Lessons learned from Yale University inventory: GHG emissions from transportation

Marco Buttazzoni
Environmental Resources Trust

Kathryn Zyla
Pew Center on Global Climate Change

Abstract

In Fall 2003, the authors were part of a team that conducted a greenhouse gas inventory of Yale University. This paper discusses the methodologies and challenges faced in one sector of the inventory: emissions from transportation. The scope of this section was considered more broadly than is often done for corporate or academic inventories. Instead of simply including direct fleet-based emissions (Scope 1 of the World Resources Institute (WRI) and World Business Council on Sustainable Development (WBCSD) GHG Protocol), we included Scope 3 emissions as well, taking into account university-related travel and faculty/staff/student commuting.

Attempts to quantify these less-defined categories of travel required methodologies and conversion factors quite different from those used in the more straightforward fleet calculations, and raised an additional set of challenges and uncertainties. Here we will describe the scope of the Yale transportation inventory and discuss the approach used in calculating these emissions, describing the simulation and uncertainty analysis tools we created. We conclude that many of the unique set of difficulties faced in this analysis are caused by a lack of methodologies and factors that are fully codified and shared across the GHG emission inventory community. To address this challenge, we propose a set of methodologies and benchmarks that could be adopted by the GHG emissions inventory community to facilitate future inventories of emissions from transportation.

I. Introduction

In Fall 2003, the authors were part of a team (the Yale Climate Initiative, YCI) that conducted a greenhouse gas inventory of Yale University. As part of this effort we analyzed and inventoried Yale's GHG emissions from transportation. This paper discusses some of the methodologies used and challenges faced in undertaking this exercise.

The scope of the inventory's transportation section was considered more broadly than is often done for institutional inventories. Instead of simply including direct fleet-based emissions (Scope 1 of WRI/WBCSD GHG Protocol), we included Scope 3 emissions as well, taking into account university-related travel and faculty/staff/student commuting.

Attempts to quantify these less-defined categories of travel required methodologies and conversion factors quite different from those used in the more straightforward fleet calculations, and raised an additional set of challenges and uncertainties. This paper will describe the scope of the Yale transportation inventory and discuss the approach used in calculating transportation emissions, describing the simulation and uncertainty analysis tools used. The paper reflects on the strengths and limitations of the approaches taken, and discusses a number of strategies for future inventory efforts that cover a wider set of transportation emissions.

The document is organized as follows:

Section II provides a brief overview of the Yale Climate Initiative, discussing its goals and procedures.

Section III discusses the general approach used for the inventory of transportation emissions. In particular, this section identifies the boundaries of Yale's transportation system (as set by YCI) and discusses how the team approached emissions calculations and issues of uncertainty.

The following sections illustrate in more detail the analysis undertaken for Yale's three types of transportation emissions: vehicles directly owned and operated by the University (section IV), work-related travel (section V) and personnel and student commuting (section VI).

The final two sections of the paper summarize the results of the analysis (sections VII) and discuss some of the strategies that could facilitate a more consistent analysis of transportation emissions in future inventories (section VIII).

II. YCI project overview

A. Study background

The YCI was a student-initiated study to identify, evaluate, and understand how Yale University's operations result in greenhouse gas (GHG) emissions, and to analyze a range of options to make the University more climate-friendly.

The YCI team worked with the support of faculty advisor Arnulf Grübler, a renowned expert in energy systems analysis and lead author for the Intergovernmental Panel on Climate Change. The team also solicited the assistance of University administration and staff and experts from academia, industry, and non-governmental organizations (NGOs). Over a three month period, from September to December 2003 the team met weekly to discuss the various components of the inventory exercise.

Relevant activity data were gathered from institutional sources and University suppliers. Four working groups calculated emissions from: (1) Power Plants, (2) Buildings, (3) Transportation (including Yale-owned vehicles, work-related travel and commuting), and (4) Other Sources and Sinks (including solid waste, laboratory chemicals and refrigerants, as well as carbon sequestration in forests).

The report produced by the team, *The Yale Climate Initiative: Inventory and Analysis of Yale's Greenhouse Gas Emissions,* provided:

- Background on the methodologies, strengths and weaknesses of existing GHG inventories;
- An accounting of Yale University's GHG emissions;
- A description of the methodology employed to calculate Yale's GHG inventory, as well as recommendations for improvements; and
- A general overview of GHG mitigation options for Yale, by sector.

B. Inventory

The organizational boundary established for the YCI study encompassed all activities related to the educational mission of the University. It included all direct and indirect emissions of the six major GHGs[i], and went beyond many of the current U.S. university-based GHG emissions inventories, as shown in Table 1. The study was designed to focus on the University's overall influence on GHGs, estimating its GHG "footprint", rather simply on the emissions that would likely be allocated to the University under a potential formal trading system.

	UVM	Tufts	CU-Boulder	Tulane	Rutgers	Yale
Power Generation	X	X	X	X	X	X
Electricity, Chilled Water and Steam Use	X	X	X	X	X	X
Buildings	X	X	X	X		X
Vehicle Fleet	X	X	X	X	X	X
Work-related Travel						X
Employee and Student Commuting	X	X		X		X
Student travel home						X
Waste Management	X	X				X
Refrigerants	X	X				X
Sinks						X

Table 1: Comparison of Academic Inventory Scopes

The YCI study was conducted for the calendar year 2002.[ii]

For direct emissions, most calculation methodologies and factors were obtained from the United States Environmental Protection Agency (EPA), World Resources Institute (WRI), and Intergovernmental Panel on Climate Change (IPCC). For indirect emissions, WRI's GHG Protocol provided emission factors, methodological guidance and some reference activity data. For a number of calculations, however, the team developed adhoc methodologies and gathered Yale-specific data to be used in the emissions calculations.

Recognizing the potential uncertainties of these approaches, the team sought to document calculation steps and assumptions and to understand the ranges of uncertainty that the calculations entailed. Ranges of uncertainty were calculated for the data and conversion factors. Uncertainties were associated with data errors, human errors, precision and robustness of conversion factors, and assumptions made when collecting and analyzing the data.

III. GHGs from transportation

A. System boundaries

Transportation usage at Yale can be considered in three main categories:

- Owned-vehicle travel
- Work-related travel
- Commuting

Owned-vehicle travel includes the University's departmental fleets, maintenance vehicles, and police vehicles, among others. **Work-related** travel includes air, train, and ground trips taken for university-related purposes; the University does not exert control over the selected mode of transportation. For example, faculty trips to conferences, meetings, and research sites using personal vehicles or public transportation, are work-related travel. In each of these cases, the trip is for the purpose of conducting Yale business, but the individual traveler chooses his or her own mode of transportation. Work-related trips may include flights, train travel, as well as ground transportation. **Commuting** travel covers trips taken by Yale employees and students between campus and their homes. The mode and distance of travel is determined entirely by the traveler, but Yale's role in causing the trip cannot be ignored. A fourth category of travel could include contracted vehicles—including buses leased by the athletic department for travel to games, and by the medical school for campus shuttling—but these were not included in the study due to lack of data availability.

Transportation Category	WRI scope	Description
Institutional	1	Yale-owned vehicles
Work-related	3	Individual trips for university-related purposes (conferences, research, etc.)
Commuting	3	Trips to/from Yale and employee/student homes

Table 2: Transportation Categories Considered

B. Methods and Assumptions

Data Types

Greenhouse gas emission data from transportation are not readily collected by the university administrative systems. Therefore emissions were estimated using a variety of energy, mileage, financial, and personnel data from numerous university sources, in concert with a variety of emissions parameters. The inventory data were collected through interviews with members of record-keeping departments, supplemented with interviews of departments identified as heavy transportation users. Whenever possible, fuel consumption data were used, as these figures are most directly related to CO_2 emissions. As an additional source (or sole source when fuel data were not available), data on passenger/vehicle distances traveled were used. As a third-best approach, when neither fuel nor distance data were available, financial records were used to estimate the amount of travel completed. As each of these next-best approaches requires additional assumptions and approximations, their results are noted with higher levels of uncertainty in the final inventory. Due to limitations in data availability, the inventory combines data from different time intervals, which adds additional uncertainty to the total.

Data Sources

Information on vehicle inventory, fuel purchases and mileage was obtained from the Purchasing Department. Work-related airline travel distances were obtained from the Travel Agency, and financial data on overall work-related travel was obtained through a combination of the Travel Agency and the Controller's Office. Commuter travel is based on residence zip code data obtained through the Parking and Transit Services, Human Resources, Registrar and Office of International Students and Scholars (OISS).

Assumptions, Emissions Factors and Uncertainty

The most thorough set of emissions factors for transportation sources was found in the World Resources Institute's guidelines for greenhouse gas emissions. Additional factors were collected from various sources, including the U.S. Environmental Protection Agency, the Intergovernmental Panel on Climate Change, the non-profit organization Clean Air Cool Planet, the Connecticut Department of Transportation, and others. Whenever possible, emissions factors were verified through comparison with other sources and/or derived factors. The level to which factors could be verified and the source of the parameters affected the uncertainty attributed to each.

In several steps in the process, additional assumptions were made regarding vehicle technology, travel behavior, and other information for which little data were available. In consideration of these limitations, our calculations were based on simple models in which data sources and assumptions were made explicit, and where the sensitivity of the output to each input (data, parameter or assumption) could be evaluated. The overall accuracy of the emissions estimates depends on the number of steps necessary to go from the available data to the emission numbers, and on the uncertainty associated with each step in the calculation process. While some of the data available for the calculations are accurately measured and not far removed from emissions (e.g. gasoline purchased), others require several calculation steps and assumptions. (For example, commuting emissions calculations require assumptions on number of trips made, mode of transportation used, and emissions per mile traveled.)

The picture below illustrates the graphical convention used in modeling and calculating transportation emissions.

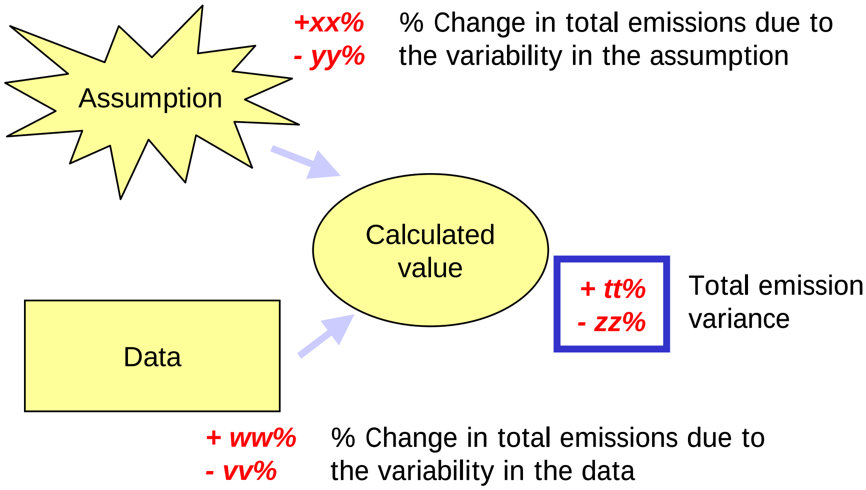

Figure 1: Graphical convention used in representing model structures

Table 3 below summarizes the main data types and assumptions, and sources of each.

Emission source	Data type/source in Yale system	Assumptions and parameters used
Institutional travel – vehicles owned	• Purchasing department • List of all vehicles owned by Yale including model year [Academic year 2003-2004] • Fuel consumption by fuel type • Miles traveled • Price and cost [Fiscal year 2003]	WRI and EPA emission factors
Work related trips	• Controllers' expense data from personnel expenses reports [Fiscal year 2003 & Calendar year 2001] • Yale travel agency data [Calendar year 2001]	• Yale Travel agency traveling parameters • WRI emission factors
Personnel commuting	• Zip code of residence for personnel [Academic year 2003]	• Commuting parameters • WRI and Clean Air Cool planet emissions factors
Students' commuting and home trips	• Zip code for current address [Academic year 2003-2004] • Zip code permanent address [Academic year 2003-2004] • Foreign students census [2001] • Informal students' survey [2003]	• Behavior parameters based on assumptions and high/low scenarios • WRI emissions factors

Table 3: Sources, Assumptions and Parameters

Other Greenhouse Gases

The bottom-up calculations described below relate exclusively to carbon dioxide emissions, not the full range of greenhouse gases. Estimates for these gases are heavily dependent on miles traveled, vehicle type and exhaust or air-conditioning technology in use, rather than simply on fuel consumed. Available emission factors – e.g. from EPA – are based on miles traveled by exhaust technology type or by emissions per year or per vehicle model. These emissions are therefore difficult to determine given the lack of relevant data for Yale University. Therefore, a top-down, aggregated benchmark was used to estimate the contributions of these gases. The United States Climate Action Report[iii] provided to the United Nations Framework Convention on Climate Change in 2002 found that non-CO_2 greenhouse gases[iv] contribute approximately 5% of the greenhouse gas emissions from the transportation sources considered here.[v] This value was used to approximate the contribution of other gases in this study, based on the calculation for carbon dioxide emissions.

IV. Owned-Vehicle Emissions

A. Definition

This emissions category comprises the emissions from Yale-owned and operated vehicles, including the University's departmental fleets, maintenance vehicles, and police vehicles, among others. Purchasing decisions for these vehicles are made by Yale University, and fuel purchases are made by Yale employees and student drivers.

B. Analysis

The most straightforward data to collect, both vehicle purchase and fuel purchase records are kept centrally by the University Purchasing Department which tracks the model, year, and department of each vehicle. In some cases, the department keeps EPA fuel economy estimates for these vehicles on record, but in most cases they do not. Fuel records for these vehicles are kept by the Purchasing Department, and they indicate the amount of fuel, type of fuel, unit cost, and total cost of each fuel purchase for Yale vehicles. These data are collected electronically at the gasoline pump via a fleet credit card that tracks fuel purchases. However, while the records are stored electronically, the odometer reading associated with each fuel purchase is entered manually by the driver at the time of purchase. Because of this system, odometer readings are often inaccurate, due either to operator error or negligence, thus fuel efficiency is difficult to determine. The identity of the vehicle being fueled is also entered by the driver, who is asked to record the vehicle's license plate number. Again, these entries are inconsistent, and make it difficult to analyze specific vehicles over time.

Despite these weaknesses, the fuel consumption data are quite robust and can be used to calculate the levels of energy use and carbon dioxide emissions more accurately than any other university transportation system. The total amount of gasoline purchased by each department was aggregated by type of fuel used and multiplied by energy content and emissions factors for each fuel type. (Factors were cross-checked between several sources: EPA, WRI, and IPCC, and assigned uncertainties based on the source.)

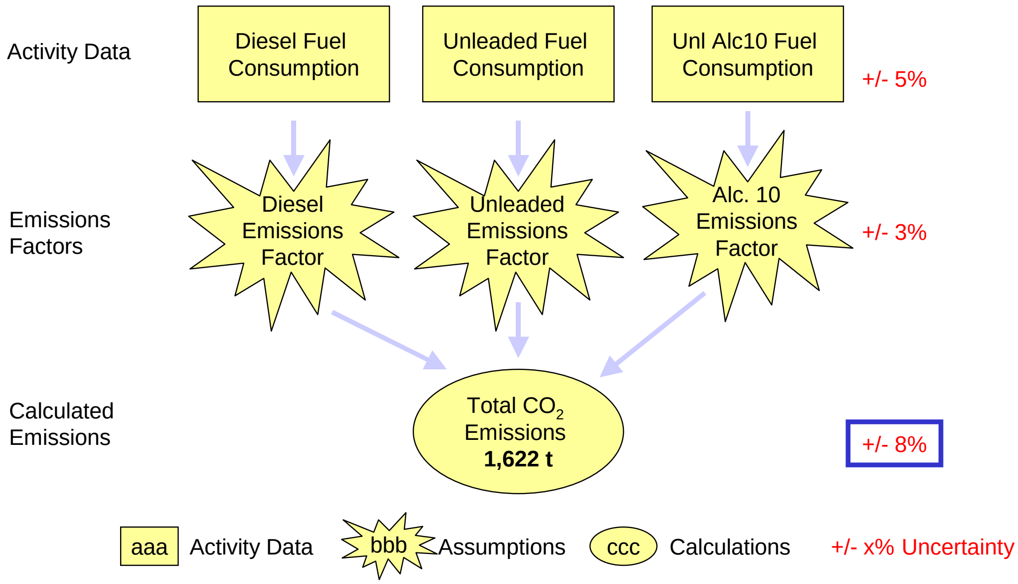

Figure 2: GHG emissions calculation – Owned-vehicle emissions

Uncertainty in the owned-vehicle emissions calculations is due to three factors: the accuracy of the original data, the precision of the meters and the uncertainty inherent in the emissions factors used. In this case, it was assumed that the metered information (gasoline purchases) was accurate within a fraction of a percent, and treated as though it were zero. Uncertainty of the original data was assumed to be +/- 5%, given that the data was from fiscal year 2003 rather than calendar year 2002. Emissions factors were assigned an uncertainty consistent across the inventory, in this case 3%. (See Appendix for standard inventory uncertainty and calculations.)

Fuel Efficiency

A consequence of the inaccurate mileage information is that a full analysis of the energy efficiency of Yale's vehicle fleet was not possible. In the future, such a study could lead to important mitigation recommendations for institutional travel. While manufacturer-reported fuel economy data is available, driving conditions rarely match those in test situations, which cover only certain speeds and road types, and do not account for vehicle idling. Because Yale's vehicles are frequently operated under idling conditions (bus pickups, police monitoring, etc.), stated mileage numbers will not accurately represent Yale's energy consumption and opportunities for improved efficiency. Lastly, because vehicle license plates are manually recorded and very inconsistent, even approximate correlations between fuel purchases and vehicle types are difficult to establish. While a systematic study of vehicle mileage was not possible, a few case study examples were analyzed.

C. Conclusions/recommendations

Analysis of owned-vehicle emissions benefits from consistent and readily available data, along with a well-established set of methodologies and emission factors. However, accurate data depends on consistent use of the systems already in place—employee education and incentives to record vehicle and mileage information would make this data much more valuable. Additionally, case studies that take advantage of this more thorough data would allow the University to determine the performance of individual vehicles in the fleet and to study whether the best vehicles are being purchased for departments' needs.

V. Work-related emissions

A. Definition

Work-related travel includes air, train, and ground trips taken for University-related purposes, without using Yale vehicles. In these cases, the University does not exert control over the selected mode of transportation. For example, faculty trips to conferences, meetings, and research sites are work-related travel. In each of these cases, the trip is for the purpose of conducting Yale business, but the individual traveler chooses his or her own mode of transportation. Trips may include flights, train travel, as well as ground transportation.

For most work-related trips, travel expenditures are paid by the school, but in some circumstances external organizers cover the travel costs incurred by Yale employees. Conversely, Yale invites external speakers to the University and pays travel expenditures for a number of those speakers. The travel expenditures registered in Yale accounts include both expenses incurred by Yale personnel and costs paid for external guests traveling to Yale (refunded by the university). The travel costs paid for Yale personnel by other institutions are not tracked by Yale systems.

For the purposes of estimating Yale's work-related travel emissions, system boundaries were drawn on the basis of these accounting practices. The inventory is based on estimated emissions associated with all trips financed by Yale University; this includes travel-related emissions of external guests and excludes travel-related emissions of Yale personnel for trips financed by external organizations.[vi]

B. Analysis

In order to estimate work-related emissions, travel expenditure data from Yale accounting systems and travel-related data and benchmarks from Yale's travel agency were used. External benchmarks and parameters were also used to obtain factors such the "average miles traveled per dollar spent in domestic car rental," "average GHG emission per air mile traveled," etc.

Yale does not collect information on GHG emissions or fuel consumption from work-related travel, and the University has only limited data on miles traveled for work-related trips. Since the University's accounting systems focus on travel expenditures, most GHG emissions are estimated on the basis of that data, leading to greater uncertainty in the results than for calculations based on fuel consumption.

About 30% of travel financed by Yale is booked through Yale's travel agency. In addition to providing cost data, the travel agency was able to provide some sample data on the air and train routes traveled. It also provided benchmark information for car rental and ground transportation costs and average miles traveled. Such data were used in combination with the total cost data to estimate miles traveled and related GHG emissions. Figure 3 summarizes the sources, steps and assumptions used to calculate GHG emissions from work-related travel.[vii]

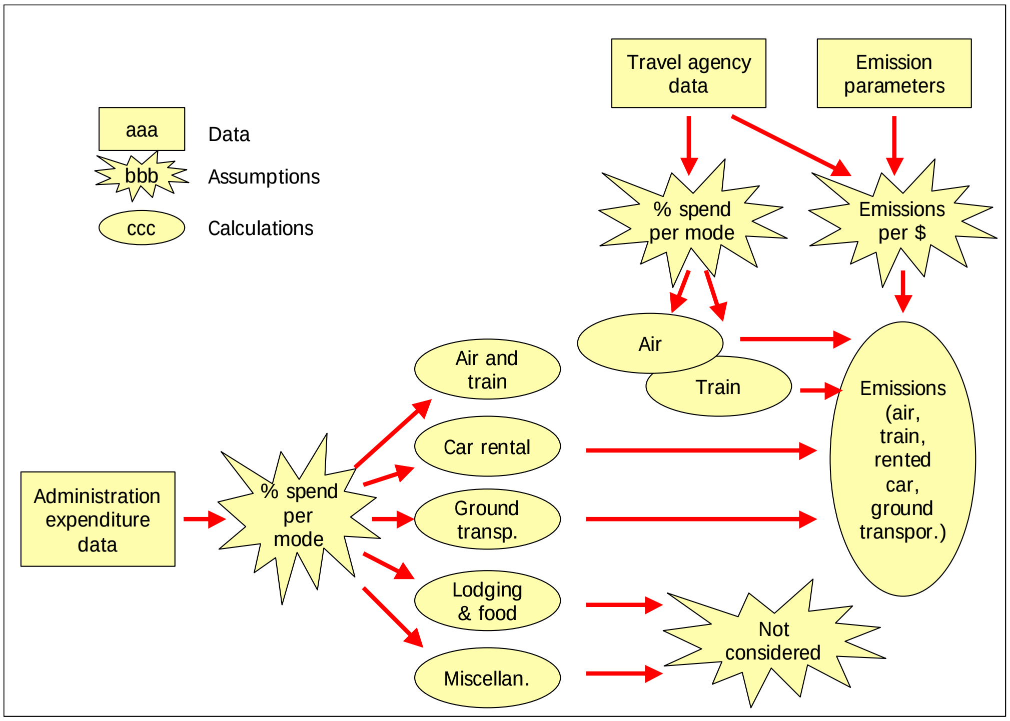

Figure 3: Transportation Cost Analysis Flow Diagram

Travel Agency Flights

Travel agency flights are the only subset of work-related travel for which anything other than financial data is available. Therefore, GHG emissions calculations from this source were handled separately in the analysis.

Yale's internal travel agency tracks the top "city pairs" booked through its service each year. These pairs refer to the endpoint cities of a trip and can be used to calculate the distance traveled by plane. (The last year for which city pair data are available is 2001. These data were used to approximate 2002 data.)

CO_2 emissions were calculated using two distinct approaches. The first calculated energy consumption and emissions by estimating the fuel efficiency of air travel and multiplying approximate gallons of fuel consumed by corresponding energy and emissions conversion factors.

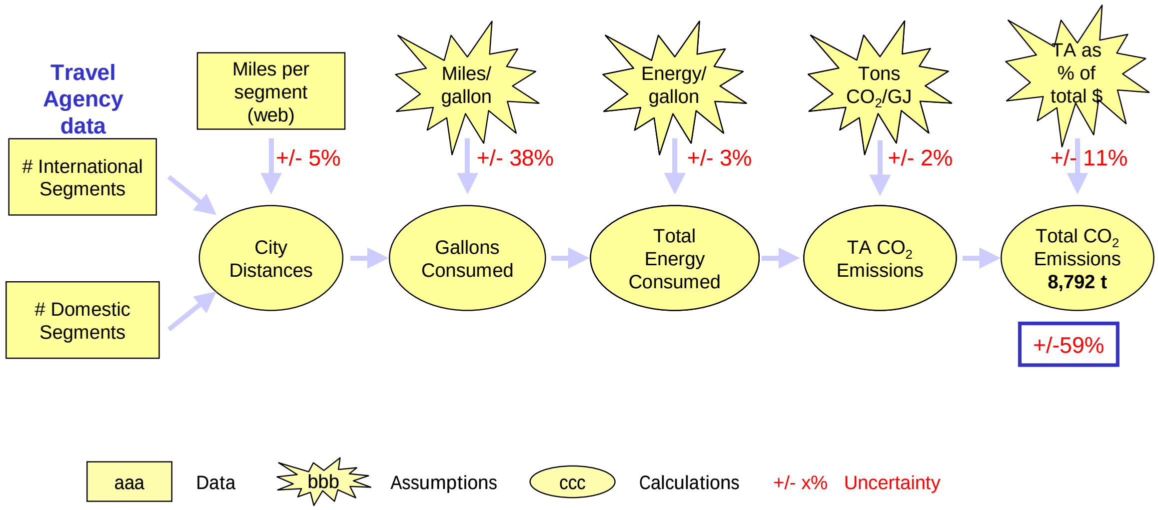

Figure 4: Work related emissions - CO_2 from air travel – energy consumption method

The second approach was based on the GHG Protocol methodology elaborated by WBCSD/WRI. WBCSD and WRI provide carbon dioxide emissions per plane-mile-traveled. These emissions factors are divided into three tiers based on flight distance, which takes into account the increased efficiency of longer trips.

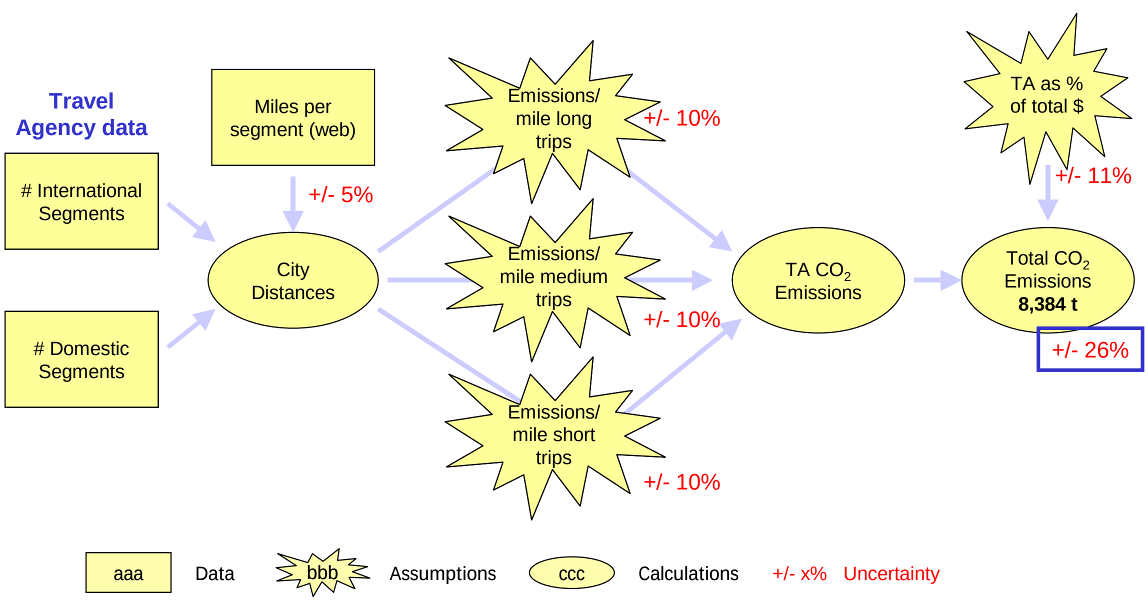

Figure 5: Work related emissions - CO_2 from air travel – emissions per passenger mile method

The total emissions calculated using the WBCSD/WRI method were compared to emissions derived from the energy consumption values found above. The energy and emissions calculations result in estimates well within one another's ranges of uncertainty, with one notable exception. Although the flight emissions totals are comparable, the allocation between domestic and international travel varied dramatically based on whether the energy or emissions calculation method was applied. The approach based on fuel consumption assigns the majority of emissions to international flights, since these account for more miles and therefore more fuel consumed using a flat miles-per-gallon ratio. The approach based on emissions per mile assigns the majority of the emissions to domestic flights, since these are the least efficient. The latter approach seems to be the most reliable, since it provides more specificity for different types of trips, but the former serves as a valuable check on the order of magnitude of the calculations.

Lastly, because not all trips are captured by the top city-pairs, YCI estimated the percentage of trips captured by the travel agency data. The additional assumption was made that the percentage of dollars captured is representative of the percentage of miles captured (i.e. constant dollars spent per mile).

Uncertainty in travel agency flight energy consumption is due to four factors: completeness of activity data, accuracy of distance calculations, fuel economy factors, and the energy factor of the fuel. Because the data source (2001) did not quite match the established YCI baseline (2002), an uncertainty of five percent was assigned to the original data. Another five percent was assumed for estimates of distances between city pairs. The largest uncertainty is due to assumptions related to fuel economy factors. Passenger miles per gallon estimates were provided by the American Institute of Physics,[viii] but these are only available for 747 and A300 jet planes. An average of these values was used with a wide uncertainty range (38%); this provides only a crude approximation of fuel economy since it does not take into account the increased efficiency of longer trips at higher altitudes. An 11% uncertainty was attributed to the dollars spent per mile, based on a statistical confidence interval of the average dollars/mile calculated from the sample.

Emissions parameters provided lower calculation uncertainty, since the extra step of calculating fuel use was not required. Assumptions for non-2002 data, distance calculations, and completeness of data were assigned uncertainties as described above. Additionally, a 10% uncertainty was assumed for the WRI emissions/mile factors. (See appendix for details of calculations.)

Additional Work-Related Emissions

The remaining work-related emissions (flights not booked through the travel agency and emissions from car rental, train and ground transportation) were calculated on the basis of financial data and using a number of assumptions and parameters, summarized in Table 4 below. (See the appendix for the details of these parameters and their contributions to the uncertainty of the calculations.)

- Flight and train expenditure as % of total
- Estimated travel agency Amtrak expenditures
- Estimated non travel agency Amtrak as % of travel agency expenditures
- Estimated Metro North expenditures as % of Amtrak
- Emissions per mile from domestic train
- Miles and emissions per dollar spent in domestic flights
- Foreign flight expenditures vs. foreign train expenditures
- Miles and emissions per dollars from car rental
- Miles and emissions per dollar ground transportations

- Miles and emissions per dollar from foreign trains and flights
- Other

Table 4: Work-related emissions parameters used

Each of these parameters influences the emissions generated by work-related travel, and each parameter had a high degree of uncertainty due to a lack of data or accepted benchmarks (especially for miles- and emissions-per-dollar parameters). Individually, however, none of these parameters influenced the total emissions from work-related travel by more than 3.3%. For Yale University, work-related GHG emissions were dominated by air travel (comprising 75% of work-related emissions), for which the university holds reasonably detailed data (on city-to-city travel). In other organizations the role of airline travel may be smaller or the data on airline travel may be less precise (most corporations are likely to have expenditure data only). In these situations the overall level of uncertainty would be higher than at Yale unless more precise parameters and benchmarks are made available.

C. Conclusions/recommendations

Corporate accounting systems focus on financial information and are not designed to enable GHG inventories. Several techniques and parameters can lead to significant improvements in inventory results:

1. Standardized (generalized) factors such as miles traveled or emissions per dollar spent. These factors can be differentiated by transportation mode (train, ground, air) and can be of various degrees of geographic granularity (federal, state, local).

2. Standardized sampling practices to calculate company-specific factors such as miles traveled per dollar spent.

3. Standardized templates for institutional mobility studies. The degree of uncertainty of transportation GHG inventories would be decreased with company-specific and trip-specific GHG inventory data instead of high-level financially-based estimates.

4. Protocols to communicate trip-specific emissions data from suppliers of travel services (e.g. air or train companies) to end-users. With an increasing number of transactions taking place online and with an increasing integration between different corporate systems, these solutions are likely to become increasingly cost effective and mainstream in financial and environmental accounting.

VI. Personnel (and student) commuting

A. Definition

Commuting travel covers trips taken by Yale employees and students between campus and their local homes. The mode, frequency and distance of travel are determined entirely by the traveler, but Yale's role in causing the trip cannot be ignored. Yale employs over 12,500 people, each of whom generates greenhouse gas emissions when commuting to campus using vehicles that burn fossil fuels.

B. Analysis

For employees, YCI based the GHG emissions calculations on information on the ZIP codes of employee residences, which were obtained through the human resources department, and assumptions about the mode that employees might use to travel to work from various distances. The calculation of GHG emission from personnel commuting was performed using the steps depicted in Figure 6.

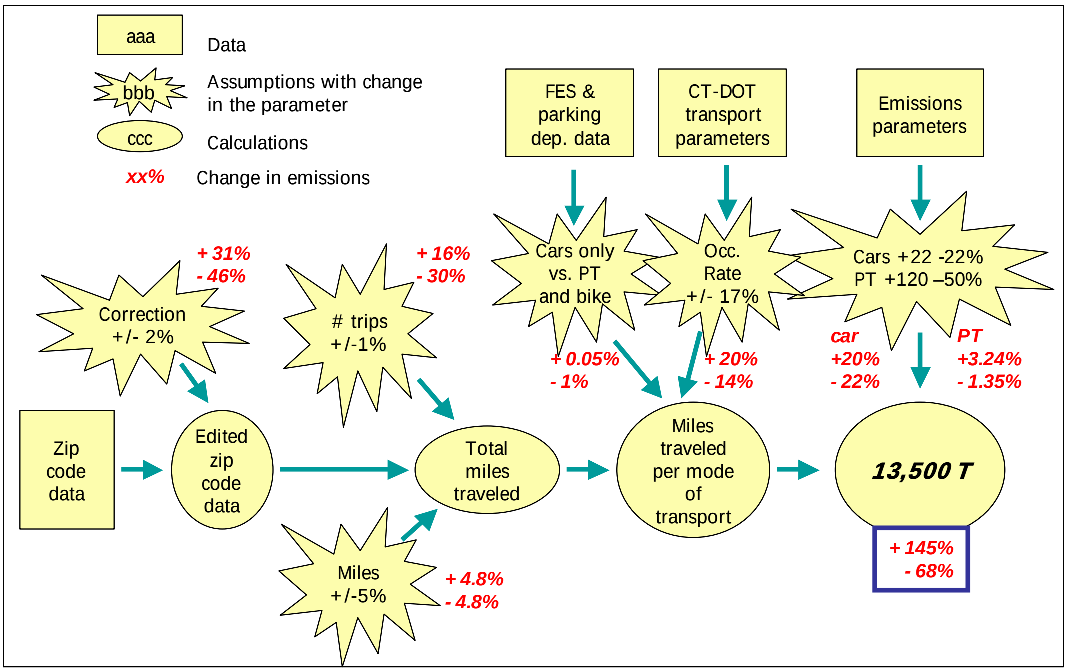

Figure 6: GHG Emissions from Personnel Commuting – Steps for Calculation

For each employee, yearly CO_2 emissions were calculated using the formula:

Yearly CO_2 emission = Employee distance from school * number of commutes per year * car occupancy rate (car only) * CO_2 emissions per mile traveled

In addition to providing information about the calculation steps undertaken, Figure 6 above indicates the uncertainties associated with the calculations. The main uncertainties in the GHG emissions estimate are as follows:

- Not all the records in the ZIP code database were accurate, and a "correction" step was therefore necessary. This step required the identification of implausible records and substitution with "assumed current addresses." In some cases, implausible records were easy to identify (e.g. a ZIP code from California or Texas). In other cases, the records were ambiguous and could either indicate a mistake or an employee commuting from a far distance (e.g. Boston or New

York). Because these corrections involved original "high mileage" numbers, the potential impact of a mistake in the correction is high.

- Information about the number of commutes per year of different employees was not available. Faculty members, post-graduate fellows, research assistants and post-doctoral associates (about 7,700 people) may have flexible working schedules (as do some of the employees in administrative and managerial positions). It is therefore plausible that these employees do not commute to school regularly, especially if they live far from New Haven. This was the basic assumption used in the emissions calculation—that those who live beyond a certain distance threshold travel to campus less often. Given that no data are available about commuting behavior, however, the assumption about the number of commutes has a high uncertainty associated with it. Since the degree of uncertainty is higher with employees that live far from New Haven, the potential impact of small mistakes in the assumption (e.g. assuming that employees from Providence, RI commute every day versus twice a week) is high.

- For commutes by car (representing over 95% of the commuting miles), the type of vehicle and the car occupancy rate are not known.

Student commutes were calculated using the same methodology described above. As was the case with personnel, the emissions of students commuting to campus are driven by the distance from campus, the number of trips to campus, and the means of transportation. YCI based the GHG emissions calculation on information on the ZIP codes of student residences and on assumptions related to the number of commutes and the percentage of students commuting by car.

A similar approach was used to estimate emissions from students traveling home during breaks and weekends. For these emissions the overall level of uncertainty was very high for both domestic and international students. The largest source of uncertainty was the lack of corroborated information about the number of trips undertaken each year.

C. Conclusions/recommendations

A number of strategies could help in calculating CO_2 emissions from commuting more accurately (or at least more consistently across different organizations). They include:

- Consistent mobility study templates—identifying standard travel questions, units, and reporting formats—for Universities and corporations. A template for determining institution-specific behavioral data (e.g. number of commutes per year, mode of transportation chosen, and car occupancy ratio) would offer greatly reduced uncertainty as well as consistency across organizations.
- More precise and current data on employee and student residences. Better data on this key factor could reduce its substantial impact on uncertainty.
- Vehicle-specific data (e.g. vehicle type or model year). This information could be collected by the parking department at Yale, which already issues individual parking permits to employees and students.

- More complete and accurate state and local data on transportation and commuting behavior. Organizations such as states Departments of Transportation currently gather data such as car occupancy (from car accident reports). Fewer data are available on other transportation-related activities (e.g. mode of transportation) or at the local (e.g. municipality) level. A set of agreed-upon parameters—and the availability of a central repository for them—could significantly improve organizations' ability to undertake GHG inventories for commuting.
- State- and local-level emission parameters (e.g. for car, train or bus emissions). As with behavioral parameters, an agreed-upon standard and repository for national, state and local vehicle data would facilitate inventory processes.

VII. Summary: Emissions from Transportation

Emissions totals

Greenhouse gas emissions from the transportation section break down as follows.

Emission source	***Energy (GJ)***	***CO_2 eq estimate (metric tons)***	**% of Yale's GHG emissions**	**Uncertainty**	**CO_2 eq lowest case (metric tons)**	**CO_2 eq highest case (metric tons)**
Owned-vehicle travel (CO_2 only)	26,278	1,622	0.55%	+/- 8%	1,492	1,752
Work-related travel						
Air travel through travel agent (CO_2 only)	122,962	8,394	2.85%	+/- 26%	6,204	10,564
Other (CO_2 only)		2,734	0.93%	+50%/-36%	1,750	4,101
Commuting						
Employees (CO_2 only)		13,500	4.59%	+145%/-68%	4,302	33,075
Students (CO_2 only)		1,700	0.58%	+297%/-69%	527	6,749
Students returning home (dom.) (CO_2 only)		5,400	1.84%	+88%/-56%	2,376	10,152
Students returning home (int'l.) (CO_2 only)		415	0.14%	+62%/-31%	286	672
Other gases		1,777	0.6%	+99%/-50%	889	3,536
Total	**149,230**	**35,542**	**12%**	**+99%/-50%**	**17,771**	**70,729**

Table 5: Greenhouse Gas Emissions from Transportation

Benchmarking Against Other Universities and National Averages

As shown in Table 6 below, Yale's inventory of greenhouse gas emissions from transportation sources is more comprehensive than other schools' inventories that were reviewed. However, estimates made for several of the transportation categories at Yale are quite uncertain. Researchers at both Tufts and Tulane were able to make use of recent mobility studies conducted within the institutions; such a study at Yale would provide much more reliable estimates of actual GHG emissions.

Emission source (all gases)	Yale (2002)	Tufts[ix] (1998)	Tulane[x] (2000)	University of Colorado[xi] (2000)
Owned-vehicle travel (university fleet)	1,707	Contribution unknown	411	256
Work-related travel	11,714	Not included	Not included	Not included
Commuting				
Employees	14,211	Contribution unknown	2,477	Not included
Students	1,789	Contribution unknown	2,390	Not included
Students returning home (dom.)	5,684	Not included	Not included	Not included
Students returning home (int'l.)	437	Not included	Not included	Not included
Total (tons)	35,542	1,067	5,278	256
% of University inventory from transportation sources	12%	6%	10%	<1%

Table 6: Benchmarking Greenhouse Gas Emissions Due to Transportation Sources at Various Universities (Metric tons CO_2 eq. Includes CO_2 and other gases)

The variation across the schools in the percentage of total emissions caused by transportation sources is quite large. Yale's is the highest of any institution reviewed (in absolute terms as well as per capita), primarily due to the fact that it considers more categories of travel. (One of Yale's largest transportation sources is work-related travel, a category not considered in any other school inventory.) However, none of the universities approaches the average United States contribution of transportation sources to overall emissions. According to the U.S. Climate Action Report—2002[xii], transportation sources contributed 30% of total greenhouse gas emissions in the United States in 1990. The disparity between this value and those found in university inventories is partially due to the fact that only travel that can be directly attributed to the University has been counted here. Errands and recreational travel for faculty, staff and students will contribute significant emissions per person, but have not been included in the YCI inventory because it is assumed that this travel would occur regardless of an association with Yale University. The difference also may be partially explained by the difference in lifestyle of a university student versus a typical American. Many students live within walking distance of the university and many of their recreation destinations, as do most of their peers. Typical Americans would seem more likely to drive on a daily basis—to work, errands, social engagements, etc— than typical university students are.

Uncertainty Relative to other Sectors

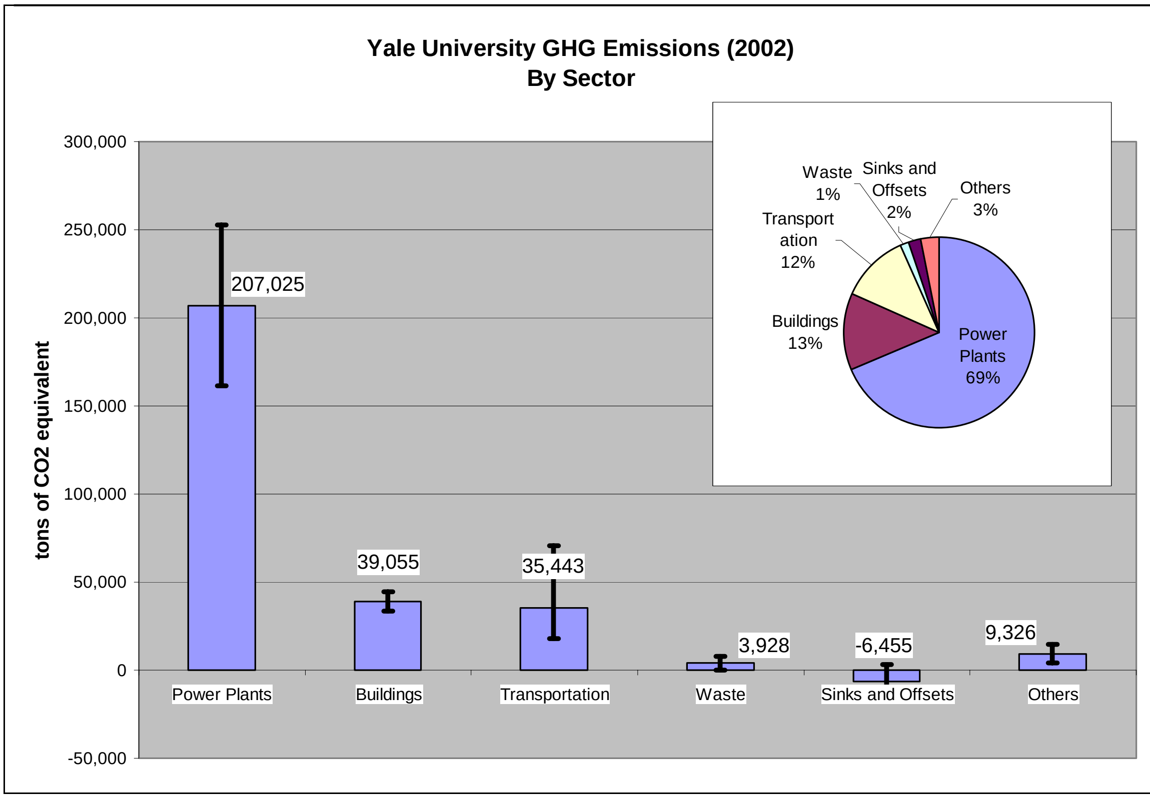

Figure 7: Yale University GHG Emissions by Sector, 2002

While transportation emissions are only 12% of the total inventory, the uncertainty of this sector relative to its size is quite high relative to other sectors. At the high end of the uncertainty range, transportation emissions could actually surpass those from buildings. This uncertainty points to the need for better data collection as well as more robust calculation tools and conversion factors in this sector.

VIII. Conclusions/recommendations for generalized transportation inventories

This paper has discussed Yale's inventory of GHG emissions from transportation sources and highlighted some of the challenges that inventory practitioners currently face. Such challenges are especially relevant when estimating emissions not directly emitted from University-owned vehicles.

Many of the difficulties appear to be caused by a lack of shared methodologies and benchmarks across the GHG emission inventory community. Significant improvements in emissions estimates (leading to a reduction of uncertainty) could be achieved in all steps of the emissions calculation process:

- Data gathering
- Benchmarks and parameters
- Calculation tools

While some aspects of this inventory are unique to universities (most corporations will likely not need to consider holiday flights home for their employees), and some are specific to Yale's management practices, the record-keeping systems of Yale University are not unique. Fleet credit cards are common tools for institutional fuel purchases, and accounting departments are much more likely to maintain financial records than information on mileage, destination, or mode of travel. Therefore, tools and conversion factors tailored to these types of records will likely benefit a variety of corporate and academic GHG inventories beyond this specific example.

A. Data Quality

The management systems of large universities (and of corporations or organizations in general) are not designed to generate accurate data on GHG emissions and emission sources. Understandably, given the incentives currently present in the market, most organizations focus on cost, revenue and cash flow data. Moreover, as discussed in section IV, information systems may be set up to collect relevant data but not used in practice (e.g. drivers not entering odometer data when refilling their vehicles). Improvements can therefore occur both in terms of supporting information technology (i.e. databases and operation management systems) and management processes. For the latter, it is particularly important to provide end users with incentives to ensure that relevant data are gathered and processed. This may require providing context and meaningful feedback (e.g. users could be provided information on their performance in terms of mileage traveled, total emissions or efficiency). Such data could also be compared at the department/company level and become part of formal employee performance evaluations. Setting up the right incentive structure is highly dependent on the culture, structure and processes of individual organizations. It is therefore advisable that each company evaluate and select data flow and incentive structures that fit with its individual environment. To facilitate this process the GHG inventory community could gather and analyze representative case studies, designed to provide ideas and insight on examples in which:

- Fleet managers can successfully gather mileage data entered by end users when refilling their vehicles
- Odometer readings take place during regular vehicle maintenance activities
- Maintenance activities provide data and parameters on non-CO_2 emissions (e.g. HFC leakages from air conditioning system)
- Expense reporting systems are able to provide granular data on work-related travel at minimum additional administrative costs
- Organizations are successfully gathering and processing data on commuting
- Organizations are able to obtain relevant GHG data from the information systems of their suppliers (e.g. travel agencies providing data on GHG emissions)

A tool that may be particularly relevant for organizations wanting to assess the emissions generated by personnel commuting is an employee mobility survey, most likely based on responses to a questionnaire. The inventory community could assist this process by creating standardized survey templates. Not only would this assist organizations that want to better estimate the GHG emissions of their employees, but it would also facilitate comparison between companies and over time.

Over time, as markets for GHGs develop, and information requirements become more sophisticated, companies are likely to require information systems that can link up and obtain GHG-relevant data from their suppliers (travel agencies, airlines, taxi companies, train operators, fleet managers, etc.). To assist this process the inventory community could start analyzing the implications of such systems and defining standards to implement them cost-effectively.

B. Benchmarks and parameters

Many organizations may not have the need or the resources to change their reporting systems, gather additional data, undertake mobility surveys, etc. In these cases emissions can be calculated using benchmarks and emissions parameters that are applicable to the industry or the geographic area in which the organization operates, and the types of data it is likely to collect.

In calculating GHG emissions for Yale University, YCI used a variety of parameters and emissions factors from many sources (see sections IV to VI). In undertaking this exercise the authors noted a lack of reliable, complete and consistent data sources (which increased the uncertainty of calculations and made comparisons with other inventories more difficult). Organizations such as WRI/WBCSD, EPA or DOT provide conversion factors and benchmarks, but they do not cover the whole spectrum of the calculations we undertook, are not organized systematically for this type of study, and are not always consistent.

The inventory community could therefore improve emissions estimates (or at least move towards more consistent calculations across organizations and over time) by gathering, analyzing, publishing, and explaining relevant behavioral and emission parameters. Parameters that could be agreed upon and used consistently in inventory exercises include the following.

- For work-related emissions:
  - Miles traveled per dollar spent for different modes of transportation (train, airplane, bus, taxi, etc.)
  - Emissions per passenger mile traveled by mode of transportation
- For emissions from commuting
  - Average distances traveled by commuters
  - Percent of commuters using each transportation mode
  - Vehicle occupancy rates
  - Emissions per passenger mile by mode of transportation

  - Emissions per passenger mile by car type (for organizations that have access to the vehicle types used by their employees)

Ideally such parameters should not simply be national benchmarks, but should be made available at the state or local level, since significant differences may be present between different states or local communities.

C. Calculation tools

Several organizations, including EPA and WBCSD/WRI, have provided methodologies and calculation tools that are extremely useful for organizations undertaking GHG inventories. In a number of areas, however these tools could be improved. In particular:

- Calculation modules or templates can be added to estimate emissions and uncertainty from work-related travel.
- Calculation modules or templates can be added to estimate miles traveled, emissions and uncertainty from commuting.
- Uncertainty analysis can be treated more explicitly in the calculation models.
- Calculation modules or templates can be added to calculate non-energy emissions (e.g. HFC from air conditioning systems).
- Tools to calculate fuel-related emissions of non-CO_2 gases from transportation, perhaps as simple as an average ratio of other emissions to CO_2 emissions for different modes of transportation.
- Tools can be offered for organizations that want to compare their emissions with other organizations.

Ideally some thought could also go into tools to help organizations understand and assess different mitigation options and the potential benefits associated with different strategies to reduce emissions.

D. Final remarks

Undertaking the GHG inventory for Yale University and analyzing the role played by transportation emissions shed light on the relative contribution of the sector, as well as the drivers and uncertainties that surround these emission sources.

By including in the analysis emissions categories that are generally excluded from GHG inventories we highlighted the need to further develop calculation tools, benchmarks and parameters for these calculations. In all these areas there is significant room for improvement if the inventory community agrees on standard analytical tools, data sources and repositories.

Appendix A: Calculations

1. Owned-Vehicle Travel Calculations

Category	Energy (GJ)	CO2 (Tons)	Uncertainty	Reason for uncertainty
Unleaded Gasoline				
Activity Data (gallons)	166,319.04		5%	Variation btn CY02 and FY02
Energy Conversion (GJ/barrel)	6.10		3%	Assumed throughout inventory
Unit Conversion (Barrel/Gallon)	0.02		0%	Unit definition
Energy Value (GJ)	24,155.86		8%	Calculation: Sum of above
Emissions Conversion (kg CO2/gallon)		8.87	3%	Variation in emission factor references
Emissions Value (metric tons)		1,475.25	8%	Calculation: Sum of above
Diesel Gasoline				
Activity Data (gallons)	14,472.05		5%	Variation btn CY02 and FY02
Energy Conversion (Btu/gallon)	139,000.00		3%	Assumed throughout inventory
Unit Conversion (GJ/Btu)	0.00		0%	Unit definition
Energy Value (GJ)	2,122.25		8%	Unit definition
Emissions Conversion		10.15	3%	Variation in emission factor references
Emissions Value (metric tons)		146.89	8%	Sum of above
Totals				
	24,155.86			
	2,122.25			
Total Energy	26,278.11		8%	0%
		1,475.25		
		146.89		
Total Emissions		1,622.14	8%	0%

Table A.1: Institutional Energy/Emissions Calculations

Energy and emissions factors provided by WRI, but checked against EPA and IPCC values.

2. Work-Related Travel Calculations

Air Travel from Travel Agent

a) Energy

*Energy from Air Travel = Number of travel segments * Miles Traveled/segment * (1/Fuel Economy of Air Travel) [average pass-miles/gallon] * Energy Factor for Jet Fuel*

Passenger miles/gallon 747: 36 pass-miles/gallon
Passenger miles/gallon A300 Airbus: 80 pass-miles/gallon
Average passenger miles/gallon used: 58 pass-miles/gallon (with 38% uncertainty)

(See Appendix B, Conversion Factors, for energy factors)

b) Emissions

*Emissions from Air Travel = Number of travel segments * Miles Traveled/segment / Emissions Factors by Travel Distance*

(See Appendix B, Conversion Factors, for emissions factors)

Category	Energy (GJ)	CO2 (tons)	Uncertainty	Reason for uncertainty
Domestic Air Travel				
Activity Data (# of segments for each city pair)			5%	Variations btn CY2001 and CY 2002
Passenger Miles Traveled	9,115,000		5%	Calculation of distance by city centers, not airport locations
Fuel Economy (Passenger-miles/gallon)	58		38%	Average of different factors
Energy Conversion (Btu/gallon)	135,000		2%	Assumed throughout inventory
Unit Conversion (GJ/Btu)	1.06E-06		0%	Unit conversion
Energy Value (GJ)	22,383			
Emissions Conversion (kg CO2/mile)		Varies by distance	10%	Assumes uniform pass-mpg regardless of plane
Emissions Value (tons CO2)		3797.5		
Percentage of Data Captured (%)	70%	70%	11%	Confidence interval of constant $/mile assumed
Extrapolated Energy Value (GJ)	31,975		61%	Total
Extrapolated Emissions Value (tons CO2)		5,425	31%	Total
International Air Travel				
Activity Data (# of segments for each city pair)			5%	Variations btn CY2001 and CY 2002
Passenger Miles Traveled	20,379,000		5%	Calculation of distance by city centers, not airport locations
Fuel Economy (Passenger-miles/gallon)	58		38%	Average of different factors
Energy Conversion (Btu/gallon)	135,000		2%	Assumed throughout inventory
Unit Conversion (GJ/Btu)	1.06E-06		0%	Unit conversion
Energy Value (GJ)	50,043			
Emissions Conversion (kg CO2/mile)		Varies by distance	10%	Assumes uniform pass-mpg regardless of plane
Emissions Value (tons CO2)		1,633		
Percentage of Data Captured (%)	55%	55%	11%	Confidence interval of constant $/mile assumed
Extrapolated Energy Value (GJ)	90,987		61%	Total
Extrapolated Emissions Value (tons CO2)		2,969	31%	Total
Totals				
Total Energy (GJ)	122,962			
Total Emissions (tons CO2)		8,394		

Table A.2: Travel Agency Air Travel Energy/Emissions Calculations

Energy and emissions factors provided by WRI, but checked against IPCC values.

Calculation of GHG emissions from work related transportation

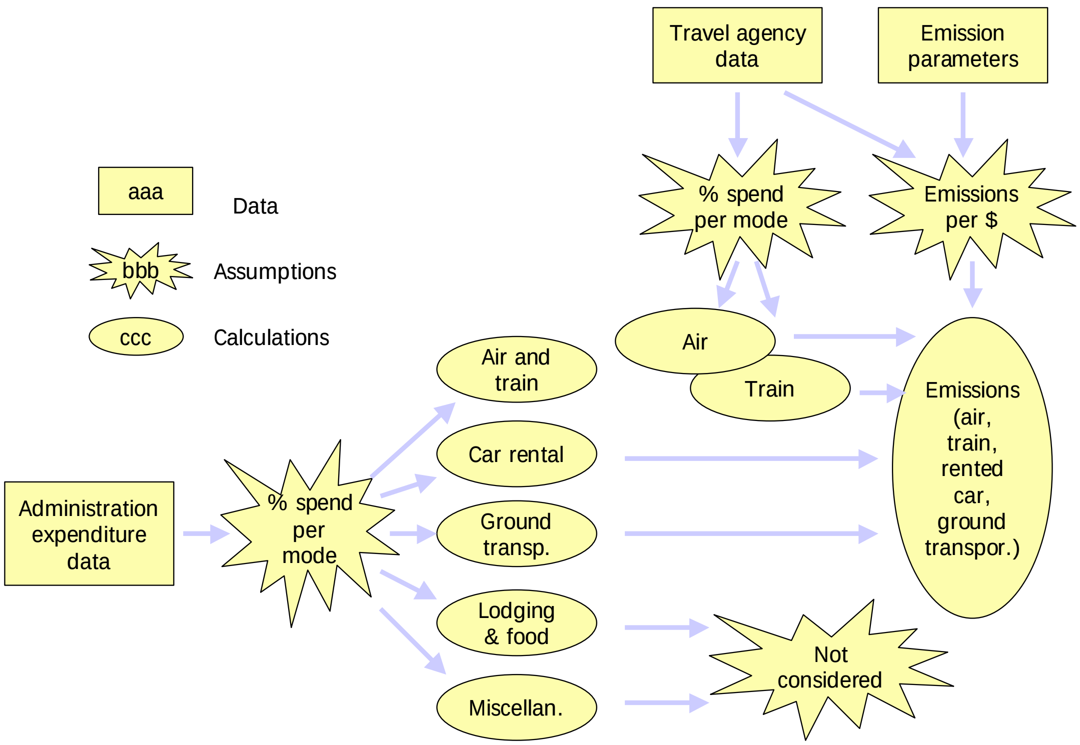

Figure A.1: GHG Emissions from work related transportation – data flow

Emissions calculation for Train and Air travel

*Emissions for Amtrak train trips not booked via travel agency = Miles for Amtrak train trips booked via the travel agency * Non travel agency Amtrak as % of travel agency Amtrak * GHG emissions per Amtrak mile traveled*

*Emissions for Metro North train trips = Amtrak train trips to New York booked via the travel agency * Metro North as % of Amtrak ration * GHG emissions per Metro North mile traveled*

*Emissions from air travel domestic = (Total Expenditures Air & train foreign – Travel Agency expenditures for domestic air travel - Estimated train expenditures domestic) * miles per $ spent * GHG emissions per air mile traveled*

*Emissions from train travel foreign = (Expenditures Air & train domestic – Travel Agency expenditures for foreign air travel) * % train expenditures * miles per $ * GHG emissions per air mile*

*Emissions from air travel foreign = (Expenditures Air & train domestic – Travel Agency expenditures for foreign air travel) * % air expenditures * miles per $ * GHG emissions per air mile*

Car rental domestic and foreign

*Emissions from car rental = Expenditures for car rental * Car rental cost per day * miles traveled per day * GHG emissions per mile*

Ground transportation domestic and foreign

*Emissions from ground transportation = Expenditures for ground transportation * Ground transportation cost per mile* GHG emissions per mile*

	Base case	High emissions scenario	Low emissions scenario
Expenses allocation travel foreign			
For. Travel - Air/Rail	60.6%	65.0%	55.0%
For. Travel - Lodging	19.9%	15.5%	25.5%
For. Travel - Car Rental	1.3%	1.3%	1.3%
For. Travel - Ground Transportation	4.3%	4.3%	4.3%
For. Travel - Meals	11.1%	11.1%	11.1%
For. Travel - Miscellaneous	2.9%	2.8%	2.8%
Total foreign	100.0%	100.0%	100.0%
Expenses allocation travel domestic			
Dom. Travel - Air/Rail	33.5%	33.5%	33.5%
Dom. Travel - Lodging	35.8%	35.8%	35.8%
Dom. Travel - Car Rental	3.2%	3.2%	3.2%
Dom. Travel - Ground Transportation	13.6%	13.6%	13.6%
Dom. Travel - Meals	11.9%	11.9%	11.9%
Dom. Travel - Miscellaneous	1.9%	1.9%	1.9%
Total domestic	100.0%	100.0%	100.0%
Travel agency flight emissions			
Travel agency emissions kg CO2	8,384,000	10,564,000	6,204,000
Flight and train			
Amtrak miles TA	774,558	821,031	728,085
Amtrak spent TA	330,648	341,890	319,406
Foreign train expenses as % of residual	5%	10%	0%
Non TA Amtrak as % of TA	50%	25%	100%
Metro North trips to NY (* Amtrak trips)	20	10	40
Car rental			
Car rental foreign $ per day	40	50	30
Car rental domestic $ per day	40	50	30
car rental foreign miles per day	50	85	30
car rental domestic miles per day	50	85	30
Ground transportation			
Ground transportation foreign miles per $	1.6	2	1
Ground transportation domestic miles per $	1.6	2	1
Emission assumption			
Foreign flights no TA - miles per $ spent	8.29	9.2019	7.3781
Foreign flights no TA - Kg emissions per $ spent	1.50	1.665	1.335
Foreign train Kg emissions per $ spend	0.54	0.7	0.4
Amtrak Kg emissions per mile traveled	0.22	0.55	0.15
Metro North Kg emissions per mile traveled	0.22	0.55	0.15
Domestic flights - miles per $ spent	7.56	8.3916	6.7284
Domestic flights - kg emission per $ spent	1.41	1.57	1.25

Car rental foreign Kg emissions per mile	0.36	0.44	0.2
Car rental domestic Kg emissions per mile	0.36	0.44	0.2
Ground transportation foreign - Kg emission per mile	0.20	0.44	0.1
Ground transportation domestic - Kg emission per mile	0.20	0.44	0.1

Table A.3: GHG emissions from work related travel – assumptions

E. Commuting Calculations

Calculation of GHG emissions from personnel commuting

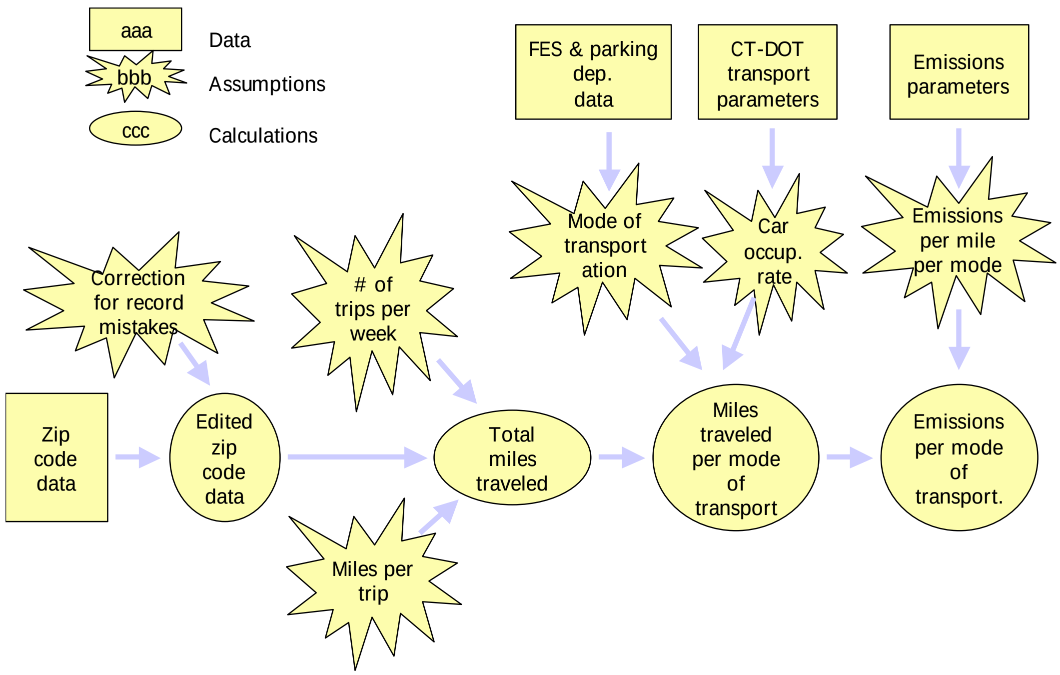

Figure A.2: GHG emissions from personnel commuting – data flow

Number of commutes is function of distance from school.

*GHG Emissions from personnel commuting by car = Miles distance from school * number of commutes per year / car occupancy rate * GHG emissions per mile*

*GHG Emissions from personnel commuting by public transportation = Miles distance from school * number of commutes per year * GHG emissions per mile*

GHG Emissions from personnel commuting by bike or foot = zero

GHG Emissions from personnel commuting by Yale bus = zero

	Base case	High emissions scenario	Low emissions scenario
Data assumptions			
Cut off point for zip codes to assume erroneous (miles)	80	Zip codes outside CT, MA. NY, NH, RI, NJ	60
Miles per trip uncertainty	0%	5%	-5%
Behavioral assumptions			
# of commutes	medium	All commute 5 days a week	Fewer commutes
Use of bikes public transportation	medium	nobody uses them	high use
Definition of walking distance (miles)	0.5	0	1
% people that live in walking distance and commutes by walking, biking or Yale bus	0.75	0.00	1.00
Nobody uses Yale bus if they live farther then these miles	3.0	0	5
Public transportation users as % of non bikers/walkers/Yalebussers	4.0%	2.0%	6.0%
Car occupancy ratio	1.2	1.0	1.4
Emission assumption			
Car emissions (Kg per mile)	0.36	0.44	0.28
Public transportation emissions (Kg per mile)	0.20	0.44	0.1

Table A.4: GHG emissions from employee commuting – assumptions

GHG Emissions from students commuting

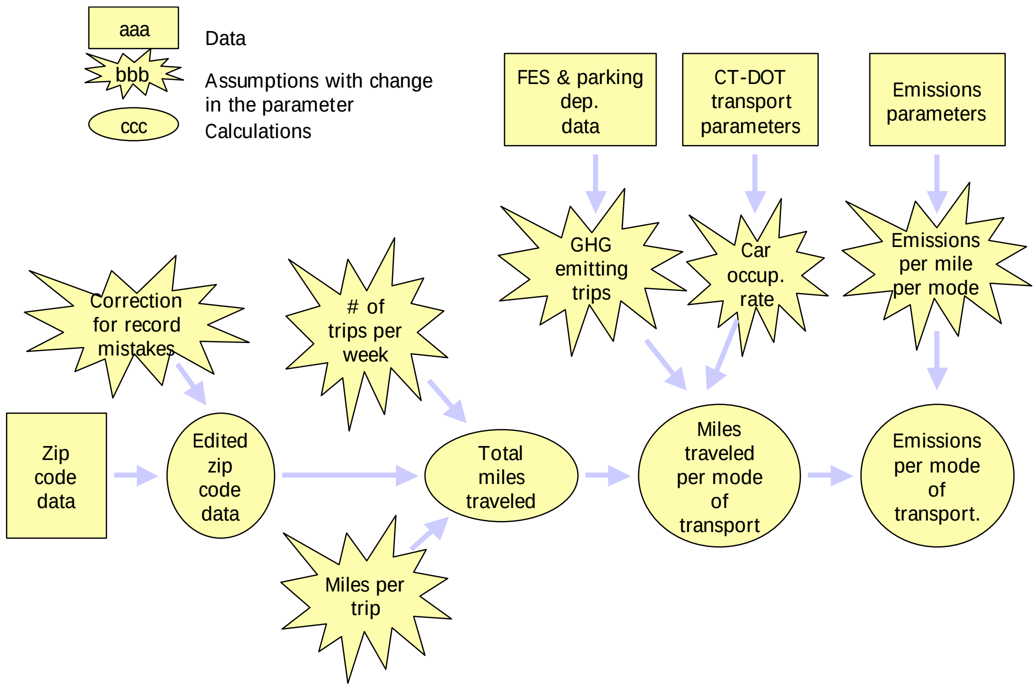

Figure A.3: GHG emissions from students commuting – data flow

Number of commutes is function of distance from school.

*GHG Emissions from students commuting by GHG emitting vehicles = Miles distance from school * number of commutes per year / car occupancy rate * GHG emissions per mile*

GHG Emissions from personnel commuting by bike or foot = zero

GHG Emissions from personnel commuting by Yale bus = zero

	Base case	High emissions scenario	Low emissions scenario
Data cleaning assumptions			
Cut off point for zip codes to assume erroneous (miles)	70	100	50
Error in miles calculation	0.0%	5.0%	-5.0%
Trips to school per week			
Less then 1 mile	10	10	9
Between 1 and 3	10	10	8
Between 3 and 30	10	10	7
Between 30 and 70	8	10	4
Over 70 (outliers)	10	10	8
Number of week per annum	30	32	28
% CO_2 emitting trips			
Less then 1 mile	5.0%	100.0%	0.0%
Between 1 and 3	50.0%	100.0%	20.0%
Between 3 and 30	100.0%	100.0%	98.0%
Between 30 and 30	100.0%	100.0%	100.0%
Over 30 (outliers)	100.0%	100.0%	100.0%
Car occupancy ratio	1.2	1.0	1.4
kg CO_2 emissions per mile traveled	0.36	0.44	0.28

Table A.5: GHG emissions from students commuting - assumptions

GHG emissions from students visiting home

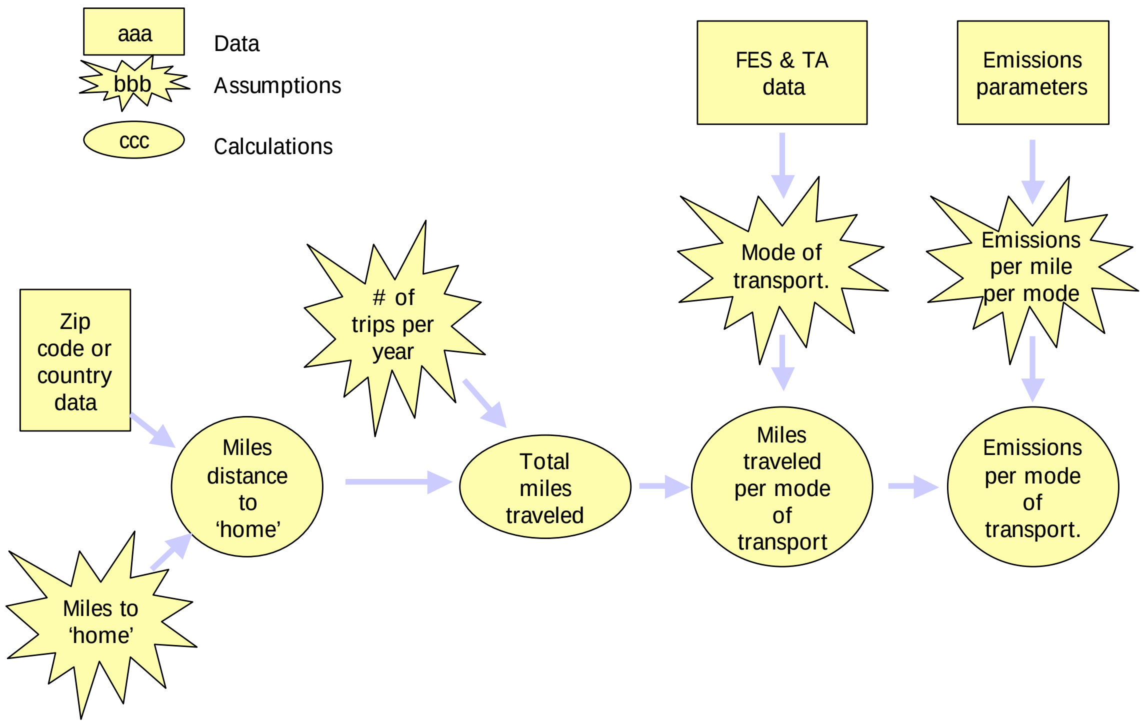

Figure A.4: GHG Emissions from Students visiting home – data flow

Number of visits home in a year are function of the distance between Home and New Haven.

All foreign students are assumed to visit home by plane.

*GHG Emissions from trips home by car = Number of visits home * Miles distance between home and school * % visits by car * GHG emissions per mile*

*GHG Emissions from trips home by public transportation = Number of visits home * Miles distance between home and school * % visits by public transportation * GHG emissions per mile*

*GHG Emissions from trips by airplane = Number of visits home * Miles distance between home and school * % visits by plane * GHG emissions per mile*

	Base case	High emissions scenario	Low emissions scenario
Data correction			
Correction on distance estimated	0.0%	5.0%	-5.0%
Number of trips home in a year (based on students' distance from home)			
Between 100 and 300 miles	6	10	4
Between 300 and 1000 miles	4	6	2
Over 1000	3	4	1.5
Traveling mode trips between 100 and 300 miles (%)			
Public transportation	10.0%	0.0%	30.0%
Car	80.0%	100.0%	60.0%
Plane	10.0%	0.0%	10.0%
Traveling mode trips between 300 and 100 miles (%)			
Public transportation	5.0%	0.0%	10.0%
Car	20.0%	100.0%	10.0%
Plane	75.0%	0.0%	80.0%
Traveling mode trips between over 1000 (%)			
Public transportation	0.0%	0.0%	1.0%
Car	5.0%	10.0%	4.0%
Plane	95.0%	90.0%	96.0%
kg CO_2 Emissions per passenger mile			
Public transportation	0.20	0.44	0.1
Car	0.36	0.44	0.28
Plane short trips (below 300 miles)	0.29	0.3045	0.2755
Plane medium trips (300-1000 miles)	0.2	0.21	0.19
Plane long trips (over 1000 miles)	0.18	0.189	0.171

Table A.6: GHG emissions from US Student traveling home - assumptions

	Base case	High emissions scenario	Low emissions scenario
Data parameters			
Distance calculation error	0%	3%	-3%
Trip parameters			
Trips per annum per student	2.0	3	1.5
Emissions per mile traveled	0.18	0.19	0.17

Table A.7: GHG emissions from foreign students traveling home - assumptions

Appendix B. Conversion Factors

	Value	Units	Remarks	Source	URL
Natural Gas (LHV)	950	Btu/cf			
Natural Gas (HHV)	1,000	Btu/cf			
#2 Fuel Oil	138,000	Btu/gal			
#6 Fuel Oil	150,000	Btu/gal			
Steam Enthalpy - sat @ 250 psig	1,202	Btu/pound	gauge pressure	The Engineering Toolbox website	http://www.engineeringtoolbox.com/28_273.html
Steam Enthalpy - sat @ 125 psig	1,193	Btu/pound	gauge pressure	The Engineering Toolbox website	http://www.engineeringtoolbox.com/28_273.html
Water Enthalpy - @ 225oF	193	Btu/pound		The Engineering Toolbox website	http://www.engineeringtoolbox.com/28_273.html
Gallon oil to MJ	147	MJ/gallon oil			
Natural Gas (HHV)	1.05506	MJ/cf gas	Grubler Table		
MSW (HHV) incinerated	5,000	Btu/pound	typical MSW		
Gasoline	124,000	Btu/gallon	125,000 in BTS notes	EIA	
Gasoline	6.1	GJ/barrel		Oak Ridge National Lab	http://bioenergy.ornl.gov/papers/misc/energy_conv.html
Gasoline	0.0448	TJ/ton	used to check WRI emission values	IPCC	
Diesel	139,000	Btu/gallon	should this be the same as #2 oil?	EIA, Bureau of Transportation Statistics confirmed	
Diesel	0.04333	TJ/ton	used to check WRI emission values	IPCC	
Jet kerosene	44.59000	TJ/ton	used to check WRI emission values	IPCC	

Table B.1: Energy factors

Unit Conversion Factors	Value	Units	Remarks	Source	URL
kWh to Btu	3,412	Btu/kWh		International Energy Agency Website	http://www.iea.org/statist/calcul.htm
kWh to MJ	3.6	MJ/kWh		International Energy Agency Website	http://www.iea.org/statist/calcul.htm
Btu to J	1,055	J/Btu		International Energy Agency Website	http://www.iea.org/statist/calcul.htm
RTons to Btu	12,000	Btu/Rtons			
lbs to Tons	4.536E-04	Tons	Google.com calculator		
ft^2 to m^2	9.290E-02	m2/ft2			
gallon oil to BOE	42	BOE/gallon oil		International Energy Agency Website	http://www.iea.org/statist/calcul.htm
kg to metric tons	1,000	kg/metric ton			
C equiv to CO_2 equiv	3.6667	N/A			
Barrels to gallons	42	gallons/barrel		Oak Ridge National Lab	http://bioenergy.ornl.gov/papers/misc/energy_conv.html
Gasoline	0.117	tons/barrel		Oak Ridge National Lab	http://bioenergy.ornl.gov/papers/misc/energy_conv.html
g to lb	0.002205	lb/g		EngNet website	http://www.engnetglobal.com/tips/convert.asp
GJ to MMBtu	0.948451	MMBtu/GJ		EngNet website	http://www.engnetglobal.com/tips/convert.asp

Table B.2: Unit Conversion Factors

	Emissions factor (kg CO_2/mile)	Source
Air travel - Long flight (>1600km, >1000 miles)	0.18	WRI
Air travel - Medium flight (452-1600km, 280-1000 miles)	0.2	WRI
Air travel - Short flight (<452 km, <280 miles)	0.29	WRI
Bus - CNG	0.23	WRI
Bus - diesel, long distance	0.08	WRI
Bus - diesel, urban	0.3	WRI
Car - large engine	0.44	WRI
Car - medium engine	0.36	WRI
Car - small engine	0.28	WRI
Rail - US transit	0.65	WRI
Train - US coal	0.37	WRI
Train - US diesel	0.28	WRI
Train - US electric	0.55	WRI

Table B.3: Transportation Emission factors by mode of travel

[i] Carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6)

[ii] For cases in which only fiscal-year data were available, uncertainty calculations took this into account.

[iii] U.S. Climate Action Report – 2002, Third National Communication of the United States of America Under the United Nations Framework Convention on Climate Change, 2002, Table 3-4; http://unfccc.int/resource/docs/natc/usnc3.pdf . Note that while the report was released in 2002, the most recent data available was for the year 1999. These are the numbers used in this estimate, adding additional uncertainty.

[iv] CH_4, N_20, and HFCs only. SF_6 and PFCs are not emitted from vehicles.

[v] Passenger cars, light-duty trucks, other trucks, aircraft, trains, and mobile air conditioners.

[vi] This approach avoids double counting if other organizations undertake a GHG inventory exercise. If the trips of Yale personnel paid by other institutions are equivalent to the trips of external guests paid by Yale, GHG emissions should be equivalent

[vii] The inventory excluded cost data on travel-related meals and lodging, under the assumption that Yale personnel and Yale guests would generate a similar amount of emissions if they were to remain at home. Miscellaneous expenditures were also considered outside the scope of this report.

[viii] American Institute of Physics, *The Energy Sourcebook*, 1991.

[ix] T. Gloria, Tufts University, "Tufts University's Green House Gas Emissions Inventory for 1990 and 1998," January 2001; http://www.tufts.edu/tie/tci/pdf/Tufts%20Emissions%20inventory.pdf

[x] L. Davey, S. Kahler, Tulane University, "Tulane University Greenhouse Gas Inventory," May 2002; http://www.tulane.edu/%7Eeaffairs/ghg_inventory5282.PDF

[xi] University of Colorado, "Carbon Emissions Inventory," http://www.colorado.edu/cuenvironmentalcenter/energy/projects/emissions/inventory.html

[xii] U.S. Climate Action Report – 2002, Third National Communication of the United States of America Under the United Nations Framework Convention on Climate Change, 2002; http://unfccc.int/resource/docs/natc/usnc3.pdf