campus students and 2,000 off-campus students at your school. In addition, there were 300 faculty members and 400 staff. There were 150 work days (210 total days) during the entire school year and 75 work days during the summer. How much N_2O was produced from human waste during the entire year?

Assume that:

- Faculty and staff work full time during the summer.
- Off-campus students are only on campus on work days.
- Off-campus students, faculty, and staff all spend half of their day on campus and thus release half of their waste there.

A: First figure out how many person-days each group is on campus over the course of the year:
1,000 on-campus students * 210 days = 210,000 person-days
2000 off-campus students * 150 work days * .5 day / work day = 150,000 person-days
700 faculty and staff * 225 work days * .5 day / work day = 78,750 person-days

Then sum and apply the emissions coefficient:
(210,000 + 150,000 + 78,750) person-days * .0006 lbs. N_2O / person-day = 260 lbs. N_2O

CH_4 from wastewater and sludge treatment

The breakdown of organic material during wastewater treatment can produce CH_4. Likewise, the handling of residual sludge,[o] a by-product of the treatment, can also result in CH_4 emissions. Only wastewater and sludge that had been treated anaerobically produce CH_4. In other words, if your school's wastewater and/or sludge is treated aerobically, no CH_4 is released. If both sludge and wastewater is treated aerobically, you may skip this section.

[o] The EPA defines sludge as the "[g]ooey solid mixture of bacteria and virus laden organic matter, toxic metals, synthetic organic chemicals, and solid chemicals removed from wastewater at a sewage treatment plant" [EPA, *Inventory 1990 – 2000*, 439].

For anaerobically treated wastewater, I suggest the following equation:

CH_4 emissions = total person-days/yr. * 0.066 lbs. CH_4 / person-day * (1 - fraction of DOC removed as sludge) - (gal. wastewater from your school * total lbs. CH_4 from wastewater flared / total wastewater flow into plant)

Similarly, for anaerobically treated sludge, I recommend the following equation:

CH_4 emissions = total person-days/yr. * 0.066 lbs. CH_4 / person-day * fraction of DOC removed as sludge - (gal. wastewater from your school * total lbs. CH_4 from sludge flared / total wastewater flow into plant)

In these equations, DOC stands for degradable organic component. Your school's wastewater treatment plant operator should know the fraction of DOC removed as sludge as well as the total wastewater inflow. The plant operator should also be able to tell you about the total lbs. CH_4 recovered and flared from both the wastewater and the sludge treatment processes. The facilities manager (or equivalent) at your school should be able to provide information on the amount of wastewater from your school. As noted above in the N_2O from wastewater section, college populations are rather dynamic in that only a portion of the population lives and produces all of their waste on campus while other segments of the population are not around all year and/or only spend a portion of the day on campus. As before, the best way to solve this problem is to break down the equation to calculate the person-days on-campus for different sectors of the campus population and add them all up at the end. To find out how these equations were derived, see Appendix 6.

Example

Q: In the 2001/2002 school year, there were 1,000 on-campus students and 2,000 off-campus students at your school. In addition, there were 300 faculty members and 400 staff. There were 150 work days (210 total days) during the entire school year and 75 work days during the summer. Your school produced 100,000 gal. of wastewater. At your school's wastewater treatment plant, 35% of the DOC is removed as sludge. In total, the plant treated 60,000,000 gal. of wastewater and captured 3,000,000 lbs. CH_4 from wastewater and 1,500,000 lbs. CH_4 from sludge treatment during the year. How much CH_4 was produced from your school's wastewater and sludge treatment during the entire year?

Assume that:

- Faculty and staff work full time during the summer.
- Off-campus students are only on campus on work days.
- Off-campus students, faculty, and staff all spend half of their day on campus and thus release half of their waste there.

A:

First figure out how many person-days each group is on campus over the course of the year:
1,000 on-campus students * 210 days = 210,000 person-days
2000 off-campus students * 150 work days * .5 day / work day = 150,000 person-days
700 faculty and staff * 225 work days * .5 day / work day = 78,750 person-days

Then sum these results and calculate the emissions from wastewater treatment and sludge treatment.

Wastewater treatment:

(210,000 + 150,000 + 78,750) person-days * 0.066 lbs. CH_4/ person-day * (1 - .35) - (100,000 gal. wastewater * 3,000,000 lbs. CH_4 / 60,000,000 gal. wastewater) = 13,800 lbs. CH_4

Sludge treatment:

(210,000 + 150,000 + 78,750) person-days * 0.066 lbs. CH_4/ person-day * .35 - (100,000 gal. wastewater * 1,500,000 lbs. CH_4 / 60,000,000 gal. wastewater) = 7,600 lbs. CH_4

Total emissions from wastewater and sludge treatment = 13,800 lbs. CH_4 + 7,600 lbs. CH_4 = 21,400 lbs. CH_4

VI Calculating GHG Emissions from Other Emissions Sources

This sections shows how to estimate emissions from:

- Fertilizer application
- Limestone and Dolomite application
- Domestic animals

For most colleges, emissions from these sources are likely to be relatively insignificant.

N_2O from Fertilizer Application

Although "the extent to which adding nitrogen [fertilizer] stimulates nitrous oxide emissions is highly uncertain,"[46] an estimate based on the best available science is likely to be more accurate than using a value of zero and fertilizer emissions should not therefore be excluded from your inventory. To calculate the emissions of N_2O that occur as a result of both synthetic and organic fertilizer application, you must first obtain the amount of nitrogen applied per year. Your grounds-keeping department should be able to provide information on the types of fertilizers used and their nitrogen content. Synthetic fertilizers are labeled with a series of three numbers - ex. 20-10-5 - that represent the percentages of the three primary macronutrients contained in the fertilizer, nitrogen (N), phosphorus (P), and potassium (K). Thus, 10-15-10 fertilizer is 10% nitrogen. For non-synthetic fertilizers, the EIIP assumes that manure used as fertilizer contains 1% nitrogen and that other organics used as fertilizer contain 4.1% nitrogen.[47] I recommend emissions coefficients of 0.031 lbs. N_2O / lbs. N applied as synthetic fertilizer and 0.028 lbs. N_2O / lbs. N applied as organic fertilizer. To see how these emissions coefficients were derived, see Appendix 7.

Example

Q: If your school applied 18,720 lbs. of synthetic 18-6-18 turf fertilizer to campus grounds in 2001, how much N_2O was released?

A:

18,720 lbs. fertilizer * .18 lbs. N / lbs. fertilizer * 0.031 lbs. N_2O / lbs. synthetic N = 104 lbs. N_2O

CO_2 from limestone and dolomite application

Some of the carbon in limestone (calcite, $CaCO_3$) and dolomite ($CaMg(CO_3)_2$) oxidizes into CO_2 after application to the soil. To take into account these emissions, I recommend emissions coefficients suggested by the EIIP and IPCC of 0.12 metric tons C/metric ton limestone [0.44 lbs. CO_2 / lbs. limestone] and 0.130 metric tons C metric ton dolomite [0.477 lbs. CO_2 / lbs. dolomite][p].[48]

Example

Q: How much CO_2 is produced if 2 short tons limestone and 1,500 lbs. of dolomite were applied to campus grounds over the course of a year?

A: 4,000 lbs. limestone * 0.44 lbs. CO_2 / lbs. limestone = 1,800 lbs. CO_2

[p] The EIIP cautions that "[a]lthough liming leads to emissions over a period of several years, the accounting method attributes emissions to the year in which the lime is applied. Additionally, some fraction of the carbon loading from liming leaches to ground water, but this fate is not addressed in the methodology; all of the carbonate is assumed to be converted to gaseous CO_2" [EIIP, *Soils*, 9.4-19].

1,500 lbs. dolomite * 0.477 lbs. CO_2 / lbs. dolomite = 716 lbs. CO_2

Domestic animals

CH_4 is produced as part of normal digestive processes in animals. To account for this emissions source, I recommend the following EPA emissions coefficients:[49]

	1990 (lbs. CH_4 /head/year)	2000 (lbs. CH_4 /head/year)
Calves 0-6 months	0	0
Dairy		
Cows	249	254
Replacements 7-11 months	90	90
Replacements 12-23 months	140	140
Beef		
Cows	183	183
Replacements 7-11 months	104	104
Replacements 12-23 months	160	160
Steer Stockers	140	140
Heifer Stockers	120	120
Feedlot cattle	104	71
Bulls	220	220
Other livestock		
Sheep	18	18
Goats	11	11
Horses	40	40
Swine	3	3

The management of farm animal manure can generate both CH_4 and N_2O. However, unless you have large numbers of farm animals on your campus, these emissions are likely to be relatively small. Since estimating these emissions is fairly complicated, I recommend ignoring this source. For agricultural schools with large farm animal populations, I encourage you to refer to the latest EPA inventory for guidance on how to estimate these emissions.

Example
Q: How much CH_4 was produced over the year if your school owned 25 sheep, 2 horses and 8 dairy cows in 2000?

A: 25 sheep * 18 lbs. CH_4 /sheep = 450 lbs. CH_4
2 horses * 40 lbs. CH_4 /horse = 80 lbs. CH_4
8 dairy cows * 254 lbs. CH_4 /dairy cow = 2032 lbs. CH_4
Total : 450 + 80 + 2032 = 2562 lbs. CH_4

VII Calculating Potential GHG Sinks

This section shows how to account for reductions in your schools net GHG emissions from:

- Electricity generation from waste combustion
- Composting

Electricity generation from waste combustion

If emissions from waste combustion are accounted for, it is also appropriate to deduct the amount of electricity produced from this combustion from one's total electricity consumption, assuming that the incinerator does indeed produce electricity. I recommend EPA-provided averages of 550 kWh per ton of MSW incinerated in a mass burn facility[q] and 572 kWh per ton of MSW (.286 kWh / lbs. MSW) incinerated in a refuse-derived fuel facility.[50] Your school's waste hauler should be able to help you find out what kind of WTE facility your school's waste goes to.

Example

Q: How many kWh would you subtract from your school's total electricity consumption if your school sent 346 tons of MSW to a WTE?

A: 346 tons MSW * 550 kWh / ton MSW = 190,300 kWh

Composting

Some campuses have on-campus compost heaps. According to the EPA, "[w]hen organic materials are composted, most of their organic mass quickly decomposes to CO_2" but because "[t]he materials that may be composted (e.g., leaves, brush, grass, food waste, newspapers) are all originally produced by trees or other plants … the CO_2 emitted from these materials during composting is biogenic CO_2, and thus is not counted in GHG emissions."[51] The EPA analysis further suggests that "well-managed compost operations usually do not generate methane because they typically maintain an aerobic environment with proper moisture content to encourage aerobic decomposition of the materials" and moreover, "even if methane is generated in anaerobic pockets in the center of the compost pile, the methane is most likely oxidized when it reaches the oxygen-rich surface of the pile."[52] There are thus no GHG emissions from compost heaps to account for.

In fact, since some of the carbon in compost heaps stays locked up in the humus that is produced, compost heaps actually sequester carbon. The EPA provides upper and lower bounds for carbon sequestration from the composting of yard trimmings (assumed to "comprise 50 percent grass clippings, 25 percent leaves, and 25 percent branches, by weight").[53] "Combining the two bounds for incremental humus formation [above the "baseline" conversion to humus rate if residues were left on the ground] (5 percent and 25 percent) and the two bounds for half-lives [of stable carbon compounds in soil](20 years and 2,000 years)" and "estimate[ing] the incremental carbon storage implied by each scenario over a period of 100 years" the EPA calculated that "[t]he upper bound on the incremental carbon storage from composting is about 0.05 MTCE per ton of yard trimmings" while "the lower bound is about 0.001."[54] With regard to carbon sequestration from

[q] According to the EPA, "[a] mass burn facility generates electricity and/or steam from the combustion of mixed MSW" while a refuse-derived fuel facility "combusts MSW which has undergone varying degrees of processing, from simple removal of bulky and noncombustible items to more complex processes (shredding and material recovery), resulting in a finely divided fuel" which "yields a more uniform fuel that has a higher heating value" [EPA, *GHG from MSW*, 79-80.].

composting food scraps, the EPA notes, "[d]ata were not available on the amount of carbon sequestered in humus when food scraps are composted" and they thus "assumed that backyard composting of food scraps converts all of the carbon in food scraps to CO_2, and that none of the carbon is sequestered in humus."[55] I thus recommend accounting for yard trimming compost carbon sequestration using an emissions coefficient of -.0255 MTCE / ton composted yard waste [-0.103 lbs. CO_2 / lbs. composed yard waste[r]], the midpoint of the two bounds.

Example

Q: If your school composted 6 tons of yard waste in 2001, how much CO_2 was sequestered?

A: 6 tons * 2000 lbs. / ton * -0.103 lbs. CO_2 / lbs. yard waste = -1236 lbs. CO_2

1236 lbs. of CO_2 are sequestered.

[r] -0.0255 MTCE/ton yard waste * 1000kg/MT * 2.205 lbs./kg * ton/2000 lbs. * 44 CO_2/12CE = -0.103 lbs. CO_2 / lbs. yard waste

VIII Emission Sources that Cannot be Evaluated

This section explains why it is currently not possible to account for the following in your inventory:

- Land Use
- Lifecycle emissions
- Recycling
- Construction/Subcontracting
- Refrigerants
- Landfill Sequestration

Land Use

Some ecosystems, such as wetlands, release GHGs, while others, like forests, sequester GHGs. Natural emissions sources or sinks should not be included in your inventory since these emissions occur independent of human action. However, activities potentially taken by your school such as logging or reforestation affect GHG emissions and would ideally be accounted for in your inventory. Unfortunately, the science to quantify the GHG emissions land use is fairly sketchy and often requires expert examination of the site to develop reasonable emissions estimates. To my knowledge, no standard or average emissions coefficients exist to account for emissions from land use. Therefore, it is not possible to account accurately for such emissions.

Lifecycle emissions

Ideally, lifecycle emissions from all purchased products would be desirable to include in a GHG inventory. Unfortunately however, lifecycle analysis is a relatively new science and moreover, the complexity of taking into account all of your school's purchases precludes taking these emissions into account.

Recycling

Accounting for recycling in a GHG inventory is rather confusing. It is clear that the recycling process does release actually GHGs. However, the manufacturing process for the products made from recycled materials generally uses less energy than making these same products from virgin materials. The EPA even provides values for total GHG emissions reductions for using recycled inputs instead of virgin inputs.[56] Ideally, one could account for the emissions from the recycling process and then, if one were including lifecycle analysis of purchased products, subtract the recycled products produced from your school's waste from the total products purchased by your school. However, since we are unable to include lifecycle emissions of products, I don't see a fair way to account for recycling. Thus, until better information becomes available, I assume zero net emissions from recycling. No other inventory models I examined, including the EPA, EIA, and IPCC national inventory guidelines, accounted for GHG releases or reductions from increased recycling except to the extent that any waste recycled does not go to a landfill where CH_4 would be released.

Construction/Subcontracting

Colleges and universities often engage in construction projects. Because the fuel used to power the equipment is not paid for directly by the college these emissions are difficult, if not impossible, to obtain and therefore, it is not possible to evaluate these emissions. Similarly, colleges may also contract out the janitorial service, food service and bookstore and the GHGs they emit are usually not possible to account for.

Refrigerants
Refrigerants often have a very high global warming potential. However, I have not been able to find any data on average leakage amounts from regular use of refrigerants. I do not think it is fair to assume that all purchased refrigerants will eventually leak because in my understanding, a significant amount is often captured and recycled. Fortunately however, these gases probably make up a relatively small portion of your school's total climate footprint and thus excluding this source, at least until more information becomes available, seems excusable.

Landfill sequestration
According to the EPA, "[b]ecause food scraps, yard trimmings, and paper are not completely decomposed by anaerobic bacteria, some of the carbon in these materials is sequestered in the landfill."[57] Indeed, "landfilling some materials, including branches, newspaper, and leaves, results in net sequestration (i.e., carbon storage exceeds methane plus transportation energy emissions) at all landfills, regardless of whether gas recovery is present."[58] Theoretically, we could count this carbon sequestration as a sink. However, since almost all of the carbon in your school's waste stream is from products that are purchased from somewhere else, and since the emissions from the manufacture of these products is not going to be accounted for, it is not appropriate to credit your school for this sequestration.

IX Instructions for Accompanying Excel Spreadsheet

This guide comes with an accompanying Excel Spreadsheet designed to help you calculate your school's GHG emissions using the emissions coefficients and methodologies described above. (Contact me for an electronic version of the spreadsheet). In general, the spreadsheet works as a calculator. All you have to do is fill in the colored boxes to the left of the black dividing column with the relevant data for your school; yellow boxes are for information from 1990 while green boxes are for information from 2001-2002. All calculations are shown on the right side of the black dividing line and thus, unlike most calculators, this one allows more advanced users to see and change the methodology to better suit their needs. This section goes through each worksheet of the spreadsheet and explains how to use it.

Worksheet 1 Electricity

This worksheet is fairly self-explanatory; just enter the information for your school into the colored boxes and Excel will do the rest. The calculation assumes a line loss of 10.5%. As noted above, your school's electric company should be able to give you information on the fuel mix used to their electricity while your school's facilities services department should be able to provide information on your school's electricity consumption. Combusted solid waste is included in this section to subtract out the electricity produced from incineration as explained above. The 1990 average emissions coefficients for CH_4 and N_2O is blacked out because, again as noted above, these coefficients are believed to be inaccurate and thus I just use the latest emissions coefficients for all years.

Worksheet 2 Commuting

This worksheet calculates total vehicle miles traveled by cars commuting to and from campus as well as people riding the bus to and from campus. Depending on your school, it may be necessary to add additional groups to the calculation such as graduate students or summer school students. In addition, the calculations assume that all carpools have only 2 people in them so it may slightly overestimate your emissions. If you have more detailed information on carpooling, it may be worthwhile to modify the calculation to reflect this. Your transportation manager should be able to provide recent survey data on commuting habits but if not, it might be necessary to carry out your own survey or make some reasonable assumptions.

Worksheet 3 Landfilled Solid Waste

This worksheet calculates the total GHG emissions from transport of your school's waste to a landfill and from the decomposition of that waste. The 1s in the "how much waste did the landfill receive" boxes are placeholders. Only remove them when you are ready to fill in the real information. You may need to contact your waste hauler or landfill operator to obtain some of the necessary information.

Worksheet 4 Wastewater

This worksheet calculates the total GHG emissions from wastewater treatment. As in the commuting section, it may be helpful to modify the worksheet to account for additional population groups such as graduate students or summer students in the calculation of total person days on campus. The 1s in the "total waste flow into treatment plant" boxes are placeholders and also should only be removed when you are ready to fill in the real information. You will have to call your school's wastewater treatment plant to find out some of the necessary data.

Worksheet 5 Animals

This worksheet calculates total CH_4 emissions from animals on-campus. If your school has no animals, you may skip this worksheet.

Worksheet 6 Main

This worksheet calculates the emissions for natural gas and other fuel use, commuting, air travel, combusted solid waste (including transport to the incinerator), fertilizer application, limestone and dolomite application, and composting and combines this with all of the information from the previous five worksheets to calculate your school's total emissions. Gasoline consumption should include gas consumption by college-owned vehicles as well as other gasoline purchases for college-related purposes that are reimbursed by your school.

Worksheet 7 Charts

This worksheet shows the results of your inventory in graph format.

X Helpful Resources

Other Inventories and Inventory Tools

It may be helpful to consult the following sources to learn more about GHG emissions inventorying methods:

Climate Neutral Network, *Corporate-level Greenhouse Gas Accounting Worksheet* version 9 (Lake Oswego, OR); http://www.climateneutral.com/pages/metrics.html.

Liz Davey and Shelley Kahler, *Tulane University Greenhouse Gas Emissions Inventory* (New Orleans, LA, May 2002); http://www.tulane.edu/~eaffairs/ghg_inventory5282.PDF.

Energy Information Administration, *Emissions of Greenhouse Gases in the United States 2000* DOE/EIA-0573(2000) (Washington, D.C., November 2001); http://www.eia.doe.gov/oiaf/1605/ggrpt/index.html.

Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 2000* EPA 430-R-02-003 (Washington, D.C., April 2002); http://www.epa.gov/oppeoee1/globalwarming/publications/emissions/us2002/index.html.

Thomas Gloria, *Tufts University's Green House Gas Emissions Inventory for 1990 and 1998* (Medford, MA: Tufts Institute of the Environment, 2001); http://www.tufts.edu/tie/tci/pdf/Tufts%20Emissions%20inventory.pdf.

Intergovernmental Panel on Climate Change, *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (Geneva, May 2000); http://www.ipcc-nggip.iges.or.jp/public/gp/gpgaum.htm.

Intergovernmental Panel on Climate Change, *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual* (Geneva, 1997); http://www.ipcc-nggip.iges.or.jp/public/gl/invs6.htm.

Christopher P. Loreti, William F. Wescott, and Michael A. Isenberg, *An Overview of Greenhouse Gas Emissions Inventory Issues* prepared for the Pew Center on Global Climate Change (Cambridge, MA: Arthur D. Little, Inc., August 2000); http://www.pewclimate.org/projects/greenhouse.pdf.

Charles Thomas, Tessa Tennant and Jon Rolls, *The GHG Indicator: UNEP Guidelines for Calculating Greenhouse Gas Emissions for Businesses and Non-Commercial Organisations* (Paris, France: United Nations Environment Programme Economics and Trade Unit, 2000); http://www.uneptie.org/energy/act/ef/GHGin/docs/GHG_Indicator.pdf.

Torrie Smith Associates, e*mission Greenhouse Gas Strategy Software* (Ottawa, Canada); http://www.torriesmith.com/corp-software.cfm.

World Resources Institute (WRI), *SafeClimate carbon footprint calculator* (Washington, D.C.); http://www.safeclimate.net/calculator/.

Activist Groups working in this field

The following groups are involved in some way with GHG emissions inventories and/or college and university efforts to reduce GHG emissions:

Clean Air - Cool Planet: Clean Air - Cool Planet "is the Northeast's leading nonprofit organization dedicated to finding and promoting solutions to global warming." "Clean Air-Cool Planet's college and university partnership program is designed to engage and energize the higher education community in the climate change debate by mobilizing campus communities and providing the tools for students, faculty, and administrations to begin an effective dialogue around climate change." They recently performed a GHG emissions inventory for the University of New Hampshire. See http://www.cleanair-coolplanet.org/for_campuses.php for more information.

Climate Neutral Network: The Climate Neutral Network (CNN) "is a non-profit organization dedicated to helping companies, communities and consumers achieve a net zero impact on the Earth's climate." "The network provides technical support and a science-based "Climate Cool" certification. To offset the climate impacts of products, services or operations, certification requires creating a portfolio of projects that include internal, on-site reductions of greenhouse gas emissions, and external offset projects." CNN will become increasingly important to the college/university movement against global warming as colleges and universities begin to move beyond the limited emissions reductions mandated by the Kyoto Protocol and towards full climate neutrality. For the time being, CNN offers a helpful "metrics system" to calculate GHG emissions. See http://www.climateneutral.com for more information.

Green House Network: The Green House Network "is a Portland, Oregon-based non-profit organization committed to building the grassroots movement needed to stop global warming." They are sponsoring the College Climate Response, a campaign with the ultimate goal for all colleges and universities to achieve Kyoto compliance by 2012. See http://www.greenhousenet.org/cep_update/collegeclimate.html for more information.

Kyoto Now!: Kyoto Now! is a national network of schools working to reduce their GHG emissions. The website provides background information including contacts for over 30 colleges and universities working to stop global warming. See www.kyoto-now.org for more information.

New Jersey Higher Education Partnership for Sustainability: The New Jersey Higher Education Partnership for Sustainability (NJHEPS) "is to be an agent of transformation so that New Jersey campuses might become models and messengers of sustainability in our society and the world." NJHEPS is currently working to implement a pledge by the presidents of all 56 New Jersey colleges and universities to reduce their campus GHG emissions to 3.5% below 1990 levels by 2005. See www.njheps.org for more information.

Rocky Mountain Institute: The Rocky Mountain Institute (RMI) "is an entrepreneurial, nonprofit organization that fosters the efficient and restorative use of resources to create a more secure, prosperous, and life-sustaining world." The organization aided the 2020 Project at Oberlin College in conducting a detailed GHG emissions inventory of the college. See www.rmi.org for more information.

World Resources Institute: The World Resources Institute (WRI) "is an environmental think tank that goes beyond research to find practical ways to protect the earth and improve people's lives." WRI is a sponsor of the Greenhouse Gas Protocol Initiative, an effort "to develop internationally accepted accounting and reporting standards for GHG emissions." See http://www.ghgprotocol.org for more information.

Potential Funding Sources[s]

Doing a GHG emissions inventory can be an exhaustive and time consumptive process. I recommend doing it as a summer job or for class credit. Your school may provide opportunities to receive funding for summer research with a professor. If so, I strongly encourage you to find a supportive professor and apply for such funding. Having a professor involved gives your project credibility and ensures that someone will be around to continue the project after you graduate. If school funding is unavailable, the following groups may also provide grants to do GHG inventories:

Garden Club of America: "Each year the GCA Awards for Summer Environmental Studies provide financial aid toward summer studies doing field work or research in the environmental field. The awards offer students who have demonstrated a keen interest in the betterment of the environment an opportunity for further study in the field of ecology. With these scholarships, young men and women can pursue summer programs beyond the regular course of study to gain additional knowledge and experience. Work may award academic credit but should be in addition to required courses. College students may apply for these awards to pursue study following their freshman, sophomore, or junior year. Every year several students are awarded amounts usually placed at $1500 for each recipient." See http://www.gcamerica.org/summeraward.htm for more information.

National Wildlife Federation: The National Wildlife Federation' s Campus Ecology Fellowship Program "offers a nationally recognized opportunity for undergraduate and graduate students to pursue their visions of an ecologically sustainable future. Through tangible projects to green their campuses and communities, fellows gain practical experience in conservation and first-hand knowledge of the challenges and opportunities inherent in successful conservation efforts." The program offers up to $1,200, support from Campus Ecology staff and additional benefits. See http://www.nwf.org/campusecology/fellowships.cfm for more information.

Second Nature: The West Coast Education for Sustainability Network, a program of Second Nature, is a coalition of faculty, students, administrators and staff representing colleges and universities throughout the West. The Network is dedicated to accelerating the transformation of West Coast colleges and universities into models of sustainability. WCN works to forward the ambitious goals of creating more just, economically viable, and democratic institutions of higher education, that are much less ecologically destructive, for the benefit of current and future generations of all life.

[s] The author received funding from all three of the funding sources described herein.

Appendices

APPENDIX 1

Constants, Units, and Conversions [t]

Unit Conversions

1 kilogram = 2.205 pounds
1 pound = 0.454 kilograms
1 short ton = 2,000 pounds = 0.9072 metric tons
1 metric ton = 1,000 kilograms = 1.1023 short tons

1 cubic meter = 35.315 cubic feet
1 cubic foot = 0.02832 cubic meters
1 U.S. gallon = 3.785412 liters
1 barrel (bbl) = 0.159 cubic meters
1 barrel (bbl) = 42 U.S. gallons
1 liter = 0.1 cubic meters

1 mile = 1.609 kilometers
1 kilometer = 0.622 miles

Density Conversions

Methane	1 cubic meter = 0.67606 kilograms
Carbon dioxide	1 cubic meter = 1.85387 kilograms

Liquefied petroleum gas	1 metric ton = 11.6 barrels = 1,844.2 liters
Kerosene jet fuel	1 metric ton = 7.93 barrels = 1,260.72 liters
Motor gasoline	1 metric ton = 8.53 barrels = 1,356.16 liters
Distillate fuel	1 metric ton = 7.46 barrels = 1,186.04 liters
Residual oil	1 metric ton = 6.66 barrels = 1,058.85 liters

Energy Conversions

1 BTU = 1055 joules
1 kWh = 3.6×10^6 joules
1 kWh = 3413 BTU

Conversion Factors to Energy Units (Heat Equivalents)

Solid Fuels (MBTU/Short ton)	
Anthracite coal	22.573
Bituminous coal	23.89
Sub-bituminous coal	17.14

[t] All constants, units, and conversions in this section are taken from Annex W of Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 2000* EPA 430-R-02-003 (Washington, D.C., April 2002); http://www.epa.gov/oppeoee1/globalwarming/publications/emissions/us2002/index.html.

Lignite	12.866
Coke	24.8
Natural Gas (BTU/cubic foot)	1,027
Liquid Fuels (MBTU/barrel)	
Crude oil	5.800
Natural Gas liquids and LRGs	3.777
Motor Gasoline	5.253
Kerosene jet fuel	5.670
Distillate fuel	5.825
Residual oil	6.287

APPENDIX 2

Global Warming Potentials of Selected Gases[u]

Gas		Lifetime (years)	Global Warming Potential (Time Horizon in years)		
			20 yrs	*100 yrs*	*500 yrs*
Carbon dioxide	CO_2		1	1	1
Methane*	CH_4	12.0 †	62	23	7
Nitrous oxide	N_2O	114 †	275	296	156
Hydrofluorocarbons					
HFC-23	CHF_3	260	9400	12000	10000
HFC-125	CHF_2CF_3	29	5900	3400	1100
HFC-134a	CH_2FCF_3	13.8	3300	1300	400
HFC-143a	CF_3CH_3	52	5500	4300	1600
HFC-152a	CH_3CHF_2	1.4	410	120	37
HFC-227ea	CF_3CHFCF_3	33	5600	3500	1100
HFC-236fa	$CF_3CH_2CF_3$	220	7500	9400	7100
Fully fluorinated species					
SF_6		3200	15100	22200	32400
CF_4		50000	3900	5700	8900
C_2F_6		10000	8000	11900	18000

* The methane GWPs include an indirect contribution from stratospheric H_2O and O_3 production.
† The values for methane and nitrous oxide are adjustment times, which incorporate the indirect effects of emission of each gas on its own lifetime.

[u] IPCC, *Climate Change: the Scientific Basis* (Geneva, Switzerland: 2001) at 47; http://www.ipcc.ch/pub/wg1TARtechsum.pdf.

APPENDIX 3

Statewide and Regional Electricity Emissions Coefficients

Average Emissions Coefficients for Electricity Generation by State

	DOE 1992[v]			EIA 1998-2000[w]		
	CO_2 (lbs. /kWh)	**N_2O (lbs. /MWh)**	**CH_4 (lbs. /MWh)**	**CO_2 (lbs. / kWh)**	**N_2O (lbs. /MWh)**	**CH_4 (lbs. /MWh)**
New England				*0.98*	*0.0146*	*0.0207*
Connecticut	0.715	0.0683	0.0104	0.43	0.0120	0.0174
Maine	0.966	0.1170	0.0180	0.85	0.0270	0.0565
Massachusetts	1.459	0.1281	0.0266	1.28	0.0159	0.0174
New Hampshire	0.852	0.1077	0.0145	0.68	0.0141	0.0172
Rhode Island	1.091	0.0644	0.0487	1.05	0.0047	0.0068
Vermont	0.159	0.0152	0.0041	0.03	0.0039	0.0096
Mid Atlantic				*1.04*	*0.0145*	*0.0093*
New Jersey	0.774	0.0731	0.0241	0.71	0.0079	0.0077
New York	1.036	0.0859	0.0208	0.86	0.0089	0.0081
Pennsylvania	1.286	0.2128	0.0259	1.26	0.0203	0.0107
East-North Central				*1.63*	*0.0257*	*0.0123*
Illinois	0.866	0.1360	0.0164	1.16	0.0180	0.0082
Indiana	2.171	0.3346	0.0398	2.08	0.0323	0.0143
Michigan	1.576	0.2450	0.03227	1.58	0.0250	0.0146
Ohio	1.807	0.3020	0.0355	1.80	0.0288	0.0130
Wisconsin	1.343	0.2430	0.0292	1.64	0.0260	0.0138
West-North Central				*1.73*	*0.0269*	*0.0127*
Iowa	1.686	0.2878	0.0342	1.88	0.0298	0.0138
Kansas	1.703	0.2386	0.0302	1.68	0.0254	0.0112
Minnesota	1.627	0.2278	0.0276	1.52	0.0247	0.0157
Missouri	1.783	0.2814	0.0334	1.84	0.0288	0.0126
Nebraska	1.288	0.189	0.023	1.40	0.0219	0.0095
North Dakota	2.303	0.3194	0.0376	2.24	0.0339	0.0147
South Dakota	0.912	0.143	0.017	0.80	0.0121	0.0053
South Atlantic				*1.35*	*0.0207*	*0.0127*
Delaware	1.855	0.2161	0.0344	1.83	0.0227	0.0123
District of Columbia	2.649	0.048	0.005	1.37	0.0206	0.0118
Florida	1.294	0.1640	0.0275	1.39	0.0180	0.0150
Georgia	1.220	0.2160	0.0255	1.37	0.0226	0.0129
Maryland	1.356	0.2051	0.0260	1.37	0.0206	0.0118
North Carolina	1.350	0.2290	0.0276	1.24	0.0203	0.0105

[v] U.S. Department of Energy, *Sector-Specific Issues and Reporting Methodologies Supporting the General Guidelines for the Voluntary Reporting of Greenhouse Gases under Section 1605(b) of the Energy Policy Act of 1992* Volume I DOE/PO-00280 (Washington, D.C., October 1994) at C-2 - C-3; http://www.eia.doe.gov/pub/oiaf/1605/cdrom/pdf/gg-app-tables.pdf.

[w] EIA, *Updated State-level Greenhouse Gas Emission Factors for Electricity Generation 1998-2000* (Washington, D.C., April 2002) at 8; ftp://ftp.eia.doe.gov/pub/oiaf/1605/cdrom/pdf/e-supdoc.pdf.

South Carolina	0.688	0.1130	0.0136	0.83	0.0145	0.0091
Virginia	1.107	0.1805	0.0253	1.16	0.0192	0.0137
West Virginia	2.005	0.3356	0.0396	1.98	0.0316	0.0137
East-South Central				*1.49*	*0.0240*	*0.0128*
Alabama	1.369	0.2277	0.0271	1.31	0.0223	0.0137
Kentucky	1.930	0.323	0.038	2.01	0.0321	0.0140
Mississippi	1.075	0.1382	0.0290	1.29	0.0165	0.0132
Tennessee	1.335	0.2259	0.0266	1.30	0.0212	0.0105
West-South Central				*1.43*	*0.0153*	*0.0087*
Arkansas	1.286	0.1825	0.0250	1.29	0.0203	0.0125
Louisiana	1.388	0.1248	0.0385	1.18	0.0112	0.0094
Oklahoma	1.672	0.2211	0.0470	1.72	0.0223	0.0110
Texas	1.552	0.1637	0.0413	1.46	0.0146	0.0077
Mountain				*1.56*	*0.0236*	*0.0108*
Arizona	0.798	0.1709	0.0232	1.05	0.0154	0.0068
Colorado	2.001	0.3137	0.0385	1.93	0.0289	0.0127
Idaho	0.269	0.0382	0.0067	0.03	0.0033	0.0080
Montana	1.553	0.2317	0.0276	1.43	0.0227	0.0108
Nevada	1.875	0.2457	0.0360	1.52	0.0195	0.0090
New Mexico	1.405	0.3111	0.0404	2.02	0.0296	0.0131
Utah	1.990	0.3283	0.0399	1.93	0.0308	0.0134
Wyoming	2.194	0.3343	0.0393	2.15	0.0338	0.0147
Pacific Contiguous				*0.45*	*0.0037*	*0.0053*
California	0.756	0.0392	0.0315	0.61	0.0037	0.0067
Oregon	0.235	0.0448	0.0102	0.28	0.0034	0.0033
Washington	0.306	0.0461	0.0069	0.25	0.0040	0.0037
Pacific Non- Contiguous				*1.56*	*0.0149*	*0.0161*
Alaska	0.0031	0.1732	0.0907	1.38	0.0089	0.0068
Hawaii	1.514	0.0888	0.0120	1.66	0.0183	0.0214
United States Average	*1.291*	*0.1872*	*0.0291*	*1.34*	*0.0192*	*0.0111*

Average Marginal CO_2 Emissions Factors for Electricity Generation by EPA Region[x]

EPA Region	States Within Region	lbs. CO_2 /kWh
Region 1	MA, CT, ME, NH, RI, VT	1.726
Region 2	NY, NJ	1.679
Region 3	PA, VA, MD, WV, DC, DE	2.096
Region 4	FL, NC, GA, TN, AL, SC, KY, MS	2.215
Region 5	OH, IL, MI, IN, WI, MN	1.988
Region 6	TX, LA , OK, AR, NM	1.186
Region 7	MO, IA, KS, NE	1.404
Region 8	CO, UT, MT, WY, ND, SD	1.244
Region 9	CA, AZ, NV	1.240
Region 10	WA, OR, ID	1.202
National Average		1.640

[x] ICF Consulting, *Emissions factors, Global Warming Potentials, Unit Conversions, Emissions, and Related Facts* (Fairfax, VA: November 1999) at 2; http://www.epa.gov/cpd/pdf/brochure.pdf.

APPENDIX 4

Derivation of Transportation Emissions Coefficients

This Appendix explains how the transportation emissions coefficients provided above were developed.

Automobile Travel

Lbs. CO_2 */ mi.; Lbs.* N_2O */ mi.; Lbs.* CH_4 */ mi.*

The two EPA-provided charts below show that in 1990, 100% of vehicle miles traveled in gasoline passenger cars would have been under Tier 0 control technology while 95% of vehicle miles traveled in gasoline light-duty trucks would have been under Tier 0 control technology and the remaining 5% would have oxidation control technology. As shown, 100% of vehicles from both categories now have Tier 1 emissions control technology:[59]

Control Technology Assignments for Gasoline Passenger Cars (Percent of VMT) [excluding California VMT]

Model Years	*Non-catalyst*	*Oxidation*	*Tier 0*	*Tier 1*
1973-1974	100%			
1975	20	80		
1976-1977	15	85		
1978-1979	10	90		
1980	5	88	7	
1981		15	85	
1982		14	86	
1983		12	88	
1984-1993			100	
1994			60	40
1995			20	80
1996-1999				100

Control Technology Assignments for Gasoline Light-Duty Trucks (Percent of VMT) [excluding California VMT]

Model Years	*Non-catalyst*	*Oxidation*	*Tier 0*	*Tier 1*
1973-1974	100%			
1975	30	70		
1976	20	80		
1977-1978	25	75		
1979-1980	20	80		
1981		95	5	
1982		90	10	
1983		80	20	
1984		70	30	
1985		60	40	
1986		50	50	
1987-1993		5	95	
1994			60	40
1995			20	80
1996-1999				100

For simplicity, I assume that all vehicles in 1990 met Tier 0. The EPA provides the following per km emissions coefficients:[60]

Emission Factors (g/km) for CH_4 and N_2O and "Fuel Economy" (g CO_2/km) for Highway Mobile Combustion

Vehicle Type/Control Technology	*N_2O*	*CH_4*	*CO_2*
Gasoline Passenger cars			
Tier 1 (2002)	0.0288	0.030	285
Tier 0 (1990)	0.0507	0.040	298
Gasoline Light-Duty Trucks			
Tier 1 (2002)	0.0400	0.035	396
Tier 0 (1990)	0.0846	0.070	498

Converted in per mile emissions coefficients, the chart looks like:

Emission Factors (lbs./mi) for CH_4 and N_2O and "Fuel Economy" (lbs. CO2/mi) for Highway Mobile Combustion

Vehicle Type/Control Technology	*N_2O*	*CH_4*	*CO_2*
Gasoline Passenger cars			
Tier 1 (2002)	0.000102	0.000106	1.01
Tier 0 (1990)	0.000180	0.000142	1.06
Gasoline Light-Duty Trucks			
Tier 1 (2002)	0.000142	0.000124	1.405
Tier 0 (1990)	0.000300	0.000248	1.767
All values were converted by multiplying the g/km figure by 1 kg/1000g * 2.205 lbs./kg * 1.609 km/ mi to get lbs./mi			

To be fully accurate, I used these coefficients to develop an average pounds per mile emissions coefficient based on the mix of cars to light trucks on the road in the United States in 1990 and in 1998, the latest year for which such figures are available. According to the Bureau of Transportation Statistics (BTS), in 1990, passenger cars traveled 1,408,000 miles[61] while other 2-axle 4-tire vehicles, of which BTS notes "[n]early all vehicles in this category are light trucks, which include vans, pickup trucks, and sport utility vehicles," traveled 575,000 miles.[62] Thus, 29% of miles traveled by commuters were in gasoline light-duty trucks while the other 71% were traveled in gasoline passenger cars in 1990. In 1998, passenger cars traveled 1,545,830 miles[63] while other 2-axle 4-tire vehicles traveled 866,228 miles.[64] This works out to 35.9% gasoline light-duty trucks and 64.1% gasoline passenger cars. I used these percentages and the EPA emissions coefficients above to calculate the following weighted average emissions coefficients per vehicle mile:

	N_2O	CH_4	CO_2
1990	.000215 lbs. / mi	.000173 lbs. / mi	1.26 lbs. / mi
1998 (latest year available)	.000116 lbs. / mi	.000112 lbs. / mi	1.15 lbs. / mi
All values were calculated by multiplying the EPA emissions coefficients by the percentage of vehicle miles traveled and summing the results. For example, the 1990 CO2 coefficient = (.29 * 1.767) + (.71 * 1.06) = 1.26			

Lbs. CO_2 / gal. gasoline

On a per gallon basis, the VRGGP suggests an emissions coefficient of 19.564 lbs. CO_2 / gal.[65] However, according to other EIA data, because of changes in motor gasoline density between 1990 and 2000, the emissions coefficient for gasoline has also changed. For 1990, the EIA provides an emissions coefficient of 19.41 million metric tons carbon per quadrillion Btu. For 2000 (the latest year available), it suggests a coefficient of 19.34 million metric tons carbon per quadrillion Btu.[66] Thus, for 1990, I recommend an emissions coefficient of 156.9 lbs. CO_2 /

MBTU[y] and for 2000, 156.4 lbs. CO_2 / MBTU.[z] In lbs. CO_2 / gal., this comes to 19.62 for 1990[aa] and 19.56 for 2000.[bb]

Lbs. N_2O / gal. gasoline

N_2O / gal. emissions coefficients differ based on control technology. The latest and probably most accurate estimates come from the IPCC:[67]

UPDATED EMISSION FACTORS FOR USA GASOLINE VEHICLES

Control Technology	Emission Factor	
	(g N_2O / kg fuel)	(g N_2O /MJ)
Three-Way Catalyst (USA Tier 1; 2002)	0.32	0.0073
Early Three-Way Catalyst (USA Tier 0; 1990)	0.54	0.012

Converted in the standard lbs. per gallon the emissions coefficients are:

	Tier 0 (1990)	Tier 1
lbs. N_2O / gal.	.0034	.0020
To get lbs. N_2O /gallon: g N_2O /kg fuel * 1kg/1000g * 2.205lbs./kg * 1000kg/8.53barrels * 1barrel/42gallons		

Lbs. CH_4 / gal. gasoline

For CH_4 emissions from American vehicles, the IPCC provides the following average estimates:[68]

	Tier 0 (1990)	Tier 1
g CH_4 / kg fuel (passenger cars)	0.37-0.48	0.28-0.39
g CH_4 / kg fuel (light-duty trucks)	0.47-0.63	0.21-0.30

Using the midpoints of these figures and converting into lbs. / gal., I get:

	Tier 0 (1990)	Tier 1
lbs. CH_4 / gal. fuel (passenger cars)	.0026	.0021
lbs. CH_4 / gal. fuel (light-duty trucks)	.0034	.0016

Since the vehicles that consume this gas are likely to be a mix of passenger cars and light trucks and since the CH_4 coefficient differs for these two categories, I calculated a weighted coefficient based upon the proportion of fuel consumed by cars and trucks in 1990 and 2000. In 1990, passenger cars in the United States consumed 69,568 million gallons of fuel[69] while other 2-axle 4-tire vehicles consumed 35,611million gallons.[70] By 1998, the latest year for which such data is available, passenger cars consumed 72,209 million gallons of fuel[71] and other 2-axle 4-tire vehicles consumed 50,579 million gallons.[72] Thus, light trucks consumed about 34 percent [35,611 / (69,568 + 35,611)] of the fuel in 1990 and 41 percent [50,579 / (72,209 + 50,579)] in 1998. Using the same process as above, I used these figures to calculate the following weighted emissions coefficients:

	Tier 0 (1990)	Tier 1

[y] 19.41 MMTC/10^{15} BTU * 44 CO_2/12C * 10^9 kg/MMT * 2.205lbs./1kg = .0001569/ BTU = 156.9/MBTU
[z] 19.34 MMTC/10^{15} BTU * 44 CO_2/12C * 10^9 kg/MMT * 2.205lbs./kg = .0001565/ BTU = 156.5/ MBTU
[aa] 156.9 lbs. / MBTU * 5,253,000 Btu / barrel gasoline * 1 barrel / 42 gal. = 19.62 lbs. / gal. gasoline
[bb] 156.4 lbs. / MBTU * 5,253,000 Btu / barrel gasoline * 1 barrel / 42 gal. = 19.56 lbs. / gal. gasoline

lbs. CH_4 / gal.	.0029	.0019

Bus Travel

The IPCC provides emissions coefficients for US heavy duty diesel vehicles such as buses:[73]

ESTIMATED EMISSION FACTORS FOR US HEAVY DUTY DIESEL VEHICLES

	Moderate Control			Advanced control		
	CO_2	N_2O	CH_4	CO_2	N_2O	CH_4
Average (g/km)	1011	0.025	0.05	987	0.025	0.04

The IPCC also explains that Heavy-Duty Diesel Vehicles with moderate emissions control came out in 1983 while advanced control began in 1996 and thus, for simplicity I assume that all buses in 1990 had moderate control technology while all currently-operating buses have advanced technology. I have converted the IPCC coefficients into lbs. per mile:

	Moderate Control (1990)			Advanced control		
	CO_2	N_2O	CH_4	CO_2	N_2O	CH_4
Average (lbs./mi)	3.587	0.000089	0.00018	3.50	0.000089	0.00014
All converted by multiplying the g / km by kg / 1000g * 2.205 lbs. / kg * 1.609 km / mi.						

Since buses carry multiple people it is necessary to develop an emissions coefficient on a per passenger mile basis rather than just a per mile basis. To do this I first calculated the average passengers per mile on transit buses using BTS statistics:[74]

	A	B	C
	Passenger miles (millions)	Vehicle miles (millions)	Avr. passengers per mile (A/B)
1990	20,981	2,130	9.850
1998	20,602	2,291	8.993

To estimate a lbs. / passenger mi. coefficient I divided the lbs. / mi. coefficient by the average passengers / mi.:

	Moderate Control (1990)			Advanced control		
	CO_2	N_2O	CH_4	CO_2	N_2O	CH_4
lbs. / pass mi.	.3642	0.0000090	0.000018	0.389	0.0000090	.000016

Air travel

The BTS provides the following data for BTU/passenger air mile:[75]

Energy intensity (BTU/passenger-mile)	**1990**	**1999 (the latest year available)**
Domestic operations	4932	4053
International operations	4546	4123

To develop an emissions coefficient in miles per gallon from these figures, I used the EIA emissions coefficient for jet fuel of 156.258 lbs. CO_2 / MBTU[76]:

Emissions (lbs. CO_2 /passenger-mile)	**1990**	**1999 (the latest year available)**
Domestic operations	.7707	.6333
International operations	.7103	.6443

These coefficients are fairly consistent with the emissions coefficient for air travel of .00018 tonnes CO_2 per person per km (equal to .64 lbs. CO_2 per person per mile[cc]) suggested by both the World Resources Institute[77] and the United Nations Environmental Programme.[78] Similarly, the Climate Neutral Network (CNN) uses an emissions coefficient of .63 lbs. CO_2 per passenger mile.[79] However, according to the CNN, "[t]he average warming potential [of] non CO_2 greenhouse gas emissions from airtravel is double the CO_2 emissions." They therefore double CO_2 emissions coefficient for a total coefficient of 1.26 lbs. CO_2e per passenger mile. They source this estimate to an IPCC document,[80] but it is unclear exactly how CNN derived their figure from this document. Therefore, until better data comes out, I recommend the CO_2 emissions coefficients from the table above.

For N_2O emissions, the EPA estimates that combustion of jet fuel releases 0.1 g N_2O / kg of fuel.[81] To calculate the kg of jet fuel combusted per passenger, I had to calculate the barrels of fuel per passenger-mile. To do this, I worked backwards from the CO_2 emissions per passenger mile and used the EIA emissions coefficient of 885.98 lbs. of CO_2 per barrel of jet fuel combusted to calculate barrels of fuel per passenger-mile.[82] I then used EPA provided density of kerosene jet fuel[dd] of 7.93 barrels per metric ton[83] to convert to metric tons per passenger miles and finally convert this to lbs. per passenger-mile:

Emissions (lbs. N2O /passenger-mile)	**1990**	**1999 (the latest year available)**
Domestic operations	.00002	.00002
International operations	.00002	.00002
All values converted by multiplying the lbs. CO_2 / passenger-mile figure from the table above by barrel / 885.98 lbs. CO_2 * tonne / 7.93 barrels * 1000kg/tonne *.1g N2O/kg * kg/1000g *2.205 lbs/kg		

It's worth noting here that according to Michael Gillenwater, of the Greenhouse Gas Inventory Program of the Office of Atmospheric Programs at the EPA, "[e]mission factors for N_2O from aircraft combustion are notoriously uncertain" and moreover, "compared with the CO_2 emissions from air travel, they are most likely quite small (within the uncertainty range of the CO_2 estimates themselves)."[84] Michael's advice notwithstanding, I recommend including N_2O emissions from air travel since I believe that an estimate based on the best currently available science is more likely to be accurate then an estimate of zero.

With regard to CH_4, Gillenwater pointed out that "[s]ome studies have actually suggested that aircraft jet engines may be a next [*sic*] 'sink' for methane, meaning that the concentration of methane coming out of the engine is less than that of the intake air (i.e., they are burning ambient methane)."[85] He therefore recommends "for now, that for all but the most comprehensive and detailed inventories, that [sic] people skip the estimating of CH_4 and N_2O from air travel, as the numbers will be extremely small relative to the total inventory." Since it is unclear whether airplanes are a source or sink of CH_4, I believe it makes sense to leave CH_4 out.

[cc] .00018 tonnes CO_2 /person km * 1.609km/mile * 1000kg/tonne * 2.205lbs/kg = .64 lbs. CO_2 /person mile

[dd] The EPA provides densities for both kerosene and naphtha jet fuel. I used the density of kerosene jet fuel of the advice of Michael Gillenwater, from the Greenhouse Gas Inventory Program of the Office of Atmospheric Programs at the EPA, who explained that "[c]ommercial jets almost exclusively use kerosene-type jet fuel" [personal email]

Appendix 5

Estimating GHG Emissions from Solid Waste Decomposition

Several different approaches for measuring CH_4 emissions the decomposition of MSW in SWDSs are available. The IPCC provides both a "default method" and a First Order Decay (FOD) method. The main difference between the two approaches "is that the FOD method produces a time-dependent emission profile that better reflects the true pattern of the degradation process over time, whereas the default method is based on the assumption that all potential CH_4 is released in the year the waste is disposed of."[86] Since "[t]he use of the FOD method requires data on current, as well as historic waste quantities, composition and disposal practices for several decades,"[87] and since this data is likely to be unavailable or sketchy at best for colleges, I recommend using the default method.

As I explain in more depth below, in order to calculate CH_4 emissions from waste in a SWDS you must:

1. Calculate or estimate the percentage of degradable organic carbon (DOC) in the wastestream
2. Use the percent DOC to calculate the methane generation potential (MGP)
3. Use the MGP to calculate the total CH_4 emissions

DOC is "is the organic carbon that is accessible to biochemical decomposition."[88] It can be calculated with the equation:[89]

DOC = (0.4 Fraction of MSW that is paper and textiles) + (0.17 Fraction of MSW that is garden waste, park waste or other non-food organic putrescibles) + (0.1 Fraction of MSW that is food waste) + (0.3 Fraction of MSW that is wood or straw)

Since there is likely to be very little data on the composition of your school's wastestream, I recommend using a value of 19.5 percent, the midpoint of an EPA suggested range of 18-21 percent for the default DOC in North America.[90]

Then I use the DOC to calculate the MGP in lbs. CH_4 /lbs. of your school's waste:[91]

MGP = MCF * DOC * % DOC that dissimilates * fraction by volume of CH_4 in landfill gas * 16 CH_4 / 12 C

In this equation, MCF is the methane correction factor, which is used to account "for the fact that unmanaged SWDS produce less CH_4 from a given amount of waste than managed SWDS, because a larger fraction of waste decomposes aerobically in the top layers of unmanaged SWDS."[92] A managed SWDS will "have controlled placement of waste (i.e. waste directed to specific deposition areas, a degree of control of scavenging and a degree of control of fires) and will include some of the following: cover material, mechanical compacting or levelling of waste."[93] The SWDS that ultimately takes your school's MSW is likely to be managed. The IPCC suggests default MCF of 1 for a managed SWDS. The percent of DOC dissimilated is "an estimate of the fraction of carbon that is ultimately degraded and released from SWDS, and reflects the fact that some organic carbon does not degrade, or degrades very slowly, when deposited in SWDS."[94] The original IPCC guidelines suggest a default value of .77; but the IPCC *Good Practice* guidelines suggest that "this default value may be an overestimate" and argues that "[i]t is also *good practice* to use a value of 0.5-0.6 (including lignin C) as the default."[95] I thus use a default of 0.55. Finally, the fraction by volume of CH_4 in landfill gas is "usually taken to be 0.5," according to the IPCC.[96] Using all default values provides an MGP of 0.0715 lbs. CH_4 /lbs. waste.

I then plug this into the final equation:[97]

$$CH_4 \text{ emissions (lbs./yr)} = [(\text{MSW disposed at SWDS (lbs./yr)} * \text{MGP}) - \text{Recovered } CH_4 \text{ (lbs./yr)}] * (1 - \text{the Oxidation factor})$$

Recovered CH_4 "is the amount of CH_4 generated at SWDS that is recovered and burned in a flare or energy recovery device."[98] It is important to note however that, "CH_4 recovered and subsequently vented should not be subtracted from gross emissions."[99] The IPCC default figure for recovered CH_4 is zero and "[t]his default should only be changed when references documenting the amount of methane recovery are available."[100] Moreover, "[r]ecovered gas volumes should be reported as CH_4 not as landfill gas, as landfill gas contains only a fraction of CH_4" and "[t]he use of undocumented estimates of landfill gas recovery potential is not appropriate, as such estimates tend to overestimate the amount of recovery."[101] Finally, the oxidation factor "reflects the amount of CH_4 from SWDS that is oxidised in the soil or other material covering the waste."[102] Thus, "[i]f the oxidation factor is zero, no oxidation takes place, and if OX is 1 then 100% of CH_4 is oxidised."[103] "The default oxidation factor in the *IPCC Guidelines* is zero," but as the *Good Practice* guidelines note, "most industrialised countries with well-managed SWDS use 0.1 for OX, which is a reasonable assumption based on available information."[104] Since the EPA "assumes that 10 percent of the methane generated that is not flared or recovered is oxidized in the soil,"[105] I also recommend an oxidation factor of 10 percent.

As the IPCC guidelines were designed primarily to estimate emissions from the whole landfill rather than emissions from just a portion of the waste, some slight adjustments are necessary to apply this method to the college level. Instead of subtracting all of the recovered CH_4, you should only subtract the portion of captured CH_4 that your school is responsible for. This can be calculated relatively easily by dividing the total lbs. CH_4 recovery by the total tonnage of waste accepted. As a result, the correct equation for my purposes is:

$$\text{Lbs. } CH_4 = [(\text{lbs. MSW from college} * \text{MGP}) - (\text{lbs. MSW from college} * \text{Recovered lbs. } CH_4 / \text{ total lbs. incoming MSW})] * (1 - \text{the Oxidation factor})$$

Simplified out using all default figures, this reduces to:

$$\text{Lbs. } CH_4 = .9 * \text{lbs. MSW from college} * (.0715 - \text{total } CH_4 \text{ lbs. recovered / total lbs. incoming solid waste})$$

Appendix 6

Estimating GHG Emissions from Wastewater Treatment

N_2O from wastewater

To calculate emissions of N_2O from wastewater, the IPCC provides the following equation:[106]

lbs. N_2O-N released/yr = population * per capita protein intake (lbs./person/ yr) * fraction of N in protein * EF

The default fraction of nitrogen in protein provided by the IPCC[107] is .16 lbs. N/ lbs. protein. The default emissions factor (EF), again provided by the IPCC,[108] is 0.01 lbs. N_2O-N/lbs. sewage-N produced. According to the United Nations Food and Agricultural Organization (FAO), Americans consumed 107.5 g protein/person/day in 1990 and 114.9 g protein/person/day in 1999 (the latest such data is available).[109] Both the EIA[110] and EPA[111] use this methodology and these default values in their national inventories.

I modified the equation to account for the fact that colleges have several population subgroups - on-campus students, off-campus students, staff, and faculty - some of who are only on campus for parts of the day over parts of the year:

lbs. N_2O-N released/yr = person-days/year * per capita protein intake (lbs./person/day) * fraction of N in protein * EF

I simplified the equation using all default values as described above to yield a final emissions coefficient of .0006 lbs. N_2O per person-day.[ee] Note that this emissions coefficient applies to both 1990 and 2001 since the small difference in protein consumption disappears during simplification and adjusting for significant digits. The final equation is thus:

lbs. N_2O released/yr. = person-days / yr. * .0006 lbs. N_2O / person-day

CH_4 from wastewater and sludge treatment

The IPCC provides the following equation to calculate CH_4 emissions from treated wastewater:[112]

lbs. CH_4 = population * DOC * (1 - %DOC removed as sludge) * maximum CH_4 producing capacity of wastewater * MCF - lbs. CH_4 captured and flared

Similarly, the to calculate emissions from treated sludge, the IPCC suggests the following equation:

lbs. CH_4 = population * DOC * %DOC removed as sludge * maximum CH_4 producing capacity of sludge * MCF - lbs. CH_4 captured and flared

[ee] .1075kg protein/person-day * .16 kg sewage N/kg protein * .01 kg N_2O -N/sewage N * 2.205 lbs./kg * 44 N_2O /28 N = .0006
.1149 kg protein/person-day * .16 kg sewage N/kg protein * .01 kg N_2O -N/sewage N * 2.205 lbs./kg * 44 N_2O /28 N = .0006

In both equations, DOC stands for degradable organic component. The IPCC suggests a default value of .05 kg BOD5/person/day [.11 lbs. BOD5/person/day] for North America.[113] The Revised 1996 IPCC Guidelines suggest a default maximum CH_4 producing capacity of both wastewater and sludge of 0.25 lbs. CH_4 / lbs. BOD.[114] However, the more recent IPCC Good Practice guidelines adjust this estimate and suggest the use of 0.6 lbs. CH_4 / lbs. BOD[115] so I recommend these updated figures. MCF stands for methane correction factor and accounts for the portion of maximum CH_4 producing capacity that is actually achieved. According to the IPCC, "[t]he MCF varies between 0.0 for a completely aerobic system to 1.0 for a completely anaerobic system. … If no data are available, as a default, use 0 for *aerobic* systems, and 1.0 for *anaerobic*."[116] The wastewater treatment plant operator should be able to provide information on the proportion of DOC removed as sludge and on the total lbs. of CH_4 captured and flared from both wastewater and sludge treatment. If no data is available on the amount of CH_4 recovered and flared, the IPCC suggests a default of zero.[117] In its inventory of US GHG emissions, the EIA also assumed that "recovery of methane at municipal wastewater treatment facilities is negligible."[118]

As with N_2O emissions from wastewater, the equation must be modified to account for the fact that the various population subgroups do not spend all of their time on campus. As before, I replace "population" with total person-days on campus and simplify the equation using all default values as described above to develop the following final equations:

Wastewater treatment:

CH_4 emissions = total person-days/yr. * 0.066 lbs. CH_4 / person-day * (1 - fraction of DOC removed as sludge) - (gal. wastewater from your school * total lbs. CH_4 from wastewater flared / total wastewater flow into plant)

Sludge treatment:

CH_4 emissions = total person-days/yr. * 0.066 lbs. CH_4 / person-day * fraction of DOC removed as sludge - (gal. wastewater from your school * total lbs. CH_4 from sludge flared / total wastewater flow into plant)

Appendix 7

Estimating N_2O Emissions from Fertilizer Application

I used IPCC methodology to derive the emissions coefficients for fertilizer application.[119] This method is almost identical to process suggested by the EIIP[120] and used by the EIA and the EPA in their annual inventories.

The IPCC explains that:

> Nitrous oxide (N_2O) is produced naturally in soils through the microbial processes of nitrification and denitrification. A number of agricultural activities add nitrogen to soils, increasing the amount of nitrogen (N) available for nitrification and denitrification, and ultimately the amount of N_2O emitted. The emissions of N_2O that result from anthropogenic N inputs occur through both a direct pathway (i.e. directly from the soils to which the N is added), and through two indirect pathways (i.e. through volatilisation as NH_3 and NO_x and subsequent redeposition, and through leaching and runoff).[121]

According to the IPCC, 10% of the nitrogen in synthetic fertilizers and 20% of the nitrogen in animal manure volatilizes into NO_x and NH_3 gases upon application.[122] The EIIP suggests that "this 20 percent figure should also be applied to the other organic fertilizers."[123] The equation for direct N_2O emissions from fertilizer application is thus:

$$[(\text{lbs. N synthetic} * .9) + (\text{lbs. N organic} * .8)] * \frac{.0125 \text{ lbs. } N_2O\text{-N}}{\text{lbs. N not volatized}} * \frac{44 \text{ lbs. } N_2O}{28 \text{ lbs. } N_2O\text{-N}} = \text{lbs. } N_2O$$

To calculate indirect N_2O emissions from "the volatilisation of applied N as ammonia (NH_3) and oxides of nitrogen (NO_x) followed by deposition as ammonium (NH_4) and NO_x on soils and water,"[124] the IPCC provides the following equation:

$$[(\text{lbs. N synthetic} * .1) + (\text{lbs. N organic} * .2)] * \frac{.01 \text{ lbs. } N_2O\text{-N}}{\text{lbs. volatized } NH_3 \text{ and } NO_x} * \frac{44 \text{ lbs. } N_2O}{28 \text{ lbs. } N_2O\text{ -N}} = \text{lbs. } N_2O$$

According to the IPCC, "[a] large proportion of nitrogen is lost from agricultural soils through leaching and runoff. This nitrogen enters the groundwater, riparian areas and wetlands, rivers, and eventually the ocean, where it enhances biogenic production of N_2O."[125] To estimate these emissions, the IPCC suggests that about 30% of non-volatized N runs-off into the water supply[126] and that of this 30%, .025 lbs. N_2O-N is released per lbs. N leached and runoff.[127] Thus the equation:

$$.3[(\text{lbs. N synthetic} * .9) + (\text{lbs. N organic} * .8)] * \frac{.025 \text{ lbs. } N_2O\text{ -N}}{\text{lbs. N leached and runoff}} * \frac{44 \text{ lbs. } N_2O}{28 \text{ lbs. } N_2O\text{ -N}} = \text{lbs. } N_2O$$

To derive the emissions coefficients used above, I derived the emissions coefficient from each equation above and summed the results. For example, simplifying the equations above, I get the following emissions coefficients:

	lbs. N_2O / lbs. synthetic N	lbs. N_2O / lbs. organic N
Direct Emissions	0.018	0.016
Volatilization and redeposition	0.002	0.003
Runoff	0.011	0.009
Sum	0.031	0.028

The sum of each of the 3 emissions coefficients is thus the aggregate emissions coefficient given above.

Notes

[1] U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 1999* EPA 236-R-01-001 (Washington, D.C., April 2001) at N-1; http://www.epa.gov/oppeoee1/globalwarming/publications/emissions/us2001/index.html.
[2] *Id*., N-1 - N-2.
[3] U.S. Department of Energy, Energy Information Administration, Voluntary Reporting of Greenhouse Gases Program, "Fuel and Energy Source Codes and Emission Coefficients" (Washington, D.C.); http://www.eia.doe.gov/oiaf/1605/factors.html .
[4] Energy Information Administration, *Emissions of Greenhouse Gases in the United States 2000* DOE/EIA-0573(2000) (Washington, D.C., November 2001) at 140; http://www.eia.doe.gov/oiaf/1605/ggrpt/index.html.
[5] Energy Information Administration, *Updated State-level Greenhouse Gas Emission Factors for Electricity Generation 1998-2000* (Washington, D.C., April 2002) at 8; ftp://ftp.eia.doe.gov/pub/oiaf/1605/cdrom/pdf/e-supdoc.pdf.
[6] Christopher P. Loreti, William F. Wescott, and Michael A. Isenberg, *An Overview of Greenhouse Gas Emissions Inventory Issues* prepared for the Pew Center on Global Climate Change (Cambridge, MA: Arthur D. Little, Inc., August 2000) at 29; http://www.pewclimate.org/projects/greenhouse.pdf.
[7] Energy Information Administration, *Annual Energy Review 2000* DOE/EIA-0384(2000) (Washington, D.C., August 2001) at 223, 327; http://www.eia.doe.gov/aer/.
[8] VRGGP, "Emission Coefficients."
[9] Rob Edwards, "No smoke without . . .," *New Scientist*, September 12, 1998, at 50.
[10] Nigel Mortimer, "Nuclear Power and Carbon Dioxide: The Fallacy of the Nuclear Industry's New Propaganda," *The Ecologist*, Vol. 21, No. 3, May/June 1991, at 130.
[11] VRGGP, "Emission Coefficients."
[12] World Commission on Dams, *Dams and Development; A New Framework for Decision-Making* (Sterling, VA: Earthscan Publications Ltd., November 2000) at 75; http://www.dams.org/report/contents.htm.
[13] Vincent L. St. Louis, Carol A. Kelly, Éric Duchemin, John W. M. Rudd, and David M. Rosenberg, "Reservoir Surfaces as Sources of Greenhouse Gases to the Atmosphere: A Global Estimate," *BioScience*, Vol. 50, No. 9, September 2000, at 767.
[14] Patrick McCully, *Flooding the Land, Warming the Earth: Greenhouse Gas Emissions from Dams* (Berkeley, CA: International Rivers Network, June 2002) at 11; http://www.irn.org/wcd/IRNGHGsfromDams.pdf.
[15] WCD, *Dams and Development*, 76.
[16] McCully, *Flooding the Land*, 8-9.
[17] *Id*., 3.
[18] *Id*., 7.
[19] EIA, *State-level 1998-2000*, 3-4.
[20] Energy Information Administration, *Updated State-level Greenhouse Gas Emission Factors for Electricity Generation* (Washington, D.C., March 2001) at 2.
[21] ICF Consulting, *Emissions factors, Global Warming Potentials, Unit Conversions, Emissions, and Related Facts* (Fairfax, VA: November 1999) at 2; http://www.epa.gov/cpd/pdf/brochure.pdf.
[22] Terry H. Morlan [tmorlan@nwppc.org], “Web Request,” personal email, 30 Jul 2001, email on file with the author.
[23] VRGGP, "Emission Coefficients."
[24] *Id*.
[25] EIA, *Emissions 2000*, 140.
[26] EIA, *State-level*, 8.
[27] U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 2000* EPA 430-R-02-003 (Washington, D.C., April 2002) at W-3; http://www.epa.gov/oppeoee1/globalwarming/publications/emissions/us2002/index.html.
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[29] *Id*.
[30] EIA, *Emissions 2000*, 140.
[31] VRGGP, "Emission Coefficients."
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[36] EPA, *GHG from MSW*, 82.
[37] EIIP, *Waste*, 5.4-15.
[38] *Id*., 5.2-1.
[39] IPCC, *Good Practice*, 5.25.
[40] EPA, *Inventory 1990 – 1999*, 7-5 - 7-12.
[41] EPA, *GHG from MSW*, 81.
[42] *Id*.
[43] EIIP, *Waste*, 5.4-14.
[44] EPA, *GHG from MSW*, 82.
[45] Intergovernmental Panel on Climate Change, *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual* (Geneva, 1997) at 6.28; http://www.ipcc-nggip.iges.or.jp/public/gl/invs6.htm.
[46] EIA, *Emissions 2000*, 132.
[47] EIIP, *Soils*, 9.4-4.
[48] *Id*., 9.4-21.
[49] *Derived from*: EPA, *Inventory 1990 – 2000*, 321-322.
[50] EPA, *GHG from MSW*, 86.
[51] *Id*., 12-13.
[52] *Id*., 72.
[53] *Id*., 74.
[54] *Id*.
[55] *Id*., 76.
[56] *Id*., 68.
[57] *Id*., 95.
[58] *Id*.
[59] EPA, *Inventory 1999*, D-7.
[60] *Derived from* EPA, *Inventory 1999*, D-9.
[61] U.S. Department of Transportation, Bureau of Transportation Statistics, *National Transportation Statistics 2000* BTS01-01 (Washington, D.C., April 2001) at 246; http://www.bts.gov/btsprod/nts/entire.pdf.
[62] *Id*., 248.
[63] *Id*., 246.
[64] *Id*., 248.
[65] VRGGP, "Emission Coefficients."
[66] EIA, *Emissions 2000*, 141.
[67] *Derived from*: IPCC, *Good Practice*, 2.47.
[68] *Derived from* IPCC, *Reference Manual*, 1-70 - 1-71.
[69] BTS, *Transportation 2000*, 246.
[70] *Id*., 248.
[71] *Id*., 246.
[72] *Id*., 248.
[73] IPCC, *Reference Manual*, 1.75.
[74] *Derived from* BTS, *Transportation 2000*, 350.
[75] *Derived from* BTS, *Transportation 2000*, 258.
[76] VRGGP, "Emission Coefficients."
[77] World Resources Institute, *SafeClimate carbon footprint calculator* (Washington, D.C.); http://www.safeclimate.net/calculator/.
[78] Charles Thomas, Tessa Tennant and Jon Rolls, *The GHG Indicator: UNEP Guidelines for Calculating Greenhouse Gas Emissions for Businesses and Non-Commercial Organisations* (Paris, France: United Nations

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