2009

Our Big Green Future: Steps

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27 May 2009

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Chapter 1: Introduction and Summary

I. Our Proposal for Dartmouth College

In the coming decades Dartmouth College will have to face the dual crises of global warming and peak oil. There is one solution for protecting ourselves from both: weaning our institution off of fossil fuels as quickly as possible. Dartmouth has a long history of leadership in issues pertaining to sustainability; we constructed one of the first campus cogeneration plants, we started one of the first Environmental Studies departments in the country, and we are perennially cited as one of the greenest institutions in the College Sustainability Report Card. In light of this tradition, we applaud the strong beginning Dartmouth has made in committing to reduce CO_2 emissions by 30% from 2005 levels by 2030 (without resorting to the purchase of largely unverified offsets as other leading institutions are doing). However, we believe that Dartmouth can and should do better. Climate experts say that we in the developed world should really be aiming for carbon neutrality if we wish to keep atmospheric carbon from reaching a catastrophic level. With this proposal we aim to provide a plan for reducing Dartmouth's carbon footprint with the ultimate goal of carbon neutrality by 2050.

II. Background on Climate Change and Carbon Neutrality

1. What is carbon neutrality?

Jim Merkel, Dartmouth's former Sustainability Coordinator, said: "Carbon neutrality is defined as having a net of zero carbon dioxide equivalents (CDE), which include carbon dioxide, methane, nitrous oxide, and in very few cases, other greenhouse gases like fluorocarbons and sulfur hexafluoride." Carbon neutrality is such an important goal because scientists have confirmed that anthropogenic sources of greenhouse gases are the cause of global warming. We recognize that true carbon neutrality may currently be a near impossible goal without the use of carbon offsets, an option that we strongly advise against using. Although this limitation exists, carbon neutrality by 2050 may require the purchase of offsets. With that said, we believe that both technological and fiscal developments in the future can augment the reduction of purchased offsets in order to achieve carbon neutrality by 2050.

2. Why should we be concerned about Climate Change?

The International Panel on Climate Change (IPCC) is a "scientific intergovernmental body" created by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP). The IPCC is charged with objectively assessing the latest research on climate change, and they have determined with "very high confidence" that the warming experienced over the past few hundred years is due in large part to human activity. The negative impacts of climate change primarily include:

- Rising sea levels
- Rapid glacial melt
- Disruption of natural ecosystems
- Disruption of agriculture

- Loss of freshwater resources/Drought
- Storm intensification
- Risk of heat wave

For a deep scientific review of how anthropogenic carbon dioxide emissions have caused each of these events, we refer you to the 2007 IPCC Synthesis Report.

According to the Department of Energy (DOE), the United States is responsible for 21.7% of the world's energy use, though we account for less than 5% of the world's population. Of the United States' total energy load, buildings account for 33%. It is for this reason that this report focuses heavily on reducing the energy load of Dartmouth College buildings.

Scientists say that, in order to avoid catastrophic impacts of climate change, global carbon emissions need to be reduced 80% by 2050. This is why we believe that, while President Wright's commitment to 30% by 2030 is a good start, we need to do more. Dartmouth has a responsibility to seek carbon neutrality not only as an institution in the developed world, but also as an institution of higher education and research.

3. Peer Institutions Seeking a reduced Carbon Footprint:

Our peer institutions have already begun making significant strides toward carbon neutrality. Yale is installing small wind turbines and solar panels, has built several LEED gold certified buildings, and is committed to a GHG emissions reduction of 43% below 2005 levels by 2020. Harvard has committed to a minimum LEED silver certification, and an emission reduction of 30% below 2006 levels by 2016.

Several hundred colleges and universities have already signed the President's Climate Commitment and, in doing so, have pledged to move their institution toward carbon neutrality. Cornell University became the first in the Ivy League to sign in 2007; other northeast peer institution signatories include Middlebury, Colby, and Bowdoin. The President's Climate Commitment states: "The fight against global warming will shape the 21st century. Colleges and universities must exercise leadership in their communities and throughout society by modeling ways to eliminate global warming emissions."

III. Our Recommendations:

We recommend taking a multi-phase approach in order to achieve carbon neutrality by 2050. The first phase tackles the energy demand on campus, whereas the second phase looks at ways to produce energy in lieu of burning heating oil at the central heating plant, as is currently practiced. Each phase contains several different ways of achieving carbon reductions, and outlines detailed recommendations for the best mix of methods.

Phase one has three components. The first is writing guidelines for sustainability and energy efficiency of all new construction. The second component is replacing existing lighting with LED light bulbs, and the third is improving insulation. This includes windows as well as using heat recovery technology.

The second phase, which looks at the supply side of carbon emissions at Dartmouth, begins by implementing technologies that do not replace the power plant, but can begin to reduce emissions. These four technologies include solar hot water (on the power plant and Sustainable Living Center), photovoltaic cells (on Leverone, Thompson Arena, and Alumni Gym), shallow geothermal wells, and replacement of #6 heating oil with waste vegetable oil and biomass. The second part focuses on technologies that could continue to reduce the demand on the power plant. These technologies include sewage heat recovery and deep geothermal. As these technologies are evolving rapidly and the costs are changing quickly, we suggest the college monitor how best they can be applied on campus. In order to satisfy the energy needs of the campus, a future energy mix must include these technologies. In the future, we recommend that all buildings become zero net energy buildings, and that the College continue to evaluation carbon capture and storage technologies.

These two phases, though distinct, should occur simultaneously. In order to carry out this work, we have outlined which classes and organizations could be charged with implementing parts of our plan. Marketing this carbon neutrality plan is a key component of its success, and we have come up with marketing strategies for several different populations.

This plan is an important step forward for Dartmouth College, and a necessary one. It needs to be approached with a combination of careful planning and bold implementation. We believe that this document achieves these dual goals.

To summarize these recommendations here is a general layout of our strategy:

- Expand current conservation efforts by investing in education programs similar to GreenLite for all members of the Dartmouth community
- Accelerate implementation of energy efficiency measures for the 20 buildings that use 75% of energy on campus
- Undertake audit and act on recommendations for remaining buildings based on metering
- Adopt energy efficiency standards for all renovations and new building projects that take into account how these new buildings will be maintained
- Focus projects on buildings whose carbon footprints can be reduced substantially
- Develop a campus space plan with reduced occupancy space goals for staff, students, and faculty and apply this to any retrofits and new construction
- Convert existing loan program into revolving loan fund and provide necessary staffing to support implementation
- Convert the combustion of No. 6 oil at the heating plant to other fuels as well as reducing the amount of fuel oil burned
- Monitor the development of technologies that may further reduce and replace the need to burn controversial fuel oil

Chapter 2: Phases

I. Phase 1, Part 1: Reducing Load

Introduction

Phase 1 aims to reduce the energy load at Dartmouth. This approach cuts carbon emissions by reducing the amount of energy required for everyday operations, therefore reducing the amount of fossil fuels burned. Phase 1does not focus on changing the fuel type at Dartmouth.

Decreasing load is one of the easiest ways to reduce greenhouse gas (GHG) emissions without making infrastructure changes on the scale of replacing the heating plant. Investment in newer technologies, such as photovoltaic cells or solar hot water, becomes less volatile when each is responsible for less and less energy production (Merkel). Purchasing offsets to achieve complete carbon neutrality, or even carbon negativity (Dorsey), is more plausible when those offsets are responsible for the least possible amount of GHG emissions (Merkel).

There are many ways to reduce Dartmouth's energy demand. Among them are changing end user habits, improving boiler and steam tunnel efficiency, and implementing retrofits and renovations. Phase 1 will focus on possibilities for retrofitting and renovating by specifically discussing recent Dartmouth retrofits, LED lighting, heat recovery systems, new construction guidelines, and transportation.

A summary of the load reduction recommendations includes the following:

- Goals and systems must to be established for energy-efficient, cost-effective, environmentally conscious buildings and maintenance of these buildings
- Conservation through education and behavioral changes that apply to the entire campus population
- Conservation through transportation modifications

1. Dartmouth College Strategic Energy Conservation Plan: Summary

Prior to our report, Dartmouth had begun to take steps towards reducing our energy load. In February 2008, Dartmouth College's Facilities Operations and Management outlined a Strategic Energy Conservation Plan. The report included recommendations, finances, and a payback period. Below is a summary of the FO&M report:

1.1 Report Recommendations

- Reduce Outdoor Air Load
  - Steps to reduce this load would include repairing, recalibrating, or replacing sensors on existing equipment, installation of demand and/or occupancy sensors, repair/replace antiquated equipment.
- Eliminate Conflicting Practices
  - In many cases, the infrastructure for efficiency exists but is negated by conflicting practices. The example used is conflicting Steele Laboratory airflow monitors that eliminate possible reductions in airflow during off-peak or low-demand times.

- Optimize BMS Control Strategies
  - By optimizing Building Management Systems (BMS) to reflect demand would greatly improve system efficiency.
- Reduce System Operational Run Times
  - A number of systems can be found running when they could be completely shut down. A comprehensive strategy to eliminate this waste is required.
- Recover Heat from Lab Exhausts
  - Technology exists to recover heat from lab exhausts. Currently only Cummings has limited heat recovery. Burke and Vail both vent 100% lab exhausts with no heat recovery technologies.
- Reduce Steam Piping Losses
  - By insulating steam piping, heat losses to poorly or non-insulated pipes can be eliminated relatively inexpensively.
- Shut Off Unused Steam Lines & Equipment for Summer
  - With drastically reduced heating demands, many systems can be shut down during the summer months, reducing standby energy demands, for no cost.
- Shut Off Unused Process Equipment When Not Needed
  - By utilizing either automated or manual controls of process equipment like café toasters, waste could be easily eliminated.
- Install High-performance Glazing
  - Many buildings (including the Hopkins Center) have single pane, non-glazed windows that are both a safety hazard as well as an energy and savings hog. Installation of high-performance glazing will provide consistent savings.
- Install Daylighting Controls
  - There exist a number of examples of use of lighting despite the availability of sufficient daylighting. (See Berry Library Main Corridor). By installing daylighting controls, significant savings can be found for little or no cost.
- Install Programmable Lighting
  - Installation of occupancy or timed lighting switches would greatly reduce the cost of lighting unoccupied spaces or spaces with only little demand (Library Stacks).
- Perform Retrocommisioning of Energy-Intensive Buildings
  - "Experience indicates that substantial savings will be realized by implementing a recurring retrocommissioning program." (Strat. Energy Plan Highlights, 8)
- Institute Trap Maintenance Program
  - A steam trap maintenance program for the entire campus would significantly improve leak detections, adding to the overall efficiency of the steam system (Strategic Energy Plan Highlights, 5-8).

1.2 Finances and Payback

Implementation Costs: $10.5 million

Savings: $2.2 million/year

Payback: 4.8 years

The study concludes that in order to meet future steam demands, Dartmouth must both acquire a new boiler (currently being installed) and pursue a program of conservation and efficiency improvements. Neither course of action alone will provide future energy security (Strategic Energy Plan Highlights, 15).

While the FO&M recommendations are a step in the right direction, they are not stringent enough to ensure carbon neutrality by 2050. Phase 1 will continue to address issues of reducing energy load, but through more drastic and widespread measures.

2. Retrofits and Renovations

2.1 Background Information

After meeting with Steve Campbell, Director of Dartmouth's Office of Planning, Design and Construction (OPDC), we were able to learn of their in-house energy-efficiency strategies. The OPDC is in charge of Dartmouth's capital projects, which include new buildings and renovations. According to Campbell, sustainable methods are always taken into account in the creation or renovation of a campus building, and inherent in their architectural design processes. When focusing on a renovation, the OPDC works on buildings that use the largest energy loads, because fixing them would bring forth the largest financial return. This financial theme is prevalent in the OPDC, whose methodology is controlled by financial constraints of the Board of Trustees.

Sustainability, in general, should be inherent in the design of capital projects. But renovations do not always provide beneficial results. In addition, there have been issues with the application of new technologies in renewable energy systems, such as Fahey-McLane Cluster's geothermal wells, which are not working as well as project managers had hoped. Despite these setbacks, however, experimental projects in the latest green energy sources should be encouraged and supported.

Because energy-efficiency projects are more expensive to install in existing buildings, the OPDC appropriately directs their efforts on new construction. Full-scale renovations, like Hitchcock and New Hampshire Halls, are currently out of question because there are no more funds in the Office of Residential Life to support project of such a scale.

2.2 Retrofitting Existing Buildings

In October 2008, President James Wright formally announced the college's commitment to lowering its greenhouse gas emissions (Knapp 2008). The 2008 commitment came from the recommendations of the Energy Task Force. As mentioned before, the College pledges to reduce its carbon emissions by 30 percent by 2030, by investing $12.5 million dollars in energy-saving upgrades in existing buildings. After auditing the 25 percent of buildings which collectively use 70 percent of the campus' energy, Shadford found many areas for potential energy efficiency projects. Of these, the areas listed on Dartmouth's Sustainability Initiative website are: (1) lighting, (2) heating, cooling and ventilation, (3) building envelopes, (4) water, (5) energy metering and management and (6) renewable energy (Knapp 2008).

After meeting with Shadford, we became clear on FO&M's current energy efficiency strategies. The priorities for the $12.5 million investment lie in big payback items, for example the implementation of a heat recovery system in the Burke Chemistry building. The financial payback is crucial, which is why Shadford audited the buildings that consume the most energy. Other investments under this category include the use of smart system energy metering technologies and optimization of software control strategies. Shadford also identified several issues that might hamper improvements in energy use.

2.2a Energy Metering

Shadford's current push includes the application of a smart energy metering system, which uses live weather forecast data to predict building energy use patterns. Shadford also broke down the metering objectives into other categories, including fixing the energy billing method and automating the building meters across campus. He believes improving this aspect of Dartmouth's infrastructure will be extremely beneficial for sustainability efforts. Next, the Green Lite program (by Professor Lorie Loeb)—real time energy usage displayed by a polar bear on the wall—is a successful method of energy metering transparency. Students have responded well; the energy use in the dormitories has been reduced. Conservation will be an integral part in energy-efficiency retrofits, but it can be leveraged with transparency and community involvement.

2.2b Lighting

Shadford is working with students and outside consultants to examine the compact fluorescents and LED lighting—a recently introduced technology—will be implemented at many locations around campus and greatly reduce lighting energy use on campus. Further innovative lighting solutions include a lighting efficiency project in the West Gym. Shadford worked with an outside consultant to design a system that would use occupancy sensors that allow for different light use in different parts of the gym. Currently, the gym's lighting stays on all day and night, because of the time needed to warm the lights up. The new system would (1) replace the lights with high efficiency fluorescents, and (2) install a grid-system to manage lighting levels and zoning. The system would have three different levels of lighting: low, normal, and high. Different configurations of lighting can be chosen by a touch screen on the wall; you can have half the court lit, or just a quarter, depending on the actual need. If successful this project can be applied to many venues on campus, such as Leverone Field House, Leede Arena, and Thompson Arena.

2.2c Building Envelope

Improving the energy efficiency of campus buildings is one of the most important steps in reaching carbon neutrality. Buildings are part of our infrastructure, and by nature, will be used for many years to come, thereby continuing to emit greenhouses gases such as carbon dioxide (Strategic Energy Conservation). They are inefficient in their use of energy, and are not easily or inexpensively replaced. Retrofitting and specific renovations are the best ways to improve efficiency.

Insulation and window technology will be integral in energy retrofits. Shadford just completed a walkthrough of the Hopkins Center with another outside consultant, to discuss different strategies for the building. Windows will be a large category; using double or triple-glazing on the windows will increase the efficiency of a building's envelope considerably. The large single-pane windows in front of the Hopkins Center are of main concern. Full-scale insulation retrofits would be more challenging as they are much more easily accomplished when renovating an entire building.

2.2d Issues

Shadford identified two issues that can hamper energy-efficiency retrofits: maintenance and reliability, and cooperation by building occupants. Even if beneficial to the college, a system is inefficient if it needs to be fixed all the time; the system needs to be reliable. This poses a problem for experimental and cutting edge green technologies, which, because they are new, may not be as reliable as an older, tried-and-true technology. Next, building accessibility has hampered some of Shadford's work. The West Gym lighting project, for example, will be delayed until the Athletic Department can find time to fit it into their usage schedules. Also, there is a need for additional staff support and a greater focus on the Sustainability Office as well as prioritizing sustainability issues within other building offices.

3. LED Lighting

3.1 Background Information

The United States Department of Energy has "made a long-term commitment to advance the development and market introduction of energy-efficient white-light sources for general illumination" (U.S. Department of Energy: Solid-State Lighting 2008). Through this commitment, LED technology has vastly improved in the last ten years. Advances in material sciences have enabled LEDs to produce light in a variety of colors, including white and warm white that appeals to the human eye (Shadford 2009).

Demand for LEDs for all types of applications increased 9.5% in 2007, reaching revenues of $4.6 billion. LEDs used for illumination purposes account for 37% of total usage, falling second to mobile applications by only 2% (Anderson 2008: 28). In 2007, the LED lighting market was worth $330 million, "a 60% increase from 2006, and is projected to grow to $1.4 billion by 2012" (Anderson 2008: 28). LED technology is widely dispersed throughout the world and applicable in many different technological sectors. LED lights are presently used for many different purposes, including traffic lights and signals, street lights, exit signs, LCD televisions, cell phone screens, and even to illuminate landmarks, like Buckingham Palace and the Severn Bridge (Engineering and Physical Sciences Research Council 2009).

3.2 Benefits

Because of the unique technology of LEDs, they are extremely energy efficient. The greatest potential for "large energy savings involves high-brightness white-light LEDs" for commercial use (Allan 2009: 31). Current LED light bulbs can meet or exceed the efficiency of compact fluorescent lamps. These statistics are only increasing, in favor of LEDs, as the materials and technology continue to improve (Shadford 2009). LEDs are able to turn 20-50% of input energy into light (American Institute of Physics 2009). Gallium Nitride LEDs can burn 30-

50,000 hours, which means they are replaced less often and fewer light bulbs end up in our landfills (U.S. Department of Energy 2008). Gallium Nitride LEDs also do not contain mercury or other hazardous materials typically used in fluorescent and compact fluorescent lighting (Engineering and Physical Sciences Research Council 2009).

Changing old lights to LED fixtures not only contributes to huge savings in energy, but also decreases "the overall light pollution caused by lighting…if employed in higher power, white-light applications" (DeNicholas 2009: 37). Lighting tends to be one of the most wasteful contributors to global warming. Most streetlights cannot turn off because of their long re-strike times. However, LED lights can easily turn on and off to account for high and low usage times, therefore polluting less light (DeNicholas 2009: 37). It is estimated that "19% of worldwide electricity goes toward lighting and that LEDs can help reduce light energy consumption by 30%" (Allan 2009: 37). There are clear efficiency and environmental advantages to using LED lights as an alternative.

3.5 Costs

The overall costs of LED devices have dramatically decreased in the last ten years, as the technology continues to improve. In 2001, the cost of a white light LED device was more than $200 per kilo-lumens. In 2007, average prices dropped to around $30 per kilo-lumens (U.S. Department of Energy 2008). Prices of LED fixtures range depending on the level of watt output. Additionally, consumers need to consider installation costs of LED-compatible light fixtures. Some LED light projects require complete replacement of lighting fixtures, in order to support LED light bulbs. Other companies produce LED light bulbs that are compatible with older sockets and their installation can be as simple as changing the light bulb.

3.6 LEDs on the Dartmouth Campus

Stephen Shadford, Dartmouth College's FO&M energy engineer, has done significant work on promoting the implementation of LEDs, for certain areas with considerably long burn hours. Shadford has established a successful working relationship with a South Korean company, called Fawoo, that exports LED fixtures, in all shapes and size. Because of Fawoo's dependable products and reasonable prices, Shadford has begun switching out old light bulbs and replacing them with LED light bulbs. He recently retrofitted eight light bulbs in McNutt, the Undergraduate Admissions Office, where "we want to make a statement…I felt that it was important that parents and prospective students visiting Dartmouth for the first time should not be staring up at the ceiling and seeing energy inefficient incandescent lamps. Not a great sign for a campus that is supposed to be 'green'" (Shadford 2009). He replaced 75-watt light bulbs with 8-watt LED light bulbs. These retrofits did not need replacement fixtures because the LED light bulbs are designed to screw into existing equipment. This type of project is extremely cost-effective in certain buildings that represent the large share of campus electricity usage. While McNutt is not one of the heavy electricity sinks, it makes a statement for the College, as to its commitment to sustainability and carbon neutrality. LED lights are also used in the north colonnade walkway outside Berry Library, Kemeny and Haldeman, and the Blunt Alumni Center. All of these projects have less than a four-year payback period.

Stephen Campbell, Director of Dartmouth's Office of Planning, Design, and Construction, also praised the use of LED lights on campus. He explained that LEDs have become more feasible for campus use within the last year, as costs have significantly decreased. As LEDs become more proficient in generating colored light, we will begin to see an increase in campus use. The lighting consultants that work with OPDC have suggested LED lights for interior and exterior use in future buildings and retrofits. Specifically, he mentioned that LED lights will be used for the upcoming renovation of the President's House, on Webster Avenue (Campbell 2009).

Campbell also commented on choice between writing an LED lighting policy, as the standard for future buildings, or using LEDs an alternative light source for retrofits. He believes that is not an either-or question. We should work from both angles and utilize LEDs in the most efficient and cost-effective ways. If LED lighting is taken into consideration in the design phase, buildings can reap the benefits of downsizing branch panels and wiring for lights (Campbell 2009).

3.7 Future LED Projects

Shadford also discussed the potential for large-scale LED usage in the main exhibition hall in Baker Library. He ran the numbers, as an example of the quick payback period and enormous energy and money savings. The current incandescent fixtures in Baker's exhibition hall are 450-watt lights and could be replaced with Kawoo's 72-watt LED lamps. Each lamp would save 378 watts per lamp, which is an 84% reduction in wattage usage per lamp. Because these lights are on 126 hours per week, 52 weeks per year, they would annually run for 6,552 hours. In just one year and in just one hallway, Dartmouth would save 59,440 kWH and $7,787 in energy bills. The kWH savings translates into about 32 metric tons of CO_2 saved per year. The project would cost around $10,800, which translates into a 1.4 years payback period (See Figure 2 for exact numbers). This is just one example of the dramatic energy reductions from retrofitting high electricity usage areas at Dartmouth.

Another retrofit option would be to replace commonly used light bulbs in buildings on campus. For example, 75-watt incandescent light bulbs are commonly used in campus classrooms, buildings, and offices. These light bulbs can easily be replaced with Kawoo's 8-watt LED light bulbs. A hypothetical retrofit of 2,000 of these light bulbs on campus would cost $120,000, as each LED light bulb costs $60. Assuming annual run hours of 3120 per light bulb and electricity costs of $0.13 per kWH, the College would save $54,340 per year on electricity bills (Shadford 2009). This type of project would have a 2.2 years payback period. Additionally, the retrofit would save 418,000 kWH of electricity and about 224.5 metric tons of carbon annually. This is a 0.25% reduction from the 2007 MTCE. Small retrofit projects targeting different areas of the Dartmouth campus would contribute to overall electricity and carbon emission savings.

3.8 Conclusions

We must consider retrofitting lighting intensive buildings with LED lights and implementing a policy to use LED lights as the standard for future buildings. LED technology is only getting better, while the costs continue to decrease. Dartmouth has already begun employ LED lighting in certain buildings and each project has seen significant benefits with few costs. There is strong campus support for retrofitting existing buildings to improve efficiency, building new state-of-the-art low energy usage facilitates, and reducing Dartmouth's overall carbon footprint. LED lighting is a viable long-term solution to push Dartmouth forward towards carbon neutrality.

4. Heat Recovery Systems

4.1 Background Information

At Dartmouth, buildings such as the Burke Chemistry building, Gilman Life Sciences, Vail (Medical School), Moore Psychology, and Cummings (Engineering School) rank among the most energy-intensive buildings at Dartmouth (Strategic Energy Conservation). For example, Burke uses 493,103 BTU/square foot, which is more energy per square foot than any other building on campus (Strategic Energy Conservation). As energy prices continue to rise, lab buildings also have the most potential for reducing the cost of energy to Dartmouth. Because toxic chemicals are routinely mixed in lab environments in the course of research experiments and for student instruction, the air inside must be continuously replaced, typically between 6 and 15 times each hour (Energy Recovery). Currently, the exhaust from between 50 – 100 individual fume hoods is expelled directly outside, and 100% outdoor air is then heated or cooled and introduced back into the labs (Shadford). A heat recovery system would capture the waste heat (or cooling) for use by the incoming air (Energy Efficiency).

The energy demand for this process is twofold: first, to run fans that remove air from labs and replace it with outside air, and second, to condition that air to the appropriate humidity and temperature (Energy Recovery). This process of heating, ventilating, and air conditioning, abbreviated as HVAC, accounts for 40 to 60 percent of energy used in U.S. buildings (U.S. Department of Energy), and presents huge opportunities to Dartmouth for reducing its energy demand.

The Energy Task Force has recommended that Dartmouth implement glycol run-around loop technology in its lab buildings, specifically Burke, which would recover heat from exhaust air and use less energy to heat and cool outside air (Strategic Energy Conservation). Among the many improvements recommended in the Burke Chemistry Building, the most aggressive would be to combine exhaust ductwork from individual lab hoods into one central exhaust system, install variable flow control devices for several large central exhaust fans, and install a glycol run-around heat recovery system (Strategic Energy Conservation).

4.2 Benefits

Aside from the financial benefits that arise from estimated dollars saved per year, many variable benefits exist. Since any reduction in energy cost continues indefinitely, even in light of volatile energy prices, the potential future savings to Dartmouth is exponential (Shadford). Especially in colder climates like New Hampshire where the heating season is long, heat recovery is a logical investment (Coil Loop).

Other benefits, such as health and safety improvements, lie outside monetary expenditures and savings. With the current system of individual fans responsible for individual exhaust hoods, if a belt in the motor slips off, the hood ceases to remove air and becomes an immediate hazard. If the exhaust hoods were combined to a common, central exhaust system, the other fans would increase their speed to accommodate for a faulty hood, and the system would still function safely (Shadford). Furthermore, installing a new exhaust system, such as the Axijet® High Plume Blower, would increase the system's exhaust capacity without adding additional fume hoods or significant ductwork. It would also dilute the exhaust plume more and expel it at a higher velocity, which are both important safety measures (Laboratory Exhaust).

With any energy-saving upgrade, public relations benefits also exist. Now that Dartmouth's current president has committed to reducing the College's emissions, abiding by that plan renders the commitment itself more solid and credible. If Dartmouth stays on track with its plan, it will undoubtedly use this credibility to lure prospective students and maintain alumni support.

4.3 Costs

Making accommodations for not shutting down Burke completely, such as erecting interim research facilities or renovating at a slower, less intrusive rate (a phased implementation), will raise costs. Also, costs will also be higher as unanticipated projects are upgraded or fixed in the course of making planned upgrades (Shadford).

4.4 Case Study: Burke Lab

For the Burke Chemistry building in particular, it is encouraging that a cost-benefit analysis has been fairly easy to procure, and lack of information will be the least daunting barrier to implementation. The Strategic Energy Conservation Plan found the following figures for this specific upgrade:

Total ECM Electrical Savings (KWH/Yr): 183,227 KWH/Year
Total ECM Electrical Savings ($): $24,003
Total ECM Thermal Savings (MMBTU/Yr) – site: 3,834
Total ECM Thermal Savings (MMBTU/Yr) – source: 5,112
Total ECM Thermal Savings ($): $48,735
Total ECM Savings Electricity & Thermal ($): $72,737
Estimated Construction Cost ($): $615,750
Simple Pay-back period (Years): 8.5

The above figures were calculated assuming a thermal rate of $1.43/gallon, an electrical rate of $0.13/kWh, an absorption cooling cost of $0.229/ton-hr, and a boiler transmission efficiency of 75%. This particular set of technologies is the most expensive proposed at Burke, and also has the longest payback period. However, in attempting to reduce Dartmouth's greenhouse gas emissions by 2030, the 8.5 year payback period becomes more of a short-term investment than a long-term cost (Strategic Energy Conservation).

4.5 Conclusions

In terms of potential variable costs, more research will need to be done into how much electricity costs will rise, if at all, for added fan power and to run the glycol pumps (Coil Loop).

The lifespan of the technology will also need to be determined. Finally, the maintenance needs, whether more or less than current systems, should be determined to further project variable costs.

The proposed changes above—namely, combining exhaust ductwork from individual lab hoods into one central exhaust system, installing variable flow control devices for each hood, and installing a glycol run-around heat recovery system—also have the longest simple payback period of any of the proposed changes in Burke. It is worth bundling these improvements with projects that have longer and shorter payback periods in order to diminish the magnitude of initial investments (Shadford).

Finally, though the economic downturn of late is circumstantial, it does provide unusual possibilities for investment in campus infrastructure. President Obama has authorized many federal programs for investments in infrastructure and energy efficiency. Because new construction has slowed, the price of building materials has dropped. Contracting and engineering firms are now having discounts on hiring contractors for construction work (Shadford). Even though the budget is tighter than ever, this may be the College's window of opportunity for investing in infrastructure.

5. LEED Certification

5.1 Background Information

One of the most significant aspects of energy demand at Dartmouth comes from the buildings on campus. Therefore, any attempt to reduce demand must take into account both future construction plans as well as renovations to historic buildings. Dartmouth considers itself a leader among its peer institutions, we recommend that the college create binding guidelines for new construction that adhere to a minimum Platinum certification under the Leadership in Energy and Environmental Design (LEED) system, as well as the continuation and expansion of the current policy that requires new buildings to perform within the top 5% of similar buildings in the United States. This step will ensure that any new building or renovation, through a variety of technologies and techniques, will require less energy to function, thereby bringing carbon neutrality within reach.

5.2 What is LEED?

The U.S. Green Building Council (USGBC) consists of a nonprofit coalition of building industry leaders that "promote design and construction practices that increase profitability while reducing the negative environmental impacts of buildings and improving occupant health and well-being" (usgbc.org). LEED is a globally recognized green building rating system that allows green industry leaders from different backgrounds to work collaboratively to evaluate and provide feedback on how sustainable an individual or institution is designing, operating, and constructing its buildings. Making LEED Platinum certification a requisite for new Dartmouth buildings would create a positive image of Dartmouth as not only a sustainability leader amongst its peers, but would furthermore contribute to the global community and appeal to prospective students, visitors, and environmentally minded investors. LEED Platinum certification currently requires that applicants be approved for 80 points or above, and with Dartmouth's proven innovation they could credibly attain those points in the mandated seven green building sections that include: sustainable sites, water efficiency, energy and atmosphere, materials and resources, indoor environmental quality, innovation in design, and regional priority. Past critiques have pointed out that LEED Certification could be attained with very little attention paid to energy efficiency, however with the newest version of the rating system appropriating 35 points to energy and atmosphere, Dartmouth would be highly encouraged to focus its building standards to include more detail to energy efficiency. (Reference alternative renewable energies that could be used in Phase 2)

5.3 Benefits

The LEED rating system initially provided a nationally recognized system that established sustainable development as a feasible and cost-effective objective, but with the new rating system, LEED is inciting greater steps to be taken to reach a higher level of green building. If Dartmouth went beyond sustainable building and utilized the numerable sources available, such as investing in researchers to find alternative renewable energy sources to fuel the buildings, the College could earn global recognition for having fulfilled its sustainability pledge and through a business partner earn tax credits from the federal government.

Sustainable building, with LEED Platinum certification in mind, would ensure:

- Lowered operating costs and increased asset value
- Reduced waste sent to landfills
- Conserved energy and water
- A healthier and safer environment for occupants
- Reduced harmful greenhouse gas emissions (usgbs.org).

"Overall, the changes [in LEED certification] increase the relative emphasis on the reduction of energy consumption and greenhouse gas emissions associated with building systems, transportation, the embodied energy of water, the embodied energy of materials, and where applicable, solid waste" (usgbc.org). It is time Dartmouth looked beyond and noted the progress the federal government and fellow institutions are making towards lowering the embodied energy required to build and fuel a building.

5.4 Costs

In a 2004 study conducted by Davis Langdon entitled *Costing Green: A Comprehensive Cost Database and Budgeting Methodology*, a number of buildings, both LEED-seeking and non-LEED-seeking, were studied in terms of construction costs per square foot and deviations from initial budget. The study found that, even when taking into account the types of buildings, location, and date of construction, there is no statistically significant relation that suggests buildings that seek LEED certification cost more per square foot. Additionally, when analyzing the deviation from initial budgets, the study found that:

"A majority of the buildings we studied were able to achieve their goals for LEED certification without any additional funding. Others required additional funding, but only for specific sustainable features, such as the installation of a photovoltaic system. Additionally, our analysis suggested that the cost per

square foot for buildings seeking LEED certification falls into the existing range of costs for buildings of similar program type." (Matthiessen et al, 25)

Still, the sustainable building market has changed dramatically since 2004. To address this issue, Davis Langdon commissioned another report in 2006 entitled *The Cost of Green Revisited: Reexamining the Feasibility and Cost Impact of Sustainable Design in the Light of Increased Market Adoption.*

"The 2006 study shows essentially the same results as 2004: there is no significant difference in average costs for green buildings as compared to non-green buildings. Many project teams are building green buildings with little or no added cost, and with budgets well within the cost range of non-green buildings with similar programs." (Davis/Langdon, 3)

Additionally, it can be argued that sustainable practices have been even more widely adopted since 2006, when this study was published. Sustainable products can be easily and cheaply acquired at large stores like Wal-Mart and Home Depot.

Evaluating buildings on just their construction costs or initial budget requirements does not give sustainable buildings their due. These buildings should be evaluated holistically, including long term costs of operation and maintenance. Buildings that incorporate sustainable practices will have dramatically lower utility bills and often lower maintenance costs, both of which contribute to a building that has a lower cost over its lifetime. Obviously, requiring LEED Platinum will require some additional funding. However, the buildings built will have a long, useful life, allowing Dartmouth to take full advantage of the buildings savings opportunities. Dartmouth has already taken some steps, including the requirement for new buildings the perform in the top 5% of similar buildings in the United States. From our research, these premiums would add anywhere from 0% to 2% or more to the cost of the building, but the lifetime costs clearly cover these costs in a relatively short payback period.

5.5 Going Beyond LEED Platinum

Gorman notes, "but the College has aims to reach beyond LEED in many areas. We have a long history of paying attention to energy efficiency, not just in new construction, but in remodeling and retrofitting existing buildings as well." (Dartmouth.edu/~vox)

LEED Platinum provides a timeline and markers that Dartmouth could follow in order to complete its pledge to reduce greenhouse gas emissions by thirty percent by 2030. However, those are only steps towards a future that requires that all buildings to be in the top 5% of energy efficiency of buildings of its type and ultimately be zero energy. For example, the research conducted by the Environmental Studies 50 class of 2005 (Green Living at Dartmouth College) and Phase 2 of the report, provides excellent energy alternatives such as solar heating systems and retrofitting heating systems in dormitories that Dartmouth could implement in the near future. To once again gain recognition as a leader in sustainable development and greenhouse gas emissions reductions, Dartmouth must pledge to act beyond simply reducing emissions and invest in renewable energy and technologies that would encourage zero energy buildings.

By studying the actions of peer institutions that are current leaders in innovative green designs and that have attained LEED Platinum, Dartmouth College could begin to adopt similar strictures for the design and renovation of their buildings. Dartmouth has a remarkable history of environmentalism, but in a time of dire need the College needs to look back at its actions and see how existent buildings could be retrofitted to uphold the new pledge to sustainability that has been made. Dartmouth has the aid of a supportive community and various researchers that are at the top of their field, by utilizing those resources and incorporating what is recommended by the USGBC and the federal government, Dartmouth could gain notable recognition for its innovation. Ultimately, by making all buildings in the near future LEED Platinum and then rank in the top 5% of energy efficient buildings of its type, Dartmouth would begin to greatly decrease its carbon footprint and instead leave a lasting mark on the global community. The philosophy of philanthropy must be maintained by Dartmouth College, but making it necessary that in the future buildings are zero energy is a great element that Dartmouth should incorporate into its mission statement, which would effectively place Dartmouth College as a leader in green building and as an example to follow.

Conclusions

One of the central concerns of this report is determining whether the implementation of heat recovery systems – and other retrofits in general – is feasible within the College's operations. According to Steve Shadford, the energy engineer for Facilities, Operations, and Management (FO&M), even more challenging than gaining administrative support or financing is coordinating with the appropriate stakeholders is scheduling a time for these renovations to actually take place. For example, Burke is a building where research is active and ongoing. Likewise, at the Hopkins Center, performances are often scheduled two years in advance, and spaces are constantly used for study, performances, gallery exhibitions, and lectures. For renovations to take place, these activities would need to be paused for a certain period of time. This requirement is difficult to fulfill, even on weekends, because ongoing projects have often been scheduled weeks and months in advance (Shadford).

In scheduling time for upgrades, Shadford noted that planning meetings would ideally take place every two weeks. The stakeholders include the researchers whose work may be disrupted, department chairs, and the workers actually performing the construction. Coordinating the schedules of these people is challenging and presents one of the major problems in implementing the Energy Task Force's recommendations (Shadford).

As previously noted, the nature of renovating a building is that problems unrelated to the project at hand are often uncovered as renovations progress. It is impossible to guess which ducts will need to be replaced due to age or damage, and "we need to fix those things that we find wrong in the course of putting in new technologies" (Shadford). Thus, deciding to install heat recovery systems in a central exhaust system cannot be scheduled with only these discrete upgrades in mind.

Because of these scheduling challenges, there is currently no proposed timeline for implementation of upgrades at the Burke Chemistry Building, or at other, similar buildings. Additionally, the scheduling of meetings to make the appropriate building upgrades—for all of campus—falls to Shadford alone. He is also one of the few, if not the only, person on campus who references the full report of vanZelm Energy Service's Energy Conservation Plan. It is difficult to implement these projects with only one person with the task of implementation as their primary responsibility. Similarly, it would be difficult to impose a particular timeline without consulting directly with the occupants of each building to find the least inconvenient times for disruption, since building use is circumstantial (Shadford).

Part One:

In conclusion, Dartmouth College's renovation policy needs to focus on the following points in order to achieve more energy-efficient, cost-effective results in future projects.

- Very clear, environmentally-conscious goals need to be set.
- The Office of Planning, Design, and Construction (OPDC) and Facilities, Operations, and Management (FO&M) should aim to collaborate as plans transition from one department to the other. If the experience or expertise to carry out a particular project are lacking, an outside source should be hired to complete the job so that Dartmouth can reap the highest payback from the installation of new technologies and still maintain its commitment to energy efficiency.
- Dartmouth should establish a more comprehensive, systematic plan for follow-up with already-completed projects. This process is twofold: first, to determine if efficiency standards were actually met, and, second, so that any mistakes that arose during constructions can be repaired by the appropriate group. It is revealing to analyze the electric and steam use of a building—even during the first two years—because small adjustments can still be made for optimum efficiency. Careful documentation of the construction process would help to troubleshoot future problems by routing them to the responsible parties.
- Furthermore, adding meters that monitor energy use more accurately than on a building-wide scale would provide instantaneous feedback to energy users, encouraging them to make real-time energy saving decisions. This would also improve troubleshooting in the short-term.
- Lastly, Dartmouth should reconsider how much personal space is necessary per student.

Part Two:

Conservation through Student Behavior Modification: The GreenLite Project

Dartmouth's lauded history can be attributed to its culture of experimentation. In April 2008, the computer science department's Lorie Loeb launched a research project called GreenLite. The program consists of low-energy computer screens (in selected dormitory buildings) that show residents their real time energy use. A dormitory living unit's use is represented by a polar bear on ice. The polar bear is alive and well when the students are using less energy, and correspondingly, the bear's ice melts and it drowns when the students are using too much energy. Loeb's research, which has been applauded in numerous publications (Newsweek, The Boston Globe), is considered a success for several reasons.

The GreenLite program is successful because it influences students to use less energy, provides real-time and long-term energy data, and highlights a collaborative faculty-student educational relationship. In this regard, it is our recommendation that Dartmouth adopt year-round educational pilot programs concerning sustainability. Due to the work intensity of every student's life on campus, apathy toward sustainability is a real problem at Dartmouth. Research programs like Green Lite ensure the ideal of higher education, in that they continue to teach students outside of the classroom.

According to Loeb, dorms with GreenLite screens are reducing their electricity use (Loeb). From dormitory energy competition charts seen on the GreenLite website, the electricity use shows an 8% reduction in merely a week. Loeb estimates (although confirms that it is an assumption) that we can hopefully find a reduction percentage in the double-digits (Loeb). Even half of that, or a third, of that, would put the electricity reduction, from simple behavioral changes and no other changes to the building itself.

Additionally, this project is a demonstration of a liberal arts education at its best. Students from varying background came together to meet with professors to help solve a campus and global issue. Undergraduate Computer Science students successfully programmed the entire project as extra curricular and independent study work. A professional software engineering company would have charged $50,000 according to Professor Loeb, but these brilliant Dartmouth students did the entire program on their own. Then sociology students were brought in to analyze data and determine best practices for positive behavior modification. Other students were involved in website design and publicity. The entire project was the epitome of Dartmouth's homogeneous and worldly education.

GreenLite is currently modifying student behavior by reducing energy use by 9% (a low estimate) (Loeb). If the most of campus had GreenLite screens (55 more installations) we could see an overall reduction of 7,920 MTCE per year.

Recommendations for Student Behavior Modification

Based on the outstanding results from the GreenLite program and the pressing need to reduce Dartmouth's energy consumption, the GreenLite program should be actively funded by the college. Using our communications resources, Dartmouth should be actively publishing stories of this success. A program that highlights the ingenuity of Dartmouth students, the synergy of liberal arts, and Dartmouth's commitment to sustainability makes for a fantastic press story.

Garnering media attention for world-leading environmentalism will boost alumni support from the growing body of alumni but will also attract the attention another important group: prospective students. Environmental activism and sustainability operations are playing an increasing role in where worldly and globally aware students chose to matriculate. Students desire schools and student body's that are concerned for the world and initiative to improve it. Almost two thirds (63 percent) of the 10,300 respondents to The Princeton Review's 2008 College Hopes & Worrisurvey indicated that they would value having information about a college's commitment to the environment and that it might impact their decision to apply to or attend the school. Nearly a quarter (23 percent) said this information would "strongly" or "very much" contribute to decisions about which schools to apply to or attend. Forbes Magazine also released an article in May of 2008 which outlined the growing interest in "Green Colleges" and cited Dartmouth as a school chosen for its work on sustainability.

Additionally, Dartmouth should be constantly striving to remind students of its commitment to sustainability. While some students are incredibly concerned and proactive regarding the issues of environment and climate change, others remain apathetic and uneducated and no liberal arts institution would be doing its job if students went into the world unprepared to face the growing demand for sustainability and environmental solutions.

II. Phase I, Part 2: Transportation

1.1 Introduction

Throughout North America, college and university campuses have experienced significant growth in numbers of students, staff and faculty over the last several decades. The traditional approach to campus transportation planning has tended to assume the primary solution to higher demand is to increase supply, i.e. provide more parking spaces. A new vision has been emerging across American campuses, based on expanded transit access, better bicycle and pedestrian facilities, and financial incentives for students, faculty and staff. This new vision falls under the general rubric of "transportation demand management", or TDM. Transportation Demand Management is the application of strategies and policies which attempt reduce automobile travel demand, as an alternative to increasing capacity. Some universities have taken on additional leadership roles, introducing infrastructure and vehicles utilizing biofuels, converting diesel vans and buses to run on biodiesel and creating special incentives for owners of hybrid cars. Dartmouth needs to follow suit and carefully examine the long term costs and benefits of diversifying its fleet with hybrid and electric vehicles.

1.2 Possible Improvements to Dartmouth's TDM Strategy

To build upon the success of this program, Dartmouth should open this incentive to students, and remove the requirement that one first hold a parking permit. Such a requirement encourages an employee to drive to work alone for up to a year until new permits are issue and the employee is eligible to enroll in the buy-out program. By offering the program to anyone who commutes to work, Dartmouth could eliminate up to a year of single-occupant vehicle (SOV) commuting for many employees. (Whitcomb: 2009) Such an open program would be necessary if students were to be enrolled, as it's unlikely that students living off campus would bring a car to school, buy a parking permit, and then not drive it to class unless much more expensive incentives were involved. It would be much more effective for Dartmouth to continue and increase subsidies for public transportation and other transportation options like Zip Cars and encourage student to not bring cars in the first place. The van pool program, which has seen preliminary success, should be expanded to further encourage ride sharing and more covered bike racks should be provided around campus. Much more also needs to be done to promote Zimride, the student run ridesharing program, as well as the Zip Car program mentioned above.

The University of Washington's Fleet Services has introduced the campus's first plug in hybrid as part the UCAR program, which provides vehicles for rent for those affiliated with the university. The car can be reserved 24 hours a day online and the key retrieved from a solar powered dispenser in the parking lot. (UCAR Information Page: 2009) (Plug In America: 2009) Dartmouth could have the Thayer School of Engineering in a project to develop a similar Plug-in Electric Hybrid set up for the campus. This wouldn't be a terribly big step for the school as they already host Plug-In America's hybrid formula race, and would provide an excellent educational opportunity for students. (Plug In America: 2009)

Besides offering positive incentive programs like buy-outs, Dartmouth can also put disincentives into place. In 2006, the Planning and Operational Report of the Parking and Transportation Committee made several suggestions on raising parking permit fees in order to reduce demand for parking and the use of SOV's. (Planning and Operation Report: 2009) A combination of positive and negative incentives has been shown to be a success at other schools. At Stanford, parking permit prices were doubled while buy-out incentives were offered. These efforts, along with free public transportation, led to a 20% drop in SOV's at Stanford. If Dartmouth continues working to improve its TDM strategies it is likely to reap similar results. (Planner's Notes: 2009)

1.3 Fleet Fuel Efficiency

Besides trying to influence the driving habits of students and college employees, Dartmouth needs to address the carbon emitted by its own vehicle fleet. The best way for Dartmouth to do so at this time is by buying hybrid electric vehicles to replace the traditional internal combustion vehicles in the fleet. The college has already begun heading in the right direction, with 10 hybrid vehicles as part of its fleet. Unfortunately, at this time most vehicles in the fleet lack viable hybrid alternatives. There are currently no heavy duty truck or minivan hybrids on the market. While there are light trucks on the market, there aren't enough different models and the ones that are available are not financially viable replacements for most of Dartmouth's trucks. Where Dartmouth can invest its money and save is with hybrid sedans and SUV's. By investing its money in hybrids for the fleet Dartmouth could cut its carbon dioxide emissions by 529 MTCE and save the college over $27,000.

1.4 Hybrid Recommendations

The college should also look to replace its SUV's with Ford Escape hybrids. In the past, Escape hybrids owned by the college did not achieve the fuel efficiency that was expected, and Safety and Security decided to go back to purchasing traditional models. However, with the 2010 model year Ford has significantly improved its hybrid technology, so the Escape Hybrid should be given a second look. In fact, it implements the same technology being used in the new Ford Fusion Hybrid that is getting a lot of attention in the press. (Car and Driver: 2009) The improvements made will allow for the vehicle to accelerate to a greater speed before the internal combustion engine kicks in, and the gas engine should no longer run when idling with the heat on. However, as Rick Hoffman explained, if the college is going to invest in more hybrids, it should also provide training for getting the most fuel efficiency out of such vehicles. (Hoffman: 2009)

The biggest problem however, is the price difference between the hybrid and traditional models. Without any tax credits, the improved fuel efficiency of the Escape Hybrid isn't enough to make up for the higher sticker price. This is especially true given that vehicles are bought on a department by department basis, and Safety and Security is unlikely to want to take a loss on these vehicles. If one were to be bought before April 1, 2010, when the tax credit for the Escape Hybrid sunsets, (New Energy Tax Credits for Hybrids: 2009) it would be a more viable option. However, if the college were to increase Safety and Security's budget so they could get the more fuel efficient vehicles, (Hoffman: 2009) as a part of a fuel efficient purchasing strategy that is profitable as a whole, then purchasing Escape Hybrids makes sense, as it saves the college money in fuel and lowers its carbon footprint. While many tax credits for hybrids are soon to sunset, with President Obama's new plan for fuel efficiency, the relative cost of hybrids to traditional vehicles will shrink and hybrids like the Ford Escape will only become an even clearer choice.

1.5 Conclusion

A more cohesively publicized and expanded transportation demand management strategy and a vehicle fleet with significantly more hybrid vehicles would go a long way to improve the college's image in sustainability. Dartmouth needs to make itself stand out and make sustainability in transportation a part of working and living at Dartmouth. Our college on the hill can, and should be, a leader in sustainable transportation.

III. Phase 2: Renewable Energies

Introduction

Supply-side management is the focus for Phase 2 of Dartmouth's progression to carbon neutrality. It is imperative that Dartmouth sets an example for other educational institutions and the community by taking critical steps toward sustainability and alternative energy solutions. Currently, the cogeneration heating and power plant provides 45% of the electricity used on campus. Our ultimate goal is to reduce reliance on fossil fuels until use of this plant can be either cut-back significantly or completely discontinued. To accomplish this ambitious but necessary task, we have laid out a comprehensive plan including several renewable energies for immediate and future implementation. Other renewable sources will become feasible in the years to come and these technologies should be carefully followed. We have outlined many of these in this report as well. The cost of this plan is not only financially possible, but due to technological advances in the renewable energy systems we are recommending, will also prove to be a good investment for the college. Preliminary work for Phase 2 has already begun, but what Dartmouth has attempted so far needs to be expedited drastically. Dartmouth has the chance to cement itself as a leader of sustainability and what we are recommending is a path to make this possible.

A summary of our recommendations that will be discussed is as follows:

- Install the major renewables where feasible
- Implement fuel-switching to further reduce the amount of heating oil burned-
- Monitor next generation renewables
- Investigate grant opportunities and financing options

1. Immediate Implementation

There are four technologies that are ready for immediate implementation at Dartmouth. While none of these can replace the power plant entirely, they can alleviate some of its load. These four technologies are solar hot water, photovoltaic energy, biofuels, and shallow geothermal wells. The attached chart shows the contribution each of these technologies can make toward reducing Dartmouth's carbon emissions. We also looked at both large and small-scale wind, but have found it to be not appropriate for on-site energy production at Dartmouth. For more information on each of the technologies discussed below, and for a discussion on wind, please see Appendix C.

1.1 Photovoltaics

Photovoltaic panels (PVs), also known as solar cells, are a technology that directly converts sunlight and ultraviolet radiation into electricity. PVs utilize the photoelectric effect, which is when a material absorbs a photon of light and then releases electrons that can be captured as an electric current and used to make electricity. Many Zero Energy Building models rely heavily on the use of photovoltaics. The sun is a renewable, free energy source, and thus it is extremely important that Dartmouth invest in solar technology such as PVs.

For implementation of photovoltaic cells at Dartmouth, we focused on three buildings: Thompson Arena, Leverone, and the Alumni Gym. These buildings have approximately 50,000 square feet available on their roofs for photovoltaic panels. Because of our location, the panels would be South-facing flat panels at an installation cost of $4,000,000. They would produce 638.75 MWh annually, offsetting 1.5% of Dartmouth's purchased electricity. This level of photovoltaic use could reduce Dartmouth's CO_2 emissions by 24.37 metric tons.

1.2 Geothermal Wells

Dartmouth's implementation of geothermal well technology will limit the school's consumption of fuel oil and decrease its rate of greenhouse gas emissions. Geothermal wells operate by utilizing the constant 55°F temperature of the earth to heat buildings in the winter and cool them in the summer. In the winter, groundwater is pumped from a well into a heat exchanger that works in conjunction with a vapor compression (refrigeration) cycle to increase the temperature of water. This hot water is circulated throughout the building to heat the spaces. Discharge pipes return water from the heat exchanger, back to the well after releasing its heat content inside the building. During the summer, this process operates in reverse, serving as a "sink" for the heat rejected by the vapor compression refrigeration cycle, discharging warmed water back into the well.

At Dartmouth, two 1,500 foot geothermal wells are currently used in the Fahey and McLane dormitories to provide 89.3% of the heating and 100% of the cooling in these buildings. When this project was installed, the total cost for drilling and installation amounted to $375,000. This technology is projected to save the college $18,500 on an annual basis when taking into account the price saved on fuel oil as well as the expenditure needed to operate the water source heat pumps and interior water pumps using electricity. The Fahey and McLane geothermal well project currently reduces Dartmouth's annual fuel oil demand by 18,180 gallons, and reduces CO_2 emissions by 278 metric tons.

Future projects for this technology include renovations to the President's house and to the buildings on Administration Row that may require air conditioning during the summer. Experts believe the Fahey and McLane wells have additional heating and cooling capacity to serve buildings and therefore, the President's house can potentially be attached to this system. In addition, the economic and energy savings from implementing geothermal wells for administration buildings will make this project justifiable. The installation of geothermal well systems should also be prioritized for the construction of new buildings as well as renovated buildings that can support a higher load capacity in order to take into account the weight of installing additional water piping.

1.3 Solar Hot Water

The most feasible applications of solar hot water at Dartmouth College are at the Sustainable Living Center (SLC), the central heating plant, the new visual arts center, and possibly the pool in Alumni Gymnasium. Currently, the least expensive technology to use in all of these cases is an *active* solar hot water system with flat-plate collectors (see Appendix C). All of these locations show great promise for solar hot water because these buildings have south facing rooftops, thus they will never be in shadow.

As a residential building, the SLC will most likely require standard equipment, so a solar hot water system can be implemented immediately without technical problems. The central heating plant has the space and existing brackets for 32 flat-plate collectors, which can be mounted in 40 sq. ft. sizes and 27 sq. ft. sizes. This work can also be done immediately. However, the associated plumbing and piping will need to be done as custom work in order to feed pre-heated makeup water into the existing boiler feed system. Current estimates are that this system will save $4,000 annually. A solar hot water system on the new Visual Arts Center could also feed into the central heating plant. Because of the low cost, low maintenance, and high returns, this technology should absolutely be implemented on these buildings and all newly constructed buildings.

Beyond conventional solar hot water systems, technology for "concentrated" solar hot water systems exists, which may allow for pre-heating systems with efficiencies that are orders of magnitude higher than conventional solar hot water. While many concentrated solar technologies are applied in electricity production utilities, the technology can be applied quite readily to heating water (or another substance) for the purpose of pre-heating boiler water or providing hot water to a residence. Concentrated solar technology has the advantages over traditional solar hot water that the liquid becomes hotter more quickly and takes longer to cool down, hence providing a hot water influx with a longer duration and higher volume. One example of a 12-18ft long micro concentrated solar hot water trough device potentially ideal for application at Dartmouth College provides water in the temperature range of 200°F to 400°F (93°-203°C). To put these temperatures into context this amount of heat produced through concentrated solar technology creates the capacity for steam to be produced before entering the power plant, thus making more efficient the phasing of water to steam. Another advantage to using concentrated solar technology for thermal production is that direct solar to thermal efficiencies range around 60%, while solar to thermal to electric systems only reach about 12% energy conversion efficiency.

These types of new and cutting edge technologies provide ample room for increased opportunities in research and development here at Dartmouth. The solar hot water trough device could be implemented at first as research project or class experiment, providing hands-on experience with exciting green technology. This sort of experimental research is rarely available at Dartmouth in the fields of green and sustainable sciences. The expanded opportunities for academic and student involvement on both undergraduate and graduate levels is an important aspect of renewable technologies implemented at the College.

1.4 Biofuels

If Dartmouth chooses to keep its heating plant in the future, it must at least replace number six fuel oil, an extremely dirty fuel, with a more sustainable energy source. An important path to consider is switching to straight vegetable oil (SVO) as a replacement of #6 heating oil. SVO can be purchased and burned at the large scale required by the central heating plant. SVO, it should be noted, is different from biodiesel. Biodiesel is the product of waste vegetable oil (WVO) put through a chemical process called transesterification. Instead, SVO is the product after WVO has been filtered of particulate matter and the water has been eliminated. Burning SVO fuel at the heating plant would require the conversion of the nozzles on the boilers. SVO could be purchased from Smartfuel America, a company out of Seabrook, NH, at 86% of the rack price of No. 6 oil.

It is well understood that, due to our current scientific constraints, the world is not in a position to be run off of biofuels presently. We understand that the model we created for Dartmouth College is specifically for Dartmouth College because of the unique set of parameters living in the White Mountains presents us with. We understand that this model is not necessarily one that can be widely applied, as each infrastructure will call for a specific set of renewable energies determined by their geographic location and available resources. However, we do believe that there is a significant future in biofuels, if carried out the proper way. In an effort to present both sides of the argument, I have chosen specific arguments for each side from some of the most cutting edge biofuel research being carried out presently.

Pros:

- The possibility of "carbon negativity" through growth of low-input-high-diversity mixtures of native grassland perennials:
    - "LIHD biofuels are carbon negative because net ecosystem carbon dioxide sequestration (4.4 megagram hectare_1 year_1 of carbon dioxide in soil and roots) exceeds fossil carbon dioxide release during biofuel production (0.32 megagram hectare_1 year_1). Moreover, LIHD biofuels can be produced on agriculturally degraded lands and thus need to neither displace food production nor cause loss of biodiversity via habitat destruction" (Tilman, 2006).
- The possibility of using "waste biomass" over biofuel production to decrease waste and increase efficiency:
    - "The two major classes of biomass for biofuel production recognized to date are monoculture crops grown on fertile soils (such as corn, soybeans, oilseed rape, switchgrass, sugarcane, willow, and hybrid poplar) (3–6) and waste biomass (such as straw, corn stover, and waste wood) (7–9)" (Tilman, 2006).

Cons:

- Current process of biofuel production seen as detrimental to the environment:
    - "Current biofuel production competes for fertile land with food production, increases pollution from fertilizers and pesticides, and threatens biodiversity when natural lands are converted to biofuel production" (Tilman, 2006).

- Carbon "debt" by converting natural landscapes into biofuel-producing land:
    - "Converting rainforests, peatlands, savannas, or grasslands to produce food-based biofuels in Brazil, Southeast Asia, and the United States creates a 'biofuel carbon debt' by releasing 17 to 420 times more CO2 than the annual greenhouse gas (GHG) reductions these biofuels provide by displacing fossil fuels. In contrast, biofuels made from waste biomass or from biomass grown on abandoned agricultural lands planted with perennials incur little or no carbon debt and offer immediate and sustained GHG advantages" (Fargione, 2008).
    - Why is this land in Brazil, Southeast Asia, and the U.S. being converted? Demand for alternatives to petroleum.
        - "Demand for alternatives to petroleum is increasing the production of biofuels from food crops such as corn, sugarcane, soybeans and palms. As a result, land in undisturbed ecosystems, especially in the Americas and Southeast Asia, is being converted to biofuel production and to crop production when agricultural land is diverted to biofuel production" (Fargione, 2008).
- Corn-based ethanol
    - "By using a worldwide agricultural model to estimate emissions from land-use change, we found that corn-based ethanol, instead of producing a 20% savings, nearly doubles greenhouse emissions over 30 years and increases greenhouse gases for 167 years" (Searchinger, 2008).
- Switchgrass, if grown in U.S., increases emissions:
    - "Biofuels from switchgrass, if grown on U.S. corn lands, increase emissions by 50%. This result raises concerns about large biofuel mandates and highlights the value of using waste products" (Searchinger, 2008).

The purchase and consumption of SVO is integral to reducing Dartmouth's carbon footprint, reducing SO_2 and NO_x emissions, and would move us away from the volatile and unsustainable oil market. Burning SVO instead of No. 6 would decrease carbon emissions by about 3,000 MTCE, and save the college $380,500.00. This value was calculated by using the average price of No. 6 fuel oil, from January to April 2009, and by assuming that SVO would cost 86% of this price (the cost from Smartfuel America). This change would also lead to a decrease in SO_2 emissions by 5,200 tons (97% reduction), and NO_x emissions by about 50 tons (57% reduction) (Eliason 2).

1.5 Biomass

The 2006 report on Sustainable Energy Futures looked at the potential for wood chip energy at Dartmouth and the surrounding region. The report lays out the economic benefits of a wood chip plant and details the steps for implementing it. Our proposal supports the conclusions drawn in this 2006 report.

Biomass is both an ancient and re-emerging energy source that is extremely feasible in the state of NH. NH is the second most wooded state in the United States; in terms of utilizing the potential in the local region, wood is what NH does well. Taking all concerns into account regarding biomass, we suggest that Dartmouth build a biomass plant to replace the base load of the current power plant. The base load is 28,000 pounds per hour of steam, which translates to 14,000 tons of wood or 9,940 tons of wood after the phase I reductions. This would reduce the amount of carbon emitted by 45,673 metric tons as well as decreasing both the SO2 and NOx emissions of the power plant. If, as we suggest, Phase I projects are implemented first, then Dartmouth College's base load should be even lower than this by the time a biomass plant is operational. By replacing the base load, Dartmouth can have consistency with the local providers.

The timescale of implementation of this project extends into the next decade. Scott Brown, Dartmouth Alumni and CEO of New Energy Capital, believes that it would take Dartmouth College about 10-15 years to design, plan, fund, and install a biomass plant. If we started planning now, this plant could be fully operational by 2025. This timing aligns nicely with the probable timing of boiler replacement at the current central heating plant and Dartmouth's next cycle of building, therefore we must not let this auspicious moment pass us by. Mr. Brown estimated that biomass at Dartmouth would have a cost of $3,000 per kW which, compared to the renewable energy estimates we have looked at, is quite low. Mr. Brown also suggested the location of the plant could potentially be across the river near the railroad tracks in Norwich, VT or in Dewey Lot. As a bonus to the financial cost of biomass implementation, this would enable us to use all of the original infrastructure in piping, heat, and energy circulation around campus.

What about the remainder of Dartmouth's energy load? We understand that the existing infrastructure associated with the central heating plant is too valuable to simply be destroyed or left unused, therefore we suggest leaving the current heating plant to pick up the remainder of the steam and electricity demands for the campus. After the base load, there are 51,000 million BTUs that must be produced still. We suggest that half of this energy be produced as usual by No. 6 heating oil through the existing plant and the other half be produced by SVO through the existing plant. In that way, an eventual phase-out of oil use at the central heating plant can occur.

While there are numerous advantages of biomass (specifically wood chips), there are also questions about whether it truly is a carbon neutral fuel. Burning wood still releases carbon into the atmosphere at a rapid rate. The carbon neutrality of biomass assumes that trees are being replaced as they are cut down, and that this replacement rate is equal to the rate of burning. If the wood is being consumed without new plantings, then the net carbon in the atmosphere is increasing.

Also, though New England has an abundance of forests, there are very few foresters who are committed to harvesting wood in a sustainable manner. Middlebury came up against this issue when they began sourcing wood for their biomass plant. They had initially planned on using wood from sustainable foresters only, but could not find an adequate supply and were forced to use wood from multiple sources, none of which are sustainable (Jack Byrne). Using waste wood, as mentioned in the 2006 ENVS 50 report, is a possibility, but it is questionable as to whether supplies are available in adequate amounts and with sufficient reliability.

Another debate surrounding biomass relates to soil carbon. Andy Friedland, chair of the Dartmouth Environmental Studies Department and an accomplished soil scientist, has concerns about the effects that disturbing soils can have on carbon release. Carbon is stored throughout the soil layers, and more intensive management of land (as required for the forestry needed to turn biomass into a major energy source) would disturb these soil layers, potentially releasing large amounts of carbon. Studies are currently being done on this, and Middlebury is taking data as well. These issues need to be resolved before biomass can be an effective alternative to oil, and can truly be considered as a carbon neutral fuel source.

2. Long Term Solutions

While the technologies mentioned above can replace some of the power plant load, they will not come close to phasing out the steam plant. However, there are technologies that could do this. Deep geothermal and sewage heat recovery technologies are very promising, but are a few years away from possibly being implemented at Dartmouth. Biomass could be implemented in the very near future, but we believe that there are biomass is not as simple as some (including Middlebury) make it out to be. The 2006 report has more information about biomass. For more information about sewage heat recovery and deep geothermal, please see the phase two appendix.

2.1 Sewage Heat Recovery

With the flush of a toilet, water around 60°F leaves a building via pipe lines, flows into a main sewer line, and heads toward a sewage treatment center. Since energy was used to heat this water to 60°F, when the warm water exits the building through the sewage lines this is a significant loss of heat and waste of energy. Preventing heat loss from buildings is a huge challenge in sustainable engineering. New technologies in chimneys, ventilation systems, and insulation have created notable increases in heat capture and recycling. Still, around 15% of buildings' thermal energy is lost via sewage lines, and even in buildings this percentage can even be as high as 30% (Schmid). Recently, however, heating systems have been developed that capture sewage heat and use it to pre-heat hot water for heating/cooling systems and hot water distribution. Although these systems are new, they are already being utilized in major building plans like the 2010 Olympic Games Athletes' village in Vancouver, Canada; several universities like Harvard University and the University of Washington are also in the midst of negotiating with Rabtherm (the company that installs these systems) so they can make use of this technology on their campuses.

If Dartmouth College wants to be a leader in cutting edge sustainable technology, implementing sewage heat recovery systems would be a perfect way to reach this goal. More specifically, there is a pipe leaving Dartmouth's power plant with waste-water from the boilers that has an average temperature of around 450°F. Although Dartmouth is already using a heat exchanger to capture some of this energy, the water leaving the pipe is still around 160°F. If a wastewater heat recovery system were installed on this line this could help preheat the 10% water that is added to the 90% condensate so that the boiler burns less #6 oil. Dartmouth could save around $30,457in oil expenditures and reduce the plant's carbon emissions by 30.07 metric tons if the sewage heat recovery system was able to heat the water headed to the boilers by just 4°F. Assuming this is the case, the system would have a payback period of less than 10 years because Rabtherm, a European company, installs 30m heat exchangers and heat pumps for roughly $300,000.

Wastewater heat recovery systems should also be installed on the line with 160°F water leaving the power plant to preheat the water for nearby buildings. Since many nearby buildings are being renovated or constructed around the power plant (like Topliff and the new studio arts center), it is very feasible for this technology to be incorporated into their design. If water in the buildings was preheated with this system, this would reduce the amount of hot water from the heating plant needed to raise the water within the buildings to a desired temperature. Then, if these new buildings installed a hot water heating system instead of a steam heating one, the potential for wastewater heat recovery to reduce carbon emissions and fuel costs at the power plant could be even greater. Hot water systems are also more efficient than their steam counterparts because the water temperature can be controlled and lowered when it is warmer outside.

2.2 Deep Geothermal

Enhanced geothermal systems (EGS) or deep geothermal is an emerging "renewable" energy technology with the potential ultimately to supply Dartmouth with enough both thermal and electrical energy to replace the heating plant. The big draw of EGS is that it provides a constant source of baseload power while most renewable technologies are intermittent, making storage a significant problem. Another advantage EGS has over most renewable energy technologies is that it takes place underground so there are no visual impacts beyond the plant itself (similar to the current heating plant).

EGS works by drilling two holes in the ground to a depth of around ten kilometers (in New Hampshire, at least). The rock is then fractured between the two holes, creating a thermal reservoir. A liquid (probably water), is pumped down, gathers heat from the rock and then is pumped back to the surface where the heat from the ground is converted to a usable form of energy, electrical or thermal.

The location of a plant at Dartmouth would depend in large part on the analysis of Dartmouth's geothermal potential and bedrock. Drilling costs make up more than half of the cost of an EGS and the costs currently are quite high. It is an emerging technology, though, and as improved drilling techniques continue to be developed, drilling costs will come down, maybe the technology more attractive from a cost standpoint. At this point, Dartmouth would be well-served by hiring a consultant to analyze the deep geothermal resource in this particular area.

2.3 Zero Emission Buildings

Background Information

Zero net Energy Buildings (ZEBs) have already begun to impact energy policies in progressive states and European countries ardent about the issues of carbon neutrality. These buildings are pushing the boundaries on present carbon emitting buildings. Zero Emission Buildings are defined as buildings that produce as much energy as they consume on an annual basis. They are referred to as net-zero-energy buildings because they consume energy but they equal or outweigh the facility's energy demand by replacing their supply with on-site generation (Buildings). ZEBs are extremely effective because they integrate multiple technologies within one single building. Using layers of renewable energies to effectively minimize carbon output, they adequately "reduce site energy use through low-energy building technologies" such as the techniques we mentioned in Phase I (Buildings). ZEBs incorporate technologies that we have mentioned in Phase II, such as photovoltaic cells, solar hot water, and wind (not a part of Phase II). Though we mention ZEBs in Phase II, they actually represent the merging of Phase I and Phase II steps into one architectural unit.

The present high cost makes a "future implementation" technology for Dartmouth. But it might not be as futuristic as some might think; California's "Assembly Natural Resources Committee" is being pressured to require "homes to emit no carbon and give power back into the grid"(Treehugger). Therefore, though they may be on the distant horizon, ZEBs should have a certain future at Dartmouth.

Changing Policy

Many studies indicate that present buildings contribute to a third of CO_2 emissions through heating and cooling buildings (Accion). California's initiatives in energy policy are a good model for the successful implementation of various renewable energies. If large states can demand such a drastic shift towards looking for ways to require future buildings to be Zero Emission Buildings then Dartmouth should be able to take the step as well.

The proposals for a Zero Emission Building will place Dartmouth College in one of the top positions among Ivy League institutions as well as other institutions in general. With decisions made early, it is possible to for the College to make a preemptive move in the right direction.

"A June 2006 conference paper titled Assessment of the Technical Potential for Achieving Zero-Energy Commercial Buildings, 22 percent of buildings today have the potential to be ZEBs. Through advancements in technology, an estimated 64 percent of buildings could be ZEBs by 2025"(Buildings).

Action needs to be taken to establish a new agenda promptly in order to push our community far beyond the scope of present energy policy and energy policy abroad.

Even though California is in the middle of debates over implementation of Zero Emission Buildings, European countries are already solidifying their plans to mandate all future construction to be built using Zero Emission guidelines.

The UK is well ahead of many countries in issues pertaining to Zero Emission buildings and homes.

"In 2007, new housing regulations were agreed upon and go into full force in stages over the upcoming years. The regulations stipulate that from 2016 on, all new homes in the UK will have to be zero-emission for heating, hot water, cooling, ventilation, and lighting. Debates over implementations have already been resolved and strategic plans of converting and constructing new buildings is already underway...The code was introduced as a voluntary standard in April 2007, and will become a mandatory label in April 2008"(Leonardo Energy)

This campus is in the elementary stages of reducing carbon emissions. Efforts have been made to combat these rising problems but they do not suffice. For the sake of Dartmouth College, creative and intelligent decisions need to be pushed in order to provide substantial opposition to growing climate issues. We need to understand our present predicament and look towards other countries and states as models for constructing guidelines to make carbon neutral buildings a vital part of Dartmouth's carbon neutrality agenda.

Implementing Zero Net Energy Buildings at Dartmouth

In order to implement a zero emission building on Dartmouth campus, we must expect a long anticipatory process. It is possible, however, to overcome the initial barriers of implementation by targeting three main areas. First, goals need to be set early to usher in a long-term process, meaning re-organizing construction guidelines to permit Zero Emission Buildings for future projects. Second, energy loads particularly regarding the Dartmouth Power plant need to be drastically reduced. At the moment, the Dartmouth Power Plant directly supplies the college with forty-five percent of the College's electrical energy needs and 90% of its heating needs (Dartmouth College). Although, a reliable source of energy, the Dartmouth Power Plant is a fossil fuel based plant consuming #6 fuel oil and contributing to carbon emissions directly. Finally, to reduce the load on the Dartmouth Power Plant one more step must be taken. An investment in on-site renewable power generation must be made.

In order to reduce the load of the energy plant substantially, the college must combine multiple efforts in various technologies and practices to reduce dependency on the Dartmouth Power Plant. Future construction on campus will benefit substantially, even more so than, older buildings which require retrofitting.

"New construction projects offer the greatest opportunity to achieve zero energy. 'In a new building, you have a lot more opportunity to think about how the building systems interact. If you're doing a retrofit of an existing building, it's often difficult to put more insulation in the walls or on the roof…'" (Buildings).

Precedents

a.) Acciona is a company based in Spain committed to sustainable development projects and promoting initiatives based on sustainability. It is one of the first companies to construct and document the first Zero Emission Building in the world. The building provides a prime example of a functioning Zero Emission Building. It sufficiently provides the building with all its energy needs without releasing greenhouse gases into the atmosphere.

Acciona- Zero Emission Building:

- It consumes 52 percent less energy than a conventional building of the same characteristics and the remainder is covered by renewable energy sources. This prevents over 127 tons of CO_2 emissions per year.
- The climate control and lighting installations feature sophisticated energy efficiency solutions, such as light intensity regulators, presence detectors, radiant floors and ceilings and intelligent temperature controls.
- The photovoltaic solar installations - 48.3 kW on the façade and roof connect to the grid - and thermal solar installations - 110 kW on the roof - cover 89 percent of the total consumption. The remaining 11 percent is provided using biodiesel produced by ACCIONA itself.
- The building also has a geothermal system, which takes advantage of the temperature difference between the subsoil and the exterior to provide cold or warm air, whichever is necessary(Acciona)

b.) Zero Net Energy Residence in Vermont:

- The 2,800 square foot, single family residence houses a family of four and over the 12 months from January 2008 to January 2009 actually exported 16kWh of electricity into the grid.
- A Bergey 10kW wind turbine generated energy on site, producing 6,286 kWh over the course of the year.
- The house featured super insulated passive solar design, thermal bridge mitigation, an air sealed envelope, high efficiency windows, and a ground source heat pump, as well as lighting

and appliances with the highest efficiency ratings and a polished concrete slab for thermal mass with hydronic tubing.

The Zero Emission Home provides ample feedback for outlining a viable plan to implement these buildings in our geographic location. The argument often posed against integrated renewable technologies is they will not work in our geographic zone. The push for carbon reduction is already beginning to expand into new areas of development and construction. Dartmouth College could make a substantial and educated move that will require future buildings to be constructed on the basis of Zero Emission Buildings (Northeast Sustainable Energy Association)

c.) Lewis Center-Zero Net Energy Campus Building

One of the most laudable examples of PV use in an academic building can be found at the Adam Joseph Lewis Center for Environmental Studies at Oberlin College (AJLC). Completed in 2000 at a cost of $6 million, this building integrates many environmentally-friendly technologies into one structure that not only generates enough energy to operate itself, but is able to export excess energy to the remainder of Oberlin's campus (Oberlin 2007). Among the many eco-friendly technologies in use at the AJLC, none is more critical to the building's net energy production than the large PV arrays on the roofs of the center and its adjacent parking structure (Solar Design Associates 2009).

The photovoltaic array on the roof covers 4,671 square feet on the south-facing side of the Center for Environmental Studies (International Energy Agency). This array, made of monocrystalline photovoltaic panels, can produce up to 60 kW at any given moment, meeting nearly 50% of the building's annual electrical usage. In 2006, Oberlin installed a second large photovoltaic array above the parking lot adjacent to the building capable of producing an additional 100 kW of electricity (Green Energy Ohio). This "solar pavilion," covering 8,800 square feet, has enabled the AJLC to produce around 30% more electricity than it uses in a given year, making it the first college or university to have an academic facility that is a net energy exporter (Green Energy Ohio). Having one of the only academic buildings in the United States that is a net energy producer has catapulted Oberlin into the number four position of the "Greenest Colleges in America" list by The Daily Green (Howard 2008).

Conclusions on Zero Energy Buildings

Our present dependence on old technology is waiting to be replaced with insightful technologies that produce sufficient amounts of energy without being counterproductive. Dartmouth's Development is still in the early stages of reducing greenhouse gas emissions. It is very important in the decision making process to integrate decisions early in order to allow future changes to occur on campus. Implementing Zero Net Energy Buildings for future construction is a smart anticipatory action for our future goal of a carbon neutral Dartmouth.

2.4 Carbon Capture and Storage

The appeal of CCS

Carbon Capture and Storage (CCS) has the attractive potential to bring us towards carbon negativity, because it can remove previously released carbon dioxide, whereas other renewable energy technologies merely prevent the further release of CO_2. Carbon negativity—the capture of more CO_2 than we emit--is one step more sustainable than carbon neutrality, because it can more quickly reverse the immense load of CO_2 that has accumulated in the atmosphere over the past few centuries of human activity. The experts say that carbon cycle geo-engineering shows great promise, and may even be able to reverse atmospheric carbon to preindustrial levels.

How it works

Carbon Capture and Storage (CCS) can take many forms, biotic and abiotic. Biotic forms include: ocean fertilization for the promotion of algal growth, reforestation, and agriculture. Abiotic techniques include: carbon mineralization in rock formations, biochar charcoal creation out of biomass, chemical scrubbers, and Integrated Gasification Combined Cycle (IGCC) power plants which capture emissions before they are emitted. Scientists agree that these last two options (chemical scrubbers and IGCCs), perhaps have the most potential.

Precedents

The United States Department of Energy is the main proponent of CCS technology in this country. The DOE provides funds for the development and research of CCS. Recently an organization called the CO_2 Capture Project was formed. An alliance of "eight of the world's leading energy companies" (Chevron, BP, ConocoPhillips, Eni, Petrobras, Shell, Suncor, StatoilHydro) and "three government organisations" (US DOE, Norges forskningsrad, EU), the CO_2 Capture Project advocates for the further research and promotion of Carbon Capture and Storage. They are on the forefront of making CCS marketable, and should be viewed as a potential resource.

In 2008, the DOE announced a restructuring of their $1 billion FutureGen project. The project now is aimed at supporting multiple Integrated Gasification Combined Cycle (IGCC) power plants, that is, power plants that are equipped to capture and store their own carbon emissions. In addition the DOE is currently forming "regional partnerships" around the country to analyze the potential for carbon storage in different locales, but unfortunately, the Northeast appears to not be included as a region of exploration.

The Big Sky Carbon Sequestration Partnership (BSCSP) is a partnership dedicated to the research and development of carbon capture and storage. The participants are universities, national laboratories, private companies, state agencies and Native American tribes in Montana, Wyoming, Idaho, South Dakota and the eastern part of Washington and Oregon. The organization is based at Montana State University. In November 2008, the US DOE awarded $66.9 million to BSCSP for undertaking an ambitious CSS project. $14 million of this was given to Montana University for hosting the initiative.

Many precedents exist in Europe. Norway currently has four major carbon capture and storage experimental sites, and it plans to develop more. Germany developed the world's first complete demonstration CCS power plant when it retrofitted Shwarze Pumpe power plant in 2008. This power plant captures and stores its own CO_2 by combusting the fossil fuels in pure oxygen. Britain's Energy and Climate Change Secretary Ed Milibrand said he expects that by 2025 all power plants built in Britain will be required to use CCS technology.

Costs and applicability to Dartmouth College

Currently the DOE says that CCS measures cost $150/ton of carbon, and so far this high cost of CCS technology has kept it from the private market. Centrica, a British utility, says it will probably take fifteen or twenty years of development "to roll out CCS plants in large numbers" (Economist, 3/5/09). However, though Dartmouth doesn't yet have the option of installing such technology on its power plant, we should watch this technology carefully and contribute to CCS development through research. The Earth Sciences and Engineering departments would be the likely locations for this research.

Professor Bostick in the Dartmouth Earth Sciences Department studies tropical agriculture and agro-forestry as a means of carbon sequestration, and he believes that carbon negativity is actually a "necessary" step for our society. According to Professor Bostick, approximately half of the Earth Science professors already study aspects related to carbon capture and storage, because of the fact that their research relates to some piece of the carbon cycle (atmosphere, soil, rock). He agrees that Dartmouth could provide a fundamental service to the mitigation of climate change by encouraging research on CCS technology.

3. Carbon Offsets and Sequestration

Philosophy behind carbon neutrality and offsets

In order to make Dartmouth College carbon-neutral, there must be a combination of new fuels, technologies, high performance design, and conservation. Still, even with a rigorous plan across these areas, it may not be possible for the College to become completely carbon neutral by 2050 without purchasing carbon offsets. Despite any new changes, for the foreseeable future there will still be certain buildings and practices that are inefficient but too expensive to replace. Though there is technology available to significantly reduce carbon and greenhouse gas emissions, it is not all practical for Dartmouth to implement them all for a number of reasons, mainly financial strain in the current state of the economy. In order to become carbon-neutral sooner, Dartmouth can purchase carbon offsets to make up for the carbon emissions that can not be reduced at the College. However, if a carbon-neutral by 2050 plan is not adopted, the College should not purchase offsets because of the uncertainty of the offset market and practice in general.

The best way to approach carbon offsets in a sustainable manner is to do as much as possible to directly reduce emissions, and when you've reduced as much as possible for a given time, purchase offsets to make up for the carbon you are still emitting. There are several ways to offset carbon emissions, including by planting trees, cogeneration using materials that otherwise would have been wasted, make buildings and factory processes more efficient, and capturing or sequestering carbon. According to the non-profit organization The Climate Trust, carbon offsets, "counteract or offset greenhouse gases that would have been emitted into the atmosphere; they are a compensating equivalent for reductions made at a specific source of emissions" (Climate Trust). In order to ensure that carbon offsets are in fact offsetting carbon, The Climate Trust states that the offsets must be quantifiable and only be used in a project that otherwise would not happen 'without the funding provided by the offset purchaser," (Dartmouth's Energy Usage Report).

Unfortunately, carbon offsets can create an easy way out for companies trying to become carbon neutral without making any significant changes to their practices. Additionally, some offsets are not well verified and can be difficult to monitor since offsets are located far from the source of the carbon emissions. Certain offset projects may still be harmful to the environment, such as monocultures of trees that are overcrowded and may take up land for native species. It can also be difficult to determine just how much carbon trees are offsetting or to prove that tree would not already by naturally growing in the offset location (Friedland). All of these are reasons for why Dartmouth should not purchase carbon offsets now unless we make a commitment to be carbon neutral in the near future.

Specific offsets

Carbon offsets can be involuntary to comply with government mandates, and voluntary as a way to reduce your personal carbon footprint for the sake of the environment or to improve the sustainability of your business. One carbon offset is equivalent to one metric ton of carbon being offset. A 2007 report by the Ecosystem Marketplace identified the types of offsets as forestry, methane, renewable, energy efficiency, industrial gas and mixed/other, with forestry being its main method of offsetting carbon. The cost of each offset varies from less than $1 to $45 depending on the source of the offset, with well-verified reforestation projects and methane landfills costing the most. (The Katoomba Group's Ecosystem Marketplace)

Use at Dartmouth College

Carbon offsets maybe a good way for Dartmouth to become neutral because of the land it already owns. Dartmouth owns a large amount of land at the Skiway and the Second College Grant, so it has many trees that could be counted as offsets and for their carbon sequestering capabilities, and there may be room for planting more trees in some areas. However, these trees are already in existence, so they would not be removing any additional carbon from the atmosphere. Next, Dartmouth already has cogeneration plant that harnesses the energy not used in steam production to make enough electricity to supply roughly 40% of the campus’s needs. Since our plant has been in use for over a century now, it should not be considered as an offset because it’s been going on for so long and is not a new initiative. When calculating its potential on-campus sources of offsets, Dartmouth should try as much as possible not to include existing projects, since they would be around regardless of new neutrality goals.

As stated in Dartmouth’s 2008 Energy Usage report, the College emitted 87,751 metric tons of CO2 in 2007 (Dartmouth’s Energy Usage Report). The majority of those emissions come from the # 6 oil burned at the cogeneration steam and electricity plant, with around 5,000,000 million gallons being consumed per year for the last several years (Dartmouth’s Energy Usage Report). Total energy consumption at the College is still increasing despite reductions efforts. This is likely due to increased construction projects, as well as the general increase in technology and computer use. As emissions continue to increase, carbon offsets are necessary for carbon neutrality, because even if the College were to shift to more renewable fuels, there will still be significant carbon consumption.

The Second College Grant

The Second College Grant is Dartmouth's largest land holding at 27,000 acres (Evans). It is located in the north country of New Hampshire in Clarksville. Its acreage is primarily forested, giving an idea of how many trees are in the area to serve as carbon sinks. With an average of 198 trees per acre, the Grant has approximately 5,346,000 trees on its premises. These trees could be used as offsets and for sequestration. While the exact carbon offsetting capabilities is uncertain, it can be roughly estimated that each tree can sequester one metric ton of carbon per year (EPA). This brings up problems with counting the amount of carbon being offset by trees because grown trees are already near their sequestering capabilities, so they are not necessarily removing any new emissions from the air, rather they are continuing to store older carbon. Carbon can be sequestered by capturing it in trees that are cut and stored or made into permanent fixtures such as furniture that would hold the carbon instead of emitting it into the atmosphere. There has been sustainable, commercial logging at the Grant for many decades make a profit and to clear areas to allow different re-growth for certain species of trees over others. College forester Kevin Evans says, "between 2-4 % of the land area is logged yearly, less than 1000 acres" at the Grant (Evans). Both Friedland and Evans believe that sustainable logging is important for the Grant, and Evans suggests that products harvested by logging may be better sinks than an unhealthy, overgrown forest. The Grant should not be considered a carbon offset for Dartmouth because the trees already exist, and sustainable logging practices there provide $80,000- $125,000 to Dartmouth each year (Evans). One possible way to increase the existing offset and sequestration capability of the Grant would be to cut trees when they are reaching their carbon holding maximum, and replant new trees. The College would make money by using the wood for furniture, and have expenditures to pay for new trees that will take decades to mature.

Other Colleges

Oregon State University recently received funding from The Climate Trust to build a $39 million cogeneration steam and electricity plant that is projected to offset 338,790 metric tons of carbon over 20 years (Climate Trust). While this project is an improvement for Oregon, Dartmouth already has a cogeneration plant, so this would not be included in our offsets, rather we are trying to reduce from the levels already in place including the heating plant. Middlebury currently has a plan to be carbon neutral by 2016. In order to do this they are using a combination of several different energy sources, as well as utilizing carbon offsets from local, Middlebury-owned and commercially purchased offsets (Winning the Race Together). Middlebury is making up for about 5000 tons of carbon through purchased offsets (Middlebury lecture). Given its proximity and similarities to Dartmouth, we should look more into Middlebury's model for carbon neutrality to see how their plan can help Dartmouth. Additionally, other colleges are purchasing energy from renewable sources, which may be a more reliable method than offsets because the energy source is more verifiable.

Conclusions

In order to become carbon neutral by 2050, Dartmouth will need to use carbon offsets. However, for the current goals or reduction, no matter how high they are, Dartmouth should not purchase offsets. Trees at the Second College Grant are already existing and not removing additional carbon, so they do not even meet certain definitions of term offset. Dartmouth's 2008 Energy Task Force report recommends that Dartmouth reach a goal of 30% carbon reduction from 2005 levels by 2030 without purchasing offsets because,

> The Task Force is skeptical about the effectiveness of this investment at this time. The current market for these investments is not robust, and there is no independent means of verifying the impact of an investment. Offsets should periodically be re-evaluated in the future. (Dartmouth's Energy Usage Report)

Professor Andy Friedland, chair of Dartmouth's Environmental Studies department said, "The overall philosophy is that it's far better to reduce emissions to than to pursue any offsets." It is important to remember that carbon offsets are not an excuse to continue unsustainable practices, rather a way to continue to help the environment on the path to carbon neutrality.

4. Green Electricity and Renewable Energy Certificates

Dartmouth purchases more than half of the electricity it uses on campus from National Grid Electric Company. This purchased electricity results in the emission of almost 15,000 tons of carbon dioxide emissions each year, roughly 17% of Dartmouth's total carbon dioxide emissions (EYP Energy, 2008). One way that Dartmouth could potentially eliminate this share of its emissions is to directly purchase renewable electricity directly from its supplier. National Grid recently launched a "Green-Up" program which gives customers the option of purchasing power generated by renewable energy suppliers. Unfortunately, this program is not yet open to National Grid customers in New Hampshire so Dartmouth cannot take advantage of this program at this point (National Grid, 2007) but it is something that the College should consider seriously when it becomes available.

Another option Dartmouth should consider to reduce the carbon footprint of its purchased electricity is the purchase of Renewable Energy Certificates (RECs). RECs are tradable certificates that certify that a given unit of renewable energy has been generated from a renewable source. RECs require the purchaser to pay a premium in order claim that they have purchased renewable electricity. The electricity is generated and consumed somewhere else but the logic is that the electricity would not have been generated if the purchaser had not paid a premium. Thus the (non-renewable) electricity the purchaser consumes is balanced by the fact that the actual consumer of the renewable electricity (who did not pay a premium) would have consumed non-renewable carbon-emitting energy if the purchaser had not bought RECs. Therefore, a certain amount of dirty electricity is replaced by renewable electricity thanks to the purchase of RECs. Prices for can range between one and five cents per kilowatt-hour, so purchasing RECs to account for Dartmouth's annual purchased electricity would between $40,000 and $200,000 annually (Green Power Network, 2008) and reduce Dartmouth's annual carbon dioxide emissions almost 15,000 tons.

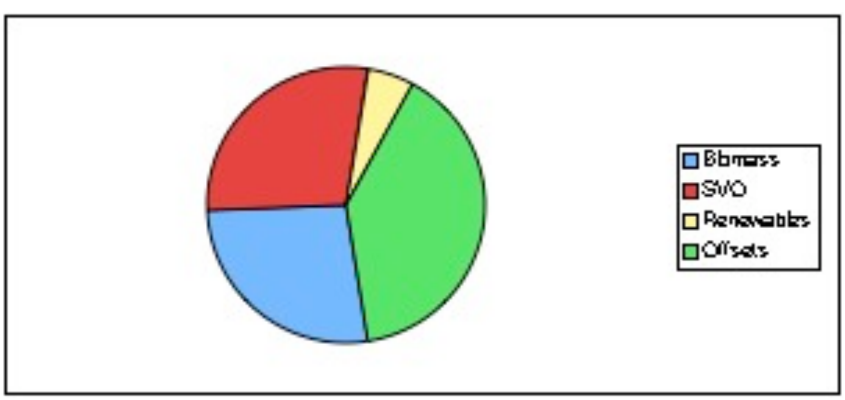
There are advantages and disadvantages to pursuing this strategy. The biggest advantage to this strategy is that it could be implemented immediately and is a relatively easy way to reduce Dartmouth's official carbon footprint. Additionally, any investment in renewable energy technology will help to make renewable energy cheaper in the long-run. One of the biggest drawbacks to this technology is that it has no financial return. Most of the projects recommended in this report eventually will pay for themselves and at some point will make the College money; RECs will not save the College any money. There also is the philosophical critique that RECs are simply a way for the College to pay its way out of its problem and that the purchase of RECs does not change anything for Dartmouth. Similar to carbon offsets , there are issues with licensing and additionality (the issue of whether the investment in the renewable energy would have occurred without the purchase of RECs), although the certification of RECs generally is considered to be much more accurate than carbon offset certification. Many other colleges/universities, organizations, and companies are pursuing the purchase of RECs as a strategy to reduce their carbon footprints. The University of Pennsylvania has been a leader among universities, purchasing 193 million kilowatt-hours of RECs primarily of wind power, representing almost half of the school annual electricity usage (McWilliams, 2009). While RECs can be problematic, they represent a better option than carbon offsets and should be considered as the College takes steps toward achieving carbon neutrality.

5. Conclusions

5.1. Energy Mix

Time	Project	% Energy Saved	Yearly CO2 Emissions (MT) or CO2 Saved
Now			88,000
	Phase I		
	Education and Conservation	14%	
	Renovations	15%	
By 2020		29%	62,480
	Replace Baseload with Biomass	16,807	45,673
By 2025	Replace 1/2 Remaining load with SVO	17,628	28,045
By 2030	Phase II	3,334	24,711

Final Mix	
Biomass	16,807
SVO	17,628



Renewables	3,334
Offsets	24,711
Total	62,480

Chapter 3: Finances

Introduction

Many of the outlined proposals are cost saving projects that will generate positive cash flow for years into Dartmouth's future and pay better than traditional investments. Others are expenditures that impose costs and work mostly to lower our carbon footprint and wean us off increasingly expensive and price-volatile fossil fuels. With smart investment and allotment of funds, Dartmouth can cut _____% of our emissions for ____% of our annual operating budget.

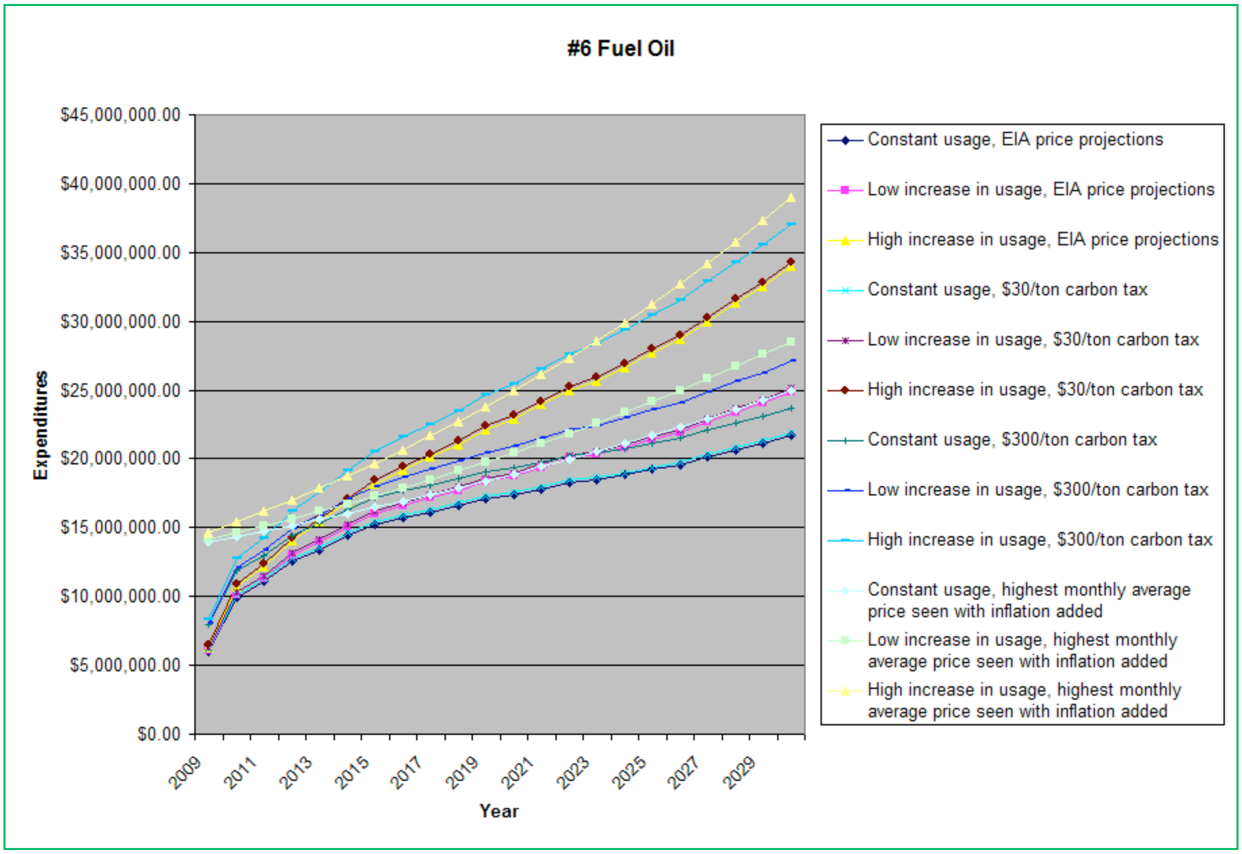
Reducing Dartmouth's dependence on fossil fuels is a generally sound business strategy as forecasts look bleak for those dependent on fossil fuels. Factoring in budget cuts and rising fuel costs, Dartmouth can expect to spend 2.5% of its operating budget on #6 fuel oil by 2011, up from 1% in recent years. With the climbing price of oil, Dartmouth can predict to pay as much as $25 million per year by 2030 (using government projections and our current level of demand growth). Dartmouth has the opportunity to avoid this growing financial burden by investing in steps to reduce demand and switch fuel supply now, providing stability and continuity for Dartmouth's energy strategy in the future.

The cost of business as usual, from a global financial perspective, is too dire for inaction to even be an option. Nicholas Stern, chief economist to the British government, found "the cost of inaction on climate change to be 5 to 20% of global GDP, while greenhouse gas mitigation would cost 1 to 2% per anum of global GDP in his landmark report" read Stern Review on the Economics of Climate Change. He cited climate change as "the greatest market failure ever seen" and urged "urgent global response." Being the worldly institution that the college is, it makes sense for Dartmouth to tackle this next great global problem with the heart and morals of the Tucker Foundation and the worldly oversight of the Dickey Center. However, sound fiscal policy remains the key driver behind any changes, whether towards carbon neutrality or not, that the college will see throughout its future.

In the following pages you will find specifics as to the financial potential for Dartmouth to save itself from a growing financial burden as well as lead other institutions in an effort to avoid financial and climate catastrophe.

1.1: Graphs of Projected Future Expenditures:

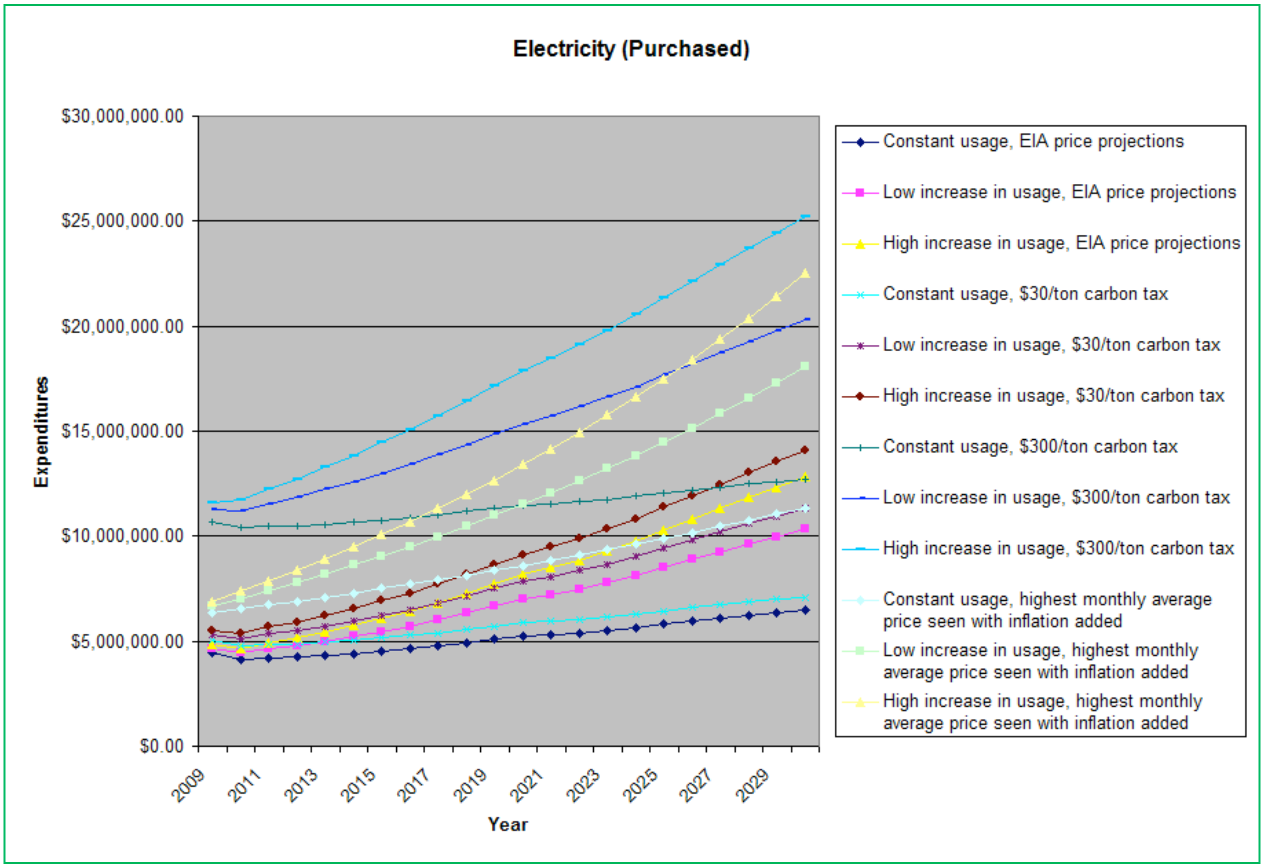
Figure 1: *Projected expenditures on #6 fuel oil through 2030*



	EIA price projections	$30/ton carbon tax	$300/ton carbon tax	Peak with inflation
Constant usage	$361 million	$366 million	$404 million	$416 million
Low increase in usage	$393 million	$398 million	$439 million	$452 million
High increase in usage	$485 million	$490 million	$541 million	$555 million

Table 1. *Cumulative expenditures during 2009-2030 on #6 fuel oil under various price and usage regimes.*

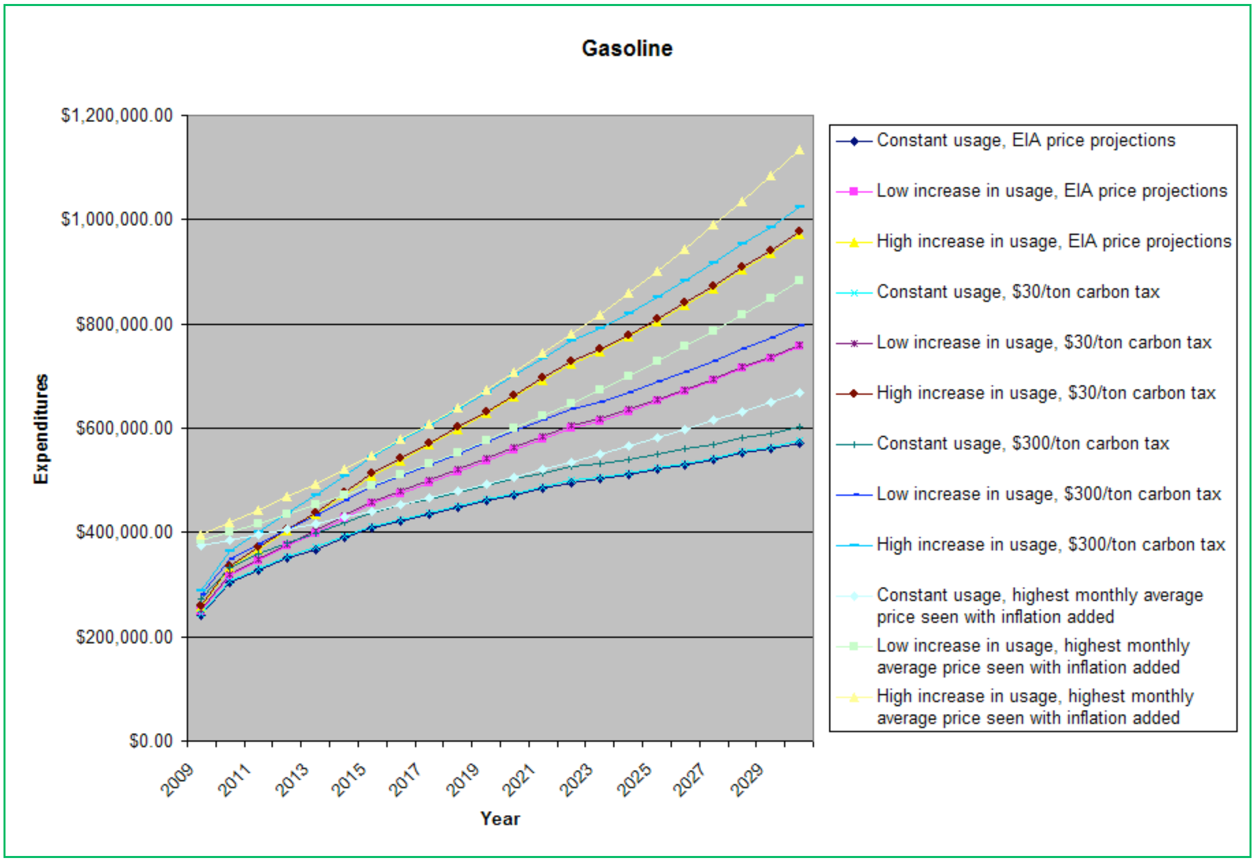
Figure 2: *Projected expenditures on electricity through 2030*



	EIA price projections	$30/ton carbon tax	$300/ton carbon tax	Peak with inflation
Constant usage	$114 million	$128 million	$251 million	$190 million
Low increase in usage	$153 million	$200 million	$390 million	$256 million
High increase in usage	$179 million	$171 million	$335 million	$300 million

Table 2. *Cumulative expenditures during 2009-2030 on purchased electricity under various price and usage regimes.*

Figure 3: *Projected expenditures on gasoline through 2030*



	EIA price projections	$30/ton carbon tax	$300/ton carbon tax	Peak with inflation
Constant usage	$9.9 million	$10 million	$11 million	$11 million
Low increase in usage	$12 million	$12 million	$13 million	$13 million
High increase in usage	$14 million	$14 million	$15 million	$16 million

Table 3. *Cumulative expenditures during 2009-2030 on gasoline under various price and usage regimes.*

We tried to project the College's energy expenditures if we make no changes and continue doing business as usual. We combined different levels of usage and price for each of the three main forms of energy that Dartmouth purchases. For usage, the three levels were: (1) a freezing of usage at 2007 calendar year levels (which is extremely unlikely), (2) relatively low increases in usage based on the increases between about 2004 or 2005 and 2007, and (3) higher increases in usage based on the best-fit line for the graph of energy usage between 1995 and 2007 (Ager 8, 11-12).

For price, we took the price changes projected by the Department of Energy's Energy Information Administration as a baseline because they are rather optimistic in that most of the increases predicted are due to inflation ("Forecasts and Analyses"), resulting in more conservative future expenditures. (All amounts are in nominal dollars because that is what we actually spend. The numbers for gasoline include taxes, but the numbers for the other fuels don't.) We then increased those prices to simulate future carbon taxes, both at the relatively low \$30/ton of CO_2 emitted and a higher \$300/ton of CO_2 emitted. To get a better sense of how high prices may get in the future, we also took the highest recorded monthly average price during the energy crisis in the past year or two—over the entire country for #6 fuel oil and gasoline ("Petroleum Navigator") but specifically in New Hampshire for electricity because that data was available ("Average Retail Price of Electricity")—and incorporated inflation. It must be noted that the price of electricity was much less affected by the recent energy crisis than were the prices of #6 fuel oil and gasoline, so the \$300/ton carbon tax would have a much greater proportional effect for electricity, and thus produce the highest expenditure projection.

No inflation projections were available, but we averaged the inflation that has occurred since 1990 to get a value of 2.8% ("Consumer Price Index"). Of course, the fact that Dartmouth buys energy in bulk and on contract means that the market price (much less the forecasted price) will not necessarily reflect the price Dartmouth pays, but if the market price goes up, the price Dartmouth pays will eventually go up as well. Understandably, expenditures increased with higher increases in usage, but expenditures also generally increased from the bare EIA projections through the two levels of carbon taxes to the energy crisis projections. The market has thus demonstrated a stronger corrective power than carbon taxes at the levels currently proposed, but that only happens when unfavorable circumstances converge, which will admittedly have a higher likelihood as we approach the period of peak oil. It would not be wise to wait and hope that those sharp corrections do not occur again. Even without more energy crises, the College will be spending more on fossil fuels in the future. In taking into account the current economic downturn, the hindered endowment and recent budget-cutbacks, fossil fuels may soon be a luxury that the College cannot afford. Indeed, the total projected costs with the higher estimates from all three fuels combined approach or surpass the recent losses from the endowment ("Protecting the Student Experience").

1.2. Cash-Flow Analyses

Cash-flow analyses were performed for the majority of the recommendations within the plan with results reported separately for each project as well as aggregated into a summary. For the latter, the savings of each project were simply stacked instead of weighted because we judged any overlap to be small enough that it was negligible. (Financial and carbon emissions estimates were lacking for several projects in the time that we had, so those unfortunately had to be sidelined for the time being) Each project was examined on its own as well as with the changing costs of fuel explicitly accounted for. The minimum and maximum fuel savings scenarios were taken from the lowest and highest expenditure projections, respectively, in Part I for each fuel. Said savings were either modeled as a constant proportion of energy usage or a constant amount of energy saved, depending on the project. The addition of these fuel savings (Figure 9, Table 9, Figure 11, Table 11, Figure 13, Table 13) made some projects feasible that would not have otherwise been.

These analyses looked at a 21-year period ending in 2030, setting 2009 as year 0 and assuming that all of the projects are immediately implementable. The inflation of 2.8% per year from Part I of this section was used to predict the nominal values of the cash flows at each point in time, and the interest rate given by the Renewable Energy and Energy Efficiency Business Loan program was used for the capital cost, with 3.25% being the banks' prime rate in the past few months, according to the Federal Reserve's records on interest rates. Tax credits (assuming that we had an alumni corporation to take advantage of them and pass the savings on to Dartmouth) and other financial incentives are already included in the initial cost values we used. However, maintenance costs have not been factored in.

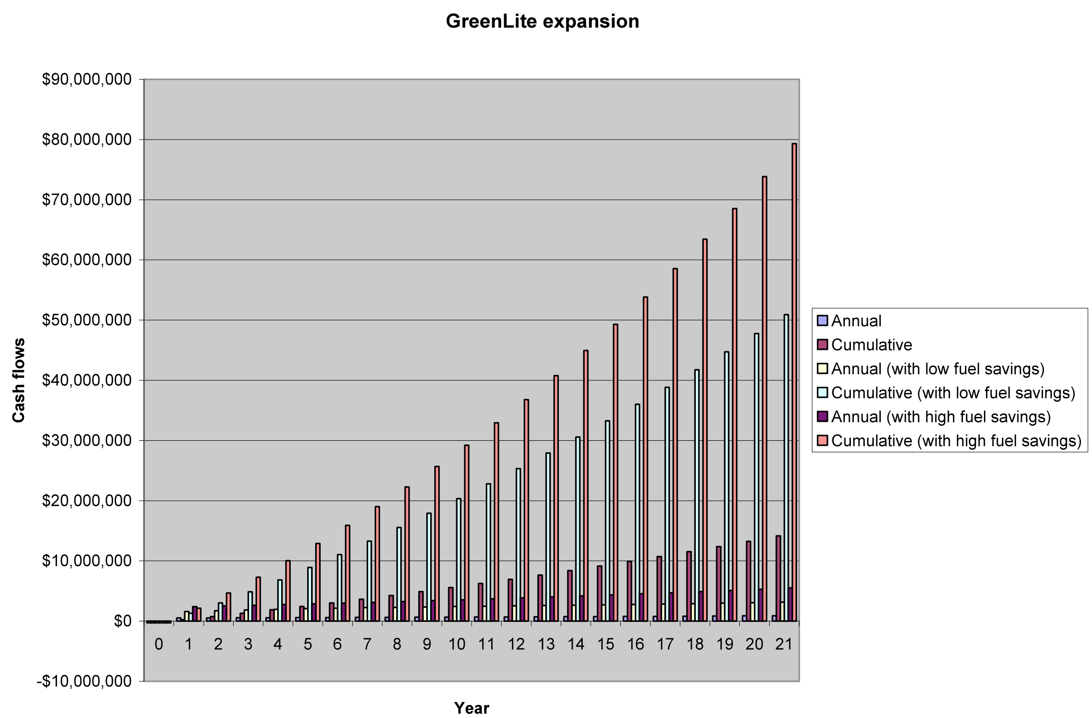


Figure 4. *Cash-flow analysis with two different levels of complexity for expanding the GreenLite energy conservation program.*

	Simple analysis	Including low fuel savings	Including high fuel savings
Payback period	1 year	1 year	1 year
Net present value	$11 million	$38 million	$59 million
Rate of return	190%	586%	881%

Table 4. *Summary of results for expanding the GreenLite energy conservation program. It saves 9% of Dartmouth's #6 fuel oil usage and 4.4% of the purchased*

electricity usage per year (the latter is less because Dartmouth has to buy more electricity to make up for less cogeneration).

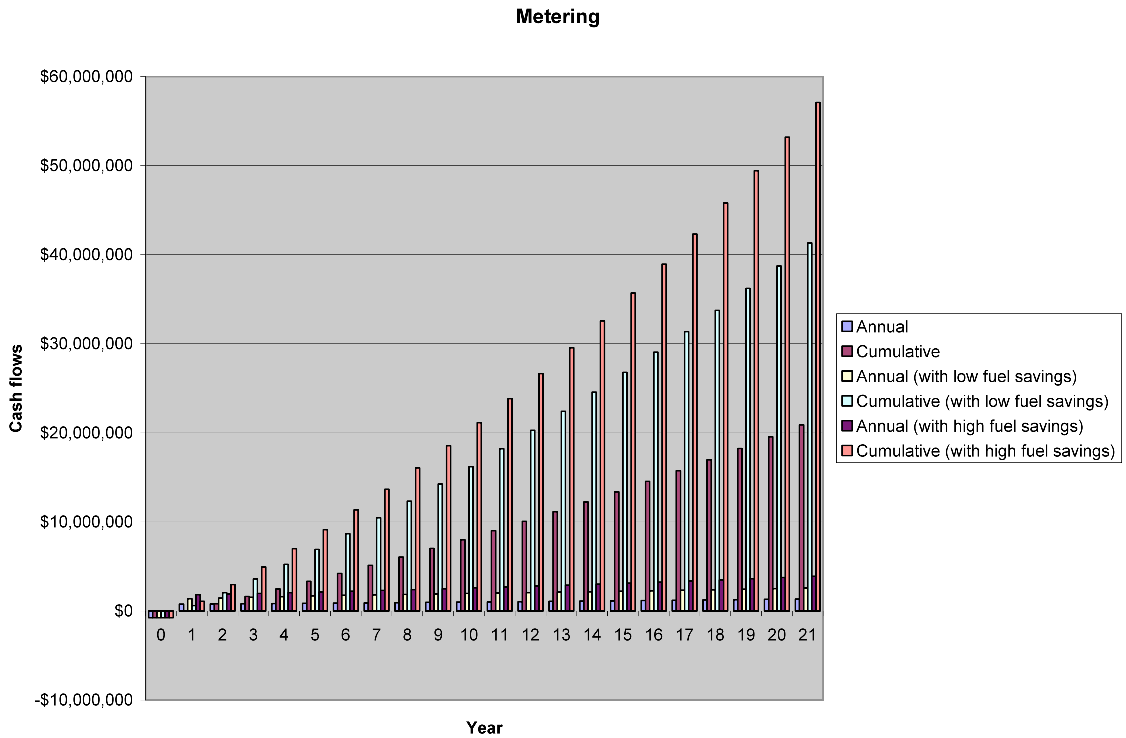


Figure 5. *Cash-flow analysis with two different levels of complexity for installing energy meters.*

	Simple analysis	Including low fuel savings	Including high fuel savings
Payback period	1 year	1 year	1 year
Net present value	$16 million	$31 million	$43 million
Rate of return	106%	188%	247%

Table 5. *Summary of results for installing energy meters. They save 5% of Dartmouth's #6 fuel oil usage and 2.4% of the purchased electricity usage per year (the same caveat applies as above).*

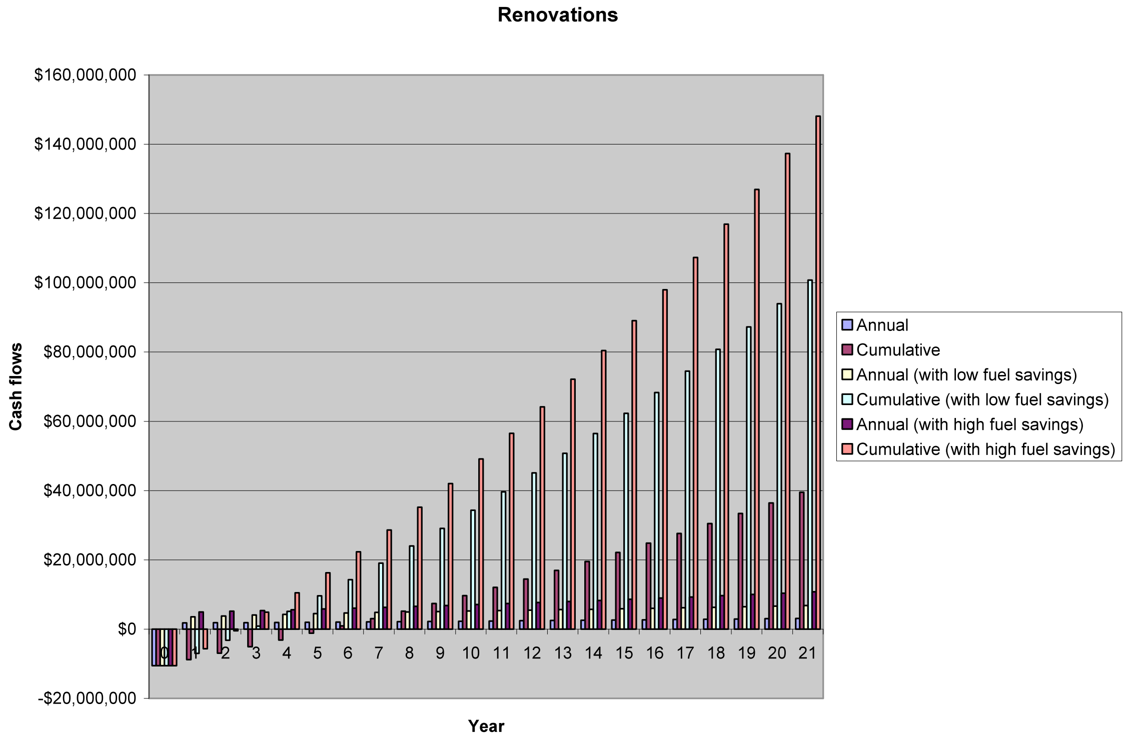


Figure 6. *Cash-flow analysis with two different levels of complexity for renovating buildings to be more energy-efficient.*

	Simple analysis	Including low fuel savings	Including high fuel savings
Payback period	6 years	3 years	3 years
Net present value	$27 million	$74 million	$108 million
Rate of return	19%	39%	51%

Table 6. *Summary of results for renovating buildings to be more energy-efficient. It saves 15% of Dartmouth's #6 fuel oil usage and 7.3% of the purchased electricity usage per year (the same caveat applies as above).*

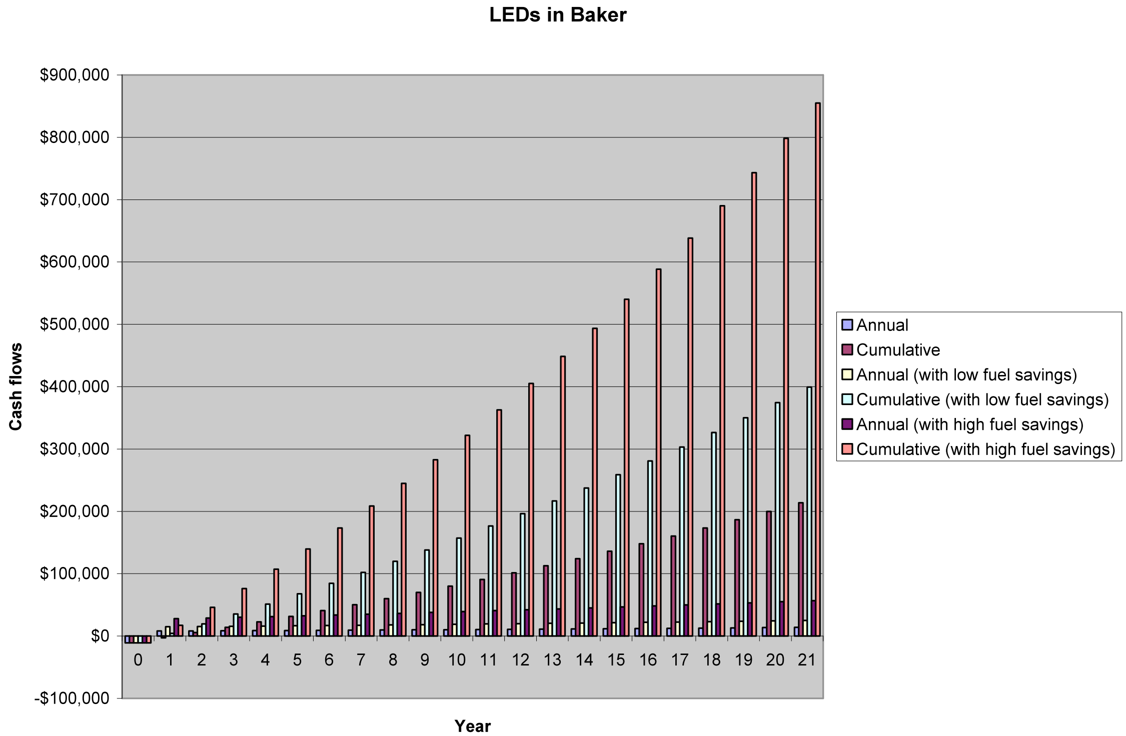


Figure 7. *Cash-flow analysis with two different levels of complexity for replacing the light bulbs currently in Baker Library with LEDs.*

	Simple analysis	Including low fuel savings	Including high fuel savings
Payback period	2 years	1 year	1 year
Net present value	$159,000	$300,000	$639,000
Rate of return	77%	141%	262%

Table 7. *Summary of results for replacing the light bulbs currently in Baker Library with LEDs. They save 0.17% of our purchased electricity usage per year.*

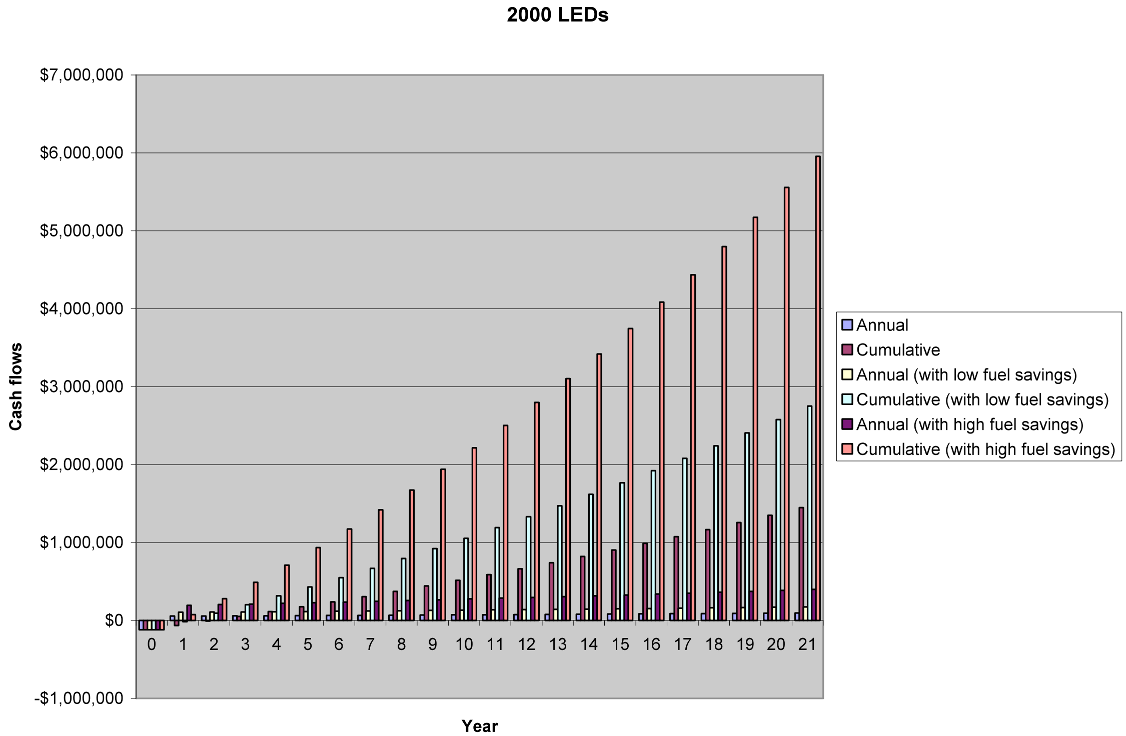


Figure 8. *Cash-flow analysis with two different levels of complexity for doing a general replacement of 2000 current light bulbs with LEDs, excluding the ones in Baker Library.*

	Simple analysis	Including low fuel savings	Including high fuel savings
Payback period	3 years	2 years	1 year
Net present value	$1.1 million	$2.1 million	$4.4 million
Rate of return	49%	90%	167%

Table 8. *Summary of results for doing a general replacement of 2000 current light bulbs with LEDs, excluding the ones in Baker Library. This action is projected to reduce 1.2% of our purchased electricity usage per year.*

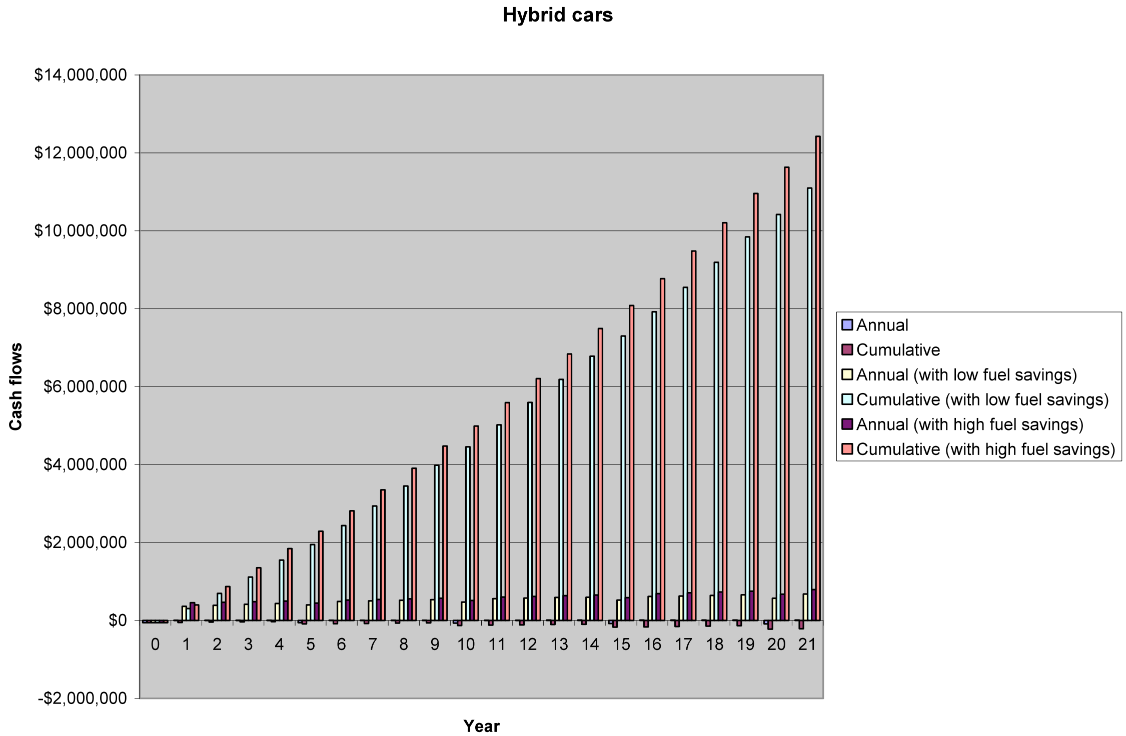


Figure 9. *Cash-flow analysis with two different levels of complexity for replacing Dartmouth's vehicle fleet with hybrids.*

	Simple analysis	Including low fuel savings	Including high fuel savings
Payback period	N/A	1 year	1 year
Net present value	-$167,000	$8.4 million	$9.4 million
Rate of return	N/A	660%	826%

Table 9. *Summary of results for replacing Dartmouth's vehicle fleet with hybrids. Hybrids save 119,000 gal of gasoline every year, but the cost is reapplied every 5 years as individual vehicles are replaced.*

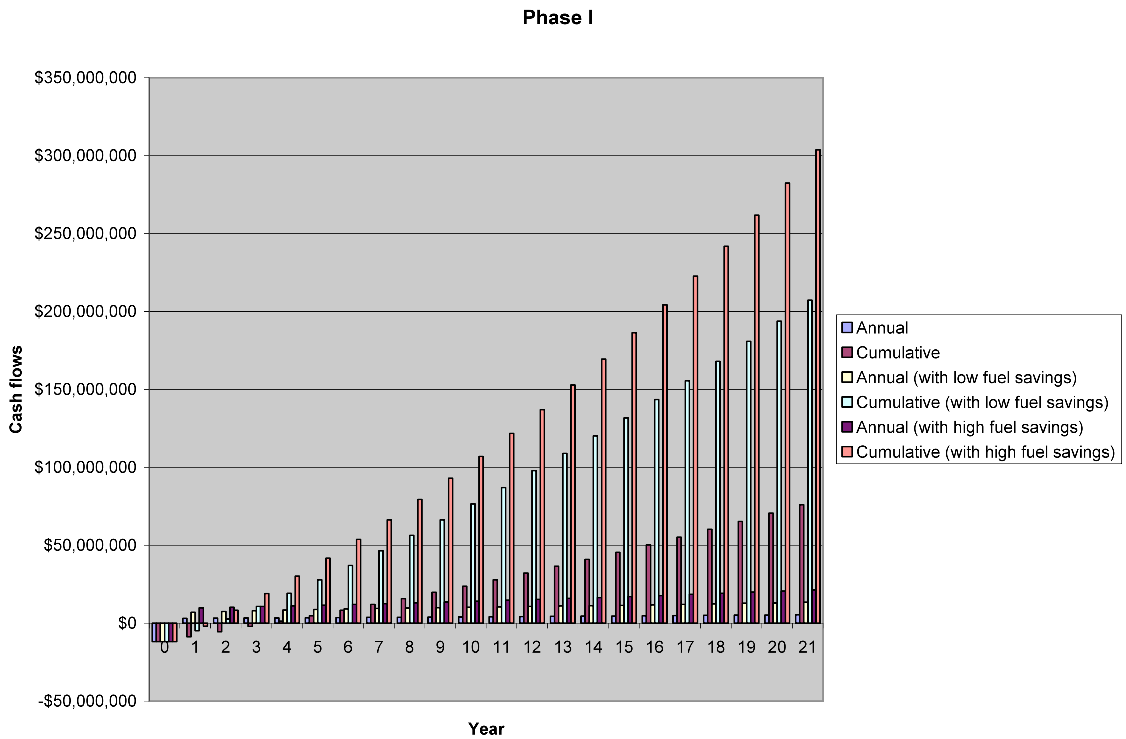


Figure 10. *Summary of the cash-flow analyses for the above projects from Phase I.*

	Simple analysis	Including low fuel savings	Including high fuel savings
Payback period	4 years	2 years	2 years
Net present value	$55 million	$154 million	$225 million
Rate of return	29%	65%	88%

Table 10. *Summary of results for the above projects from Phase I.*

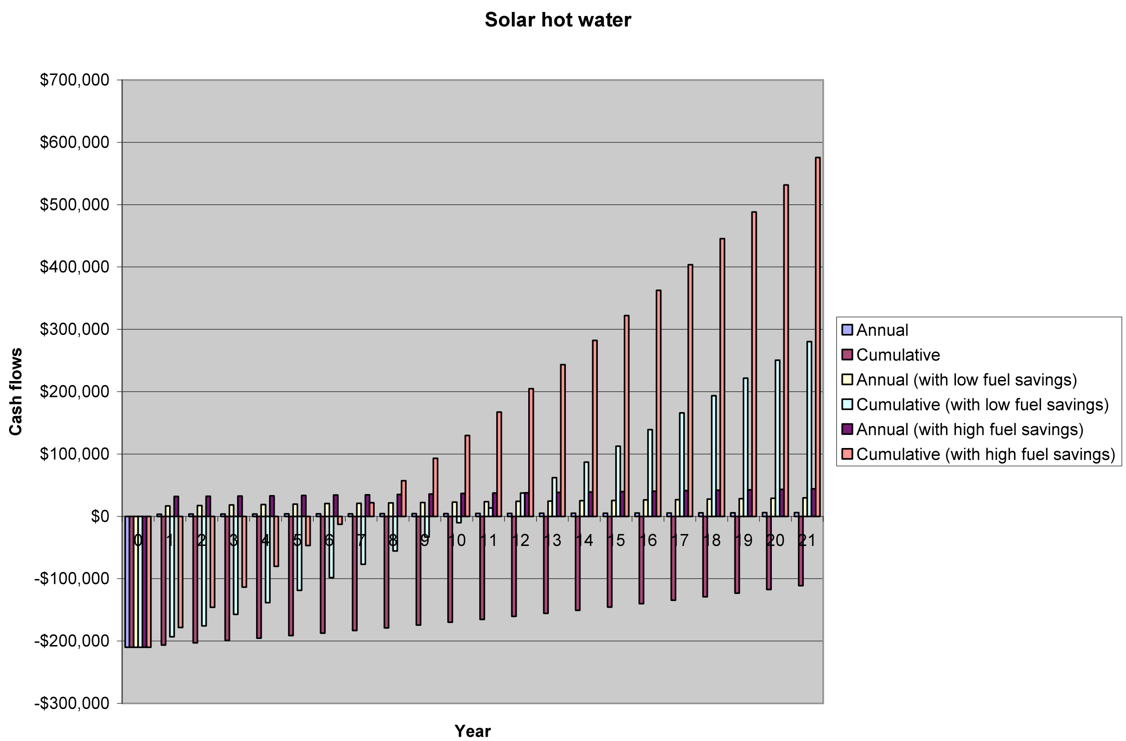


Figure 11. *Cash-flow analysis with two different levels of complexity for installing solar hot water systems.*

	Simple analysis	Including low fuel savings	Including high fuel savings
Payback period	More than 21 years	11 years	7 years
Net present value	-$131,000	$165,000	$394,000
Rate of return	N/A	8%	16%

Table 11. *Summary of results for installing solar hot water systems. They save 2300 gal of # 6 fuel oil and 88,000 kWh of purchased electricity per year (decremented for the loss of cogenerated electricity).*

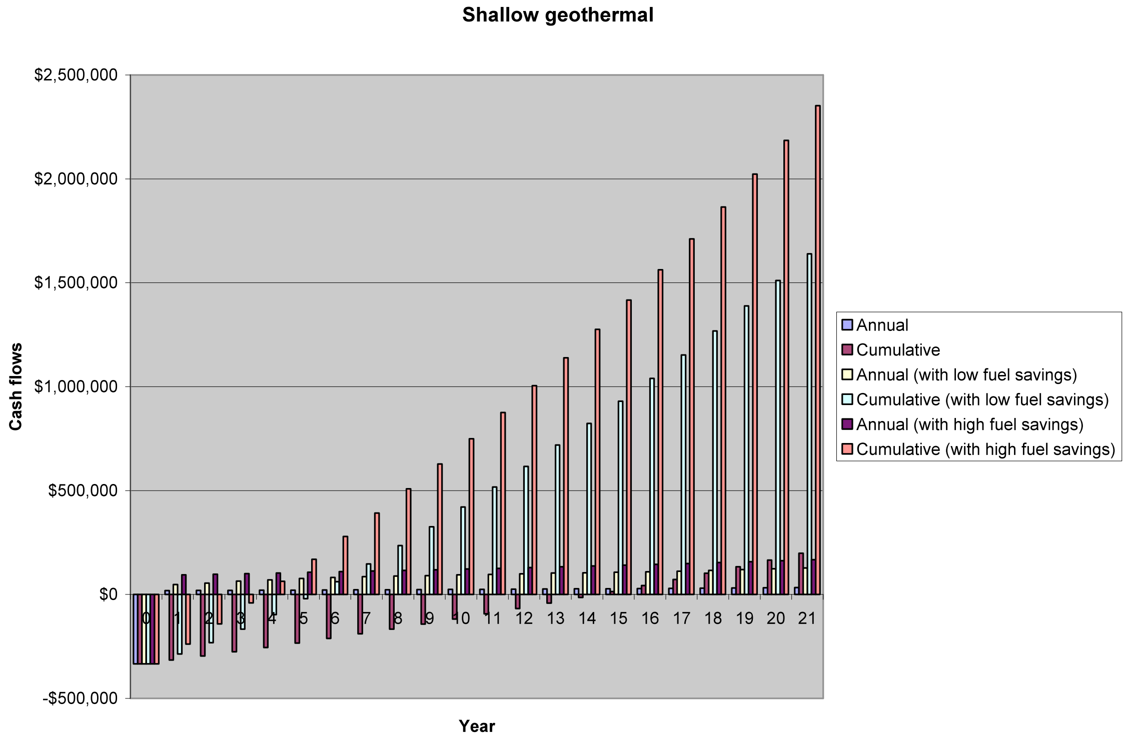


Figure 12. *Cash-flow analysis with two different levels of complexity for installing ground-source heat pumps.*

	Simple analysis	Including low fuel savings	Including high fuel savings
Payback period	15 years	6 years	4 years
Net present value	$76,000	$1.2 million	$1.7 million
Rate of return	4%	21%	31%

Table 12. *Summary of results for installing ground-source heat pumps. They save 31,000 gal of #6 fuel oil but increase Dartmouth's purchased electricity usage by 135,000 kWh per year (to make up for the loss of cogenerated electricity).*

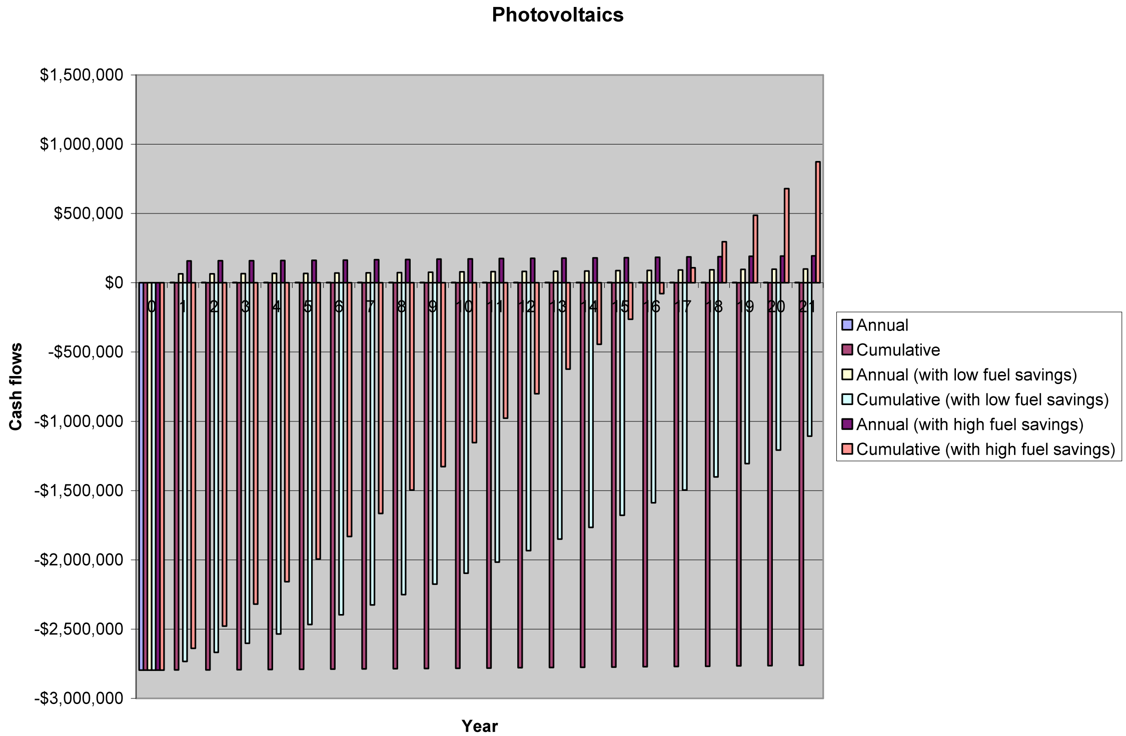


Figure 13. *Cash-flow analysis with two different levels of complexity for installing photovoltaic arrays.*

	Simple analysis	Including low fuel savings	Including high fuel savings
Payback period	More than 21 years	More than 21 years	17 years
Net present value	-$2.7 million	-$1.5 million	$76,000
Rate of return	N/A	N/A	3%

Table 13. *Summary of results for installing photovoltaic arrays. They save 639,000 kWh per year.*

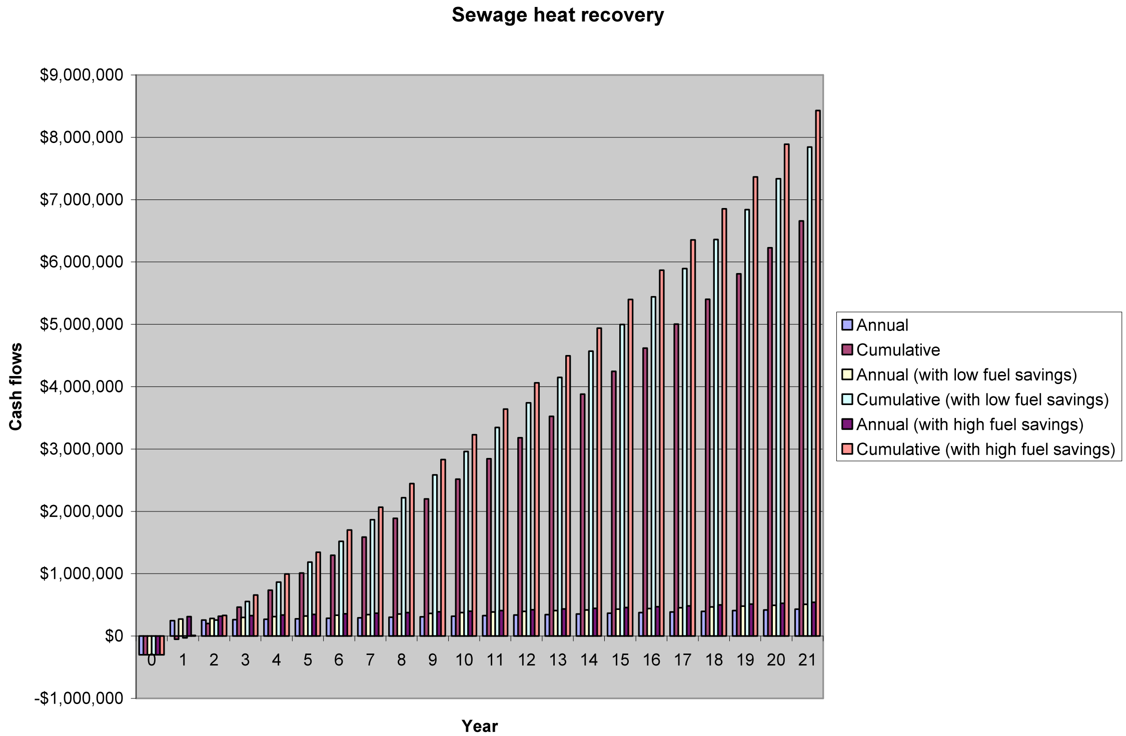


Figure 14. *Cash-flow analysis with two different levels of complexity for installing sewage heat recovery systems.*

	Simple analysis	Including low fuel savings	Including high fuel savings
Payback period	2 years	2 years	1 year
Net present value	$5.0 million	$5.8 million	$6.3 million
Rate of return	85%	95%	106%

Table 14. *Summary of results for installing sewage heat recovery systems. They save 26,000 gal of #6 fuel oil but increase Dartmouth's purchased electricity usage by 111,000 kWh per year (to make up for the loss of cogenerated electricity).*

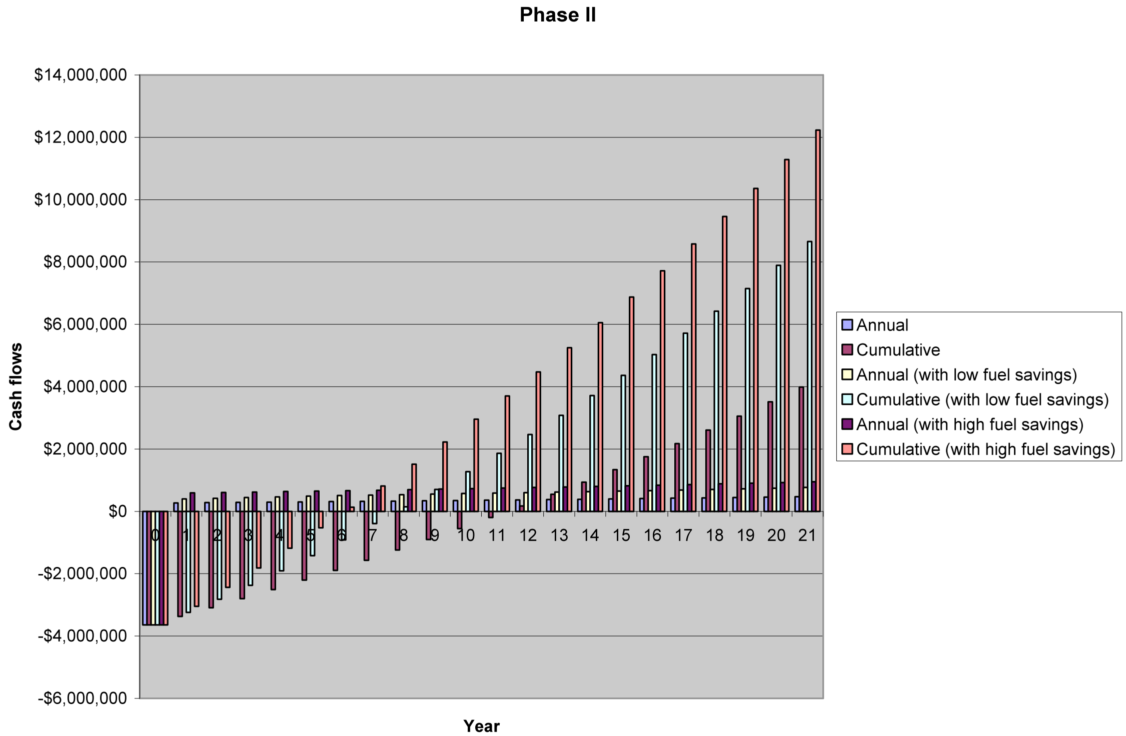


Figure 15. *Summary of the cash-flow analyses for the above projects from Phase II.*

	Simple analysis	Including low fuel savings	Including high fuel savings
Payback period	12 years	8 years	6 years
Net present value	$2.2 million	$5.7 million	$8.5 million
Rate of return	7%	13%	18%

Table 15. *Summary of results for the above projects from Phase II.*

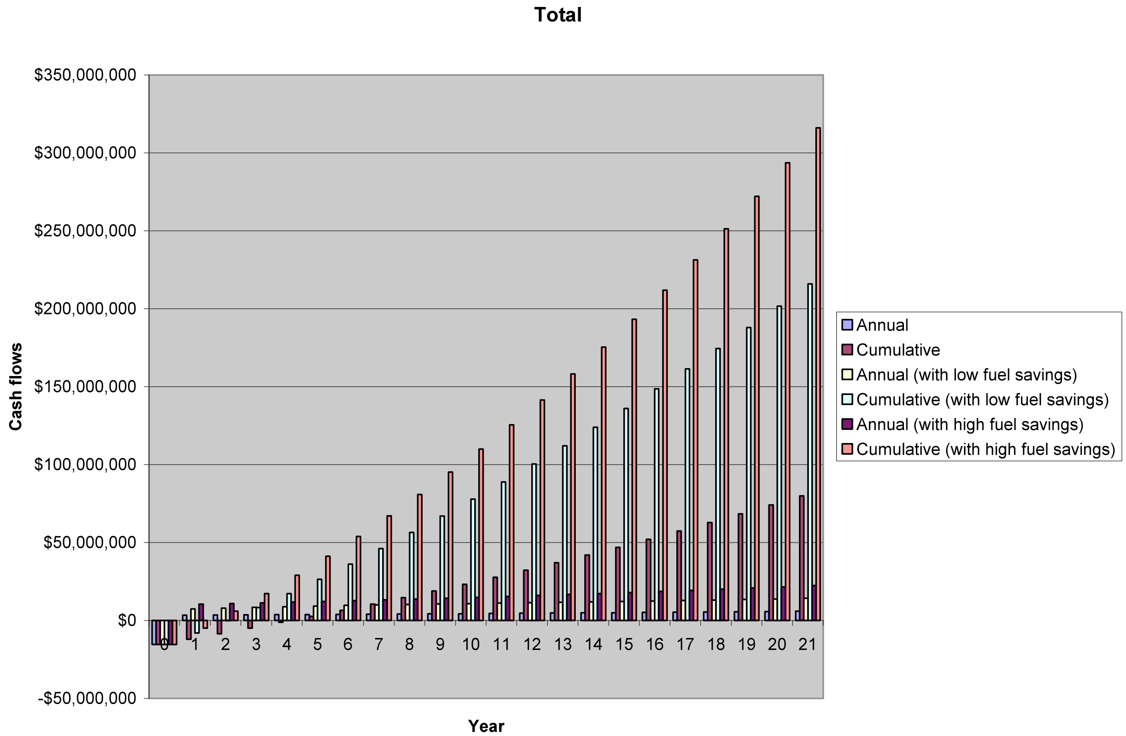


Figure 16. *Summary of the cash-flow analyses for all of the above projects.*

	Simple analysis	Including low fuel savings	Including high fuel savings
Payback period	5 years	3 years	2 years
Net present value	$57 million	$159 million	$233 million
Rate of return	24%	54%	72%

Table 16. *Summary of results for all of the above projects.*

1.3. Tax Incentives

Additionally, if the College, rather than waiting for an external carbon tax to be imposed, instead instituted its own carbon tax, a fund (to potentially be invested in parallel to the endowment) would become available to finance future sustainable initiatives on campus (Table 17, Table 18, Table 19).

	Constant 2007 usage	Low increase scenario	High increase scenario
$30/ton carbon tax	$4.3 million	$4.6 million	$5.6 million

$300/ton carbon tax	$43 million	$46 million	$56 million

Table 17. *Assets Dartmouth would accumulate to invest over 2009-2030 from two different levels of self-imposed carbon taxation under various usage scenarios for #6 fuel oil.*

	Constant 2007 usage	Low increase scenario	High increase scenario
$30/ton carbon tax	$14 million	$18 million	$21 million
$300/ton carbon tax	$137 million	$182 million	$211 million

Table 18. *Assets Dartmouth would accumulate to invest over 2009-2030 from two different levels of self-imposed carbon taxation under various usage scenarios for purchased electricity.*

	Constant 2007 usage	Low increase scenario	High increase scenario
$30/ton carbon tax	$66,000	$77,000	$91,000
$300/ton carbon tax	$657,000	$772,000	$907,000

Table 19. *Assests Dartmouth would accumulate to invest over 2009-2030 from two different levels of self-imposed carbon taxation under various usage scenarios for gasoline.*

2. Securing Funding

2.1. Alumni Donations

Peer institutions have recognized the potential to secure new or added alumni support by creating specific sustainability funds. The University of California Irvine set a fund-raising record last year thanks to donations to energy and environmental research. Stanford Alums gave a combined $100 million to build an energy institute dedicated to research of everything from solar cells to alternative green investments.

Environmentally minded donors include both the rising number of young alumni as well as older philanthropists. Half of Stanford's $100 million energy institute was donated by a single man hoping for Stanford to "more effectively manage energy consumption at the individual, corporate and government level." Independent of the school, Dartmouth alums have set up websites and interest groups dedicated to socially responsible alumni, networking, and updates on what Dartmouth is doing with respect to these issues. The alumni provide a substantial support network for future carbon reducing, cost saving initiatives.

Alumni also have the potential to invest in specific renewable energy projects, using state and federal tax credits. There are numerous individual tax credits that are available for investments in renewable energy and conservation measures. Dartmouth College itself, as a non-profit entity, is eligible for just a fraction of these savings amounting to $7,000. This credit comes from a New Hampshire rebate program that provides a maximum incentive of $3,500 for both solar thermal and photovoltaic projects.

However, if Dartmouth College was willing to lease roof space to a corporation, possibly founded by alumni and friends of the College, it could see a much larger return on investment, as the commercial sector is eligible for considerably larger tax credits than are non-profits. In this scenario, solar thermal and photovoltaic arrays would both qualify for Business Incentive Tax Credits amounting to 30% of their installation costs, and shallow geothermal would qualify for a 10% credit. Based on the calculated costs of the three technologies, this would save the College $1.3 million. To go further, National Grid, the company who supplies Dartmouth with its purchased electricity, offers commercial customers an additional $100,000 towards the cost of a solar thermal array, bringing the total savings to $1.4 million.

Finally, energy efficiency and renewable energy projects qualify for a number of loans and cost-recovery programs. These include the New Hampshire Renewable Energy and Energy Efficiency Business Loan, which provides an interest rate of the prime minus 1% (floating), the US Department of Energy Loan Guarantee Program, which focuses on large-scale projects, and the federal Modified Accelerated Cost-Recovery System (MACRS) + Bonus Depreciation, which allows businesses to recover investments through depreciation deductions. While these loans and programs are much more difficult to quantify, they would enable Dartmouth to realize a faster return on investment, making the proposed projects more financially feasible.

2.2 Revolving Green Loan Fund

Through the creation of a "Green Loan Fund," Dartmouth has the chance to create an inexhaustible program to finance environmentally beneficial projects and mark them as capital gains rather than expenditures. A green loan fund is an account set aside to pay the up-front costs of conservation projects that accumulate wealth through energy savings. The underlying principle is that most environmental projects pay for themselves in less than ten years from the energy savings accrued. When projects receive up-front financing, energy savings pay off the loan.

The benefits of such a fund are three-fold, the first and most important of which is the positive environmental impact. Harvard was the first school to implement a revolving green loan fund in 2002. To date it has financed 153 projects and prevented thousands of tons of carbon dioxide and other pollutants from entering the atmosphere. A revolving green loan fund is an innovative and proven way of helping Dartmouth forward its environmental mission.

The second advantage of such a fund is the economic savings it provides. As mentioned, once that time is elapsed, these projects generate positive cash flow for the school. In its first two years, the Harvard Green Campus Loan Fund, with an initial investment of $3 million, saved the school nearly $900,000. Thus, if nothing else, it can certainly be considered part of a sound fiscal strategy.

The third gain to be had from a revolving green loan fund is the education and empowerment of the students and campus. For a Dartmouth student to go through the process of devising and implementing a lasting campus improvement is an invaluable opportunity for both the school and the individual. Additionally, since green technology on campuses is the way of the future, it only makes sense that faculty and staff would want to work in classrooms and settings that are at the top of society's ecological standards

With set guidelines for accepted projects as well as a board that could approve loans, the revolving green loan fund could be quite self-sustaining and successful, thus raising Dartmouth's status as a forward-thinking, environmentally-minded institution. To date, Harvard has already issued $8 million in loans, and several schools and institutions have followed its leadership, including: Yale, Connecticut College, University of Maine, and the state of Texas (Texas LoanSTAR). Outlined below are the details of the fund, procedures, and possibilities.

Criteria

This revolving green loan fund would not be limited to just student initiatives. The loans would be available to anyone affiliated with Dartmouth, from Dining Services to the Accounting department who can demonstrate a potential for environmental improvement. In order for a project to be approved, it will need to address one or more of the following topics:

- Greenhouse gas reductions
- Energy conservation
- Water conservation
- Sewage and storm water output reductions
- All types of pollution reduction:
    - Hazardous waste
    - Solid waste
    - Liquid waste
    - Gaseous emissions
- Operations improvements that decrease environmental impacts
- Environmental procurement practices
- Environmental leadership development within the Academy
- Number of individuals with improved environmental literacy and increased levels of participation in conservation activities
- Education of and reputation building with surrounding community

These projects must generate infrastructural or behavioral improvements that directly decrease Dartmouth's current environmental impact. Additionally, projects must be able to demonstrate a payback period of less than 10 years.

Procurement of Funds

The fund could be set up one of four ways. One option is to go directly to the alumni for donations to the fund. There would likely be no shortage of alumni willing to donate so that Dartmouth could become the first Ivy League college to undertake the formation of a green loan fund and a carbon neutrality commitment. Supplementing the current Campaign for Dartmouth, an amount as high as $500,000 could be raised in short order.

The next option is a direct allocation of the funds (this is what was done at Harvard University). These funds could either come from the College operating budget or directly from the trustees. Either way, these funds need to be approved by the trustees in the annual budget.

There is also the option of utilizing the $12 million the trustees recently allotted to Steve Shadford for energy saving initiatives. If that money were to be made into a loan fund, Dartmouth would have a fund that is equal in size to Harvard's, and Mr. Shadford could still follow through with all his projects (but savings would be used to replenish the fund first).

The most intriguing option is the possibility of using funding from the endowment to set up the loan fund. Rather than investing the endowment in stocks, a small fraction (as small as 1/100th of 1%) could be invested back into Dartmouth. Savings are recorded as return on investment (ROI) and would, where this year's endowment fell significantly, instead perhaps prove to be approximately 27% like that seen at Harvard.

Whatever the method employed, greenhouse gas mitigation and general environmental stewardship are of the most rapidly expanding and worthwhile causes that institutions of higher learning face, and so committing Dartmouth and its resources to this future will no doubt be both applauded and assisted by all those affiliated.

Project Selection

Currently, efficiency measures are being taken by Steve Shadford after securing the aforementioned $12 million to pursue various projects, and departments may chose to pursue some environmental measure when there is time. A revolving green loan fund would be an easy way for many campus members to get involved with efficiency projects at Dartmouth.

However, guiding those applicants through the approval and execution process would be a labor-intensive occupation. It is suggested that student environmental groups (ECO or possibly a new group) be constantly educated and involved with assisting the various projects on campus. Students could help each project with feasibility assessments, rebates and grants research, project management and implementation, new technology identification and evaluation, targeted education and training for those engaged by the improvements, and publicity and communication.

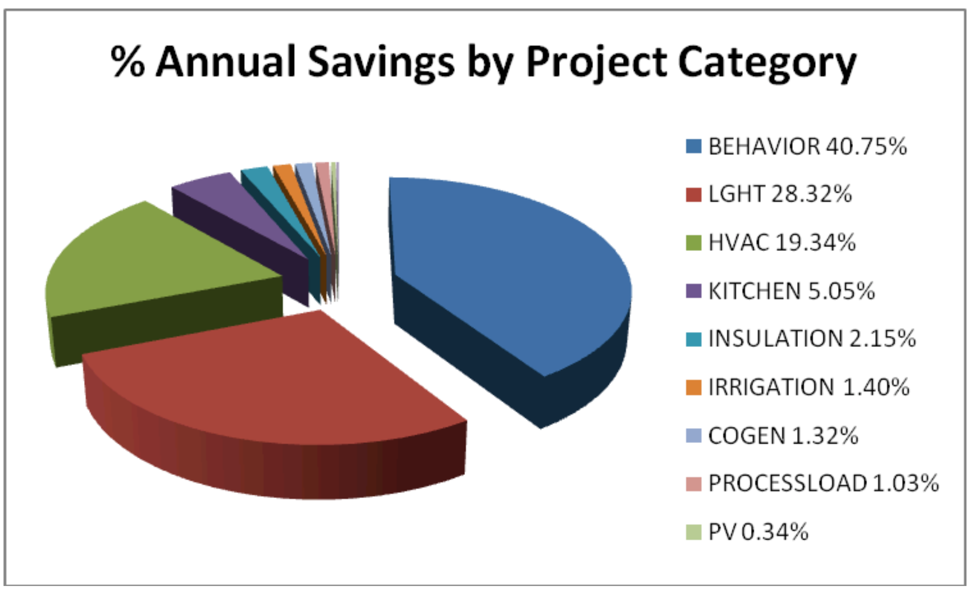
Those projects of a magnitude beyond the ability of students may then be guided directly by the sustainability coordinator or a similarly suited faculty position. While Harvard hired a new employee of the Harvard Green Campus Initiative to manage the loan fund directly, at Dartmouth it would be possible to work this financing opportunity into our existing structure.

Research Review

Harvard.

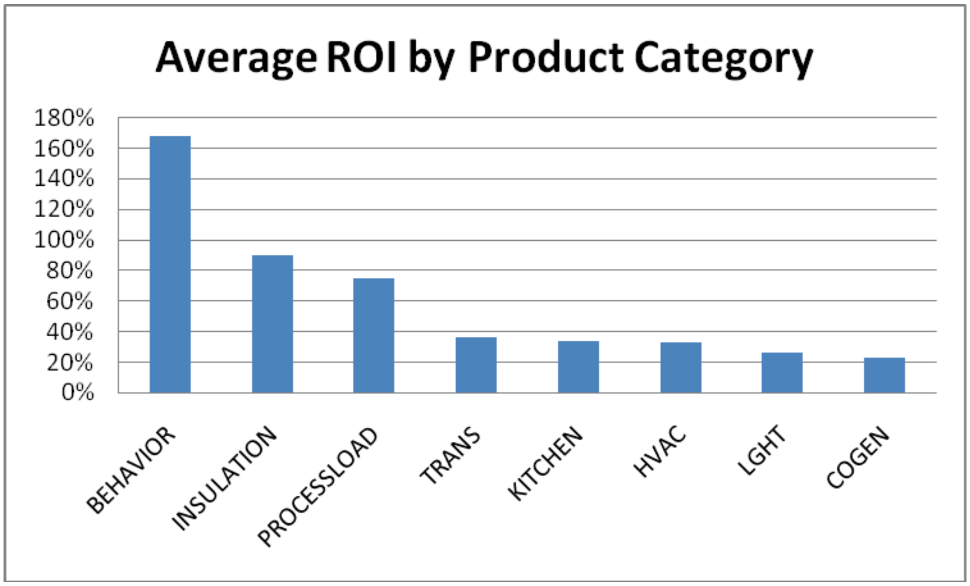
The most prominent source for information is the Harvard Green Campus Initiative ("HGCI") website. The HGCI is responsible for maintaining and managing the revolving green loan fund of 12 million dollars at Harvard University. When flicking through the site, one of the first pages that catches one's attention is the *achievements* page. In a simple graph the HGCI shows how Harvard has prevented 27,414 metric tons of CO_2 from being emitted into the atmosphere, as well as saving 15,269,877 gallons of water, and 200,000 pounds of trash from being wasted. The next and arguably more impressive figure given is the annual savings from the loan fund. The Harvard Green Campus Loan Fund is expected to save the school approximately $4 million this year, with an annual ROI of 35%. That makes this greening measure more profitable than most standard, fiscally oriented investments.

Another element of the HGCI that Dartmouth can draw upon is the delineation of what projects produce what sort of results. As it turns out, projects striving to change behavior (conservation projects) produce the most in savings, racking up approximately 41% of the $3,912,099 Harvard will save this year from the green loan fund. This serves to emphasize the true need for and effectiveness of general conservation on campuses; small changes in behavior yield huge results when spread about the entire institution. The large savings accrued from heating, ventilation, and air conditioning ("HVAC") improvements only support the idea that Dartmouth can make huge bounds by improving the radiators and heating in rooms on campus. For example, the number of windows thrown wide open on campus in the dead of winter is astounding, all because of faulty radiator controls, and there is not a day that goes by that a student is not complaining about their antiquated radiator controls. Letting students solve the problem, rather than FO&M running around trying to keep up with the problem, may prove quite successful.



An additional graph from Harvard shows the return on interest for their 126 various projects. With the exception of one solar photovoltaic array, every project has an annual ROI of

20% or higher. The graph below again shows the benefits of behavior modification projects, which tend to pay for themselves in under a year.



The Harvard Green Campus Loan Fund (GCLF) website also offers more abstract information on benefits to a revolving green loan fund, like the cross-fertilization of project ideas. Since the HGCI manages the GCLF, it allows them to be a focal point of green thought on campus, and help spread ideas from one building or department to other locations on campus.

New York.

The New York Times ran an article May 17th, 2007, about what will be the largest revolving green loan fund yet. Spearheaded by Michael Bloomberg, Mayor of New York City, and former President Bill Clinton, a coalition of mayors from the sixteen largest cities in the world got together with five major banks to negotiate the creation of numerous billion dollar green loan funds that will allow city governments and landlords to receive the upfront cost necessary to make green, energy saving retrofits throughout the participating cities. When revolving green loan funds become staples in major U.S. cities with bureaucracies as complex as those in New York City, there is no reason a similar fund cannot be instituted at Dartmouth.

AASHE.

The Association of the Advancement of Sustainability in Higher Education ("AASHE") guide to revolving green loan funds provides a full-length guide to putting together a loan fund on any institution of higher education. Written by two students at Macalaster University, it provides a wealth of information including what schools have done, previously-formed loan funds, and how to write the funding application. The information about efforts around the country has proven extremely valuable already and can already be included in the Dartmouth proposal.

Conclusion

A revolving green loan fund at Dartmouth is entirely feasible and would be highly successful. If Dartmouth truly hopes to reduce its carbon footprint, it will take innovation, dedication, and involvement from every aspect of the campus, students to staff members, and a fund like this provides the means. If the projects undertaken by various members of the community offer anything even close to the 30% ROI that Harvard has achieved, then the money put into a revolving green loan fund will far outperform any funding kept in the current endowment process. While saving money and the environment in one act, a revolving green loan fund would also serve to educate and empower the community, allowing them to involve themselves in the acting of greening the Big Green.

2.3 Financial Conclusions

In the future, fiscal security is going to be the bottom line on any and all new policy recommendations and actions taken by the college. In writing this report, the economic viability of any options discussed has been analyzed and emphasized in an effort to legitimize the real potential of carbon neutrality at Dartmouth College. As can be seen in the expenditure analysis, the costs of #6 fuel oil, gasoline and electricity are projected to rise considerably even in as short a timeframe as the next 21 years. These increases in energy costs will only be exacerbated by state and federal carbon taxes and will thus lead to very real economic losses for the college over the next 21+ years. In taking into account the cash flow analyses and proposal for a Dartmouth Revolving Green Loan Fund, it can be seen that initiatives associated with minimizing dependence on oil and grid electricity will have up-front costs, but will also be paid for, in most cases, within 21 years, after which these initiatives will in fact become internally profitable.

For future raw analysis as to costs associated with implementing sustainable measures compared to relying on oil and grid electricity, the following equation can be applied to any and all initiatives using future costs of oil and electricity:

$$(((\text{COI } \$/\text{yr}) - (\text{Tax Credits } \$/\text{yr})) \times (\#\text{yrs installed})) \div (\$/\text{yr saved}) = \text{Payback pd.}$$

*COI = Cost of Implementation

**$/yr saved are adjusted from fuel and electricity costs abated using $/BTU or $/kWh

For Carbon Reduction Cost Efficiency, use the equation:

$$(\text{Adjusted Cost (raw cost - tax credit) } \$/\text{yr}) \div (\text{MTCO}_2 \text{ abated/yr}) = \$/\text{MTCO}_2$$

*$MTCO_2$ = metric tons of carbon emissions abated, use $MTCO_2$/BTU or $MTCO_2$/kWh for fuel or electricity

**This equation will indicated the most cost effective means of carbon reduction, not necessarily the largest carbon reduction strategies

Chapter 4: Marketing, and Publicity

I. Marketing

One of the key benefits of forming a commitment to carbon neutrality at Dartmouth is the ability to utilize this to generate positive press, garner increased fundraising rates and attract an even more discerning applicant student.

1. Background

The problem, however, becomes the question of how to "market" and sell the plan to the greater Dartmouth community, because a truly progressive movement like this requires full involvement from the entire community. One of the fundamental problems of environmental causes is the difficulty they encounter marketing and publicizing their causes. Green marketing is so difficult because of the current market culture in the United States. Our society is used to, and expects, immediacy—in profits and results. One of the fundamental "problems" with sustainability is that to the generally environmentally illiterate public, the required green changes have longer payback periods than their conventional counterparts and they often do not deliver real results, in terms of emission reductions, for a long time. This also brings to point a second inherent problem in marketing sustainability and carbon neutrality—there is no concrete product to market to the average consumer. The problem with sustainability is that immediacy and consumerism in our culture encourage the public to expect a direct, physical result; especially when they are making a sacrifice, monetary or otherwise. Since environmental efforts create changes on both minuscule scales (like the weaning off of pesticides improves the health of the local insect ecosystem) and immense, global scales (like the emission from a single car in Argentina aids in ice cap melting in the North Pole), it is often hard for the uninformed consumer to understand why these sacrifices have to made. Even when they do agree to make the sacrifice, there is no concrete proof that the measures are making a difference. This is why the movement has found such success with getting consumers to switch to compact fluorescent light bulbs. By providing a concrete object for consumers, and providing an immediate effect (in the lowering of their electrical bill), the compact fluorescent light bulb becomes an instantly marketable product.

2. Marketing at Dartmouth

What is exciting about this report is that it has created a concrete idea to sell—the overall "steps" or final plan to carbon neutrality. This is a big benefit, as it allows the college a "product" that can be aggressively marketed to the student body, alumni and surrounding community.

Despite the problems with marketing, sustainability has become a "hot-button" issue in the country today. Steps towards sustainability among college campuses frequently make the news in major publications. On April 29, 2009, The New York Times ran a cover story on the seemingly small issue of college cafeteria trays. The reason the story made the front page was the relationship between discontinuing cafeteria tray use, monetary and food waste savings and sustainability improvements (eliminating cafeteria trays saved Williams College an estimated 14,000 gallons of water annually). This is just one example of the impressive positive press that can be garnered from making sustainability commitments on campus. In order to fully compete with other prestigious universities, Dartmouth must make a firm, strong commitment to carbon neutrality.

For example, Middlebury College is an institution that competes with Dartmouth for similar applicants. In 2009, Middlebury revealed a plan for carbon neutrality by 2016, using a combination of efficiency measures, a new biomass heating plant and localized offsets. In a New York Times online search including the past 12-months of articles, the very first page of search results for Middlebury College returned three articles on their sustainability efforts while the same search for Dartmouth returned not a single article. Beyond national coverage, Middlebury aggressively markets their new neutrality efforts to their community. In line with theory behind truly sustainable planning, Middlebury continues to make efforts to educate the community and alumni of the plan. In addition to extensive information available on the website for the Administration's Sustainability Integration Office, but the plan—smartly titled "Winning the Race Together"—also has its own website, with a frequently updated blog, easy to find information and tips as to how the average student can reduce their own footprint and help to "win the race." Additionally, they have printed a well-designed, easy-to-read pamphlet that highlights the important aspects of the plan and stresses, once again, what the individual can do to help.

Our report includes a sample pamphlet that Dartmouth College could use to publicize this plan for carbon neutrality (see Chapter 4, Section II). We have created a slogan for the plan, much like Middlebury's, that emphasizes the joint, collective effort necessary for success and highlights the responsibility that Dartmouth has to creating a healthy, long-lasting community for the future of our College. The slogan, "Our Big Green Future: Steps Towards Carbon Neutrality at Dartmouth" also draws on our student-created logo. Using experience informed from research with professional, creative branding agencies, we have personalized an inked baby footprint into a sophisticated symbol that represents our efforts to minimize Dartmouth's collective green "footprint." The Lone Pine transposed into the heel of the print represents Dartmouth's traditional, long-standing connection to its local environment, while the green step represents our impact on the wider world. We believe this logo, which also plays on the recent "thumbprint" logo of the 2009 Dartmouth Energy Campaign, is eye-catching and memorable, allowing for myriad uses throughout campus to farther promote our plan. Imagine green footprints chalked over Collis Center porch, or printed adhesive appliqués walking down Baker Hall, leading to the display highlighting the key steps to Dartmouth's carbon neutrality. The logo can be used to create a permanent, visible sign of Dartmouth's commitment to our future that would be instantly recognizable and a calling card of environmental concern to all future applicants. Additionally, the pamphlet, branded with the new logo of carbon neutrality, can be distributed throughout campus, linked on our already created website and mailed out to alumni to quickly but thoroughly inform of the brave new steps Dartmouth is taking to commit to a long-lasting, sustainable future community.

With a professional logo and an educational, informative pamphlet on the plan, we believe Dartmouth's new efforts towards sustainability could be used to generate significant donations from the concerned (and now newly informed) alumni. Current opportunities to give to the College fund range from refurbishing study rooms in the Baker-Berry library to updating coach offices in the Alumni Gym to protecting a cultural tradition close to the giver—however, there is no place for a concerned alumni to donate to sustainability efforts on campus. The very first paragraph of the "vision" statement in the current capital campaign, "A Campaign for the Dartmouth Experience," informs that the campaign is "An Investment in the Long Term" and states that "What's really important" is creating the kind of "communities that sustain you and that you sustain." In this vein of co-dependence, Dartmouth has a responsibility to offer the opportunity for donors to define their own idea of a "sustainable community." There should certainly be a place for alumni to donate to the continued existence of a beautiful, green Dartmouth. Additionally, given the popularity of sustainability causes these days, I believe that marking carbon neutrality or green initiatives an imperative of the campaign or a "identified priority" would actually increase the number and variety of gifts donated to the College fund.

Scott Brown, '78, the CEO and founder of New Energy Capital and a well-connection Dartmouth alumnus, told our class he believes the alumni interest in a greener Dartmouth is vital and well spread. He recommended a new capital campaign for the College that focused, at least partly, on carbon neutrality and green initiatives on campus. At the very minimum, the College should provide at least one fund for concerned alumni to donate towards sustainability efforts. After speaking with Adam Keller, Executive Vice President, we believe that the best strategy to give alumni an opportunity to contribute to the cause of sustainability is to create a "mini" or interim capital campaign that would begin at the close of the current campaign (the end of 2009). These sorts of specialized campaigns are common during the time right after a major campaign and can be extremely successful in reaching new donors who have been looking for a special cause to donate to Dartmouth. Since the current campaign is just drawing to a close, the time is now to step forward and being a specalized campagin for Dartmouth's Big **Green** Future.

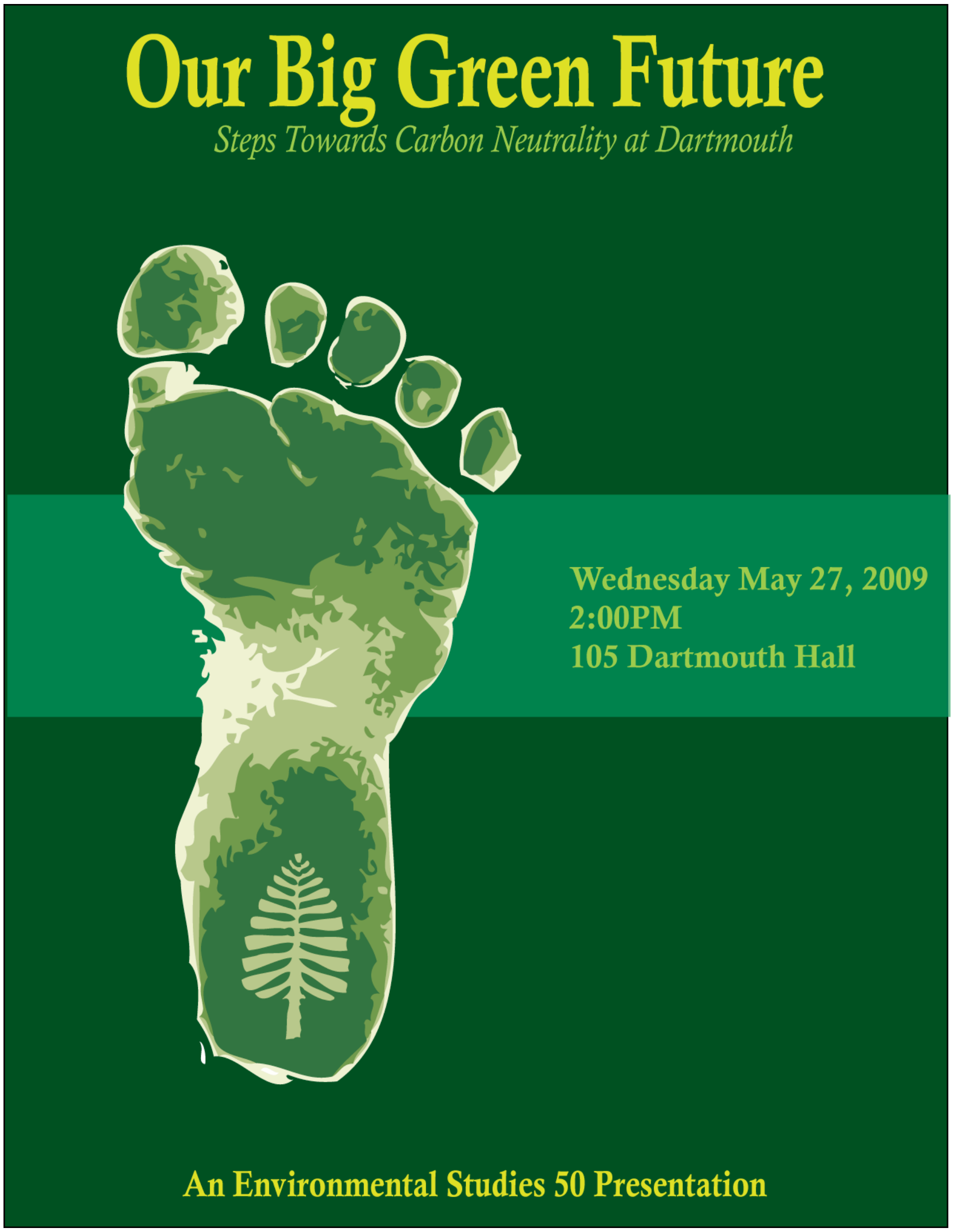
We believe that "Our Big Green Future: Steps towards a carbon neutral Dartmouth" would be a impetus to generate significant, positive and fresh press for Dartmouth College, would appeal to prospective students as a concrete sign of Dartmouth's commitment to a larger future and would encourage new and increased donations from alumni.

II. Publicity

Publicity is the application of techniques formed during a marketing study that visibly promote the product (in this case, steps towards carbon neutrality at Dartmouth). Publicity also allows for the education of the student body, alumni, and the administration in the steps being taken to reach carbon neutrality at Dartmouth and how each individual can join the community in taking these steps. This sort of awareness is absolutely vital to the success of this type of plan, because it cannot be achieved without support from every member of the community. We have created a series of educational fliers, pamphlets, emails, postcards, websites and social media networking sets to publicize the plan and educate Dartmouth (and beyond). In this section we put our research into demonstrate how we might publicize the plan of carbon neutrality at Dartmouth to the student body, general campus and greater community of alumni and trustees.

Below are examples of these forms of communication and education, designed and created by students in ENVS 50:

1. Sample Poster



ENVS 50 Presentation poster, containing Dartmouth's "Our Big Green Future" carbon neutrality footprint logo

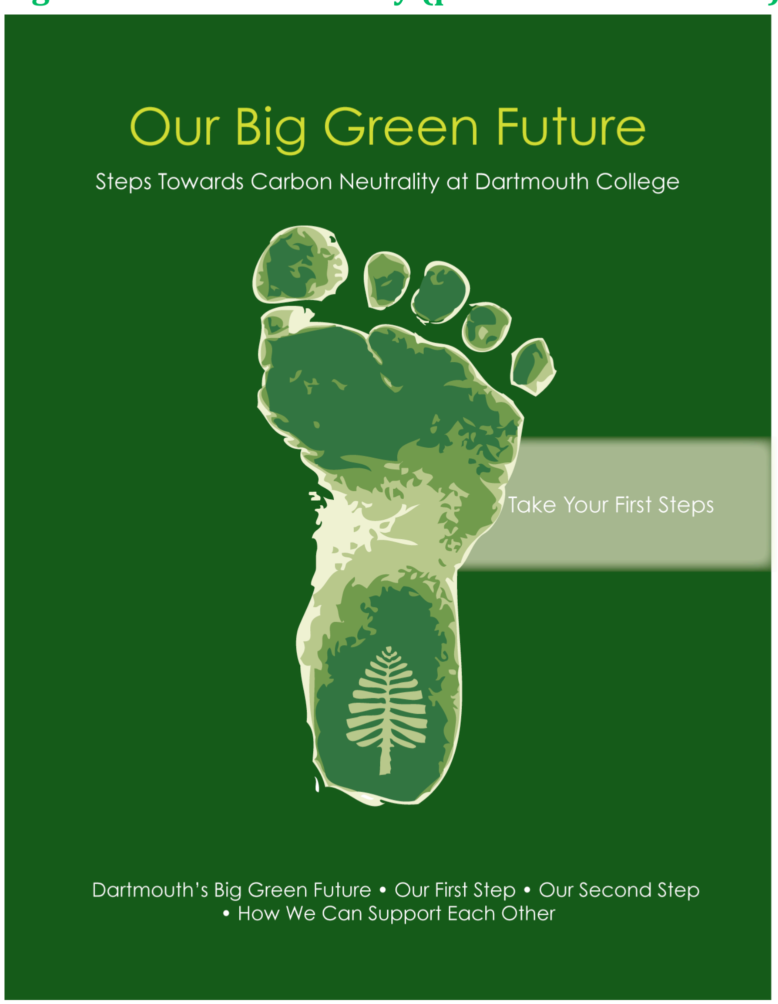
2. Sample Postcard

In the event that our next Capital Campaign highlights campus sustainability, or that a revolving green loan fund is created, postcards can be sent to alumni older than the median of graduating classes (classes<1981) who may be predisposed to snail mail rather than email or internet updates. Below is the cover of the postcard. On the reverse side, information on how to donate to the green loan fund/carbon neutrality components of the capital campaign will be included, as well as educational material on how to live more sustainably on a personal level.

3. Sample Handouts / Pamphlets

Handouts describing first and second "steps" towards carbon neutrality, and how the reader can take their own personal "steps".

3.1 handout designated for student body (printed and attached)



Dartmouth's Big Green Future

Dartmouth College is a place of innovation.
Dartmouth College is a place of education.
Dartmouth College is a place of beauty.
Dartmouth College is a place of social responsibility.
Dartmouth College is dedicated to a Big Green Future.

The level of education taking place at Dartmouth is profound. We are learning how to directly address the greatest problems of our generation.

As Dwight Eisenhower once stated while visitng Dartmouth, "This is the way a college should look". By commiting ourselves to making Dartmouth carbon neutral, we are ensuring that the incredible sense of place felt by members of the Dartmouth community will live on for future generations.

Dartmouth was at the forfront of leadership in sustainability in the 1970's with the introduction of one of the first Environmental Studies Programs in the country. We now have an opportunity to serve as an example for other institutions to follow in their own paths towards carbon neutrality.

As Dartmouth's mission statement readsr, the college seeks to instill a "responsible leadership" in the student body as they enter the world. It is imperative that Dartmouth lead by example to display the extent to which Dartmouth, as an educating and incredibly influential body, can be a responsible leader.

Dartmouth's dedication to a Big Green Future comes down to our first steps towards carbon neutrality. By commiting ourselves to reaching carbon neutrality, these steps will be felt throughout the world as a solid statement of wisdom and responsibility.

Our First Step

The first step towards carbon neutrality at Dartmouth is reducing the energy load on campus. This approach cuts carbon emissions by reducing the amount of energy required for everyday operations without changing the type of fuel burned.

Decreasing the load of energy being used at Dartmouth is one of the easiest ways to reduce greenhouse gas emissions without making large infrastructure changes. Investment in newer technologies, such as photovoltaic cells or solar hot water, becomes less volatile when each is responsible for less energy production.

There are many ways to reduce Dartmouth's energy demand. Among them are changing end user habits, improving boiler and steam tunnel efficiency, and implementing retrofits and renovations.

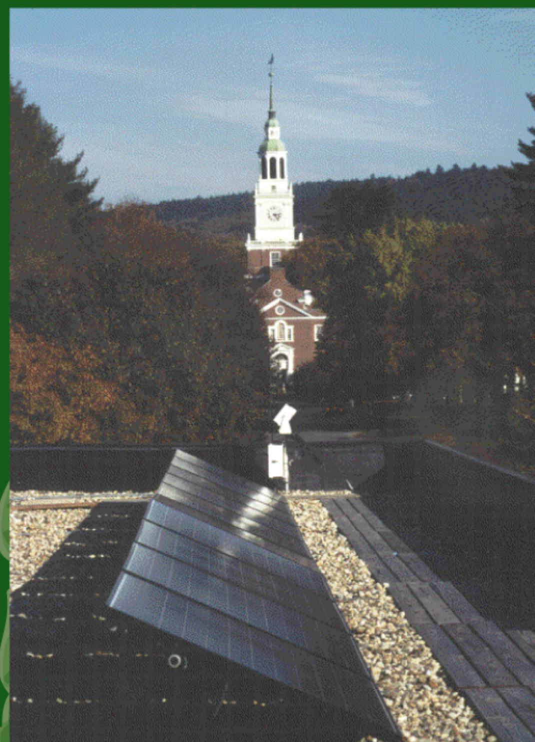
Our first step will be implementing education and conservation programs for students, faculty, trustees and administrators, LED lighting, heat recovery systems, and LEED certification requirements for all future building projects.

Our Second Step

Our second step towards carbon neutrality at Dartmouth focuses on the supply-side of energy usage on campus. By reducing the load of energy consumed on campus in our first step, we can now manage this greatly reduced energy load with renewable energies.

"The cost of taking our second step is not only financially possible, but also due to technological advances in the renewable energy systems we have chosen, they will also prove to be a good investment for the college."

- ENVS 50 Report, 2009



Preliminary work for this second step has begun, but only in limited capacities.

Our second step will be marked by the immediate implementation of photovoltaics, geothermal wells, solar hot water, and biofuels, and long term projects revolved around sewage heat recovery and deep geothermal.

How We Can Support Each Other

As a student of the College, we need your help to take that first step. Cutting the load of energy used on campus is highly dependent upon our collective actions and social responsibility to correctly treat-ing our surrounding and supporting environment.

Unsure how to take your first step? Read on!

When you're doing work...

- Shut down your computer when it's not in use or put it in sleep mode
- Buy used books
- Print duplex on recycled paper
- Do as much work as you can on your computer before printing documents
- Ask professors if you can blitz in your assignments

When you're getting a meal...

- Eat "for here!" or frequent dining facilities that use minimal packaging
- Go trayless in the dining halls to conserve water used for washing them

When you're in your dorm...

- Lower the temperature in your dorm if possible
- Report leaks in faucets or broken windows to your house manager or dorm custodian
- Take shorter showers
- Use a fan in the spring and summer (it uses %98 less energy than the A.C.!)
- Use FO&M as a resource for recycling the following: aluminum, batteries, cardboard boxes, computers and electronics, glass, lightbulbs, paper, plastic, and Styrofoam packing peanuts
- Use a drying rack instead of a clothes dryer
- Take the stairs instead of the elevator

When you're partying...

- Refill your cup instead of getting a new one
- Recycle cans, glass bottles and plastic cups

Looking Forward to a Big Green Future!

Your education never stops

Visit http://www.dartmouth.edu/~sustain/ to learn more about what steps Dartmouth is taking to reach carbon neutrality and what steps you can take to live more sustainably.

Follow the progress

On Twitter: https://twitter.com/carbonneutralD

and

On our blog: http://carbonneutraldartmouth.blogspot.com/

Thanks to those who have supported this effort

Steve Shadford
Bill Rheil
Jim Merkel
Terry Osborne
Woody Eckel
Steve Campbell
Lorie Loeb
Susan Knapp
Michael Dorsey
Kathy Lambert
Mary Gorman
Bo Peterson
Larry Fabian

3.2 Handout designated for alumni, administrators, trustees, and faculty (printed and attached).

This handout will include the same basic format, except with a new "How We Can Support Each Other" page.

How We Can Support Each Other

As a member of the Dartmouth community, we need your help to take that first step. Join Dartmouth in celebrating the environment by taking your own personal step. Our success, as a community, is highly dependent upon our collective actions and social responsibility to correctly treating our surrounding and supporting environment.

Unsure how to take your first step? Read on!

When you're thinking of traveling...

- Drive less and plan your trips
- Carpool, use public transportation, walk, or take a bike
- Pump up your tires and monitor tire pressure
- Schedule a car tune-up
- Purchase a hybrid, plug-in hybrid or electric car

When you're buying food...

- Buy organic, local and seasonal, whole rather than processed
- Think: do I need that? can I make it myself? can I reuse something else?
- Read labels: where does this come from? what are the ingredients?
- Use: a crock pot, a microwave oven, a solar oven or a pressure cooker instead of an over
- Start a vegetable/herb/flower garden to grow your own ingredients

When you're at home...

- Conduct a home energy audit
- Use energy efficient appliances
- Install low-flow toilets and showerheads
- Use a fan in the spring and summer (it uses %98 less energy than the A.C.!)
- Do full loads of laundry and dishes, use cold water instead of hot and air dry your clothes
- Turn down your water heater and thermostat
- Buy into clean energy plans through your local utility
- Make retrofits using renewable energy sources

When you're in the voting booth...

- Vote for candidates and legislation that promotes clean and renewable energy, energy efficiency, sustainable food production, and consumer education
- Research and demand rebates and tax incentives for home energy retrofits, energy efficient appliances, and advanced, fuel-efficient vehicles
- Think: what connects you to the environment and gives you a sense of place? What are the environmental issues and concerns affecting your neighborhood, state, region, and country?

These handouts to be handed out to attendees of the ENVS 50 presentation along with presentation outlines (to facilitate clarity between presenters and attendees) containing links to our blog so that they might provide anonymous feedback.

4. Website

Our class has created a website sample that we hope to link to from the Dartmouth homepage for use as a forum for education, research, and advice. Students/faculty/administrators will have the opportunity to post research and ideas, and describe progress being made at the college in the realm of campus sustainability. All visitors to the sight will have a forum to express opinions/share ideas. ENVS 50 has already created both Twitter and blog sides where information can be easily posted and spread throughout not only the Dartmouth community but also the greater public forum. By using popular social media networking sites like Twitter and Blogspot, we are modernizing and diversifing our reach, aiming for a younger, more "hip" audiance that is increasingly receptive to these forms of marketing.

a. Links on the website will include:
    i. Twitter account updating general public on progress towards carbon neutrality
        1. https://twitter.com/carbonneutralD
    ii. ENVS 50 blog containing current research being conducted by Dartmouth students on real issues at the college
        1. http://carbonneutraldartmouth.blogspot.com/
    iii. Dartmouth's Sustainability Initiative
        1. www.dartmouth.edu/~sustain

5. Student Organizations and Administrative Support

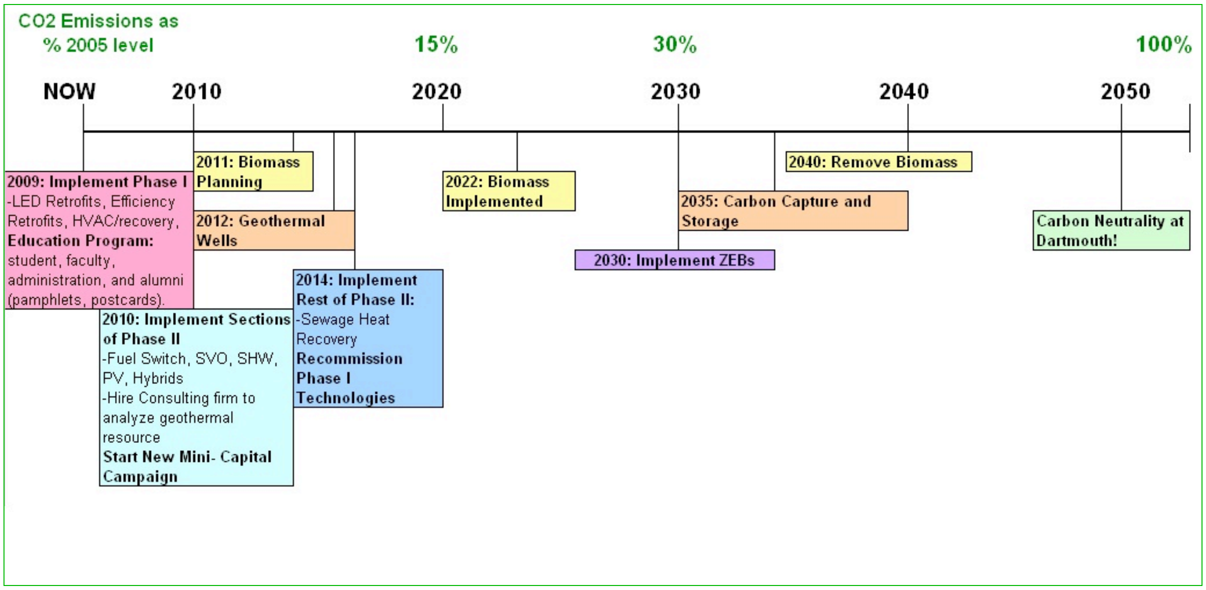
There are currently several campus organizations for students interested in environmental issues, including Ecovores, the energy reduction campaign, Environmental Conservation Organization, Sustainable Dartmouth, the Big Green Bus and the Dartmouth Council on Climate Change. Each group works on different goals related to specific aspects of protecting the environment, but they should work together to determine how each group can be part of a carbon reduction plan. The College will be more likely to make more expensive and drastic changes if there if the push for change is demanded by students, as well as supported by alumni. According to Joe Cassidy, Dartmouth's Dean of Student Life, for many Dartmouth students, environmental issues are "not on their radar screen" due to a geographically diverse student body which has not necessarily been exposed to environmentally-friendly initiatives as basic as recycling (Cassidy). Therefore, educating the incoming freshmen classes early in their freshman year is essential to ensure that sustainable practices become part of typical Dartmouth life, with support increasing with each new class.

Additionally, Kathy Lambert is the College's sustainability manager who oversees several student interns and works with other college employees to develop a plan for a more sustainable campus. The 2008 Energy Usage report was very helpful in assessing the College's energy consumption and suggesting future plans, but now it is time to implement these plans and work forward, using the $12.5 million approved by the trustees to make more significant changes. The administration must show more support for environmental and carbon reduction initiatives. Just as ORL supports Greek and affinity life on campus and OPAL supports diversity and leadership initiatives, there should be more administrative support to help students focus their interests and provide long term continuity of projects once those students have graduated. This could be done by creating more structure under the sustainability manager, as well as increasing communication between existing environmental organizations.

Chapter 5: Timeline

I. Goal of the Class

Projected implementation timeline for proposed initiatives towards carbon neutrality in 2050



II. Next Steps

Further Proposals

Due to the restrictions of time inherent with single-term courses, there were a few elements that were not incorporated into this report that should be considered in future iterations of such campus energy policy recommendations.

Forest Carbon Sequestration

Dartmouth's ownership of the Second College Grant in northern New Hampshire and potentially of other land has the potential to factor in significantly to offsetting carbon. Forest carbon sequestration is thus far a somewhat experimental and inexact science although there exists enormous potential for cost analysis with respect to provision of carbon offsetting capacity and costs associated with purchasing tracts of land to be designated "sequestration zones." There have also been studies conducted as to the most efficient short and long term carbon sequestration capacities of various species of flora that should be taken into account when analyzing longevity of such projects. For further information on forest carbon sequestration, please refer to Robert Stavins and Kenneth Richards 2005 *The Cost of U.S. Forest-Based Carbon Sequestration.*

Utilization of Hydropower – Connecticut River

The Connecticut River remains a largely untapped resource for electricity production. Despite the proximity of the Wilder Dam, Dartmouth does not currently own significant hydropower generating capacity. Three options for remedying this situation include installation of stream-flow turbines in the river, installation of stored-water electrical generation in conjunction with an intermittent electricity source to utilize the potential energy of falling water (in other words, pumping water to elevation using excess electricity, utilize potential energy of elevated stored water to run turbines to provide power in off-peak hours – can be incorporated with an inconsistent renewable energy source like solar or wind), and finally purchasing the Wilder Dam. All of these options require further analysis specific to Dartmouth College. (For more information on stream-flow turbines, please see Appendix B.8)

Efficiency of Building Use

Currently, Dartmouth's strategy for dealing with expansion of the student body has been to build more buildings instead of focusing on utilizing available space more efficiently. Because classes are only held during particular parts of the day on particular days of the week, classrooms on campus are left unoccupied for the majority of the 24-hour day. While it would be ineffective to offer courses in the middle of the night, a re-evaluation of potential classroom space usage should be conducted in order to make sure that additional future construction is actually necessary in the first place. This analysis, and an alteration of the course schedule to incorporate more classes at different times of the day/days of the week could potentially prove to be a major cost-saving measure.

The Future of ENVS 50

As a class, we understand that our research, efforts, and ideas cannot be implemented on a substantial scale overnight. With this in mind, the class is analyzing the longevity of the project to ensure that the massive amount of information and contacts ENVS 50 has built up during the past term is not lost in translation or set on a shelf to accumulate dust. There should consistently be a course at Dartmouth dedicated to making campus carbon neutral and improving upon existing energy strategies, and it is with great anticipation that we look forward to the Environmental Studies Department's decision to continue ENVS 50's efforts through ENVS 80 in the fall term of 2009 (once again under the dedicated and enthusiastic direction of Karolina Kawiaka). Once the College announces its support for the decision to become carbon neutral, classes can be directed in far more specific ways to more efficiently help the administration and student body in this transition.

Aside from the continuation of the specific topic as a class, and as a movement, in the Dartmouth curriculum, the ENVS 50 report will be given to all club heads involved in environmentalism and sustainability, as well as being offered to all other interested student body parties. This will help extracurricular clubs maintain contacts with alumni, administrators, professors, other students, and individuals working in the sustainability office in order to expedite projects or ideas these clubs have for helping Dartmouth on the path towards carbon neutrality.

These sentiments have lead ENVS 50 to strongly urge Dartmouth to reconsider the core curriculum. We fiercely believe that a class in environmental education or sustainability should be added as a distribution requirement for all students attending Dartmouth College in order to raise awareness and increase overall environmental education of members of the Dartmouth community. We also believe that classes designated as such should incorporate students from multiple disciplines whenever they are offered in order to draw upon numerous vantage points and skill sets. Another recommendation we feel is necessary to make is to expand the reach of the ENVS department to create a new, inter-disciplinary major that will draw upon courses in the Environmental Studies, Engineering Sciences, Architecture and Economics departments in order to more effectively communicate all aspects associated with policy recommendations regarding sustainable initiatives in the future.

Appendix A: More Information on Phase I

A.1 Retrofits and Renovations

A.1.1 Case Study: Hitchcock Hall

One of the more recent renovations on campus occurred at Hitchcock Hall in 2006-2007. The renovation was a costly but much-needed upgrade of an older dorm on campus and was also a pioneering example of retrofitting with new materials and technologies. Some initial critiques of the successes and failures of the renovation can now be made as the building is in its second year of operation. We conclude that more could have been done to ensure that Hitchcock Hall was as energy efficient as possible.

The $8,656,000 renovation successfully preserved the classic brick structure of the building while introducing a brand new interior (Shadford). Insulation in the walls, roof and basement was installed, as were double glazed windows. Steam water pipes were replaced with hot water pipes and a mechanical ventilation system was installed (Eckels). Changes in the building include a significant increase in lounge space, the addition of an elevator, and an increase in larger, lower-occupancy rooms. While the renovation's upgrades made the building more comfortable, they did not necessarily make the building more energy efficient.

Hitchcock Hall's energy efficiency has actually decreased because of the choices made during the renovations. While its steam use has remained at about 13.7m lbs. of steam/yr, its electric use has doubled, from an average of 125,085KWH/yr to 263,059KWH/yr in 2008-9 (Shadford). The consistency of the steam use can be explained by a few factors. First, the more insulated building envelope allows for better heat retention, which requires less steam. The insulation is indeed retaining heat more effectively because despite an addition of 1,468 sq. ft. of space, the steam usage has remained steady. While there is conflicting data on the exact square footage of Hitchcock Hall, estimates put it at around 32,500 sq. ft., making the addition a 5% increase. Despite this 5% increase in space, steam use is steady, saving Dartmouth about 680,000 lbs. of steam a year. This small increase in efficiency, however, does not seem as significant as it should for a full-scale renovation that added insulation.

Electric use, on the other hand, has doubled in Hitchcock since its renovation. Steam heating has been replaced by hot water heating in the dorm for safety and maintenance reasons, but hot water heating requires an electric pump. Unfortunately, there is no meter installed to gauge the breakdown of electricity consumption, so it is hard to know how much more electricity the hot water pump uses. Another big addition to the electric load of Hitchcock is its mechanical ventilation system. Before the renovation, only windows were used as ventilation for the building, so the ventilation system clearly accounts for a significant additional electric load as well (Shadford). The doubling of electric use can also be attributed to recent overworking of the ventilation system, which has had operational problems since its installation. Other electric use includes the addition of an elevator. These additional electric energy costs add up to about $19,300/yr ($.14/KWH*137,974KWH), which are significant additions to both Dartmouth's carbon footprint and energy bill every year (Energy Information Administration website). While there seems to be agreement that hot water heating saves money through its lower maintenance costs, which offsets its electric bill, there is no evidence that a mechanical ventilation system is necessary when windows are a carbon-free and cost-free alternative.

Another factor in considering the energy efficiency of Hitchcock is the change in capacity the renovation implemented. In 2003, there were 110 students living in Hitchcock; after the renovations, there are now 86 students in the dorm (Eckels). This makes the energy use per person increase substantially from 1,137 KWH/person and 124,360 lbs of steam/person before the renovations to 3,058 KWH/person and 160,034 lbs of steam/person after the renovations (Shadford). While society's demands for comfort and personal space continue to rise, we must consider the environmental and cost implications of dorm policy changes that allow more heated, lit, and ventilated space to fewer students.

A.2 LED Lighting

A.2.1 Technology Information

LEDs produce light differently than conventional lighting sources. Traditional incandescent light sources heat a tungsten filament by electric current to emit light. Fluorescent light sources excite mercury atoms in order to emit ultraviolet radiation, which is then converted into visible light (US Department of Energy 2008). Conversely, an LED is a semiconductor diode, which is treated to create a positive-negative junction. When this junction is connected to a power source, current flows from the positive side, anode, to the negative side, cathode, but not in the reverse direction. The charge-carriers, electrons and electron holes, flow into the junction. When an electron meets an electron hole, it falls into a lower energy level and releases energy in the form of light (See Figure 1 for an illustration of the described light creation process). The color of light emitted by the LED depends on the materials used to create the semiconductor (US Department of Energy 2008). Advances in material sciences have enabled LEDs to produce light in a variety of colors, including white and warm white that appeals to the human eye (Shadford 2009).

LEDs come in two basic categories: low power LEDs and high power LEDs. Low power LEDs are typically only 0.1-watt and produce a small amount of light, anywhere from 2 to 4 lumens. High power LEDs come in 1-3 watt packages and can produce 40-80 lumens, per 1-watt (US Department of Energy 2008). LED light fixtures are often comprised of multiple LED lights, to produce enough lumens per watt and to ensure illumination if one light fails (Shadford 2009).

A.2.2 Precedents

As the technology continues to improve resulting in cheaper LEDs, businesses are taking advantage and retrofitting old light fixtures with new LED fixtures. In the end of March 2009, Lighting Science Group Corporation announced that they completed a parking garage lighting retrofit for TXU Energy. TXU Energy replaced their existing 175-watt metal halide light fixtures with 78-watt LED low bay parking garage fixtures. They installed 53 pyramid shaped low bay LED fixtures. Each pyramid shaped fixture is assembled with 108 LED lights, arranged so that if one light fails, the other LEDs will continue to illuminate the area (Lighting Science

Group 2009). This is the first garage project of its kind in North Texas. These new lighting fixtures will help "reduce TXU Energy's energy consumption by 54,700 kilowatt hours a year, which is equivalent to the carbon sequestered by nearly 880 trees in ten years" (Lighting Science Group 2009). The LED fixtures offer an extended life of up to 50,000 hours, compared to 10,000 hours for the old 175-watt metal halide lamps. This is a significant improvement in TXU Energy's energy usage, solely through switching to more efficient, more environmental friendly lighting products.

Similarly, two years ago, Camp Borden Military Base, located north of Toronto, installed an LED-based streetlight prototype. Remco Solid State Lighting, the LED fixture provider, announced, "the LED streetlight…is outperforming the existing high-pressure sodium (HPS) street lighting at the military base" (Kure 2008: 18). Camp Borden confirmed a 20% energy savings, "even taking into account the losses incurred by retrofitting the LED lighting fixture within an HPS fixture" (Kure 2008: 18). Because of the longevity of LED lights, Camp Bolden will only need to change the light fixture every 27.4 years. Mark Matthews, Remco's President and CEO, found this project a success because it is "a significant contribution towards reducing global warming, especially for utilities, municipalities, cities, towns and regions that are demanding LED streetlighting now to reduce greenhouse gas emissions and accumulate carbon credits" (Kure 2008: 18). Again, we have another successful example of retrofitting old light fixtures with new LED lights, to reduce energy demand, cut GHG emissions, and save money. Many other cities are following suit and slating new city lighting projects to emulate these successful examples. San Jose, California "plans to convert 100 lights this spring and is seeking $20 million from the stimulus package to install 20,000 new lights" (Tuite 2009: 35). Los Angeles, California also plans to replace 140,000 existing street light fixtures in the next five years. Such retrofitting should save the Los Angeles at least $48 million over seven years and should reduce "carbon emissions by approximately 40,500 tons a year" (Tuite 2009: 36). Streetlights, especially in metropolitan areas, consistently have long run hours. These types of retrofits are extremely economically sensible because they create short payback periods and extensive savings in energy and money.

Universities around the world are stepping up, by joining LED University. This is an initiative to expand the "community of universities and LED industry leaders and innovators working to promote and deploy LED lighting technology across the full range of the campus infrastructure to help:

- Save energy
- Protect the environment
- Reduce maintenance costs
- Improve light quality for improved visibility and safety
- Save tax and donor money" (Cree 2008).

Madison Area Tech, Marquette University, NC State University, Tianjin Polytechnic in China, UA Anchorage, University of Arkansas, UC Davis, UC Santa Barbara, University of Miami, and University of Notre Dame are all currently participating in the program. The program was designed to "accelerate the adoption of LED lighting in an effort to significantly reduce the amount of electricity used to power lighting on campuses throughout the world" (Cree

2008). In order to become an LED University, one must identify and execute a pilot LED project. The President of the university must then agree to release results, evaluate LED lighting, and utilize LED lights where they are financially sound. Then one must analyze the "the energy savings, energy cost savings and maintenance cost savings as compared to the traditional lighting solution" (Cree 2008). UC Santa Barbara has converted 23 streetlights into BetaLED lights and is considering converting all campus streetlights to LEDs. UCSB's pilot project has reported energy savings of 44% (Cree 2008). These types of programs are especially important to encourage other universities to undertake similar pilot programs and to give publicity to those that are committing to carbon emission reduction, through the use of LED lights.

A.2.3 Barriers to Implementation

While LEDs have made significant progress in the last ten years, some are still concerned with the "extremely directional light" of LED illumination, "rather than emitting light in all directions" (DeNicholas 2009: 37). However, Dr. Faiz Rahman, the leading researcher for an LED project at the University of Glasgow, said: "By making microscopic holes on the surface of the LEDs, it is possible to extract more light, thus increasing the brightness of the lights without increasing the energy consumption" (University of Glasglow 2008). This process of making holes is very time consuming and expensive, which hinders the introduction of LED lights into standard home lighting. However, scientists at the University of Glasglow have "found a way of imprinting the holes into billions of LEDs at a far greater speed, but at a much lower cost" (University of Glasglow 2008). This team of researchers uses a technique called "nano-imprint lithography", which directly imprints holes onto the LED, allowing for more dispersed light (University of Glasglow 2008). Such recent breakthroughs will soon allow for cheap household use of LED light bulbs.

Even with all of the current benefits of LED lighting, we need to consider that LEDs are still in the development process. This technology remains three to five years away from actual household implementation. LEDs continue to face problems with dimming capacities, heat discharge, and inconsistent product standards. LED light bulbs do not have full dimming capabilities, which will hinder direct replacement of old Edison light bulbs. While scientists are continuing to work on dimming designs, "this doesn't mean just changing out old bulbs and tubes. Instead, it means replacing existing can and overhead fixtures at the junction box in the ceiling" (Tuite 2009: 36). LEDs also continue to release a significant about of heat. The U.S. Department of Energy estimates 75-80% of energy used to power LEDs is converted into heat, which can often reduce light output. Scientists are looking into solutions "via better materials and improving driver techniques" (Allan 2009: 38). Heat sink attachments currently play an important role on LED light bulbs, in order to redirect heat output and help maintain extended lifetimes (Shadford 2009). Additionally, the National Institute of Standards and Technology (NIST) has not yet established product standards for solid-state lighting and LEDs, due to the novelty of such products. Within the last year, scientists have begun to set standards for LED products. These standards are "important to ensure that products will have high quality and their performance will be specified uniformly for commerce and trade" (National Institute of Standards and Technology 2008). The standards include details on color specification, color quality, test methods, and energy efficiency. As standards for such lighting products are established, LEDs will become more commercially equal, tradable, and acceptable.

A.3 Heating Recovery Systems

A.3.1 Technology Information

Put simply, a glycol run-around loop system would place a series of water coils in the supply and exhaust air streams of the ventilation ductwork. The coils are connected in a closed loop, and typically contain an anti-freeze solution. This fluid, circulated between the two air streams, preheats supply air when outside air is cooler than desired, and pre-cools supply air when outside air is warmer than desired (Coil Loop). The run-around technology would only recover the heat content of the air (sensible energy), not its humidity. First, a runaround (coil) loop recovery system is most appropriate for Dartmouth's lab buildings because it avoids cross-contamination of air streams, which similar technologies, like enthalpy wheels, do not prevent. This is an issue particular to lab buildings, where it is essential that toxic chemicals not be reintroduced to incoming air. Furthermore, unlike enthalpy wheels, the supply and exhaust air streams do not need to be adjacent (Energy Recovery).

A.3.2 Precedents

The introduction of heat recovery systems has been implemented in many other lab buildings in New Hampshire and in the greater United States. A database of innovative buildings, compiled by the U.S. Department of Energy, Energy Efficiency and Renewable Energy division, can be found online at: http://eere.buildinggreen.com/index.cfm

More locally, McCulloch Hall in the East Wheelock Cluster has heat pipe energy recovery units, and Kemeny, Haldeman, and the Tuck Mall Residence Halls use enthalpy wheels (Dartmouth Building Performance). Steele Hall, a lab building, is using a run-around heat recovery system, similar to the one that could be implemented in Burke. Preliminary testing results have shown that the performance of these systems have not been as good as anticipated (Shadford): Kemeny Hall at 36% energy savings, McCulloch at 42%, and the Tuck Mall dorms at 45% (Dartmouth Building Performance), however, these are classroom and residential buildings, not labs. A detailed analysis of Steele Hall's energy reductions would provide a benchmark for the reality of energy savings in Burke. Furthermore, the new Class of 1978 Life Sciences Center will provide a great opportunity to analyze new systems and the energy efficiency of the building overall.

A.3.3 Barriers to Implementation

One of the central concerns of this report is determining whether the implementation of heat recovery systems is feasible within the College's operations. According to Steve Shadford, the energy engineer for Facilities, Operations, and Management (FO&M), even more challenging than gaining administrative support or financing, is coordinating with the appropriate stakeholders to schedule a time for these renovations to actually take place. For example, Burke is a building where research is active and ongoing. For renovations to take place, these activities would need to be paused for a certain period of time by directly contacting the researchers and requesting that they pause their work. This requirement is difficult to fulfill, even on weekends, when ongoing projects have often been scheduled weeks and months in advance (Shadford). In general, the summer term may provide more opportunity for renovations that the fall, winter, or spring terms, since there are fewer undergraduates on campus.

In scheduling time for upgrades, Shadford noted that planning meetings would ideally take place every two weeks. The stakeholders include the researchers whose work may be disrupted, department chairs, and the workers actually performing the construction. Coordinating the schedules of these people is challenging and presents one of the major problems in implementing the Energy Task Force's recommendations (Shadford).

As noted earlier, the nature of renovating a building is that problems unrelated to the project at hand are often uncovered as renovations proceed. It is impossible to guess which ducts will need to be replaced due to age or damage, and "we need to fix those things that we find wrong in the course of putting in new technologies" (Shadford). Thus, deciding to install heat recovery systems in a central exhaust system cannot be scheduled with only these discrete end goals in mind.

Because of these scheduling challenges, there is currently no proposed timeline for implementation of upgrades at the Burke Chemistry Building, or at other similar buildings. Additionally, the scheduling of meetings to make the appropriate building upgrades—for all of campus—falls to Shadford alone. He is also one of the few, if not the only, person on campus who references the full report of vanZelm Energy Service's Energy Conservation Plan. It is difficult to implement these projects with only one person with the task of implementation as their primary responsibility. This report has also analyzed similar institutions for the number of personnel in their equivalent to the Offices of Sustainability and Facilities, Operations, and Management. Similarly, it would be difficult to impose a particular time line without consulting directly with the occupants of each building to find the least inconvenient times for disruption, since lab use is circumstantial (Shadford).

A.4 New Construction Guidelines

A.4.1 Why LEED?

The LEED system is particularly suited for implementation at Dartmouth. First, it has firmly established itself as the most commonly utilized system for evaluating green building around the world. This credibility extends not just to attraction of perspective students, but to the Dartmouth brand as a whole. Second, Dartmouth has already pursued LEED certification on campus, including the McLaughlin Cluster, Fahey/McLane, Kemeny/Haldeman, and the forthcoming Life Sciences Center. It has since already been proven that LEED has a place and history on this campus. Third, LEED is a system by which you earn points for a variety of technologies or techniques used in the construction of a building. This system inherently allows for flexibility and widespread application for all types of buildings at Dartmouth. Lastly, the newest LEED requirements speak both to new buildings as well as renovation and retrofits, which is particularly well suited to the Dartmouth campus.

A.4.2 Precedents

In mandating a minimum level of new construction sustainability and efficiency, Dartmouth would not be alone among its peers. Many other institutions have mandated minimum standards based on the LEED system, as well as beyond that system. We recommend that Dartmouth College mandate a minimum of LEED Platinum for all new construction and continue to require that new buildings be within the top 5% for efficiency of similar buildings in the United States. A building policy of this nature would launch Dartmouth into a leadership role in the field of sustainability.

In reviewing the building standards for other schools, four schools of thought have emerged: a minimum of LEED-Certification, a minimum of LEED Silver certification, a minimum LEED Gold certification, or the use of some other, often internally mandated, system of guidelines.

Institution	**New Building Policy**	**Additional Policy Requirements**
Alleghany College	LEED Certification	
Bates College	LEED Silver	
Bowdoin College	LEED Certification	
Brown University	LEED Silver	
California Institute of Technology	LEED Gold	All new construction and major renovations aim for LEED Gold certification. Caltech's overall campus design guidelines are under review to incorporate green building design standards. The new Center for Global Environmental Science is in the design stage of a LEED Platinum renovation.
Columbia University	Other	"The Manhattanville expansion plan is in the LEED for Neighborhood Development program. In fall 2008, Columbia will launch its first green dorm, which features a new energy-efficient boiler, efficient windows, and an energy monitoring system."
Connecticut College	LEED Certification	
Cornell University	LEED Certification	

Harvard University	LEED Silver	LEED Silver only for projects over $5 million
Harvard University - Allston Campus	LEED Gold	Harvard has committed its newest campus, across the river in Allston, to a standard of LEED Gold for all future academic buildings.
Johns Hopkins University	LEED Certification	
Keene State College	Other	
Massachusetts Institute of Technology	LEED Silver	
Middlebury College	LEED Silver	
Princeton University	LEED Certification	Minimum efficiency 50% below building code
Skidmore College	Other	"Skidmore has established sustainable guidelines that employ LEED criteria benchmarks for assessment in the design process, including the requirement that all new buildings and major renovations be 30 percent more efficient than is required by code. Skidmore uses sustainably harvested wood for trim, as well as recycled material for roofs, doors, and steel frames."
Stanford University	LEED Gold	Stanford has increased its goals for energy efficiency, greenhouse gas reduction, and water conservation in its new buildings beyond existing guidelines, to a LEED Gold equivalent. The new Graduate School of Business Knight Management Center is seeking a LEED Platinum rating.
Tufts University	Other	
University of British Columbia	LEED Gold	The campus has numerous green buildings, including the LEED Gold Life Sciences Centre. All new construction greater than 600 meters squared is required to achieve LEED Gold certification and all new residential construction follows guidelines set forth in the UBC Residential Environmental Assessment Program. Aging

		academic buildings are renovated to achieve LEED Silver certification.
University of California System	LEED Certification	
University of Connecticut	LEED Silver	LEED Silver only for projects over $5 million
University of Vermont	LEED Silver	
Yale University	Other	

(*Information compiled from the Green Report Card. www.greenreportcard.org)

Dartmouth College currently pursues a policy that new buildings must perform within the top 5% of similar buildings in the United States. While this policy is an excellent one, it does not afford the flexibility or name recognition of the LEED system. Our recommendation, therefore, is the continued pursuit of the top 5% policy as well as a mandatory LEED Platinum certification for all new building.

There are no comprehensive numbers on what LEED Platinum and high-efficiency requirements can save an institution in terms of dollars or carbon emissions. Due to the fact that Platinum and efficiencies can be achieved through an infinite combination of techniques and technologies, there is no way to compute specific numbers for savings. In the end, a building that requires less fuel and adds to the productivity and health of the occupants will result in a building that costs less over its lifetime, both in financial and environmental costs

A.4.3 Dartmouth's History with LEED Certification

"Achieving the gold certification for this and other recent construction reflects Dartmouth's broader commitment to energy efficiency and green technology." - Assoc. Provost Mary Gorman

Dartmouth has in recent years renewed its pledge to sustainability by ensuring that certain academic and dormitory buildings received LEED certification. Currently, Silver and Gold status has been granted, but with the newest flexible version of the rating system for LEED, Dartmouth has a great potential to act more progressively and institute LEED Platinum designs for new buildings and for the renovations of existing ones.

Within the past five years, LEED Gold certification has been attained by dormitory buildings such as the McLauglin Cluster, McLane, and Fahey on the merits of having a "highly efficient thermal envelope, high-efficiency windows, radiant heating and cooling floors and heat recovery systems in the ventilation. The aforementioned buildings were also granted credit for having 50 percent of their electricity supplied by renewable power sources" (Dartmouth.edu/~news). In the same news release the Associate Provost and Executive Officer, Mary Gorman commented that, “achieving the gold certification for this and other recent construction reflects Dartmouth’s broader commitment to energy efficiency and green technology.” While gold certification is a definite step in the right direction, it is evident that Dartmouth is still not utilizing all its resources to fulfill its true potential as a leader in sustainability and energy efficiency.

Another step in the right direction has been taken with the recent construction of the Haldeman Center and Kemeny Hall academic buildings. Both buildings received LEED Silver certification, which is the next level on the nationally recognized rating system. Kemeny and Haldeman implemented a structure design that was more energy efficient than past buildings in several ways. By implementing systems and fixtures that would be 40 percent more efficient with water usage, windows that would allow a view of the outdoors and sunlight to enter and be used, and a tight envelope that seals against unwanted air exchange, the Kemeny and Haldeman buildings were able to provide a high-quality indoor environment for inhabitants and attain accreditation from the USGBC (Dartmouth.edu/~vox).

Dartmouth College has also begun to include and target athletes and the athletic department in its endeavor to reduce greenhouse gas emissions, which further proves Dartmouth's commitment to the community at large. The Floren Varsity House was recently recognized by the USGBC as qualifying for LEED Silver certification. LEED certification was an objective during the design process and later provided benchmarks during construction, which provided proof that Dartmouth College could accomplish LEED Platinum and a higher degree of energy efficiency if it designed and constructed with a higher LEED certification from the beginning. Building with LEED Platinum as the initial goal would ensure that Dartmouth would be nationally recognized as a leading institution in green architecture, and that the building would continue to function sustainably in a cost-effective manner for many years to come.

A.4.4 Future Buildings: LEED Platinum, version 3

“Working for energy efficiency is a good economic decision for the College.”

“LEED certification is an important part of Dartmouth’s sustainability plans.”

-Associate Provost, Mary Gorman

On April 27, 2009 the USGBC released an updated version for attaining LEED certification that takes into account the advancement in new technologies and in building science. At the same time, the USGBC is prioritizing carbon dioxide emissions reductions and the new American Recovery and Reinvestment Act that President Barack Obama signed earlier this year where billions of dollars are awarded for green building and energy efficiency (usgbc.org). Under the new LEED certification system, Dartmouth has a greater potential to simultaneously build LEED Platinum buildings, and to invest in rising renewable technologies that would ultimately make them via a business partner, eligible for rebates to pay back that initial cost while also benefiting from the return and praise received from having contributed to many on a global scale.

The previous checklist for LEED certification had five key areas that targeted the use of sustainable sites, water efficiency, energy and atmosphere, materials and resources, and indoor environmental quality. The newest version awards points for innovation in design and regional priority, which helps combat the critique that the USGBC did not take into consideration the different technologies that would only be available to certain regions. Building LEED Platinum would place Dartmouth closer to a decrease in energy usage, greenhouse gas emissions, and ultimately excess costs associated with unsustainable technologies.

"With escalating energy costs and a growing need for facilities, each facility must make a contribution to the overall improvement of operating cost control and sustainability at Dartmouth. The financial risks of designing and constructing new buildings without regard to environmental impacts are greater than the risks of making additional investments in higher efficiency, better performing facilities" (Rationale and Business Case for Sustainability Improvements, 2006). By establishing high LEED rating goals for new projects (Platinum certification based on version 3), Dartmouth will place a higher emphasis on the costs associated not only to the initial phase of construction, but also to the utility costs associated to the operation of the building. Making energy efficiency and conservation the highest priorities when attaining LEED Platinum would ensure that Dartmouth lowered the impact on our environment, while simultaneously lowering the utility costs associated to the excess energy that is lost due to a weak building envelope and the costs associated to technologies that use a surplus of energy.

A.4.5 Case Study: The Class of 1978 Life Sciences Building

"By accelerating the effort to reduce consumption of costly resources including energy, Dartmouth will benefit its own fiscal standing and environment. At the same time, it will set the best possible example for students, creating teaching and learning opportunities."

-Rationale and Business Case for Sustainability Improvements (2006)

One of the greater benefits of building with LEED Platinum in mind is that it provides a timeline and benchmarks that Dartmouth could follow in order to complete its pledge to reduce greenhouse gas emissions by thirty percent by 2030. Already Dartmouth is trying to implement some of the ideals held by the USGBC and translating it to goals that are more adaptable to Dartmouth's community by requiring that all new buildings be within the top 5% of energy efficiency compared to buildings of the same type. For example, the new 1978 Life Sciences building is expecting to be accredited LEED Platinum certification (version 2) because it has made improvements in its building envelope, window glazing, heat recovery, lighting system, has used a greater percentage of recycled and regional content, is expecting a 50% reduction in energy use over the baseline and at least a 40% reduction in potable water usage (Interview with Matt Purcell, 5/12/09).

In a study of laboratory buildings found in similar climate zones and that ranked in the top 5% of energy efficiency, Dartmouth calculated that they had the following energy usage and annual heating energy consumption:

Electric converted to BTU 50,293 to 60,699 BTU/gsf/yr

Heating 27,796 to 53,984 BTU/gsf/yr

TOTAL SITE ENERGY 78,089 to 114,683 BTU/gsf/yr

Based on the listed range, Dartmouth determined that the Life Sciences Building could operate as desired by having a reduced total site energy of **100,000 BTU/GSF/year** as opposed to the Burke Chemistry Building that in 2006 utilized 493,103 BTU/Sq. Ft. and resulted in the utility cost of $1,238,490. By investing in energy efficient technology that not only reduces energy costs, greenhouse gas emissions, and operating costs in the present, Dartmouth is investing in a sustainable future that will have a short payback period and ensure that Dartmouth reduces its overall operating costs (Life Sciences Building: Laboratory Benchmarks).

A.5 GreenLite

A.5.1 Introduction

In order to obtain carbon neutrality, Dartmouth needs to publicize its sustainability efforts. Publicity is beneficial for the College in two ways: reminding the community about its progress fosters a culture of experimentation, and also bolsters the College's fundraising and student recruitment. Many prospective students consider sustainability as a factor in their college choice, and this runs parallel for many donors. Because Dartmouth is a leader in higher education, it is an ideal forum to integrate its formal response to climate change with its educational goals

A.5.2 Costs

The cost of one meter's installation and software development is around $5,000. This number could significantly decrease if meters get less expensive or if the college can get quantity discounts. There are currently 11 installations on campus, so if the college put in 5 times that (55, covering most of the buildings on campus) the cost would be around $275,000. Loeb states, "If Dartmouth 's students reduce electricity use by 5% in all the dorms, the savings could be around $500,000 annually" (Loeb).

There is a need for more college-sponsored activities like the GreenLite project. Right now, the only funding comes from Alumni contributions and grants. If the college took the initiative to sponsor this student-professor collaboration, we would see a stark decrease in electricity consumption campus. Conservation will act hand in hand with the college's push for carbon emission reductions.

A.6 Transportation

A.6.1 Transportation Demand Management at Dartmouth

Since 2002, Dartmouth has offered its own TDM strategies in an attempt to reduce the number of SOV's (Single Occupant Vehicles) driving to and parking on campus. This has had the effect of reducing road and parking congestion on campus, improving air quality, and lowering the Dartmouth community's GHG emissions. Although notable improvements have been made, Dartmouth's TDM program needs to grow, building on past successes and taking note of failed initiatives. Incentives need to be increased, as well as the cost of permits. Dartmouth's public vehicles need to be increased in usage and incentivized. Its 300+ owned and leased vehicles need to be replaced or converted to more efficient, clean-burning, and electric alternatives. Zipcar and Zimride initiatives require more support and publicity. Visibility for such a program is key as much of the value of such an initiative is drawn from its PR value, and Dartmouth has failed to capitalize on this in comparison with other institutions, notably Stanford and the UC system (UC and Stan. web).

A.6.2 Current Policies

One important piece of Dartmouth's TDM strategy is the permit buy-out program that was started in July of 2002. It offers $180 or $360 (depending on commuting distance) for employees to find ways other SOV's to get to campus. Over 300 employees are currently involved in the program, (Parking Management: 2009) a sign of progress that the college can build upon. There are several ways employees can get to work with out driving an SOV and take advantage of the permit buy-out program: carpooling, the van pool program, using public transportation, walking, biking and getting dropped off ("kiss n' go"). (Whitcomb: 2009) While carpooling, public transit, and monetary incentives to use them are crucial aspects of TDM policy, Dartmouth must also address the full range of disincentives to abandoning SOV's. One problem with public transport and carpooling is the lack of autonomy during breaks during the day and the reduced ability to head home early or late from work if a ride isn't available. Dartmouth's Guaranteed Ride Home Program, which provides employees a free taxi ride home in case of a family emergency, is a good first step in addressing these concerns. The college's fledgling Zip Car program is an important second step. For a yearly fee and hourly rate, employees can use one of two Toyota Priuses, giving employees who car pool additional flexibility to run errands during lunch breaks, etc.

A.6.3 Challenges to Creating a Hybrid Fleet

While the lack of certain types of hybrid vehicles currently available is a limiting factor, this won't be the case for long. The Obama Administration has announced increased fuel efficiency standards, ensuring that automakers offer more hybrid models. His plan will raise fuel efficiency standards by 5 mpg every year from 2011 to 2016. (Washington Post: 2009) While there are hybrid pickups offered by Chevrolet and GMC (the Silverado and Sierra 1500s), they are not currently financially viable. This is because they only offer the trucks with crew cabs and a six liter V8, which cost over $40,000 per vehicle. While they still get five miles per gallon more the 4.8 liter V8, it's still nowhere near enough cover a price difference of around $18,000 between the hybrid and a two door, smaller model. (All vehicle price estimates based on Edmunds.com) However, the hybrid technology implemented in these trucks is good. The V8 engines cuts down to run on only four cylinders when cruising and the hybrid engines offers further fuel savings. If this technology is implemented in smaller models, or if Dartmouth has a crew cab truck it needs replace, the department needing the vehicle should look into buying one of these trucks.

A.6.4 Hybrid Recommendations

It is clear that Dartmouth should replace all of its sedans with hybrid models. In each case it was clear that the money saved through fuel efficiency, assuming the vehicles are driven the maximum 75,000 miles before they are replaced, was sufficient to not only cover the higher purchase cost of the vehicle but save the college additional money as well. Besides saving the college money, replacing the vehicles listed below with hybrids would reduce the college's carbon footprint. In the chart below, traditional sedans were replaced with hybrid sedans of comparable size. For instance, a Toyota Camry would be replaced with a Ford Fusion hybrid. However, if the college wanted to save even more money, and reduce it carbon footprint even further, it could replace these vehicles with a slightly smaller Toyota Prius.

Comparison	Metric Tons CO2 Saved	Original Model at $4/gallon***	New Hybrid at $4/gallon***	Fuel Savings	Vehicle Cost Difference	Total Savings
Buick Park Avenue/Ford Fusion Hybrid	16.0776	15000	7692	7308	-1195	8503
Ford Taurus/Ford Fusion Hybrid	14.50533333	14285	7692	6593	2100	4493
Volkwagon Jetta/Toyota Prius	14.3	12500	6000	6500	4485	2015
Toyota Camry Hybrid/Ford Fusion Hybrid (3)*	22.3872	8823	7692	1131	1120	11
Toyota Camry/Ford Fusion Hybrid (3)*	45.6984	10000	7692	6924	6825	99
Toyota Corolla/Toyota Prius	13.2	12000	6000	18000	6650	11350
Toyota Matrix/Toyota Prius	10.36933333	10714	6000	4714	4640	74
Ford Escape/Ford Escape Hybrid (4)**	355.0624	13043	9375	14672	32000	-17328
Honda Pilot/Ford Escape Hybrid	14.11226667	15709	9375	6334	350	5984
Ford Explorer/Ford Escape Hybrid	23.37573333	20000	9375	10625	-1555	12180
Totals	529.0882667			82801	55420	27381

*Dartmouth has 3 Toyota Camrys and 3 Toyota Camry Hybrids. All figures are multiplied by 3 to reflect this.
**Dartmouth has 4 Ford Escapes. Figures are multiplied by 4.
***Fuel costs estimated on $4/gal gas; vehicles driven max 75,000 miles allowed by college

Appendix B: Description of Phase II Technologies

B.1 Photovoltaics

Introduction

Over the past century, human activities on Earth have led to numerous perturbations in our system's cycles and changes in the environment. Globally we are witnessing an average increase in temperature, a rise in the ocean level, a decrease in snow cover, as well as multiple other significant modifications. All of these are results of, as well as contributors to, a global climate change. A major factor of this climate change is a consequence of human presence on Earth, and more specifically our recent industrial revolution.

During the Industrial Revolution in the late 18th and early 19th centuries, new practices were developed in the fields of agriculture, manufacturing, mining, and transportation that contributed to a sharp increase in overall fossil fuel use. With an increasing amount of fossil fuel combustion, the concentration of anthropogenic greenhouse gas emissions in the atmosphere also grew at a considerable rate. The most common anthropogenic green house gases on Earth include CO^2, CFCs, N_2O, and CH_4. H_2O vapor and O_3 are also significant greenhouse gases, but are also naturally occurring and important in the keeping the Earth's system stable.

In general, green house gases (GHGs) are able to absorb solar radiation and emit radiation back into the atmosphere, having a large impact on the global temperature. It has been proven that humans have caused a dramatic increase in GHG concentrations in recent decades, which have led to detrimental effects on our environment. Fossil fuels have also been found to be a finite resource that we have used to excess, and they threaten to run out. Because of this, it is crucial that our society starts using new and renewable sources of energy.

With a goal of becoming carbon neutral, it will be imperative for this class to look at using different renewable energy technologies at Dartmouth. Through class discussions, looking at precedents, and research, it has become clear that the installation of photovoltaic cells deserves some serious consideration. By using the Earth's incoming solar energy, photovoltaics are able to exploit an energy resource we have infinite amounts of without producing any harmful gases or otherwise hurting our environment. With such a large and powerful energy source like solar radiation, it is almost a waste to not use it in some fashion.

Technical Aspects

The process of a basic PV cell is shown below. Most PV cells are constructed with a semiconductor material, typically silicon. The material used is then treated so that one side is positive and the other is negative, creating an electric field. When photons hit this surface, they will cause electrons to be separated from the atoms in the semiconductor material and knocked into a higher state of energy, and they can then be used to create an electric current (Knier).

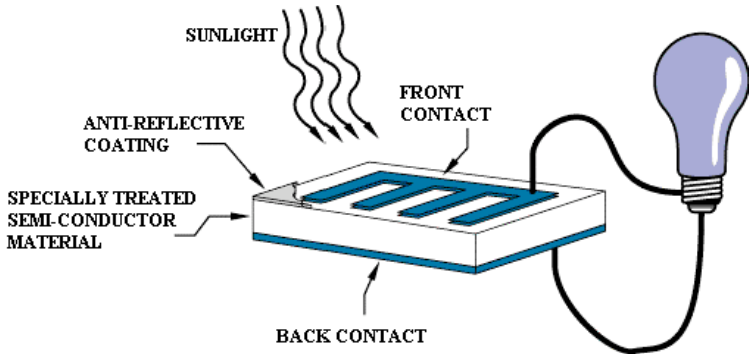


Figure 1: *http://science.nasa.gov/headlines/y2002/solarcells.htm*

The electricity produced from PV cells is a direct current and can be used to power a load immediately, such as a light bulb as shown above, or can charge a battery that is available to use at any time.

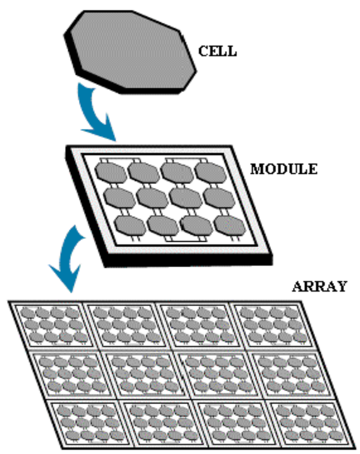


Figure 2: *http://science.nasa.gov/headlines/y2002/solarcells.htm*

Multiple PV cells are usually combined into modules, which can then be mounted in a PV array. About 10-20 arrays produce enough power for an average home ("The Basics of Solar Power"). These arrays can be arranged at a fixed angle facing south that will receive the most sun energy based on the location, or they may be mounted onto a solar tracker which will follow the sun throughout the day and through seasons to the most effective position for that time and location. These systems are more efficient than a fixed module, but are also more complex and difficult to install.

The angles used for photovoltaic cells are extremely important to maximize their efficiency and produce the most energy possible. For this reason, some locations are better than others because of their distance from the sun at a given latitude and the strength of the UV radiation at that specific spot. Usually the angle a PV cell is positioned at will be in the range of the latitude +15° or -15°. The amount of energy received by a PV cell is then determined by the average number of full sunlight hours per square meter (or "Peak Sun" hours) on the panel throughout the year. It is assumed that one peak sun hour can provide 1000 Wh/m^2 which is equal to 1 kWh/m^2 ("The Basics of Solar Power"). The diagram below shows the potential kWh/yr for a kilowatt of solar installed.

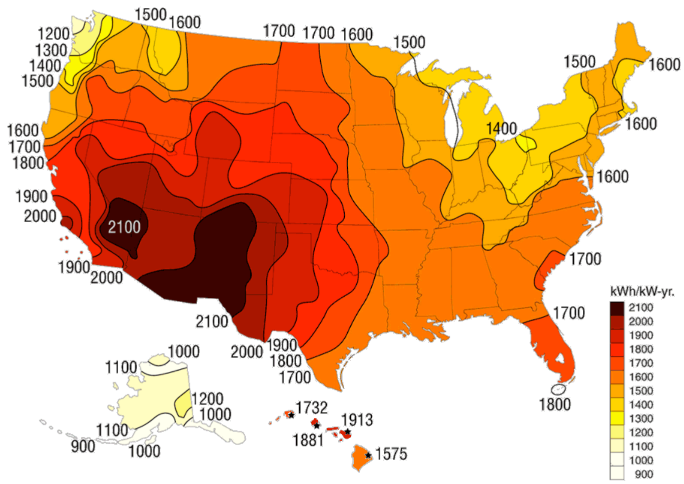


Figure 3: *http://www.seia.org/cs/news_detail?pressrelease.id=342*

Photovoltaics have multiple applications that can be used for a range of project sizes, locations, and uses. The largest scale use of PV cells can be seen in power stations, or photovoltaic power plants. Most PV power plants have been built very recently and are located mainly in Europe. As of now, the largest plant is the Olmedilla Photovoltaic Park in Spain, which was completed in 2008 and generates 60 MW. This station integrates agriculture into their system and also uses a tracking system to optimize their generation of electricity.

On a smaller scale, photovoltaics can be used for standalone devices as well as rural electrification. Standalone devices that implement the use of PV cells are usually fixed to one location and have a constant demand for electricity, such as traffic signals and parking meters. PV cells is helpful for rural electrification if a community is too remote to obtain power from the grid, and can use photovoltaics to generate the small amount of electricity they use.

Another application of photovoltaics that will be the focus for this project is building-integrated photovoltaics, as they appear to be the most appropriate option here at Dartmouth. BIPVs are solar panels incorporated into a building's design, or are retrofits installed onto existing buildings, usually located on roofs, walls, or as roof tiles. The PV cells may also be constructed apart from the building and a cable is used to transfer the power.

Along with the multiple applications of photovoltaics, there is also a wide range of types. Solar energy is an important and continuously growing field, so new technology is constantly being developed and updated. For this project, it will be important to only focus on a couple of these technologies. A recent report was completed for the Sustainable Living Center (SLC) at Dartmouth, which narrows down a couple different photovoltaic options that best fit Dartmouth's need: Thin Film (Si), SunPower PV, Thin Film (CIGS), and DSSC (a summary of their findings for installation at the SLC is provided below).

Technology	Efficiency	Area (m^2)	Cost ($/W)	Total Cost ($)	Payback (yrs)
Thin Film (Si)	0.08	49.6	3	15000	19
SunPower PV	0.22	18.0	9	45000	58
Thin Film (CIGS)	0.14	28.3	3	15000	19
DSSC	0.12	33.0	2.5	125000	16

Thin Film (Si), also known as amorphous thin film, is a silicon-based panel. Because it is amorphous (non crystalline), it is extremely flexible and can be applied to a range of different surfaces. This technology is the least efficient (about 6-8%) but is also the cheapest option and the easiest to install ("Photovoltaics"). Another drawback of amorphous thin film is that the power output can decrease with time, especially in the first few months.

SunPower is a photovoltaic company that uses silicon PV panels, the standard in the industry (Gromadzki et al). There are two types of silicon PV panels, monocrystalline and polycrystalline, that very in efficiency and cost. Monocrystalline panels, which are cut from a single crystal of silicon, are more efficient, but also more expensive. Polycrystalline panels are cut from a block of silicon with a large number of crystals, and are slightly less efficient and costly. Overall, silicon PV panels are 12-20% efficient.

The next technology they looked at, Thin Film (CIGS) is similar to amorphous thin film but uses copper indium gallium selenide as the semiconductor. This option is much cheaper, with costs around $2.50 per watt, but requires a large metal surface for installation (Gromadzki et al). This may limit the installation options at Dartmouth as not all buildings would be able to provide such a surface.

The last option considered was dye-sensitized solar cells (DSSC). DSSC is a fairly new development that can be applied to glass surfaces. While the efficiency is only about 12%, it is also extremely low-cost, and so it has a high price-performance ratio and the shortest payback time.

B.1.3 Case Study: Oberlin College

Numerous academic institutions have embraced photovoltaic technologies and installed large arrays on buildings in order to reduce carbon emissions and energy costs. One of the most laudable examples of PV use in an academic building can be found at the Adam Joseph Lewis Center for Environmental Studies at Oberlin College (AJLC). Completed in 2000 at a cost of $6 million, this building integrates many environmentally-friendly technologies into one structure that not only generates enough energy to operate itself, but is able to export excess energy to the remainder of Oberlin's campus (Oberlin 2007). Among the many eco-friendly technologies in use at the AJLC, none is more critical to the building's net energy production than the large PV arrays on the roofs of the center and its adjacent parking structure (Solar Design Associates 2009).

Figure 4: *http://www.buildinggreen.com/hpb/overview.cfm?projectid=18*

Figure 5: *http://www.greenenergyohio.org/page.cfm?pageID=968*

The photovoltaic array on the roof covers 4,671 square feet on the south-facing side of the Center for Environmental Studies (International Energy Agency). This array, made of monocrystalline photovoltaic panels, can produce up to 60 kW at any given moment, meeting nearly 50% of the building's annual electrical usage. In 2006, Oberlin installed a second large photovoltaic array above the parking lot adjacent to the building capable of producing an additional 100 kW of electricity (Green Energy Ohio). This "solar pavilion," covering 8,800 square feet, has enabled the AJLC to produce around 30% more electricity than it uses in a given year, making it the first college or university to have an academic facility that is a net energy exporter (Green Energy Ohio).

Because photovoltaic cells are only able to produce electricity during the day time, the two arrays on the AJLC are connected to the local electric grid (Oberlin 2007). On sunny days when electricity production is at its maximum, the photovoltaic arrays are able to meet 100% of the energy needs of the center and export the remainder into the grid. At time with low solar intensity, the building imports electricity from the grid (Oberlin 2007). In order to track the net energy use of the building, Oberlin has installed numerous monitors, available in real-time on the

AJLC's website, that calculate photovoltaic output, electricity use, and net energy use (Oberlin 2007).

By examining these monitors, it is also possible to see trends in the electricity production over a given period of time. In an individual day, the energy use peaks during work hours—roughly from 8 am to 5 pm (Oberlin 2007). However, this coincides with the time of day when solar radiation is at its maximum, allowing the building to generate more electricity than it consumes. During off-peak hours when the photovoltaic arrays are generating little to no electricity, the building must purchase the small amount of power it consumes from the grid (Oberlin 2007). Over the course of a year, it is possible to observe a slightly different trend; in the winter time, the photovoltaic output is low and the energy usage is relatively high. Conversely, in the summer time, photovoltaic output is at its peak while energy usage is minimal as a result of the decrease in summer occupancy, resulting in the exportation of electricity to the grid (Oberlin 2007). These trends clearly show that although the photovoltaic system in the AJLC generates excess electricity over the course of the year, it is not a steady supply, and cannot meet the buildings needs at all times. As a result, it is still essential for this building and most others like it to be connected to the electricity grid in order to ensure there is sufficient energy at all times (Oberlin 2007).

These photovoltaic panels are not just beneficial to Oberlin as a means to cut down on energy expenditures and carbon emissions, but they have very strong PR value. Having one of the only academic buildings in the United States that is a net energy producer has catapulted Oberlin into the number four position of the "Greenest Colleges in America" list by The Daily Green (Howard 2008). While there is still some debate as to whether or not this will produce any tangible benefits for Oberlin such as increased application rates, it does elevate the school's national recognition and position it as a leader of the sustainability movement (Howard 2008).

B.1.4 Case Study: Tin Mountain Conservation Center

Photovoltaic technology is also being used at academic buildings in New Hampshire. The Tin Mountain Conservation Center is an education center dedicated to educating children and the community about the local environment and environmental issues. Located in Albany, NH, the TMCC provides multiple programs and summer camps for those in the Mount Washington Valley. One of the main goals behind TMCC is to raise awareness and promote appreciation for the environment through their hands-on activities (TMCC).

Located on 98 acres of forest, the TMCC facility is resource-efficient and zero-energy that was recently constructed by Solar Design Associates and a local architect, Christopher Williams (Solar Design Associates). The building incorporates multiple special features that contribute to its overall carbon neutrality. These features include a heat-recovery ventilation system, a superinsulated building envelope, radiant heating, and three solar systems: a roof-integrated photovoltaic system, a roof-integrated solar thermal system for space and water heating, and advanced solar glazings.

Figure 6: *http://www.tinmtn.org/indextinmtn.cfm*

Though zero-energy buildings may sometimes see a few setbacks and have difficulties in becoming truly “zero-energy”, the construction of the TMCC building was completely successful. Even in its first year, the building was able to produce more than enough electricity and was able to deliver the extra power to the surrounding communities. This case is important to look at because of its similar location and climate/solar radiation conditions to Dartmouth, it approximately 50 miles NE of our campus. This shows that though we are not in a prime location for solar, it is still a feasible option and can be highly successful. Also, the construction of their headquarters as a completely carbon-neutral building helps educate the community and raises awareness and pride among the locals. Ideally, this would also be a positive result from installation of photovoltaics at Dartmouth.

B.1.5 Photovoltaics at Dartmouth

This course has not been the first to look at photovoltaics at Dartmouth. A previous ENVS 50 class taught by Professor Bolger in 1995 wrote their report on reducing energy use in Dartmouth buildings, and their final recommendation was to use a photovoltaic system. After the class was completed, Professor Bolger along with a professor from the Thayer Engineering School, Alvin Converse, continued to pursue the idea of a small photovoltaic demo installation. Through some research and work they applied and received grant money from the Department of Energy with matching funds from Dartmouth totaling to $50,000.

A Dartmouth alumnus, Ed Kern, is a director of Ascension Technology Corporation in Vermont and has over twenty years of experience with photovoltaic systems. With the grant money, Dartmouth hired Ed Kern to design and install two arrays with ten modules each onto the roof of Murdough Hall. The panels were placed at a 25° angle to the roof, and cover an area of 44.80 square meters. For this system, the energy collected is converted to direct current, which is then fed into the Dartmouth energy grid.

The goals of installing these panels were to: "1) Support research on photovoltaic system design 2) Be used as part of the curriculum in Environmental and Engineering Sciences classes 3) Increase awareness of energy use and conservation among a broad spectrum of students, faculty, and staff." (Bolger). At first the data from these panels was sent directly to the Dartmouth Photovoltaic website, but unfortunately it has not been updated since the year 2000 and at this time current information from the photovoltaic system could not be obtained. However, the data from the years 1996-2000 are posted below, and it is seen that the average electrical output from the two arrays was about 5000 kWh. It should also be noted that photovoltaic technology has been advanced and improved by a large degree since 1996 when this particular system was installed.

Year	Electrical Output	In-plane Insolation	Global Horizontal Insolation	In-plane Efficiency	Footprint Efficiency
1996	5353 kWh	66250 kWh	102833 kWh	8.1%	5.2%
1997	4380 kWh	57646 kWh	86197 kWh	7.6%	5.1%
1998	4750 kWh	54536 kWh	82737 kWh	8.7%	5.7%
1999	5776 kWh	67794 kWh	103241 kWh	8.5%	5.6%
2000	5411 kWh	64278	99706 kWh	8.4%	5.4%

Figure 7: *http://www.dartmouth.edu/~photov/PV_system_performance.shtml*

The Sustainable Living Center at Dartmouth has also seriously looked into installing a photovoltaic system to account for some of their electricity needs. After performing thorough research of the different options available, the SLC proposed to install 18 m^2 of monocrystalline silicon panels through the company SunPower. These panels have 22% efficiency, and would be located on the roof of the nearby dorm Brown in the Choates Cluster. The panels would be mounted on racks at an angle of 45° latitude in order to receive the maximum amount of sunlight throughout the year. This system would produce 6000 kWh/yr and would save a total of $780 per year on electricity. Because this PV system is eligible for state rebates as well as federal tax credits, the total cost of installation would be approximately $27,000. The payback period for this system is approximately 23 years, after which it will start to save Dartmouth money for the remainder of its lifetime.

From looking at these current and proposed projects already at Dartmouth, it is easy to see the feasibility of a larger scale installation that could significantly reduce our electricity needs and save Dartmouth money in the end.

B.1.6 Cost and Feasibility

Dartmouth College is currently a huge electricity consumer, using over 65,000 megawatt hours last year alone, a number that is predicted to rise in the upcoming years (Ager 2008). Of this electricity, 21,569 megawatt hours (33.1% of the total) are generated on-site at the Dartmouth College heating plant as a "byproduct" of steam production. The remaining 43,787 megawatt hours (66.9%) are purchased from National Grid, formerly known as Granite State Electric Company (Ager 2008). There are numerous utility accounts at the College including three “main” accounts: one for Dartmouth properties on West Wheelock Street, one for properties on College Street, and one for electricity that enters through the heating plant which is then distributed to the majority of the campus (Fournier). This account, which is by far the largest, cost the College $834,911.77 in 2008 at a cost of $.0019 per kWh during peak demand and $0.00057 per kWh during off-peak demand (Fourneir).

Of this electricity, a small fraction could easily be produced on campus through the use of photovoltaic arrays. According to GroSolar, each dollar of electricity purchased from the local utility can be offset with 7 to 8 square feet of photovoltaic panels, with each square foot producing about 10 watts (GroSolar). For Dartmouth, this means that in order to negate all of the electricity that we purchase, we would need to cover an area of 3.4 million square feet. Clearly, this figure far exceeds the total square footage of roofs that we have available on campus, much less the requisite south-facing, unobstructed roofs. Thompson Arena, which is second only Leverone in term of total roof space, has a south-facing area of approximately 18,000 square feet (Jones et al 2007). According to the figures provided by GroSolar, if Dartmouth covered the south-facing roof with photovoltaic cells, it could produce 229.95 megawatt hours each year, just .35% of the College’s total electrical use. Other large, south-facing roofs on campus include Leverone, the Boss Tennis Center, Alumni Gymnasium, the Hopkins Center, Baker-Berry Library, the Fairchild complex, and numerous other dorms, academic buildings, and Dartmouth owned buildings in the town of Hanover. It would also be possible for Dartmouth College to install free-standing photovoltaic arrays. Such arrays, in addition to producing carbon-free electricity, could be used to serve a variety of functions including covered parking lots, covered bike racks (which would also promote a more bike-friendly campus atmosphere), and covered walkways.

Unfortunately, one of the major drawbacks with investing in photovoltaic technology is its cost. Currently, photovoltaic arrays are quite expensive to install, ranging from $3 per watt to $70 per watt, both considerably more than electricity from the local power grid (Gromadzki et al 2009). According to Dori Wolfe, President of GroSolar, the fifth largest photovoltaic supplier in the United States, customers in the Upper Valley looking to install commercially available solar panels should budget about $8 per watt to install on an existing roof and $10 per watt to install on a ground mount racking system to hold the panels (Wolfe). These prices, however, are just approximations that do not take into account other factors that could affect the price per watt such as the pitch and height of the roofs or the overall size of the photovoltaic array (Wolfe). Furthermore, these prices are constantly changing due to technological advances, political trends, and the state of the economy, so in order to calculate a more precise figure, a detailed analysis of Dartmouth’s buildings and grounds would need to be performed (Wolfe).

A second concern when installing photovoltaic panels is their effectiveness at a given geographical location. While Hanover, which is located at 43 degrees north, is certainly not an ideal location, it is surprisingly not bad, either. In fact, due to New England’s clear spring, summer, and fall weather, the region receives an average of 3-4 full hours of sun each day, compared to just 4-5 full hours in Florida (Wolfe). Furthermore, Germany is located at much higher latitude and does not receive as good solar irradiation, yet they have become the world’s leader in photovoltaic technologies (Wolfe).

Although installing photovoltaic panels at Dartmouth would certainly be a large investment on the part of the College, they would pay for themselves overtime by reducing the amount of electricity purchased from National Grid. Assuming that Dartmouth could install around 50,000 square feet of solar panels on the roofs of buildings connected to the primary grid, which is a relatively conservative number, and the campus receives an average of 3.5 hours of sunlight each day, 638.75 megawatt hours could be produced annually. Considering all of the sunlight that would power the photovoltaic arrays would offset "peak demand" electricity purchases (roughly 9am-8pm), this would save the College $1,213.63 each year. Furthermore, having a power system connected to the Dartmouth grid would also reduce the utility's $4.02 kV/kWh "demand charge" by providing up to 500 kW at any given moment, saving an additional $55,757.40 each year. If cost of installation is roughly $8 per watt, the total installation cost would $4 million. This data alone gives such a system a payback period of just over 70 years, however, when state and federal tax breaks are factored in, this number decreases significantly.

The installation of renewable energies is eligible for numerous tax breaks and other financial incentives. The state of New Hampshire provides a maximum incentive of $3,500 for installing photovoltaic arrays as well as loans with interest rates of 1% for photovoltaic installation, both of which Dartmouth would qualify for (DSIRE.org). However, as a non-profit, Dartmouth is not eligible for many state and federal tax breaks available only to commercial sectors. As suggested by Ms. Wolfe, it would be in Dartmouth's best interest to find a group of alumni or investors who need a tax shelter and enter into a "Power Purchase Agreement" with them (Wolfe). In this scenario, the College would not technically own the photovoltaic array, but would benefit from reduced energy costs by selling the green rights to the financier who can then capitalize on the federal 30% incentive opportunities as well as accelerated depreciation (Wolfe, DSIRE.org). This sort of agreement would allow Dartmouth to benefit from much lower rates, further reducing the payback period. In fact, the SLC, which is in the process of installing PV panels on a much smaller scale, calculated a payback period of just 23 years. However, in order to calculate the payback period for a large scale system, professional accountants must be consulted.

B.1.7 Further Research:

In order to move forward with the installation of photovoltaic panels at Dartmouth, a considerable amount of research must still be performed, mainly in the areas of feasibility and actual cost. The best way to gather this data would be to hire an outside consultant from a photovoltaic company such as GroSolar, a company located in White River Junction, VT with a great deal of experience installing photovoltaic panels in New England. With the expert help of an engineer from one of these companies, the College would be able to gather a much more comprehensive dataset on the actual feasibility of photovoltaic at Dartmouth including suitable roof area, cost to install, and electricity produced. These companies would also be able to work with the administration to propose a photovoltaic scheme that is both effective and fits in with the current aesthetics of Dartmouth College.

Further research should also be done on the possibility of creating a mandate that new construction projects on campus must utilize photovoltaic cells if at all possible. Not only is the installation of photovoltaic panels in a new building is cheaper than retrofitting an existing building, but new construction could also be planned to maximize the solar irradiation by increasing south-facing roof area, resulting in more efficient photovoltaic operation.

B.1.8 Conclusion

Dartmouth College stands to gain a great deal from installing photovoltaic arrays on the campus. Photovoltaic arrays would provide the campus with renewable, carbon-free electricity, reduce the College's current utility costs, and be of great public relations value. While many different types of photovoltaic panels exist at a broad range of efficiencies and prices, the industry standard for commercial installation is thin film silicon cells, which have already been installed in academic facilities at Oberlin College and even here in New Hampshire. If Dartmouth also chose to install a modest 50,000 square foot array located on the south side of some of the campus' roofs, 638.75 megawatts could be produced annually given Hanover's geographic location. An array of this size, while somewhat costly, could have a payback period of a few decades of less depending on tax breaks and other financial incentives, and certainly deserves some further research. If Dartmouth actively pursues photovoltaic technology, it will be a strong, visible step towards carbon neutrality, once again elevating the College to a position of leadership among institutes of higher education.

B.2 Geothermal Wells

B.2.1 Background Information

Geothermal wells operate by utilizing the stabilized 55°F temperature of the underground bedrock to regulate and moderate the ambient air temperature of buildings. These systems offer numerous environmental, aesthetic, and operational benefits and they would be optimal to implement at Dartmouth (Harvard University Operations Services, 2007). For example, geothermal heat pump technology is 44 percent more efficient than air source heat pumps and 72 percent more efficient than electrical resistance heating (US DOE, 2008). In addition, geothermal heat pumps use 25 to 50 percent less electricity than typical heating or cooling systems. The technology is located completely underground and in the equipment rooms of buildings. Therefore, the traditional layout of Dartmouth buildings, including the interior and exterior appearances, can be preserved. Lastly, geothermal well systems are easy to operate once they are constructed since they reside safely inside buildings, are durable, and have relatively few moving parts (US DOE, 2008). Typically geothermal well technology has a long life span and is covered by a warranty of up to 50 years (AEENY, 2008). Most importantly, geothermal well technology is environmentally friendly and does not cause the direct release of carbon dioxide or greenhouse gases into the atmosphere during operation.

When geothermal wells are constructed, they are drilled deep into the ground in order to gain access to a region of soil or bedrock which is not influenced by daily or annual temperature swings. For the most part, geologists consider the ground's annual temperature to be stabilized once a well depth of greater than 10 meters is obtained. By gaining access to this region, buildings will have a constant supply of energy, equivalent to the stabilized ground temperature, which can provide heating or cooling depending on the season. In New England, the ground temperature is estimated to be roughly 55°F. During winter months, this 55°F heat can be pumped to the surface and used to heat the interior of buildings. Likewise, during the summer months, heat from the buildings can be pumped down to the 55°F heat sink at the base of the geothermal well. This will allow buildings to be effectively heated or cooled using geothermal heat exchange technology.

One common concern people have regarding geothermal wells is that they will not be able to sufficiently heat buildings if they only pump 55°F heat from the ground. This concern is valid in the sense that water coming up from the ground is only 55°F, but then heat exchangers and heat pumps residing within a building's pump room allow the water to be warmed to a temperature which is suitable for heating. In the winter, when 55°F water is pumped up from the ground, heat contained within the groundwater is transferred to cooler water residing in the interior pipes of a building. Therefore, the interior water pipes experience a net heat gain and water inside a building becomes sufficiently warm as this process is repeated within a heat exchanger.

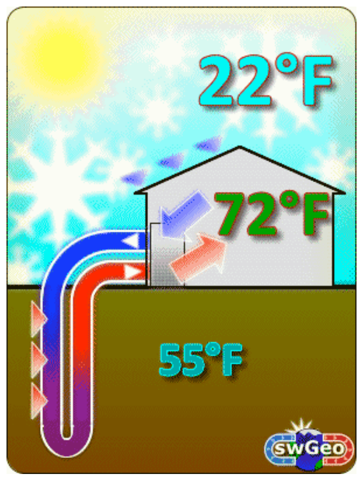


Figure 1 *– Schematic Diagram of Geothermal Well*
http://swgeothermal.com/Geothermal.aspx

B.2.2 Bedrock Geology of Dartmouth College

One factor to take into consideration during the construction of geothermal wells is the hardness of underlying bedrock where the bore holes are proposed to be drilled. Depending on the hardness of this bedrock, the drilling cost for digging wells can significantly vary. For example, a hard rock such as schist requires a harder and more durable drill bit to be used as opposed to limestone which is softer and easier to drill through. Therefore, a significantly higher amount of money must be spent to drill a well through schist.

Here at Dartmouth, the bedrock situated underneath the campus primarily consists of hornblende schist, amphibolite, feldspathic schist, gray to black mica schist, and quartz-mica schist (Lyons, 1949). On the southeast section of the Dartmouth campus, border gneiss, quartz diorite, oligoclase, quartz, biotite, epidote, microcline, and muscovite can also be encountered when digging into deeper sections of bedrock situated about 1,000 to 1,500 feet deep. Schist is classified as a hard but brittle rock and drilling through it would require a durable drill bit as opposed to drilling through softer bedrock such as limestone. According to a boring report done at the site for the new Visual Arts Center, the bedrock in this region of campus consisted of medium to hard quartzite and phyllite (M&W Soil Engineering, 2007).

The price of drilling the two 1,500 foot wells at the Fahey and McLane dormitories at Dartmouth by Cushing & Sons was approximately $75,000, or $37,500 per well. At other schools however, the price for the drilling cost for each well averaged $150,000 at Harvard University and $175,000 at the General Theological Seminary (Harvard University Operations Services, 2007; Frawley, 2009). This shows that Dartmouth was able to obtain a relatively low cost for its geothermal wells by hiring a local company in New Hampshire despite having hard underlying bedrock. Part of the reason for the low cost is that a minimal amount of steel casing needed to be used to reinforce the wells since the bedrock at Dartmouth is close to the surface. However, when the wells were drilled at Dartmouth, some costs were saved by eliminating procedures which could have improved the heat exchange capacity of the wells. For example, additional hydrofracturing of the bedrock adjacent to the well was not requested by Dartmouth in order to save money on this project. However, this could have up-regulated the flow of groundwater through the well and permitted the wells to have a larger capacity for heat exchange.

B.2.3 Geothermal Well Operation and Bedrock Water Flow

The geothermal wells at Dartmouth function using an open loop system as opposed to a closed loop system since an open loop system is cheaper to construct as long as the underlying bedrock has a sufficient flow rate for groundwater. When the geothermal well is initially constructed, the heating and cooling load for a building must be taken into account when determining the depth to drill the well. For example, larger buildings necessitate that wells are drilled to a depth of 1,500 feet since these buildings have a larger heating and cooling capacity. This means that a sufficient amount of water must be stored within the 1,500 foot well column in order to prevent the building's discharge water from circulating too rapidly towards the well's base. This will allow the discharge water from a building to have a sufficient amount of time to moderate back to the 55°F temperature of the bedrock and groundwater. In the well, the maintenance of a constant 55°F water temperature is aided by the fact that groundwater in the bedrock percolates through the well and displaces a portion of the discharge water coming from buildings. In general, the higher the flow rate of groundwater through the bedrock and into the well, the higher the probability that the geothermal well system will operate at a maximal efficiency.

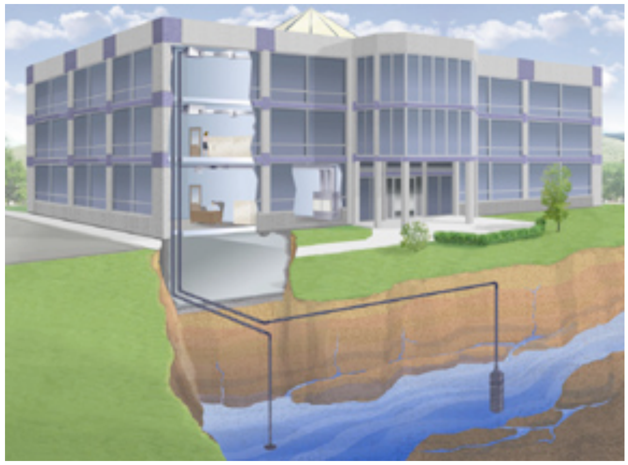


***Figure 2** –Diagram of Open Loop Geothermal Well System*
http://www.mcquay.com/McQuay/ProductInformation/WSHP/WSHPpage

When the geothermal wells were installed at Dartmouth, the groundwater in the bedrock adjacent to the geothermal well had a flow rate of 40 gallons per minute (Gratiot, 2009). This was determined to be sufficient by Dartmouth to meet the heating and cooling needs of the Fahey and McLane dormitories. However, hydrofracturing of the bedrock could allow a much higher rate of groundwater flow. For example, the 1,500 foot geothermal wells at the General Theological Seminary in New York City have a groundwater flow rate of 90 gallons per minute since the bedrock next to each well was fractured to allow for a higher rate of groundwater percolation (Frawley, 2009).

B.2.4 Current Inefficiencies in the Fahey and McLane Geothermal Wells

During the initial drilling phase for the geothermal wells at the Fahey and McLane dormitories, the infiltration of groundwater into the wells did not appear to occur at a high rate. This was evidenced during drilling operations when bore holes for the wells were dug. Initially water was pumped out of the well during the drilling process, but water from fractures in the bedrock did not immediately percolate through the bedrock to fill in the well again (Argüello, 2009). This presented a problem for the Tuck Mall geothermal wells since efficient heat exchange cannot occur if an insufficient amount of water is flowing past the open loop well system. Eventually the groundwater seeped back into the well to fill it again before the geothermal wells were turned on to commence operation in the dormitories. However, to date, the Tuck Mall wells are not performing up to par in terms of heating the Fahey and McLane dormitories.

***Figure 3** –Fahey and McLane Dormitories, Dartmouth College*
http://www.dartmouth.edu/~vox/0708/0303/residence-halls.html

The Haley and Aldrich company has been recently working to ameliorate this heating problem and they have initially determined that significant inefficiencies are occurring in the current wells as of late May 2009 (Gratiot, 2009). The prevailing hypothesis for these inefficiencies is that all of the piping was only connected to one well while the other well remains unused. This puts a large strain on the one well that is in operation and causes a large amount of electricity to be used by the heat pumps that are operating that one well. During an examination of the system on May 24, 2009, the Haley and Aldrich company determined that one of the two heat pumps is malfunctioning (Eckels, 2009). In addition heat is potentially being lost through the underground piping that reaches into the wells.

B.2.5 Current Performance and Operation Cost of Fahey and McLane Wells

Based on calculations including the total heating capacity of these dormitories and the total amount of steam that these buildings receive from the heating plant during the heating season, approximately 89.3 percent of the Fahey and McLane heating is covered by the geothermal wells and ground source heat pumps. However, the amount of electricity these dormitories use to operate the current setup is excessively high. This is leading to unreasonable electricity costs and is currently causing Dartmouth College to lose approximately $88,000 on a yearly basis. However, if the inefficiency problem of the geothermal wells is ameliorated, profits from this project would amount to approximately $18,500 on an annual basis when fuel cost savings and electricity expenditures on pump operation are taken into account.

Electricity represents the predominant operating cost of this technology since it is needed to operate two Mammoth water source heat pumps that circulate water from the base of the geothermal well up to the basement of the dormitory. In addition, eight Baldor water pumps are used to circulate water throughout the interior of the dormitory. To ensure the most environmentally friendly use of geothermal well and ground source heat pump technology, building owners need to determine the way their electricity distributor produces electricity since electricity generation represents the only step during operation in which greenhouse gases are released to the atmosphere. If clean and environmentally friendly electricity can be produced, then this technology will reduce greenhouse gas emissions to an even greater extent on top of the 25 to 50 percent less electricity this system uses than conventional heating and cooling systems (US DOE, 2008).

Figure 4 *–Mammoth Water Source Heat Pump*
http://www.mammoth-russia.ru/eng_prod04.shtml

Current heat pumps installed in the Fahey and McLane dormitories have an ability to provide a 60 ton capacity to the buildings for distribution (Gratiot, 2009). When determining the number of heat pumps to install, the square footage and the heating and cooling requirements of a building must be properly taken into account. In addition, the number of geothermal wells drilled for a particular building need to be based on the building size and its heating and cooling requirement. Currently, one 1,500 foot geothermal well is predicted to provide 420,000 to 480,000 BTU per hour based on optimal well efficiency (Geothermal Heat Pump Manual, 2002). However, actual usage of heat pumps and geothermal wells has shown that full capacity is not always achieved. For example, only 21 tons or 252,000 BTUs per hour of heating and cooling capacity is being achieved with one of Harvard's heat pumps for a 1,500 foot well instead of the predicted 30 tons or 360,000 BTUs per hour (Harvard University Operations Services, 2007).

B.2.6 Precedents in Academic Institutions Regarding Geothermal Well Construction

At the General Theological Seminary in New York City, one of the most prominent geothermal well projects in the Northeast is currently in progress. The project is designed to install 22 wells that all reach depths of 1,500 feet (AEENY, 2008). Currently the first phase of the project is complete and has resulted in the installation of 7 open loop geothermal well systems in which groundwater is circulated up the geothermal well by a heat pump, passed through a heat exchanger, and then released back into the well. One aspect which makes this project of particular interest is that this project might provide a rough cost estimate for retrofitting older buildings with geothermal well systems since the General Theological Seminary is retrofitting 190 year old buildings with this technology (AEENY, 2008).

For the 7 wells currently drilled at the General Theological Seminary, the initial cost estimate was $6 million, but the actual cost wound up being $9 million (AEENY, 2008). The reasons that this first phase went over budget was that the General Theological Seminary had to take extra measures to appease community members as well as planning committees working for New York City. For example, unforeseen costs occurred in monitoring drilling vibrations and noise, ensuring the wells were dug vertically with only a 3 degree margin of error so as not to interfere with one of New York City's underground water tunnels, appeasing regulatory agencies and community concerns, and retrofitting buildings with additional new equipment to use geothermal heating and cooling (AEENY, 2008). Here at Dartmouth, the predominant unforeseen cost that would significantly impact geothermal well system pricing would be retrofitting costs for older buildings. At the General Theological Seminary, the simple payback time for its geothermal well project is currently estimated to be 19 years when the new estimated cost of project completion is taken into account (AEENY, 2008).

A strong initiative towards the construction of geothermal well systems is also being undertaken by other Ivy League schools. For example, the construction of new geothermal well systems at Harvard University is quite significant. Blackstone Station has 2 geothermal wells at a 1,500 foot depth, Quadrangle Recreational Athletic Center has 2 geothermal wells at a 1,500 foot depth, 90 Mount Auburn has 3 geothermal wells at a 450-650 foot depth, Radcliffe Gym has 2 geothermal wells at a 1,500 foot depth, 2 Arrow Street Condominium has 3 geothermal wells at a 1,500 foot depth, 1 Francis Avenue has 2 geothermal wells at 750 and 850 foot depths, and Byerly Hall has 5 geothermal wells with 4 of them at a 1,500 foot depth and 1 at a 600 foot depth (Harvard University Operations Services, 2007; Boston/SF, 2008). In addition, Harvard has future plans for an 88 geothermal well field at Weld Hill. At Yale University, Kroon Hall has constructed 4 wells at a 1,500 foot depth and an extensive geothermal well field is currently being designed at the university (Conroy, 2009). At Columbia University, Knox Hall has constructed 4 geothermal wells at a 2,000 foot depth (Kasdin, 2009). Lastly, at Princeton University, 2 geothermal well fields were constructed (Princeton Campus Plan, 2008). A 100 well field currently exists at the Lawrence Apartments and a 12 well system is currently being built at the Campus Club with a projected completion date of summer 2009 (Facilities Design & Construction, 2009).

B.2.7 Implementation of Additional Geothermal Wells at Dartmouth

Even though the Fahey and McLane geothermal well systems are operating at 89 percent of the dormitories' heating capacity, Dartmouth officials need to determine the exact reasons for inefficiencies in this geothermal well system. This way, the system will be able to operate at 100 percent capacity and the electricity cost to run the heat pumps will be significantly reduced. This will allow a judgment to be made on whether the implementation of future geothermal well projects will be feasible. The Haley and Aldrich company plans to continue working with Dartmouth in the near future to ameliorate the current problem with the geothermal well system.

Once the efficiency problem with Fahey and McLane geothermal wells is ameliorated, Dartmouth should move ahead with plans to apply this technology to the President's house and to buildings on Administration Row (Campbell, 2009). The President's house can utilize excess heating and cooling capacity that is available from the currently installed Fahey and McLane geothermal wells. In addition, the installation of additional geothermal wells for the administration buildings will be economically and environmentally beneficial since it will replace the large number of air conditioners used in these buildings during the summer and the conventional steam heating in the winter.

Geothermal well technology should also be applied to all new construction projects as well as a select portion of renovation projects. For renovations, one concern about adding a geothermal well system is the weight of water piping and the weight of concrete and materials needed to reinforce the piping. Many old buildings on campus have a limited load capacity since they were built using earlier construction guidelines (Eckels, 2009). Today however, buildings have to be updated to conform to the latest earthquake guidelines set forth by New Hampshire when a particular load capacity is surpassed. If this load capacity is exceeded, the only way to bring many campus buildings up to code is to knock down the existing structure and build a new one. The demolition of functioning buildings is not economically or environmentally practical. Therefore, the installation of geothermal well systems is only recommended for buildings with a sufficient load capacity that can conform to New Hampshire's current building codes when renovated.

B.3. Solar Hot Water

B.3.1 Technical Definitions

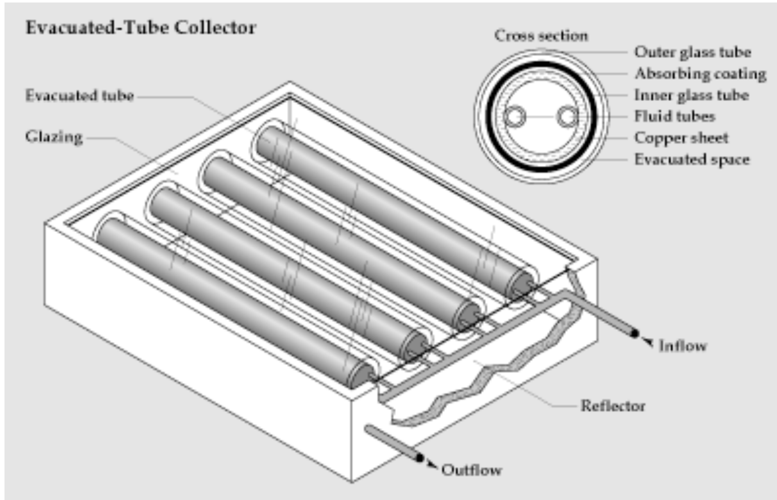
Solar hot water systems (or solar water-heating systems) serve as a source of renewable hot water. The working parts of the system are solar collectors, a pump, a heat exchanger, and at least one liquid storage tank. To summarize, the system works when sunlight directly heats an enclosed liquid that is installed in the "collector" on the roof the building. If that liquid is clean water, then it can be used directly as hot water. In some cases, that liquid can be some non-toxic mixture which can be heated and piped around a water tank to heat the water inside without contaminating it. This type of system is considered "active" if it relies on electric pumps and controllers to circulate the water and "passive" if it relies on gravity for water flow.

B.3.2 Active Solar Systems

There are two main types of solar thermal collectors, evacuated-tube and flat-plate, that are used to physically heat the water before it is pumped to a storage tank. These are by far the most applicable technologies to Dartmouth College. Some general information on the size of these systems - *A standard system for a family of 4 would be (2) 4x8 panels and an 80 gallon pre-heat tank, using ½" or ¾" supply and return piping, depending on installation. The standard run of piping is from the roof of a one story home down to the basement (say 20'-30'). If substantially longer run (or outside building, or underground), we might consider adding an additional panel to make up for the heat loss in the run.*

B.3.3 Evacuated tube collector

These powerful collectors are very efficient for industrial purposes and for air cooling systems. They are about twice as expensive (per unit area) as flat-plate collectors. The diagram below shows how liquid travels through the inflow and outflow areas and is heated as it flows through the collector. Note the evacuated space which serves to create a vacuum in the tube to reduce heat loss.

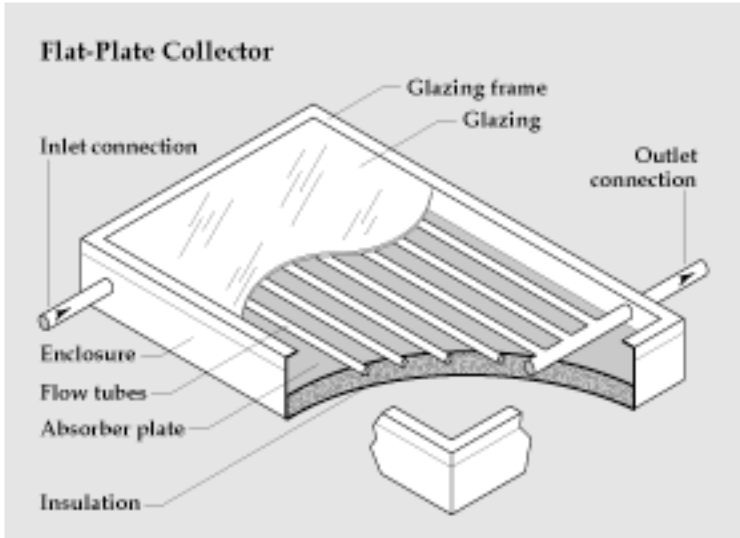


http://www1.eere.energy.gov/solar/sh_basics_collectors.html

http://neuralfibre.com/paul/tree-hugging/diy-solar-hot-water

B.3.4 Flat-plate collector

These are the most common types of systems found in residential applications. This system consists of a dark absorber plate that absorbs heat from the sun while underneath, the liquid flowing through the collectors tubes is heated. This liquid can be potable water and used directly.



http://www1.eere.energy.gov/solar/sh_basics_collectors.htm

Merkel: CN ppt

B.3.5 Passive Solar Systems

These hot water systems are considered more reliable than active solar systems because there are not electrical components. Types of passive solar includes integral-collector storage systems and thermosyphon systems. Unfortunately, integral-collector systems do not work well in climates with below-freezing temperatures so this is not an appropriate technology for Dartmouth College. Thermosyphon systems rely on natural convection of water, which means that as it warms, it rises while cold water sinks which creates a natural circulation system.

B.3.6 Other Solar Systems

A linear concentrator system uses mirrors to reflect and focus the sun's energy onto a receiving tube. Inside this tube is some fluid which, when heated, is capable of creating superheated steam. This goes beyond simply using sunlight to heat water – in this case, sunlight can be used to generate electricity! The superheated steam spins a turbine which drives a generator that produces electricity. For this technology, a large space is needed for the mirrors which work on a sun-tracking system so the can reflect sunlight as efficiently as possible all day. This technology is far removed from Dartmouth College right now, but may one day be a great alternative to using oil at the CHP.

B.3.7 Pool Heating

"In a solar pool-heating system, the existing pool filtration system pumps pool water through the solar collector, and the collected heat is transferred directly to the pool water. Maintenance of solar pool-heating systems is minimal. The systems are pre-engineered and can be sized for any pool by simply adding additional solar panels to obtain an adequate solar collector area."

B.4 Biofuels

Biofuels present a possibility for the college to move away from burning No. 6 fuel at the co-generation plant. The co-generation began in 1904 and supplies the campus with steam as well as fulfilling 45% of the electricity demand. The rest of the electricity is bought from National Grid electric. What is important to recognize is the control we, as the Dartmouth community, have in determining how the 45% of the electricity and the steam are produced. Burning biofuel instead of 100% heating oil would be a more green way to heat, cool and at times light the campus.

Dartmouth Dining Service produces a significant amount of waste vegetable oil every week and this waste product could be utilized as bioheat at the power plant. Bioheat is the combination of biodiesel and heating fuel; thus, the biodiesel could be mixed with the No. 6 fuel ("Bioheat Frequently Asked Questions"). No. 6 heating oil is viscous and must be heated at all times, even during transport, in order to keep it fluid enough to be combusted in the boilers. Such a heating process would allow WVO to also remain fluid; thus, one may simply want to mix the WVO after straining it for particulate matter and removing any water mixed in from cooking processes (Schulz). Although the boilers would most likely be able to burn this dilute mixture of WVO and No. 6, there are New Hampshire regulations that do not allow combustion of this mixture.

The American Society for Testing and Materials (ASTM) statute D 6751 lays out the standards a fuel must meet in order to be burned or mixed; in order to use WVO it must first be processed into biodiesel. Table 1 explains the standards that a fuel must meet in order to be combustible.

SPECIFICATION FOR
BIODIESEL (B100) – ASTM D6751-08

Nov. 2008

Biodiesel is defined as the mono alkyl esters of long chain fatty acids derived from vegetable oils or animal fats, for use in compression-ignition (diesel) engines. This specification is for pure (100%) biodiesel prior to use or blending with diesel fuel. #

Property	ASTM Method	Limits	Units
Calcium & Magnesium, combined	EN 14538	5 maximum	ppm (ug/g)
Flash Point (closed cup)	**D 93**	**93 minimum**	**degrees C**
Alcohol Control (One of the following must be met)			
1. Methanol Content	EN14110	0.2 maximum	% volume
2. Flash Point	D93	130 minimum	Degrees C
Water & Sediment	**D 2709**	**0.05 maximum**	**% vol.**
Kinematic Viscosity, 40 C	D 445	1.9 - 6.0	mm^2/sec.
Sulfated Ash	D 874	0.02 maximum	% mass
Sulfur			
S 15 Grade	**D 5453**	**0.0015 max. (15)**	**% mass (ppm)**
S 500 Grade	**D 5453**	**0.05 max. (500)**	**% mass (ppm)**
Copper Strip Corrosion	D 130	No. 3 maximum	
Cetane	D 613	47 minimum	
Cloud Point	**D 2500**	**report**	**degrees C**
Carbon Residue 100% sample	D 4530*	0.05 maximum	% mass
Acid Number	**D 664**	**0.50 maximum**	**mg KOH/g**
Free Glycerin	**D 6584**	**0.020 maximum**	**% mass**
Total Glycerin	**D 6584**	**0.240 maximum**	**% mass**
Phosphorus Content	D 4951	0.001 maximum	% mass
Distillation, T90 AET	D 1160	360 maximum	degrees C
Sodium/Potassium, combined	EN 14538	5 maximum	ppm
Oxidation Stability	**EN 14112**	**3 minimum**	**hours**
Cold Soak Filtration	**Annex to D6751**	**360 maximum**	**seconds**
For use in temperatures below -12 C	**Annex to D6751**	**200 maximum**	**seconds**

BOLD = BQ-9000 Critical Specification Testing Once Production Process Under Control

* The carbon residue shall be run on the 100% sample.

\# A considerable amount of experience exists in the US with a 20% blend of biodiesel with 80% diesel fuel (B20). Although biodiesel (B100) can be used, blends of over 20% biodiesel with diesel fuel should be evaluated on a case-by-case basis until further experience is available.

Table 1: *(http://www.biodiesel.org/pdf_files/fuelfactsheets/BDSpec.PDF)*

The National Biodiesel Board clearly states on their webpage that WVO cannot be mixed with heating oil and burned because it does not meet the standards outlined in Table 1 ("Specifications for Biodiesel (B100) – ASTM D6751-08"). In order to use WVO, it must be put through a chemical reaction called transesterification to produce biodiesel. Transesterification transforms the fatty acid methyl ester (FAME) into an ester and glycerol. Essentially, the process replaces the fatty acid, the glycerol group, with a methyl group. The esters, with a new methyl group, are the biodiesel and the hydrogenated fatty acids are the glycerol. Diagram 1 shows a flow chart of the transesterification process.

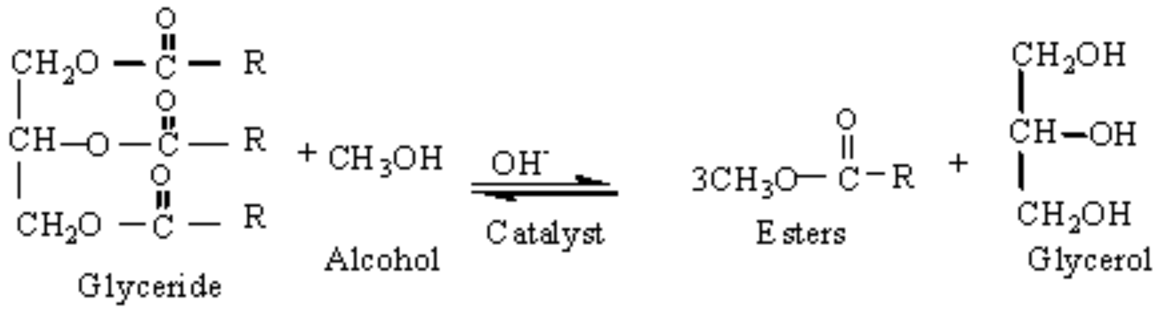


Diagram 1 *("What is Biodiesel?)*

WVO is a source of glyceride that can be put through the transesterification reaction yielding biodiesel. Currently Dartmouth renders its WVO to Baker Commodities, a company with a facility in Williston, VT (*"Reducing Fossil Carbon..."*, Baker Commodities). The service charge is $30 for 25 gallons resulting in a total charge per year is $720.00 in 2003 (*"Reducing Fossil Carbon..."*). Could Dartmouth invest in its own transesterification facility to deal with these 600 gallons of WVO every year in order to turn it into usable fuel? At the University of Colorado Boulder five engineering students built a small-scale biodiesel processor to fuel a bus (*"Reducing Fossil Carbon..."*). Although the technology is cheap and requires minimal labor, the University is not investing in self production. Dartmouth could invest in self production; however, it is not efficient for the 600 gallons of WVO that DDS produces.

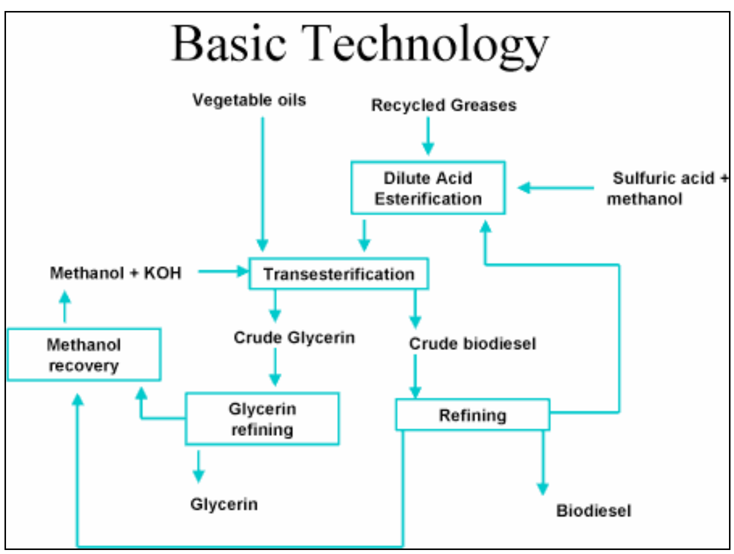


Diagram 2*-(BioFuel Industries)*

Diagram 2 shows the process for taking "Recycled Greases", or WVO, and producing biodiesel. WVO requires and extra step in order to isolate FAMEs within the fuel, and this is after a thorough straining process. The main products are glycerin and biodiesel. Glycerin is used to make soap; however, the methanol, sulfuric acid, and potassium hydroxide (KOH) required are nasty ingredients that may deter small-scale users from investing in a biodiesel synthesizer. However, there are many examples of those who have built their own production systems.

The technology and large scale production of biodiesel makes the possible small-scale production at Dartmouth seem inefficient and unnecessary. Baker Commodities is a nation wide company with 21 facilities located in the northeast and west coast of the United States (Baker Commodities). Although they have many rendering facilities, including one in Williston, VT, their primary production of biodiesel comes from first-use veggie oil. Meaning they buy enormous amounts of vegetable oils to produce fuel, and most of the rendered WVO goes into the production of feed stock (Baker Commodities, Schulz). Instead Dartmouth could purchase biofuel (*"Reducing Fossil Carbon..."*). Although purchasing biofuel is a comparable fuel to No. 6 heating oil, the ideal situation would be burning WVO.

Biodiesel and No. 2 heating oil have comparable energy outputs, and No. 6 has an even larger output than biodiesel. The heating value of biodiesel is 138,000 BTU1 per gallon, and that of No. 2 heating oil is 139,000 BTU per gallon ("Fuel & Energy Conversion…"). Contrary to this comparability, the No. 6 heating oil that Dartmouth primarily burns has a heating value of 151,000 BTU per gallon (Reihl). In order to make up for the difference in heating value, 1.1 gallons of biodiesel would have to be burned for every gallon of No. 6 heating oil. In one year, this amounts to burning 500,000 more gallons of fuel2 to a total of 5,500,000 gallons of biodiesel. Currently Dartmouth has two 125,000 gallon tanks for 0.5% sulfur No. 6 oil and 1.5% sulfur No. 6 oil. At 5 million gallons of fuel each year, the tanks must be refilled twenty times, and if biodiesel were burned instead of No. 6 the tanks would have to be refilled twenty two times. Delivery of this biofuel and the use of the two 125,000 gallon fuel tanks seem to be feasible at Dartmouth. After discussing the matter with Bill Riehl, a head operation manager at the central power plant, he said it "seems like we could do a 10 - 20% blend of biodiesel into our existing #6 tanks" (Riehl). The current distributor of heating oil is Sprague Energy out of Portsmouth NH, but in July Dartmouth will be switching to HESS Albany (Riehl). It's possible to find a biodiesel distributor in a shorter or equivalent distance than Albany, for there are a number of biodiesel pumps in Enfield. In fact, there is a network, of sorts, along the I-89 route (Biodiesel by Evans). More research is needed to determine the cost disparity between the current distributing fee of No. 6 heating oil and that of biodiesel. However, it is encouraging to hear that Riehl thought the switch feasible. Another possible fuel switch in the future is straight veggie oil (SVO).

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1 BTU is a British thermal unit and is the amount of energy required to raise one pound of water one degree Fahrenheit, from 60 to 61, at a constant pressure of one atmosphere (Wikipedia http://en.wikipedia.org/wiki/BTU)

2 Dartmouth burns 5,000,000 gallons or about 120,000 barrels of oil in one year.

SVO could be utilized as a replacement for No. 6 oil combustion on campus resulting in a number of benefits. SVO is WVO after going through a filtration process within precision of 1 micron of particulate matter and after the water is driven off (Laslett). First, by using SVO instead of biodiesel the reagents and byproducts of transesterification avoided. As seen in Diagram 2, the process requires sulfuric acid, methanol and potassium hydroxide. In the process of SVO production, water is removed and sent to the waste water treatment plant and the food particulate is sent to a composting facility. The lack of reagents reduces the carbon footprint of this fuel. Most biodiesel is produced from virgin veggie oil instead of rendered WVO. Most of the rendered WVO that biodiesel companies collect is currently used in animal feed and cosmetics (Laslett). Using virgin veggie oil becomes controversial when one thinks about the lack of food in some areas of the United States as well as the world. Although this controversy is founded in philosophy and based on principle, it is something to consider[3]. On the contrary, SVO is produced from rendered WVO and although there is not enough WVO in ME, NH, and VT to fuel Dartmouth's energy needs, SVO can be bought on the open market (Laslett). Thus, SVO utilizes a waste product for fuel and does not use chemical reagents. Another benefit of SVO is the decrease in emissions compared to burning No. 6 heating oil.

SVO emissions are lower for sulfur dioxide (SO_2), nitrous oxide (NO_x) and carbon dioxide (CO_2).

Total No. 6 2008 (gal)	4860000	
Total equivalent SVO (gal)	5424000	12% increase
2008 total SO2 from No. 6 (tons)	5416	
2008 equivalent SO2 from SVO (tons)	162	97% decrease
2008 C from No. 6 (kg)	13462200	
2008 equivalent C from SVO (kg)	1048800	78% decrease
2009 No. 6 price @ $1.95 estimate (dollars)	$9,467,700.00	
2009 SVO price @ $1.68 estimate (dollars)	$9,087,200.00	4% decrease

Table 2

Laslett explained that he would not be able to produce, from his plant in Seabrook, NH, the equivalent to 5 million gallons of No. 6 oil. However, the 3rds plan reduces the SVO load substantially. By utilizing a mix of energy, SVO, biomass, and No. 6 oil, the amount of SVO needed will be significantly less than replacing all of the No. 6 oil. These figures and tables may be referenced in Phase II section. It is important that Dartmouth move away from No. 6 oil by burning SVO and biomass.

B.5 Sewage Heat Recovery

From washing machines, to showers, and even toilets, wastewater has a surprisingly high average temperature that can serve as a significant heat source. Inside buildings, wastewater has been measured to have an average temperature of around 77°F, which drops to around 59°F when it drains. Although the temperature of wastewater fluctuates throughout the day and seasons (in the summer the drainage water ranges from 64-72°F and in the winter it ranges from 50-54°F), overall there is a significant source of heat here (Rabtherm). This lukewarm water even retains most of its temperature as it travels to a sewage treatment plant; by the time it reaches a plant it has usually only cooled a maximum of 3-5°F (only cools 1°F over a 24 hour day) (Schmid). Capturing heat from this water is a largely untapped energy source.

Since the amount of wastewater available is dependent on the water usage of the building, sewage as a heating source does have limitations. Ideally a constant supply of wastewater is needed in the sewage pipes for heat exchange to occur, however, water flow has great variations depending on the building's purpose or the time of day (Schmid). The potential for harvesting energy from wastewater is higher when water usage is abundant, thus sewage heat recovery systems are most effective when implemented in large infrastructures or building clusters. However, when planning a sewage heating system, the long-term availability of wastewater must be considered. This is especially important to consider as efficiencies in buildings' infrastructures are decreasing the available water consumption (Schmid). Installing these heating systems on a main sewage lines that are feed by multiple buildings is the best way to ensure a constant water supply so sewage heating systems can serve as a reliable heating source.

The main idea behind sewage heating systems is to reduce energy costs by using already heated water (wastewater) to pre-heat new, incoming water. When domestic hot water is pre-heated before it reaches the boiler, the change in temperature and need for additional propane or electrical heating is significantly reduced. Pre-heating hot water from the sewage lines has been proven to reduce the needs for alternative energy sources by nearly 50% (and if sewage heating is combined with solar water heating there is a possibility that propane, natural gas, or electrical heating could be eliminated altogether) (Bother). Once water is heated with the assistance of sewage heat recovery, it can fuel heating/cooling systems and also serve as a hot water source.

There are three main ways sewage heat recovery systems can be installed. They can be installed directly in buildings, in sewage mainlines, or in sewage treatment plants. The potential for capturing heat energy is obviously highest at the treatment plants because this is where the flow of sewage is highest and constant. However, since these plants are often on the outside of towns, installing the infrastructure necessary for bringing heat energy to places where it is demanded it not very economical (Schmid). The systems installed directly within buildings also have their own challenges, most often dealing with wastewater contamination (Schmid). No matter what metal is used for the sewage lines, eventually this will corrode due to the acidity of the wastewater. If freshwater pipes are wrapped around these sewage lines, there is a chance this water can be contaminated when the sewage lines corrode (theoretically this shouldn't happen, however, since the freshwater pipes are under pressure while the sewage lines are not) (Roberts). Due to these various issues surrounding wastewater heat transfer systems within buildings or at sewage treatment centers; sewage heat recovery systems have been most successful when installed in main sewer lines.

To capture heat from the wastewater in the sewage lines, heat exchangers are incorporated into these lines. Cool water flows through these exchangers, is heated by the wastewater, and then travels to a heating pump that helps further heats the water with compressors and condensers. With energy supplied by propane or electricity, the heating pump is able to bring the freshwater temperature up from around 50°F to 150°F; a temperature that is adequate for space heating and water supply (Rabtherm) In order for the heat exchanger to be incorporated into the main sewer lines and extract significant heat energy, the lines must have a diameter greater than 1200mm ("Feasibility…"). For smaller projects heat exchangers can be installed in lines as narrow as 400-500mm; however, the heat energy that can be extracted from these lines is definitely more limited (Rabtherm). The length of heat exchangers also has a variety of ranges depending on the project size; they can be as small as 1-3m in length for small projects and up to 300m in lengths for larger projects (like the one that supplies heat energy to the city of Oslo, Norway) (Bother). Once these exchangers are integrated in the channels they are durable and can last around 50 years (Rabtherm).

By using heat pumps to boost the temperature of warm water to one that is adequate for heating and hot water, wastewater heating systems appears to have many similarities geothermal heating systems. However, when compared to the geothermal systems, sewage heating has been proven to be superior in both efficiency and cost effectiveness. To begin with, the average temperature of wastewater is typically around 10°C warmer than ground temperature (Baber). This warmer temperature contributes to the efficiency of the heat pump in a sewage heating systems because more heat is being generated for every unit of electricity used to fuel the system.

Sewage heating systems are also more effective than geothermal ones because the transfer of heat from the source to the water is direct; the source sewage passes straight through a heat pump evaporator. Geothermal systems differ from these systems because they rely upon intermediary glycol loops to move heat from the ground to the heating pump. These secondary loops create inefficiencies because heat is lost through the loops and energy is required to pump the glycerol intermediary fluid (Baber). In addition to these extra operating costs, the drilling of wells and necessity of open spaces make the implementation of a geothermal system not nearly as cost effective as sewage heat recovery systems (Baber).

Sewage heating systems are an effective alternative energy source that provides the consumer and environment with several direct benefits. A main sewer line with heat exchangers covering 36m can reduced net energy consumption by 106kW (Rabtherm). According to Rabtherm, a European company that implements these systems, around 20% of a building's the total heat energy can be reduced with wastewater heat recovery. This means that the building's fuel consumption can drop anywhere between 60-70% and its operation costs can be lowed by nearly 30% (when compared to more classical systems). Also, since a wastewater heating system emits no particulate matter or carbon dioxide, implementing a system like this can reduce a building's carbon emissions anywhere between 30-70% (Rabtherm).

Other benefits of sewage heat recovery technology, in addition to reducing carbon emissions by more than half that of traditional systems, is the innovation of the technology and its use of a local energy source. Before sewage heating systems, wastewater heat was a largely unutilized source of energy. Capturing heat at a local level not only helps recycle already produced energy, but is also more cost effective than other alternative energy systems that require implementing expensive infrastructure (Baber [2]). Since sewage heating systems are incorporated into the already existent sewage systems, this gives them a uniquely flexible infrastructure that can adapt to technological advancements (Baber). By utilizing wastewater, a local heating source, sewage heating reduces the use of internationally produced fossil fuels or expensive regional electricity and helps make buildings more self sustaining entities (Baber [2]). Also, when a building's heat supply is dependant upon a local source, this helps "future proofs" the building so that its energy supply is not vulnerable to price fluctuations or limitations (Baber).

Although sewage heat recovery systems may seem ideal, they bring with them their unique set of challenges. Already, it has been discussed how compensating for daily and seasonal fluctuations in the flows and temperatures of the wastewater is a necessity if sewage heating is to be a reliable energy source (which is why these systems are typically only installed on main sewage lines that connect several large facilities) (Schmid). Other challenges with these systems are associated with the management of waste solids and the system's reliance upon an additional energy sources to increase the temperature of the preheated water. Often a pretreatment and cleaning system is implemented to help handle the solids while increasing the efficiency of the heating systems is the only way to cut back on their necessity for additional energy sources (Baber).

Oslo, Norway, a city that is seeking to reach carbon neutrality by 2050, is one example of a place where these sewage heating systems have been implemented with great success (Bother). Here the city retrofitted a 300m tunnel with heat exchangers that transfer sewage heat to heat hot water supplied to radiators and taps around the city. Overall this heat pump generates 18MW of energy, which is enough to heat nearly 9,000 homes (Bother). Another place sewage heat recovery technology is being used is Vancouver, Canada for the 2010 Olympic Game's athletes' village. When planning this 6 million square foot development that houses 16,000 people, designers were trying to be as environmentally conscious as possible (Baber). The original plan entailed building a biomass power plant to fuel the village; however, when this idea was rejected by the city, designers turned towards sewage heat recovery technology. Although this project is not scheduled to be finished until 2009, upon completion its sewage heating system is expected to provide around 70 percent of the village's space heating and hot water demands (Baber).

Sewage heating is exciting because it is such a new technology. Once the sewage heating system in the Olympic Village is completed, it will be the first of its kind to be in North America (Bother). Including this system and the one in Oslo, there are currently only four large scale sewage heat recovery systems in the world (the other two are in Japan). When a design project chooses to implement wastewater heat recovery technology, it is clearly marking its project a leader in innovative sustainable technology (Baber [2]).

Already Dartmouth has invested in technology that capitalizes on the idea of hot water heat exchange through installation of GFX energy-saving heat exchangers in the showers of new dormitories. These exchangers help reduce the hot water lost from showering by coiling around the shower's drainage pipes. As cool water flows through these heat exchangers it is preheated so that when it exits through the shower head there is a reduced demand for hot water necessary to get the shower to a pleasing temperature ("Two Great New Ways…").

Frank Roberts, one of the FO&M engineers, discussed how Dartmouth likes this GFX heat exchange system because it operates at the point-of-use and is a small system with an isolated loop. He discussed how since the shower water is always draining while the faucet is flowing, this makes the system reliable because water will always be present in the drainage pipes to heat the incoming water. Although these systems seem good in theory, they have a questionable payback and may have been emitted from Dartmouth's future building plans (Roberts). Also, since these heat exchangers are reliant upon elaborate piping systems, the college has only installed them in new buildings and not renovated ones. Small changes will only result in minimal carbon reductions; in order for Dartmouth to see real changes in energy reductions, the college must be more innovative and take greater risks with their use of sustainable technology.

Another place Dartmouth is using heat exchange through wastewater is at the power plant. When the condensate returns to the plant it is around 160F, and before this enters the boilers for reheating it is passed through a heat exchanger surrounding the boiler blow down water. The boiler blow down water is typically around 450 F and has an average flow of around 5700 gallons/day (this varies depending on how many boilers are on line). When the 90% condensate water and 10% city water pass through the heat exchangers this raises the water temperature to around 164 F; the boilers then bring this temperature to 260 F before distributing it to campus. The blow down water leaving the heat exchanger is cooled from 450 F to 161 F, however, this must be cooled further to around 130 F by mixing 55 F city water before entering the sewer lines (Riehl). Dartmouth College was encouraged to install this heat exchanger after the water running from the plant actually melted the city's PBC sewage lines (Kulbacki). Although the college is recovering some heat from the water, the 130F (and potentially 160F) wastewater entering the sewage lines still has great, untapped energy potential!

One of the major challenges with implementing a sewage heat recovery system at Dartmouth is the ownership and location of the current sewer lines. According to Frank Roberts, Dartmouth only owns and controls the sewer lines that are located directly beneath the college's property. This is problematic because all the main sewage lines Dartmouth's buildings drain into are located under the main streets running through Hanover; making them town property instead of college property. Working with the town of Hanover to implement such a system could be a very expensive and lengthy process. However, since Dartmouth has such a good standing relationship with the town and since the college owns the town's water company (but contracts everything out), this obstacle does not seem as daunting as it may first appear.

Peter Kulbacki, head of the Hanover sewage treatment plant, said that since the town works with the college all the time, he personally did not see Dartmouth accessing the sewage lines as much of an obstacle. If Dartmouth were to install the heat exchangers within the existing sewage lines, the college would have to meet Hanover's standards and maintain the lines properly throughout the year; Kulbacki said the treatment center works with people on this all the time. In terms of legality, "there would have to be an easement if it was not on College property. The specific conditions would be negotiated between the Town and College. If it involved an above ground structure there would be Planning and Zoning requirements" (Kulbacki).

If Dartmouth utilized Hanover's main sewage lines, these lines would have to fulfill certain requirements in order to meet the college's heating demands. For a sewage heat recovery system to preheat a campus building's hot water, logistically the main lines for this system would have to be located within 200-300 feet of the building and would have to be over 1200mm in diameter (Rabtherm). There is a main sewage line that runs down Main Street and is within the required distance of many campus buildings, however, Frank Roberts doubts that the flow of water running through this line is consistent and sufficient enough to heat the amount of hot water necessary for the college's use.

The sewage lines throughout the Dartmouth campus are arranged in such a way that the wastewater drains to certain areas where it is then pumped to sewage treatment centers. Several of these pumping stations exist on campus, including one by Dewey Field and another one by the Leyard parking lot (Roberts). Since the flow of wastewater is highest near these pumping stations, this is where the implementation of a sewage heat recovery system could be most effective. Frank Roberts thinks that the idea of implementing one of these systems down by Leyard might be the best option for sewage heat recovery technology. If a sewage heating system were installed by Leyard, however, it could only serve that section of campus; rerouting all of the campus' hot water lines to center around this system instead of the current power plant would not be very cost effective. According to Peter Kulbacki, the pump station by Leyard is also relatively small compared to other pump areas in the Hanover area. The pump station by Dewey field, for example, is bigger than all the other pump stations combined and collects 60-65% of the Hanover's wastewater (Kulbacki). This high and constant flow would make this a perfect place to invest in this technology. The only problem is what to do with water that could be preheated from here, since there is no pre-existing system in place that could distribute it to campus or no nearby buildings that could utilize it on site.

Sewage heat recovery systems are an ideal form of technology for large buildings and complexes that are in the process of being built. With sewage heating systems in mind, designers are able to lay out the piping for wastewater in such a way so it flows towards main lines where the heat exchange can take place. Retrofitting preexisting sewage lines with this technology is definitely more of a challenge because the location of reliable main lines near source heating centers is very important. If retrofitting the sewage lines at Dartmouth turns out to be too impractical or too costly, the college should at least look into in-building sewage heating systems. Putting one of these systems in the basement of new dormitory buildings would make the most sense because no energy would be used to pump the water there. Frank, however, fears that the flow of water within dorm buildings is too sporadic and that the hot water from showers and laundry becomes too diluted by the toilet water for in-building sewage heating systems to be reliable and an effective heat source.

Even though a heat exchanger already exists at the Dartmouth power plant to preheat the hot water leading to the boilers, the temperature of this water could be even further raised with the addition of a wastewater heat recovery system. The water leading to the boiler is composed of 90% condensate water and 10% city water. The condensate water comes back to the plant around 180F, however when it is mixed with 60°F city water this temperature drops to 160°F (Riehl). Once the water passes through the heat exchanger with the 420 °F boiler blow down water its temperature increases to 164 °F, which then reduces the work of the boiler that heats the water to 260 °F. The temperature of the water leaving the heat exchanger and heading towards the sewer is roughly 160°F, if a wastewater heat recovery system were installed on the lines this could preheat the city water that gets added to the condensate. Adding hotter city water to the condensate water would reduce the amount the water heading towards the boiler is cooled and thus decrease energy expended by the boiler to heat the water to a temperature adequate for campus distribution.

If it is assumed that preheating the city water that mixes with the condensate results in an over 5°F increase in water temperature entering the boilers, this could really help reduce both carbon emissions and operating costs for the college. According to Bill Riehl's DA manual, 48,000,000 lbs steam are required to heat 500,000,000 lbs water (close to the college's annual usage) from 160°F to 260°F while only 45,000,000lbs steam were needed to heat the same amount of water from 165°F to 260°F. This results in a savings of 3,000,000 lbs steam. Since Dartmouth's boilers have an efficiency of 87%, Dartmouth burns 25,500 gallons of oil to make 3,000,000 lbs steam. This means that installing a wastewater heat transfer system would save Dartmouth 25,500 gallons of oil a year (which is roughly $30,457) and would reduce CO2 emissions by 30.07 metric tons. According to Rabtherm, a 30m heat exchanger and heat pump that generates around 106 kW of energy costs roughly $300,000; if a system of this size was installed at the power plant, the payback time would be just under 10 years. Since majority of the infrastructure for these heating systems is underground, implementing this technology is relatively cost effective because it does not require the clearing of any more land or the building of an expensive operating center (this can be incorporated into the existing power plant).

When talking with Rabtherm, the company that installs these heat exchangers, the company told me that they could really make use of 160°F line leaving the power plant. With roughly 3,667.98 gallons of 160°F water leaving the power plant a day and roughly 18,339.90 daily gallons of 60°F make-up water being heated a day, there is a lot potential for capitalizing on this enormous energy loss (2008 Energy Usage Report). The only problem, however, is that the line leaving Dartmouth's power plant is only 4 inches in diameter; which is too small for Rabtherm to install their technology. Since the line is a gravity flow line, Rabtherm was concerned that expanding the line might create problems with the wastewater flow. Bill Riehl at the Dartmouth power plant did not seem to think that expanding the line would be that big of an issue; however, Frank Roberts at FO&M is concerned because there is already limited room at the plant and the sewer lines exiting the building are below the basement floor (which could make access to them problematic). *Rabtherm is currently in the process of thinking of solutions for recovering the energy from this line with only a 4 inch diameter.*

Installing heat exchangers in the 160°F wastewater lines leaving the power plant could not only be used to preheat the water for the boilers, but they could also be used to preheat the hot water for nearby buildings. This is especially important to explore now while there are so many nearby building being renovated or constructed around the power plant (like Topliff and the new studio arts center). Since the hot wastewater line leaving the plant is within 300 yards of these two building, it is very feasible for these buildings to benefit from a wastewater heat transfer system (Rabtherm). If water in these buildings was preheated with this system, this would reduce the amount of hot water from the heating plant needed to bring the water up to a desired temperature. Or better yet, these buildings could incorporate a hot water heating system instead of a steam heating system for the buildings. According to Frank Roberts, heating buildings with hot water is much more efficient than heating buildings with steam, for the temperature of hot water systems can be controlled and lowered when it is warmer outside.

Even though this technology may be new, it is gaining recognition and had been growing quickly! Just recently Rabtherm, the company that installs theses systems, set up an office in North America and has been busy negotiating contracts on the new continent ever since. It just so happens, that college campuses are places where this technology is expanding most rapidly in North America; for these are areas with a high density and constant load. Right now Rabtherm is in the middle of negotiating contracts with Harvard University, University of British Columbia, and University of Washington; three universities that are all major leaders in sustainability. If Dartmouth were to implement this technology now, the college would be joining the ranks of institutions that make real change through actions!

Although challenges may face the implementation of a sewage heat recovery system on the Dartmouth campus, this should not deter the college from pursuing this technology. If Dartmouth were to invest in its own wastewater heat recovery system not only be working towards a carbon neutrality commitment, but it also would be designating itself as a clear leader in sustainability by investing in such novel technology. Greatness is only achieved when risks are taken and challenges are met; if Dartmouth wants to achieve greatness, implementing a sewage heat recovery system would be a step in the right direction.

B.6 Deep Geothermal

B.6.1 Introduction

One clean energy technology Dartmouth would do well to consider is deep geothermal often referred to as enhanced/engineered geothermal systems (EGS). The heat beneath the earth's crust is a tremendous untapped source of energy. Almost all of the efforts thus far to use this energy have focused on capturing the energy from hot water (hydrothermal) on the surface and using it to generate heat or electricity. These have overshadowed geothermal energy, both shallow geothermal and especially EGS, as the potential of these forms of energy are much less visible. EGS is beginning to get some close attention from energy experts across the globe. Here at Dartmouth, google.org's Dan Reicher '78 spoke about the potential of EGS technology and the investments that google.org is making. Additionally, several of the visitors to our ENVS 50 class have brought up deep geothermal as an energy technology that the College is open to considering and which merits our close consideration as we formulate a proposal for Dartmouth to become carbon neutral by 2050. In light of this, this paper examines EGS technology, its current status, and considers its potential here at Dartmouth.

B.6.2 Technology

EGS refers to a system in which hot rock deep below the earth's crust is used to heat some liquid which is brought to the surface to generate electricity and/or provide heat. It differs from hydrothermal energy which makes use of hot water already present in the earth. The basic process involves drilling a hole down to a depth between 3 and 10 kilometers below the surface into hot rock (typically more than 200 degrees C). High pressure water then is pumped down to fracture the rock, creating a high-volume reservoir from which heat can be extracted and another hole is drilled into the fractures. A liquid (often water) is pumped down the first (injection) well, flows through the fissures, capturing the heat of the rock and then is pumped back up through the second (production) well (Mone, 2007). At the surface, a plant uses the heat from the liquid to generate electricity and/or provide heat for buildings. It is possible to employ EGS technology anywhere, but some places require much deeper drilling than others.

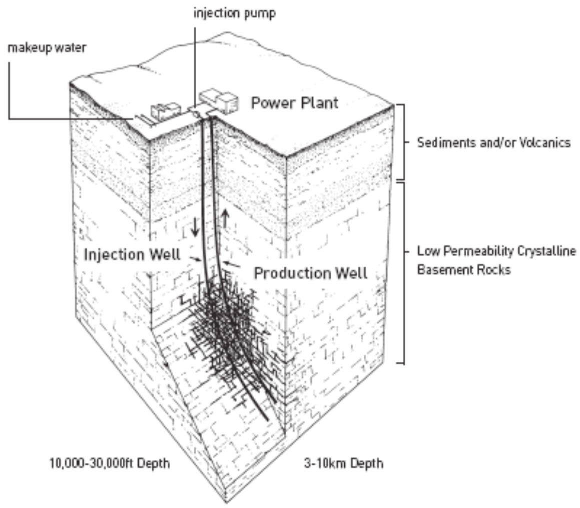


Figure 1 *- EGS Diagram (Tester, 2006).*

There are three main areas for technological improvement for EGS: drilling technology, reservoir technology, and power conversion technology. The current drilling technology for EGS wells come from the oil industry and rely on hard drill bits. The benefit of this is that it shows that it shows that it is possible to grill to these great depths. The problem with this is that the bits wear down from the hard rock and need to be replaced frequently, costing valuable time and money. Therefore, several companies are exploring alternative drilling methods that do not rely on drill bits. Researchers in a lab at MIT are exploring thermal spallation, a drilling technique which uses a jet flame rather than a drill bit. This eliminates the problem of drill bits wearing down and also has the potential to significantly speed up the drilling process (Mone, 2007). Meanwhile, google.org has invested $6 million in Potter Drilling, a company which is developing technology for hydrothermal spallation. This involves using extremely hot water (over 800 degrees C) to drill through the rock. The potential benefits of this technology are the same as thermal spallation: elimination of the use of drill bits and the potential to dramatically reduce the time it takes to drill (Wooey, 2009). Other possible improvements in drilling technology which would lower EGS costs include better electronic sensors (able to withstand the extremely high temperatures) and improved cementing and casing techniques to secure the holes.

In order to create an EGS, it is necessary to create fissures within the rock so that the liquid is able to flow through it, collecting heat. Past drilling has shown that rocks with low permeability offer the best heat resource. Early efforts to create these heat reservoirs focused on creating fractures with high pressure water while more recent efforts have focused on stimulating existing fractures within the rock. As EGS technology develops, one of the main focuses will be on improving the connection between the heat reservoir creating the rock fractures and the injection and production wells which cycle the liquid up to the surface and back. Several researchers have explored the possibility of using carbon dioxide in its supercritical state, rather than water, to circulate through the EGS (Brown, 2000). This has the potential to improve the efficiency of heat extraction as well as to sequester some carbon dioxide (Pruess and Azaroual, 2006).

Once the hot liquid has been brought to the surface, it must be converted into usable energy. The energy from EGS can be used to generate electricity or provide heat directly or for combined heat and power through cogeneration. Since geothermal liquids tend to be lower in temperature (often less than 200 degrees C when they reach the surface), binary cycle power plants often are used. These plants rely on hot water pumped up from geothermal reservoirs to enter a heat exchanger and exchange heat with a binary liquid that has a low boiling point. The binary liquid then turns to vapor used to power a turbine, before cooling and going through the cycle again. This enables the lower temperature liquid to be utilized to produce power. The efficiency of the conversion offers an opportunity for improvement, however. Current systems have efficiencies between 25% and 50% while efficiencies upward of 60% are the goal (Tester, 2006).

B.6.3 Advantages and Disadvantages

One of the biggest draws of EGS is that the thermal energy beneath the earth's crust is so abundant. Researchers at MIT have estimated the accessible resource for EGS in the United States at depths up to 10 kilometers is more than 13 million quads, over 130,000 times annual energy consumption. It certainly would not be economically feasible to recover all of that energy (at least for a very long time) but even we were able to capture only 2% of this energy (a conservative estimate), it would still be far more energy than we need. Another advantage of EGS is that it provides baseload energy; it is available all the time with no interruptions. One of the biggest drawbacks of most renewable energy is that it is intermittent, but that is not an issue for EGS. Generation of EGS power also produces no carbon emissions and even has the potential to sequester carbon (if carbon dioxide is used as the circulating fluid). EGS energy is considered a renewable resource as well, although it is estimated that the wells with need to be re-drilled every 5 or 6 years and that the lifetime of a plant will be between 20 and 30 years after which the geothermal energy will be depleted, requiring 50 to 100 years to replenish. Lastly, there are minimal visual and environmental impacts, less than other renewables such as wind and solar, since the energy source is underground (Tester, 2006). EGS also provide a stable domestic source of energy which is not vulnerable to price fluctuations or supply disruptions as oil is.

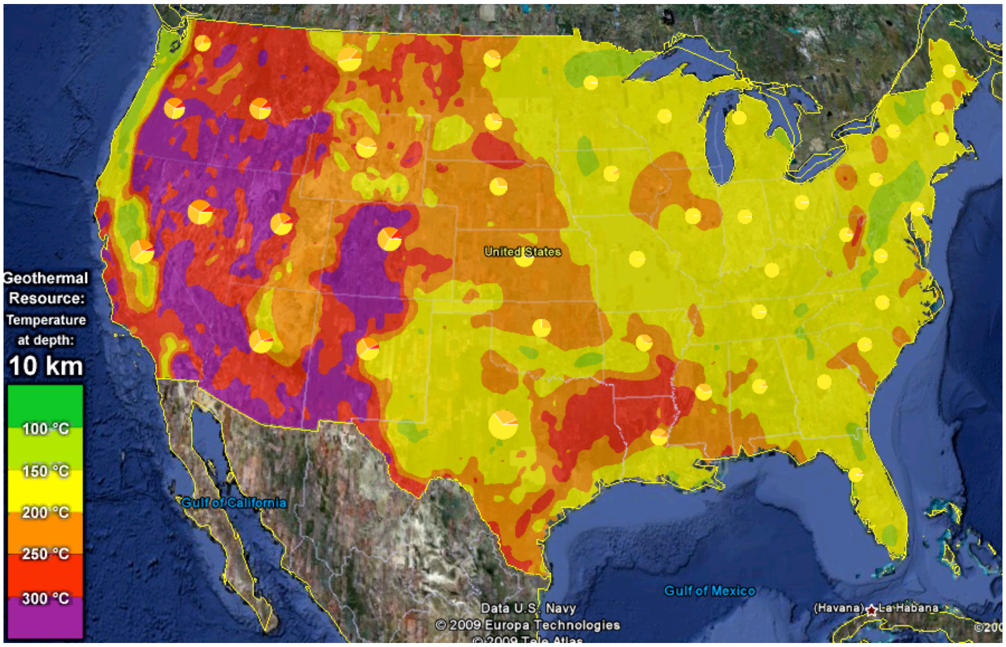


Figure 2 *- Geothermal Resource Map of the United States (depth of 10 km) (Google, 2009).*

Nevertheless, there are drawbacks to EGS. The biggest issues for EGS that have been raised so far are concerns about seismic activity resulting from deep drilling as well as concerns about groundwater contamination. There also is the economic risk from the possible collapse of the well walls due to insufficient stabilization. Experts believe that these issues are manageable, though, and should not prevent continuing development of EGS technology (Tester, 2006). Drilling was halted at an EGS facility in Basel, Switzerland in 2006 after it produced several minor earthquakes (the largest was 3.3 on the Richter scale). This project was plagued by very poor planning, however, as Basel is located in a region known to be seismically active. Careful planning is required to avoid locating EGS facilities in seismic areas and none of the other EGS facilities that are being undertaken have experienced issues with seismic activity (Swissinfo, 2007).

B.6.4 Current Status

Enhanced geothermal systems are beginning to generate significant buzz among energy experts. The authors of the comprehensive MIT report on EGS concluded "that none of the known technical and economic barriers limiting widespread development of EGS as a domestic energy source are considered to be insurmountable (Tester, 2006: 22)." The biggest obstacle for EGS at this point is efficiently connecting the heat reservoir with the injection and productions wells and researchers are working to improve the efficiency of this part of the system. The MIT report suggested that with a total investment (public and private) of about $1 billion (less than the cost of a single clean-coal power plant) over the next 15 years, that EGS could supply 10% of our power by 2050. There currently are EGS plants producing power in both France and Germany. The system in France is a demonstration plant located in Soultz and produces 1.5 megawatts while the system in Germany is a commercial plant (thanks to a generous production tax credit). There also are several commercial plants under construction in Australia with the potential to produce thousands of megawatts of power and a demonstration project under construction here in the United States at Desert Peak, Nevada (Google, 2009).

One of the main messages of the MIT report is that there should be significantly more public support for the development of EGS technology (Tester, 2006). Thus far, the Obama administration has made available up to $84 million in the form of matching funds for the research and development of EGS technology (Kessler, 2009), but more needs to be done to spur EGS development. In addition to increased funding for research and development of EGS, the federal government could provide additional financial incentives in the form of loans or EGS-specific tax provisions, enact a national renewable energy portfolio standard, and implement some sort of carbon pricing (through a direct tax or cap-and-trade). Any of these would help to make EGS a more commercially viable alternative to fossil fuels.

B.6.5 Economic Feasibility at Dartmouth

While New Hampshire has relatively poor thermal resources compared with the western part of the country, it still does have a substantial amount of thermal energy beneath its surface; it just requires drilling deeper to access it.

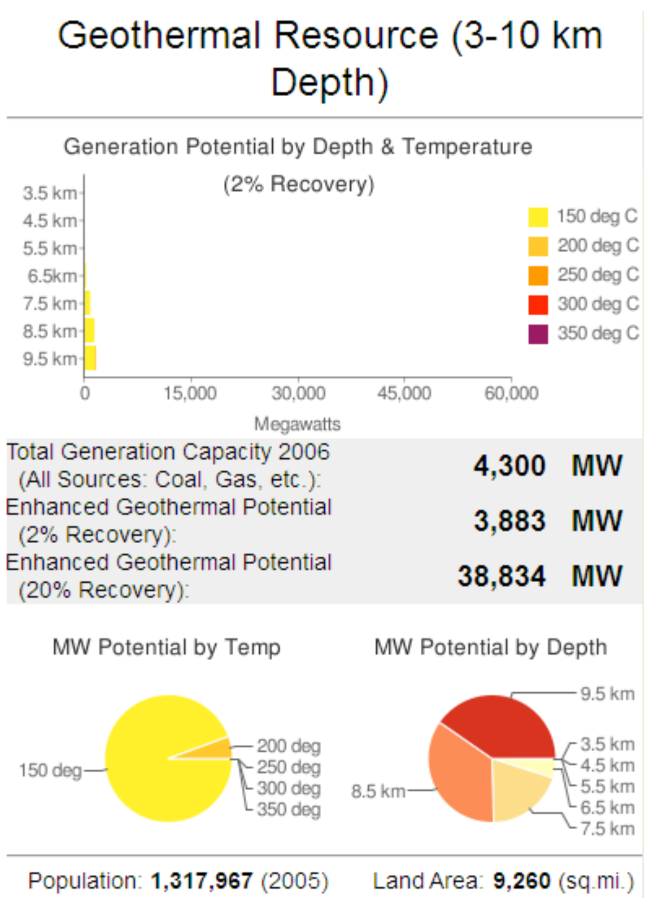


***Figure 3** – Geothermal Resource Chart for New Hampshire (Google, 2009)*

As the chart illustrates, even if only 2% of New Hampshire's potential EGS resource base were captured, that would almost cover the entire state's generating capacity from 2006.

While there is virtually no Hanover or Dartmouth specific data available given current technology, the MIT report analyzes the potential for EGS at various sites throughout the country, and one of the sites it considers is Conway, NH, about 70 miles east of Hanover. The authors of the report chose Conway to demonstrate the potential of a low-grade EGS site. The authors use several models incorporating a variety of factors (drilling costs, plant costs, flow rate, thermal drawdown rate, and several interest rates) to estimate the break-even point for electricity generation or levelized cost of electricity (LEC). They estimate that for a 10 km with a reservoir flow rate of 80 kg/s (fairly high), the LEC could be as low as 8.3 cents per kilowatt-hour (Tester, 2009) while electricity rates averaged almost 14 cents per kWh in New Hampshire in 2007 (EIA, 2007). Figure 4 shows how these electricity rates change with changes in the input variables. The MIT report models drilling costs for EGS wells and projects that a 10 kilometer deep well could cost $20 million. The cost of drilling the well can account for upwards of 60% of the total cost of an EGS so improvements in drilling technology should dramatically lower the cost of constructing an EGS, especially in a low-grade site where deep drilling is required (Tester, 2006).

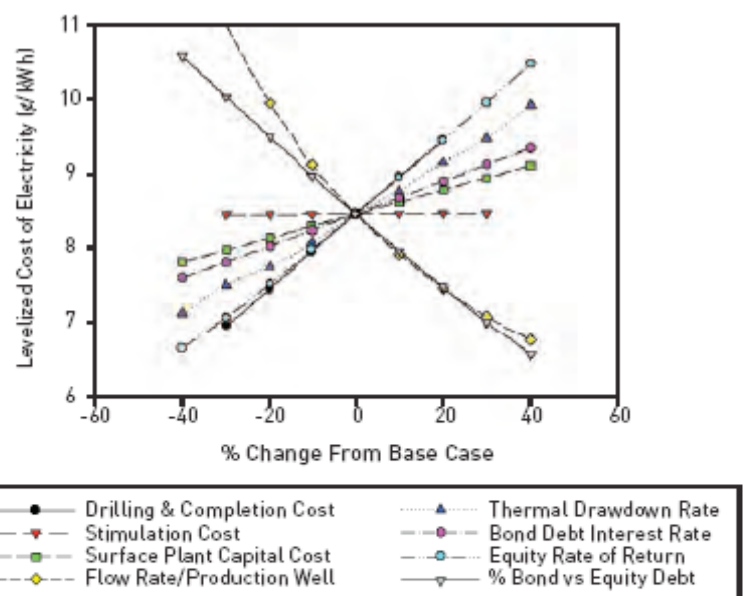


Figure 4 *– LEC Sensitivity to Factor Price Changes for Conway, NH (Tester, 2009)*

B.6.6 EGS and Cogeneration

Almost all of the development of EGS has focused on electricity production. While this technology is the most developed at this point, there also is significant potential for EGS as a means of co-generating thermal and electrical energy. A pilot project was undertaken in Basel, Switzerland beginning in 2001 on an EGS cogeneration facility. The project consisted of three wells drilled to a depth of five kilometers below the surface. This facility was projected to have an output of twenty megawatts of thermal energy and three megawatts of electrical energy, serving the energy needs of 5,000 households and leading to a reduction of over 40,000 tons of carbon dioxide emissions annually. The cost of the entire project was estimated to be about $95 million with generating costs between one and two cents per kilowatt-hour electric and 2 and 5 cents per kilowatt-hour thermal (Hopkirk & Haring, 2006). This project was abandoned in late 2006, however, after the injection of water into one of the wells caused a series of minor earthquakes (the largest was 3.3 on the Richter scale). A risk analysis of the situation is being undertaken currently and there is the possibility of resuming drilling in 2011. This is a significant setback for the Basel project and for EGS technology in general (if for no other reason than the fact that there are no EGS cogeneration projects currently being developed). It appears that significant mistakes were made in the development and planning of the Basel project, however, as Basel is in a known earthquake zone, having experienced a 6.5-magnitude earthquake in the 14th century, the most significant seismic event recorded in Central Europe (Swissinfo, 2007). Significant steps should be taken in the development of EGS projects to protect against seismic activity.

If Dartmouth ever were to pursue development of an EGS, it likely would be a co-generation plant that could replace (wholly or partially) the current heating plant or a future biomass plant. The technology is still in its infancy and so cost projections are extremely difficult to project but based on the costs of the Basel plant, Dartmouth's possible geothermal resource, and Dartmouth's energy demand, replacing the heating plant with an EGS facility likely would require drilling five wells to a depth of ten (or more) kilometers with a cost of $150-200 million. This cost should come down significantly in the coming years as public and private investments in EGS technology lead to improvements and lower costs.

B.7 Wind Energy

B.7.1 An Introduction

Wind Energy, although presently inapplicable at Dartmouth College, is a "free" resource that is very under-utilized in the United States. There are two wind classes we researched, small (or micro)* and big, which refer to both the size of the turbine and more importantly to the scale of energy being harnessed. We have looked at the possibility of both small wind and big wind projects for Dartmouth because, as they would have different applications on campus, the existence of either does not necessarily remove necessity for the other. Turbines are able to generate electricity from the air that flows past the rotor (which in some cases resembles an airplane propeller) that spins to drive the shaft of the electric generator to rotate and produce electricity, otherwise converting the kinetic energy in wind into mechanical energy ("About Wind": 2008). No matter the size, wind turbines produce renewable energy with zero carbon or other greenhouse gas emissions (besides initial instillation and maintenance). Wind also has fewer resource extraction costs than fossil fuels and we now have the technology in big wind to harness megawatts of energy (Seiler: 2006). Because of advancements in technology and increased government subsidies, the cost of this power has rapidly been decreasing. Investing in wind would be a very visible and strong statement toward carbon neutrality, but it is still unfeasible at Dartmouth with the available technology and low wind speeds. Investing in a wind farm out west would be the most feasible solution at the time, but would have less of an impact on Dartmouth's campus.

B.7.2 Big Wind: An Introduction

The majority of wind turbines used currently are large turbines, as tall as 300 feet, and installed in clumps or "farms". These are the turbines that the general public thinks of when wind power is mentioned, or the Cape Wind project, or wind farms in the Midwest. For this report, this style of turbine and installation will be called "big wind." The blades on these turbines are "similar in size to large airplane wings", and the turbine can weigh hundreds of tons (IEEEE). These are horizontal axis turbines, and need to face into the wind in order to be most effective. Modern versions will have computers to help them rotate as the breeze changes. These turbines need a significant wind speed in order to operate; most industrial size turbines require at least 13 mph in order to even begin producing electricity ("Wind Energy Basics").

Big wind has its advantages; a farm with multiple turbines on it can generate the same amount of power as a traditional coal burning power plant, with absolutely no carbon emissions beyond those needed to initially build the turbine. However, there are also disadvantages; finding acceptable locations is difficult, the turbines require a lot of wind to begin producing energy, and there are some reported negative effects for bird populations. For these reasons, big wind, while a great option in some places (including other areas in New England, as described in the case study below), is not a suitable option for Dartmouth College, either in Hanover, at the Skiway, on Mount Moosilauke, or at a remote site.

B.7.3 Big Wind: A Case Study

Big wind does work in New England, as a case study of a wind farm in Searsburg, Vermont, shows. Green Mountain Power installed eleven turbines on a ridgeline there in 1997. Combined, these turbines produce six megawatts of power, enough to provide electricity to 2,000 Vermont homes (Green Mountain Power).

Image courtesy of Green Mountain Power

Green Mountain Power had initially begun looking for a site for wind in Vermont in the 1970's, and picked the Searsburg site due to its high elevation (and therefore persistent winds) and proximity to existing infrastructure (powerlines and roads). Over the past ten years, the site has averaged winds between 15 mph and 17mph. The turbines begin producing electricity at 10 mph, and maximize at 29 mph (Ibid). The Searsburg site does not have the ideal wind speed, but it seems to have enough to make the project worth it, as they are currently proposing the addition of twenty to thirty more turbines to the farm (Renewable Energy Vermont Newsletter).

B.7.4 Big Wind at Dartmouth

While Big Wind may work well in other areas of New England, it runs into complications at Dartmouth College. The Hanover area does not have the large ridges needed that are the main areas of suitable wind velocities in New Hampshire ("Wind Powering America: New Hampshire Wind Resource Map"). Secondly, land in Hanover is scarce and expensive, making the land necessary for a wind farm difficult to acquire. However, the College does already own two parcels of land that may have the wind resources necessary for Big Wind: the Dartmouth Skiway in Lyme and Mount Moosilauke, north of Warren. A more thorough look at both of these sites tells a lot about the possibilities of Big Wind for the College.

The 2004 ENVS 50 report looked in detail at the possibility of large scale wind turbines at the Skiway, and much of their report is still applicable and useful. A summary will be discussed here, but for more information their report is available through the Dartmouth College Environmental Studies Department. The Skiway, located twenty minutes northeast of campus in Lyme, has two separate hills, separated by a road: Winslow Ledge and Holts Ledge. The 2004 report found both ledges to have average windspeeds adequate (but just barely) for power generation from large turbines, with Winslow having a slightly higher average. The Skiway also already has the infrastructure needed, with work roads already existing to get to the summit, and powerlines in place for the chairlifts (2004 ENVS 50 report, page 149). Holts Ledge also is home to a population of peregrine falcons, a bird that has been listed as endangered in New Hampshire. Since the writing of the 2004 report, peregrine falcons have been downgraded to "threatened" ("NH's Peregrine Falcons Have Successful Breeding Season"). However, any turbines on Holts Ledge would need to be close to the ledge itself, and so could interfere with the still fragile nesting area of the peregrines. Holts Ledge is also not an ideal spot for turbines because the Appalachian Trail runs directly across it.

The 2004 report initially proposed six turbines on Winslow and none on Holts. However, they found that significant resistance would come from the Appalachian Trail Conservancy (ATC), a group that seeks to preserve the experience of the Trail. While AT doesn't cross Winslow Ledge as it does Holts, Winslow can still be viewed from the Appalachian Trail, both from Holts Ledge and from parts of Smarts Mountain. For this reason, the 2004 report cites the ATC as strongly opposing any wind developments on Winslow Ledge (2004 ENVS 50 report, page 166). In November of 2007, the ATC adopted an official policy on wind turbines. This policy entirely opposes any turbines on Appalachian Trail Corridor Lands (therefore entirely ruling out Holts Ledge), and generally opposes any turbines within a four mile viewing area from the trail. However, they do say that specific analysis is necessary, and that sites with existing developments such as ski areas are more suitable for wind development (Appalachian Trail Conservancy). Clearly, Winslow Ledge is not a simple choice for Big Wind. While certain factors appear to make it a strong candidate (see the 2004 report for a cost-benefit analysis), the opposition by the ATC is a formidable obstacle. Turbines at the Skiway should be kept under consideration, and communication with the ATC as their stance on turbines evolves needs to be continued. In a later section, this report will return to the Skiway, as it still has advantages for some forms of wind power.

If the Skiway is a complicated case, Mount Moosilauke is far simpler. While it has the wind resources needed to generate power (as any hiker knows), its open summit is heavily protected. The Appalachian Trail crosses directly over the summit, which is a rocky area of fragile alpine tundra. While the College does own 4,600 acres on the peak, it also invests heavily in the protection of the peak. In the summers a steward is stationed on the peak, solely to make sure that hikers don't trod on the fragile vegetation of "Mount Moosilauke". While there used to be a lodge on the top of Moosilauke, it is lacking the infrastructure necessary to construct a turbine and to transport the electricity. Any investment in building turbines on the summit would need to be far greater than required at the Skiway. Having the wind resources is not the only requirement for being a good candidate for turbines, and Moosilauke fails the rest of the criteria.

Summit Ridge and Appalachian Trail on Mount Moosilauke. Photo Kendall Reiley.

The final option for Big Wind at Dartmouth is to use a much more remote site. This site could be either the Second College Grant or a piece of land in North Dakota; it is defined in this report by being a site where the power generated would not feed immediately back to the College, but rather go back into the grid. This is not the ideal solution for Dartmouth; as a research and learning institution, we have a commitment to our community. If we are to be a leader in carbon neutrality and renewable energy, we need to do it in our own community. Buying a plot of land in North Dakota and installing turbines there is a similar solution to carbon offsets, and needs to be treated as such.

Recently, developers have approached Dartmouth about a potential wind turbine location in Canaan, New Hampshire (approximately two towns southeast of Hanover). (Steve Shadford) This project would be at Tug Hill, where a wind farm was located in the mid 1980s. That farm was shut down due to "wind speeds considered low for a commercial wind farm" (Wind Powering America), and so we do not believe that Dartmouth should invest in further development at this site, at least not without extensive studies.

The only possibility for large scale wind turbines at Dartmouth is at the Skiway, and there are significant barriers to an installation there. Big Wind, while incredibly successful in some areas, is not a piece of Dartmouth's path to carbon neutrality. It needs to be mentioned though, as it is close to being a possibility at the Skiway and could be an option for many of our neighbors.

B.7.5 Small Wind: An Introduction

By scaling down the size of wind projects to small turbines, we can avoid many of the hurdles that currently prevent big wind from being feasible at Dartmouth. The energy produced by small wind will be available for direct use of the campus, unlike the "bulk" electricity typically produced by large turbines to be fed into the utility transmissions and distribution system. Wind, even if it does not mean discontinuation of the heating plant, is still a "free" resource that will provide supplementary energy to the college, reducing the need for our consumption of No. 6 oil, and therefore our production of greenhouse gases. With today's technology, even the carbon emissions from construction will be offset within the first 3 to 6 months of the turbines operation, leaving it truly carbon neutral for the remainder of its 20 year lifespan (Bhattacharya et. al.: 2009).

When compared with other renewable resources, production from small wind seems to be similar to solar, and if implemented appropriately could even be cheaper (AWEA). Yale University has already experimented by installing 10, 1kW turbines on top of their Benton Engineering building ("Energy at Yale"). Unfortunately advances in small wind have not yet made it viable in this area. Although we believe that Dartmouth should not only match, but hold a goal of surpassing the commitments of other institutions, small wind is not the tool to do it.

B.7.6 What is Small Wind?:

Small and micro wind turbines can be as small as a meter in diameter and can be considered for much more innovative installations than large turbines, such as on lamp posts or even rooftops. They can either be Horizontal or Vertical Axis Wind Turbines (HAWTs or VAWTs), each demonstrating different pros and cons. HAWTs need to face upwind, but are therefore more common in prevailing winds and often cheaper because of their increased efficiency. VAWTs on the other hand are less efficient, but are great for testing, can operate with wind from all directions, and typically have slower start-up wind speeds ("Rooftop Wind: Where We At?": 2006). Both designs can be installed on either towers or rooftops; the key to ensuring optimum power generation is to choose the correct type for the wind quality in any given placement (See Fig. 1 below).

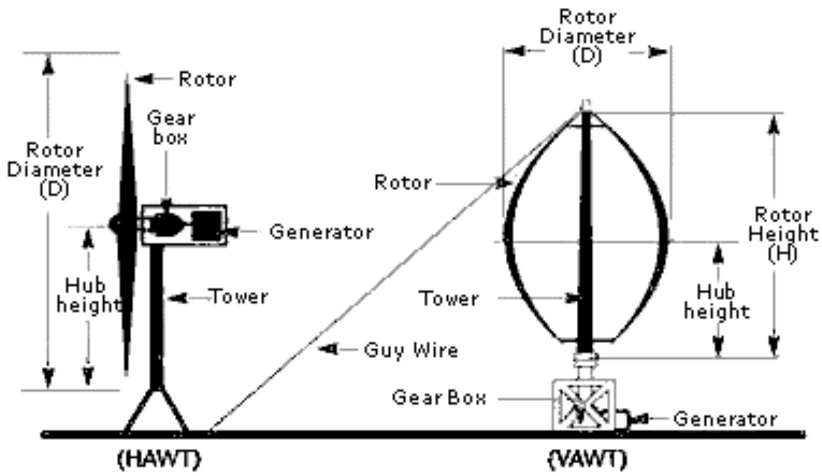


Figure 1: *Wind Turbine Configurations ("The Home of Renewable Energy")*

B.7.7 Small Wind: Installation and Concerns

Whether we are dealing with small turbines located on a roof or a tower, there needs to be wind available for the turbine to function. The next logical step is then choosing the type of installation appropriate for this area given our wind speeds. In researching wind speeds and wind power on campus, we used wind maps that are available at different heights through FirstLook-Wind or TrueWind Solutions ("Wind Resource Maps": 2009). Because at low heights and near obstructions there is less chance that the turbine will operate, locations such as windy farms and open parking lots are good for tower turbines and high rooftops with less surrounding obstructions are good for roof installment. This scale of wind speeds is useful for most small turbines:

- An annual average wind speed of 6m/s or greater is excellent.
- An annual average wind speed of 4.5m/s to 6m/s or greater is good.
- If your site has an annual average wind speed of 4.5m/s or less, you can still generate energy, but longer payback periods can be expected ("Assess the Site": 2008).

After researching and speaking with experts from NRG Systems, Inc. in Vermont, we have concluded that inadequate wind speeds in the Hanover area would probably lead to low power generation ("About Wind": 2008). This fact makes both small and large wind much less feasible and considerably less cost effective.

B.7.8 Small Wind: A Case Study

A bustling international airport is not a place one expects to see advanced energy technology. However, at Logan International Airport in Boston, amid the constant bustle of planes arriving and departing, the future of wind technology is on display. In March of 2008, 20 small turbines were installed on the roof of the Logan Office Center by Groom Energy, partnering with AeroVironment (Massport press release). These turbines are only six feet high, but by using the airflow generated by the shape of the building (air currents tend to come up the sides of buildings), they generate over 100,000 kilowatt hours per year. While this is only about two percent of the building's load, it is still a reduction of almost 100,000 pounds of carbon a year (Groom Energy). The turbines should save about $13,000 a year, with a total payback time of ten years ("Logan Airport Wind Energy Excursion A Success": 2008).

The turbines used at Logan are vertical turbines that begin producing energy at wind speeds of five miles per hour. This wind speed, however, is not the average wind speed for the area; according to AeroVironment's wind pattern data, wind speeds at the corners of buildings should be higher than the regional average, due to the way wind bends around the building (AeroVironment: 2009). These small, roof-mounted turbines not only produce energy with windspeeds that are too low for standard large turbines, but also take advantage of artificially raised speeds.

In addition to their energy use, the wind turbines at Logan Airport make a strong architectural statement. In fact, AeroVironment refers to them on their website as Architectural Wind™, and says that they provide a "visible, compelling and architecturally enhancing statement of the building's commitment to renewable energy" (AeroVironment: 2009). The turbines at Logan have definitely met this goal, as the press coverage has been plentiful and overwhelmingly positive. While the Office Center is not as high profile of a building as the terminals are, the fact that an established transportation center is taking this bold step makes a strong statement. At the time of this report, the turbines have been in place for over a year. While this is not long enough for a full evaluation of the project to be done, no negative feedback has been arisen thus far.

B.7.9 Small Wind: Example Technology

An example of a new turbine that experiments with different types of wind is slated to be in production by 2010 by MicroWind Technologies (pending performance data from current testing). This VAWT will be able to collect wind from any direction with a minimum wind speed of 3 mph, and produce a significant amount of energy at 10 mph. The expected average power generation of each turbine for homes is 3kW, which will produce roughly 6000 kWh a year in 10 mph winds. So far testing has shown the turbines to be inaudible at test sites (above background noise) and vibration issues have been almost nonexistent (Easton, Personal Communication).

The AeroVironment Inc. 1 kW AVX1000 turbines that were installed on the parapet of the roof of Logan International Airport were designed to combat roof turbulence issues ("Energy Technology Center: Architectural Wind": 2009). The wind velocity can increase as it shoots up and over the roofline, and field testing has shown a 40% boost in wind speed, which translates into 2.7 times as much energy in the wind. (See Figures 2, 3, and 4) (Malin: 2006). Another benefit of AVX1000s is that they are designed to operate at relatively low speeds, which will dramatically reduce turbine noise and vibration ("Energy Technology Center: Architectural Wind": 2009). Most AeroVironment projects start with anywhere between 8-12 turbines, and add more as it becomes feasible. These turbines are designed for quick and easy installation onto concrete tilt-up buildings ("Energy Technology Center: Architectural Wind": 2009).

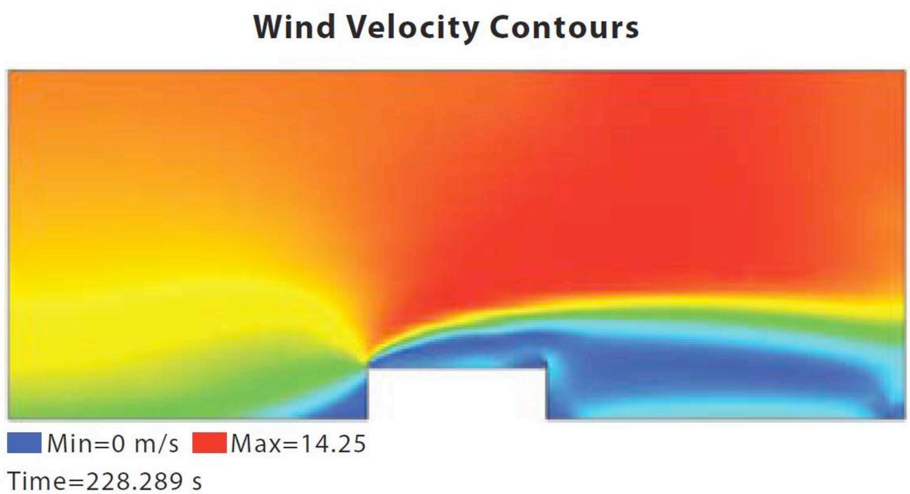


Figure 2: *Wind Velocity Contours Around a Building (AeroVironment)*

Figures 3 and 4: *AeroVironment AVX1000; "Parapet Turbines" (AeroVironment)*

Michael Easton, founder and chief engineer of MicroWind Technologies, said that costs of the new system may end up being $10-20 thousand per turbine, but that ideally will have a five year payback (this does not include factored in incentives). He also pointed out that like all other underdeveloped technologies, costs are going to initially be higher than they will be when in full market production. To get the costs for the AeroVironment turbine, we have used the recent (5 April 2009) cost analysis data compiled by a group of students at the University of Arkansas – Fayetteville, who did a similar sustainability study. Their cost analysis, which includes nearly all parameters needed for ultimate cost approximation, is as follows:

"At wind speeds of 12 mph, each turbine's annual energy production is approximately 1200 kWh (AeroVironment: 2007). Other assumptions for this project are installed costs of $73,048 for 12 turbines (total of 120,000 W potential), operations and maintenance costs of $0.0012/W,

*insurance costs of $0.0055/W, a 30% equipment cost-federal tax credit, $0.18 per watt SWEPCO** offset incentive (AEP: 2009), an additional SWEPCO kWh cost incentive for 1 year of turbine production (Ibid), 3% annual electricity rate increases (inflation rate), 3% discount rate, and an estimated additional 30% carbon tax (initial C tax) is projected for year 2 of this project (Bhattacharya et. al.: 2009).*

Given these calculations, they found that there would be financial savings, that 363,778 kWh (1241.2 MMBTUs) were generated, and that 364 metric tons of CO2 emissions were avoided. Another important claim made by this report was that the entire AeroVironment turbine system was implementable within 1 year (Bhattacharya et. al.: 2009). The numbers presented here give us a rough estimate of the kinds of savings (in costs and emissions) we could expect if small wind were implementable here. Numerous experts we have talked with believe that this system will not function similarly in the Hanover area, and that we need to wait for more advances in turbine technology.

B.7.10 Small Wind: Rooftop Installation

Although small building mounted turbines seem more appropriate for urban settings and for implementation at Dartmouth in general, this may not be the case just yet. Buildings are major sources of turbulence that prevent high speed winds from ever reaching the turbine if it is not positioned correctly. Although some turbines counteract this by instead using the building's shape to dictate power generation potential, it does not mean that power production will be high, and from research we have reason to believe it will not be ("Energy Technology Center: Architectural Wind": 2009).

In addition to wind speed concerns, noise from both the turbine's generator and spinning rotor have been a common complaint of wind turbines. This could be a problem if we plan to install these turbines in close proximity to dormitories and academic buildings. The last issue has to do with the vibration caused by rooftop turbines. All wind turbines vibrate and transmit this vibration to the structure on which they are mounted, so it is important to determine that a building is structurally suitable for turbine installation ("Assess the Site": 2008). According to Mr. Easton, no major vibration issues have been found in the testing of MicroWind Technologies' turbines. It is true that rooftop turbine technology has improved over the past few decades to produce quieter turbines that are able to operate at different heights, production power, and collect wind at different speeds despite obstacles. However, brick is one of the most commonly used building techniques on Dartmouth's campus, and one of the least structurally sound available; it would be susceptible to any vibrations that did arise. A more ideal situation would be to mount turbines on wood or concrete, where the supports can be drilled in (Michael Easton, personal communication). At Dartmouth, there are several buildings that would have the best surfaces for roof mounted wind turbines, including Thompson Arena (the hockey rink), the flat roof of the Hopkins Center, Fairchild Tower, and possibly the McLane Family Lodge at the Skiway. Yet even these buildings do not make up for the fact that rooftop turbine power generation is unproven and would not provide enough electricity to make up for the investment with the technology as it is today. We have found, therefore, that rooftop wind currently does not have a place in bringing Dartmouth to Carbon Neutrality.

McLane Family Lodge at the Dartmouth Skiway, photo from Dartmouth College

B.7.11 Cost and Payback:

The cost of generating electricity with wind has fallen over 80% since the early 1980s, and will only continue to fall with improved technology. On February 17, 2009 President Obama signed the American Recovery and Re-Investment Act into law. This removed previous "cost caps," which allow consumers to take a 30% tax credit off the cost of wind turbine purchase and installation. The American Wind Energy Association predicts this federal subsidy could help the small-turbine market grow by 40 to 50% annually. For Dartmouth the steepest cost will be that initial investment of purchasing and installing the turbines, and in order to take advantage of this new federal tax credit, it must partner with a taxable, private entity which could purchase the system and then lease the equipment to the university (Bhattacharya et. al.: 2006). Available turbine models require minimal maintenance, have fairly low operating expenses, and generally last 20 years or longer. If it were not for Dartmouth's low average wind speeds, the decreasing costs and federal incentives would have brought wind energy costs to a competitive enough range to make investing in several rooftop turbines feasible.

B.7.12 Education, Awareness, and Dartmouth's Image:

If Dartmouth invests in wind energy in the future, our turbine installation should be designed for high visibility, acknowledging that we are proud of our investment in a renewable energy system. It should not be considered as compromising the aesthetic value of "traditional" Dartmouth. Turbine presence would represent a powerful environmental statement, and raise awareness about renewable energy. For example, the aforementioned Architectural Wind™'s AVX1000 turbine system, designed by AeroVironment, Inc., combines function with aesthetic to architecturally enhance the structure on which it sits ("Energy Technology Center: Architectural Wind": 2009). Moreover, the effect would educate and may even inspire the campus and community to change its behavior related to energy consumption ("Assess the Site": 2008). This education effect could prove invaluable because a considerable amount of opposition to wind energy projects stems from ignorance about the nature of the technology. If it becomes feasible to install a small turbine simply to raise consciousness, we believe it would have a positive effect on the student body and should be done.

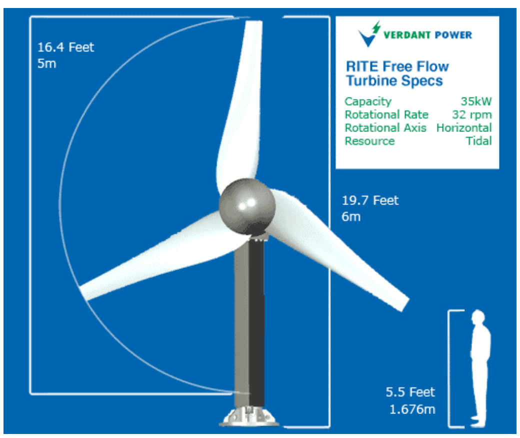
B.7.13 Conclusion

On Dartmouth College's path to carbon neutrality, wind is not yet feasible for installation. Wind speeds in the area, environmental and aesthetic preservation, and financial investments all pose obstacles to both types of wind turbine installation. New, innovative wind harnessing technologies are being developed every day. They are becoming extremely reliable, require much less maintenance, and are able to generate electricity 99% of the time or more, even at slow wind speeds. Wind will need to reach this degree of power generation at low costs before it will be implementable on Dartmouth's campus.

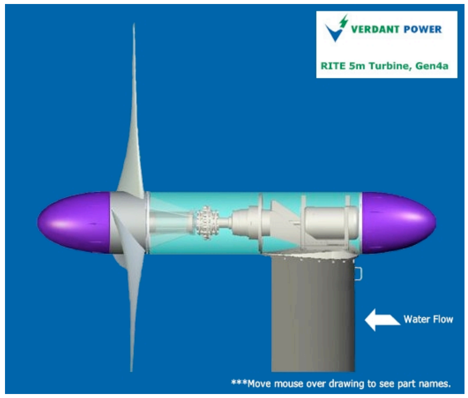
B.8 Stream-flow Water Turbines in the Connecticut River

One of the most intriguing prospects for power generation at Dartmouth is utilization of the flow of the Connecticut River. When the Wilder dam downstream is open in particular, the flow of the river is considerably strong(15,000+ cubic ft/sec http://waterdata.usgs.gov/nh/nwis/uv/?site_no=01144500&agency_cd=USGS).

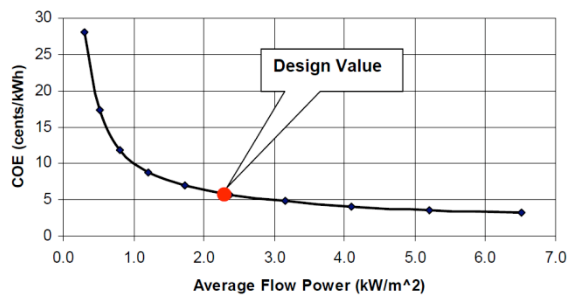
The Technology

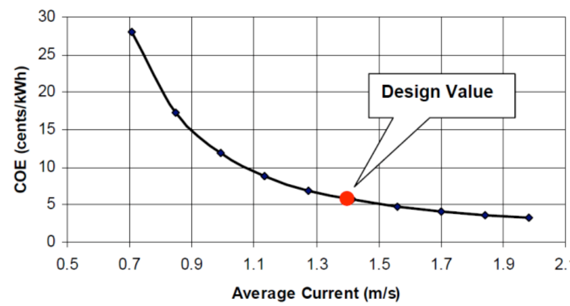


Verdant Power Systems utilizes a 35kW turbine system, capable of producing 306,600 kWh/yr. These turbines spin at an incredibly slow rate of 32 rpm. It is possible for a water turbine to spin so much slower than a wind turbine of comparable size due to the superior energy density of water compared to that of wind. (On a related note, the capacity factor for tidal stream flow power is 46%, whereas wind power ranges from 30-42% and solar thermal is approximately 33%) (EPRI Maine hydro project cost analysis) Much like a wind turbine, a water turbine collects the horizontal energy of the flowing material and turns it into rotational energy through use of a rotor with hydrodynamically engineered blades. This rotor turns fairly slowly, so within the nacelle (same term as is used in wind turbines), there is a low speed shaft that enters a gearbox which steps up the speed of the rotation to a usable rpm level which is transferred to an electric generator by means of a high speed coupling. The idea behind water turbines is that they are connected in a grid network and all of the electric power generated among the field of turbines is collected at a single source, converted to DC current to get a stable power curve, then converted back to AC current to provide usable electricity to the consumer, in this case: Dartmouth college or the town utilities grid.

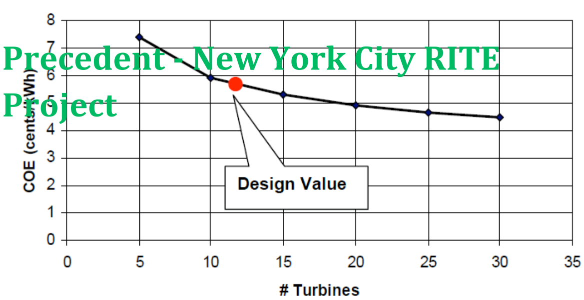


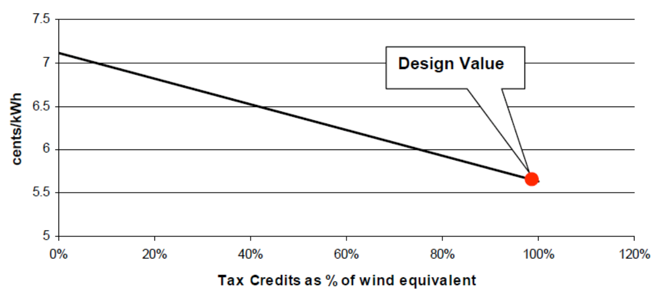
As average flow speeds increase, cost of producing electricity ($/kWh) decrease significantly, indicating that the faster current available would provide the most cost effective electricity.





2008 COE in NH approximately $0.14 (http://www.puc.state.nh.us/Legislative-Jan2009/Tom%20Frantz%20STE%20Presentation%20011509.pdf slide 9) although only about $80/month for ~500kW





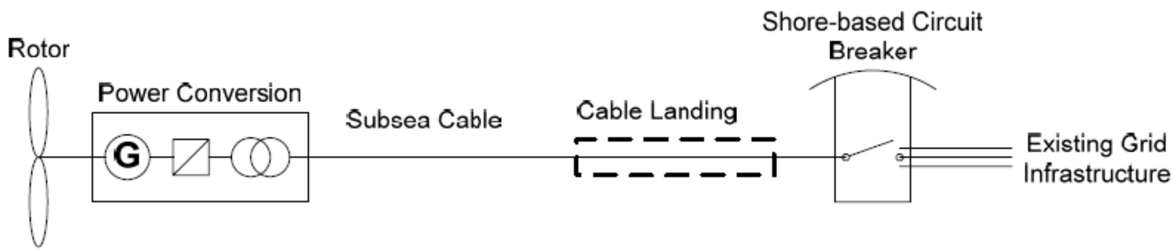
Precedent - New York City RITE Project

http://www.verdantpower.com/what-initiative

http://www.treehugger.com/files/2008/09/east-river-tidal-turbine-project-gets-retrofit.php

Cost Breakdown for similar sites in Maine

http://www.umaine.edu/MechEng/peterson/Classes/Design/2007_8/Project_webs/Tidal_test/pdf/Tidal%20Turbine%20Cost%20Estimation%20Research%202.pdf

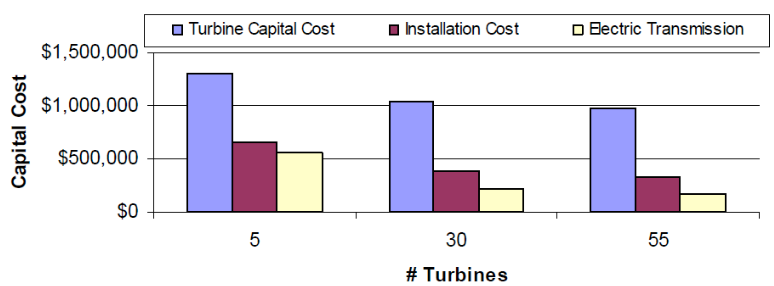


http://oceanenergy.epri.com/attachments/streamenergy/reports/006_ME_RB_06-10-06.pdf

	Capacity Factor (%)	Capital Cost[1] ($/kW)	COE (cents/kWh)	CO2 (lbs per MWh)
Tidal In Stream	46	$2,000	4 – 6.5	None
Wind	30-42	1,150	4.7-6.5	None
Solar Thermal Trough	33	3,300	18	None
Coal PC USC (2)	80	1,275	4.2	1760
NGCC[3] @ $7/MM BTU)	80	480	6.4	860
IGCC[2] with CO2 capture	80	1,850	6.1	344[4]

Installed cost in Maine project involves much larger turbines than could be utilized in the Connecticut River due to depth restrictions of the river itself, however costs normalized to $/kW produced fall within the range of approximately: $2,378 - $5,693/kW (commercial vs. single scale because cost drops per kW installed as more turbines are installed considering shared transportation and installation costs) –

http://oceanenergy.epri.com/attachments/streamenergy/reports/006_ME_RB_06-10-06.pdf



Problems for Dartmouth's utilization

- River freezes in winter (but doesn't freeze all the way to the bottom - how deep does the ice go?)
- Fish/wildlife species in river - could they be damaged?studies in East River project indicated that, since turbines spin so slowly (32 rpm), they do not pose a danger to fish
- On a river lined with trees, lots of floating and partially submerged debris - hazardous to turbines?

Conclusions/Recommendations for the Future:

- Viable renewable energy resource for the upper valley area/Dartmouth college without potential visual distraction delays associated with wind installations, etc.
- There is a wide range of types of turbines – both size and style wise – and it is unclear exactly what size is economically correct for the Connecticut river at this time
- Economies of scale are yet to be realized with tidal power in the Connecticut – whereas wind turbines started at less than 100kW and are now 3+MW for cost reduction, turbines applicable to the Connecticut Rvier are currently ~35kW, so installations may need to be quite large for economic viability
- Detailed velocity and fluid dynamic measurements as well as studies of winter conditions and open vs. closed dam conditions are necessary for a full evaluation of the applicability of tidal power for Dartmouth College.
- Detailed bottom bathymetry of the river as well as a seabed survey and ecological impact analysis need to be conducted (possible for a future class to do this)
- What % of the kinetic energy resource is desired? – Need accurate, detailed stream flow analysis to find total power available, then apply economies of scale to see how many turbines at what size and location would be feasible

Meet the Authors

Anthony Arch IV- Class of 2009; San Francisco, CA; Environmental Studies Major. My activities on campus include the 08-09 Big Green Bus, Greek Sustainability Intern, Dartmouth Rugby Co-Captain, and the 08-09 Inter-Fraternity Council President. Upon graduation, I plan to return to the Bay Area and take the LSAT and LEED AP exam, and continue playing rugby.

Jennifer E. Argote - I'm a junior Environmental Studies and Government double major from New Orleans. I am interested in carbon reduction plans, especially in order to reduce global warming and it's effects on coastal zones and wetlands. I would like to see a better connection between students, faculty and the administration workking to make more significant carbon reductions. On campus I am the editor of The Dartmouth Mirror and a chair on Student Assembly.

Julie M. Carson - Class of 2010; Caribou, ME; Environmental Studies Major, French Minor. As a result of this project, I have learned so much about energy efficiency, and I hope to apply this next year at Dartmouth. In my free time, I like to run, ski, climb, and write.

Katharine G. Cholnoky - Class of 2010; Darien, CT; Double majoring in Environmental Studies (concentrating in global water issues) and Studio Art. I am the Director of the Dartmouth Ski Patrol, Head of Design for the 09-10 Big Green Bus, and part of a group on campus promoting coeducation at Dartmouth. I'm interested in combining art with environmentalism through either graphic design or high arts, and skiing deep powder.

Gabriela Davila - Class of 2009: Environmental Studies major, Portuguese minor. Interests in environmental policy and law, community development, environmental justice and education.

Nicholas S. Devonshire – Class of 2011; Lake Forest, IL; double major in Environmental Studies and Economics. On campus I am the student appointee to the Resource Working Group and the co-chair of the Environmental Conservation Organization. Off campus I have been an employee of the Green Report Card of the Sustainable Endowments Institute. I also intern at Solargenix Energy LLC, and a marketing intern for the green handsets division of Motorola.

Julia E. DeWahl - Class of 2009; Greenwich, CT; History Major. Although this is only my first ENVS class, I have always been committed to sustainable living and environmental issues, and love the outdoors and natural sciences.

Trevor S. Granger - Being from southern California, I love anything to do with the sun and beaches, as you might expect - but another result of hailing from one of the most threatened hotspots of biodiversity in North America, I also grew to become a passionate and avid environmentalist. Choosing which major I wanted to pursue at Dartmouth wasn't an immediately obvious decision due to my many interests, but the choice of environmental studies has been greatly rewarding. In addition to my passion for wildlife and conservation I am an avid filmmaker and photographer and I hope to advocate and educate others on environmental issues through my films. This fall I'm going to be volunteering abroad before applying to graduate programs in biological conservation next year.

Heidi A. Heller - 2010 Environmental Studies major and Engineering minor, from Evanston, IL and Santa Barbara, CA. This summer I will either be interning at the Community Environmental Council or Continental Wind Power, both in Santa Barbara. Within environmental studies, I am very interested in the conservation and renewable energy/environmental engineering fields.

Cory M. Hoeferlin - Class of 2010; Columbia, MO; Environmental Studies major, Chemistry minor. I am primarily interested in how the environment affects human health, and this summer I will be interning at the CDC in Atlanta researching aspects of environmental health.

Gwendolyn D. Jones - Class of 2010; North Salem, NY; Environmental Studies Major, Creative Writing Minor. I have been involved with ECO, the Stonefence Review and am social chair for my sorority, Kappa Delta Epsilon. I am primarily interested in how the environmental movement can learn to market itself successfully and lose its image as a "hippie dippie" phenomon. Espeically in how concepts of creative design and branding can be applied in this field. I will be working with the ENVS department on this project in the summer, under the Pearl Family Fund and the Stockwell Fund.

Tara C. McNerney - Class of 2009; Amherst, MA; Environmental Studies Major, French Minor. Next year I plan to work on an Organic Farm in France through the WWOOF program. In the long term, I hope to pursue a degree in law, with a specialty in environmental law.

Ian P. Murphy – Class of 2009; Greenwich, CT; Environmental Studies Major, Engineering Sciences Minor. I am particularly interested in sustainable design and engineering consulting and I hope to pursue a masters degree in urban planning.

Katrina F. Ortblad - Class of 2010; Seattle, WA; Biology Major Modified with ENVS. I am primarily interested in the relationship between health and the environment; this past winter I was in rural Ghana working with a team of community health care workers on a malaria outreach program. For the past three years I have been a member of the Varsity Swim Team and this winter I will be the community developmnet officer for the Nicaragua CCESP.

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Courtney E. M. Robinson - ENVS major/EARS mionr/pre-health; Eagle, CO. Special interest in environmental global health and the ecological identity. I enjoy skiing and biking as well as running and doing handstands.

Santiago B. Romero - Class of 2010; Los Angeles, CA; Environmental Studies Major. I am interested primarily in studio arts but after our recent time spent in the ENVS 50 course I have become very interested in Zero Emission Buildings and Design.

Leigh B. Rorick - 2010. Hometown: Toledo, Ohio. Double major: Economics and Environmental Studies. I am especially interested in Environmental Law and Policy. This project has taught me how difficult this type of goal is, and how ambitious Dartmouth and other institutions will have to work to actually achieve carbon neutrality.

Matthew J. Schlossberger - Class of 2009; Plainview, NY; Biology and Environmental Studies Double Major. I have always been interested in preserving the environment since it has been a place of comfort, entertainment, and serenity. By spearheading environmental initiatives with this class, I hope to raise public awareness regarding natural resource and energy conservation. Here at Dartmouth, I have been an active member of the Dartmouth Wind Symphony and Multi-Faith Council. After graduating this June, I will be heading off to my first year of medical school beginning in August.

Carly M. Silverman- Class of 2010; Santa Barbara, CA; Economics Major Modified with ENVS. I am very interested in third world countries, both in terms of economic development and environmental consequences. I am also interested in sustainable clothing, which I hope to pursue after college. I am a mentor through DREAM and I am very involved in my sorority, KDE.

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John P. Smith - I'm an Economics and Environmental Studies double major from Ferrisburgh, VT. I'm especially interested in public policy issues and have enjoyed the challenges and rewards ENVS 50 has presented through the focus on a local policy issue. Following graduation, I will be apprenticing at Luna Bleu Farm in South Royalton, VT under Dartmouth alumna Suzanne Long '83.

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References

Thank You

The 2009 Environmental Studies 50 class would like to thank the following people for all of their help with our project. We could not have done any of the work we did without the help of numerous people, some within the Dartmouth community and some outside of it. We hope that part of our legacy can be in opening the communication lines between all of these people, who are all doing valuable work to our community and the world.

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