Yale Climate Initiative

Mitigation Strategies Report
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Yale University Advisory Committee on Environmental Management

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Background

The Yale GHG Inventory was an initial effort to identify and quantify the emissions associated with the operations and activities of Yale University. The emissions inventory identified the University's most significant emissions sources, the emissions sources that offer the greatest opportunities for reductions, and the emissions sources that can be controlled most readily through University actions. Alongside these elements, we identified cost, feasibility, and timeframe as important factors in deciding which mitigation options to recommend. This report will examine a broad set of mitigation options, evaluating them according to these criteria.

Mitigation Options Underway at Yale

Before offering a set of recommended mitigation options for Yale, it is worth noting some examples of building-related energy initiatives already underway at the University. Yale has been increasing its focus on energy conservation measures in the past year, but some of the measures implemented in the past include:

- Replacing old lighting systems with energy-efficient, fluorescent lighting has saved Yale $800,000 per year.[1]
- The installation of room-level individual heating control systems in Becton Laboratory and Kline Geology Laboratory has saved Yale $700,000 per year.[2]
- Yale has adopted LEED (Leadership in Energy and Environmental Design) standards for two new buildings.[3]
- The School of Forestry and Environmental Studies is in the process of commissioning a pilot "green" building to demonstrate sustainable design and cutting-edge energy performance.

While encouraging, these efforts are still somewhat piecemeal when one considers the amount of work that must be done to significantly reduce Yale's greenhouse gas emissions over the coming decades. The University is in the midst of renovating its 12 residential colleges, and spent more than $300 million in fiscal year 2002 on renovations for classrooms, research facilities, and student housing.[4] Yale is also undergoing the design and planning of several new buildings, including a $1 billion investment in Yale's science, engineering, and medical facilities.[5] In addition, the School of Management is planning to expand its facilities.[6]

At the same time, budget constraints will force the University to, as outlined in a recent Provost's letter to the community, seek savings in the capital budget by lowering the costs of construction

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[1] Thomas Graedel et al., "Resource Use and Environmental Performance at Yale University,"Yale School of Forestry and Environmental Studies, 2000.

[2] Ibid.

[3] Roberto Meinreth, presentation to YCI seminar, 29 September 2003.

[4] Yale University, Yale University Financial Report 2001-2002, p. 1.

[5] Ibid.

[6] Erica Youngstrom, "SOM Looks to Expand Facilities," Yale Daily News, 7 November 2003.

and delaying the authorization of some building projects that are not already in the construction or planning stage.[7] This may greatly hamper GHG mitigation efforts that involve lower lifetime costs through energy savings but require higher initial investments.

Methodology

YCI set forth some mitigation options at the end of its inventory report, but did not analyze any of them fully. In this report, we highlight a few measures, and suggest some new ones in addition. Due to limited data availability, we have not performed in-depth feasibility assessments or cost-benefit analyses of all the options, but have focused on those that we have determined to have the best overall profile. Appendix B ranks the mitigation options and identifies those actions with the greatest potential for mitigation. The decision to pursue any of these or other options depends on University priorities, which include cost, time frame, leadership opportunities, and educational functions.

In order to pick the best mitigation options we scored each mitigation option according to the following criteria: (1) Size of Source, (2) Control, (3) Cost, (4) Reduction Potential, (5) Feasibility, and (6) Timeframe. Each mitigation option was ranked on a scale between 1 and 3, with one being “worst” and 3 being “best” in terms of reducing Yale’s emissions. We divided the mitigation options into three groups based on timeframe; within each group the options are ranked by average score of criteria 1-5.

Table 1 shows the options that scored above 2.5 in our ranking system. We grouped several of them together under the heading of “Building Retrofits” and picked two others. The three options we chose to explore in depth are as follows:

- Building Retrofit (HVAC, Insulation)
- Cost Incentives, (have each building pay their own energy bill)
- BioFuels for the Yale Central Power Plant

We did not look at “energy efficient computer/equipment” because many departments within Yale have already begun replacing computers and other equipment with energy efficient models as the old ones reach the end of their useful lives. Replacing fume hood is already a top priority of the facilities department, and will be carried out over time as funds allow.

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[7] “Provost’s Letter to Yale Community,” Yale Bulletin & Calendar, 7 November 2003.

Table 1.

Reduction measure	Size of source	Control	Cost	Reduction potential	Feasibility	Score
Have each dept pay own energy bill	3	3	3	2	3	2.8
Replace lighting (building retrofit)	3	3	3	2	3	2.8
Window replacement (building retrofit)	3	3	2	3	3	2.8
Insulation (building retrofit)	3	3	2	3	3	2.8
Incorporate biodiesel into fuel mix of power generation facilities (boilers)	3	3	2	3	3	2.8
Replace fume hoods	3	3	1	3	3	2.6
Occupancy sensors (building retrofit)	3	3	2	2	3	2.6
Energy efficient computers/equipment	3	3	3	1	3	2.6
Energy efficient HVAC (building retrofit)	3	3	2	2	3	2.6
Incorporate biodiesel into fuel mix of power generation facilities (turbines)	3	3	2	3	2	2.6

Option 1: Building Retrofits

Elizabeth Martin

Buildings in Design and Construction Phase

The design and construction of new buildings represents the largest mitigation potential. By addressing energy use and GHG emissions early in the process, it is possible to achieve an "integrated building design". In addition to the implementation of LEED standards, the following initiatives can be considered:

- Work with stakeholders to establish building guidelines, including energy performance benchmarks that are integrated upfront into the renovation, design, and construction processes. Stanford University's Land and Buildings office has adopted a set of Guidelines for Sustainable Buildings that
  - Place sustainability considerations at the same footing as cost, schedule, and program concerns;
  - Integrate sustainability considerations into building design and construction process at Stanford; and
  - Suggest strategies for improving the energy performance of Stanford buildings.[8]

Buildings in Renovation Phase

Renovations also present a high mitigation potential. During renovations, many building components, such as windows, will be replaced, limiting the incremental costs of energy efficiency retrofits. Among the available mitigation options for building renovation:

- Adopt LEED standards for building renovations. MIT has adopted LEED standards for both new and renovated buildings, designating a "Silver Plus Level" for MIT-specific requirements.[9] If necessary, Yale could similarly designate its own level for Yale-specific requirements.
- Study the feasibility of installing meters in individual rooms of renovated buildings.
- Establish a coordinated energy retrofit program to share information on ongoing renovations. Stanford has since 1993 run a successful Energy Retrofit Program (ERP). By 2002, the ERP had spent $7M on retrofits, financed through utility recharge rates paid for by Stanford energy consumers.[10] Yale might explore a similar mechanism for financing retrofits.

Other Buildings

Many Yale buildings are not undergoing renovation, yet hold considerable potential for mitigation through equipment upgrades. This potential ranges widely, due to untapped opportunities in lighting and metering.

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[8] Chang, p. 12; Stanford University, "Guidelines for Sustainable Buildings," Environmental Stewardship Committee, March 2002.

[9] Chang, p. 7.

[10] Chang, p. 11.

- Initiate replacement of standard lighting with compact fluorescent lighting (CFL). A Harvard initiative launched in 1999 to replace halogen lamps with CFL units has saved the College $300,000 and reduced GHG emissions by 2,000 tons.[11]
- Work with the EPA Energy Star Program to spur introduction of energy-efficient equipment, lighting, appliances, and electronics. The Energy Star products can save between 10-90% in energy consumption, with a potential savings of 70-90% for residential commercial lighting fixtures.[12]
- Work with United Illuminating to promote energy-efficient products at Yale-area stores. UI recently announced a partnership with Home Depot and Technical Consumer Products, an energy-efficient light-bulb manufacturer, to sell the light bulbs at a steep discount at Home Depot stores in Southwestern Connecticut.[13]
- Consider creative energy use competitions among residential colleges. Over Thanksgiving, Harvard University runs a College-wide competition among residential houses to reduce energy consumption.[14]
- Initiate analysis of options for efficiency gains from computers. Harvard has instituted a Computer Energy Reduction Program for the 18,000 computers on its FAS and Longwood campuses. The Program, which recently won an Energy Star Leadership Award, expects to save $350,000 and 1800 metric tons of CO_2.[15]

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

[12] R. Brown, C. Webber, and J.G. Koomey, “Status and Future Directions of the Energy Star Program,” Energy 27 (2002), 505-520.

[13] Issei Morita, “UI-Home Depot Share Bright Idea With Consumers,” New Haven Register,19 December 2003.

[14] Christine M. DeLucia, “Straus, Mather Top Turkeys in Energy Saving Contest,” Harvard Crimson, 17 December 2002.

[15] Harvard Green Campus Initiative, “Computer Energy Reduction Program,” www.greencampus.harvard.edu/CERP, viewed 11 November 2003.

Option 2: Energy Cost Allocation

Victoria Thompson

Although improvements to building envelopes and equipment are necessary to energy conservation, it cannot achieve all the savings possible. A great deal of energy waste is due to the behavior of people, who are the consumers of energy. Getting people to change their behavior is usually difficult, and people tend not to change a comfortable habit (such as leaving a computer on at the end of the day) unless they are given some incentive, either positive or negative.

As a way to save money on their energy bills, a growing number of universities have been turning to energy sub-metering and allocation of energy expenses among departments. This is a strategy that makes sense: as mentioned above, people are more likely to change and control their energy-use behavior when they have an incentive. Depending on how it is used, energy cost allocation can provide positive or negative incentives, or both, to conserve energy.

In April 2002 the EPA's Energy Star released a report on "Sub-Metering Energy Use in Colleges and Universities: Incentives and Challenges" (a copy of this report is appended). This report was intended as a "resource document for energy, facility, and financial managers." The report pointed out the necessity of knowing patterns and magnitudes of current energy use before effective measures can be taken to reduce energy use. Although this report deals mainly with institutions that buy the bulk of their energy from utility companies, rather than producing their own, as Yale does, the report is still instructive.

The report claims that sub-metering can benefit universities from business, engineering, and management perspectives. From a business perspective, the main benefits include allowing allocation of energy costs to the end-user (as we have been suggesting) to encourage efficiency, allocation of costs to specific research grants, and the verification of savings from installed projects. From an engineering perspective, the main benefits mentioned are ability to monitor improvements in system performance due to upgrades, and to identify components that may need attention (higher load that usual). From a management perspective, sub-metering aids decisions about upgrades to buildings by facilitating comparisons, and encourages the reduction of energy use by holding managers accountable for "energy hogs."

Payment at the departmental level would encourage more responsibility towards energy use, because it stands to reason that faculty and staff usually feel more accountable to their department, which houses their direct supervisors and their colleagues.

Case Study: Stanford University

The institutions that have implemented this type of cost incentive include Stanford University, Bowling Green State University, Lycoming College, and University of Delaware. It can be helpful to know how other institutions have addressed similar problems, to identify best practices and pitfalls to avoid. To this end, here follows a summary of Stanford's program. It seemed most applicable as a peer institution to Yale, and additionally was the program we were able to obtain the most information about

Stanford University recently implemented an Energy Conservation Incentive Program (ECIP). In March of 2004 Stanford began billing electricity use directly to 20 administrative units, rather than having it paid by the central Budget Office. Each unit is given a budget (in kilowatt-hours): any excess kWh used in the budget period must be paid for by the unit, and the unit is reimbursed for kWh not used. The budgets were determined by a baseline analysis. The program began with a six-month grace period, in which departments were rewarded but not penalized. In the first six months of the program, the average savings was two percent, but officials estimate a savings of five percent is achievable through no-cost measures, based on voluntary measures experienced during the 2001 energy crisis.[16] More savings would presumably be achievable with some investment in energy-conserving equipment.

Susan Kulakowski, Stanford's campus energy manager, was kind enough to discuss the details of the program with YCI. Those involved with energy management had been interested for a long while in doing something along these lines. This was out of a dual concern for reducing energy-use at the university, and also to encourage a culture that would take more responsibility for previously hidden costs.

Like Yale, Stanford produces its own electricity, steam, and chilled water on campus. They decided to focus only on electricity in this conservation program for a number of reasons: there was already building-level metering; its use was essentially weather independent (because heating and cooling is provided almost exclusively with steam and chilled water); it is the most expensive utility on a per-unit basis; and it is under the control of occupants, creating real opportunities for behavior-based savings.

While Stanford considered billing at the department level, they determined that this would be cumbersome to enact, because departments often share buildings and often change which spaces they use. Instead billing is assigned to 20 previously existing administrative units, corresponding in some cases to schools within the university (such as the School of Education) and in other cases to units such as the university library system. These administrative units vary largely in size. Some facilities, such as the medical complex and the athletics department have been responsible for their own energy bills for a long time, and have not been included in this program. Shared spaces, such as large classrooms and lecture halls used by many units are assigned to the Registrar's Office unit.

Since billing is at a level larger than departments, there are fewer cases where buildings are not wholly allocated to one unit or the other. In cases where units do share a building, cost allocation is based on square footage and updated yearly. They decided not to use building sub-metering because of the expense and the fact that electrical circuits do not always conform to space allocation.

The budget comes from a baseline number of kilowatt-hours measured for a unit (the baseline for the past five years), multiplied by the current electricity rate—rates are updated annually. The main concern here is that departments should be responsible for the amount of energy they

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[16] Pena, Michael, "Energy conservation program and penalties now in effect," *Stanford Report*, 22 September 2004 <http://news-service.stanford.edu/news/2004/september22/energy-922.html>

consume, but not liable for changes in electricity rates which are beyond their control. If programmatic needs call for the addition of new equipment, or other large increases in electricity use, a unit must submit its application for an increased electricity budget to the Budget Office, who will determine each case on its own merits. In the case of new construction or major renovation, the new building's budget will remain under the purview of the Budget Office for a year until a baseline can be established, at which time responsibility will be turned over to the appropriate unit, along with an increase in budget.

This program did require a lot of work initially to establish baselines, and Stanford also hired a programmer to deal with the software needs associated with the initiative. The Budget Office has seen a small additional workload, as has the Facilities Office. The response of individual units is really up to them, in terms of how much time and resources they wish to devote to saving energy and earning rewards under this program. The Energy Manager has made an effort to support schools in this endeavor by providing education on ways to save energy.

Because this program started less than a year ago, it remains to be seen what the outcome will be. One of the keys to the success of implementing this project was the enthusiastic support of the Provost of the university, one of whose goals was to run a more business-like university and to make administrators more aware of the full costs of doing their work. Ms. Kulakowski noted that the success of the project will also hinge on whether the Provost sticks to his guns at the end of the financial year in August. If administrative units are over their budget, and plead for leniency/exception, the ability of the Provost to hold firm will make or break the initiative.

Feasibility of Cost Allocation

Yale University Energy Manager, Tom Downing expressed his support for the idea as an emissions reduction measure. He also outlined three main hurdles that need to be overcome before Yale can implement cost incentives for energy conservation at Yale. The first is that the exact space that a department occupies changes frequently, sometimes on a monthly basis. Secondly, that, steam and chilled water, which account for at least 60 percent of campus energy use, are more difficult to meter (although Yale does so), and need frequent calibration. The concern is for the accuracy of these figures in relation to a budget assigned to a department. Thirdly, there are many spaces in the University that belong to no one department, and are used by many—how would these costs be allocated?

The problem of allocating costs in an environment where occupancy frequently shifts might be addressed by instituting a similar system to Stanford's, breaking down costs by larger administrative units rather than individual departments. Someone more familiar with the university's administrative structure would be better suited to suggest what exactly these units might be. However, examples of appropriate units might be residential colleges, and the four units of the Faculty of Arts and Sciences (biological sciences, humanities, physical sciences, and social sciences). Since many if not all of the professional schools already pay their own bills, they would not have to be included. However, they too might benefit from whatever education about saving energy might accompany such a program.

Allocating costs in shared buildings on a square-footage basis, while not a perfect solution, might provide a workable allocation of costs. And while sub-metering might not be appropriate for every situation, shared building situations should be evaluated to see if it might provide a better solution in cases where a high degree of accuracy is required.

As for shared spaces, if billing were based on larger administrative units rather than individual departments, it seems likely that acceptable homes could be found for shared spaces—presumably the Yale library system would constitute a unit, as would athletics. Shared lecture halls would be more difficult, but no doubt appropriate arrangements could be made.

The Energy Star report estimates a cost of $6,300 per building for metering equipment and data acquisition software (assuming two meters per building). I met with a representative of E-MON, a sub-metering software and equipment company, to see what sorts of possibilities were offered by this technology. From my examination the E-MON prospectus, it appears that costs could be somewhat lower than $6,300, depending on what kind of meters are needed. There could also be a certain economy of scale, as one set of software is sufficient to gather data from all meters that might be installed on campus.

It seems clear that, certainly for any initial program, it would only be possible to allocate electricity costs. While this does cover only about one-third of the energy use on campus, it is the form of energy that consumers have the most control over and that seems to offer the greatest potential for behavior-based savings.

Yale already has an energy monitoring system in place, as well as a good amount of historical energy-use data, these factors make the idea of implementing an energy cost allocation system more feasible than at many universities. Such a program could certainly be implemented at Yale: the question is whether the desire to do so is there. The savings that such a program could achieve would be appealing: for example, a five percent savings on electricity, such as is anticipated by Stanford. If Yale would like to promote a culture of taking more responsibility for one’s own actions, a cost allocation system might be a good place to start. This looks like a win-win situation: not only would it be good for the environment, but also for the university’s pocketbook

Option 3: BioFuels for the Yale Central Power Plant

Virginia Lacy

For the third and final mitigation strategy, YCI focused on the University's largest greenhouse gas emitter – Yale's onsite electricity generation plants. As stated earlier, YCI evaluated potential mitigation strategies by taking into account three factors: 1) the University's most significant sources of emissions; 2) the emissions sources that offer the greatest opportunities for reductions; and 3) the emissions sources that are most readily controlled through University actions. After carefully considering YCI's GHG Inventory data, the team determined that Yale's power plants not only met these criteria, but they could also be used as a platform for gaining experience and expertise in fuel substitution for future mitigation efforts in other areas around the University, such as transportation. Thus, as a GHG mitigation strategy, fuel substitution in Yale's power plants could enable the University to receive "more bang for its buck", while serving as a strategic starting point for future mitigation efforts. Based on a review of internal and external factors discussed in further detail below, YCI chose to explore the feasibility of incorporating biodiesel into the fuel mix of the University's largest power generation facility and its largest GHG emitter, the Central Power Plant. From our preliminary examination, Yale can cut over 8,400 tons of CO_2 emissions annually by substituting the use of No. 2 diesel oil and No. 6 residual oil with biodiesel at Central Power Plant.

<u>Criteria 1. Yale's Power Generation Plants: A Significant Source of Emissions</u>

YCI's Inventory revealed that Yale's three power plants emitted 207,025 tons of CO_2 equivalent in 2002, or approximately 70% of the University's 288,322 tons of GHG emissions for that year.[17,18] (See figure below.) Thus, Yale's power plants were the largest source of GHG emissions by a margin of almost two to one.

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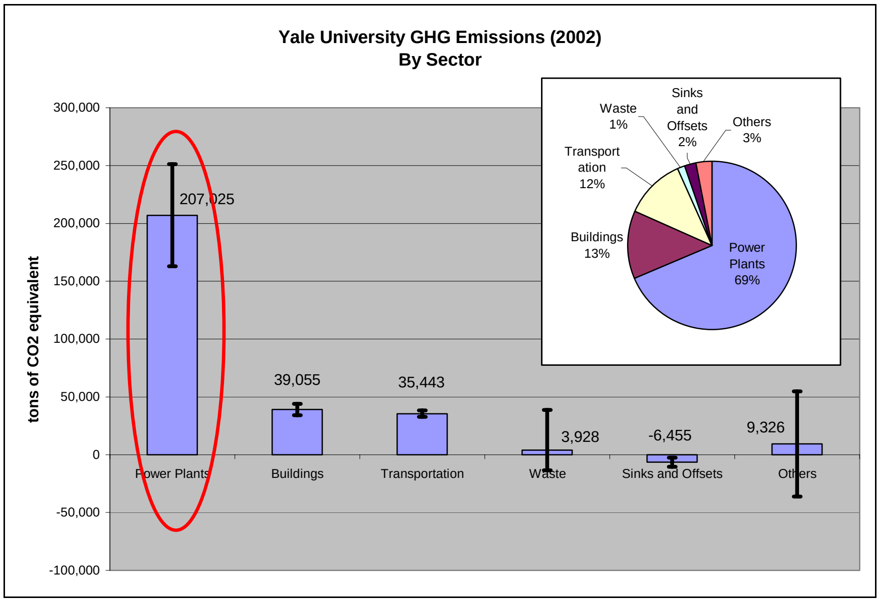
[17] In 2002, YCI calculated a total of 288,322 tons of GHG emissions (CO_2 equivalent), with an uncertainty high of 373,598 tons (29.6%) and an uncertainty low of 220,384 tons (-23.6%).

[18] Emissions from the operation of Yale power plants were calculated based on fuel inputs for equipment type multiplied by specific emission factors of fuel inputs.



Source: Yale Climate Initiative Greenhouse Gas Inventory, 2002

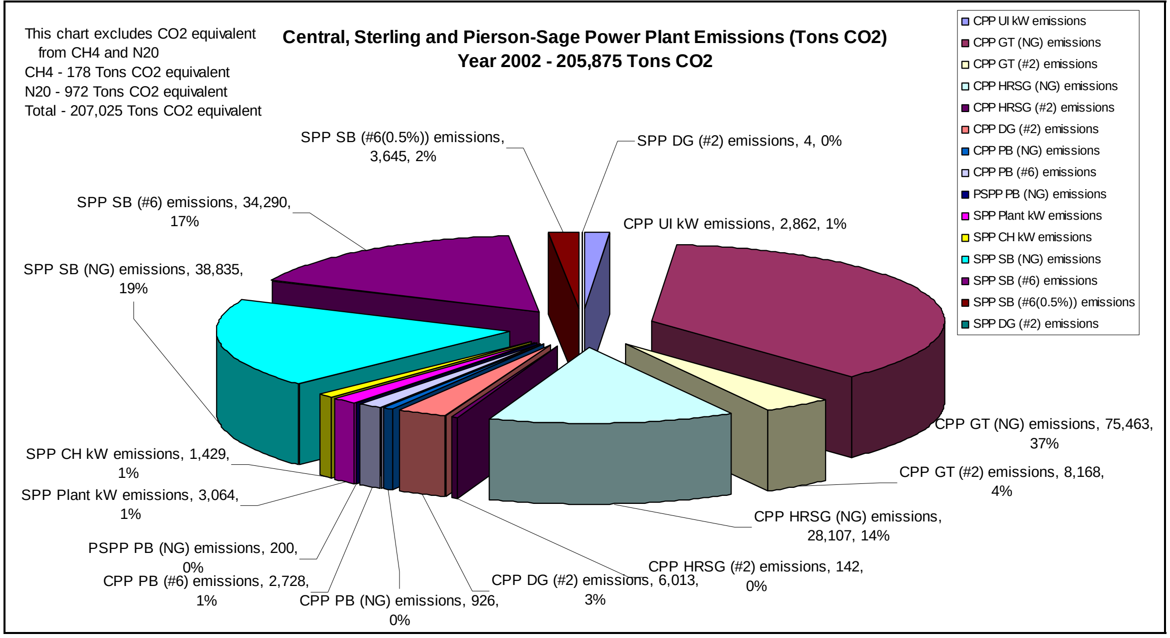
The Central Power Plant was the University's largest single source of emissions with 125,233 tons of CO2, or 42% of the University's total emissions. Sterling Power Plant was the University's second largest emitter with 81,592 tons, or 26.9% of total emissions. Pierson-Sage made up less than 1%, or 200 tons, of the University's total. (See Table 2 below.) These figures easily qualify the power plants as the most significant sources of Yale's emissions.

Table 2. GHG Emissions from Yale Power Plants

Power Plant	**GHG emissions (2002)**	**Percentage of Yale's total emissions (2002)**	**Uncertainty**		**GHG emissions**	
			(High)	**(Low)**	**High**	**(Low)**
	tons CO2 eq.	%	(+/-) %	(+/-) %	tons CO2 eq.	tons CO2 eq.
Central	122,371	42.0%	22%	-22%	149,292	95,449
Pierson-Sage	200	0.1%	22%	-22%	244	156
Sterling	78,529	26.9%	22%	-22%	95,805	61,252
Total (Power Plants)	**201,100**					
Total (Yale)	**291,696**	**69.0%**				

Source: Yale Climate Initiative Greenhouse Gas Inventory, 2002

Figure 2.



Source: Yale Climate Initiative Greenhouse Gas Inventory, 2002

Figure 2 presents a break out of the GHG emissions by power plant and fuel type. While natural gas dominates as the largest source of emissions with 143,330 tons of CO2, or 69%, of the total GHG emissions released by Yale's power plants, No. 2 fuel oil and No. 6 residual fuels are still responsible for almost one third of the University's GHG emissions from power plants. No. 6 fuel contributed 40,663 tons of emissions, or 20%, of Yale's power plant emissions. No. 2 fuel oil contributed 14,328 tons of emissions, or 7%, of the power plants emissions. Eliminating No. 2 and No. 6 fuel oils from the University's power generation fuel mix would reduce emissions by 54,991 tons, or 27% of total power plant emissions. This elimination would translate into a 19% reduction of the University's total emissions. While substituting biodiesel (or another fuel) would not equate to the full elimination of carbon emissions, this still provides a sense of the magnitude of eliminating No. 2 and No. 6 residual fuels from Yale's power generation fuel mix.

Criteria 2: Emissions Source Readily Controlled by University Actions

In its 2002 GHG Inventory, YCI used the World Resource's Institute's GHG Protocol as a guide for accounting for and reporting Yale's emissions. The Protocol defines three "scopes" for reporting purposes: Scope 1, direct greenhouse gas emissions that are owned or controlled by the institution; Scope 2, indirect greenhouse gas emissions from electricity, heat or steam from third parties; and Scope 3, other indirect greenhouse gas emissions. Central and Sterling power plants both fall under Scope 1, indicating that Yale has almost absolute control over the major aspects of their emissions and is in a significant position to influence the reduction of its emissions.

Criteria 3: Cost

One of the great advantages of biodiesel fuel is that it is often considered a "drop in" technology, one that requires little to no capital intensive investment for transitioning to its use from that of conventional diesel fuel. This advantage would apply to the oil fired boilers used in Yale's power generation facilities. As discussed further in this report, additional study is required to assess the costs associated with converting the gas turbine to use biodiesel fuel.

The cost of biodiesel itself, which in the past has been an additional $1.10 per gallon in comparison to that of conventional diesel fuel, is expected to fall considerably due to increasing production and anticipated demand. Recent estimates have put the cost of a gallon of a blend of 20% biodiesel and diesel fuel (B20) on par with a gallon of conventional No. 2 diesel fuel.

Criteria 4: GHG Reduction Potential

Including biodiesel in the fuel mix of the Central Power Plant is an excellent first step towards further reductions in other areas around the University through the use of biodiesel fuel. Biofuels reduce net atmospheric carbon by displacing fossil fuel combustion, which releases carbon stores to the present-day carbon cycle. According to a study conducted by the US Department of Energy, over the lifecycle of production and use, biodiesel produces 78% less carbon dioxide emissions when compared to conventional diesel fuel.[19] Preliminary calculations show that an emission reduction of approximately 8,404 tons of CO_2 equivalent could be achieved by switching from No.2 and No 6 to biodiesel in the Central Power Plant.

Criteria 5: Feasibility

Incorporating biodiesel into the fuel mix at the University is feasible both from a technical standpoint and an institutional standpoint. With regards to technical ease, the same chemical properties that make biodiesel an ideal substitute for conventional diesel fuel also make it an excellent alternative for conventional fuels used in oil-fired boilers and diesel generators, such as No. 2 and No. 6 fuel oils.

In terms of institutional feasibility, exploring the use of biofuels in Yale’s Central Power Plant builds on growing interest and activity in biofuels at Yale, both in the student population and the administration:

- Recently, Yale engineering student Giovanni Zinn earned media attention for converting his diesel-fueled to truck to partially run on vegetable oil from a local restaurant. This spring, he earned a Green Fund grant from Yale’s Advisory Committee on Environmental Management to form a team and build a chemical processor for converting waste oil from Yale dining halls to biodiesel. The recycled oil will be used to heat a campus greenhouse and run Yale tractors.
- In Yale’s Facilities Office, Sam Olmstead, Environmental Compliance Manager, has taken the lead to assess the potential for biofuel use at Yale.

Yale’s Central Power Plant

The Central Power Plant is a cogeneration plant with a supplementary package boiler, three diesel generators and five steam driven chillers. The major pieces of equipment are listed in Figure 3 below. Electricity generated from the gas turbine electricity generators and diesel generators are supplied to the Central Campus, Science Hill Campus and the Central Power Plant

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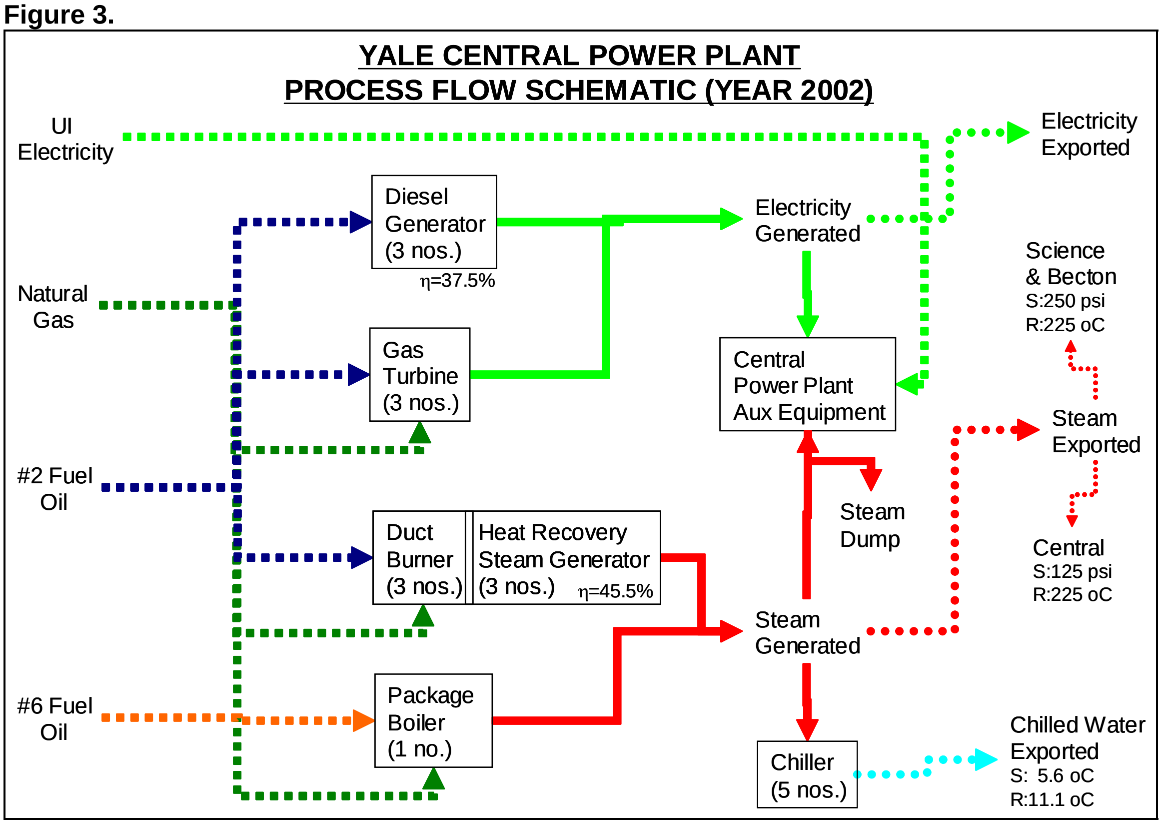
[19] US Department of Energy, US Department of Agriculture, “Lifecycle Inventory of Biodiesel.” May 1998.

to operate auxiliary equipment. Steam generated from the heat recovery steam generators and package boilers are supplied to the Central Campus (at 125 psi), Science Hill Campus (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 the Central Campus and Science Hill Campus.

Figure 3.



Source: Yale Climate Initiative Greenhouse Gas Inventory, 2002

Table 3. Central Power Plant Major Equipment List

Equipment	Brand / Model	Quantity	Capacity	Fuel Source
Gas Turbine Generator (GTG)	Nuovo Pignone PGT 5M heavy-duty industrial gas turbine (serial numbers 05815,05681 & G06083)	3	5,220 kW at ISO conditions	Natural Gas / #2 (0.05% sulfur) Fuel Oil
	Ideal synchronous generator (with a GE EX 2000 excitation control)	3	Control equipment	
	GE Mark V Speedtronic turbine control system	3	Control equipment	
Heat Recovery Steam Generator (HRSG)	Aalborg Heat Recovery Steam Generator	3	Fired – rated at 80,000 lbs/hr 250 psig saturated process steam	Waste Heat / Natural Gas / #2 (0.05% sulfur) Fuel Oil
		3	Unfired – rated at 24,000 lbs/hr process steam	Waste Heat
Package Boiler (PB)		1	Rated at 100,000 lbs/hr process steam	Natural Gas / #6 (0.5% sulfur) Fuel Oil
Diesel Generator (DG)	Mitsubishi 8 cylinder 4 stroke units with Newage Generators	3	Rated at 1500 kW	#2 (0.05%) Fuel Oil
Chillers (CH)	Carrier R-134a	4	2,250 tons	Steam
	York R-22	1	5,600 tons	Steam

Source: Yale Climate Initiative Greenhouse Gas Inventory, 2002

Fuels Used in the Central Power Plant

Like Yale’s two other power generation facilities, Sterling Power Plant and Pierson-Sage Power Plant, the Central Power Plant uses natural gas, No. 2 diesel fuel, and No. 6 residual fuel to operate plant equipment. Electricity is also drawn from United Illuminating to operate the power plant building facilities. None of the power plants use coal.

In 2002, natural gas comprised 79% of the fuel used in the power plants, while No. 2 and No. 6 residual fuels comprised 4% and 15%, respectively. Total energy import into the three power plants was equal to 3,681,017 GJ, while total energy export was equal to 2,357,480 GJ.

Fuel Characteristics and Differences Between No. 2 and No. 2 Fuel Oils

No. 6 residual fuel is a residual product of crude oil left over during the refining process. It is thick, viscous oil, which is most often used for industrial applications such as powering steam boilers and power generators. Due to its tar-like consistency, No. 6 residual fuel must be heated between 150 and 250 degrees Fahrenheit prior to use to ensure that it flows easily and burns most efficiently.

No. 2 fuel oil is a petroleum distillate that is physically similar to No. 2 diesel fuel, or conventional diesel, although No. 2 diesel fuel is blended with kerosene to increase its liquidity during cold weather. In comparison to No. 6 fuel oil, No. 2 fuel oil is lighter and flows more easily.

No. 2 fuel oil has a lower carbon and sulfur content than No. 6 fuel oil and therefore emits less CO2 and SOx when burned. However, No. 2 fuel oil is also more expensive than No. 6 fuel oil. In 2003, the average price for No. 2 fuel was $1.36 per gallon, while the average price of No. 6 residual fuel was $0.66 per gallon.[20] According to findings in YCI's GHG Inventory, Yale has maintained its No. 6 fuel oil package boiler because of a price advantage offered by the fuel supplier.

Why Consider Biodiesel?

The use of biodiesel as an alternative to conventional petroleum products for transportation, heating, and electricity production has grown steadily over the last decade. Several oft-cited benefits of biodiesel use include energy security, growth in domestic agricultural production, and the reduction of greenhouse gas emissions. In addition, many recent studies have that biodiesel actually improves the performance and reduces the maintenance costs of the systems in which it is used.

One of the biggest advantages to using biodiesel is the ease with which it can be substituted into the currently used fuel mix. In fact, when blended with petroleum diesel at a concentration of 20% (called B20) or less, biodiesel is often considered to be a "drop in" technology. No new equipment and no equipment modifications are necessary. Further, B20 can be stored in diesel fuel tanks and pumped with diesel equipment.

What is Biodiesel?

Biodiesel is a fatty-acid based fuel derived from vegetable oils and animal fats. It is a legally registered fuel and fuel additive with the U.S. Environmental Protection Agency (EPA). According to the EPA, "registration includes all biodiesel meeting the ASTM International[21] biodiesel specification, ASTM D 6751, and is not dependent upon the oil or fat used to produce the biodiesel or the specific process employed."[22]

Environmental Advantages of Using Biodiesel

- ***Reduced CO2 Emissions***
  Biofuels reduce net atmospheric carbon by displacing fossil fuel combustion, which releases carbon stores to the present-day carbon cycle. By contrast, the production and use of biofuels participates in the current carbon cycle, rapidly taking up carbon from the atmosphere to produce the biomass that is used for biofuel. Thus, the net effect of shifting

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[20] US Energy Information Administration, "Crude Oil and Petroleum Product Prices." http://www.eia.doe.gov/neic/infosheets/petprices.htm. Accessed January 12, 2005.

[21] ASTM International is a consensus based standards group comprised of engine and fuel injection equipment companies, fuel producers, and fuel users whose responsibilities among others are setting standards for fuel quality and characteristics.

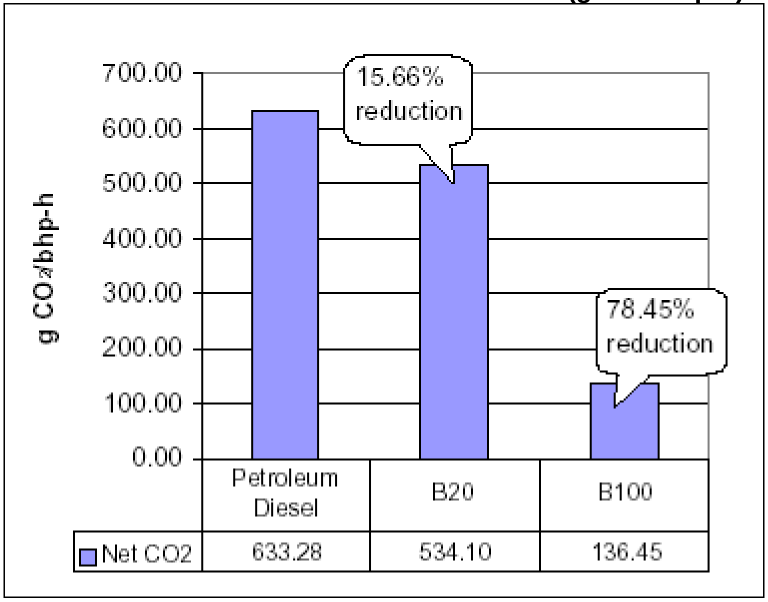
[22] Tyson, Shaine. "2004 Biodiesel Handling and Use Guidelines." National Renewable Energy Laboratories.

from fossil fuels to biofuels is to reduce the amount of CO_2 in the atmosphere. According to a study conducted by the US Department of Energy, over the lifecycle of production and use, biodiesel produces 78% less carbon dioxide emissions when compared to conventional diesel fuel.[23]

- ***Reduced Particulates, Sulfur and Other Emissions***
  Biodiesel reduces tailpipe particulate matter (PM), hydrocarbon (HC), and carbon monoxide (CO) emissions because B100 contains 11% oxygen by weight. The presence of fuel oxygen allows the fuel to burn more completely, which results in fewer unburned fuel emissions. This same phenomenon reduces air toxics, which are associated with unburned or partially burned HC and PM emissions. Testing has shown that PM, HC, and CO reductions are independent of the feedstock used to make biodiesel. The EPA reviewed 80 biodiesel emission tests on CI engines and has concluded that the benefits are real and predictable over a wide range of biodiesel blends.

In addition, biodiesel typically contains less than 15 parts per million (ppm) of sulfur. By comparison, in New England, No. 2 distillate has a sulfur content of 1500-2500 ppm (0.15-0.25% by weight).[24]

Figure 4. Comparison of Net CO2 Life Cycle Emissions for Petroleum Diesel and Biodiesel Blends (g CO2/bhp-h)



Source: U.S. Department of Agriculture and U.S. Department of Energy

- ***Reduced Fossil Fuel Energy Intensity***
  The fossil fuel energy required to produce biodiesel from soybean oil is approximately one third, or 31%, of the energy contained in each gallon. In other words, by burning biodiesel, the consumer receives 3.2 units of energy from biodiesel for every unit of fossil

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[23] US Department of Energy, US Department of Agriculture, “Lifecycle Inventory of Biodiesel.” May 1998.
[24] Massachussets Energy Consumers Alliance and People’s Power and Light, “Use of Biodiesel as a Heating Oil in New England.” October 15, 2004.

fuel energy used to produce the fuel. Thus, biodiesel not only displaces fossil fuels in its direct use but also indirectly throughout its production, which means we conserve petroleum resources and discourage additional imports of foreign oil.

Potential Emissions Reductions from the Use of Biodiesel in the Central Power Plant
The potential GHG emissions reductions from Central Power Plant's conversion to biodiesel are summarized in Table 4 below. Original emissions from the operation of the Central Power Plant were calculated in the YCI GHG Inventory based on fuel inputs for equipment type multiplied by specific emission factors of fuel inputs. Preliminary calculations show that an emission reduction of approximately 8,404 tons of CO_2 equivalent can be achieved by switching from No.2 and No 6 to biodiesel in the Central Power Plant.

Table 4. Central Power Plant GHG Emissions, 2002

Gas Turbine	
No. 2 Fuel Oil = 831,135 gal (from power plant data)	**100% Biodiesel** = 831,135 gal #2 * $\frac{138{,}000 Btu}{gal\#2}$ * $\frac{galBiodiesel}{120{,}000 Btu}$ = 955,805.25 gal
CO_2 emissions from #2 fuel oil 831,135 gal #2 * $\frac{23.550 lbCO2}{gal\#2}$ = 19,573,229.25 lb CO_2 = 8,878 tons CO_2	**CO_2 emissions from Biodiesel (over life cycle)** = 955,805.25 gal * 5.181 lb CO_2/gal = 4952027.00 lb CO_2 = 2476 tons CO_2 **Lifecycle reduction = 6402 tons CO_2**
Duct Burner	
No. 2 Fuel Oil = 13,361 gal (from power plant data)	**100% Biodiesel** 13,361 gal #2 * $\frac{138{,}000 Btu}{gal\#2}$ * $\frac{galBiodiesel}{120{,}000 Btu}$ = 15,365.15 gal
CO_2 emissions from #2 fuel oil 13,361 gal #2 * $\frac{23.550 lbCO2}{gal\#2}$ = 313,983.5 lb CO_2 = 142 tons CO_2	**CO_2 emissions from Biodiesel (over life cycle)** = 15,365.15 gal * 5.181 CO_2/gal = 79606.84 lb CO_2 = 39.80 tons CO_2 **Lifecycle reduction = 102 tons CO_2**
Package Boiler	
No. 6 residual fuel = 240,597 gal (from power plant data)	**100% Biodiesel** 240,597 gal#6* $\frac{150{,}000 Btu}{gal\#6}$ * $\frac{galBiodiesel}{120{,}000 Btu}$ = 301,196.25 gal

CO_2 emissions from #6 fuel oil	**CO_2 emissions from Biodiesel (over life cycle)**
= 240,597 gal#6 * $\frac{25.0lbCO2}{gal\#6}$ = 6,014,925 lb CO_2 = 2,728 tons CO_2	= 301,196.25 gal* 5.5 lb CO_2/gal = 1,656,579.375 lb CO_2 = 828.29 tons CO_2 **Lifecycle reduction = 1900 tons CO_2**

Switching #2 & #6 Fuel Oil to Biodiesel Fuel

CPP Gas Turbine:	CO_2 reduction	= 6402 tons CO_2
CPP Duct Burner:	CO_2 reduction	= 102 tons CO_2
CPP Package Boiler:	CO_2 reduction	= 1900 tons CO_2
	Total CO_2 reduction	**= 8404 tons CO_2**[25]

Other Advantages

- ***Smells Better***
  Burning biodiesel actually smells better than burning petroleum diesel. Some people say it smells like cooked French fries!

- ***Improved Lubricity***
  Low-level blends of biodiesel such as 2% can improve lubricity of diesel fuels, which could be particularly important for ultra low sulfur diesel as these fuels can have poor lubricating properties. Better lubrication can preserve moving parts, especially fuel pumps, from wearing prematurely.

- ***Technological Adaptability***
  One of the biggest advantages to using biodiesel is the ease with which it can be used. In blends of B20 or less, it is often called a "drop in" technology. No new equipment and no equipment modifications are necessary. B20 can be stored in diesel fuel tanks and pumped with diesel equipment.

Biodiesel Cautions

There are caveats and precautions that should be followed when using biodiesel due to some of the very properties that make it desirable, including increased lubricity. The National Biodiesel Board provides the following list of precautions to undertake when using biodiesel[26]:

- **Ensure B100 fuel meets the biodiesel specification for pure biodiesel before blending with diesel.** The specification for biodiesel is designed to ensure that consumers will not experience operational problems from the fuel's use. Make sure that biodiesel meets this specification and that the fuel supplier will warrant this fact. Quality fuel will provide the consumer with improved air quality and enhanced operability. Purchase fuel only from a reputable source.

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[25] 78% reduction is in comparison to conventional #2 fuel oil.

[26] National Biodiesel Board, "Biodiesel Use Checklist" http://www.biodiesel.org/pdf_files/bdusage.PDF.

- **Check fuel filters on the vehicles and in the delivery system frequently upon initial biodiesel use and change them as necessary.** Biodiesel and biodiesel blends have excellent solvent properties. In some cases the use of petrodiesel, especially #2 petrodiesel (has not been observed with #1), leaves a deposit in the bottom of fueling lines, tanks, and delivery systems over time. The use of biodiesel can dissolve this sediment and result in the need to change filters more frequently when first using biodiesel until the whole system has been cleaned of the deposits left by the petrodiesel. This same phenomenon has been observed when switching from #2 to #1 petrodiesel.

- **Be aware of biodiesel's freezing properties and take precautions as with #2 petrodiesel use in cold weather.** A 20 percent blend of biodiesel with petrodiesel raises the freezing properties approximately 3° to 5° F (pour point, cloud point, cold filter plugging point). In most cases, this has not been an issue. Twenty percent biodiesel blends have been used in the upper Wisconsin area and in Iowa during -25° F weather with no problems. Solutions to biodiesel winter operability problems are the same solutions used with conventional #2 petrodiesel (use a pour point depressant, blend with #1diesel, use engine block or fuel filter heaters on the engine, store the vehicles near or in a building, etc.). Neat biodiesel will begin to freeze at about 25° F and, if used or stored on site, will need to be kept in an area that will not get below that temperature. Most underground tanks are around 50° F and are not a problem.

- **Wipe painted surfaces immediately when using biodiesel.** As mentioned earlier, biodiesel is a good solvent. Biodiesel can, if left on a painted surface long enough, dissolve certain types of paints. Therefore it is recommended to wipe any biodiesel or biodiesel blend spills from painted surfaces immediately.

- **Store biodiesel or biodiesel blend soaked rags in a safety can to avoid spontaneous combustion.** Biodiesel soaked rags should be stored in a safety can or dried individually to avoid the potential for spontaneous combustion. Biodiesel is made from vegetable oils and animal fats which can oxidize and degrade over time. The oxidizing process can produce heat. In certain environments, for example, a pile of oil soaked rags can become concentrated enough to result in a spontaneous fire.

- **Use the biodiesel within one year.** All fuels, including #2 and #1 petrodiesel, have a shelf life. This is also true with biodiesel and biodiesel blends. Industry experts recommend that biodiesel be used within one year to ensure that the quality of the fuel is maintained. Storage time does not impact biodiesel distribution given biodiesel’s production logistics. Biodiesel is generally not stored for long periods of time. Production levels and rates are established to meet demand (similar to "just in time" inventory methods). This is an advantage enjoyed by renewable fuels, like biodiesel, that cannot be shared by its fossil fuel counterparts.

Financial Viability of Biodiesel Substitution

The costs associated with substituting No. 2 and No. 6 fuel oils with biodiesel can be apportioned into investment costs and operational costs. The principal investment costs include one time expenditures such as the physical modifications of the boilers and gas turbine equipment. Operational costs include the maintenance costs to service the equipment and the costs of the fuel.

Investment Costs

As stated earlier, one of the biggest advantages to using biodiesel is the ease with which it can be used in existing infrastructure. With most diesel engines, no new equipment and no equipment modifications are necessary. Biodiesel can also be stored in diesel fuel tanks and pumped with diesel equipment. These advantages would apply in the case of the Central Power Plant's oil fired boilers, which would require little conversion to use biodiesel, even at concentrations of 100%. However, in the case of the gas turbine, there remain outstanding questions regarding the amount of conversion would be required to accommodate biodiesel fuel. Thus, in order to get an accurate cost estimate for using biodiesel in Yale's Central Power Plant gas turbine, YCI includes among its recommendations the need to consult with representatives at the National Biodiesel Board as well as of the contacts made through this research.

Operational Costs

Needless to say, the largest operational cost associated with the use of biodiesel fuel is the cost of the fuel itself. The price of biodiesel depends on fluctuations in the price of petroleum, the price of soybean oil, the demand for biodiesel, the location of the facilities and the method of transport. Approximately 75% of the final biodiesel product cost is attributable to cost of the feedstock, typically soybean oil or recycled cooking oil, which is often referred to as yellow grease. The remaining 25 percent is attributable to processing, handling, and capital costs.

Biodiesel from yellow grease is closer to being cost-competitive with petroleum diesel than biodiesel from soybean oil, but the available supply of yellow grease is limited. A comparison of total production costs of diesel fuel by type of feedstock is shown in the table below. The figures include energy costs and operating costs in addition to the cost of the raw materials. The petroleum diesel prices also include the cost of capital, but are still much lower than the biodiesel prices, which do not.[27]

Projected Production Costs for Diesel Fuel by Feedstock, 2004-2013
(2002 Dollars per Gallon)

Year	Soybean Oil	Yellow Grease	Petroleum
2004-05	2.54	1.41	0.67
2005-06	2.49	1.39	0.78
2006-07	2.47	1.38	0.77
2007-08	2.44	1.37	0.78

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[27] Energy Information Administration "Biodiesel Performance, Costs, and Use"

2008-09	2.52	1.40	0.78
2009-10	2.57	1.42	0.75
2010-11	2.67	1.47	0.76
2011-12	2.73	1.51	0.76
2012-13	2.80	1.55	0.75

Source: Energy Information Administration
“Biodiesel Performance, Costs, and Use”

Recent Biodiesel Prices in the New England Market

Biodiesel Prices in New England
Week of January 20, 2005[28]

Location	**B100**	**B20**	**B2**	**#2 Diesel**
Albany, NY	$2.4574	$1.6166	$1.4274	$1.4064
Boston, MA	$2.3374	$1.6017	$1.4362	$1.4178
Providence, RI	$2.3074	$1.5886	$1.4269	$1.4089
Philadelphia, PA	$2.6000	$1.6262	$1.4071	$1.3828
Manchester, NH	$2.3903	$1.6616	$1.4976	$1.4794
Burlington, VT	$2.6500	$1.7128	$1.5019	$1.4785
U.S. Average:	$2.5778	$1.6119	$1.3927	$1.3683

Source: DTN Energy’s Alternative Fuels Index

For further financial analysis, see Appendix C

Future Demand, Supply and Price Projections

The US Energy Information Administration (EIA) estimates that demand for biodiesel “will be at least 6.5 million gallons in 2010 and 7.3 million gallons in 2020. Based on biodiesel's potential as a lubricity additive, demand could reach as much as 470 million gallons in 2010 and 630 million gallons in 2020.”[29]

A December 2004 study by the Fredonia Group forecast an increase for the demand for biodiesel of 32% per year. The study cited “government support through incentives” as the principle driver for the increase, which would translate into a demand of 150 million gallons in 2008 and 350 million gallons in 2013.[30] The study also anticipated the price for biodiesel to continue to decline from $2.50 per gallon in 2003 to $1.46 per gallon in 2013. The report noted, "The cost of biodiesel has been falling due to lower feedstock prices, which has helped make the additive an attractive option in light of the volatile prices of conventional petroleum diesel.”

Biodiesel Tax Incentive

One of the biggest factors to affect the projected supply, and therefore price, of biodiesel is the Biodiesel Tax Incentive passed in 2004. On October 22, 2004, President Bush signed the nation’s first biodiesel tax incentive into law. The biodiesel tax incentive, which is structured as a federal excise tax credit, amounts to a penny per percentage point of biodiesel blended with

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[28] According to DTN Energy, “prices do not includes taxes and may be net of certain subsidies. Blended prices may be higher due to additional transportation and blending. Prices are in U.S. dollars and U.S. gallons derived from sources deemed reliable.”

[29] US Energy Information Administration, http://www.eia.doe.gov/emeu/plugs/plbiodsl.html. Accessed January 16, 2005.

[30] Renewable Fuel News, “Study: U.S. Biodiesel Demand Headed For 32% Per Year Increase” December 6, 2004.

petroleum diesel for first-use oils, such as soybean oil, and a half-penny per percentage for biodiesel made from other sources, such as recycled cooking oil. The measure will effectively lower the cost of biodiesel to consumers. According to DTNEnergy's Alternative Fuels Index, the average price of No. 2 diesel in mid-October was $1.53 per gallon. The price of B20 was $1.72 per gallon. According to the National Biodiesel Board, the tax incentive could lower the price of B20 to be approximately the same price as conventional diesel, or about $1.52 per gallon.[31] As a result, the tax incentive is expected to increase biodiesel demand from an estimated 30 million gallons in fiscal year 2004 to at least 124 million gallons per year, based on a United States Department of Agriculture study.

Cases of Biodiesel Use for Power Generation

Until recently, biodiesel has been widely used as an alternative fuel for transportation. However, the same chemical properties that make biodiesel an ideal substitute for conventional diesel fuel also make it an excellent alternative for conventional fuels used in oil-fired boilers and diesel generators, such as No. 2 and No. 6 fuel oils. Therefore, and not surprisingly, there have been increasing examples of using biodiesel for other applications such as powering oil-burning boilers for heat generation. For the most part, these studies document the relative ease of switching conventional fuel oil to biodiesel in oil-burning boilers.

While examples of using biodiesel for electricity generation applications are considerably fewer, they are increasing. Many cases involve US federal agencies, such as the National Park Service, the Environmental Protection Agency and the Department of Agriculture. Some cases involve private sector businesses, school and utilities. The cases range in the biodiesel mix used (B2 to B100). The following is an annotated list of select projects that have been undertaken:

- **St. Mary's Medical Center, Long Beach, CA.**
  In 2001, St. Mary Medical Center in Long Beach, California, began using biodiesel as the secondary fuel for one 1,490 horsepower boiler, which primarily runs on natural gas, and the primary fuel for six standby generators. B100 was source tested and approved by the South Coast Air Quality Management District for a formulation that includes an additive for NOx reduction. B100 has been the only fuel serving the seven standby generators totaling 1,765 kW. St. Mary's main supplier is Supreme Oil, which receives its biodiesel from World Energy of Boston, Massachusetts.[32]

- **Alameda Power and Telecom, Alameda, CA.**
  In 2002, Alameda Power and Telecom announced the purchase of four previously leased emergency power generators of 1.5 MW each. The utility said it planned to use B20 fuel as well as low-sulfur diesel fuel to run the backup generators. YCI unsuccessfully attempted to contact Alameda Power and Telecom to determine the utility's experience to date.33

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[31] National Biodiesel Board, "Tax Incentive Fact Sheet," http://www.biodiesel.org/members/membersonly/files/pdf/fedreg/20041022_Tax_Incentive_Fact_Sheet.pdf

[32] Cox, John W., "Biodiesel Suddenly Hot Stuff." *Press Telegram* (Long Beach, CA), June 25, 2001. http://www.rxp.com/Press_Telegraph.htm. Accessed January 11, 2005.

[33] Alameda Power and Telecom Press Release, "Alameda Power and Telecom Switches to Biodiesel for Power Generators." http://www.alamedapt.com/newsroom/pressreleases/pr_20020711.html. Accessed December 21, 2004.

- **Blooming Prairie Public Utilities, MN.**
  Since 2001, a blend of 2% to 5% biodiesel has been used by Blooming Prairie Public Utilities in Minnesota to operate a 2 MW and another 1.2 MW generator when needed by the Southern Minnesota Municipal Power Agency. The agency is comprised of 18 municipal utilities of which 13 operate generators upon request. The units total 190 MW and typically run 300-400 hours per year for peak load and unplanned outage conditions.

- **McMinnville Electric System, McMinnville, TN.**
  In September 2004, the McMinnville Electric System received over $980,000 in funding from the US Department of Energy to become the first municipal utility to demonstrate the use of B100 biodiesel in a fuel diesel generator in a grid-connected service. Tests will be conducted at McMinnville Electric System's existing diesel generator installation, using a single 2MW Diesel generator for the tests. The selected engine will be retrofit with EmeraChem's SCONOx technology, which absorbs NOx and other pollutants in the exhaust stream.

<u>Recommendations for Next Steps</u>

- **Contact GE to Discuss Gas Turbine Warranty**
  One of the most important next steps for the University to take in integrating biodiesel into its fuel mix is to contact GE, the manufacturer of the gas turbine, to ensure the company will ensure its parts and workmanship if biodiesel is used. Often, as in the case with Yale, the engine or turbine manufacturer defines the fuel that should be used in order to guarantee parts and service under the warranty and/ or service contract. Manufacturers could have the following concerns about the use of biodiesel fuel:

    - Quality specifications may not be adequate
    - Lack of stability requirement in quality specifications
    - Lack of a quality specification for biodiesel blends
    - Need for long-term durability data
    - Compatibility with 2007+ emission control systems[34]

- While according to the National Biodiesel Board, “most major engine companies have stated formally that the use of blends up to B20 will not void their parts and workmanship warranties,”[35] this is not yet the case for power generation facilities, especially gas turbines. Thus, Yale should contact GE to discuss options with regard to use of biodiesel fuels.

- **Contact National Biodiesel Board and Referenced Contacts to Assess Costs and Logistics Involved with Boiler and Gas Turbine Conversions**

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[34] McCormick, Bob. “Effect of Biodiesel on Pollutant Emissions.” National Renewable Energy Laboratories (NREL). Presented at 10th Annual Clean Cities Conference, May 3, 2004. http://www.eere.energy.gov/cleancities/conference/2004/pdfs/mccormick_nrel.pdf. Accessed January 12, 2005.

[35] National Biodiesel Board, “Standards and Warranties,” http://www.biodiesel.org/resources/fuelfactsheets/standards_and_warranties.shtm. Accessed February 2, 2005.

- Another important step is assessing the capital costs associated with using biodiesel in the boilers and gas turbine. In the case of the gas turbine, there remain outstanding questions regarding the amount of conversion would be required to accommodate biodiesel fuel. Thus, in order to get an accurate cost estimate for using biodiesel in Yale's Central Power Plant gas turbine, YCI recommends consulting with representatives at the National Biodiesel Board as well as of the contacts made through this research.

- **Explore Potential Study with Other Universities, DOE, or National Biodiesel Board** When speaking to Mr. Kelly Strebig, a research engineer at the University of Minnesota's Center for Diesel Research, he could not point to a number of studies of conversion to biodiesel at the size (2MW - 15 MW) Yale is considering. However, he did note that there are many studies planned for 2005 and invited Yale to join. Further cooperation should be conducted to explore the potential options for the conversion of Central's gas turbine.

Future Mitigation options

Beyond these phase-specific recommendations, several general institutional recommendations emerge for GHG mitigation in buildings:

- Consider creating a University-wide program aimed at sustainable or "green" buildings. Harvard has established a Sustainable Buildings Program to develop a database of products and service providers and green building specifications, and to disseminate information on and document efforts related to green buildings.[36]
- Exchange information on building energy intensity, consumption, and costs with peer universities, including Harvard and other Ivy League schools. Stanford engages in this type of information exchange with other California universities.
- Examine the features of pilot green buildings at other universities. The Lewis Center at Oberlin College and the C.K. Choi building at the University of British Columbia are commonly cited as leading examples of new green buildings.
- Consider holding a "Green Building Summit." Stanford's 2001 summit on this topic helped to coordinate activities across the university.[37]
- Clarify the accounting of building-related construction, renovation, and energy consumption expenditures in University financial reports. Yale's FY02 expenditure of $300 million on renovations was provided in a general description of the 2001-2002 financial report, but it is unclear where these expenses are actually treated in the statement of activities.[38] Activities of this size might merit their own entry.
- Conduct life-cycle assessments (LCA) and other studies of university buildings. Researchers at the University of Michigan have conducted a case study LCA of a six-story building, as a starting point for modeling energy and material requirements of new buildings.[39] This study concludes that usage dominates the life-cycle energy costs of

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[36] Harvard Green Campus Initiative, "HPRE Sustainable Buildings Program," www.greencampus.harvard.edu/programs/HPRE, viewed 11 November 2003.

[37] Chang, p. 69.

[38] Yale University, Yale University Financial Report 2001-2002, p. 29.

[39] C. Scheuer, G.A. Keoleian, and P. Reppe, "Life Cycle and Environmental Performance of a New University Building: Modeling Challenges and Design Implications," Energy and Buildings 35 (2003) 1049-1064.

buildings, pointing to the high importance of upfront design to minimize energy use. Engineering faculty at Perugia University in Italy have constructed a sophisticated "energetic diagnosis" of the entire university, using guidelines for conducting energy audits in public buildings.[40]

- Consider bringing in outside energy auditors and/or ESCOs to assess overall building mitigation potential.

Yale Inventory Website and the Future of the Yale GHG Inventory

Yale Climate Initiative Web Site

Kate Zyla has developed an attractive website to house the GHG inventory conducted by YCI. This website features a summary of the main findings of the inventory, an outline of the methodology, and the possibility to download the inventory report. The website is currently located at http://www.xylophone.net/yci/. We have approval to house this site on Yale's server, and it will soon be moved to its permanent home there.

Future Recommendations for Yale GHG Inventory

It is important that Yale update its inventory on a regular basis—it is the only way to determine accurately if progress is being made on reducing greenhouse gas emissions. However, for ease and reproducibility it might be better in future inventories to employ an existing inventory protocol. While the protocol created for the existing inventory includes a wider and more comprehensive range of emissions sources than most inventories, there is a tradeoff to be made between comprehensiveness and being able to get the job done. We would recommend the use of an existing program, such as the EPA's State Inventory Tool, the World Resources Institute's protocol, or the campus inventory tool provided by Clean Air-Cool Planet.

In addition, it would be advantageous to find a permanent home for the inventory, to institutionalize it. It is excellent to have student involvement in the GHG inventory, and provides and unparalleled learning experience. However, student turnover and short institutional memory make leaving it entirely in the hands of students inadvisable. Since the Sustainability Director is in the process of coordinating new activity and groups interested in climate change and energy on campus, we recommend that YCI continue working with her to find an appropriate place to house the inventory.

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[40] L. Barelli and G. Bidini, "Development of an Energetic Diagnosis Method for the Buildings: Example of Perugina University," Energy and Buildings, in press, 2003.

Appendix A—Contact Information

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Appendix B—Scoring of Mitigation Options

Timeframe	Reduction measure	Size of source	Control	Cost	Reduction potential	Feasibility	Score
Short	Have each dept pay own energy bill	3	3	3	2	3	2.8
	Replace lighting (building retrofit)	3	3	3	2	3	2.8
	Incorporate biodiesel into fuel mix of power generation facilities (boilers)	3	3	2	3	3	2.8
	Occupancy sensors (building retrofit)	3	3	2	2	3	2.6
	Energy efficient computers/equipment	3	3	3	1	3	2.6
	Minimize energy intensity of existing wet labs (In progress)	3	3	2	2	2	2.4
	Adopt LEED for building renovations and new buildings (In progress)	3	3	2	1	3	2.4
	Implement intercollege energy use competition	3	2	3	2	2	2.4
	Switch primary fuels (natural gas)	3	3	1	2	3	2.4
	Educate employee drivers	1	3	3	1	3	2.2
	Consider fuel costs in vehicle purchasing decisions	1	3	3	1	3	2.2
	Install organic material traps at cafeterias	1	3	3	1	3	2.2
	Ensure contractors test for chiller leaks	1	3	3	1	3	2.2
	Promote energy efficient products at Yale stores	3	1	3	1	3	2.2
	Provide GHG info to people booking travel	1	2	3	1	3	2
	Tax breaks for use of public transportation	1	2	3	1	3	2
	Buy GHG offsets	NA	2	3	1	2	2
	Invest in RECs	NA	3	1	1	3	2
	More car-sharing	1	1	3	1	3	1.8
	Charge parking by vehicle type	1	3	3	1	1	1.8
Medium	Incorporate biodiesel into fuel mix of power generation facilities (turbines)	3	3	2	3	2	2.6
	Energy efficient HVAC (building retrofit)	3	3	2	2	3	2.6
	Identify and reduce transmission losses	3	3	1	2	3	2.4
	Energy efficient design for new buildings	3	3	1	2	3	2.4
	Install meters in individual dorm rooms and bill	3	3	2	2	1	2.2
	Leakage monitoring program	1	3	2	1	3	2
	Purchase low GWP refrigerants	1	3	2	1	3	2
	Improve recycling on campus	1	2	3	1	3	2
	Explore wind energy potential on Yale lands	NA	3	2	2	1	2
	Combine construction and operations and energy cost budgets	3	2	2	1	1	1.8
	Fuel efficiency of power plant	3	3	1	1	1	1.8
	Encourage use of landfill gas for energy production	1	1	3	1	1	1.4
	Separate waste streams for more efficient combustion	1	2	1	1	1	1.2
Long	Window replacement (building retrofit)	3	3	2	3	3	2.8
	Insulation (building retrofit)	3	3	2	3	3	2.8
	Replace fume hoods	3	3	1	3	3	2.6
	Encourage forest mgmt practices that maximize sequestration	1	3	2	1	2	1.8
	Distributed generation (Solar PV)	3	3	1	1	1	1.8

Appendix C—Biodiesel Cost-Benefit Analysis

Central Power Plant - Cost Comparison of Biodiesel Blends and No. 2 Fuel Oil

*Biodiesel blends are biodiesel and No. 2 fuel oil

Fuel	Cost Per Gallon	BTUs	Gallons Required	Total Cost
No. 2 Fuel Oil	**$1.40**	**138,000**		
Biodiesel	**$3.00**	**120,000**		
B5	$ 1.48	137,100	1,094,456.66	**$1,619,795.86**
B20	$ 1.72	134,400	1,122,547.65	**$1,930,781.96**
B100	$ 3.00	120,000	1,272,366	**$3,817,098.75**
	$2.50			
B5	$ 1.46	137,100	1,094,456.66	**$1,592,434.44**
B20	$ 1.62	134,400	1,122,547.65	**$1,818,527.19**
B100	$ 2.50	120,000	1,272,366	**$3,180,915.63**
	$2.00			
B5	$ 1.43	137,100	1,094,456.66	**$1,565,073.03**
B20	$ 1.52	134,400	1,122,547.65	**$1,706,272.43**
B100	$ 2.00	120,000	1,272,366	**$2,544,732.50**
	$1.50			
B5	$ 1.41	137,100	1,094,456.66	**$1,537,711.61**
B20	$ 1.42	134,400	1,122,547.65	**$1,594,017.66**
B100	$ 1.50	120,000	1,272,366	**$1,908,549.38**

Fuel	Cost Per Gallon	BTUs	Gallons Required	Total Cost
No. 2 Fuel Oil	**$1.00**	**138,000**		
Biodiesel	**$3.00**	**120,000**		
B5	$ 1.10	137,100	1,094,456.66	**$1,203,902.33**
B20	$ 1.40	134,400	1,122,547.65	**$1,571,566.71**
B100	$ 3.00	120,000	1,272,366	**$3,817,098.75**
	$2.50			
B5	$ 1.08	137,100	1,094,456.66	**$1,176,540.91**
B20	$ 1.30	134,400	1,122,547.65	**$1,459,311.95**
B100	$ 2.50	120,000	1,272,366	**$3,180,915.63**
	$2.00			
B5	$ 1.05	137,100	1,094,456.66	**$1,149,179.50**
B20	$ 1.20	134,400	1,122,547.65	**$1,347,057.18**
B100	$ 2.00	120,000	1,272,366	**$2,544,732.50**
	$1.50			
B5	$ 1.03	137,100	1,094,456.66	**$1,121,818.08**
B20	$ 1.10	134,400	1,122,547.65	**$1,234,802.42**
B100	$ 1.50	120,000	1,272,366	**$1,908,549.38**

Fuel	Cost Per Gallon	BTUs	Gallons Required	Total Cost
No. 2 Fuel Oil	**$2.00**	**138,000**		
Biodiesel	**$3.00**	**120,000**		
B5	$ 2.05	137,100	1,094,456.66	**$2,243,636.16**
B20	$ 2.20	134,400	1,122,547.65	**$2,469,604.83**
B100	$ 3.00	120,000	1,272,366	**$3,817,098.75**
	$2.50			
B5	$ 2.03	137,100	1,094,456.66	**$2,216,274.74**
B20	$ 2.10	134,400	1,122,547.65	**$2,357,350.07**
B100	$ 2.50	120,000	1,272,366	**$3,180,915.63**
	$2.00			
B5	$ 2.00	137,100	1,094,456.66	**$2,188,913.33**
B20	$ 2.00	134,400	1,122,547.65	**$2,245,095.30**
B100	$ 2.00	120,000	1,272,366	**$2,544,732.50**
	$1.50			
B5	$ 1.98	137,100	1,094,456.66	**$2,161,551.91**
B20	$ 1.90	134,400	1,122,547.65	**$2,132,840.54**
B100	$ 1.50	120,000	1,272,366	**$1,908,549.38**