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Working Paper Number 7

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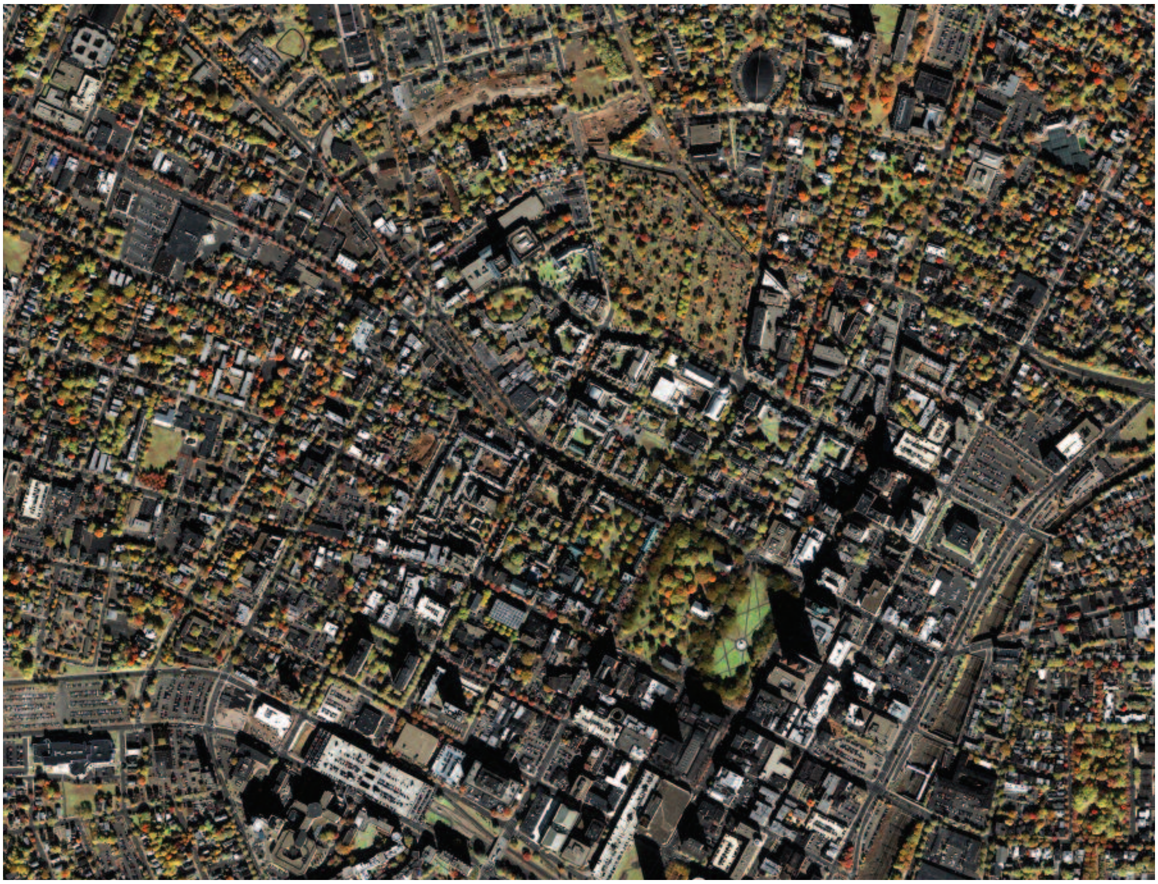

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Yale School of Forestry & Environmental Studies
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Preface

This Working Paper reports on the results of the Yale Climate Initiative (YCI), a student-initiated research project that developed a detailed greenhouse gas emissions inventory for Yale University in 2004 based on 2002 data – the most recent available at the time.

The results are being published and thus made available for a wider readership for three reasons: 1) to provide a methodological template; 2) to document the inventory results for future reference (both within Yale as well as in other universities aiming to develop similar emission inventories); and 3) to demonstrate that the analytical capabilities academic institutions apply so formidably in environmental assessments and benchmarking of firms, sectors, and even nation states can also be applied in an introspective mode of self-reflection, assessment, and comparative benchmarking.

Many universities in the U.S. and abroad have already developed some form of GHG inventories for their institutions. Yale therefore cannot claim to be a leader in this respect. However, the present Yale Climate Initiative inventory sets several new standards for this type of analysis:

- The system boundary adopted for the emission inventory is deliberately large, making the YCI inventory likely the most complete and encompassing of all university emission inventories published to date.

- Reflecting the specifics of Yale as the owner of large forests and thus carbon sinks (the forest system of Yale's School of Forestry & Environmental Studies comprises over 4,403 hectares in New England), the inventory includes both sources as well as sinks of greenhouse gases.

- The inventory is the first to extend the traditional annual flow concept of emission inventories by including stock variables, thereby identifying potential future emission sources. As such, the inventory is a useful application of concepts developed within the field of industrial ecology here at Yale.

- Finally, the inventory is the very first emissions inventory of any organization to perform a systematic uncertainty analysis including all salient factors determining emissions. It therefore sets both a useful example and provides a convincing demonstration about the inevitable uncertainties inherent in any environmental performance ranking, uncertainties that are too often ignored in the quest for seemingly robust "best guess" numbers.

The members of the Yale Climate Initiative team are therefore to be commended for their initiative and the hard work that provided the basis for this publication. I also wish to join the YCI team in their thanks to the many individuals at Yale who have graciously lent their time and expertise in identifying, providing, and evaluating a plethora of data sources synthesized in this inventory. Without their exemplary spirit of cooperation, this study would not have been possible. Special thanks go also to Dean Gus Speth of the School of Forestry & Environmental Studies for his continuous support of this activity and for making sure that the YCI team, along with its academic advisor, also took the final step on this academic journey – a publication. Finally, I wish to extend special thanks to Andreas Mueller of the Technical University in Vienna, who meticulously crosschecked all data and text for consistency and possible sources of error. Without his essential input at the last stages of this project, this publication would not have been possible. Nonetheless, I wish to emphasize that the final responsibility for the report and any omissions, errors, or misinterpretations it still may contain rest with me, the academic advisor to this project.

A final personal note: While emphasis throughout the YCI inventory process was on research, a project assessing the environmental externalities of a university clearly also has a policy dimension. By all accounts of absolute and specific GHG emissions, Yale's environmental performance ranks low. Yale's emissions rival those of small island nations, and its emissions per capita, energy use per unit service (like floor area), and many other indicators are all many times greater than those of comparable operations and educational institutions in a comparative international context. Being "big" in sources of environmental impact may in fact ultimately serve as a comparative disadvantage in a competitive environment where "intangible" social and environmental factors add to the traditional yardsticks of defining comparative advantage among competing educational institutions.

An adage attributed to Harvard, but equally valid for Yale, states that students stay for years, faculty for life, but the university stays forever. Who else if not an institution that embraces a centuries-long perspective in both its history and future prospects should be concerned about the issue of *sustainability*? From that perspective, I join the YCI team in their feeling that Yale no longer can remain unconcerned about its environmental "footprint," as exemplified by its GHG emissions. After all, current emissions from Yale will influence the "climate" in which future generations of students will pursue their careers for many decades to come.

I am therefore particularly pleased to report that in October 2005, at the time this report went to print, Yale's President Richard Levin made the announcement to commit the university to an emission reduction goal of 10 percent below 1990 levels (which translates to an approximate emission reduction of 40 percent over the 2002 Tier 1 and Tier 2 emissions as calculated in this inventory). President Levin's announcement states:

> "Yale is committed to a level of investment in energy conservation and alternate energy sources that will lead, based on current projections, to a reduction in its greenhouse gas emissions by 10% below our 1990 levels by the year 2020. This is consistent with a similar commitment by the Connecticut State Legislature and the New England Governors and Eastern Canadian Premiers Climate Action Plan.

By adopting this goal Yale is one of the first universities in the country to commit to a fifteen-year strategic energy plan. We intend to reach our goal through a combination of a strong energy conservation program, investing in alternative energy sources, purchasing Renewable Energy Certificates, and implementing on-site renewable and clean energy demonstration projects.

Every one of us on campus has a role to play in helping achieve this goal, by conserving energy and by reducing the greenhouse gas emissions that flow from its use. Effective conservation programs can further free up funds within the University budget that will in turn be invested in renewable and non-CO_2 emitting forms of energy. Specifically, we are setting out to achieve the following conservation targets:

15% reduction at residential colleges over a three-year period.
10% reduction at all other facilities."

With this initiative, Yale's response to the climate change challenge has begun.

Arnulf Grubler
Professor in the Field of Energy and Technology
Yale School of Forestry & Environmental Studies

Section 1: Executive Summary

1.1 INTRODUCTION

As momentum builds for governments and corporations to respond to the climate change challenge, the role of institutions of higher education has not escaped notice. A growing number of U.S. colleges and universities has begun to assess their energy use (inventory their greenhouse gas emissions) and consider options for reducing the climate impact of their operations. A handful of university presidents has established emission reduction goals for their schools and joined emission-trading initiatives.

The premise of this report is that Yale University, as a leading global university with an acclaimed school of the environment, should be cognizant of its environmental footprint and subsequently engage in a leadership role in the response by higher education institutions to climate change.

As with all public and private institutions, the first step in crafting a climate change response for a university is to prepare a greenhouse gas emissions inventory. Such accounting is essential for identifying and prioritizing among an institution's emission sources. An inventory also establishes a basis for regular reporting and for developing a baseline against which to assess emissions trends and to measure the impact and cost-effectiveness of mitigation measures.

The Yale Climate Initiative (YCI) is 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 Grubler of the Yale School of Forestry & Environmental Studies. The team also solicited the assistance of university administration and staff and experts from academia, industry, and non-governmental organizations (NGOs).

This report, *Inventory and Analysis of Yale University's Greenhouse Gas Emissions*, goes beyond many U.S. university-based GHG emissions inventories in the scope of its investigation. In particular, it provides:

- Information on the global, regional, state and institutional drivers that promote reduction of GHG emissions;
- Background on the methodologies, strengths, and weaknesses of current GHG inventories;

- An accounting of Yale University's GHG emissions that is differentiated by sector and by varying systems boundaries that are deliberately chosen to be more comprehensive than most other comparable university GHG inventories;
- Detailed estimates of the associated uncertainties inherent in developing the estimates of a GHG emissions inventory;
- An inventory that, in addition to annual flows, addresses some stocks of GHGs that could constitute potential future emissions;
- The methodology employed to calculate Yale's GHG inventory, as well as recommendations for methodological improvements; and
- A brief overview of GHG mitigation options by sector.

1.2 KEY FINDINGS

1.2.1 Yale Emissions in 2002

The results of the YCI assessment provide a "best estimate" of greenhouse gas emissions from Yale operations in calendar year 2002 of 284,663 (metric) tons of carbon dioxide equivalent (CO_2e). Considering the uncertainties in estimating activity variables, emission factors, and GHG-equivalences, Yale's emissions in 2002 are estimated to be within a range of 227,458 to 360,542 metric tons* of CO_2e, or *between 10 to 16 tons of CO_2e per university member (staff, faculty, and student).*

Yale's emissions are dominated by energy-related CO_2 which totals some 279,000 metric tons, or some 98% of all GHG emissions of the university (not accounting for the forest sinks). To put these energy-related CO_2 emissions into perspective: They are larger than those of 30 developing countries[1], roughly equal to the emissions of countries like the Central African Republic, Gambia, American Samoa, or the Cayman Islands, and about as high as the combined emissions of Nauru and Samoa. If Yale were a small island state, it would rank 22nd in energy-related CO_2 emissions among the 39 member states of the Alliance Of Small Island States (AOSIS).

Yale's total GHG emissions (for which comparable detailed inventory data for small and developing countries are sparse) are close to 285,000 metric tons CO_2e. This is comparable to the emissions of the Seychelles or Cape Verde, according to the latest inventory data for the year 1995 submitted to the UNFCCC secretariat.

Yale's emissions can also be compared with those of other U.S. colleges and universities. Its emissions are approximately four times those of the University of Vermont, five times those of Tulane University and Oberlin College, and 16 times those of Tufts University. Per capita emissions are also significantly higher, although statistical gaps in comparable inventories prevent a complete apples-to-apples comparison across schools.

*Unless otherwise specified, "tons" refers to metric tons in all instances in this report.

[1] All country numbers refer to the year 2002 and are based on the statistics compiled by the Oak Ridge National Laboratory's Carbon Dioxide Information Analysis Center (CDIAC) http://cdiac.esd.ornl.gov/trends/emis/top2002.tot

Table 1.1 Yale "Best Estimate" Greenhouse Gas Emissions: Comparison with Selected Countries and Schools

College/University/Country	Emissions (metric tons CO_2e)*	Per Capita Emissions ($mtCO_2$e per person)**
Yale University	*284,663*	*12.6 (25.1 students only)*
Seychelles[†]	256,000	3.5
Cape Verde[†]	302,000	0.8
Yale University	*284,663*	*12.6 (25.1 students only)*
University of Vermont	63,900	6.2 (students and faculty)
Tulane University	52,981	2.8 (4.1 students only)
Oberlin College	50,417	8.4 (16.8 students only)
Univ. Colorado-Boulder	34,567	1.0 (1.2 students only)
Tufts University	17,783	1.3 (2.2 students only)

* Baseline years vary: 2002 for Yale; 2000 for Oberlin; 1998 for Tufts; 2000 for Tulane; 1990-2000 average for UVM. Part of the difference between Yale and other schools also arises from differences in the comprehensiveness of their respective GHG emissions inventories.

** Per capita emissions metrics vary among schools. Where possible, students, faculty, and staff were all included.

[†] 1995 emissions as reported to UNFCC http://ghg.unfcc.intl.

1.2.2 Yale Emissions in 2002, By Sector

A sectoral breakdown reveals that buildings (and the power plants that provide building energy) account for 86% of the university's GHG emissions (Table 1.2). The YCI analysis in the main body of this report treats power plants and buildings as separate sectors. However, as buildings are the dominant end use for energy from Yale's power plants, we combine the two here to illustrate the importance of building energy consumption into the overall emissions profile.

Table 1.2 Yale Greenhouse Gas Emissions, By Sector

Sector	Emissions ($mtCO_2$e) Best Estimate	Uncertainty Range	Share of Total (Best Estimate)
Power Plants/Buildings	244,814	207,230 – 285,571	86%
Transportation	34,904	20,027 – 65,008	12%
Other Sources	11,236	3,347 – 25,691	4%
Sinks	-6,291	-3,146 – 15,728	-2%
Total	*284,663*	*227,458 – 369,542*	

1.2.3 Yale Energy Expenditures in 2002

Measures that achieve both energy and cost savings are the optimal approach for institutions (including universities) under pressure to control costs while addressing emissions. Consistent with the principle that "what gets managed, gets measured," the YCI team found that Yale's expenses on energy are not optimally measured and reported. However, the team was able to estimate that Yale spent $70M in fiscal year 2002 on building energy use including power plant generation. Thus, in 2002 Yale's energy expenses equaled 21% of the university's $328M in capital spending for the renovation of existing facilities and the construction of new facilities. This high proportion suggests that Yale's high GHG emissions numbers also translate into a high energy bill, implying that reducing emissions would also result in corresponding cost savings for the university.

1.3 THE CLIMATE CHANGE UNIVERSE

1.3.1 The Scientific Evidence

There is growing scientific evidence that anthropogenic sources of GHGs in the atmosphere are contributing to change in the earth's global climate system with potentially significant ecological and socioeconomic risks. The 2001 Third Assessment Report (TAR) of the Intergovernmental Panel on Climate Change (IPCC) provides the most recent and up-to-date assessment of the scientific literature on the subject. The main results of the report can be summarized as follows:

(1) There is evidence of climate forcing caused by the emission of anthropogenic GHGs;

(2) changes in climate and increased climate variability bring significant risks for human societies and for ecosystems; and

(3) the path of development chosen for the next 100 years (and thus the magnitude of the climate change challenge) depends largely on near- and medium-term policy choices.

1.3.2 Climate Change-Related Policy Making

In response to the threat of climate change, policy responses have occurred at international, federal and state levels. At the international level, the initial policy response was the signature of the United Nations Framework Convention on Climate Change (UNFCCC) in 1992[1]. The commitments in the UNFCCC, however, were voluntary and the framework was not followed by effective policies at the national level. The Conferences of the Parties (COPs) followed the UNFCCC, leading to the Kyoto Protocol in 1997 (COP 3), which created binding targets for developed countries. To enter into force, the Protocol requires ratification by 55 parties to the Convention, including Annex 1 countries representing 55% of the group's 1990 emissions. The Protocol came into effect on February 16, 2005. In the meantime, however, the United States government, representing over 36% of the GHG emissions of Annex 1 countries, has decided against ratifying the Kyoto Protocol.

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[1] The United Nations Framework Convention on Climate Change (UNFCCC) has been ratified by 189 countries (status as of May 24, 2004), including the United States of America. Source: http://unfccc.int/files/essential_background/convention/status_of_ratification/application/pdf/ratlist.pdf.

The ensuing Kyoto Protocol that contains binding emission reduction targets for Annex-I (i.e. developed) countries went into force on February 16, 2005. 155 countries had ratified the Kyoto Protocol as of August 31st 2005, with the U.S. being a notable exception. Source: http://unfccc.int/files/essential_background/kyoto_protocol/application/pdf/kpstats.pdf.

Despite non-participation in Kyoto, a number of voluntary GHG emission reduction initiatives are being articulated and implemented in the United States. At the federal level, the U.S. Environmental Protection Agency (EPA), Department of Energy (DOE), and Department of Agriculture (USDA) have sponsored a variety of voluntary programs. A number of U.S. states are developing climate change strategies and setting emission targets (Table 1.3).

Table 1.3 Climate Change Initiatives at the State Level in the U.S. as of 2004[2]

Initiative	States
Renewable Portfolio Standard	18 States
Net metering	17 States
Green electrcity pricing programs	29 States
Completed climate change action plan	28 States
States involved in regional initiatives on climate change and clean energy	33 States
GHG emissions reductions target	ME, MA, NJ, NY
Public Benefit Funds that support energy efficiency or renewable energy	22 States

GHG initiatives have also been undertaken by industry and NGOs (Table 1.4).

Table 1.4 Selected Industry and NGO Climate Change Initiatives

Name	Participants	Goals/Targets
Business Environmental Leadership Council	Led by the Pew Center on Global Climate Change. Participants include Boeing, DuPont, Shell, Weyerhauser and 36 others (as of 9/05).	GHG reduction target levels and structures are voluntary and selected by each company independently. A variety of targets and emission reduction methods are pursued.
Climate Savers	Created by the WWF and the Center for Energy and Climate Solutions. Initial participants are 6 companies, including IBM, Johnson & Johnson, Polaroid, Nike, Lafarge, and the Collins Companies, specifically focusing on carbon dioxide emissions.	All these companies made specific commitments to reduce their energy consumption. The WWF and the Center pledge to "work with a select group of companies to customize progressive business plans for reducing greenhouse gas emissions."
Partnership for Climate Action	Seven companies, including BP, DuPont, and Shell, joined Environmental Defense to create this partnership. (http://www.pca-online.org/)	Each company has made a firm commitment to reduce GHG emissions and has agreed to measure and publicly report its emissions.
CCX	Business driven. Started by 14 large GHG emitters accounting for 4.3% of total U.S. emissions. Currently has 40 participants.	Create a market for GHG emissions. 1% emission reduction target per annum for the 2003-2006 period (on a 2002 baseline). *CCX Features (January 16, 2003).* First GHG emission auction held in November 2003.

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[2] Pew Center on Global Climate Change: Learning from State Action on Climate Change. http://www.pewclimate.org/docUploads/States%5FInBrief%2Epdf)

In addition, a growing number of Yale's peer universities have established or are in the process of establishing comprehensive energy audits and GHG inventories. Among the more prominent examples:

- Harvard University has launched a Greenhouse Gas Inventory, jointly sponsored by the Harvard Green Campus Initiative and Harvard's Department of Environmental Health and Safety.
- Stanford University has established a major Energy and Climate Initiative research program, with the support of GE and ExxonMobil, and has established campus-wide guidelines for climate-friendly buildings.
- Tufts University, through the Tufts Climate Initiative, has established a GHG Inventory dating back to 1990, established a goal of returning emissions to 1990 levels by 2000, and was the first university to join the Chicago Climate Exchange.
- Oberlin College has conducted a GHG Inventory for 2000, commissioned an Oberlin 2020 project to assess the feasibility of becoming climate-neutral by 2020, and built a widely acclaimed model green building.
- Other universities with GHG inventories include:
    - University of Colorado-Boulder
    - Tulane University
    - Rutgers University
    - University of Vermont.

1.4 YALE GHG CONTEXT

These initiatives at the regional, state, local, and peer institution level create a broader context for Yale University regarding its responsibilities related to climate change. Yale has direct responsibilities for responding to GHG emissions at the regional level (through the New England Board of Higher Education) and at the state level (through the Office of the Governor). The Yale College Council has additionally signed onto a joint resolution with six other Ivy League institutions to press for university GHG emissions reductions, and the City of New Haven is looking to increase renewable energy use in the city – a program in which Yale could play a significant role.

Beyond these internal and external "stakeholder" pressures, Yale has several interests in developing a GHG inventory:

- Yale aspires to be, in the words of its president, a "truly global university." As such, it should develop a proactive strategy for addressing global challenges such as climate change.
- Yale also aspires to global leadership on environmental issues – not only as home to one of the world's leading environment schools, but as a whole institution.

- For an institution of higher learning, development of a GHG inventory and a subsequent university climate policy presents enormous educational opportunities. Possibilities for research and experimentation include:
    - Law and regulation (e.g. GHG emissions trading rules – at the international, national and state level)
    - Economics and business (e.g. emissions trading, economic analysis of emission reduction measures)
    - Architecture (e.g. building energy efficiency, city planning)
    - Engineering (e.g. energy and transportation systems technologies)
    - Computer science (e.g. information economy and energy efficiency)
    - Social sciences (e.g. organizational behavior and institutional change)

Other motivations relate to the university's strategic planning and economic situation:

- Development of a Yale GHG inventory is the essential first step toward the institution's development of a long-term mitigation strategy, but does not limit Yale's strategic options or prematurely commit it to a specific course of action.
- A Yale GHG inventory may identify cost saving opportunities for reducing or avoiding energy consumption, thus alleviating budgetary pressures.
- Yale has a window of opportunity to pioneer climate-friendly campus design through its ongoing college renovations and ambitious construction plans for new buildings, particularly for science facilities currently being planned.
- A Yale GHG inventory may also identify economic opportunities for low-cost mitigation, via participation in emissions trading or the purchase of renewable energy certificates.

1.5 GHG INVENTORY BACKGROUND

A GHG inventory is an accounting and reporting standard to measure emissions of greenhouse gases (GHGs) that typically accounts for the six gases covered by the Kyoto Protocol: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF_6). An inventory is the mandatory first step for an organization to develop an effective GHG management strategy as well as to consider potential mitigation options. The Yale Climate Initiative builds on the Greenhouse Gas Protocol, developed by the World Resources Institute (WRI) and the World Business Council on Sustainable Development (WBCSD), which is used by many corporations and voluntary climate initiatives. YCI has also drawn upon other GHG inventory methodologies such as those of the Intergovernmental Panel on Climate Change (IPCC), the U.S. Environmental Protection Agency Climate Leaders Program, and those used by other universities.

1.6 YCI METHODOLOGY

1.6.1 Study Boundary

The organizational boundary established for the YCI study encompassed all activities related to the educational mission of the university. The operational boundary of the study included all direct and indirect emissions of the six GHGs. Direct emissions are those emissions from sources that Yale University owns or controls (e.g. for Yale's power plants), while indirect emissions are the emissions resulting from Yale's activities, but not necessarily owned or controlled by Yale (e.g. emissions generated by power generation of electricity purchased by the university). This study was conducted for the calendar year 2002 (note is made where only fiscal year data were available).

1.6.2 Study Scope

The inventory system boundaries divided emissions into six tiers:

- **Tier 1.** Yale emissions from Yale power plants;
- **Tier 2.** Yale emissions from activities for which Yale has the decision-making power, either through the procurement process or an equivalent;
- **Tier 3.** Yale emissions from Yale activities that are decided on and transacted by other individuals;
- **Tier 4.** Yale's emissions from its outsourced activities where decisions are made through contract provisions;
- **Tier 5.** Yale's incidental emissions; and
- **Tier 6.** Yale's emissions from embodied energy.

This study was limited to the first four tiers for which (partial) data were available. In terms of system boundaries, the numbers reported here thus represent lower bound, conservative estimates.

1.6.3 Study Organization

All relevant activity data were gathered from institutional sources and university suppliers, and emissions from the sources were calculated based on a four working group organization structure delineated by Power Plants, Buildings, Transportation (including fleet, community and institutional travel) and Other Sources (including solid waste, laboratory chemicals and refrigerants, as well as sinks).

1.6.4 Emission Calculations

Emissions factors are source-specific and convert activity data into emissions values. Published emissions factors were researched and collected from leading sources, such as IPCC, EPA, and others. Once activity data and emissions factors for a specific source were identified, GHG emissions in tons CO_2-equivalent were calculated using the established IPCC equivalence factors (so-called Global Warming Potentials or GWPs[3]) to aggregate the overall warming contribution from specific GHGs.

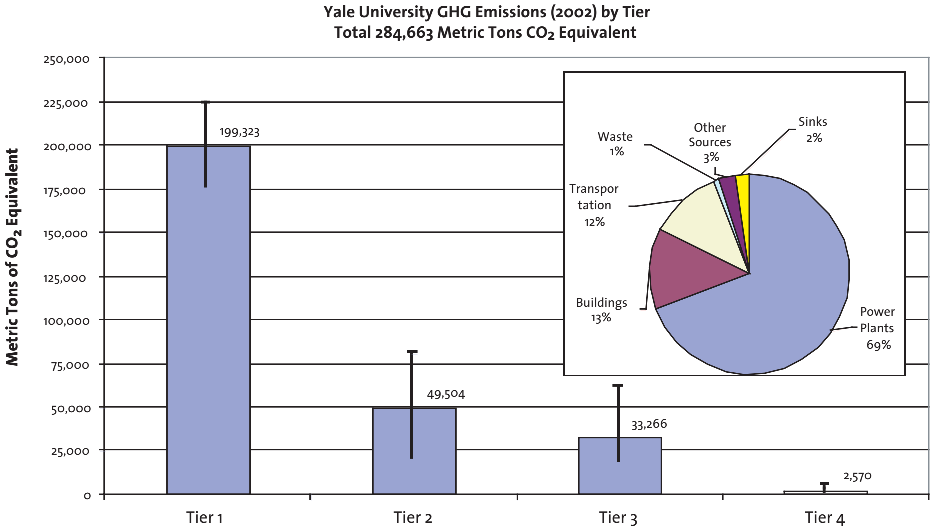
1.6.5 Uncertainty

Uncertainties of the emission inventory were calculated for activity data and conversion factor(s). Uncertainties were subsequently aggregated into lower and upper bound estimates of emissions by different source categories to complement the "best estimate" point estimates.

1.7 YALE'S INVENTORY

This section provides summary information on distinct types of greenhouse gases associated with Yale University. Figure 1.1 shows the proportion of emissions by tier and university sector. As mentioned above, Tier 1 and 2 reflect emissions directly under the decision control of Yale's administration, whereas Tier 3 and 4 represent emissions that are associated with Yale's educational missions, but are controlled by other individuals (e.g. faculty or students). Power plants and buildings are by far the two dominant emission sources for Yale.

Figure 1.1 Yale University and Yale-New Haven Hospital GHG Emissions by Tier (2002)



1.7.1 Power Plants

Yale University has three power plants – Central Power Plant, Sterling Power Plant and Pierson-Sage Power Plant – that are responsible for over 70% of the university's GHG emissions. The power plants use electricity, natural gas, No. 2 diesel fuel and No. 6 residual fuel to provide the campus with electricity, steam and chilled water. The power plants predominantly use natural gas in most of their equipment, with

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[3] GWPs consider differences in radiative forcing and atmospheric residence times of different GHGs.

No. 2 and some No. 6 oil as secondary fuels, and co-generate both electricity and steam. Chilled water is produced in steam driven chillers. Total energy import into the power plants is equal to 3,330 TJ. Total energy export is equal to 2,380 TJ for the three power plants, yielding a comparatively high efficiency of over 70 percent, characteristic for cogeneration systems. It should be noted that without cogeneration, emissions from Yale would be potentially higher even if part of the emissions (from electricity purchased) no longer originated on campus.

Emissions from the power plants arise mostly from the natural gas turbines in both the Central Power Plant and the Sterling Power Plant and the heat recovery steam generators from the Central Power Plant. The Sterling Power Plant also has significant emissions from its No. 6 residual fuel use. Total emissions (including emissions from electricity purchased) equaled 206,716 metric tons of CO_2-e for the power plants. Sixty percent (or 123,445 metric tons) came from the Central Power Plant, less than 1% or 194 metric tons from the Pierson-Sage Power Plant, and about 40% or 83,077 metric tons from the Sterling Power Plant.

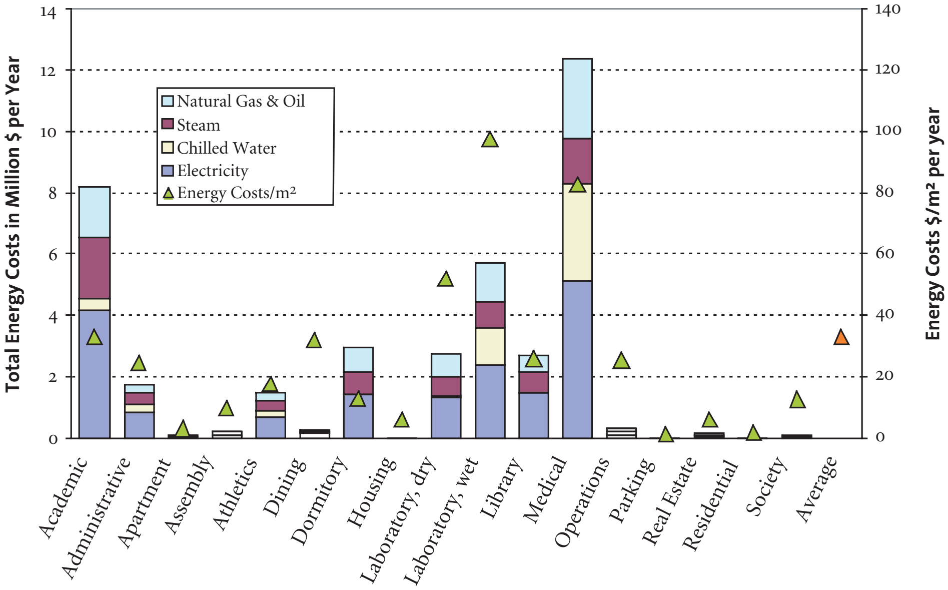
1.7.2 Buildings

The YCI building energy study encompassed a total sample size of 257 buildings, excluding the three power plants owned by the university. These buildings represent a total of 1,117,345 m^2 (12,630,455 ft^2) of floor area and a total energy usage of 2,638 TJ (2,262 billion Btu) in 2002. Most of this energy is provided by the power plants, with some 400 TJ purchased from outside-university sources. GHG emissions directly attributable to buildings outside the scope of emissions from the power plants (206,716 metric tons CO_2) totaled 38,098 metric tons CO_2 in 2002.

Energy costs for building energy use at Yale vary between campus areas, as well as according to the origin of the energy used. Total energy costs for the buildings covered in this study were $39M in FY2002. Per-unit energy costs equaled $16.4/GJ, which can be compared to the IPCC average of $14/GJ for energy-related building costs. As with energy consumption, the medical, academic, laboratory, dormitory, and library buildings dominate energy expenditures (Figure 1.2), with a collective share of more than 80% of university energy costs.

Compared to the average U.S. academic building, the energy intensity of Yale's academic buildings is about twice as large and is substantially higher than in modern academic buildings incorporating energy efficient designs.

Figure 1.2 Total Energy Costs, by Building Use (bars) and Specific Energy per Sq. Meter of Floor Space (triangles)



1.7.3 Transportation

Yale University spends about $20 million on faculty and staff travel every year. Such expenditures include costs for transportation, lodging, and meals. Typically 75% of the expenditures are for trips in the U.S. and 25% for trips abroad. Air and rail expenses represent the highest share of travel expenditures. Transportation accounts for almost 35,000 tons CO_2e, which represents about 12% of the total GHG emissions of Yale.

Yale employs over 12,500 people. Collectively, they commute an estimated 46 million miles per year, approximately half by car. The yearly emissions from personnel commuting are around 12,000 tons or about one ton per employee. This compares to an average of 0.8 tons CO_2 emitted by the average commuter in the U.S., according to the Bureau of Transportation Statistics.

About 86% of Yale students live less than 3 miles from campus, with only a small proportion of the student commutes under 3 miles taken by car. The yearly GHG emissions associated with students commuting were assessed to be about 1,700 tons.

Overall transportation accounts for 34,904 tons CO_2e, or for some 12% of Yale's GHG emissions. Due to insufficient travel survey data, the YCI inventory emissions estimates are affected by a considerable degree of uncertainty. The uncertainty range of YCI's best estimate is between 20,027 to 65,008 tons CO_2e.

1.7.4 Other GHG Emission Sources and Sinks

This category encompasses all emissions not captured by the previous sections. The activities include waste management and purchased lab gases, as well as sequestration from Yale forest properties. In 2002 these emissions were estimated to total 11,236 tons CO_2e. With a CO_2 sequestration of about 6,300 tons CO_2, the 10,880 acres (4,403 hectares) of forest owned by Yale's School of Forestry & Environmental Studies have a significant effect on the emissions from this sector, counterbalancing more than half of the emissions. Resulting net emissions from this sector are thus 4,945 tons CO_2e.

Refrigerant leakage from chillers represents the main source of GHG emissions. Although the absolute amount of refrigerants released through leaks is small, refrigerants have high global warming potential. The total amount of 2002 GHG emissions from chiller releases is about 8,341 tons CO_2e. Other GHG emissions include 2,253 tons CO_2e from municipal solid waste disposed or incinerated, 317 tons CO_2e associated with the treatment of Yale's wastewater, as well as 324 tons CO_2e of laboratory gases.

The uncertainties in the estimates reported below are substantial, reflecting incomplete information and uncertain emission factors. YCI's best estimate of 11,236 tons CO_2e needs to be contrasted with an estimated uncertainty range of between 3,347 and 25,671 tons CO_2e in this emission category. The forest carbon sink uncertainty is estimated to range between –3,146 and –15,728 tons CO_2e.

Even if annual emission flows in this category are small, YCI has identified a large stock of sulfur hexafluoride (SF_6) on campus (Wright Nuclear Lab) that represents potential emissions over 850,000 metric tons CO_2e if it were released, representing three times the annual total GHG emissions of Yale and being comparable to the carbon stock of all of the above-ground biomass of the Yale School of Forestry & Environmental Studies forests.

1.8 OPTIONS FOR EMISSIONS REDUCTION

A detailed GHG inventory provides the necessary basis for any subsequent analysis of mitigation options. Although such an assessment was outside the scope of the present report, our results suggest some illustrative orders of magnitude as well as priority areas for subsequent mitigation studies. Four criteria should be kept in mind in assessing mitigation potentials or their priority ranking: (a) size of emissions, (b) mitigation potential, (c) degree of Yale control, and (d) degree of ancillary benefits of emissions reductions such as cost savings.

On account of these four criteria, improving the energy efficiency of Yale buildings ranks on top of the mitigation options that deserve further in-depth analysis. Buildings are by far the largest source of energy use on campus and thus the largest source of GHG emissions of Yale, as they are the main consumers of the energy provided by the Yale power plants that are traditionally assumed to be the largest energy use and emission source on campus.

Energy use (and reduction potential) is determined by the thermal integrity characteristics of the buildings (determining heating and cooling energy needs), the existence of active air-conditioning, as well as the number and efficiency of electricity-using appliances used in Yale's buildings. The benchmarking of Yale buildings' energy use revealed that, in the aggregate, the university buildings, while comparable to other universities in North America, have substantially higher energy use (and costs) compared to European universities, not to mention best practice academic buildings.

Best practice academic buildings are characterized by: a) high degrees of thermal insulation; b) passive heating and cooling through building and ventilation design; c) use of the most energy efficient equipment; and d) energy-conscious building use (e.g. switching off appliances during night hours). A comparison of existing buildings and use practices to best available designs indicates potential for improvements of up to a factor of 10. However, these are primarily considerations about "theoretical" energy efficiency improvement and emission reduction potentials. A more pragmatic short-term goal might be to reduce energy use in existing buildings by a sufficient amount to allow for the planned expansion of the university's total square footage (new buildings) of some 20 percent over the next decade without additional energy use. This could also save on the substantial investments in infrastructure upgrades and increasing energy bills that would otherwise be associated with growth in the building area at Yale.

YCI has analyzed the energy use patterns of all buildings on campus in detail. Based on that analysis, it recommends that Yale perform detailed energy audits and energy efficiency improvements and GHG mitigation analysis of the top 25 energy-consuming buildings on campus. Together, they account for 14% of Yale building square footage but for about half of the total building energy use.

The average specific energy use of these "energy giants" (if not "dinosaurs") is 7,141 MJ/m^2 per year (628 $kBTU/ft^2/yr$), up to an order of magnitude larger than the average educational or medical building in the U.S. or Europe, confirming that these buildings (Table 1.5) are first priority candidates for energy audits and detailed recommendations for efficiency improvements and cost savings.

In these energy audits, a thorough analysis should determine how much of the high energy use (compared to appropriate benchmark buildings) is technologically determined (e.g. in the case of the Magnetic Resonance building) and how much of the energy use could be reduced by which measures and at what costs and paybacks. Such energy audits appear particularly timely considering the ambitious expansion plans for campus buildings that are likely to exceed the existing capacity of the university power plants and cogeneration system, thus requiring capital intensive capacity expansion that could be offset by energy efficiency improvements in existing buildings.

Table 1.5 **Top ranking 25 Yale buildings with highest energy use per unit floor area and an annual energy use greater than 10 TJ per building in 2002. These "energy giants" are suggested as top candidates for subsequent detailed energy audits with the aim of simultaneously achieving substantial reductions in energy use, emissions, and energy costs.**

Facility ID	Building	m²	TJ	MJ/m²
3315, 3360	DANA CLINIC BLDG (and CLINIC BLDG)	784	16	19,814
0	IMU (YSM)	1,179	17	14,810
3325	MAGNETIC RESONANCE	1,288	17	13,082
3115	STERLING HALL MED B	10,760	119	11,019
3000/3010/3015	YALE PSYCH INST BLDG1/2/3 (YPI(YSM))	1,585	17	10,463
3335	LAB FOR MEDIC, PEDIAT	4,054	39	9,742
3350	WINCHESTER BLDG	2,567	25	9,650
520	MARSH HALL	1,168	11	9,500
3125	STERLING HALL MED I	12,277	108	8,780
3355	BOARDMAN BLDG	1,663	15	8,780
3300	LAB FOR SUR, OBST, GYN	6,487	54	8,285
3155	LAB OF EPIDEM, PUBLIC HEALTH	8,424	67	7,950
3330	LIPPARD LABORATORY F (LCI)	6,276	45	7,149
3310	TOMPKINS MEMORIAL PA (TOMPKINS/ TOMPKINS (YSM))	2,029	14	7,112
3165	BOYER CTR MOLEC MED	12,102	80	6,590
1040	KLINE GEOLOGY LAB	11,005	72	6,576
3375	BRADY MEMORIAL LAB	8,013	52	6,465
1049	ENVIRONMTL SCIENCE CTR	9,229	58	6,240
3380	LAUDER HALL	2,621	16	6,046
3105	STERLING HALL MED C	7,473	45	6,012
440	STERLING DIV. QUAD.	14,959	86	5,722
1090	KLINE CHEMISTRY LAB	6,249	36	5,702
3200	YALE PHYSICIANS BLDG	7,547	43	5,668
1080	KLINE BIOLOGY TOWER	18,826	103	5,494
1030	BASS CENTER	8,493	41	4,784

Next to the buildings, the Yale power plants constitute the largest category of emission reduction potential. It should be noted that the fact that Yale generates its own electricity, heat, and chilled water through so-called cogeneration (at the Central Power Plant) has a number of advantages. These include higher overall energy efficiency compared to traditional segmented energy end-use systems (i.e. electricity purchased from the grid, and heating/cooling energy provided in each individual building through boilers/chillers), a high degree of management control as well as comparatively fast implementability of improvements through centralized decision-making and investment. The fact that the power plants are on campus (with a corresponding need for unobtrusiveness) implies also that they are already comparatively low emitting systems, predominantly burning clean natural gas.

The only "disadvantage" of Yale's cogeneration system is that the resulting emissions are owned and reported by the university and accountability cannot be externalized upstream to electric utilities.[4]

Four general options exist for reducing emissions from Yale's power plants: (1) reduction in secondary energy (electricity, steam and chilled water) demand (demand side management, cf. discussion of buildings above); (2) reduction in secondary energy (electricity, steam and chilled water) transmission and distribution losses; (3) reduction in primary energy needs through improvement in secondary energy generation (cogeneration) efficiency; and (4) switching of primary energy fuels to those of lower emissions (carbon) intensity. All of these options rank high with respect to the criteria of emissions source size, mitigation potential, and degree of Yale control.

YCI has identified a number of options for emission reduction at the Yale power plants, including reductions in transmission/distribution losses (steam dumps), a complete switch to natural gas as fuel, substituting for stream-driven chillers with (high efficiency) electric-driven ones at the power plants, and, finally, converting the Sterling Power Plant serving the medical campus to a cogeneration facility. With the exception of reduction of transmission/distribution losses, none of the above options is likely to yield very substantial energy efficiency or emission reduction gains. Nonetheless an upper bound for all mitigation measures taken together[5] indicates a reduction potential of up to 10 percent of Yale's GHG emissions.

Compared to buildings and power plants, transportation and other GHG sources and sinks rank lower on our scale for emission reduction potential. This is either because emissions are low (e.g. university car fleet) or because of limited direct Yale control (e.g. on commuting behavior[6] of faculty, staff, and students) or both. Nonetheless, because of their high visibility on campus and because of comparably short technical lifetimes that allow continuous replacements of the university's vehicle fleet, a transition to more fuel-efficient vehicles, ultimately to less emission intensive vehicles such as those powered by natural gas (trucks) or hybrid technology (cars, SUVs) should be investigated. Moving from average actual vehicle fuel efficiencies to more efficient vehicles across the different types of vehicles used on campus could yield emission reductions of up to 50 percent in this category, but total emission reductions would be minor (~0.1 percent) compared to the total emissions of Yale.

Absolute emission reduction potential is also comparatively small for the "other emissions" category. A priority area identified in the YCI emission inventory is a detailed examination of fugitive losses of refrigerants from large chillers in use at Yale. Even if the absolute amounts of emission reduction were small (measured in kg rather than in tons), they could nonetheless translate into much larger GHG emission reductions due to the high global warming potential of the gases used in chillers and air conditioners.

In the end, any analysis of emission reduction potentials at Yale requires some guidance on targets for energy use and emissions in order to be able to identify emission reduction potentials as a function of ambition levels, implementation

[4] It is not anticipated that this might become a legal accountability problem in the future as all currently available or suggested emission inventories include upstream emissions from electricity generation in the system boundary of the organization for which the inventory is prepared. Yale therefore would "own" the emissions arising from generating the electricity it consumes, independently of whether this happens on campus or off campus (say at the Bridgeport power plant).

[5] For the conversion of Sterling Power Plant to a cogeneration facility, substantial gains are only possible if the new cogeneration plant has substantially higher conversion efficiencies than the existing plants on campus. With comparable efficiency, emission reduction potentials are modest, but the interest of a new cogeneration facility on the Sterling Power Plant site resides precisely in the possibility of substantial efficiency gains by entirely new equipment at the performance and efficiency frontier. Further detailed engineering studies would be required to be able to assess the emission reduction potential of this option.

[6] Important leverages nonetheless exist for the university through appropriate incentives and disincentives. For instance, raising parking fees on campus can act as an incentive for lowering car use or for promoting car sharing; subsidizing public transport can act as an incentive for changed transportation choices of Yale employees or students.

potentials, as well as upfront and life-cycle costs. To assist this decision-making process, it might be useful to perform a more detailed emission reduction options analysis that outlines a gradation of levels of ambitiousness for emission reduction efforts at Yale. Such a gradation could range from emission reduction potentials that are classified in the relevant literature as "free lunch" (i.e. reductions in emissions that would simultaneously yield cost savings for the university) to a target of stabilizing emissions levels at current levels even under the anticipated substantial growth plans of the university, to even more ambitious targets of absolute emission reductions. Any priority ranking of emission reduction potentials as well as a detailed analysis of their cost effectiveness and implementation possibilities – in order to be useful – is, however, ultimately contingent on the recognition that GHG emissions indeed should figure in the criteria of environmental performance of Yale and the resulting formulation of related environmental "benchmarks" and policies. We hope that this inventory will contribute toward the development of such university policies.

Section 2: The State of Climate Change Science and Policy

This section summarizes scientific understanding of climate change, provides an overview of current U.S. and international policy developments, and discusses climate-related initiatives by the government, NGO, and corporate sectors.

2.1 STATE OF CLIMATE SCIENCE

The 2001 Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) established a clear consensus of the world scientific community that global mean temperature has increased over the past century. This rise is attributable in part to anthropogenic activities, predominantly the emission of carbon dioxide into the atmosphere. The core purpose of the IPCC report was to examine the anthropogenic influence on observed climate change, together with the associated potential ecological and socioeconomic effects of projected future climate change.

The Intergovernmental Panel on Climate Change (IPCC) was established in 1988 by two United Nations organizations – the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP).

Since 1988, the IPCC has summarized the understanding of the scientific community on climate change in three major assessment reports (1990, 1995, 2001)[7]. The IPCC represents the consensus of the world scientific community and its work has been reaffirmed by other scientific bodies such as the U.S. National Academy of Sciences.[8]

The Third Assessment Report (TAR), produced by IPCC in 2001, summarized the results of three working groups:

1. Working Group 1, which assesses scientific understanding of climate change;
2. Working Group 2, which assesses impacts, adaptation, and vulnerability;
3. Working Group 3, which analyzes mitigation strategies.

The main results of the report can be summarized as follows:

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[7] Several other thematic publications are also produced by the IPCC. See http://www.ipcc.ch/about/about.htm

[8] See Senate testimony of Eric Barron, Committee on the Science of Climate Change, National Academy of Sciences, http://www4.nas.edu/ocga/testimony.nsf/

1. There is evidence of human-induced climate forcing caused by the emission of GHGs (mostly through burning of fossil fuels and land use change).
    a. There is compelling evidence that the amount of GHGs in the atmosphere has increased significantly due to human activities since the beginning of the industrial revolution.
    b. The climate system is affected by the increase of GHGs in the atmosphere. There is greater scientific confidence in the detection of climate change, i.e. global mean temperatures have increased already by some 0.6 degrees Celsius and this change is largely attributable to anthropogenic influence. There is also evidence – even if uncertain – that, in addition, climate variability (extremes) has been increasing.
    c. In absence of climate policies, the IPCC projects an increase in global mean temperature of between 1.4-5.8 degrees Celsius by 2100.
2. Changes in climate (and higher climate variability) bring significant risks for human economies and societies. Given current scientific knowledge, however, it is not possible to exactly quantify climate risks comprehensively, especially for unmanaged ecosystems.
3. The long term path of development chosen for the next 100 years, and thus the magnitude of possible future climate change, depends on short and medium-term policy choices. Therefore different scenarios of GHG emissions and resulting changes in global mean temperature and climate change impacts could unfold.

2.2 STATE OF CLIMATE POLICY

The threat of climate change has spurred policy responses at the international, national, and subnational levels. At the international level, the initial policy response was the signature of the United Nations Framework Convention on Climate Change (UNFCCC) in 1992[9]. The ultimate goal of the Convention, as articulated in Article 2, is to:

> *"achieve . . . stabilization of GHG concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system."* (United Nations 1992)

The Convention committed developed countries to aim to stabilize their GHG emissions at 1990 levels by the year 2000. Such commitment, however, was voluntary and was not followed by adequate policies. The 1997 Kyoto Protocol established legally-binding emission reduction targets for Annex I nations (developed countries

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[9] The UNFCCC has been ratified by over 189 countries, including the USA, all EU countries, India, China, and Russia (status as of May 24, 2004). The United Nations Framework Convention on Climate Change (UNFCCC) has been ratified by 189 countries (status as of May 24, 2004), including the United States of America. Source: http://unfccc.int/files/essential_background/convention/status_of_ratification/application/pdf/ratlist.pdf

and countries with economies in transition), amounting to a collective emissions cut for these nations of 5.2% below 1990 levels by the 2008-2012 time period. The Protocol also introduced several flexible implementation mechanisms, such as emissions trading, joint implementation, and the Clean Development Mechanism, to reduce the cost of achieving these targets. Non-Annex I nations committed themselves to further advancing their efforts to manage GHG emissions, but did not set reduction targets.

To enter into force, the Protocol required ratification by 55 parties to the Convention, including 55% of the Annex I countries' 1990 emissions. The Protocol came into force on February 16, 2005. 155 countries have ratified the Kyoto Protocol (status as of August 31, 2005)* Non-ratifying Annex I nations include the United States, which accounts for more than 36% of the Annex I GHG emissions, and Australia, which accounts for another 2.1%. The European Union, Japan and Canada have moved forward with implementation strategies, including the creation of markets for GHG emissions trading. Non-Annex I signatories, meanwhile, are also implementing GHG reduction strategies even in the absence of binding emission reduction targets.

While the U.S. government has to date refrained from ratification of the Kyoto Protocol, a growing number of GHG emission reduction initiatives are being implemented in the United States:

- GHG emission reductions are promoted at the federal level through voluntary programs sponsored by the U.S. Environmental Protection Agency (EPA), the Department of Energy (DOE), and the U.S. Department of Agriculture (USDA).
- A number of U.S. states are developing climate change-related strategies and setting emission targets. (See Table 2.1)

Table 2.1 GHG-Related Initiatives at U.S. State Level[10]

Initiative	States
Renewable Portfolio Standard	18 States
Net metering	17 States
Green electrcity pricing programs	29 States
Completed climate change action plan	28 States
States involved in regional initiatives on climate change and clean energy	33 States
GHG emissions reductions target	ME, MA, NJ, NY
Public Benefit Funds that support energy efficiency or renewable energy	22 States

At the regional level, Northeastern states appear to be aggressively pursuing GHG reduction initiatives. The New England Governors and Eastern Canada Premiers have jointly created a Climate Change Action Plan with the following goals:

- o To reduce GHG by 20% by 2020 (compared to 1990 emissions);
- o To reduce emissions by 65%-85% in the "long term" (New England Governors and Eastern Canada Premiers 2001).

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* Source: http://unfccc.int/files/essential_background/kyoto_protocol/application/pdf/kpstats. pdf

[10] Pew Center on Global Climate Change: Learning from State Action on Climate Change. http:L//www.pew climate.org/docUploads/States%5FInBrief@2Epdf)

- The State of Connecticut is working with other Northeast states to create a regional GHG registry. The medium term goal is to introduce a GHG cap and trade system, which is likely to be based on mandatory GHG emissions reduction targets.
- In an effort to achieve state GHG emission reduction goals, the State of Connecticut is pursuing reduction targets in its operations and is soliciting the help of other organizations, including universities, to address GHG emissions.
- The New Haven, CT Board of Aldermen passed a resolution supporting the statewide renewable energy campaign "20% by 2010." Mayor John DeStefano, Jr. has formed a Clean Energy Task Force to plan how the city of New Haven can meet this goal and begin utilizing energy from clean sources.

In addition to government-driven activities, corporations and NGOs have also undertaken climate-related initiatives (see Table 2.2).

Table 2.2 Non-Governmental Emissions Reduction Initiatives

Name	Participants	Goals/Targets
Business Environmental Leadership Council	Led by the Pew Center on Global Climate Change. Participants include Boeing, DuPont, Shell, Weyerhauser, and 36 others (as of 9/2005).	GHG reduction target levels and structures are voluntary and selected by each company independently. A variety of targets and emission reduction methods are pursued.
Climate Savers	Created by the WWF and the Center for Energy and Climate Solutions. Initial participants are six companies, including IBM, Johnson & Johnson, Polaroid, Nike, Lafarge, and the Collins Companies.	All these companies made specific commitments to reduce their energy consumption. The WWF and the Center pledge to "work with a select group of companies to customize progressive business plans for reducing greenhouse gas emissions, specifically focusing on carbon dioxide emissions."
Partnership for Climate Action	Seven companies, including BP, DuPont, and Shell joined Environmental Defense to create this partnership.	Each company has made a firm commitment to reduce GHG emissions and has agreed to measure and publicly report its emissions (http://www.pca-online.org/).
CCX (Chicago Climate Exchange)	Business driven. Started by 14 large GHG emitters accounting for 4.3% of total U.S. emissions. Currently has 40 participants.	First multinational, multisector market for GHG emissions trading. One percent emission reduction target per annum for the 2003-2006 period (on a 1998-2001 baseline). First GHG emission auction in November 2003, trading commenced in December 2003.

In addition to these initiatives, a number of companies, recognizing the importance of goal-setting, have unilaterally established internal emissions objectives and/or engaged in intra-firm emissions trading. For example, in 1998, BP Chairman

John Browne, speaking at the Yale School of Management, committed his firm to a 10% cut in emissions from operations between 1990 and 2010. The firm reported in early 2002 that it had achieved its goal eight years ahead of schedule.

Whether with national governments or multinational corporations, a prerequisite for climate mitigation is a thorough understanding of emissions, reduction potentials, and the costs and benefits of various approaches to emissions reduction. In each of the above examples, institutions have begun this learning process by developing an inventory of GHG emissions. The following sections discuss why and how such an inventory was done for Yale University.

Section 3: Why a GHG Inventory for Yale University?

A growing number of Yale's peer universities have established or are in the process of establishing comprehensive energy audits and GHG inventories. Among the more prominent examples:

- Harvard University has launched a Greenhouse Gas Inventory, jointly sponsored by the Harvard Green Campus Initiative and Harvard's Department of Environmental Health and Safety.
- Stanford University has established a major Energy and Climate Initiative research program, with the support of GE and ExxonMobil, and has established campus-wide guidelines for climate-friendly buildings.
- Tufts University, through the Tufts Climate Initiative, has established a GHG Inventory dating back to 1990, established a goal of returning emissions to 1990 levels by 2000, and was the first university to join the Chicago Climate Exchange.
- Oberlin College conducted a GHG Inventory for 2000, commissioned an Oberlin 2020 project to assess the feasibility of becoming climate-neutral by 2020, and built a widely acclaimed model green building.
- Other universities with GHG inventories include:
    - University of Colorado-Boulder
    - Tulane University
    - Rutgers University
    - University of Vermont

On November 15th, 2003, The Yale College Council, along with representatives from six other Ivy League Student Councils, passed the Ivy Council Resolution urging their universities' administrations to take concrete steps toward reducing campus greenhouse gas emissions.

Beyond these internal and external "stakeholder" pressures, however, the YCI team believes that Yale University, like any corporation, has its own interest in developing a GHG inventory and climate strategy. Some of these motivations relate to the university's mission and leadership role:

- Yale aspires to be, in the words of its president, a "truly global university." As such, it should develop a proactive strategy for addressing global challenges such as climate change.
- Yale also aspires to global leadership on environmental issues — not only as the home of one of the world's leading environment schools, but as a whole institution.
- For an institution of higher learning, development of a GHG inventory and a subsequent university climate policy presents enormous educational opportunities. Possibilities for research and experimentation include:
    - Law and regulation (e.g. GHG emissions trading rules – at the international, national and state level)
    - Economics and business (e.g. emissions trading, economic analysis of emission reduction measures)
    - Architecture (e.g. building energy efficiency, city planning)
    - Engineering (e.g. energy and transportation systems technologies)
    - Computer science (e.g. information economy and energy efficiency)
    - Social sciences (e.g. organizational behavior and institutional change)

Other motivations relate to the university's strategic planning and economic situation:

- Development of a Yale GHG inventory is the essential first step toward the institution's development of a long-term mitigation strategy, but does not limit Yale's strategic options or prematurely commit it to a specific course of action.
- A Yale GHG inventory can identify cost-saving opportunities for reducing or avoiding energy consumption, thus alleviating budgetary pressures.
- Yale has a window of opportunity to pioneer climate-friendly campus design through its ongoing college renovations and ambitious construction plans for new buildings, particularly for science facilities now being planned.
- A Yale GHG inventory may also identify economic opportunities for low-cost mitigation via participation in emissions trading or the purchase of renewable energy certificates.

Section 4: What is a Greenhouse Gas Inventory?

A GHG inventory is an accounting and reporting standard to measure emissions of greenhouse gas (GHG) emissions that typically accounts for the six gases covered by the Kyoto Protocol. Conducting a greenhouse gas inventory is the first step for an organization to take to create a foundation for effective GHG management. Tracking sources and quantities of GHG emissions provides an organization with the ability to identify cost-effective reduction opportunities, set reduction targets, measure progress, and participate in voluntary climate mechanisms. An inventory is vital in order for an organization to begin to understand its GHG emissions and explore potential mitigation options.

4.1 ACCOUNTING AND REPORTING STANDARDS

Many organizations have developed protocols and standards to follow when creating an inventory. The Intergovernmental Panel on Climate Change (IPCC), World Resources Institute (WRI) and the World Business Council on Sustainable Development (WBCSD), U.S. Environmental Protection Agency (EPA), and many universities have developed methodologies for GHG inventories. These methodologies help identify boundaries for the inventory, define which sources and GHGs should be included in the inventory, as well as provide templates to calculate emissions based on source activity data and emissions factors.

As with financial reporting, generally accepted GHG accounting principles must ensure that reported information represents a true and fair account of an organization's GHG emissions. Many corporations and climate initiatives that quantify GHG emissions use the Greenhouse Gas Protocol, developed by WRI and WBCSD. In June 2002, a new working group within the International Organization for Standardization (ISO) began developing an international standard for measuring, reporting and verifying GHG emissions. If it follows the path of other ISO standards, the ISO GHG standard will be incorporated into climate policies in many companies and will become a component of "best practice" for industry.

While there is currently no universally accepted GHG inventory standard at the subnational level, the new ISO standard is expected to incorporate much of WRI's work on standards.[11] The YCI inventory follows to a certain extent the WRI accounting standards, but in some respects is more ambitious. The description of these standards will be explained in more detail below.

4.2 INVENTORY RESULTS AND MITIGATION RECOMMENDATIONS

Performance measurement plays an essential role in developing strategy and evaluating to what extent organizational objectives have been met. Opportunities for emissions reductions to achieve an organization's target can be evaluated after a credible inventory is conducted. There are two categories of emissions reductions: "internal reductions" and "offsets." Internal reductions are those that take place within an organization's operations, such as installing double paned windows to improve energy efficiency. An offset is the reduction or removal of emissions through a project outside an organization's operations, such as purchasing carbon offsets from tree plantings in other areas. Credible GHG accounting is a prerequisite for participation in GHG trading markets and for demonstrating compliance with government regulations.

4.3 INVENTORY PROTOCOLS AVAILABLE

4.3.1 The Intergovernmental Panel on Climate Change (IPCC)

IPCC current methodologies provide comparative methods for calculating emissions data by region or country for those parties attempting to compile inventories from limited information resources. The latest published IPCC methodologies are the *1996 Revised IPCC Guidelines*. National GHG inventories must use "methodologies accepted by the IPCC." Generally, the IPCC methodologies are flexible and open-ended.

4.3.2 WRI and WBCSD GHG Protocol Initiative

The Greenhouse Gas Protocol Initiative is a broad international coalition of businesses, non-governmental organizations (NGOs), and governmental and inter-governmental organizations operating under the umbrella of WRI and WBCSD. Through a collaborative process with these groups, WRI and WBCSD have been working to develop internationally accepted accounting and reporting standards for GHG emissions and to promote their use in companies and other organizations. The GHG Protocol Initiative also provides practical guidelines to help companies manage their GHG emissions. The five main principles for GHG accounting and reporting in the protocol are[12]:

1. **Relevance:** Define boundaries that appropriately reflect the GHG emissions of the business and the decision-making needs of users.
2. **Completeness:** Account for all GHG emissions sources and activities within the chosen organizational and operational boundaries. Any specific exclusions should be stated and justified.
3. **Consistency:** Allow meaningful comparison of emissions performance over time. Any changes to the basis of reporting should be clearly stated to enable continued valid comparison.

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[11] ISO GHG Inventory Standards Development with the NGO Ecologia, http://www.ecologia.org/ems/ghg/docs/applications-approaches.pdf, site accessed in November 2003.

[12] GHG Protocol: A Corporate Accounting and Reporting Standard, WRI and WBCSD, http://www.ghgprotocol.org/standard/ghg.pdf

4. **Transparency:** Address all relevant issues in a factual and coherent manner, based on a clear audit trail. Important assumptions should be disclosed and appropriate references made to the calculation methodologies used.
5. **Accuracy:** Exercise due diligence to ensure that GHG calculations have the precision needed for their intended use, and provide reasonable assurance of the integrity of reported GHG information.

4.3.3 EPA Climate Leaders Program

The EPA GHG Inventory Guidance is based on the existing corporate GHG inventorying protocol developed by WRI and WBCSD. EPA's Climate Leaders program is a voluntary program to guide companies in accounting and reporting their greenhouse gas emissions. Climate Leader GHG Inventory Guidance is an effort by EPA to enhance the GHG Protocol to fit more precisely what is needed for Climate Leaders. EPA is building on the protocol and providing more detailed guidance, calculation tools, and reporting forms.

4.3.4 Other University Approaches

GHG inventories from five universities were reviewed before the Yale inventory was conducted – the University of Vermont (UVM), Tufts University, the University of Colorado-Boulder (CU-Boulder), Tulane University, and Rutgers University. It should be noted that the buildings section of this report also explores the efforts of Harvard and Stanford, but these schools are, like Yale, still developing more comprehensive GHG inventories. The inventories were evaluated with respect to both their scope and processes. Table 4.1 compares the activities included for each university inventory surveyed.

Table 4.1 Comparison of GHG Inventories, U.S. Universities, in Terms of Coverage of Emission Sources

	UVM	Tufts	CU-Boulder	Tulane	Rutgers	Yale
Power Generation	✔	✔	✔	✔	✔	✔
Electricity, Chilled Water and Steam Use	✔	✔	✔	✔	✔	✔
Buildings	✔	✔	✔	✔		✔
Vehicle Fleet	✔	✔	✔	✔	✔	✔
Staff and Student Commuting	✔		✔			✔
Waste Management	✔	✔				✔
Refrigerants	✔	✔				✔
Sinks						✔

Energy

Of the five schools, only CU-Boulder and UVM have generation capacity on campus, like Yale. Therefore the inventories for Tufts, Tulane, and Rutgers all measured purchased electricity, steam and chilled water. Many of the universities used physical plant utility billing records to define the scope of their inventories and serve as the source of the majority of data used. CU-Boulder, UVM and Yale all meter their energy generation and consumption, providing more data for analysis.

Buildings

For many universities, utility billing records were all that was used to measure energy use and efficiency of buildings on campus. Heating and cooling of buildings were calculated into the overall energy usage of the university. Mitigation recommendations in most universities focused on improving the efficiency of energy consumption in buildings.

Transportation

When calculating CO_2 emissions from transportation, some universities accounted only for university fleet vehicles and disregarded commuting faculty, staff, and students. UVM, CU-Boulder and Tufts did include estimates for commuting faculty, staff and students.

Other Sources and Sinks: Waste Management, Refrigerants, and Sinks

UVM and Tufts made greenhouse gas emission estimates based on the amount of municipal solid waste the university sent to landfills and incinerators. In addition, these universities also made estimates of the amount of refrigerant leakage from large chillers. None of the universities surveyed attempted to calculate sequestration at school-owned forests. With the exception of Tufts, the universities also disregarded indirect emissions attributed to new construction. Furthermore, none of the universities incorporates either indirect upstream emissions or indirect downstream emissions in any of the respective inventories.[13]

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[13] The upstream emissions are associated with the embodied energy in every material or piece of equipment purchased by the university and are embodied in production and distribution of the products. Downstream emissions are due to releases from solid waste end-of-life disposition activities such as re-use, recycling and disposal.

Section 5: YCI Inventory – Overall Methodology and Results

5.1 METHODOLOGY

5.1.1 Study Boundary

The organizational "system boundary" for the YCI study was set to include all activities related to the educational mission of the university. The study included all direct and indirect emissions of the six GHGs covered by the Kyoto Protocol. Direct emissions are those emissions from sources that Yale University owns or controls. Indirect emissions occur as a consequence of Yale's activities, but arise from sources that are not necessarily owned or controlled by Yale. This study was conducted using data from calendar year 2002, though in some cases FY02 figures were used, as no calendar year data were available.

5.1.2 Study Scope

The study scope was further divided into six tiers:

- **Tier 1** – Emissions from Yale power plants, including emissions from electricity, steam, and chilled water production;
- **Tier 2** – Yale emissions from activities for which Yale has decision-making power, either through the procurement process or an equivalent, which includes purchased electricity and energy consumption by buildings;
- **Tier 3** – Yale emissions from Yale activities that are decided on and transacted by other individuals, for example, work-related travel and commuting;
- **Tier 4** – Yale's emissions from its outsourced activities where decisions are made through contract provisions, including waste generation in landfills and wastewater;
- **Tier 5** – Yale's incidental emissions, for example, emissions from tourists visiting Yale's museums; and
- **Tier 6** – Yale's emissions from embodied energy and resulting emissions – for instance, cement or steel used in the construction of university buildings or embodied in equipment like PCs owned by the university.

This YCI assessment was limited to the first four tiers, due to limited data availability. Tier 1 and Tier 2 emissions that are either caused by university operations like its power plants or are determined by the university's purchase decisions are the dominant sources of GHG emissions of Yale.

Study Organization

All relevant activity data were gathered from institutional sources and university suppliers. Four working groups within YCI calculated emissions: Power Plants, Buildings, Transportation (including corporate fleet, community and institutional travel) and Other Sources and Sinks (including solid waste, laboratory chemicals and refrigerants, as well as carbon sequestration in forests).

5.2 BASELINE SETTING

Since the most accurate data available were from 2002, this year's inventory should be used as a baseline to compare emissions over time. There are currently not enough relevant emissions data available in past years to extrapolate Yale University's emissions to the future to establish an emissions baseline over time. Therefore, in order to reduce emissions through future mitigation efforts, a comparison should be made to the 2002 inventory. This baseline can also be used to adjust emissions from growth or decline in the university's activities and other structural changes that affect total emissions from year to year.

5.2.1 Emissions Calculations

Emissions factors are source-specific and convert activity data into emissions values. Published emissions factors were researched and collected from leading sources such as the IPCC, EPA, and others. Once activity data and emissions factors for a specific source were identified, GHG emissions in tons of CO_2e were calculated. The conversion of non-CO_2 GHG emissions into CO_2e are based on the so-called Global Warming Potentials (GWP)[14] for each gas given by the 2001 Third Assessment Report of the IPCC (Table 5.1) and that are also incorporated into the Kyoto Protocol.

Table 5.1 Global Warming Potential of Different GHGs Relative to CO_2

Time Horizon in Years		*Global Warming Potential*		
		20	**100**	**500**
Carbon Dioxide	CO2	1	1	1
Methane	CH4	62	23	7
NitrousOxide	N2O	275	296	156
HFC-134a	R-134a	3,300	1,300	400
SulfurHexafluoride	SF6	15,100	22,200	32,400
Dichlorodifluoromethane CFC-12	R-12	10,600	10,600	10,600
Chlorodifluoromethane HCFC-22	R-22	1,700	1,700	1,700

[14] GWPs consider the different radiative forcing and residence times of different greenhouse gas species in the atmosphere.

The 100-year global warming potentials were used to aggregate different GHGs into CO_2 equivalents in the YCI "best estimate" calculations, and the 20 and 500 year potentials were used in the uncertainty analyses. No 20 and 500 year potentials have been found for R-12 and R-22 and thus the 100 year time integration potentials were retained for all calculations.

5.2.2 Uncertainty

Ranges of uncertainty were calculated for the activity data and conversion factors used in the analysis. Uncertainties are associated with data and reporting errors, as well as with assumptions that needed to be made in cases of incomplete data and assumptions in the emissions factors reported in the literature. According to the information available to YCI, our inventory for Yale is the first inventory made for an organization that explicitly recognizes and calculates the uncertainty range inherent in an emissions inventory.

Inventory Summary

The YCI calculated total GHG emissions in 2002 of 284,663 tons of CO_2e, with an uncertainty high of 360,542 tons of CO_2e (27%) and an uncertainty low of 227,458 tons of CO_2e (-20 %). Table 5.2 below provides further detail on the inventory results.

81% of the best estimate emissions come from the three largest activity sources:

1. Central power plant – 120,655 tons of CO_2e, 42%, Tier 1.
2. Sterling power plant – 78,473 tons of CO_2e, 28%, Tier 1.
3. Buildings (purchased electricity) – 30,003 tons of CO_2e, 11%, Tier 2a.

Since the activity of the Central and Sterling Power Plants is to supply the Yale buildings with electricity, steam, and chilled water, this result is especially significant as it suggests that future GHG emission reduction assessments should be focused primarily on the energy consumption of Yale buildings. Nevertheless, caution should be taken to assess the results further, as the actual scope of emissions reduction is also determined by the level of control (as shown by the tier categories) as well as technological and economic feasibility. The Central Power Plant and the Sterling Power Plant are in Tier 1, indicating that Yale has almost absolute control over the major aspects of these emissions.

The next 13% (81%-94% cumulative range) comes from a mix of activities:

1. Employee commutes and visits – 12,016 tons of CO_2e, 4%, Tier 3
2. Work-related air travel booked through Yale's travel agents – 9,339 tons of CO_2e, 3%, Tier 3
3. Refrigerants – 8,341 tons of CO_2e, 3%, Tier 2b

4. Buildings (boilers and furnaces for heating energy) – 8,096 tons of CO_2e, 3%, Tier 2b

The remaining 6% of emissions is comprised of a diversity of activities of different levels of control by the university (tiers) including *inter alia* emissions resulting from Yale students traveling home (Tier 3) or refrigerant leakage from chillers (Tier 2b), among others.

Table 5.2 Summary of YCI GHG Inventory, 2002

TIER	Description	WRI Category	GHG Emissions Best Estimate	Percentage of total Emissions	Uncertainty (High)	Uncertainty (Low)	GHG emissions (High)	GHG emissions (Low)
			Tons CO_1e	%	%	%	Tons CO_1e	Tons CO_1e
Tier 1	*Power plants*							
	Central power plant	Scope 1	120,655	42.4%	14%	-14%	137,592	104,092
	Pierson-Sage power plant	Scope 1	194	0.1%	15%	-15%	224	164
	Sterling power plant	Scope 1	78,473	27.6%	10%	-10%	86,033	70,929
Tier 2a	*Purchased electricity*							
	Central power plant	Scope 2	2,790	1.0%	37%	-36%	3,811	1,793
	Sterling power plant	Scope 2	4,604	1.6%	37%	-36%	6,288	2,959
	Buildings	Scope 2	30,003	10.5%	41%	-32%	42,284	20,361
Tier 2b	*Buildings (boilers/furnaces)*	Scope 1	8,096	2.8%	15%	-14%	9,339	6,932
	Institutional travel	Scope 1	1,638	0.6%	9%	-9%	1,785	1,490
	Laboratory gases	Scope 3	325	0.1%	5%	-45%	340	179
	Refrigerants	Scope 3	8,341	2.9%	138%	-75%	19,841	2,090
	Forest sink	Scope 3	-6,291	-2.2%	150%	-50%	-15,728	-3,146
Tier 3	*Work related travel (Co_2)*	Scope 3						
	Air travel through travel agent	Scope 3	9,339	3.3%	25%	-25%	11,674	7,004
	Other work-related travel	Scope 3	2,734	1.0%	50%	-36%	4,101	1,750
	Commutes and visits	Scope 3						
	Employees	Scope 3	12,016	4.2%	100%	-50%	24,032	6,008
	Students	Scope 3	1,700	0.6%	300%	-50%	6,800	850
	Students returning home (domestic)	Scope 3	5,400	1.9%	100%	-50%	10,800	2,700
	Students returning home (int'l.)	Scope 3	415	0.1%	100%	-50%	830	208
	Transport 'other GHG gases' (non CO_2)	Scope 3	1,662	0.6%	300%	-99%	4,986	17
Tier 4	*Waste*							
	Incineration	Scope 3	2,197	0.8%	73%	-51%	3,806	1,072
	Landfilling	Scope 3	56	0.0%	286%	-89%	215	6
	Wastewater	Scope 3	317	0.1%	370%	-100%	1,489	0
Total			**284,663**		**27%**	**-20%**	**360,542**	**227,458**

Table 5.2 demonstrates that Yale is in a significant position to influence the reduction of its emissions. The largest sources fall within Tier 1, and decrease moving down the various tiers. It is an encouraging sign that affecting change is a highly possible proposition. But as mentioned before, technological and economic factors have to be further considered in mitigation options.

Table 5.3 summarizes Yale's emissions broken down by greenhouse gas species. CO_2 is the dominant greenhouse gas with 96%, derived almost in its entirety from fuel use in power plants, buildings and transport activities. (Excluding the negative emissions from the forest sinks, energy-related CO_2 makes up 98% of total emissions.) Refrigerants comprise some 3% of total GHG emissions, with methane and nitrous oxide accounting for about 1% of total GHG emissions. This highlights the conclusion that GHG emission management above all needs to address energy-related CO_2, with refrigerant leakage from large chillers being the only additional option for consideration, even if small.

Table 5.3 Summary of (best estimate) GHG Emissions for Yale by Gas (in metric tons CO_2e)

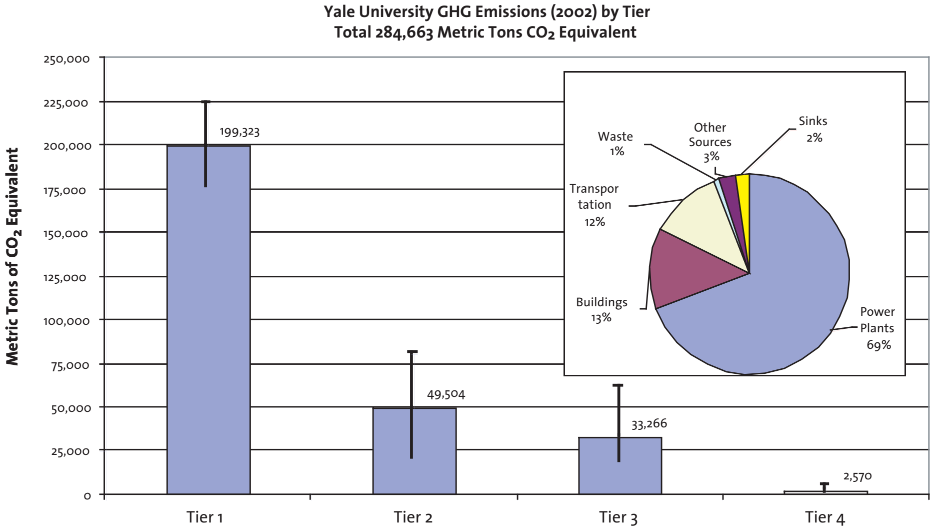
<table>
<tr><th></th><th>CO_2</th><th>CH_4</th><th>N_2O</th><th>HFCs & PFCs</th><th>Total</th></tr>
<tr><td>Power plants & buildings</td><td>243,678</td><td>205</td><td>931</td><td>*</td><td>244,814</td></tr>
<tr><td>Transport**</td><td>33,242</td><td colspan="2">1,662</td><td>n.e.</td><td>34,904</td></tr>
<tr><td>Others</td><td>2,178</td><td>358</td><td>359</td><td>8,341</td><td>11,236</td></tr>
<tr><td>Sinks</td><td>-6,291</td><td>n.e.</td><td>n.e.</td><td>0</td><td>-6,291</td></tr>
<tr><td>Total</td><td>272,807</td><td colspan="2">3,515</td><td>8,341</td><td>284,663</td></tr>
</table>

n.e. = not estimated
* included in "Others" category
** no separate breakdown between CH_4 and N_2O available

Figure 5.1 below shows the emissions by sector. Although the uncertainty factors for the power plants are not as great as for some of the other sectors, the magnitude of the emissions amplifies the absolute uncertainty emissions figure. The uncertainty for the power plants is very significant when compared to other sectors, and it will also affect the certainty of any cost-benefit analysis performed for mitigation options. The magnitude of the uncertainty argues for a better energy metering and monitoring system for the power plants and buildings.

The uncertainty for transport is also very large. This is due to the quantity and quality of data available to conduct the inventory. Nevertheless, it serves as a strong incentive to improve on the available research in transportation emissions.

Figure 5.1 Yale University GHG Emissions and Uncertainy Ranges by Sector, 2002.



Section 6: Inventory of Power Plants

6.1 OVERVIEW

One of the distinguishing features of Yale University is that it both purchases energy in the form of fuels and electricity and generates its own energy through a cogeneration system producing electricity and heat as well as chilled water. To that end, Yale University owns and operates three power plants:

1. Central Power Plant (CPP) supplies the Central Campus and Science Hill with electricity, steam, and chilled water.
2. Pierson-Sage Power Plant (PSPP) is a small standby steam generation plant for the Central Power Plant.
3. Sterling Power Plant (SPP) serves the Yale Medical School (YMS) and Yale-New Haven Hospital (YNHH) with steam and chilled water. SPP currently has no cogeneration of electricity. The Medical School and Hospital receive their electricity directly from United Illuminating.

The power plants use natural gas, #2 diesel fuel, and #6 residual fuel. Electricity is also drawn from United Illuminating to operate the power plant building facilities. Almost 80% of the fuel used in the power plants in 2002 was natural gas. #6 (15% in 2002) and #2 (4% in 2002) fuel oil are secondary fuel inputs.

Emissions from combustion of fuel in the power plant are classified under Tier 1 of the GHG inventory. The electricity purchased for use in the power plants is classified under Tier 2 (purchased electricity) and is summarized in Table 6.1.

Table 6.1 Greenhouse Gas Emissions from Power Plants

Emission Source	GHG Emissions	Percentage of Total Emissions	Uncertainty	GHG Emissions (High)	GHG Emissions (Low)
	metric tons CO_2e	%	%	metric tons CO_2e	metric tons CO_2e
Tier 1: Power Plants					
Central power plant	120,655	42.4%	+/-14%	137,592	104,092
Pierson-Sage power plant	194	0.1%	+/-15%	224	164
Sterling power plant	78,473	27.6%	+/-10%	86,033	70,929
Tier 2a: Purchased Electricity					
Central power plant	2,790	1.0%	+/-37%	3,811	1,793
Sterling power plant	4,604	1.6%	+/-37%	6,288	2,959
TOTAL	206,716	73		233,947	179,937

Total GHG emissions (including purchased electricity) from the power plants in 2002 were 206,716 tons of CO_2e. Sixty percent of the emissions came from the Central Power Plant and 72% percent of GHG emissions from the power plants in 2002 came from burning natural gas. 2002 emissions as reported here are estimated to be accurate within an uncertainty range of between 780,000 and 234,000 metric tons CO_2e.

6.2 CENTRAL POWER PLANT

The Central Power Plant is a cogeneration plant with a supplementary package boiler, three diesel generators and five steam driven chillers. At full load the CPP is capable of supplying the campus with 20 MW electricity, 150 tons of steam (250 psig* saturated steam) and 15,000 Rtons[15] of chilled water. Electricity generated from the gas turbine electricity generators and diesel generators is supplied to the Central Campus, Science Hill, and the Central Power Plant itself (to operate auxiliary equipment). Electricity is also received from United Illuminating. The gas turbine electricity generators' and diesel generators' electrical switchboards can be switched to receive electricity from United Illuminating if necessary. Thus, in case of equipment failure at the Central Power Plant, the power plant is able to supply all buildings with electricity from the United Illuminating grid. Steam generated from the heat recovery steam generators and package boilers are supplied to Central Campus (at 125 psi), Science Hill (at 250 psi), and the Central Power Plant (to operate the five steam driven chillers and auxiliary equipment). Chilled water produced by the five chillers is supplied to Central Campus and Science Hill.

6.2.1 Pierson-Sage Power Plant

Pierson-Sage Power Plant is used as an additional standby steam generator for the Central Power Plant. The major pieces of equipment are two package boilers that use natural gas as fuel.

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* Pounds per square inch gauge.

[15] Rtons: refrigerant tons.

6.2.2 Sterling Power Plant

The Sterling Power Plant is a heating plant producing steam and chilled water with six package boilers, five steam driven chillers, one electric driven chiller and one diesel (back up) generator. Steam and chilled water generated at the Sterling Power Plant are supplied to the Medical School and Yale-New Haven Hospital.

6.3 METHODS

Data Sources

The data for the Yale power plants were obtained from the Power Plant Utilities Distribution Department (Utilities Department) of the Yale University Office of Facilities. The fuel used by the equipment, the energy output of the equipment, and energy output of the plant are all metered. Some of the meters record individual equipment while others record a group of equipment. Some of these metered data are gathered by the plant operations and maintenance personnel and transmitted to the Utilities Department daily. Others are collected electronically by the FIX and Maxnet systems and by the Plant Engineering Facilities Department (Engineering Department). All data are collated by the Utilities Department and entered manually into an Excel spreadsheet.

The general data supplied by the Utilities Department are listed below:

1. Fuel and electricity consumption data by the power plants – natural gas in cubic feet, #2 (0.05% sulfur) diesel oil and #6 (0.5%, 1% sulfur) residual oil in gallons, electricity in kilowatt-hours.
2. Electricity, steam and chilled water production by the power plant equipment – electricity in kilowatt-hours, steam in pounds-of-steam, chilled water in refrigerant-tons.
3. Electricity, steam and chilled water delivered to the university – electricity in kilowatt-hours, steam in pounds-of-steam, and chilled water in refrigeration-tons.
4. Power plant equipment operating hours.
5. Weather data.

6.4 DATA ANALYSIS

All calculations were performed on an Excel spreadsheet. The description below briefly explains the general steps taken in the analysis:

1. All data are categorized in four major groups:
    a. Fuel Import – fuel/energy imported into the Yale power plants (i.e. #2 fuel oil, #6 fuel oil, natural gas and electricity from UI).

   b. Fuel Input – fuel/energy consumed by the Yale power plant equipment (i.e. #2 fuel oil, #6 fuel oil, natural gas and electricity from UI).
   c. Energy Output – energy produced by the Yale power plant equipment (i.e. steam, chilled water and electricity from generators).
   d. Energy Export – energy exported out of the Yale power plants (i.e. steam, chilled water and electricity from generators).
2. All equipment of the same type was grouped together and data aggregated (i.e. in groups for gas turbines, package boilers, etc., for each of the three power plants).
3. All energy data (#2 fuel oil, #5 fuel oil, natural gas, electricity, steam and chilled water) were normalized to Joules by multiplying with:
   a. the respective caloric value for fuel data (fuel oil consumption and natural gas consumption) and secondary energy data (steam produced and chilled water produced), and
   b. the appropriate unit conversion factor for the data in energy units (electricity input and output).
4. Emissions were calculated by multiplying the fuel inputs with the appropriate emission factors (this is explained in more detail below).

Emissions were calculated for GHGs including:

1. Direct sources (carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O))
2. Indirect sources (nitrogen oxides (NO_x), sulfur oxides (SO_x), carbon monoxide (CO), sulfur dioxide (SO_2) and volatile organic compounds (VOCs)).

Emissions factors were taken from IPCC, EPA, emission permits of the power plants and other relevant sources. These factors are equipment specific as well as fuel specific. Electricity purchased is classified as energy (i.e. fuel) input data similar to fuel oil and gas purchase data. Upstream CO_2, SO_x and NO_x emissions from electricity purchased from United Illuminating are calculated with the Northeast regional power pool emissions factors based on a study carried out by ISO New England[16]. To calculate the CH_4 and N_2O emissions, the YCI assumed for purchased electricity the same CH_4/CO_2 resp. NO_2/CO_2 ratios as for the onsite gas turbine. Methane and nitrous oxide emissions were normalized to CO_2 equivalents by multiplying their 100-year global warming potentials given by the IPCC. The 20/500-year global warming potentials were used to determine upper and lower emission bounds for the uncertainty analysis.

[16] ISO New England Inc., 2002 Nepool Marginal Emission Rate Analysis, 2003. The study presents average and marginal emissions associated with electricity production in the northeast Nepool Region which we consider representative for the electricity purchased by United Illuminated and distributed to Yale.

Indirect emission sources are included in the inventory because they also contribute to global warming, albeit in indirect way and with different effects, including both positive (warming) as well as negative forcing (cooling such as in the case of sulfate aerosols). These emissions are also reported because they have negative impacts on human health and are currently regulated by EPA. GHG indirect source emission factors underlying the YCI emission inventory estimates are based on the emission permits of the power plants. Even though these permits became effective in 2004, the YCI considered them the best available source of emission factors for the indirect GHG emissions for our reporting year 2002.

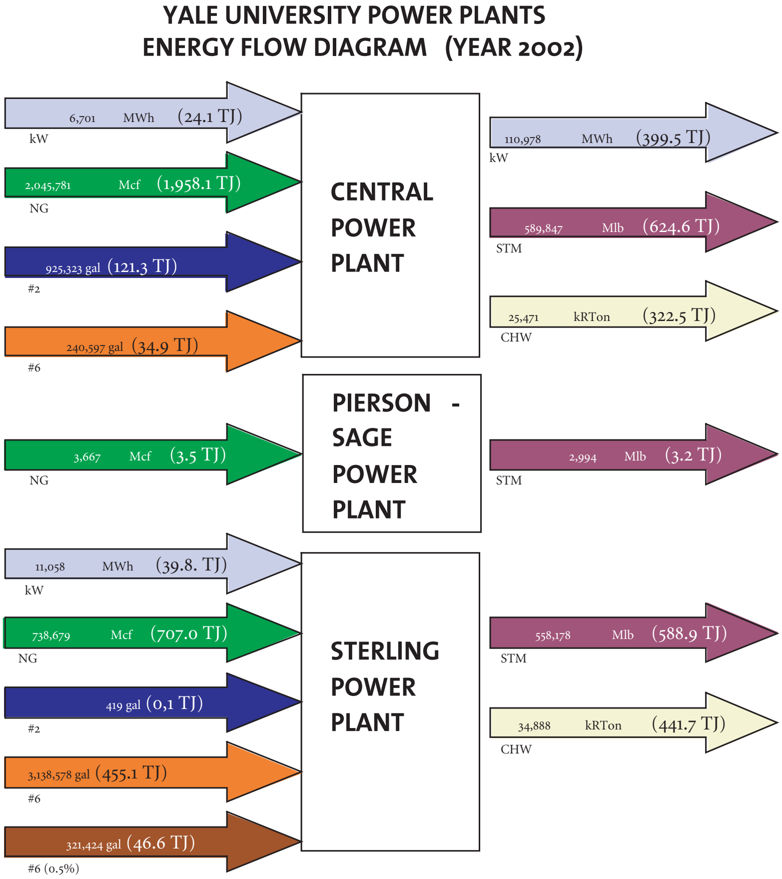
Steam production for the Pierson-Sage Power Plant is not available. An indicative value was calculated by using the Sterling Power Plant package boiler efficiency multiplied by the Pierson-Sage Power Plant boiler fuel input.

6.5 SUMMARY OF RESULTS

6.5.1 Energy Flow and Production

The energy flow through the power plants is shown in Figure 6.1.

Figure 6.1 Yale Power Plants Energy Flow (2002)



As shown in Figure 6.1, the total energy import into the power plants is about 3,330 TJ with natural gas as the main fuel (80%). The power plant equipment produces electricity, steam and chilled water. Total energy export is about 2,380 TJ for the three power plants. Steam constitutes more than 50% of all energy produced by the Yale power plants, followed by chilled water (~32%) and electricity (17%).

In addition to the steam streams shown in Figure 6.1, the power plants also have auxiliary equipment that uses some of the steam, while a small portion of the steam is wasted. The wasted steam in the power plant is referred to as steam dumping and can occur to relieve pressure in the power plant equipment or through leaks in the system. Central Power Plant auxiliary equipment consumes about 15-25% of total steam output while about 2.5% is dumped. The Sterling Power Plant has a combined auxiliary equipment steam use and steam dump of about 23%. However, available data do not allow separating out how much is associated with each activity and thereby the percentage of steam waste (dumping).

6.5.2 Power Plant Emissions

Total GHG emissions equal 206,716 metric tons of CO_2e for the three power plants, with 60% (123,445 metric tons) from the Central Power Plant, less than 1% (194 metric tons) from the Pierson-Sage Power Plant, and about 40% (83,077 metric tons) from the Sterling Power Plant (see also Table 6.1 above).

Table 6.2 Tier 1 and 2 GHG and Other Gases Emissions from Yale Power Plants (including emissions from purchased electricity)

Year 2002	CPP emissions		PSPP emissions		SPP emissions		YALE PP emissions	
	Tons	CO_2e	Tons	Tons CO_2e	Tons	Tons CO_2e	Tons	Tons CO_2e
CO_2	122,505	122,505	194	194	82,881	82,881	205,580	205,580
CH_4	7	167	<0.1	<0.5	1	38	8	205
N_2O	2	773	<0.1	<0.5	1	158	3	931
CO	24		<0.1		31		55	
NO_x	43		<0.1		87		130	
SO_x	29		<0.1		251		280	
VOC	24		<0.1		31		55	
TOTAL GHG								206,716

Table 6.2 summaries the GHG emissions by gas and power plant. CH_4 and N_2O emissions, even though they have a higher global warming potential, are insignificant sources of GHG emissions at Yale's power plants compared to CO_2 (205 tons CO_2e for CH_4 and 931 tons CO_2e for N_2O as compared to 205,580 tons CO_2.

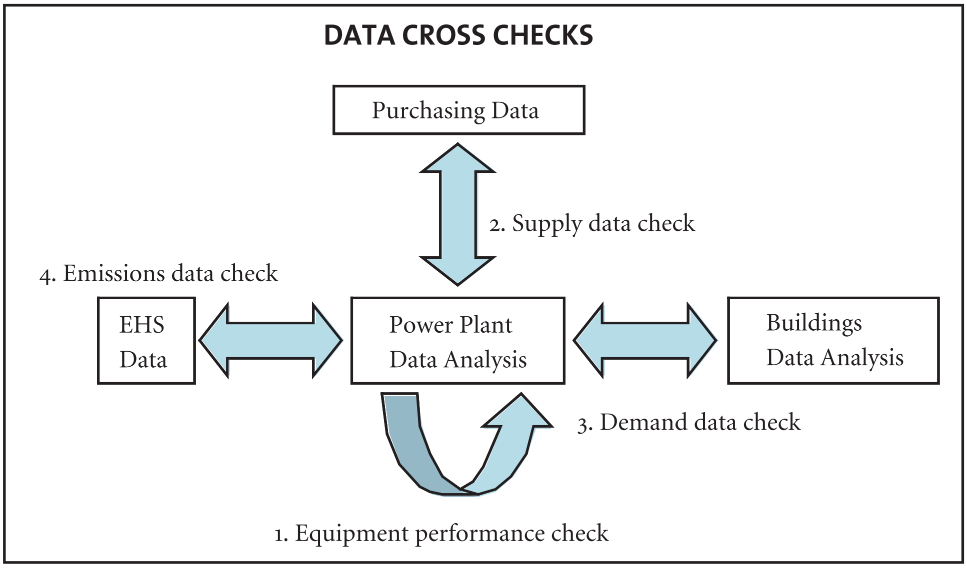
According to the Yale Environmental Health and Safety Department, indirect source emissions (CO, NO_x, SO_x, and VOCs) are in accordance with EPA regulations. There is currently no agreed method for establishing GWPs for indirect GHGs. Nonetheless, emissions calculations were performed here as a record for future analysis.

6.5.3 Data Checks

Four levels of data crosschecking were performed on the power plant data (See Figure 6.2).

1. Equipment performance check
2. Supply data check
3. Demand data check
4. Emissions data check

Figure 6.2 Power Plant Data Crosschecks



The analysis of the power plant emissions is the core piece of the GHG inventory as the power plant emissions make up the majority of Yale's emissions. Since the fiscal year isn't equal to the calendar year, this crosscheck was done primarily to compare data for similar orders of magnitude. The results of the data crosscheck are discussed in the following sections.

Power Plant Efficiency and Equipment Performance

Average efficiencies were calculated for the power plant equipment based on daily, monthly and yearly aggregated data to check equipment performance. In general, efficiencies on an annual average are within typical performance ranges, thus adding credence to the orders of magnitude of the emission calculations reported here.

The Central Power Plant has an electrical efficiency of about 27%; the total efficiency is about 63%. The thermal efficiency of the steam generators is about 85-90%. The coefficient of performance (COP) of steam driven chillers is about 1.3-1.5; the COP of electricity driven chillers is about 5-8, depending on the load.[17]

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[17] Operation under full load (at designed capacity) generally yields highest equipment efficiency and coefficients of performance.

Purchasing Data Comparison

The data and calculations were compared against purchasing data of fuels obtained from the Accounting and Finance Administration Department (Accounting Department). The data from the Accounting Department is based on a fiscal year (July to June) as compared to the calendar year used in this report. To compare orders of magnitude, the purchasing data of the fiscal year 2001 and 2002 are shown together with the metered data over the calendar year 2002 in Table 6.3.

Table 6.3 Power Plant Purchasing Data Comparison

Commodity		Purchasing Data FY 2001	Purchasing Data FY 2002	Plant Metered CY 2002
Central Power Plant				
Electricity	MWh	11,407	8,938	6,701
Natural gas	10^6 m^3	162	181	190
Oil #6	gallons	837,270	240,282	240,597
Oil #2, diesel	gallons	817,532	378,212	925,323
Sterling Power Plant				
Electricity	kWh	8,405	11,662	11,058
Natural gas	10^6 m^3	37	53	69
Oil #6	gallons	4,598,664	3,661,770	3,460,002
Oil #2, diesel	gallons	-	3,586	419
Pierson- Sage Power Plant				
Natural gas	10^6 m^3	0.5	0.1	0.3

The data are generally in the same orders of magnitude. Errors come into play probably from different metering techniques and locations at the utility level or at the power plant, comparing different years, stocked fuel errors, and different allocations of fuel use by the accounting department that may not be the actual fuel use. The accounting system is not conducive to obtaining a detailed breakdown of the fuel purchased for a more detailed analysis that can show where errors come into play. Further study and ultimately a consolidated accounting system between purchasing and plant metered energy use and disposition would be required to fully resolve data discrepancies. Such consolidated accounting is also considered a pre-requisite for a clearer attribution of energy use, emissions, and costs that can guide decision-making at various levels of the university.

Power Plants and Buildings Data

The difference in results between the power plants and building metered data are shown in Table 6.4 below.

Table 6.4 Difference between Power Plant and Buildings Data (2002)

Commodity	Power Plant Data (Production)	Building Data (Consumption)	Difference 1- BD / PPB
	TJ	TJ	%
Electricity	400	375	6
Steam	764	608	20
Chilled Water	1,214	1,000	18

The data were received during the writing of this report. Further investigation has not been conducted, but it is highly recommended that differences be checked, especially for steam and chilled water losses in the system, where the difference between plant output and building input metered data are particularly significant, representing a potential source for energy and cost savings and emission reductions. In other words, there may be potential savings in energy consumption if areas of large transmission losses can be identified. However, it is difficult to institute any demand side management mitigation options to improve energy consumption without knowing how reliable the underlying energy use data are, so the above comparison provides a good crosscheck. The data are presented here as an acknowledgement of the issue. It is highly recommended that further study and analysis of this area be conducted. We have taken account of these metering and reporting discrepancies in the uncertainty ranges estimated for the YCI emission inventory.

Emissions Data Comparisons to EHS Emissions Data

Emissions calculations were also checked by comparing the group's calculations against emissions calculations by the Environmental, Health and Safety (EHS) Department at Yale University. These data are also the basis for the emission numbers reported in the Yale University Environment Report prepared by the Advisory Committee on Environmental Management (ACEM).[18] In comparison to the YCI emission estimates reported here, Yale's Environment Report focuses only on Tier 1 CO_2 emissions and therefore reports somewhat lower numbers than those given in the YCI inventory, which covers more GHG gas species and draws a wider system boundary. The EHS department emissions factors for GHG are from EPA, and emissions for criteria pollutants SO_x, NO_x, and particulate matter (PM10) are based on telemetry or equipment suppliers' expected performance data. The comparison is presented in Table 6.5.

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[18] ACEM (Advisory Committee on Environmental Management), Yale University Environmental Report 1997-1998 through 2003-2004, April 22, 2005. http://www.yale.edu/recycling/envreport.pdf

Table 6.5 Power Plant Emissions Data Comparison (2002)

Pollutant	EHS 2002 Emissions Tons/year	EHS Emission Factors	YCI Tons/year	(YCI-EHS) /YCI
CENTRAL POWER PLANT				
CO_2	1.2E+05	AP42	1.2E+05	3%
CH_4	6.6E+00	AP42	7.1E+00	6%
N_2O	2.3E+00	AP42	2.5E+00	11%
CO	1.5E+01	manufacturer's data / emissions monitoring	2.4E+01	37%
No_x	3.4E+01	manufacturer's data / emissions monitoring	4.0E+01	14%
So_x	7.4E+00	manufacturer's data / emissions monitoring	2.0E+01	63%
VOC	2.3E+01	manufacturer's data / emissions monitoring	4.8E+00	-372%
STERLING POWER PLANT				
CO_2	7.7E+04	AP42	8.0E+04	4%
CH_4	2.7E+00	AP42	2E+00	-73%
N_2O	1.0E+00	AP42	4.9E-01	-106%
CO	3.3E+01	manufacturer's data / emissions monitoring	3.1E+01	-8%
No_x	1.1E+02	manufacturer's data / emissions monitoring	8.4E+01	-28%
So_x	2.4E+02	manufacturer's data / emissions monitoring	2.4E+02	2%
VOC	5.8E+00	manufacturer's data / emissions monitoring	5.7E+00	-1%

In terms of aggregate GHG emissions, the two estimates agree very well. However, there are important differences remaining, particularly for sulfur and VOC emissions. They, however, are not central to the YCI GHG emission inventory reported here.

For CO_2, CH_4 and N_2O, both inventory approaches are based on fuel consumption figures multiplied by emissions factors given by the EPA. As both methods rely on the same activity variable data sources (fuel purchases) and emission factors, the comparison does not constitute a true independent cross-check of emission estimates. These would only be possible through actual emission measurements at the power plants. The costs of these measurements, however, seem less warranted given the small differences between the various GHG emission estimates that are captured in the uncertainty range of the YCI emission inventory reported here (see also Section 6.6 below).

For CO, NO_x, SO_x, and VOC emissions, the comparison reported here is between actual or manufacturer's declared emissions figures (EHS) and emission permits of the power plants, which entered into force in 2004 (YCI). Since the emission factors allowed by these permits are often approximately an order of magnitude lower than standard emission factors given by various literatures (e.g. EPA AP-42), these figures were considered more accurate and retained in the YCI inventory. Again, the comparison between these different emission estimates yielded a useful metric for the uncertainty analysis of the YCI GHG emission inventory.

6.6 UNCERTAINTY ANALYSIS

Basically, uncertainty comes from four major areas: (1) data measurement and data reporting, and consolidation uncertainty; (2) conversion factor uncertainty; (3) emission factor uncertainty; and (4) global warming potential uncertainty.

For measurement and consolidation uncertainty, the YCI mainly focused on the differences between purchasing data and data collected by the power plant operators' respective differences between power plant output data and buildings input data. The uncertainties for conversion factors are estimated by comparing respective fuel specific heating values and densities given by different literature sources. Uncertainties for emission factors were estimated in an analogous manner. Uncertainties of the global warming potentials are derived from the different global warming potentials (over 20/100/500 year integration horizons) as given by the IPCC.

The total uncertainty for each process chain was calculated by the square root of the sum of the squares of the percentage uncertainties. If an uncertainty of a process chain calculated in this manner exceeded 60%, the individual uncertainties were simply summed up[19].

In general the total, compounded uncertainties of CO_2-emissions range from +/- 9% to +/- 34%. The uncertainties of CH_4 and NO_2 emissions are substantially larger: between +511/-50% to +1000/-81% respectively, excluding the uncertainty due to different GHG potentials.

Aggregated, the uncertainty range of the power plant GHG emissions (Tier 1 and Tier 2 combined) for the year 2002 is estimated to be between 179,937 and 233,947 tons CO_2-e, or ±13 percent.

[19] Following the revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, Reporting Instructions: Annex 1: Managing Uncertainties.

Section 7: Inventory of Buildings

7.1 DESCRIPTION OF DATA

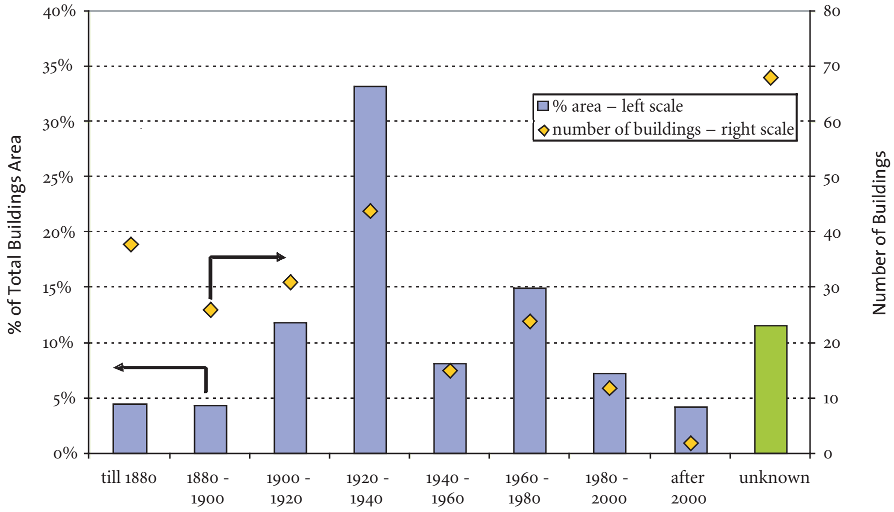
The YCI data collection procedure for buildings involved three primary sources:

- Master Building List
- Metered Energy Database (Tier 1)
- Purchased Utilities Record (Tier 2)

7.1.1 Master Building List

The Office of Facilities maintains the master list of university buildings. The list provided to the YCI buildings team contained 495 entries of buildings or spaces that are owned or leased by Yale. Each entry was categorized by facility ID, facility name, abbreviation, address, site, principal use, gross square feet (GSF), net square feet (NSF), and available square feet (ASF). An overview of the buildings ages and the related size is given in Figure 7.1.

Figure 7.1 Mean, Percent Area, and Number of Current Buildings per Construction Decade



7.1.2 Metered Energy Database

The Office of Facilities also maintains an online database of metered energy consumption for buildings that are connected to the campus grid and therefore fall into the Tier 1 category. The Maxnet database lists buildings (ID, size, etc.) on a monthly basis, and includes data on electricity, chilled water and steam, both in original units and in MBTU. The YCI buildings team collected data for the 2002 base year, which covered 188 buildings. These 188 buildings represent a subset of the 495 entries on the master list described above.

7.1.3 Purchased Utilities Record

The Office of Facilities maintains a record of data on energy that is purchased from off the grid and used in buildings, and therefore falls into the Tier 2 category. The information provided covers Facility ID, Building Name, Commodity, and data on purchased electricity, gas (#2 contract, bundled, firm, interruptible), and oil (#2, #6, diesel) in original units. The FY02 data provided to the YCI buildings team covered 232 buildings. These 232 buildings are also largely a subset of the master list, but are separate from the Maxnet list, as purchased energy is not captured by Maxnet.

7.2 MEASUREMENT METHODS AND ASSUMPTIONS

The YCI building team followed a three-step measurement methodology:

- Establish building system boundary.
- Determine appropriate conversion factors.
- Calculate energy consumption and GHG emissions for Tier 1 and Tier 2.

7.2.1 Building System Boundary

The team established a final list through the following methodology:

- Begin with master building list provided.
- Transfer Tier 1 data (metered energy) to master list, checking for consistency.
- Transfer Tier 2 data (purchased energy) to master list, checking for consistency.
- Where names differ among three sources, standardize to master list name.
- Identify and add (if data are available) buildings on Tier 1 list that are not on master list.
- Identify and add (if data are available) buildings on Tier 2 list that are not on master list.
- Identify buildings with missing energy or area data.
- Exclude building from master list where energy data are unavailable.
- Where area data are unavailable, use estimate based on comparable buildings.

Through this process, the team established a system boundary of 257 buildings for the inventory.

7.2.2 Appropriate Conversion Factors

The team employed a set of agreed conversion factors derived from sources including DOE, EPA, and IPCC among others.

7.2.3 Energy Consumption and GHG Emissions Calculations for Tier 1 and Tier 2

The conversion factors were applied to calculate energy use and GHG emissions for buildings within the established system boundary, distinguishing between the two tiers.

7.3 RESULTS

Yale's buildings use a total of 2,386 TJ energy in the form of electricity, steam, chilled water, as well as heating fuels. 83% (1983 TJ) of that amount is provided by the central cogeneration and district heating/cooling system fed by the power plants on campus. The resulting GHG emissions are accounted for as Tier 1 emissions and are reported in the power plant section of this report. About 17% (403 TJ) of building energy use consists of purchased electricity and fuels that are accounted for as Tier 2 emissions and reported separately here. These emissions arise both off-campus (i.e. at power plants producing the electricity purchased) or on campus (i.e. burning gas and #2 fuel oil for heating purposes in campus buildings not connected to the central university energy grid).

Table 7.1 provides an overview of GHG emissions of Tier 2 buildings. (For Tier 1 building emissions see the emissions presented in the power plant section). The "best estimate" for Tier 2 building emissions amounts to 38,098 tons CO_2-e (or 13% of Yale's GHG emissions) with an estimated uncertainty range of between 25,956 to 52,965 tons CO_2-e. GHG emissions are dominated by CO_2 (37,803.1 tons), with purchased electricity (29,725.8 tons CO_2), natural gas (7,479.5 tons) and #2 fuel oil (597.8 tons) as the main constituent sources. Non-CO_2 emissions associated with above fuel use are comparatively minor: 295 tons CO_2e (all values given refer to "best estimate" numbers).

Table 7.2 Tier 2 GHG Emissions from Buildings. Note that Tier 1 emissions are accounted for in Section 6.

Emission Source	GHG Emissions	Percentage of Total Yale Emissions	Uncertainty	GHG Emissions (High)	GHG Emissions (Low)
	metric tons CO_2e	%	%	tons CO_2e	tons CO_2e
Tier 2					
Purchased electricity (Buildings)	30,003	10.5%	+45 / -37%	43,629	19,019
boilers and furnaces (Buildings)	8,096	2.8%	+15 / -14%	9,337	6,937
TOTAL	**38,098**	**13%**		**52,965**	**25,956**

7.3.1 Building Area and Energy Consumption

The YCI building energy study encompassed a total sample size of 257 buildings on the Yale campus or owned by Yale elsewhere in New Haven or Connecticut. A breakdown of the buildings by campus area, type, area, and energy use is shown in Tables 7.2 and 7.3. A total of 1,173,405 gross square meters was represented in the study, and total energy usage was 2,386 TJ in 2002. (These figures exclude the three campus power plants, their area and internal energy use as accounted for in the Tier 1 emissions and activity variables in previous sections.)

Table 7.3 Building Characteristics by Campus Area

Campus Area	Number	Area (m²)	Energy Use (TJ/yr)
Central	146	685,777	831
Medical	37	213,641	874
Science	53	224,226	646
Athletic	8	20,645	20
Connecticut	9	17,175	10
New Haven	4	11,941	6
Total	257	1,173,405	2,386

Table 7.3 Building Characteristics by Use

Building Use	Number	Area (m²)	Energy Use (TJ/yr)
Academic	77	248,444	548
Administrative	25	70,750	86
Apartment	10	35,796	14
Assembly	6	22,667	10
Athletics	14	82,205	91
Dining	2	7,939	13
Dormitory	26	228,054	246
Housing	6	5,361	3
Lab, Dry	9	52,970	195
Lab, Wet	10	64,217	332
Library	8	103,102	154
Medical	32	180,387	667
Operations	8	12,546	10
Parking	1	18,395	1
Real Estate	9	141	10
Residential	5	3,930	1
Society	9	29,264	6
Total	257	1,173,405	2,386

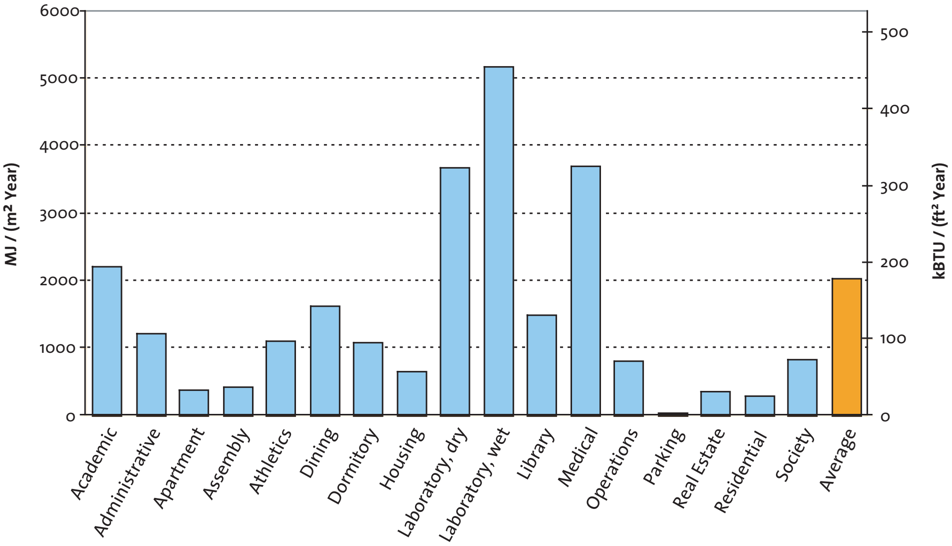
The academic, dormitory, laboratory (wet and dry, or generally biological/chemical laboratories and physical laboratories) and medical buildings account for 60% of the total buildings. They are even more prominent in the area and energy use statistics, with 66% and 83% of the respective totals.

Overall, about 20% of Yale buildings account for 80% of total building energy consumption, a ratio characteristic of a typical Pareto distribution.

7.3.2 Building Energy Intensity

The energy intensities of the buildings were calculated and averages determined for each building type (See Figure 7.2). Wet laboratories, medical buildings, and dry laboatories were by far the most energy-intensive buildings.

Figure 7.2 Energy Intensity by Building Type

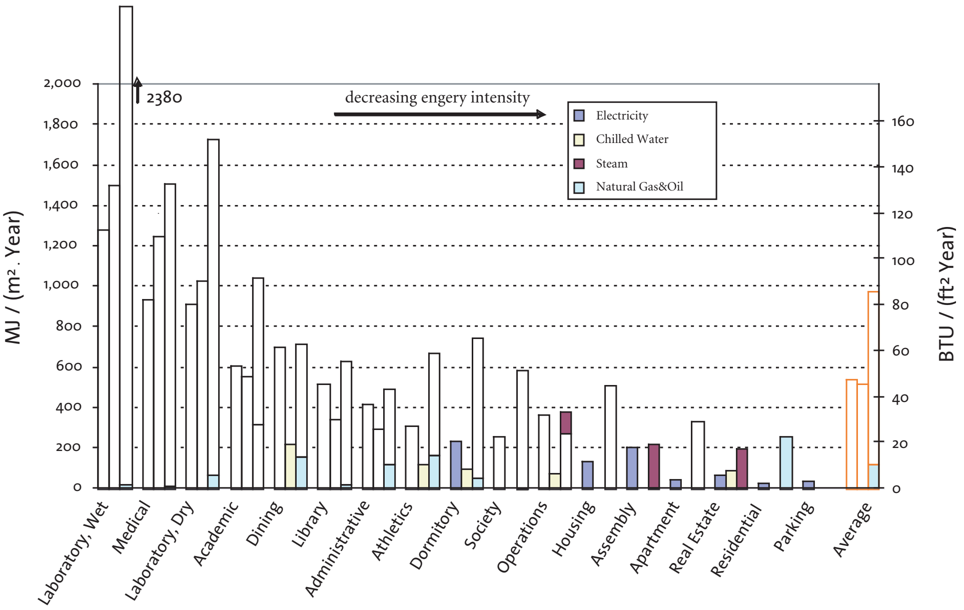


On average, Yale buildings consume 2,034 MJ/m² (179 kBtu/ft²/year), compared to Stanford's 177 kBtu/ft²/year. The average for U.S. academic buildings is 79.3 kBtu/ft²/year and the average for U.S. office buildings is 97.2 kBtu/ft²/year. The average Yale medical building consumes close to 3,700 MJ/m² (326 kBTU/ft²/year), compared to some 80 kBTU/ft²/year for health care buildings reviewed in a sample of 4,579 commercial buildings examined in detail by the Energy Information Administration.[19]

A breakdown by energy use reveals electricity as the most energy-intensive form, followed by steam (especially for wet and dry laboratories) and chilled water (see Figure 7.3).

[19] Energy Information Administration, A Look at Commercial Buildings in 1995. http://www.eia.doe.gov/pub/pdf/consumption/062595.pdf

Figure 7.3 Energy Intensity Breakdown by Energy Use



These patterns are not surprising, given the intrinsically high energy intensity of laboratories and medical facilities. However, part of these differences may also be explained by differing energy costs among campus buildings and by unrealized potentials for efficiency improvements.

7.3.3 Energy Costs

The YCI team also performed an energy cost analysis, using FY02 data provided by the Office of Facilities. As Table 7.4 and Figure 7.4 illustrate, energy costs for final building energy use at Yale vary between campus areas, as well as according to the origin of the energy (i.e. produced by campus power plants or purchased from the local utility).

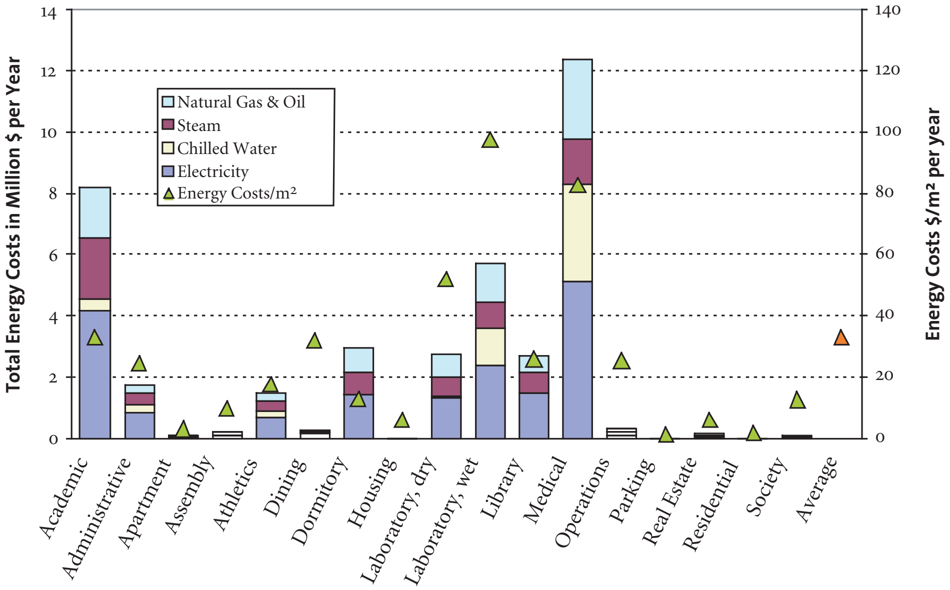
Table 7.4 End-use (final) energy for Yale buildings. Cost (in $/GJ)

Utility	**Cost (in $/GJ)**		
	Maxweb to MED	Maxweb to CEN/SCI	Purchased
Electricity	–	$ 27.5	$ 30.3
Chilled water	$ 19.0	$ 29.4	–
Steam	$ 8.5	$ 13.3	–
Natural gas	–	–	$ 4.2
Oil	–	–	$ 6.6

Total energy costs for the buildings (excluding power plants) covered in this study were $39M in FY2002. Per-unit energy costs equaled $16.4/GJ, which can be compared to the IPCC average of $14/GJ for energy-related building costs in the United States.

Figure 7.4 provides a breakdown of expenditures by building type (total and per m² building space). As with energy consumption, the laboratory, and medical buildings dominate.

Figure 7.4 Breakdown of Energy Expenditures by Building Type



Differences among buildings in energy costs are similar to the patterns of energy consumption and intensity. It is interesting to observe the impact of the cost differentials between campuses (favoring buildings on the medical campus). Without these cost differences, medical (and many of the wet laboratory) buildings would have been even more dominant in energy costs.

Benchmarking with Other Universities

Several universities, including Stanford, have benchmarked the energy intensity of their buildings against that of other educational buildings.[20] This section builds on different studies, which, while not perfectly comparable, can shed some light on Yale's building energy performance. Table 7.5 provides background comparison of four studies. In the aggregate, Yale's building energy use is within the range of other educational institutions in North America where comparable data are available. Large differences exist, however, in comparison to European universities as exemplified by the Austrian universities, which are more than twice as energy efficient per unit floor area. However, a more useful unit for energy benchmarking and identifying energy and cost saving potential (GHG) is at the level of individual buildings or groups of buildings to account for different usage patterns. Priority candidates for detailed

[20] Audrey Chang, "Green Meets Green: A Study of Energy Consumption in Stanford University Buildings," Program in Environmental Science, Technology, and Policy, Stanford University, June 2002.

energy audits are medical and wet and dry laboratory buildings because of their high energy intensity and their dominance in Yale's building energy use.

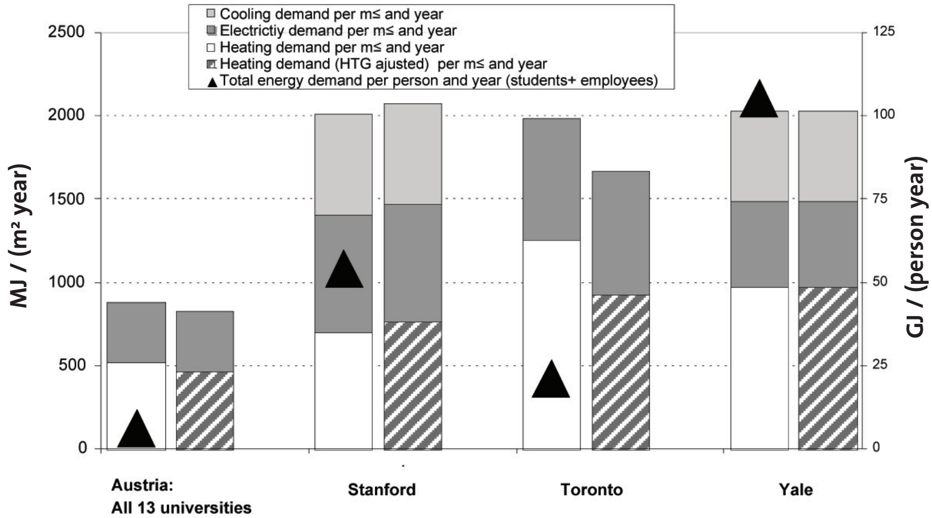
Table 7.5 Comparison of Energy Use of Different Universities

University	Buildings	Area	Heating Degrees Day	Students	Employees	Energy demand (TJ / year)		
	#	m²	18°C/65°F	#	#	Heating	Electricity	Cooling
Austria (Sum of 13 universities)	Unknown	1,453,586	3,073	193,048	11,728	751	526	0
Stanford	287	743,810	2,530	15,570	12,000	524	524	449
University of Toronto	Unknown	847,353	3,707	67,692	11,365	1061	627	0
Yale	257	1,173,408	2,754	11,385	11,244	1144	608	635

It is nonetheless interesting to compare the aggregate energy use of Yale buildings to that of other universities. Adjusting for climate differences, Yale buildings, while being comparable to Stanford University, use 20% more energy per unit floor area (bars in Figure 7.5) than the University of Toronto, and 250% more energy than the average of all Austrian universities. Per campus person (students, faculty, and staff) comparisons (triangles in Figure 7.5) are even more striking: Yale's per capita building energy use is twice that of Stanford, six times that of the University of Toronto, and 18 times that of Austrian universities.

BMVIT, "Energieeffiziente Universitäten", April, 1999. The University of Toronto, "Historical Perspective of Energy Consumption and Management at the University of Toronto." Utilities Report to the Environmental Protection Advisory Committee, http://www.facilities.utoronto.ca/epac/brucereport.htm. 2001

Figure 7.5 Benchmarking of Yale Buildings Energy Use to Other Universities. Energy use by type and total, original data/left bars) and adjusted for climate differences (right bars). Energy use per square meter floor space (bars, left side) and per person on campus (triangles, right axis).



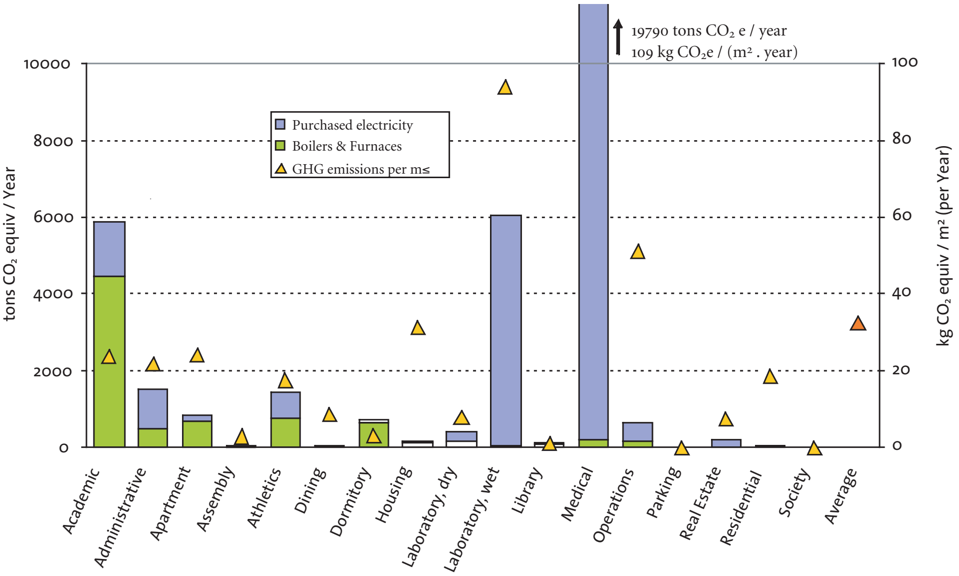
7.3.4 Greenhouse Gas Emissions

Buildings are the end users of most of the energy produced at the campus power plants. Building energy use therefore accounts for the bulk of the emissions calculated in the previous section – the Tier 1 power plant emissions of 206,716 tons CO_2e. This section addresses the Tier 2 emissions that need to be added to Tier 1 emissions and that are also related to building energy consumption in more detail.

Tier 2 GHG emissions from buildings were calculated from the purchased utility dataset described above. This dataset provided data on electricity, natural gas, and oil that was purchased for building energy use (i.e. not provided by the Yale power plants). Using appropriate conversion factors (in particular the emissions associated with purchased electricity (NEPOOL 2002 average), we calculated Tier 2 GHG emissions from buildings of 38,098 tons CO_2e in 2002.

Figure 7.6 provides a breakdown of Tier 2 emissions by building type and energy use.

Figure 7.6 Tier 2 GHG Emissions from Buildings (total bars, left axis) and per m² floor space (triangles, right axis)



Purchased energy from medical, wet laboratory, and academic buildings dominate Tier 2 building emissions. Purchased electricity is the largest single source (see Figure 7.6). Gas purchases for academic buildings are also relatively large.

7.4 UNCERTAINTY ANALYSIS

The YCI performed an uncertainty calculation to gauge the accuracy of total emissions from purchased energy and total energy consumed by the buildings. The following table describes the percentage of uncertainty attached to the use of conversion factors, the raw data sets from the university, and estimations of missing data.

Table 7.6 Building Data Uncertainties

Item	Uncertainty
Missing electricity data	±10%
Missing gas & oil data	±15%
Energy conversion factors for gas	±10%
Energy conversion factors for oil	±4%
Measurement of Maxnet electricity data	±5%
Measurement of Maxnet steam data	±20%
Measurement of Maxnet chilled water data	±20%
Energy conversion factors for steam and chilled water	±10%

7.4.1 Calculating Uncertainty of Energy Data and Emissions from Purchased Energy Data

The total uncertainty for each process chain was calculated by the square root of the sum of the squares of the percentage uncertainties following IPCC guidelines. If the total or uncertainty calculated by this approach exceeded 60%, the individual uncertainties were simply summed up. The results are displayed in Table 7.7.

Table 7.7 Energy and GHG Emission Uncertainties of Buildings

Energy consumed	TJ	Uncertainty	Range
Maxnet Energy Data (excluding power plants)	1,983	+/-13%	1,725-2,247
Purchased Energy Data	403	+/-9%	367-439
Total Buildings Energy	2,386	+/-12%	2,092-2,680
Emissions released	**Tons CO_2e**		
GHG Emissions from Purchased Electricity	30,003	+41 / -32%	20,402-42,304
GHG Emissions from gas and oil	8,096	+16 / -14%	6,963-9,391
Total GHG Emissions	38,098	+36 / -28%	27,365-51,696

Section 8: Transportation Inventory

8.1 DESCRIPTION OF DATA

Transportation at Yale can be considered in four main categories:

- Institutional
- Work-related
- Commuting
- Contracted vehicles

Institutional travel includes the university's bus and shuttle fleets, maintenance vehicles, police vehicles, departmental vehicles, and 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 projects 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. 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. The fourth category of travel is contracted vehicles – including buses leased by the athletic department for travel to games, and by the medical school for campus shuttling – which are not included in this study due to lack of data availability.

Table 8.1 Transportation Categories Considered

Transportation Category	YCI Tier	WRI scope	Description
Institutional	2	1	Yale-owned vehicles
Work-related	3	3	Individual trips for university-related purposes (conferences, research, etc.)
Commuting	3	3	Trips to/from Yale and employee/student homes
Contracted vehicles	4	3	Arrangements with outside vehicle contractors. *Not included in this study.*

The primary greenhouse gas associated with transportation is carbon dioxide, which is released as part of the gasoline combustion process. The amount of CO_2 released is directly related to the amount of fuel burned. N_2O, CH_4, and HFC releases also are a concern, but these represent only a small percentage of the overall greenhouse gas emissions in the sector. Releases of NO_x and CO, so called indirect GHGs (as influencing atmospheric chemistry and thus the residence times of direct GHGs), are not considered here explicitly, which follows EPA guidelines.

8.2 METHODS AND ASSUMPTIONS

8.2.1 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.

8.2.2 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 Yale 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 Parking and Transit Services, Human Resources, the Registrar's Office, and the Office of International Students and Scholars (OISS).

8.2.3 Assumptions, Emissions Factors, and Uncertainty

The most consistent 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, Clean Air Cool Planet 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 had to be made regarding vehicle technology, travel behavior, and other information for which little data were available. Each of these assumptions added additional uncertainty to the calculations, and sensitivity analyses were performed to determine the impact of each. The overall accuracy of the emissions estimate depends on the number of steps necessary to go from the available data to the emission numbers, and from 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.

8.3 SUMMARY AND ANALYSIS OF RESULTS

Table 8.2 below summarizes the main data types and assumptions, and sources of each.

Table 8.2 Sources, Assumptions, and Parameters

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

Greenhouse gas emissions from transportation break down as follows:

Table 8.3 Greenhouse Gas Emissions from Transportation

Emission Source	GHG Emissions, Best Estimate	Percentage of Total Emissions	Uncertainty	GHG Emissions (High)	GHG Emissions (Low)
	metric tons CO_2e	%	%	metric tons CO_2e	metric tons CO_2e
Tier 2					
Institutional travel	1,638	0.6%	+/- 9%	1,785	1,490
Tier 3					
Work related travel					
Work related air travel through travel agent	9,339	3.3%	+25 / 25%	11,674	7,004
Other work related travel	2,734	1.0%	+50 / -36%	4,101	1,750
Commutes and visits					
Employees commutes and visits	12,016	4.2%	+100 / -50%	24,032	6,008
Students commutes and visits	1,700	0.6%	+300 / -50%	6,800	850
Students returning home (dom.)	5,400	1.9%	+100 / -50%	10,800	2,700
Students returning home (int'l.)	415	0.1%	+100 / -50%	830	208
Non CO_2-GHG due to transport	1,662	0.6%	+300 / -99%	4,986	17
TOTAL	**34,904**	**12%**	**+86% / -43%**	**65,008**	**20,027**

The following analysis discusses institutional travel and work-related travel in succession.

8.3.1 Institutional Travel

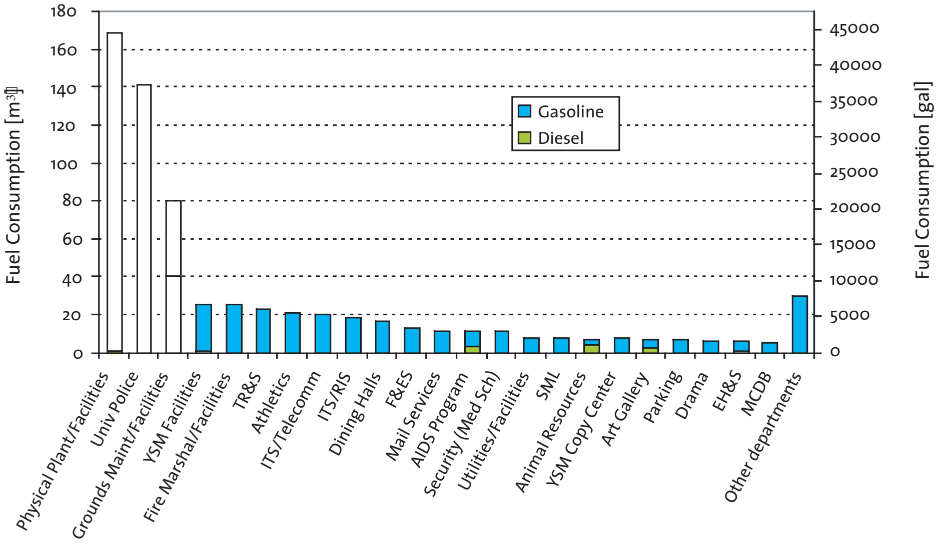
Table 8.4 Carbon Dioxide Emissions from Institutional Travel

Emission source	Energy (GJ)	CO_2 (metric tons)	CO_2 % of Yale's GHG Emissions	Uncertainty
Institutional travel	23,503	1,638	0.6%	+/- 9%

As of the 2003-2004 school year, Yale owned 366 vehicles. The owned vehicles are primarily trucks (102) and cargo vans (91), with the largest number of vehicles (91) operated by the Physical Plant Department. The vehicle inventory is maintained by the Purchasing Department, which tracks the model, year, and department of each vehicle. In some cases, EPA mileage estimates for these vehicles are kept on record, but in most cases they are 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 a Yale vehicle. This data is collected electronically at the gasoline pump via a fleet credit card that tracks fuel purchases (Figure 8.1).

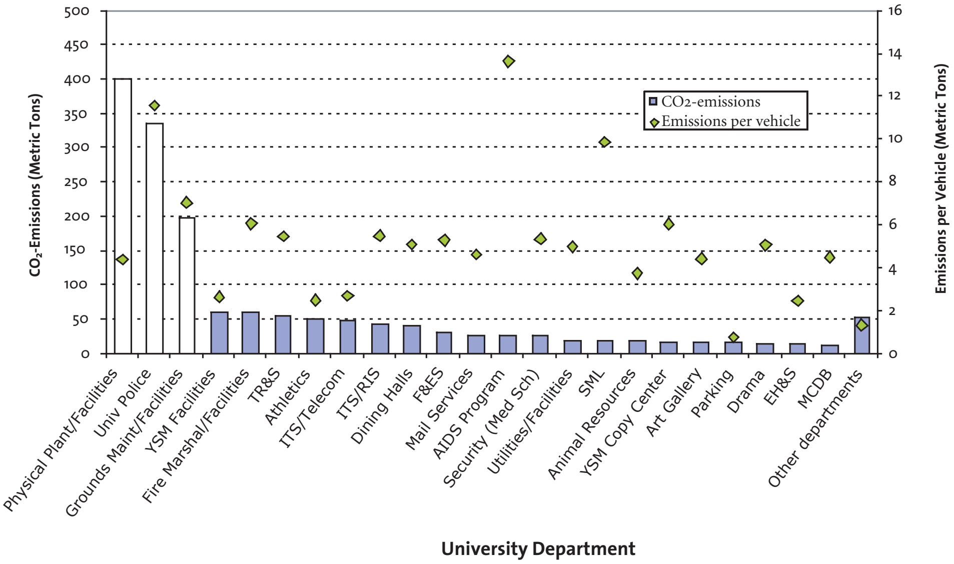
Figure 8.1 Fuel Consumption of University-Owned Vehicles per Department



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.

Despite these weaknesses, the fuel consumption data are quite robust and can be used to calculate levels of energy use and carbon dioxide emissions more accurately than any other university transportation operation. The total amount of gasoline purchased by each department was aggregated by type of fuel used and multiplied by density, heating value und emissions factors for each fuel type. Factors were cross-checked between several sources: EPA, WRI, and IPCC, and assigned uncertainties based on the source. The resulting CO_2 emissions are shown in Figure 8.2.

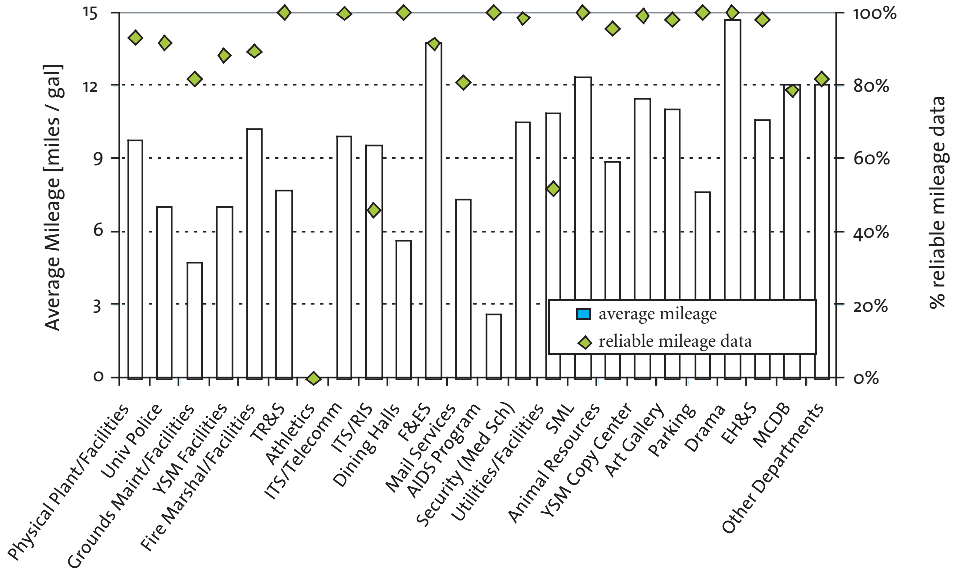
Figure 8.2 Carbon Dioxide Emissions from Gasoline and University Owned Vehicles



Emissions of other GHGs were made based on benchmarks of the relative share of GHG emissions from transportation. (See discussion of "other greenhouse gases" below.) Emissions, like fuel consumption, are dominated by the Physical Plant, Police and Grounds departments.

As described above, mileage information for Yale-owned vehicles is not very accurate, given its manual entry. Nevertheless after fixing a substantial number of errors, vehicle mileage was estimated for a subset of the data, and is discussed below (Figure 8.3). The bars indicate the average miles driven per gallon of fuel used of the considered subset of vehicles, and the diamonds indicate the percentage of fuel associated with specific odometer reading.

Figure 8.3 Average Miles Per Gallon of Fuel for University Owned Vehicles by Department.



Uncertainty

Uncertainty in the institutional emissions calculations is due to four factors: the accuracy of the conversion from fuel gallons to energy (density and heating value), 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 +/- 5%. Uncertainty of the heating value was assumed to be +/- 3%, and the conversion from volume to mass with an uncertainty of 5%. Emissions factors were assigned an uncertainty consistent across the inventory, in this case 5%.

8.3.2 Work-related Travel

Table 8.5 Carbon Dioxide Emissions from Work-Related Travel

Emission source	CO_2 (metric tons)	CO_2 % of Yale's GHG emissions	Uncertainty
Work-related	12,073	4.2%	+31 / -28%

During a typical year, both academic and administrative personnel undertake work-related trips to participate in conferences, working meetings, teaching, etc. For most of these trips, travel expenditures are paid by the University, 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.[21]

In order to estimate the miles traveled and the emissions generated, 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 used to obtain factors such the "average miles traveled per dollar spent in domestic car rental," "average GHG emission per air mile traveled," etc.

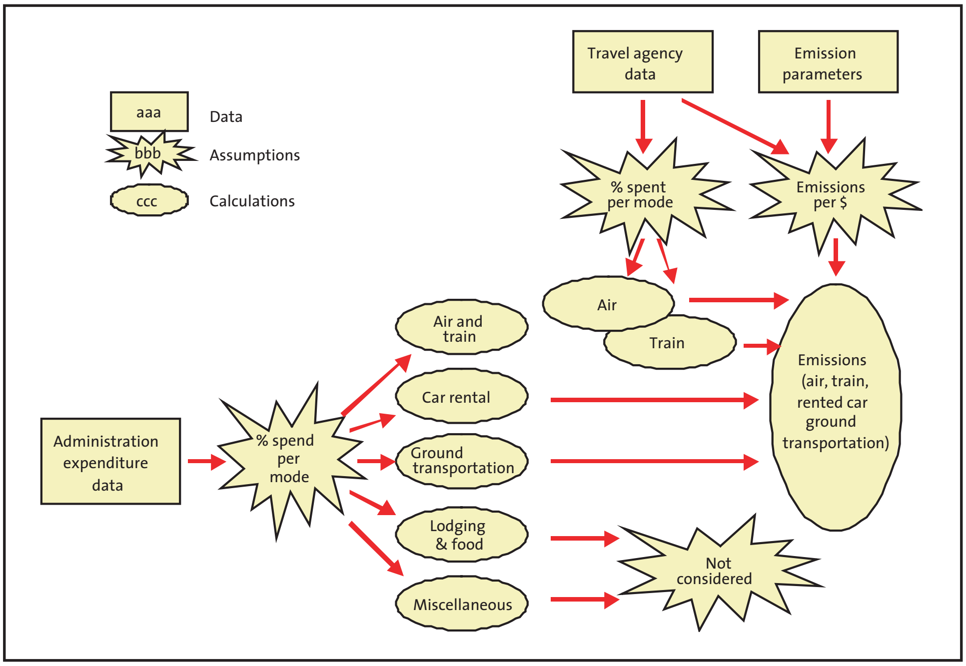
Yale does not gather information on GHG emissions or energy consumption from work-related travel, and the University has only limited data on miles traveled for work-related travel. Since the University's accounting systems focus on travel expenditures, most GHG emissions are estimated on the basis of that data. Yale University spends about twenty million dollars in travel every year. Such expenditures include costs for transportation, lodging and meals. Typically 75% of the expenditures are for trips in the U.S.; the other 25% of expenditures are associated with trips abroad. Air expenses represent the highest share of travel expenditures, followed by rail travel. Together they account for about 72% of the total travel expenses.

About 30% of travel financed by Yale is booked through Yale's travel agency. In addition to the cost data described above, 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 8.4 summarizes the sources, steps and assumptions used to calculate GHG emissions from work-related travel.[22]

[21] This approach excludes 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.

[22] The inventory did not consider emissions from meals and lodging considering that Yale personnel and Yale guests would generate a similar amount of emissions if they were to stay in their homes and eat there. Miscellaneous expenditures were also considered outside the scope of this report.

Figure 8.4 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, these were handled separately in the analysis. Table 8.6 summarizes the emissions associated with travel agency flights.

Table 8.6 Energy Use and CO_2 Emissions from Travel Agency Flights

Trip Type	**Miles Traveled**	**Metric tons CO_2**
Domestic	29,747,679	5,475
International	21,748,115	3,863
Total	**51,495,794**	**9,338**
Uncertainty	**±5%**	**±25%**

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 pairs data are available is 2001. These data are used to approximate 2002 data.

WRI provides 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. The total emissions calculated using this direct method were compared to emissions derived from the estimated energy consumption.

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 (e.g. constant dollars spent per mile).

Uncertainty

Uncertainty in travel agency flight energy consumption is due to three factors: incompleteness of activity data, accuracy of distance calculations, and emission factors per mile provided by WRI. Again, because the data source (2001) did not quite match the established YCI baseline (2002), an uncertainty of 10% was assigned to the original data. Another 5% was assumed for estimates of distances between city pairs. A 20% uncertainty was assumed for the WRI emission factors based on distance traveled. Additionally 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. In sum, these factors result in an overall uncertainty of 25%.

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 a number of assumptions and parameters, summarized in Table 8.7 below:

Table 8.7 Work-related Emissions Parameters Used

- 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 transportation
- Miles and emissions per dollar from foreign train and flights
- Other

Each of these parameters influences the emissions generated by work-related travel. Individually, however, none of these parameters influences the total emissions from work-related travel by more than 3.3%. Totals are shown below in Table 8.8.

Table 8.8 Work Related Emissions Estimates

Travel category	Emissions (metric tons)	% Contributions to Work-Related Emissions
Non-travel agency flights	1,824	15%
Trains	383	3%
Car rental	245	2%
Ground transportation	281	2%
Total	**2,734**	**23%**

8.3.3 Commuting

Personnel Commuting

Table 8.9 Carbon Dioxide Emissions from Personnel Commuting

Emission Source	CO_2 Tons	CO_2 % of Yale's GHG Emissions	Uncertainty
Personnel commuting	12,016	4.2%	+100 /-50%

Yale employs over 12,500 people, each of whom generates greenhouse gas emissions when commuting to campus using vehicles that burn fossil fuels. Overall, personnel commuting totaled an estimated 46 million miles per year; approximately 50% were traveled by car. The yearly emissions from personnel commuting are roughly 12,000 tons or about 0.95 ton per employee. This compares to an average of 0.8 tons of CO_2 emitted by the average commuter in the U.S., according to the Bureau of Transportation Statistics.

Yale employees live relatively close to campus, with over 48% of the employees living less than five miles from campus and an additional 18% living between five and ten miles from campus. An average of 10 miles per employee was assumed for the purposes of the YCI inventory.

YCI based the GHG emissions calculation on information on the ZIP codes of employee residences, which were obtained through the Human Resources Department. The calculation of GHG emission from personnel commuting was calculated using the formula:

> Yearly CO_2 emission = 2 Average distance from school Number of working days per year Number of commutes per year Fuel consumption per mile CO_2-emission factor

Uncertainty

The main uncertainties in the GHG emission 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. It was assumed that 50% of the employees commute in their own cars. Due to the high emissions of cars compared to other means of transport, emissions derived from non-car-commuting were considered to be zero.
- An additional uncertainty derives from the unknown emissions per mile traveled by car. A mileage of 20 miles per gallon was assumed.
- In total, an uncertainty of +100% and -50% was assumed.

8.3.4 Student Commuting

Table 8.11 Carbon Dioxide Emissions from Student Commuting

Emission Source	CO_2 Tons	CO_2 % of Yale's GHG Emissions	Uncertainty
Students commuting	1,700	0.6%	+297%/-69%

There are some 10,000 students studying at Yale. As was the case with personnel, the emissions of students commuting to campus are determined by their distance from campus, number of trips to campus, and 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 commuting by car.

About 86% of Yale students live less than 3 miles from campus. For commuting to school, these students have the choice to drive, use Yale buses, bike, or walk. Precise statistics about the means of transportation chosen by Yale students to commute to school are not available, suggesting a high value for a detailed transportation and commuting survey at the university. Anecdotal evidence and small-scale surveys in individual schools suggest that only a small proportion of the student's commute (less than three miles) are undertaken by car.

Uncertainty

Emissions calculations for student commutes are based on the assumption that 5% of the trips below one mile and 50% of the trips between one and three miles generate GHG emissions (e.g. are made by car or non-Yale bus[23]). The degree of uncertainty about these assumptions, however, is relatively high and potentially generates a variation in the calculated emission of +300%/-50%.

As with personnel commuting, the main sources of uncertainty in student commuting calculations are the unknown average miles per trip, the number of commuting trips per annum, and the GHG emissions factors (determined by the mix of vehicles used and their occupancy rates, which was unknown).

8.3.5 Students Traveling Home

Table 8.11 Carbon Dioxide Emissions from Students Traveling Home

Emission Source	CO_2 tons	CO_2 % of Yale's GHG emissions	Uncertainty
U.S. Students visiting home	5,400	1.9%	+100%/-50%
Foreign Students visiting home	415	0.1%	+100%/-50%

The Yale student body resides in New Haven during school terms but typically maintains a different permanent address. Trips home to visit family have therefore been included in the inventory. (Recreational travel was not included, because these trips are not due to student residency at Yale.)

Over 50% of Yale students are from out of the state, and almost 15% are from abroad.

The amount of emissions generated depends on the number of trips home that students undertake in a year and on the mode of transportation. These data are not known; this gap required YCI to make a series of assumptions.

Uncertainty

The uncertainties in the calculations are mainly driven by uncertainty over the number of trips per student. Monetary and time constraints are likely to limit the number of trips by students who live far from Connecticut. Students who live relatively close to Connecticut, however, have the opportunity to visit home more often. These shorter trips often provide students with the opportunity to choose among different modes of transportation. In total, an uncertainty of +100% and -50% was assumed.

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[23] Emissions from Yale buses are excluded because they are already accounted for in "institutional travel."

8.3.6 Other Greenhouse Gases

Table 8.12 Other GHG Due to Transport

Emission Source	CO_2 % of Tons CO_2e	Yale's GHG Emissions	Uncertainty
Non CO_2-GHG due to transport	1,662	1.9%	+300%/-99%

The above calculations relate exclusively to carbon dioxide emissions, not the full range of greenhouse gases. As mentioned above, estimates for these gases are primarily dependent on miles traveled and vehicle type rather than on fuel consumed, and are therefore difficult to determine given the lack of data on vehicle-specific mileage. Therefore, benchmarking was used to estimate the contributions of these gases. The United States Greenhouse Gas Inventory provided to the United Nations Framework Convention on Climate Change found that non-CO_2 gases (CH_4, N_2O, and CFCs) contribute 5% of the greenhouse gas emissions from transportation.[24] This value was used to approximate the contribution of other gases, based on the estimate for carbon dioxide emissions, yielding an estimate of 1,662 tons of CO_2e emissions from non-CO_2 gases in transport activities.

Other gases including NO_x and CO_2 which are important indirect contributors to greenhouse gas concentrations, are not considered here, following suggested EPA procedures.

Since different sources claim non-CO_2 GHG emissions of different transport technologies to account for between 0.1 - 15%[25] of GHG-equivalent total emissions, an uncertainty range of +300% and -99% was retained in the calculations reported here.

8.4 BENCHMARKING AGAINST OTHER UNIVERSITIES

Yale's inventory of greenhouse gas emissions from transportation sources is more comprehensive than other schools' inventories that were reviewed. Therefore the YCI can compare only subcategories of transport-related emissions. Researchers at both Tufts and Tulane were able to make use of recent mobility studies conducted within their institutions; such a study at Yale would provide much more reliable estimates of actual GHG emissions.

[24] US Government, US National Communication to the UNFCCC, GHG Inventory Table 3.4, http://unfccc.int/resource/docs/natc/usnc3.pdf.

[25] GEMIS, Global Emission Model for Integrated Systems, http://www.oeko.de/service/gemis/en. IPCC, Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, Reference Manual.

Table 8.13 Benchmarking Greenhouse Gas Emissions Due to Transportation Sources at Various Universities (Metric tons CO_2 eq. Includes CO_2 and other gases)

Emission source	**Yale (2002)**	**Tulane[26] (2000)**	**University of Colorado[27] (2000)**
# of students & employees	22,200[28]	19,000[29]	35,700[30]
	Emissions in Tons (per capita emission in kg)		
Institutional travel – university fleet	1,638 (74)	411 (22)	256 (7)
Commuting			
Employees	12,016 (541)	2,477 (130)	Not included
Students	1,700 (77)	2,390 (125)	Not included

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, not only due to the fact that it considers more categories of travel (Table 8.13). 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[31], 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 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, as do most of their peers. Typical Americans seem to be much more likely to drive on a daily basis – to work, errands, social engagements, etc. – than typical university students. Additionally, 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.

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

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

[28] Yale University website, http://www.yale.edu/oir/factsheet.html.

[29] Tulane University website, http://www2.tulane.edu/about_facts.cfm.

[30] University of Colorado website, http://www.colorado.edu/explore/ataglance.html, http://www.colorado.edu/news/facts/employees.html.

[31] 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.

Section 9: Inventory of Other Sources and Sinks

9.1 DESCRIPTION OF DATA

This category encompasses all emission sources and sinks not captured by other sections. The activities included in this analysis include waste management (incineration, landfilling, and wastewater treatment) and purchased materials (refrigerants, laboratory chemicals, and laboratory gases). In addition, this section addresses carbon sequestration from the forests owned by the Yale School of Forestry & Environmental Studies.

This set of activities falls within two different tiers in our system boundary. The emissions sources that were purchased directly by Yale constitute Tier 2 emissions. These include laboratory chemicals, laboratory gases, refrigerants, and forest sinks. The emissions sources that are attributable to Yale but not controlled by Yale constitute Tier 4 emissions, which include waste management activities.

9.2 SUMMARY AND ANALYSIS OF RESULTS

Table 9.1 summarizes the emissions from "other" categories as well as the emission uptake by forest carbon sinks (accounted for as negative emission flows in Table 9.1). Emissions, excluding the forest sink, total some 11,236 tons CO_2e (or some 4 percent of Yale's total GHG emissions). When the forest carbon sink is included, net emissions total 4,945 tons CO_2e or less than 2 percent of Yale's total emissions.

The emissions of this group of activities and emission sources are the most heterogeneous of all sectors in terms of different GHG species. The largest emission source in the category is constituted by refrigerant leakages (predominantly HFCs, i.e. substitute substances for ozone depleting CFCs) with some 8,341 tons CO_2e, followed by CO_2 emissions (predominantly from waste incineration) with some 2,177 tons CO_2. Nitrous oxides (N_2O) and methane (CH_4) emissions are minor sources, with 359 and 358 tons respectively. Emissions in this sector are also counterbalanced by carbon uptake of Yale school forests, estimated to amount to some 6,291 tons CO_2 per year.

Table 9.1 Other GHG Sources and Sinks Summary Table

Emissions Source	GHG Emissions	Uncertainty	GHG Emissions (High)	GHG Emissions (Low)
	metric tons CO_2e	%	metric tons CO_2e	metric tons CO_2e
Tier 2				
Laboratory gasses	325	+8 / -45%	340	179
Refrigerants	8,341	+138 / -75%	19,841	2,090
Forest sink	-6,291	+150 / -50%	-15,728	-3,146
Tier 4				
Incineration	2,197	+73 / -51%	3,806	1,072
Landfilling	56	+286 / -89%	215	6
Wastewater	317	+370 / -100%	1,489	0
TOTAL EXCLUDING SINK	**11,236**		**25,691**	**3,347**
TOTAL INCLUDING SINK	**4,945**		**9,963**	**201**

9.2.1 Laboratory Gases

Table 9.2 GHG emissions from laboratory gases

Emission Source	Tons CO_2e	CO_2 % of Yale's GHG emissions	Uncertainty
Lab gases CO_2	19	0.0%	+/- 5%
Lab gases N_2O	305	0.1%	+0 / -48%

Yale uses a number of compressed gases in the operation of its laboratories. The principal laboratory gases with climate change implications are CO_2 and N_2O. The YCI obtained data on the aggregate number of canisters delivered to Yale University during calendar year 2002. This information was provided by Connecticut Airgas, the company that provides Yale with all of the compressed gas used in the laboratories. Airgas estimates that 850 50-pound canisters of CO_2 and 35 65-pound canisters of N_2O were delivered to campus during 2002.

A three-month inventory from the largest chemical stockrooms on the Yale campus, which accounted for 75% of total chemical flow through Yale University, was collected. The inventory includes more than 20 chemicals that react as volatile organic chemicals (VOCs). The total amount of VOCs used at Yale in FY02 amounted to approximately 18 tons.

The indirect impact of VOCs on radiative forcing has not been calculated, and therefore this source of greenhouse gases was not considered in the inventory.

Methodology

The YCI used the data provided by Connecticut Airgas to estimate the CO_2e emissions from the compressed CO_2 and N_2O used on campus. Airgas provided information on the volume of gas in the containers, and the YCI applied a number of conversion factors to estimate the greenhouse gas emissions of the laboratory gases. We assumed that all of the gas delivered during 2002 was emitted to the atmosphere during the course of the year, which is a conservative (upper bound) assumption.

Estimating CO_2 emissions from lab gases used on campus

The volume of each of the 850 50-pound canisters of CO_2 is 437 cubic feet. Therefore, the total volume of CO_2 delivered to Yale is 371,535 cubic feet. The YCI applied the conversion factor of 0.05 kilograms/cubic foot[32] to determine the equivalent tonnage of CO_2 in the canisters. Since YCI assumed that the full amount of gases delivered during 2002 was emitted to the atmosphere, this corresponding total of 19 metric tons represents the CO_2 emissions from lab gases used on campus.[33]

Estimating N_2O emissions from lab gases used on campus

The volume of each of the 35 65-pound canisters of N_2O is 568 cubic feet.[34] Therefore, the total volume of N_2O delivered to Yale is 19,888 cubic feet. The YCI applied the conversion factor of 0.05 kilograms/cubic foot[35] to determine the equivalent tonnage of N_2O in the canisters. Since the YCI assumed that the full amount of gases delivered during 2002 was emitted to the atmosphere, this total of one ton represents the N_2O emissions from lab gases used on campus. This number was converted to CO_2 equivalent emissions by multiplying N_2O emissions by the appropriate (100 year) Global Warming Potential of 296.

Limitations of analysis and uncertainty

This analysis attributes an uncertainty of ±5% to the numbers provided by Connecticut Airgas.[36] The two conversion factors (liquid pounds to cubic feet and cubic feet to tons) are assumed to be fairly accurate. Further, YCI applied the standard uncertainty for the greenhouse potential of N_2O of +0% and -47% due to the uncertainty estimates for the IPCC-calculated global warming potential for N_2O (differences between the 20/100/500 year GWPs). The assumption that all the gases delivered during 2002 are emitted during the course of the year is an additional source of uncertainty.[37] However, since no information on the ultimate use of these chemicals (i.e. the fraction that might not be emitted but rather are bonded via chemical reactions in substances) was available, no corresponding lower bounds for the uncertainty analysis were estimated.

The total GHG emission uncertainty from all gases was calculated as +5%/-45%, due primarily to the uncertainty estimates for the IPCC-calculated global warming potential of N_2O.

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[32] Conversion factor provided by Universal Industrial Gases Inc. [http://www.uigi.com/co2_conv.html] Website visited 12/10/2003.

[33] The University recently installed a fuel cell, which is a net producer of CO_2. In the future, this CO_2 might be captured and used in the laboratories to avoid unnecessary purchases of lab gases. At this time, the CO_2 is not captured.

[34] Ralph Nigrel of Connecticut Air/Gas confirmed that the properties of CO_2 and N_2O are sufficiently similar to apply the same cubic feet and kilograms conversions for both gases.

[35] Conversion factor provided by Universal Industrial Gases Inc. [http://www.uigi.com/co2_conv.html] Website visited 12/10/2003.

[36] Ralph Nigra of Connecticut Airgas informed the members of the Climate Initiative that he "rounded up" the numbers. YCI assumed his numbers to be correct within a factor of 10%.

[37] This assumption was confirmed by Rob Klein, Associate Director, Yale Office of Environmental Health and Safety.

9.2.2 Yale Chillers and Refrigerants

Table 9.3 GHG Emissions From Refrigerants

Emission Source	Tons CO_2e	CO_2 % of Yale's GHG Emissions	Uncertainty
Refrigerants	8,341	2.9%	+130 / -58%

Refrigerants represent a potent source of greenhouse gas emissions. Their infrared absorption properties are responsible for their strong radiative forcing and hence high relative GWP compared to CO_2.

At Yale, the largest stocks of refrigerants are the chillers located at the power plants. Although stocks are addressed in detail below, the refrigerant leakage from these chillers represents a significant source of greenhouse gas emissions. Although the absolute amount of refrigerants released through leaks is small, the large global warming potentials of these refrigerants result in the largest source of CO_2-equivalent emissions in this section.

The chillers at Sterling Power Plant that use the refrigerants R-12 and R-22 have higher leakage rates than the other chillers on campus since they are older. The leakage rate for the old chillers was assumed to be 10%, compared to 5% for newer chillers.

The other sources of refrigerant leaks at Yale are the multitude of window air conditioners and the large refrigerators used in the dining halls. However, data were not available on these additional sources. A preliminary calculation of worst-case potential releases from the thousands of window air conditioners throughout the university revealed that this source is only a very small percentage of the refrigerant releases from chillers.[38] Therefore, this analysis only considers refrigerant leakage from the large chillers on campus.

Methodology

The YCI examined EPA and industry data to determine expected refrigerant leakage rates from the chillers on campus. We used high and low values for these rates to determine the range of annual refrigerant releases from each chiller. IPCC global warming potentials were applied to these releases to determine the associated CO_2e.

Estimating emissions from refrigerants used in chillers on campus

Refrigerant leakage rates determine the amount of CO_2e emissions released from the chillers on Yale's campus. Older chillers (the R-12 and R-22 chillers at Sterling Power Plant) have higher leakage rates than newer chillers. The industry average for leakage from older chillers is 8%, and the EPA "trigger rate" is 15%.[39] YCI used 10% as an estimated leakage rate for these older chillers. Similarly, the industry average for newer chillers is 0.1%, and the EPA "trigger rate" is 15%. YCI used 5% as an estimated leak-

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[38] This calculation assumed that there are 20 window units in each of the 169 buildings that do not receive chilled water. The worst-case leakage rate of R-22 (the primary refrigerant used in window units) was assumed to be 15%, which is the EPA "trigger rate" for repairs. Using these assumptions, the potential CO2-equivalents emissions from window units are only 6% of the emissions from the large chillers.

[39] Compliance Guidance For Industrial Process Refrigeration Leak Repair Regulations Under Section 608 Of The Clean Air Act, http://www.epa.gov/ozone/title6/608/compguid/guidance.pdf.

age rate for these newer chillers. The (substantial) uncertainty associated with these assumptions was included in our uncertainty calculations.

Based on these leakage rates, expected 2002 releases from each of the chillers were calculated. These refrigerant releases were converted to CO2e emissions using IPCC global warming potentials.[40]

Limitations of analysis and uncertainty

Due to data gaps, this analysis only considers emissions from large chillers on campus. Preliminary calculations indicate that these emissions constitute the vast majority of emissions associated with refrigerant releases.

The uncertainty inherent in this analysis is due to a lack of information regarding the actual leakage rates of the chillers. Due to the differences between the mean of best-case industry averages and worst-case EPA regulatory "trigger rates," the YCI considered an uncertainty range of ± 30% for the old chillers and ± 100% for the new chillers.

9.2.3 Forest Sinks

Table 9.4 CO_2 sequestration by forests

Emission Source	Tons CO_2-e	CO_2 % of Yale's GHG Emissions	Uncertainty
Forest sink	-6,291	-2.2%	+150 / -50%

All forests where annual vegetation growth exceeds harvested volumes (and where soil carbon remains balanced) are sinks for CO_2. Yale is rare among universities in that it owns and manages large forest areas. Consistent with the system boundary definition of this inventory, we consider only those forests related to the educational mission of the university and directly managed by Yale (i.e. the forests of the School of Forestry and Environmental Studies (FES)). These forests comprise more than 4,000 hectares (close to 11,000 acres) in Connecticut, New Hampshire and Vermont. Forests owned as investments by the university's endowment and typically managed by third parties are not included in this inventory as they are outside the system boundaries of our study as well as due to non-disclosure of data.[41]

Every ten years, a continuous forest inventory is performed on Yale-Myers and Toumey Forests, which represent 90% of the school's forest holdings. This inventory serves as an excellent source of information on the merchantable timber in the forests. However, techniques for estimating carbon sequestration from forest properties are often inconsistent and highly dependent on the precise characteristics of the land under examination. Therefore, YCI used the inventory data as well as high and low estimates for carbon sequestration rates to determine the range of annual carbon sequestration from the forests.

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[40] GWPs were taken from the IPCC Third Assessment Report. R12 = 10600; R-22 = 1700; R-134a = 1300.

[41] For information about the Yale School of Forestry & Environmental Studies forests, seehttp://www.yale.edu/schoolforest/forests.html To give a sense of proportion: In 2001 a debate emerged about a conservation easement involving a forest area in Maine of 656,000 acres (some 265,000 ha, or 60-times the FES forest area covered in the YCI inventory here) that was owned and co-owned at that time by the Yale endowment (Yale Daily News September 20, 2001, http://www.yaledailynews.com/article.asp?AID=16154; see also Yale Insider: http://www.yaleinsider.org/article.jsp?id=6

Methodology

The latest inventory of the Yale Forests was performed at Yale-Myers in 1993 and at Toumey in 1998-99. YCI used the inventory growth rate and harvest rate information to calculate the net annual sequestration in the forests. The rates (expressed in board-feet per year) were converted to biomass by multiplying by appropriate hardwood and softwood factors. These biomass calculations were then multiplied by a factor of 0.5 to estimate the carbon content of the biomass. The annual harvest estimates were subtracted from the annual growth estimates to obtain a net annual sequestration figure.[42]

Since the forest inventory was performed to measure merchantable timber, it underestimates the biomass present in the forest[43]. Therefore, YCI used other estimates to corroborate the inventory calculation. Because a wide range of estimates for annual sequestration in New England forest systems is present in the literature, YCI selected high and low values to capture this diversity.[44] These per-area estimates were applied to the area of the Yale Forest system to estimate annual carbon dioxide sequestration in the forests.

Estimating Carbon Sequestration from the Yale Forest system

Sequestration rates determine the amount of CO2 sequestered annually within the Yale Forest system. The rate calculated for the Yale Forest system from the inventory data is 0.6 metric tons of carbon dioxide per hectare per year.[45] The low rate gathered from secondary sources is 0.1 metric tons of carbon dioxide per hectare per year. The high rate gathered from the literature is 4.2 metric tons of carbon dioxide per hectare per year. YCI used the average of 1.6 metric tons of carbon dioxide per hectare per year as an estimated annual sequestration rate for the Yale Forest system.[46]

Based on the above average sequestration rate, the YCI determined an estimate of 6,291 tons CO_2 per year that is included in the YCI inventory as a negative emission flow.

Limitations of analysis and uncertainty

The uncertainty inherent in this analysis is due to a lack of information regarding actual sequestration rates for the forests. YCI has attempted to quantify sequestration by taking the mean of Yale Forest inventory data and high and low sequestration rates found in the literature. These rates were used to estimate an overall uncertainty range of +150%/-50% or an absolute uncertainty range of between -3,146 and -15,728 tons of CO_2. This large degree of uncertainty reflects the wide range of estimates present in the literature and the lack of consensus on appropriate methods for measuring carbon dioxide sequestration.

Due to unavailability of data, it is impossible at present to determine the uncertainty range of this CO_2 uptake estimates beyond the system boundary adopted for this inventory that covered only FES forests. Given the potential magnitude in relation to Yale's total GHG emissions, a complete inventory of all forest holdings by Yale, including its endowment, would be desirable.

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[42] This methodology of using annual growth and harvest rates to determine net annual sequestration follows the guidelines presented in the 1996 IPCC Revised Guidelines for National Greenhouse Gas Inventories.

[43] The inventory records actual lengths of any stem with a dbh ≥ 10 inches.

[44] The low estimate was provided through personal conversation with Lloyd Irland, lecturer and senior research scientist, Yale School of Forestry & Environmental Studies. The high estimate was drawn from Lucy Hutyra's study "Carbon Cycling at the Harvard Forest: Bottom-up and Top-down Approaches." http://www.eternet.edu/asm/2003/posters/posters.html#257.

[45] This calculation was based on the net uptake numbers provided in the continuous forest inventory summary developed by David S. Ellum, "40 Years of Merchantable Sawlog Growth and Yield at Yale-Myers and Toumey Forests: Looking Back – Planning Ahead," October 9, 2001. The boardfeet estimates were converted to net sequestration using the methodology described in the section above.

[46] The literature provides widely divergent estimates based on the particular characteristics of the forest stands. These estimates provide high and low limits, but additional research is required to determine appropriate sequestration factors.

9.2.4 Landfilled Waste

Table 9.5 GHG-emissions from Landfilled Waste

Emission Source	Tons CO_2e	CO_2 % of Yale's GHG Emissions	Uncertainty
Landfilling	56	0.0%	+286 / -89%

To calculate GHG emissions from Yale's solid waste management, data were collected from Yale Facilities Office and Yale Recycling[47]. A total of 4,807 metric tons of municipal solid waste (MSW) was disposed of in FY02, for which:

1) 76%, or 3,653 tons was incinerated;
2) 18% or 865 tons was recycled; and
3) 6% or 288 tons was landfilled.

For purposes of the inventory, the indirect emissions for Yale's solid waste management, such as transportation of waste, that are rather small compared to other emission sources were not estimated.

When municipal solid waste (MSW) is landfilled, the organic material in the MSW is first broken down aerobically. Then, anaerobic bacteria continue the decomposition process. Landfill Gas (LFG) is the byproduct of this decomposition; LFG is approximately 50% methane and 50% CO_2.[48] Typically, methane begins to form two years after waste is landfilled, and the waste can continue to produce methane for 20-30 years.[49]

To estimate the potential methane of Yale MSW that was landfilled in FY02, one must consider the following variables about landfill gas:

1) Composition of Waste in the Landfill: This is the most important factor influencing landfill gas production. The quantity of degradable organic matter determines the amount of landfill gas produced.
2) Calculation Method of Methane Emissions from Landfill: For this variable, a determination must be made as to whether to consider this emission to be instantaneous or to attribute its releases over a period of time. There are estimates of the integral over the period that waste is landfilled, i.e. 2,000 pounds of MSW landfilled produces 123 pounds of methane.[50]
3) Decay Function of Waste (oxidation).
4) If the LFG is captured and flared or used for energy, then methane emissions must be converted to CO_2 emissions. LFG capture will decrease the amount of methane released to the atmosphere.

[47] Cyril May, Yale Recycling.

[48] IPCC, Revised 1996 Guidelines for National Greenhouse Gas Inventories: Reference Manual, Waste Chapter.

[49] US EPA, Anthropogenic Methane Emissions in the United States: Estimates for 1990, Office of Air and Radiation, EPA 430-R-93-003.

[50] Denison *et al*. 1996, Environmental Life-Cycle Comparisons of Recycling, Landfilling and Incineration: Review of Recent Studies, *Annual Review Energy and Environment*. 21:191-237.

Methodology

The IPCC has developed a set of inventory methods to be used as the international standard for GHG accounting and reporting[51]. One of the main decisions about how to count anthropogenic sources of GHG emissions from landfills was around the issues of biogenic materials. If emissions are from biogenic materials and the materials are grown on a sustainable basis, then those emissions are considered simply to close the loop in the natural carbon cycle and therefore are not counted in the IPCC inventory. This would include biogenic material such as paper, yard trimmings, and food discards[52]. However, a large portion of landfilled waste decomposes anaerobically and releases landfill methane (CH_4), a potent greenhouse gas. The IPCC includes methane generated from landfills as an anthropogenic source. However, when landfill gas is flared and CO_2 is produced, then only CO_2 and fugitive methane emissions should be measured.[53]

Waste Composition

No data were available on the actual composition of Yale waste. Therefore the assumption is made that Yale's waste composition is similar to average U.S. municipal waste (MSW). According to the IPCC guidelines, MSW contains about 10-25% fossil carbon. The YCI used 16%. This value was determined by two factors: the total carbon content of the MSW was estimated to be 40% (IPCC: 30-50%), and it was assumed that 40% of the total carbon derives from fossil sources.

Estimating methane emissions from landfilled waste

To calculate methane emissions, the YCI used the basic integral method presented by Denison et al. (2,000 pounds MSW equals 123 pounds of methane). FY02 waste produced an estimated 39,114 pounds of methane over its entire lifetime. The YCI accounted for these emissions as being released in the year 2002; therefore, the YCI reflects the total release of landfill gas that will be produced from FY02 landfilled waste.

The majority of the landfilled waste went to the Wallingford landfill, where LFG is captured and flared. The YCI assumed that 90% of the methane produced by the FY02 waste is captured and flared and the remaining 10% is assumed to be released to the atmosphere.

Therefore the 288 tons of landfilled MSW in FY02 will produce 1.8 tons of unflared methane (41 tons CO_2e) and 15 tons of CO_2.

Limitations of Analysis and Uncertainty

The conversion of 123 pounds of methane per 2000 pounds MSW is based on a report performed for an environmental group by Franklin and Associates Research. EPA also quotes from this source. The reliability of the report is unknown[54]. Additionally, the share of uncaptured methane is not known. This uncertainty was considered to be +200% and -100%. The direct CO_2 from fossil carbon was assumed to be confident within a range of +100 / -50%. The N_2O emissions are dependent on the types of

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[51] IPCC, Guidelines for National Greenhouse Gas Inventories, three volumes, 1997.

[52] IPCC, Guidelines for National GHG Inventories, 1997.

[53] EPA, Solid Waste Management and Greenhouse Gases, 2002.

[54] Franklin Associates. 1994. *The Role of Recycling in Integrated Solid Waste Management to the Year 2000*. Stamford, CT: Keep America Beautiful.

waste burned and combustion temperature. The emission factors provided by the IPCC range from 10 to 300 g N_2O per ton MSW[55]. The YCI assumed an emission factor of 50 g N_2O per ton MSW.

The uncertainty of the IPCC-calculated global warming potential for methane (+170% / -70%) has also been taken into account.

9.2.5 Waste Incineration

Table 9.6 GHG-emissions from waste incineration

Emission Source	Tons CO_2e	CO_2 % of Yale's GHG emissions	Uncertainty
Waste incineration	2,197	0.8%	+73 / -51%

Methodology

YCI estimated the gross emissions of CO_2 and N_2O from MSW combustion. This inventory does not take CO_2 emissions avoided due to displaced electric utility generation into account. In FY02 Yale combusted 3,653 tons MSW at two local waste-to-energy (WTE) plants, one in Lisbon, CT (65 miles from New Haven) and one in Bridgeport, CT (20 miles from New Haven). Combustion of MSW results in emissions of CO_2 (2,143 tons CO_2) and N_2O (54 tons CO_2e). The methane emissions due to imperfect combustion haven't been taken into account. In line with the MSW that has been landfilled, the YCI assumed a fossil carbon content of 16%. The N_2O emissions are dependent on the types of waste burned and combustion temperatures. The YCI assumed an emission factor provided by the IPCC of 50 g per 1 ton of waste.

Limitations of Analysis and Uncertainty

Because the makeup of a given community's mixed MSW may vary from the national average, the fossil carbon content also may vary from the national average energy content used in this analysis. The YCI estimated the CO_2 emissions from this source to be confident within a range of ± 50%.

Uncertainty of the N_2O emission factor was considered to be ±100%. The uncertainty of the GWP of N_2O has also been taken into account in this uncertainty range.

9.2.6 Wastewater Treatment

Table 9.7 GHG Emissions from Wastewater Treatment

Emission Source	Tons CO_2-e	CO_2 % of Yale's GHG Emissions	Uncertainty
Wastewater treatment	317	0.1%	+370 / -100%

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[55] IPCC, Revised 1996 Guidelines for National Greenhouse Gas Inventories: Reference Manual, Waste Chapter.

In FY02, Yale discharged 1.9 million m^3 (5×10^8 gallons) of water to the New Haven sewage treatment plant. The breakdown of organic material in wastewater treatment systems produces methane. Much as with landfills, the amount of methane produced is driven by the extent to which the organic material is broken down under anaerobic versus aerobic conditions. Methane produced during anaerobic treatment in a sewage treatment plant is typically collected and flared or combusted for energy. However, whenever anaerobic conditions develop, some of the methane is released to the atmosphere in the form of fugitive emissions, which are not captured and flared. The organic content, expressed in terms of biochemical oxygen demand (BOD), determines the methane producing potential of wastewater. BOD represents the amount of oxygen that would be required to completely consume the organic matter contained in the wastewater through aerobic decomposition processes.[56] Under anaerobic conditions, wastewater with higher BOD concentrations will produce more methane than wastewater with lower BOD.

Methodology

The first step in calculating emissions is determining the amount of organic material in Yale's wastewater. Yale typically tries to meet the CT DEP Total Suspended Solids permit limit (50 mg/l of TSS) to discharge to the New Haven POTW, but Yale is often fined close to $75,000 a year for violating this permit[57]. However, YCI was not able to obtain the precise reading of TSS for Yale's wastewater and therefore has estimated that Yale wastewater contains 50 mg/l of TSS.

Methane emissions are produced from sludge processing and disposal or recycling. Nitrous oxide can be produced both during nitrification and during de-nitrification processes. According to an IPCC study conducted by Hobson and Watt in 1994, 143 kg of methane is produced per ton of dry solids fed to the digester.[58]

Limitations of Analysis and Uncertainty

Domestic wastewater emissions estimates are highly uncertain due to the lack of data on the occurrence of anaerobic conditions in treatment systems, especially incidental occurrences. It is also believed that industrial wastewater is responsible for significantly more methane emissions than domestic wastewater treatment.

The YCI estimated the methane emissions from wastewater treatment to confident within a range of +200% / -50%. Due to the uncertainty of the GWP of methane, a total uncertainty of +370% / -100% has been calculated.

9.2.7 Yale Stocks of Greenhouse Gases

A number of stocks of greenhouse gases exist on the Yale campus. Although these do not represent actual 2002 emissions, the potential of future releases from these sources is significant and warrants a brief discussion.

The largest stock of greenhouse gas emissions is in a below-ground tank at the Wright Nuclear Structure Lab, which contains 80,000 pounds of sulfur hexafluoride (SF_6). The gas is an integral part of the accelerator and is maintained very carefully

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[56] Inventory of US GHG Emissions and Sinks: 1990-1998, 2000, EPA 236-R-00-001.

[57] Conversation with Yale Office of Environmental Health and Safety Employee, October 2003.

[58] Hobson and Watt, IPCC, Waste Water Chapter section of TAR2, 1994

by the technicians in an essentially closed-loop system.[59] However, SF_6 is a very potent greenhouse gas with a global warming potential of 23,900. Potential emissions from the tank are over 850,000 metric tons CO_2e. This figure is equal to three times the annual emissions of all university activities.

The chillers represent a second stock of on-campus greenhouse gas emissions. Although actual 2002 releases have been calculated based on leakage rates, the potential exists for additional, accidental, large-scale releases. The chillers – due to their large size and the potency of the refrigerants – therefore constitute a significant stock of potential emissions. The stock of refrigerants in chillers is approximately 97,000 tons CO_2e.

The third significant stock of emissions is the methane that will be released over time at the Wallingford landfill due to waste disposal in 2002. Although YCI quantified the emissions that were released at the landfill in 2002 due to waste disposal in that year, that waste will continue to release methane over the next thirty years. YCI does not include these emissions in the inventory because they were not released in 2002.

Finally, it is also appropriate to consider the Yale forests as a "stock" of carbon. Consistent with the system boundaries adopted for this study and data available, we consider only forests owned and managed by the School of Forestry and Environmental Studies (FES) here. Estimates of carbon contained in forests typically consider both aboveground biomass as well as soil carbon. For above-ground biomass both bottom-up estimates (based on detailed forest timber inventories, e.g. based on the Continued Forest Inventory (CFI) developed at FES), as well as top-down approaches (based on vegetation cover and carbon content models) have been considered here.[60] Given the age distribution prevailing at the FES forests, a typical above-ground carbon density of 65 tC (metric tons elemental carbon) was retained in the calculation. This carbon density value is then applied to the area actually covered by forest stands (i.e. substracting wetlands, lakes, etc, that typically account for some 15 percent of forest area) to yield an estimate of total carbon embodied in tree stems, crown, litter and roots. For the FES forests, we obtained a central estimate of 243,800 tC, or 894,000 tons CO_2. Measurement data in the FES Meyers forest, by far the largest of FES's forests, indicate that soil carbon equals that of aboveground biomass, yielding a total estimate of the FES forest sink of less than 500,000 tC, or some 1.8 million tons CO_2. Compounding the underlying uncertainties of this estimate, YCI obtained a total uncertainty range of the Yale FES forest "carbon stock" of between 1 to 2.6 million (metric) tons CO_2. The uncertainty range of extending the system boundary to include all Yale owned forests can at present not be estimated due to non-disclosure of data.

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[59] Information was provided by Rob Klein, the Associate Director of the Yale Office of Environmental Health and Safety. High-vacuum pumps are used to pump the gas in and out of the tank between experimental runs.

[60] The numbers were provided and cross-checked by Profs. Mark Ashton, Lloyd Irland, Chad Olivier and Aaron Hohl of FES. We are grateful for their assistance and the time they provided to derive the estimates reported here. The implied carbon densities used in the YCI inventory compare well with the literature, e.g. Irland, L.C. and Cline M., 1998. Role of Northeastern Forests and Wood Products in Carbon Sequestration. Report to Northeast Regional Biomass Program/CONEG. Washington D.C. http://www.nrbp.org

Section 10: Mitigation Options

This section provides a brief discussion of possible GHG emission reduction (mitigation) options. Although such an assessment, for which the YCI inventory provides the necessary basis, requires further detailed analysis, we include a brief discussion here to highlight both emission reduction potentials as well as priority areas for subsequent mitigation analysis.

10.1 POWER PLANTS

Four general options exist for reducing CO_2 emissions from Yale's power plants. All of these options rank "high" with respect to the criteria of emissions source size, mitigation potential, and degree of Yale control. Options include: (1) reduction in secondary energy (electricity, steam and chilled water) demand (i.e., demand side management); (2) reduction in secondary energy (electricity, steam and chilled water) transmission and distribution losses; (3) reduction in primary energy inputs to the power plants through improvement in secondary energy generation efficiency and efficient cogeneration; and (4) switching of primary energy fuels to those with lower carbon intensity.

Yale has considerable potential for improving the efficiency of transmission and distribution from its power plants, particularly in terms of steam and condensate dumps at the power plants. Yale can also cut power plant emissions by fuel switching away from use of No. 2 oil and No. 6 residual oil in some equipment. An estimated 14,200 tons of CO_2 emissions could be avoided by switching power plant fuels completely to natural gas (Table 10.1).

Table 10.1 GHG-emissions reduction through fuel switching

	Fuel (excl. purchased electricity)	Current GHG EF	GHG EF Natural Gas	Difference in GHG Emission
	TJ	tCO_2e/ TJ	tCO_2e/ TJ	tCO_2e / year
CPP	2,114	57.07	55.66	-2,981
SPP	1,209	64.92	55.66	-11,193
TOTAL				**-14,175**

An increase of energy conversion efficiency can be achieved by using electricity-driven chillers instead of steam-driven chillers for chilled water production (Table 10.2). If all steam-driven chillers at the Sterling Power Plant were to be replaced, a reduction of more than 9,000 tons of CO_2e of GHG emissions could be achieved[60], albeit at considerable cost (some $500,000 or close to $200 per ton CO_2).

Table 10.2 Reduction of GHG emissions due to using electricity-driven chillers instead of steam driven chillers at the Sterling Power Plant.

Input	Efficiency therm	Efficiency COP	Spec. GHG emission factors	Output Chill. Water	GHG Emissions	Fuel costs Spec.	Fuel costs Total
TJ	%		tCO_2e / TJ	TJ	tCO_2e / a	$/TJ	Mill. $ / a
Steam driven chillers at Sterling Power Plant							
242	87%	1.4	66.54	389	16,083	5,313	1.3
Electricity driven chillers							
58		6.7	115.65	389	6,715	30,300	1.8
Difference between electricity driven vs. steam driven chillers							
					-9,368		**0.5**

Reducing GHG emissions by converting the Sterling Power Plant that serves the medical campus into a cogeneration facility is another mitigation option. However, if the cogeneration efficiency doesn't improve compared to the existing power plants, the emission reduction potential is rather low, not the least because of the comparatively low GHG emission factor of electricity purchased by Yale from the grid. A preliminary calculation of the GHG emissions change of electricity cogenerated in a new plant at the medical campus instead of purchased from the grid based on the NEPOOL average emissions (that are comparatively low due to a large share of nuclear generated electricity in the region) shows that the GHG emissions would decrease by about 1,300 tons of CO_2 per year if the Sterling Power Plant system were changed to a cogeneration system with the efficiencies of the current CPP (Table 10.3). However, the rationale for converting the Sterling Power Plant into a cogeneration facility is simply the efficiency gains (and cost savings) that could be obtained by using state-of-the art high efficiency equipment. The realizable emissions reduction potential could therefore be much larger than the minimum values calculated here, but requires further detailed analysis based on technical specifications of a proposed cogeneration system.

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[60] Lower refrigerant leakage rates of newer chillers as well as changing steam production efficiency due to part load conditions are not taken into account.

Table 10.3 Reduction in GHG emissions due to switching the Sterling Power Plant to a cogeneration Plant based on current efficiencies in the Central Power Plant (minimum estimates).

	Efficiency		Spec. GHG emission factors	Output		GHG Emissions	Fuel costs	
Input	therm	electr.		Steam	Electr.		Spec.	Total
TJ	%		tCO$_2$e / TJ	TJ	TJ	tCO$_2$e / a	$/TJ	Mill. $ / a
Current facility								
Sterling power plant								
1,249	87%		66.54	1,086		83,082	5,313	6.6
Purchased electricity								
485			115.65		485	56,049	30,300	14.7
Total current system						**139,131**		**21.3**
Cogeneration facility								
2,387	46%	20%	57.73	1,086	485	**137,825**	4,537	**10.8**
Difference Cogeneration System and Current System								
						-1,306		**-10.5**

10.2 BUILDINGS

Buildings are by far the largest source of energy use on campus and thus the largest source of GHG emissions at Yale. Emissions (and reduction potentials) are determined by the thermal integrity characteristics of the buildings (determining heating and cooling energy needs), the existence of active air-conditioning, as well as the number and efficiency of electricity-using appliances in Yale's buildings. The benchmarking of Yale building energy use revealed that the university buildings, while comparable to other universities in North America, have substantially higher energy use (and costs) than European universities, not to mention best practice academic buildings, which are characterized by: a) high degrees of thermal insulation; b) passive heating and cooling through building and ventilation design; c) use of the most energy efficient equipment; and d) energy-conscious buildings use (e.g. switching off appliances during night hours). A comparison of existing buildings and use practices to best available designs indicates potentials for improvements of up to a factor of 10. The YCI inventory presented here can serve as a guide for subsequent detailed energy audits of individual (groups of) buildings to tap some of this emissions and cost saving potential.

Figure 10.1 below shows the specific energy use per unit building area for all primary university buildings assessed by YCI and their resulting share in the total (cumulative) energy use of Yale's buildings (power plants are excluded in Figure 10.1). The graphic serves as a useful guide for subsequent detailed energy audits and energy efficiency improvements and GHG mitigation analysis. Twenty-five buildings on campus with 14 percent of Yale buildings' floor area account for about half of the total building energy. The average specific energy use of these "energy giants" is 7,141 MJ/m^2 (628 kBTU/ft^2/yr), up to an order of magnitude larger than average educational or medical buildings in the U.S. or in Europe, suggesting that these buildings (Table 10.4) could represent first priority candidates for subsequent energy audits and detailed recommendations for efficiency improvements and cost savings.

In these energy audits, a thorough analysis of these top ranking energy using buildings should determine how much of the high energy use (compared to appropriate benchmark buildings) is technologically determined (e.g. in the case of the Magnetic Resonance building) and how much of the energy use could be reduced by which measures and at what costs and paybacks. Such energy audits appear particularly timely considering the ambitious expansion plans for campus buildings that are likely to exceed the existing capacity of the university power plants and cogeneration system, thus requiring capital intensive capacity expansion that could be remediated by energy efficiency improvements in existing buildings.

Figure 10.1 Specific Energy per Building Floor Area and Cumulative Yale Building Energy Use. The 25 highest energy intensity buildings account for about half of total energy use and are suggested for subsequent detailed energy audits.

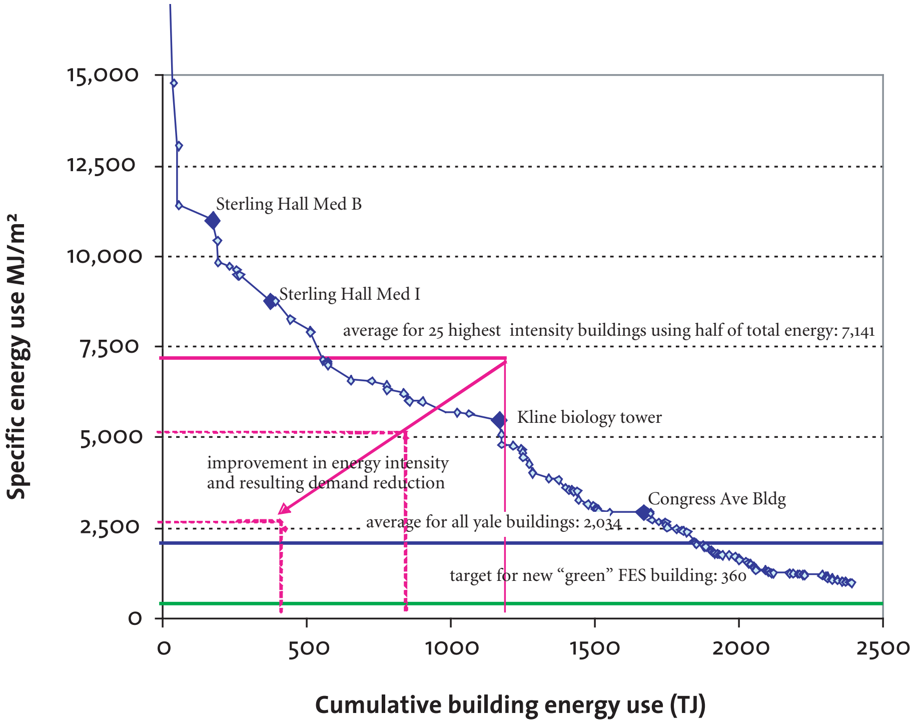


Table 10.1 Top ranking 25 Yale buildings with highest energy use per unit floor area and an annual energy use greater than 10 TJ per building in 2002. These "energy giants" are suggested as top candidates for subsequent detailed energy audits with the aim of simultaneously achieving substantial reductions in energy use, emissions, and energy costs.

Facility ID	Building	m^2	TJ	MJ/m^2
3315, 3360	DANA CLINIC BLDG (and CLINIC BLDG)	784	16	19,814
0	IMU (YSM)	1,179	17	14,810
3325	MAGNETIC RESONANCE C	1,288	17	13,082
3115	STERLING HALL MED B	10,760	119	11,019
3000/3010/3015	YALE PSYCH INST BLDG1/2/3 (YPI(YSM))	1,585	17	10,463
3335	LAB FOR MEDIC, PEDIAT	4,054	39	9,742
3350	WINCHESTER BLDG	2,567	25	9,650
520	MARSH HALL	1,168	11	9,500
3125	STERLING HALL MED I	12,277	108	8,780
3355	BOARDMAN BLDG	1,663	15	8,780
3300	LAB FOR SUR, OBST, GYN	6,487	54	8,285
3155	LAB OF EPIDEM, PUBHL	8,424	67	7,950
3330	LIPPARD LABORATORY F (LCI)	6,276	45	7,149
3310	TOMPKINS MEMORIAL PA (TOMPKINS/ TOMPKINS (YSM))	2,029	14	7,112
3165	BOYER CTR MOLEC MED	12,102	80	6,590
1040	KLINE GEOLOGY LAB	11,005	72	6,576
3375	BRADY MEMORIAL LABOR	8,013	52	6,465
1049	ENVIRONMENTAL SCIENCE CTR	9,229	58	6,240
3380	LAUDER HALL	2,621	16	6,046
3105	STERLING HALL MED C	7,473	45	6,012
440	STERLING DIV. QUAD.	14,959	86	5,722
1090	KLINE CHEMISTRY LAB	6,249	36	5,702
3200	YALE PHYSICIANS BLDG	7,547	43	5,668
1080	KLINE BIOLOGY TOWER	18,826	103	5,494
1030	BASS CENTER	8,493	41	4,784

Numerous opportunities exist for energy efficiency improvements in buildings. There are four categories of buildings in the analysis: (1) buildings in the design and construction phase; (2) buildings in the renovation phase; (3) other buildings; and (4) cross-cutting issues.

The adoption of LEED (Leadership in Energy and Environmental Design) or other quantitative energy efficiency standards for both new construction and renovations should be a priority. In addition, energy metering at the building and ultimately at the individual room level should be investigated for creating cost and emission information transparency that is a prerequisite for improved energy management of the university buildings.

Better wet lab design and increased efficiency of fume hood use could save the university an estimated $100,000 per year.[61] Energy retrofits could be coordinated

[61] Harvard Green Campus Initiative, www.greencampus.harvard.edu, accessed 11 November 2003.

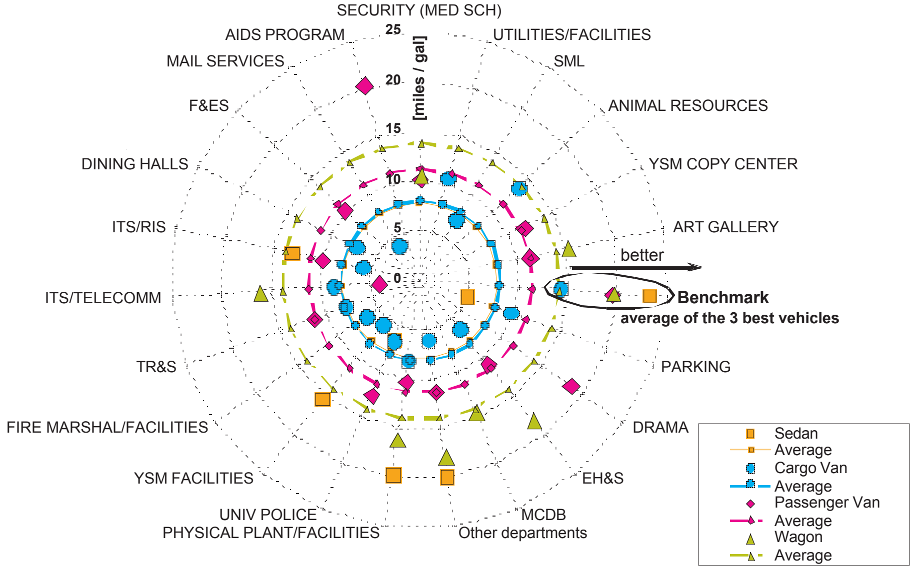
with renovations and paid for through utility recharge rates by consumers. For buildings not scheduled for renovation, efficiency opportunities exist in reducing lighting, heating and cooling and improving metering.

Beyond specific recommendations, general institutional GHG mitigation recommendations for buildings include: creating a university-wide sustainable or "green" building program; information exchange on building energy intensity, consumption, and costs with peer institutions; conducting life cycle assessments of features of pilot green buildings at other universities, as well as university buildings in general; holding a "Green Building Summit;" and clarifying the accounting of building-related construction, renovation, and energy consumption expenditures in university financial reports; and, finally,considering bringing in outside energy auditors to assess overall building mitigation potential.

10.3 TRANSPORTATION

Short-term mitigation options in transportation include a switch to more energy efficient vehicles as well as education programs to influence driving style, to improve fuel economy and reduce emissions of fleet vehicles (Figure 10.2), to encourage travelers to include GHG considerations when making travel choices, and to publicize tax breaks for using public transportation.

Figure 10.2 Fuel consumption of selected vehicles categories per department



While manufacturer-reported fuel economy data is available (Table 10.5), driving conditions rarely match those in test situations, which cover only certain speeds and road types and do not account for vehicle idling.

Figure 10.2 shows the average fuel consumption of four vehicle categories – Sedan, Cargo Van, Passenger Van, and Wagon – for different Yale departments. Additionally, a benchmark – an average of the three best vehicles of each category – is mapped. As can be seen easily, the benchmark of energy efficiency for all vehicle types is between 1.5x higher for wagons and 3x higher for sedans than for the total average of each category, suggesting substantial emission reduction potentials.

Table 10.5 Fuel economy of sample vehicles

Type /Department	Vehicle Year/Make/Model	EPA Fuel Economy Rating[62]	Yale Fuel Economy Estimate (miles per gallon)	% Difference in Performance vs Stated (city)
Sedan / Police	2001 Chevrolet Impala	20 city / 30 highway	19.5	98% of stated mileage
Sedan / Police	2003 Ford Crown Victoria	17 city / 25 highway	5.8	34% of stated mileage
Cargo van / Physical plant	2000 Chevrolet Astro	16 city / 22 highway	8.6	54% of stated mileage
Cargo van / Physical plant	2002 GMC Safari	17 city / 22 highway	9.5	56% of stated mileage

As can be seen, the benchmarks shown in Figure 10.2 match the stated test mileage of the vehicles in Table 10.5. However, in all four situations, even the stated fuel economy is well below the Corporate Average Fuel Economy standards of 20.7 mpg for light trucks and 27.5 mpg for passenger cars.

Table 10.6 gives an idea about the emissions and money that would be saved if the four categories shown in Figure 10.2 were operated with the same mileage as the benchmarks.

Table 10.6 Potential Savings Due to Increased Efficiency

Vehicle Type	Current Fuel Consumption [m²]	Current Average Mileage (miles / gal)	Benchmark Mileage (miles / gal)	Emissions Reductions [t CO_2 / year]	Money Saved[63] $ / year
Sedan	125.2	7.8	23.2	198	36,225
Passenger van	41.9	11.3	19.3	41	75,77
Cargo van	138.8	8.0	14.2	143	26,223
Wagon	17.8	13.9	19.4	12	21,90
Total	**323.7**			**394**	**72,214**

Savings of about 166 m³ (~43,800 gallons) of gasoline (or $72,200) and 394 tons of CO_2 – a 50% reduction – would be possible if these vehicles operated with the benchmark efficiencies.

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[62] U.S. Department of Energy and U.S. Environmental Protection Agency, http://www.fueleconomy.gov.

[63] Assumes gasoline price of $1.65/gallon (average price FY 03)

10.4 OTHER SOURCES

Relative to power plants, buildings, and transportation, the category of "Other Sources" makes a small contribution to Yale's GHG emissions inventory. Nonetheless, important mitigation options exist and deserve consideration. Within the "Other Sources" category, the leakages of refrigerants from chillers and GHG emissions from incineration represent the largest sources.

Priority areas in this sector include: promoting across-the-board improvements through a "pay-as-you-throw" program for departments and dorms; improving recycling; sending all non-recyclable waste to incinerators; and monitoring or replacing leaking chillers.

In terms of sinks and offsets, investments in renewable energy certificates and encouraging forest management practices that maximize sequestration could provide options for offsetting GHG emissions.

Section 11: Recommendations for Inventory Improvements

11.1 STRENGTHS AND WEAKNESSES

In the process of conducting this inventory, the Yale Climate Initiative (YCI) has been able to identify the strengths and weaknesses of data collection and storage practices at the university, as well as available methodologies for assessing emissions. This section highlights notable strengths and weaknesses of the inventory due to these data and methodological issues. These strengths and weaknesses may also inform future inventory efforts and identify priority areas for data gathering and methodology development.

The greatest strength of Yale from the perspective of the YCI emissions inventory is a combination of a wealth of data (directly metered and also made available on the web via the MAXNET data base) combined with a formidable spirit of cooperation in the university administration system that provided additional data, information and advice to the YCI team. Particularly well monitored are the Yale power plants (inputs and output flows) as well as the energy provided by the power plant system to university buildings (MAXNET data base). Energy purchasing data are also available, albeit less readily accessible. As power plants and buildings are the dominant source of energy use and GHG emissions of Yale, available data thus provide an excellent basis for the development of an integrated energy and GHG reporting system for the university. Such an integrated system could overcome some of the limitations of the existing data systems and the present YCI inventory, namely, the lack of balancing and cross-checking of various sources of energy use and GHG emissions that were reflected in YCI's substantial uncertainty estimates.

And yet for all its strength, the YCI also found that the available data is frequently not used to its full potential, or its value is somewhat diminished. For instance, at present no consolidated data system integrates energy information available from the power plants, MAXNET, purchasing data and a consistent master building list. Development of such a system would not only provide transparency for energy and GHG emission inventories, but also provide cost transparency to the occupants and improved energy efficiency management of the university's buildings. Also, the current system – in which metered data are entered (or "readjusted" to resolve metering discrepancies) manually in various reporting media (e.g. spreadsheets) – introduces additional sources of human error and diminishes the value of information available for efficiency analysis, e.g. for a detailed analysis of the differences between power plant output (plant metering) and the energy provided to the buildings (MAXNET). Combining the energy use data in MAXNET with cost data and complementing MAXNET through purchasing information for those buildings not receiving co-generated energy from the university power plants are therefore suggested as high priority candidates for improved energy and GHG information at Yale.

All other emission sources/activities comprise a comparatively small part of the GHG inventory and regular, annual updates appear less of a priority. Nonetheless, over the longer term it appears advisable to improve data availability for both transportation and waste generated at Yale. For instance, separate mobility surveys for professional travel as well as staff and student commuting could improve upon the necessarily rough and uncertain estimates underlying the YCI inventory. Even if comparatively extensive, such mobility surveys would have added benefits – in better planning for transport operations and for parking space management. Conversely, improving waste data, especially the (to date) insufficient information on solid waste and waste water composition, is a comparatively modest effort that could be achieved through small student projects or be integrated into an environmental sampling course and lab work. Finally, even if very small in comparison to the university's total GHG emissions, the rate of carbon sequestration in Yale's forests should remain an important topic for future research at the School of Forestry & Environmental Studies, with the ultimate goal of reducing the uncertainty of the estimates reported here.

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Appendix B: Data Underlying the YCI Inventory

An accompanying CD-ROM includes all data underlying the YCI GHG emissions inventory for Yale University for the year 2002. The data contained in the CD is organized as follows:

Main directory: This directory contains all final data as presented in the full report, including all graphics. Activity variables and emissions are summarized in the spreadsheet (calculations_finalreport.xls) that contains separate worksheets for each main sector/chapter of the report. Numbers as reported have been summarized and cross-checked in 2005 by Dipl.Ing. Andreas Mueller of the Technical University, Vienna under the supervision of Arnulf Grubler, based on the draft numbers assembled by the YCI team.

Directory support_materials_draft_data: This directory and its subdirectories contain all numerical data and successive versions of the YCI inventory numbers as prepared by the original YCI team over the period 2002 to 2004. Subdirectories contain all relevant inventory background data for power plants, buildings, transportation, as well as other GHG sources and sinks. In addition, technical background literature, a summary of the 2004 draft inventory numbers, as well as other statistical material presented in the final report and in project presentations are included. Readers are advised that these data are in draft form and are presented on the data CD for informational and inventory development documentation purposes only.

To obtain the YCI data-CD, please send request in writing to: Publication Series Editor, Yale School of Forestry & Environmental Studies, 205 Prospect Street, New Haven CT 06511 USA

Direct access: Due to their size and complexity, the data files have not been posted on the Web. Direct copies may, however, be made from the data-CDs attached to each YCI inventory report deposited in the Yale library system, where the report with CD can be consulted directly, or ordered via inter-library loan.

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