# Our Big Green Future

## Achieving Carbon Neutrality at Dartmouth College

ENVS 80
Final Report
December 3, 2009

Sarah Alexander '10, Jennifer Argote '10, William Blakeley '10, Timothy Bolger '10, Katherine Briggs '10, Ellie Chapman '10, Nicholas Devonshire '11, Ian Engler '12, Betsy Dain-Owens '10, Ann Elise DeBelina '10, Jensen Lowe '10, Kelly M. McGlinchey '12, Michael Swartz '12, Daniel Susman '10, Benjamin Waller '12, Jonathan Wachter '10

**Efficiency • Wind • Geothermal • Solar Thermal**
**Photovoltaic • Biofuel • Biomass**

TABLE OF CONTENTS

**Page Number ....... Title**



**Appendices**

i. Key Abbreviations

| | |
|---|---|
| B5 | Biofuel mixutre with 5% biofuel, 95% diesel |
| B20 | Biofuel mixture wih 20% biofuel, 80% diesel |
| B100 | Pure biofuel (100% biofuel, 0% diesel) |
| BAU | Business-As-Usual |
| Btu | British thermal unit |
| $CO_2$ | Carbon Dioxide |
| CWE | Canaan Wind Energy |
| FO&M | Facilities Operations and Management |
| GHG | Greenhouse gas |
| GT | Geothermal Energy |
| GSHT | Ground source heat pumps |
| HPD | High Performance Design |
| KWH | Kilowatt hour |
| MMBTU | Million british thermal units |
| MTCDE | Metric Tons of Carbon Dioxide Equivalents |
| NOx | Nitrogen oxides emissions (another type of Greenhouse gas) |
| NPV | New Present Value ST Solar Thermal Energy |
| NYMEX | New York Mercantile Exchange |
| OECD | Organization for Economic Cooperation and Development |
| PSNH | Public Service of New Hampshire-Electric Utility |
| PPA | Power purchase agreement |
| PV | Solar Photovoltaic |
| REC | Renewable Energy Credit |
| ROI | Return on Investment |
| SECP | Strategic Energy Conservation Plan; includes replacing the campus's current absorption chillers with electric cillers, implementing a steam trap maintenance program, building all new projects with High Performance Design, and applying retrofits and efficiency measures to twenty-five of the most energy-intensive buildings on campus. |
| SECP-CW | Campus-Wide Strategic Energy Conservation Plan; includes steam trap maintenance program, high performance design, and expands the retrofits and efficiency measures to every building on campus (as opposed to the twenty-five most energy-intensive buildings). |
| $SO_2$ | Sulfur Dioxide |
| SVO | Straight Vegetable Oil |
| WVO | Waste Vegetable Oil |

## 1.1 Introduction

The Fall 2009 Environmental Studies 80 class, Achieving Carbon Neutrality, is pleased to present our feasibility analysis for increased energy efficiency and renewable energy supply for Dartmouth College. This report follows President Kim's vision of turning Dartmouth into "the greenest campus in the world" and "a living laboratory for sustainability."[i] The class's mission was to evaluate the most cost-effective and reliable approach towards eliminating Dartmouth's reliance on fossil fuels and the greenhouse gas (GHG) emissions associated with the heating plant and purchased electricity. This report examines how a combination of renewable energy supply options can work in tandem with energy efficiency measures to reduce the College's carbon emissions.

Dartmouth's current fiscal crisis is a crucial opportunity to pursue "green" investments as a cost-effective and socially conscious way to move the College forward. Rahm Emanuel, the White House chief of staff, points out that one should "never let a serious crisis go to waste," asserting that crises are "opportunities to do big things."[ii] In an email address to the College, President Kim stated that the goal of current budgetary reductions should be "not just to cut costs, but to improve the way we operate the College in pursuit of its mission, [to] protect the 'Dartmouth Experience … and make necessary investments to continue to enhance it, and …preserve the College's commitment to leadership in higher education."[iii] Dartmouth should seriously consider using the current fiscal crisis as an opportunity to transition to renewable energy sources and serve as a leader to solve the global climate change crisis.

### *1.1a Environmental Context*

Global GHG emission levels resulting from human activities have risen since pre-industrial times, increasing by 70% between 1970 and 2005.[iv] Atmospheric concentrations of $CO_2$ and other GHGs exceed far above levels of the last 650,000 years, which has started to cause an "unequivocal" warming in the climate.[iv] According to NASA scientist James Hansen, "if humanity wishes to preserve a planet similar to that on which civilization developed and to which life on Earth is adapted, paleoclimate evidence and ongoing climate change suggest that $CO_2$ will need to be reduced from its current 385 ppm to at most 350 ppm."[v] As a result of anthropogenic warming, eleven out of twelve of the years between 1995 and 2006 rank among the twelve warmest years in the historical record of global surface temperature since 1850.[iv] Most importantly, increased global temperatures have an array of potential adverse consequences, such as rising sea levels, drought and water shortages, increased frequency of extreme weather events, heat waves, expanded regions with prevalence of parasitic disease, decreased agricultural production, increased species extinction, and loss in biodiversity.[vi,vii,viii,ix]

### *1.1b Social Context*

Climate change will have widespread global effects, but it is the world's most impoverished countries that will be most affected by the climatic change, which is primarily caused by emissions from developed countries. For instance, Africa, one of the most vulnerable continents to climate change due to multiple stresses and low adaptive capacity, is expected to suffer immensely in the areas of agriculture and infrastructure. By 2020, it is projected that "between 75 million and 250 million people in Africa will be exposed to increased water stress due to climate change."[iv] In Asia, glacier melt in the Himalayas is projected to increase flooding and rockslides and to decrease water availability significantly within the next 20-30 years. This decrease in freshwater availability is expected to adversely affect more than one billion lives by the year 2050.[iv]

*1.1c Academic Context*

Industrialized countries are significantly more equipped to develop and implement green technologies, making it the responsibility of leading institutions within these countries to take charge. Dartmouth College has already taken steps in the right direction, setting goals to reduce its GHG emissions in the coming years. Current targets are a 20% reduction by 2015, a 25% reduction by 2020, and a 30% reduction by 2030, compared to 2005 levels.[x] The College has already approved funding for the 2008 Strategic Energy Conservation Plan developed by Facilities Operations and Management, including a promise to invest $12.5 million in energy efficiency upgrades over the next seven years.[xi]

Dartmouth must continue to build upon these efforts in order to be, in the words of President Kim, on the "bleeding cutting edge of environmental sustainability."[i] Dartmouth's GHG reduction targets are not as ambitious as those of most of its Ivy League peers (Figure 1), and while 656 academic institutions have already pledged to be climate neutral,[1] Dartmouth College has yet to make such a commitment.[xii]

Right now, Dartmouth College is in an unusual and privileged position to fulfill a moral obligation while simultaneously seizing a financial opportunity.

[1] Climate neutrality refers to producing no net greenhouse gas (GHG) emissions. This is achieved by reducing GHG emissions as much as possible and offsetting the remaining emissions.

**Greenhouse Gas Reduction Targets within the Ivy League**

| University | Target Reduction | Base Year | Target Year |
|---|---|---|---|
| University of Pennsylvania | Climate Neutrality | -- | -- |
| Cornell University | Climate Neutrality | -- | 2050 |
| Yale University | 43% | 2005 | 2020 |
| Brown University | 42% | 2007 | 2020 |
| Columbia University | 30% | 2005 | 2017 |
| Harvard University | 30% | 2006 | 2016 |
| Dartmouth College | 25% | 2005 | 2020 |
| Princeton University | 13% [2] | 2005 | 2020 |

Figure 1: Greenhouse Gas Reduction Targets within the Ivy League

In 2008, Dartmouth produced 14.86 metric tons of $CO_2$ emissions per student. This was much more than many colleges in New England, including College of the Atlantic (4.8 metric tons/student), Brown University (8.5 metric tons/student), Smith College (8.2 metric tons/student), and the University of New Hampshire (5.5 metric tons/student in 2007).

Harvard University has solar hot water systems along with geothermal, photovoltaic installations, and significant purchases of wind energy. The University of New Hampshire uses landfill gas to supply 85% of its energy use and has committed to carbon neutrality as a signatory to the American College and University President's Climate Commitment. These colleges and universities have taken the lead in reducing their emissions, and now these measures are becoming the status quo for others. (See Appendix A for more information concerning other university precedents.)

*1.1d Financial Context*

In November 2009, Dartmouth reported that the College lost 23% of its endowment.[xiii] Dartmouth must examine every aspect of its current budget. One area in which Dartmouth can make dramatic changes in the short term that will protect its endowment going forward is through energy savings.

Over the last five fiscal years, the College has spent an average of $11.5 million per year to meet the total campus energy demand. From 2000 to 2009, oil use at Dartmouth has increased by 25% and oil costs are up 500%. Electricity use has increased by 39% and the price of electricity is up 132% from 2000 to 2009. During the fiscal year of 2009, we are projected to spend $15.6 million on our total energy needs.[xiv] According to the International Energy Agency's *World Energy Outlook 2009 Factsheet*, "price volatility will continue, but the days of cheap energy are over." Rising marginal costs of supply combined with increased demand growth in non-OECD[3]

---

[2] Princeton's formal goal is to reach 1990 levels by 2020. We converted this to reduction goal compared to 2005 levels using the following data: 1990 levels: 95,455 metric tons CO2e 2005 levels: 110,206 metric tons CO2e. This was taken from the Green Report Card at http://www.greenreportcard.org/report-card-2010/schools/princeton-university/surveys/campus-survey#climate (all facts in this section are from each respective institutions's information on greenreportcard.org)

[3] OECD countries are those that are members of the Organization for Economic Cooperation and Development have developed economies.

countries will cause an “upward pressure on prices.” Using U.S. Energy Information Agency (EIA) price predictions, and omitting future boiler infrastructure costs, in 2030 Dartmouth would need to spend anywhere from $33-$56 million to meet its energy demand under a business as usual (BAU) scenario, representing current efficiency plans and fossil fuel energy supply conditions. This cost will be even higher if the United States Congress passes climate legislation that puts a price on carbon.[4,xv, xvi]

Dartmouth has the chance to avoid this enormous cost by making investments on proven renewable energy technologies now. According to our report, the College could save between $226 million to over $600 million in twenty years. The following section explains the mix of technologies that achieves this savings.

## 1.2 Overview of Proposed Energy Mix and Potential Reductions

Our proposed energy mix to achieve cost-effective reductions in carbon dioxide emissions include campus-wide efficiency measures, a 20-MW offsite wind farm, geothermal heat pumps, solar thermal water heating panels, and the replacement of the remaining #6 fuel oil with biofuels. Our plan will reduce GHG emissions by 86% in 2030 from 2010 levels, 53% of that reduction coming from an aggressive campus-wide efficiency plan.

The mix represented in this report is the result of collaboration among students, college administrators, alumni, and outside experts. It is a snapshot of a possible green future for Dartmouth College. A more detailed analysis of our calculations will be examined in Section 1.4. Assumptions behind the calculations for each project are located in Appendix B.

Table IV in Appendix C presents a potential energy profile for 2030 with each of our projects in place. Figure IX, Appendix C is timeline of implementations of renovations necessary for our proposed technologies. Appendix C also shows the cost-effectiveness of each project, including simple payback, net present value, and the cost per $CO_2$ emission.

### *1.2a Campus-wide Efficiency Plan*

Goals:

- ✓ Reduce Dartmouth's total GHG emissions.
- ✓ Reduce energy load on campus.
- ✓ Meet Dartmouth’s total energy demand while phasing out Number 6 Fuel oil.
- ✓ Take on the most aggressive projects with the biggest financial paybacks and $CO_2$ reductions.

A campus-wide efficiency plan is necessary to make all other technologies feasible. Efficiency Phase 1 represents the Strategic Energy Conservation Plan (SECP) developed by Facilities Operations and Management (FO&M) and includes applying conservation retrofits to twenty-five of the campus's most energy-intensive buildings. Phase 2 expands the SECP to include campus-wide retrofits (SECP-CW). Efficiency and conservations measures are proven,

[4] On 26 June 2009, the US House of Representatives passed the American Clean Energy and Security Act of 2009, H.R. 2454. The Senate is currently considering their version of the bill, the Clean Energy Jobs and American Power Act. On 25 November 2009, the US administration announced that President Obama was prepared to “put on the table” a greenhouse gas reduction target at the UN climate conference in Copenhagen.

low-risk and cost-effective approaches to reducing Dartmouth's energy needs and should be given first priority (see Section 2.1). These efficiency measures allow the College to meet most of its energy usage through a comprehensive mix of renewable technologies (see Figure 2).

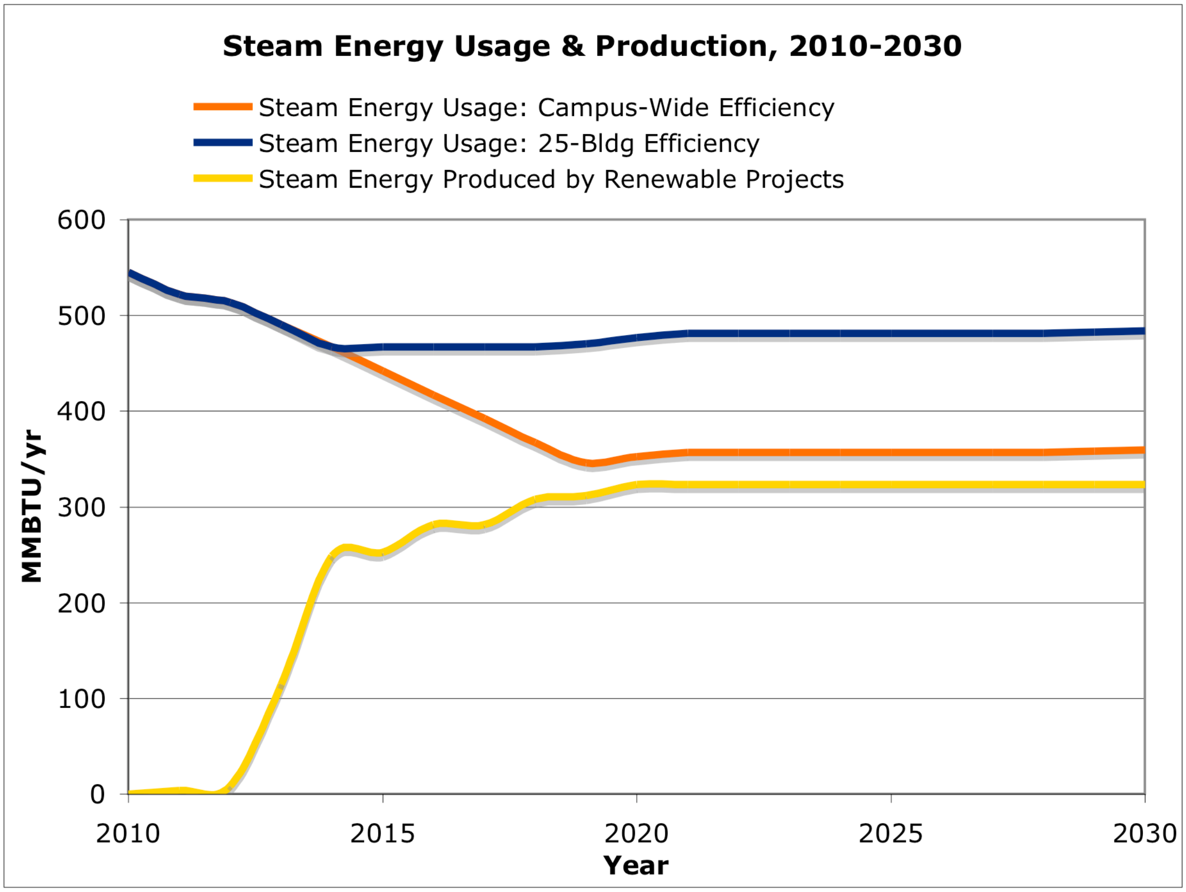



Figure 2: Campus-wide efficiency measures reduce the College's steam usage from the cogeneration plant by 46%, making it feasible to meet 90% of Dartmouth's entire heating demand through renewable technologies. Margin of difference can be met through biofuel or biomass technologies as well as behavioral conservation methods.

Geothermal and solar thermal installations are proven technologies that will be implemented in the most realistic manner; each year Dartmouth will choose a certain campus sector or cluster of buildings in which to install geothermal heating and cooling as well as solar hot water heating. The buildings best suited for these technologies should be switched first to provide our technicians with experience that will build the expertise required to take on more complicated installations later (See Section 2.3 and 2.4 for further explanations of these technologies).

Installing renewable technologies in phases will reduce Dartmouth's reliance on its cogeneration plant incrementally from year to year, ultimately enabling the College to fully transtion off of using Number 6 fuel oil. Running pure BioFuel (a processed waste-vegetable oil) or a mix of BioFuel and fuel oil in one or more of our boilers will help reduce emissions of $CO_2$ as well as $SO_2$ and $NO_X$ emissions. As geothermal and solar thermal installations decrease Dartmouth's reliance on the heating plant, the amount of energy needed from cogeneration plant decreases (see Section 2.6 for further information).

Since our efficiency measures decrease the use of the cogeneration plant, Dartmouth's source of cogenerated electricity from the heating plant is also greatly reduced (Figure 3). Wind electricity is the green answer to meet the campus's electrical demand. A remote wind farm owned by Dartmouth is an excellent asset to provide inexpensive and clean electricity, however the current proposed wind farm will not meet all of Dartmouth's electricity demand. There are a few green options the College can take to cover this gap. First, Dartmouth could purchase "green power" from Public Service of New Hampshire (PSNH), which is in the process of developing an option for interested customers to purchase electricity from renewable technologies. Secondly, Dartmouth could install solar photovoltaic cells on suitable buildings (see Section 2.5). Third, Dartmouth may purchase Renewable Energy Certificates (RECs). Our report does not encourage this practice since producing real electricity from real sources is a more sustainable way of combating climate change.

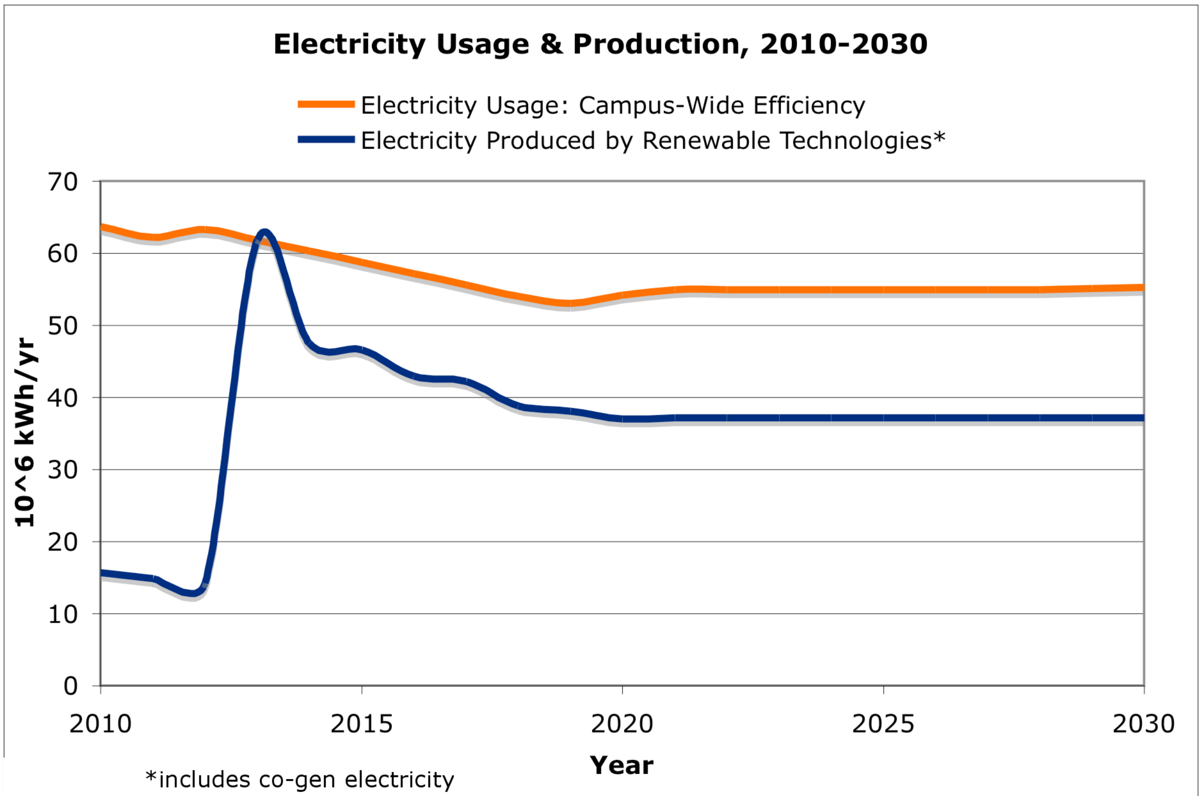



Figure 3: Energy efficiency measures will reduce Dartmouth's electricity usage by 86%. Wind power will supply 67% of Dartmouth's resulting electricity usage. Margin of difference can be met by purchased electricity, solar photovoltaic cells, or through behavioral conservation methods.

### *1.2b GHG Reductions*

Implementing our proposed mix of technologies and efficiency measures will significantly reduce Dartmouth's greenhouse gas emissions (see Figure 4). The GHG reductions are calculated from the carbon content of No. 6 fuel oil. The numbers represented for our energy mix include only the direct avoided emissions from burning No. 6 fuel oil. Life Cycle Analysis of BioFuel is explained in the Appendix D.

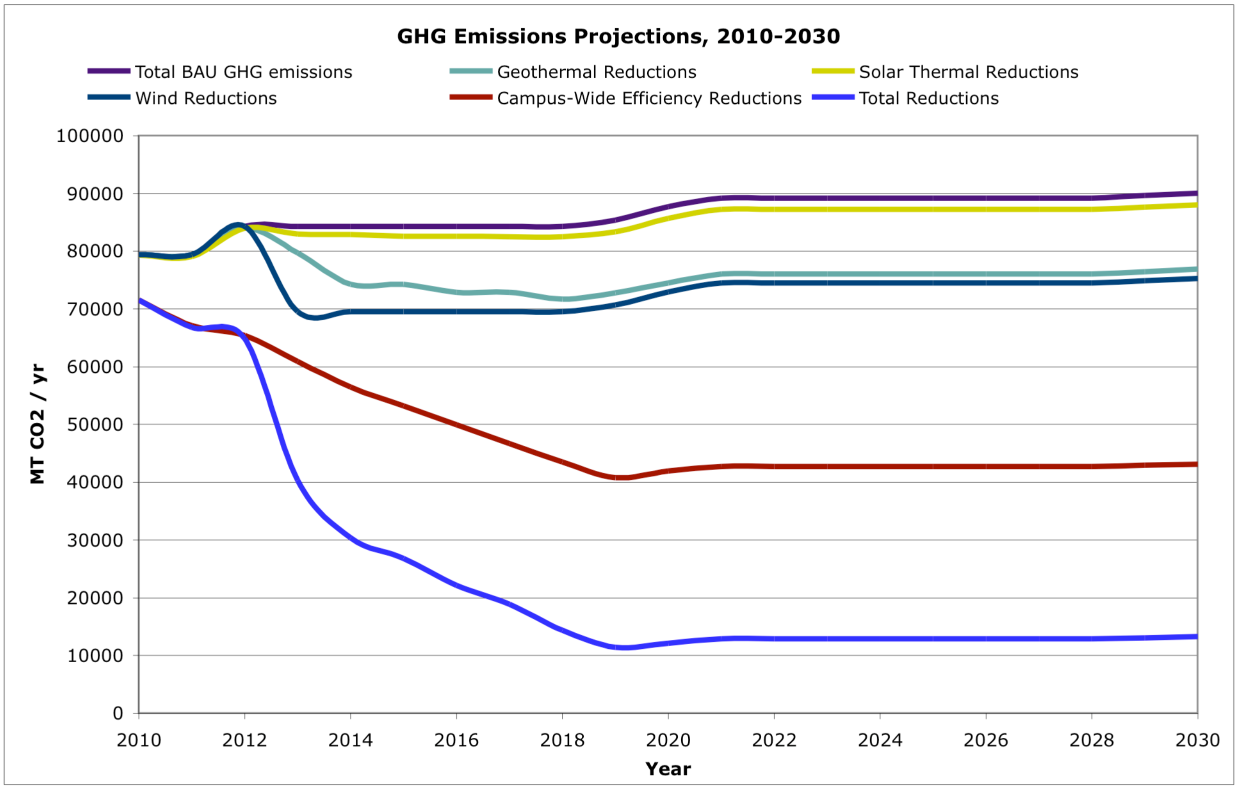



Figure 4: Potential reductions in GHG emissions from each technology compared to BAU, from 2010 to 2030. Solar thermal will reduce Dartmouth's GHG emissions by 2%, Geothermal by 15%, Wind by 16%, and Campus-wide efficiency measures by 52% from the BAU emissions in 2030. All projects combined will reduce the College's GHG emissions by 85% from the BAU emissions in 2030. See Appendix B for numbers and further explanation.

## 1.3 Costs

### *1.3a Methods*

Costs for these technologies were derived from communications with experts; in each technology's respective section, we cite the businesses or experts who helped determine the assumptions for each set of calculations (see Appendix B for a complete discussion of each technology's assumptions).

For each technology, we identified the appropriate investment and maintenance costs of the project, the amount of energy created per year, and the amount of $CO_2$ emissions reduced per year from each project. We calculated simple payback and net present value (NPV) for our financial analysis. NPV accounts for the future cost of money by discounting costs and revenues in the future (Appendix C).

*1.3b Scenarios*

We generated comprehensive final price tags from 2010-2030 for four scenarios:

- SECP measures implemented and high projected estimate of future energy prices.
- SECP measures implemented and low projected estimate of future energy prices.
- SECP-CW measures implemented and high projected estimate of future energy prices.
- SECP-CW measures implemented and low projected estimate of future energy prices.

Our high and low estimates of heating costs were based on the EIA price projections for No. 6 Fuel oil.[xvii] Our high electricity price projection assumes a 5% increase in electricity price, while the low electricity estimate assumes prices to remain constant (see Appendix B for projected energy costs).

*1.3c Price Tag*

The total investment cost of our energy mix can be broken up into five categories:

- ✓ Solar thermal and geothermal systems
  - Total costs include investment and maintenance costs. These technologies are maximized due to promising NPVs and attractive long-term energy savings.
- ✓ Efficiency
  - Total costs include initial investment and construction costs for efficiency measures for both the SECP and SECP-CW.
- ✓ Wind
  - Total cost includes maintenance, transmission of electricity, and loan payments to cover the large initial investment.
- ✓ Biofuel/biomass
  - Cumulative yearly amount of both technologies to replace the remaining demand of #6 fuel oil; costs based on EIA projections.
- ✓ Cumulative remaining electricity
  - Cost of electricity per year based on remaining electricity needed and EIA high and low price projections for electricty from 2010 to 2030.

Our business-as-usual (BAU) price was calculated from projected electricity and steam usage based on future building projects, with no savings from efficiency measures considered (see Appendix B for full discussion and table of this calculation).

## 1.4 Results

From the calculations outlined above, each scenario yields significant cost reductions. Though initial investments peak above the BAU energy prices in the short-term, we see savings of $226 million to over $600 million over the 20-year period (see Figure 5).

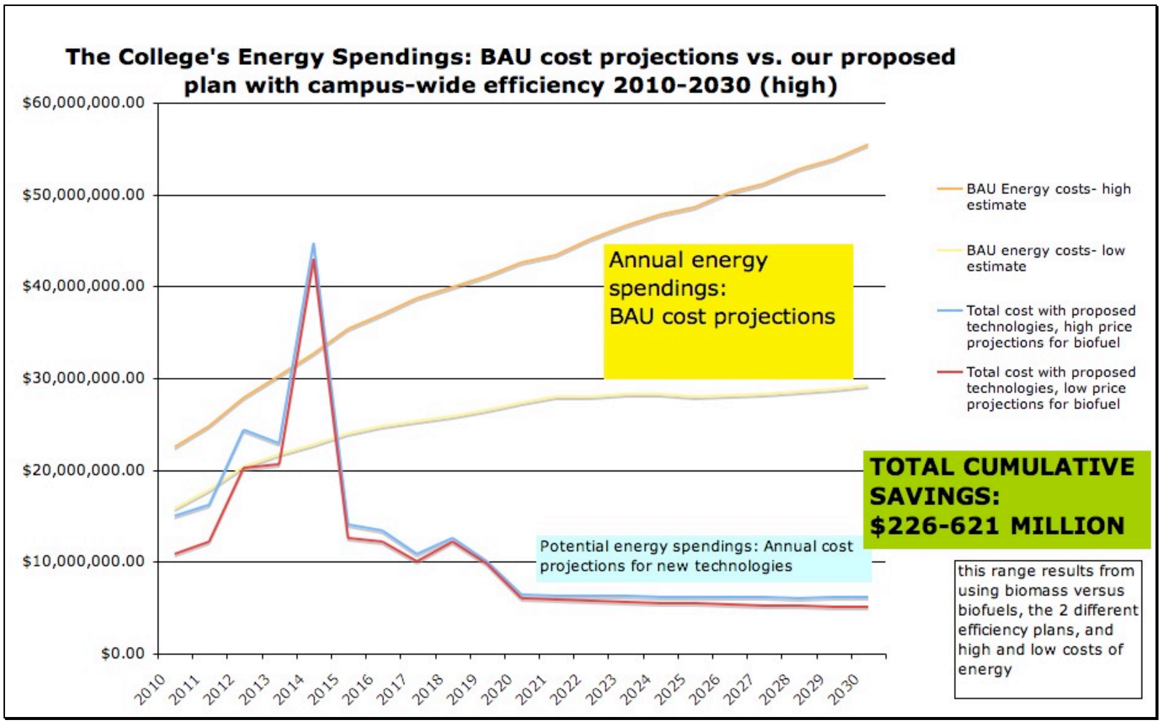


Figure 5: This graph compares the BAU annual costs of energy each year with the costs resulting from a campus-wide efficiency program, solar thermal, geothermal, wind, and 100% BioFuel running in the cogeneration plant. The highlighted yellow portion shows the BAU (with no efficiency measures) energy spending projections from 2010 to 2030. The upper line is based on high estimates of the rising price of oil from the EIA and electricity prices with a 5% yearly increase starting at the cost/kWh in 2010, and the lower based on low estimates of the rising price of oil from the EIA and no increase in electricity prices from 2010. Energy spending for our new projects spike around 2014 as the large investments are made in geothermal, efficiency and the wind farm, however from 2021 onward, our costs are significantly decreased as we essentially we be receiving free energy. The cumulative savings over this 20-year period is highlighted in green, and it is assumed that we will continue to see savings far beyond this time period. The large range in savings results from considering the low efficiency scenario and using wood fuels instead of BioFuel. (See Appendix C for further discussion on these calculations).

### *1.4a Implications of Tax Credits*

While these projects have attractive paybacks on their own, the financial benefits can be even more lucrative when tax rebates are taken into account. There are two primary government incentives for renewable energy technologies.

The first is the Renewable Electricity Tax Credit, administered through the IRS. This is a production incentive giving tax rebates based on kilowatt-hours produced. Certain technologies that contribute renewable electricity to the grid receive a tax break based on each kilowatt-hour.

Wind is the only technology we investigated that is eligible for this production incentive of $0.021 per KWH. Projects looking to file for this credit have a December 31, 2012 deadline, although the program is expected to be extended.

The US Department of Treasury also administers Renewable Energy Grants. Solar thermal, wind, and photovoltaic technologies qualify for these grants, which cover 30% of investment costs. A similar grant will cover 10% of geothermal investment costs.

Because Dartmouth is a non-profit institution which already receives tax breaks, the College is not directly eligible for these rebates. However, Dartmouth can still benefit from these grants if the renewable technologies are installed by an independent taxable entity. One possibility would be for Dartmouth alums to form a C-Corp, a limited liability company (LLC) that could serve as a "pass through vehicle" that purchases the equipment and qualifies for the tax credit but passes on the financial benefits to Dartmouth.

Another similar option is a power purchase agreement, where the technology manufacturers and installers own and operate the system at Dartmouth, take advantage of the grant, and sell cheap energy to the college for pre-determined rates. Universities around the country have favored this system for larger renewable energy projects. [See Appendix A for discussion of precedents].

By reducing $CO_2$ emissions through energy conservation measures and fuel-switching, Dartmouth would be eligible to receive $CO_2$ offset credits under the Regional Greenhouse Gas Initiative (RGGI). The market for these offsets has failed to take off thus far, and the current market price for $CO_2$ offsets is $2.50/ton. However, if national law is enacted in the future, the value of voluntary $CO_2$ reductions by Dartmouth will increase substantially—most economists project offset market value to reach at least $20/ton in the near future.

### 1.5 Achieving Carbon Neutrality

Within our proposed energy plan, there still remains a gap in heating that is supplied by biomass or biofuel. Many experts remain skeptical of the true carbon neutrality of these fuels, and therefore we consider other alternatives for filling in this gap.

One option is to install more GSHP's to supply the remaining heating demand. The previous calculations are based on an industry standard of supplying 80% of a building's heating and cooling load.[xviii] Due to the distribution of the load over the year (i.e. peak heating needs in winter), installing more GSHP's will only supply heat for brief periods of the year, and returns on investment will diminish rapidly. Furthermore, there are important considerations in balancing the amount of heating and cooling that the geothermal wells provide.[xix]

Adding additional solar thermal installations can help close the gap, although the period with the highest heat demand is when solar thermal has the lowest output, due to low sun exposure and low outside temperatures.

Futher investments in solar PV must be considered for the years 2030 and beyond to supplement any additional geothermal and solar thermal projects. Solar PV is becoming more cost-effective everyday, and the more we can invest in it, the less dependent we can be on purchased electricity. As we transition off the cogeneration plant, solar PV will be an essential addition to our energy portfolio.

One final technology option for providing for the remaining heating load is the use of on-site electric water heaters that are supplied by a combination of renewable electricity sources (additional wind power, photovoltaics, etc.).

In addition, all future campus building and renovation projects should adhere to new, stricter energy use and sustainable design guidelines, even beyond current specifications for High Performance Design, and be powered by renewable energy and be net zero energy users or even net energy exporting.

Finally, emphasis must be put on the value of behavioral change around campus and further increasing the efficiency of campus buildings. Closing down the campus for a month for a Winter Break, especially during the coldest days of the year, would result in considerable energy savings. The Sustainable Living Center used 58% less electricity in its opening term from behavior modification alone. Further initiatives to encourage students, staff and faculty to reduce electricity use and lower thermostats can greatly reduce and close the gap of the remaining campus' need for electricity and heating.

## 2.1 Efficiency and Conservation Measures

*Introduction*

In order for clean technologies to more adequately meet Dartmouth's energy needs, the College must drastically reduce its campus energy usage. Energy conservation efforts are most effective when approached through behavioral and technological pathways. Environmental student groups and college initiatives have made important headway in pushing a campus-wide behavioral shift toward energy conservation that includes the GreenLite system and various sustainability campaigns. The efforts to promote behavioral changes and paradigm shifts should be continued; at the same time, we must make changes to our technical systems. Colleges across the United States have successfully reduced energy usage and spending by installing efficiency and conservation projects, including upgrading building management systems, upgrading boilers, and installing system controls (see Appendix A, Table 1). The power of conservation retrofits is especially seen within "Deep Energy Retrofits," an extensive system of retrofitting developed by Marc Rosenbaum (P.E., Energysmiths) that has proven to reduce heating and cooling energy needs by up to 74% and electricity needs by 50% in residential projects (Marc Rosenbaum, "Affordable Comfort Home Performance"). (See Appendix A for further information regarding precedents of Deep Energy Retrofits). Dartmouth College can build upon the excellent work that is currently being done with regards to energy conservation and efficiency to effectively reduce its energy loads and greenhouse gas emissions and significantly reduce its energy spending.

*2.1a Current Work*

As stated in the Strategic Energy Conservation Plan (SECP) Highlights, a document released in February 2008 by Dartmouth College's Facilities Operations and Management (FO&M), one of the most cost-effective ways in which the College can reduce campus energy demand and greenhouse gas emissions is by applying a series of efficiency and conservation measures to our existing systems. The SECP takes into account predicted growth on campus by projecting square footage increases and decreases dependent on building renovation, construction and demolition projects. (See Appendix B for comrehensive list of assumptions, including projected campus growth). Recommended efficiency projects proposed by the SECP are outlined below.

- Steam Trap Maintenance Program (already underway):
  - Dartmouth College will annually test steam traps across the campus with ultrasonic detectors and thermal-sensing devices to monitor the location, type, size, capacity and condition of all traps. This allows the college to eliminate leaks and minimize drops in efficiency. Specific needs for the success of this program included acquiring test equipment and in-house training, and creating a database and work order system for steam traps. While this project is already underway, the College must be aggressive in following up with its status and ensuring a thourough project completion.
- Replacing Absorption Chillers:
  - Dartmouth College currently uses a series of steam absorption chillers, an outdated system that requires large amounts of No.6 Fuel Oil to run and is very inefficient. Electric driven chillers are much more efficient and would drastically decrease the need for No.6 Fuel Oil on campus. Cost factors to replace the absorption chillers would include construction costs, avoided costs of No.6 fuel oil, and added costs of increased electricity required to run the system.
  - Within the SECP (and SECP-CW) efficiency savings, we will not account for chiller replacements. We are assuming that geothermal installations will account for all cooling loads, therefore chillers will not be necessary to provide cooling for the College. Our investment costs and energy savings will only reflect steam trap maintenance, high performance design strategies, and efficiency and retrofit projects. Decreased steam usage as a result of taking the chillers off-line will be reflected in the goethermal numbers (see Section 2.3).
- High Performance Design (HPD) Strategy**:** Incorporating HPD in new building projects has the potential to reduce steam usage rates by 50% and electricity usage rates by over 70% from a "business as usual" construction strategy (See Appendix B for assumptions and calculations). HPD includes but is not limited to:
  - Tightening building envelopes by installing triple-glazed windows and increased insulation.
  - Optimizing lighting systems of buildings through maximized day lighting controls, utilizing timers and/or occupancy based sensors for light switching, and installing low-energy LED and/or CFL light bulbs.
  - Installing low-energy heating and cooling systems, such as hydronic (passive) conditioning and ventilation systems.[5]
- Efficiency and Conservation Projects (Existing Buildings): There are multiple opportunities to increase the efficiency of our existing systems and buildings. Cost factors include installation costs and avoided costs for No.6 Fuel Oil and purchased electricity. Opportunities for energy conservation include but are not limited to:
  - Implement a recurring retrocommissioning program of all energy-intensive buildings to monitor the operation of control devices, sequences of operation, scheduling, metering accuracy, energy use and fault detection alarms.

[5] Hydronic conditioning is a form of radiant heating, such as that provided by geothermal installations.

- Mechanical systems, including but not limited to heat recovery, fume hood flow control strategies, and ventilation controls.
- Lighting systems, including but not limited to day lighting controls and lighting switching (timers and/or sensors).
- Building envelope, including but not limited to installing high-performance glazing, upgrading wall and roofing insulation, and improving infiltration.

Through an analysis of energy usage rates and utility costs of existing buildings on campus, FO&M created a list of the 20% of buildings that use 80% of campus energy. The SECP recommends that the top twenty-five most energy intensive buildings should be the first to receive retrofit programs.[xi] (See Appendix B for assumptions and calculations).

By implementing the steam trap maintenance program building new projects with HPD, and implementing retrofits and efficiency measures to the twenty-five top-ranked buildings, the Strategic Energy Conservation Plan (SECP) would enable the college to reduce its steam energy demand by 20%, its electricity demand by 9%, and its GHG emissions by 7% by the year 2030.

*2.1b Energy Metering*

Steve Shadford, the College's current energy engineer, is pursuing further work with regards to energy load and efficiency. As part of the Campus Energy Monitoring System, the College is installing real-time energy meters in each building on campus that will wirelessly send real-time energy usage rates to an aggregated online database. A number of buildings have already received meter installatoins, and the resulting information has proven to be extremely useful in showing the exact amount of energy bulidings are using at any given time. Within the next half-year, meters will be installed in all buldings on campus, providing comprehensive energy usage numbers that can be used to optimize building operations and management systems. This is a crucial step toward energy efficiency, as it allows Dartmouth to analyze energy usage per building and determine where and how buildings are inefficient or losing energy unecessarily. Furthermore, the real-time moniting data will provide indispensable information when determining which retrofits should be prioritized as the College implements its conservation retrofits.

*2.1c Our Recommendation: Campus-Wide Implementation Plan*

To ensure the viability of our proposed green technologies within Dartmouth's future energy portfolio, we have determined that it is crucial to expand the SECP's retrofits program for the top twenty-five most energy intensive buildings to the entire campus. By projecting total investment costs and energy demand reductions from the SECP's twenty-five building study to the total campus square footage, we determined annual cost savings, energy usage and GHG emissions reductions from 2010 to 2030 for a campus-wide program. With the Campus-Wide Strategic Energy Conservation Plan (SECP-CW), the College can reduce its total steam energy usage by 46%, its total electricity usage by 26%, and its GHG emissions by 52% from BAU levels in the year 2030. Once our proposed efficiency measures and geothermal and solar thermal projects are installed, the amount of fuel oil that will be required is significantly decreased.

The following figures show the potential for energy savings and GHG emissions reductions for both SECP (retrofits in top twenty-five ranked buildings) and SECP-CW (retrofits in all buildings on campus) as compared to a business as usual growth scenario.

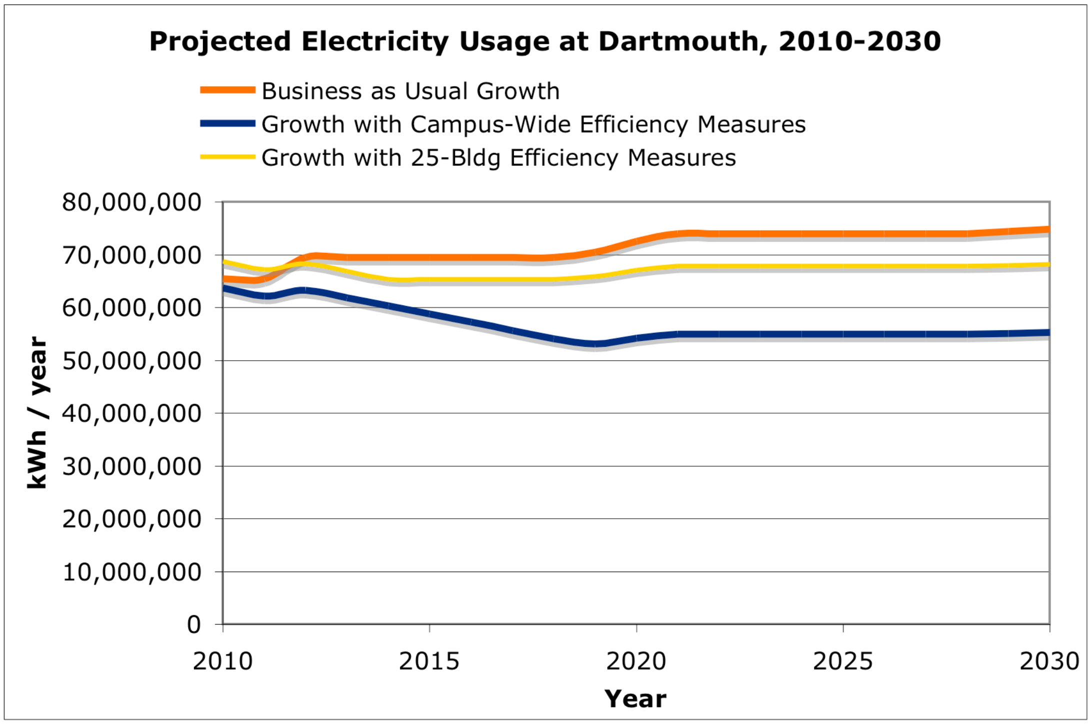



Figure 6: Predicted electricity demands of the college, comparing business as usual growth with SECP and SECP-CW implemented. Implementing the SECP results in a 9% reduction in electricity usage in 2030 from the BAU level. Implementing the SECP-CW results in a 26% reduction in electricity usage in 2030 from the BAU level.

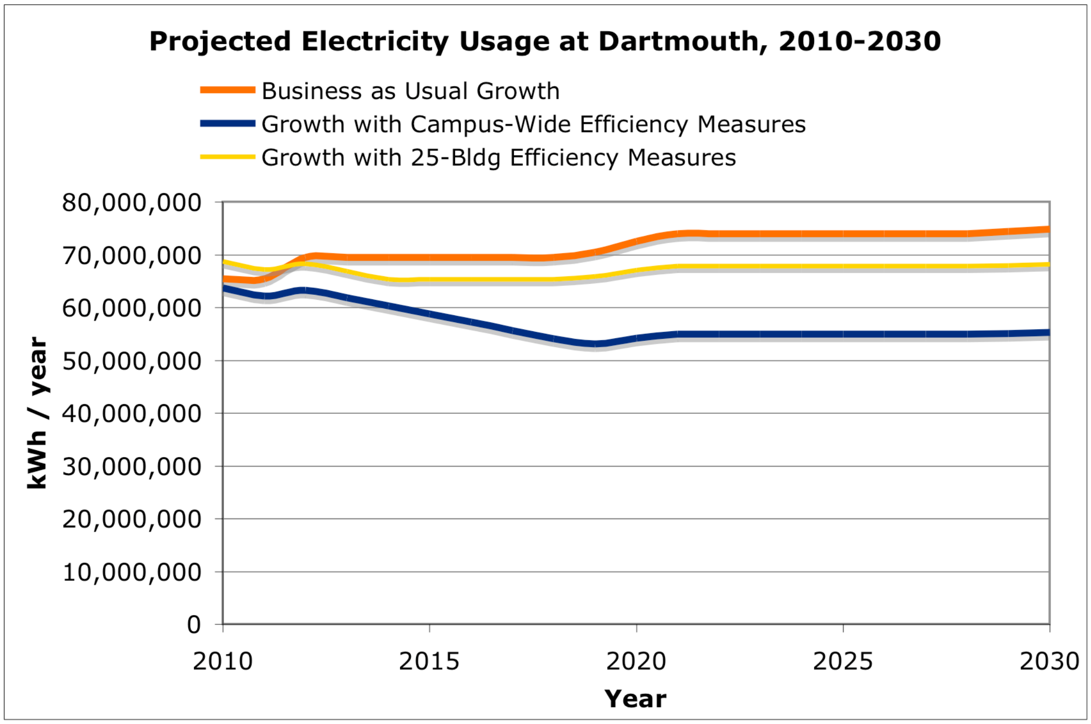



Figure 7: Predicted steam energy demands of the college, comparing business as usual growth with SECP and SECP-CW implemented. Imlementing SECP reduces steam energy usage by 20% in 2030 from the BAU levels. Implementing the SECP-CW reduces energy usage by 46% in 2030 from the BAU levels.

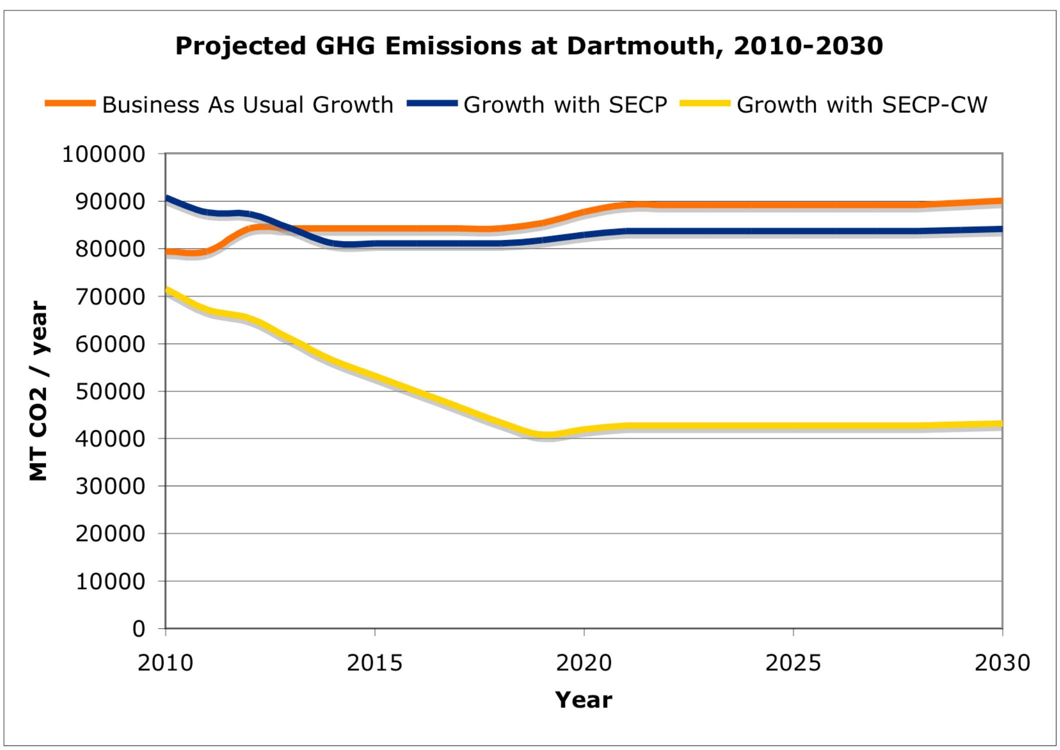



Figure 8: Potential GHG emissions reductions with SECP and SECP-CW implemented. In 2030, we see only a 7% reduction in GHG emissions from the BAU with SECP implemented, and a 52% reduction in GHG emissions with SECP-CW in place.

*2.1d Implementation*

In our implementation timeline we assume that steam trap maintenance is already underway, and that High Performance Design (HPD) can be implemented in each new building project the college will put online from now until 2030. In order for the solar thermal and geothermal technologies to be viable options in Dartmouth's near future, we must be aggressive in pursuing the recommended conservation projects. Conservation retrofits should be implemented simultaneously with solar thermal and geothermal installations to maximize the impact and cost-effectiveness of all technologies. While replacing the absorption chillers could begin immediately and can be completed within five years, we will not be incorporating chiller replacements due to the geothermal capability to account for all cooling loads (thus, chillers will not be needed). Energy conservation retrofits for the top twenty-five most energy intensive buildings, as outlined in the SECP, should be completed by 2015, and the remaining campus buildings should receive retrofits by 2020. Data from the real-time energy meters currently being installed in campus buildings should be utilized to rank the remaining campus buildings in terms of energy usage intensity and determine the most effective retrofit projects for all buildings.

## 2.2 Wind Power

Wind power is one of the cleanest forms of renewable energy, releasing zero greenhouse gas emissions once operational. In the United States, wind energy has grown in popularity over the past few decades due to the abundance of wind sources and significant improvements in the efficiency of wind turbines. As of October 2009, the installed capacity of wind power in the United States was approximately 31,000 MW, making it the world leader ahead of Germany.[xx]

*2.2a Precedents*

*Wind Energy in New Hampshire*

In May of 2007, New Hampshire enacted the Electric Renewable Portfolio Standard, which requires electricity providers to acquire Renewable Energy Certificates (RECs) equivalent to 24% of retail electricity sold to end-use customers by 2025.[xxi] This requirement is helping to encourage the development of wind energy in the state.

Bean Mountain in Lempster, NH is home to New Hampshire's first commercial wind farm. This wind farm, owned by Lempster Wind, LLC has been fully operational since 2008. It has twelve turbines, each with a capacity of 2 MW. The site generates approximately 76,738 MWH per year. The Lempster Wind Farm demonstrates how the rich wind resources along NH and VT mountain ridges can be successfully utilized to produce a signicant amount of renewable energy.[xxii]

*Wind Energy in the Ivy League*

The Ivy League is the collegiate athletic conference that purchases the greatest cumulative amount of green energy in the nation, as reported by the EPA's College and University Green Power Challenge 2008-2009. The University of Pennslyvania leads the Ivy League with 192.7 million KWH purchased. UPenn has been purchasing wind energy from off-campus sites in the greater Pennsylvania area since 2002; wind energy currently accounts for approximately 45% of the university's total electricity consumption.[xxiii] Harvard, on November 2, 2009, announced that it will be purchasing approximately 10% of the electricity used on its Cambridge and Allston campuses from the Stetson Wind II utility near Danforth, Maine. This agreement with First Wind will make Harvard the largest purchaser of wind power by a university or college in New England.[xxiv]

*Wind Energy at Dartmouth*

The Einhorn Yaffee Prescott (EYP) report, comissioned in 2008 by the College, lists an off-campus wind farm as one of Dartmouth's most promising investment opportunities for renewable energy for both economic and political reasons.

Canaan Wind Energy (CWE), LLC has approached Dartmouth College with an opportunity to collaborate on the development of a 12-MW wind farm on a large stretch of land on Tug Mountain Ridge in Canaan, New Hampshire. The site is located approximately 13 miles from Hanover. Based upon 2006 wind studies, which recorded average wind speeds in excess of 7 m/s, developers predict the site could generate approximately 35 million KWH per year.

In 2008, Dartmouth purchased approximately 56 million KWH of electricity from the grid and paid $7.3 million (at $0.13 per KWH). Assuming the current demand and price of electricity, a 12-MW wind farm could offset 63% of Dartmouth's purchased electricity.

Pros
- ✓ Off-campus wind energy offers renewable energy with almost zero-emissions to Dartmouth
- ✓ Land owned by CWE offers dependable wind resources close to Hanover
- ✓ The wind farm would have no visual impact on the campus
- ✓ Offers the College price stability and potentially high cost savings

Cons
- ✓ High initial investment required to purchase and install turbines
- ✓ Still need to complete the permitting process before installation

*2.2b Implementation Timeline*

Our timeline assumes a 20-year life span for the production of electricity from the wind farm. Predevelopment work must be completed before the turbines can become operational. During this two-year period, there must be additional environmental impact surveys in order to receive the necessary permits. Thus far, CWE has already completed engineering and environmental studies including preliminary studies for breeding birds, wetlands, and endangered species. Since the mountain is the site of an old wind farm from the 1980s, the land has already been altered. In fact, some of the old concrete foundations from the old wind farm still remain and may even be used by CWE. The remaining permits for CWE to obtain include a Wetlands permit, a NH Alteration of Terrain/Construction permit, a storm water permit, and Historic Preservation approval. CWE will additionally need to secure a grid interconnection agreement, build an access road to the site, and finance the project.

In our calculations, we assumed the predevelopment phase of the Canaan Wind Farm would begin in 2011, and the wind farm would be fully operational by 2013. After the predevelopment phase, the turbines can be installed. Purchasing and installation of the turbines would cost approximately $2 million per installed capacity. This price was suggested by CWE and is similar to the price of development for the Lempster wind farm described above.[xxv] Once operational, CWE expects minimal maintenance costs, which are included in the $2 and would mostly be covered by the wind manufacturers (see Appendix B for all assumptions and calculation summaries).

*2.2c Costs and Savings*

Our most obtainable scenario for wind energy is an investment in a 12-MW wind farm. 12-MW is the capacity originally proposed by CWE. Dartmouth currently purchases electricity from the grid at approximately $0.13 per KWH. For our price analysis, we had a low cost scenario, which assumes a constant price of electricity, and a high cost scenario, which assumes a 5% increase per year. 5% is the rate of increase that the College uses in its 5-year price projection for the electricity (see Appendix B).

Predevelopment would cost approximately $500,000. The total cost of installation would be $24,000,000 with an additional $30,000 per year to lease the land. In our model, we propose that Dartmouth pays for the wind farm by taking out a loan in order to avoid a huge upfront cost of the investment. In our scenario, the loan has an interest rate of 5.5%, with an initial down-payment of $4,800,000 (20% of the project cost) paid back over 18 years (90% of the project's lifetime). For Dartmouth to receive this power, the wind project would have to connect into the established power grid through the nearest utility, PSNH. Dartmouth would have a pay a fee of approximately $.04 per KWH to PSNH for this service.

Assuming a twenty-year lifetime for the wind farm, Dartmouth would save $119 million with a simple payback of 5.4 years in our high cost scenario. This payback period accounts for the two years of predevelopment. After just one year of being fully operational, Dartmouth would save over $4.5 million in energy savings. Using a discount rate of 5.5%, the net present value (NPV) of the total savings would equal $53 million.

In our low cost scenario, Dartmouth still accrues a significant economic profit of $27 million over 20 years. NPV of savings would be $12 million, and the simple payback would be 9 years. We used a constant price not in our low cost scenario not because we see it as an accurate depiction of what will happen but rather as a way to see a range of possible savings.

We also calculated the cost per $CO_2$. First, we calculated the total $CO_2$ emissions of the wind farm using a life cycle analysis (see Appendix B for further information). Then, we subtracted this figure from the total $CO_2$ avoided, which was calculated using EPA eGRID data. In our high cost scenario, the price per $CO_2$ reduced was -$91/metric ton. This negative cost represents a net savings.

Our analysis does not account for any savings past twenty years. However, it is very likely that the wind turbines would be able to generate electricity after this twenty-year time period.

*2.2d Added Government Incentives*

Based on the nature of this project, the Canaan Wind farm could be eligible for renewable energy incentives paid for by the federal government. These programs would significantly reduce the overall cost of the project. One program, administered by the IRS, is a renewable energy production incentive of $0.02 per KWh.[xxvi] This incentive would reduce the cost of electricity from $0.04 to $0.02 per KWH. In our high cost scenario, this production incentive reduces simple payback from 5.4 years to 4.9 years. Total savings would increase to $133 million and NPV would increase to $60 million. For the low cost scenario, simple payback would be 11 years. Savings over twenty years would be $41 million, with a NPV of $19 million.

This project could alternatively be eligible for a grant program administrated through the U.S. Department of Treasury. The grant would account for 30% of the cost of the project. This would reduce the overall cost of installation from $24 to $16 million. By accepting this grant, the project would be ineligible for the production incentive credit described above. In our high cost scenario, this incentive would reduce the project's payback period to 5.1 years. Total savings would be to $120 million and NPV would be $54 million. In our low cost scenario, the payback would still be 9 years. Total savings over the twenty-year period would be $28 million with an NPV of $13 million. Based on our calculations, we would recommend the use of the production incentive over the grant for the wind farm.

*2.2e Possible Expansion*

Representatives from Canaan Wind Energy said that the 12-MW wind farm could possibly be expanded to 20-MW. We accounted for this expansion and found that with a rising price of electricity at 5%, a 20-MW wind farm would save $199 million over a twenty-year period and would have a simple payback of 5.3 years and a NPV of $89 million (see Appendix B). In the low cost scenario, the expanded wind farm would have a simple payback of 9 years. Total savings would equal $45 million and NPV would be $20 million. Total $CO_2$ reduced from this project equals 490,000 with a cost of -$93, using similar calculations as described above. This investment is our top recommendation to the College, because it has the highest net present value and will also result in the largest $CO_2$ reductions.

*2.2f Further Revenue*

Under New Hampshire's State Renewable Portfolio Standard, this project would generate RECs that could be sold to utilities to help them meet their standards. Each REC is equivalent to 1 MWH of electricity produced from any renewable source that begins operation after January 1, 2006. The maximum price of RECs is set at $60.92.[xxi] As of October 2009, the price of RECs in New Hampshire was approximately $35.[xxvii] This price is predicted to fluctuate, but assuming the current price, RECs would generate approximately $1,225,000 annually for the owners of the 12-MW facility.

The reason this substantial revenue is not included in our calculations is that the overall goal of ENVS 80 is to achieve carbon neutrality. Selling RECs allows another utility to pay to emit $CO_2$. However, selling RECs would be an option if the College needed the additional revenue.

Some universities do choose to sell RECs. For example, the University of New Hampshire (UNH) has decided it will sell the RECs from its landfill gas-to-energy project that uses methane gas from a nearby landfill. UNH plans to use the money generated from the RECs to finance the capital costs of the project and invest in additional energy efficiency projects on campus.[xxviii] This type of financing would be available for Dartmouth.

*2.2g Alternative Approach*

If the College wanted minimal involvement in the project, an alternative approach would be to enter a power purchase agreement (PPA) with Canaan Wind Energy. This approach would secure a negotiated, stable price for a given time period. The initial price estimation we received for this type of agreement would be $0.15 per KWH (see Appendix B). In our high cost scenario, the College would save $78 million over 20 years with a NPV of $34 million. In our low cost scenario, NPV would negative -$7 million. However, this low cost scenario is highly unlikely, and an increase in the price of electricity should be expected.

One concern with not investing in the wind farm is that without Dartmouth's support, the project may not be developed. Plus, Dartmouth could not acquire the RECs from the project. Still, a PPA could be economically and environmentally viable option if CWE is able to find investors. This type of agreement is how many universities, including UPenn and Harvard, purchase wind electricity. With a signed PPA, CWE would have a significant advantage at finding investors than it would otherwise.

*2.2h Going Forward*

We recommend that Dartmouth administrators contact CWE to work towards making an agreement to develop the wind project. In the mean time, Dartmouth can support CWE to move aggressively through the predevelopment process.

Additionally, preliminary analysis of EPA wind data shows that the College-owned Grant falls into an area with rich wind resources. We recommend looking into wind surveys to see if the development of wind energy is feasible on the Grant.

## 2.3 Geothermal

Ground source heat pumps (GSHP's) use the constant water temperature (55° F) of the earth to heat buildings during the winter (earth is a heat source) and cool them during the summer (earth is a heat sink). If the heating and cooling loads are balanced and the pumps are properly managed, this technology can be used reliably for long periods. GSHP's are a proven technology and have great potential to reduce Dartmouth's GHG emissions and the cost of heating and cooling. We propose installing closed-loop wells as they are more environmentally friendly and can be applied more widely across geologic conditions than open-source wells.

*2.3a Precedents*

Dartmouth has two 1500 ft. open-source geothermal wells attached to Fahey-McLane residence hall. Beginning last Spring, the wells have supplyied 100% of the cooling load for these buildings and shows promise of suplying a signifcant fraction of the heat load. Although there were originally problems with the wells, most of these problems were a result of poor planning and implementation with a focus on cost reduction rather than an innate fault of the technology itself.

Harvard has 14 geothermal wells serving six building complexes, with a total of 420 T or 5.04 MMBTU per hour heating capacity (30 T/well). Currently, all wells at Harvard are open-loop (standing column) wells. Building on this past success, they plan on installing 88 closed-loop wells on Weld Hill. At Harvard each 1500 ft. well cost approximately $150,000. While Harvard has encountered various problems with their systems, almost all of these issues could have been avoidable through proper precautions in the design, drilling, and management phases.[xxix]

When faced with having to update their coal boilers at a cost of $65 million, Ball State University, in Muncie, IN, opted instead to invest $70 million into converting their campus heating system to a closed-loop geothermal heating system. Over the next four years they will install 4,000 wells, at a cost of $5,500 per well. Their expected heating capacity will be 10,000 T, enough to supply almost the entire campus. During the hottest and coldest times of the year heating/cooling will be supplied by three supplemental natural gas boilers. The wells will be installed under parking lots and green spaces around campus. After they are installed the spaces will be restored to their former use. Ball State estimates that they will save over $2 million/year by not buying coal for heating. Given that the replacement of old boilers with new boilers would have cost $65 million, Ball State University will start making money on their investment after just three years. With the wells installed, Ball State will avoid emitting 80,000 metric tons of carbon per year.

*2.3b Geothermal at Dartmouth*

Pros

- ✓ Potential to drastically reduce emissions from steam plant; further potential reductions when coupled with a non-emitting electricity source. In this respect, a centralized well field could replace the need for the steam plant.
- ✓ Supplies a majority of heating and cooling needs (80-100%) for buildings without any direct emissions.
- ✓ Low upkeep cost compared with steam boilers; very little maintenance necessary.
- ✓ Takes advantage of open spaces, parking lots, and fields without changing their appearance.
- ✓ Little to no visibility; wells are drilled vertically and heat pumps are often housed underground. No noise.
- ✓ Potential for even greater efficiency through the use of underground thermal storage.

Cons

- ✓ Large initial investment
- ✓ Produces low-temperature water, while the campus currently is heating by high-temperature steam. This will require large changes in current distribution system: Old radiator-heated buildings will need to be retrofitted with radiant heating systems, and new piping will need to be laid to transport heated water instead of steam.
- ✓ Significantly increases electrical load.

- ✓ May require a small supplemental heat source to handle peak loads.

2.3c *Implementation Timeline*

The implementation timeline for the geothermal project entails installing different numbers of closed wells to service various sectors of campus from 2010 until 2020. Since the installations require converting older buildings to a radiant heating system in order for geothermal heating and cooling to be possible, implementation would be most cost-effective if implemented concurrently with energy efficiency retrofits.

*2.3d Added Government Incentives*

Under H.R. 1: Div. B, Sec. 1104 & 1603 (The American Recovery and Reinvestment Act of 2009) geothermal projects are eligible for renewable energy grants.[xxx] This grant would reduce the capital cost of the project by 10%. This past year the Department of Energy awarded $338 million in this annual funding to 123 projects in 39 states. Recipients included private industry, academic institutions, tribal entities, local governments, and DOE's National Laboratories. As over 40 of these projects were universities, this grant would be very viable to attain for Dartmouth. Overall, the initial investment costs would be reduced by over $4 million to bring it down to $38 million.

## 2.4 Solar Thermal

Solar thermal technology uses the sun's energy to heat water. There are a number of options, including passive solar (does not use pumps), evacuated tubes (tubes are surrounded with vacuum sealed glass to create super insulation), and standard copper flat plate collectors (uses a large expanse of copper painted black to heat water). While the freezing temperatures of Hanover are a concern, water within the panels can be replaced with glycol, preventing damage to the system in extreme cold. Normally used for space heating and domestic hot water, solar thermal installations could also be applied to boiler plant preheat and absorption cooling at Dartmouth.[6]

### *2.4a Precedents*

Harvard has several solar thermal instillations. In June 2008, Harvard University installed a two-panel solar thermal system on a 20 person dormitory, which is currently meeting at least 20% of the domestic hot water demand. Funding was raised as part of a joint initiative to encourage students to pledge to reduce personal energy use. In 2009, Harvard installed a six-panel system which covers all 500 hundred gallons of the building's daily hot water usage. The project was financed by the school's Green Campus Loan Fund. In spring of 2009 the university funded a fourteen-panel installation on two residential Real Estate Services Buildings, which reduced boiler hot water production by 40% and offset 13 metric tons carbon dioxide equivalents (MTCDEs). These efforts have been made to reach the goal of reducing greenhouse gas production 30% by 2016.

Also, Middlebury, Amherst, and Williams Colleges have installed test solar thermal systems on campus dormitories while Amherst has taken the symbolic step of installing a solar thermal system on the home of the College President. That home receives all of its domestic hot water from this solar thermal system.

### *2.4b Solar Thermal at Dartmouth*

Considering approximately 10% of Dartmouth's $CO_2$ emissions come from domestic hot water demand and 78% come from the heating of water to make steam at the boiler plant, the provision of hot water can be a valuable service to Dartmouth.[3] For both hot water and boiler plant preheat, Dartmouth would likely use copper flat plate collectors mounted on unobstructed, southern facing roofs. For domestic hot water, a hot water heater/storage tank will have to be installed so that hot water can be stored and used throughout the day.

Pros

- ✓ Reduce dependence on volatile foreign oil - Hedge Risk.
- ✓ Simple and well-tested technology
- ✓ Accrue unwavering ROI for 30+ years
- ✓ Demonstrated commitment to renewable energy and sustainability
- ✓ Receive more environmental publicity and attract growing number of students who cite sustainability as priority choosing colleges

[6] Under our proposed energy mix, geothermal accounts for all absorption cooling. However, in the absence of sufficient geothermal projects, solar thermal could account for some of the cooling demand.

- ✓ Allow interested students to have hand in purchasing, installing, and maintaining renewable energy systems

Cons

- ✓ Some consider it a visual impairment
- ✓ Requires upfront investment
- ✓ Requires occasional maintenance and expertise of Facilities.
- ✓ Majority of energy is produced during the summer, when it is least needed

*2.4c Further Considerations*

Because a solar thermal installation delivers a large portion of its produced energy during the summer months, average annual BTU production values might not reflect the actual usable energy produced over the course of a year. If the energy is produced when it is unneeded, a large portion goes unused, and therefore the value of investing in the technology for the sake of payback decreases significantly. As a stand alone investment, this is not an issue because solar thermal would only be used to produce domestic hot water, which has a fairly constant demand over the year. And still, on a campus-wide scale solar thermal would not produce more hot water than the college uses, so it is safe to use average production values in this case. However, when used in conjunction with ground source heat pumps, solar thermal would be used to cover both hot water and a portion of space heating in the form of low temperature radiant heating, which has a seasonally fluctuating demand. Because geothermal energy would cover the large majority of the heating load and provide energy at a constant rate over the course of the year, solar thermal's load would be small enough that the system would be over-producing for a large portion of the year but still underproducing in the winter months. This cuts the possible average annual BTU production of solar thermal nearly in half because its energy is delivered at the wrong time in the year. This evident issue brought in the consideration of solar pv, because photovoltaic energy production would never exceed the available electrical load, which is not confined to the building on which the installation exists. However, solar thermal system can be sized to cover a portion of the load and elimnate overproduction concerns.

Another consideration is the reliability of the cost estimates that we recieved. Throughout our calculations, we were in contact with multiple engineers who provided guidance and suggestions on our estimates. Cost per square foot of installation, however, seemed to be a value that varied greatly, with the estimates ranging from $60 per square foot to $150. This may indicate either variability in the pricing, or that the college needs to identify a single company to do an in-depth analysis of cost per square foot of installation. Similarly, estimates of maintenance costs varied with sources.

We also completed a life cycle analysis of solar thermal installations because there is embodied energy in production of the panels and installation which affects the carbon neutrality of the technology. However, the embodied energy is relatively insignificant compared to the energy production. It technically takes about two years to pay back the carbon pollution that was created during the production of the panels, but because solar thermal installations may remain in service in excess of 30 years, it is not a reasonable concern.

## 2.5 SOLAR PHOTOVOLTAIC

*2.5a Solar Thermal at Dartmouth*

Solar PV could realistically cover approximately twelve percent of Dartmouth's current purchased electricity needs through solar installations over parking lots on campus. This parking lot project would cover every parking space on campus within a larger lot with a photovoltaic array while leaving the roadways untouched. Thus, this project would cover approximately 38,000 feet of parking while producing around 5500 million kWh of electricity per year. This new electricity supply would help replace electricity purchased from the grid while also allowing a new and reliable power supply to power our other renewable energy installations, such as geothermal and solar thermal.

Pros

- ✓ Can be used to cover added electricity costs from solar and geothermal systems onsite
- ✓ Can take advantage of otherwise unused areas on campus such as parking lots.
- ✓ Visible commitment to sustainability
- ✓ Increase educational and research opportunities around renewable energy technologies

Cons

- ✓ High initial investment
- ✓ Long payback period
- ✓ Not very cost-effective without tax incentives
- ✓ Requires large amounts of space to produce realistic amounts of electricity
- ✓ Concerns over rapid snow accumulation in winter

*2.5b Implementation Timeline*

Installation could begin immediately, as construction over campus parking lots should minimally effect parking availability.

*2.5c Further Considerations*

Solar PV technology has the potential to provide a significant percentage of Dartmouth’s electricity usage as possible installation locations are plentiful around campus. However, solar PV is simply not a cost-effective solution at the present. Pricing for solar panels varied from between seven and ten dollars per watt of capacity installed. Additionally, a conservative estimate of electricity production limited the optimal period of direct sunlight to only four hours per day on average. These considerations make solar PV a questionable investment over the installations lifetime when compared to purchased electricity from an electrical utility. When considering our proposal to purchase electricity from TransCanada, who uses hydropower for a significant proportion of their production, large PV installations are simply not viable. As a result, Dartmouth should not consider large scale PV installations as a realistic source of electricity at this time. However, solar PV should be considered in the future as the price per watt of capacity continues to fall due to technological development.

## 2.6 BioFuel: Processed Waste Vegetable Oil

Biofuel is a type of fuel produced from renewable organic material.[xxxi] It includes biodiesel and waste vegetable oil (WVO), and it can be made from anything from corn to soybeans to palm oil. Dartmouth has been considering a biofuel supplied by American Energy Independence Company (Amenico), hereafter referred to as BioFuel. This BioFuel is processed WVO, so the source is a waste product. Therefore, the crops which become the BioFuel are grown to be used as vegetable oil in restaurants and factories, not for the purpose of producing this fuel. This means there is no land use change in the production of BioFuel. The WVO feedstock is obtained from restaurants and other sources in the New England area. The Boston area alone produces more than 12 millions gallons of WVO per year, so a sufficient supply currently exists and is likely to remain available in the future.

### *2.6a Biofuel at Dartmouth*

The college should consider BioFuel as a stepping stone in the transition from fossil fuel use to renewable energy sources. Because Amenico's waste product does not entail deforestation or major land use change, burning BioFuel at Dartmouth instead of No. 6 fuel oil would drastically reduce net fossil carbon emissions. Carbon emitted from BioFuel is part of a carbon cycle; carbon in the emissions was recently absorbed from the atmosphere by the crops used to produce BioFuel (See Appendix D for discussion of modern versus fossil carbon.) The replacement of some No. 6 oil with BioFuel could be made almost immediately without any modification to the existing boilers, allowing Dartmouth to cut net carbon dioxide emissions now. However, direct carbon dioxide emissions from burning each product-including both modern and fossil carbon, which many experts deem more important than solely fossil-are not drastically different. Therefore cleaner energy sources should replace BioFuel in Dartmouth's ultimate carbon neutral energy portfolio. Yet BioFuel could still be used in the future to provide backup for peak energy loads that may not be covered by Dartmouth's renewable energy supplies; at that point the load would be drastically reduced due to those renewables.

### *2.6b Precedents*

Middlebury recently switched from burning a B5 biodiesel blend (5% biodiesel, 95% No. 2 fuel oil) to a B20 blend (20% biodiesel, 80% No. 2 fuel oil) in the furnaces not connected to the central heating plant. Middlebury conducted a test burn of B20 in 21 buildings and found that the fuel burned efficiently in several different kinds of burners.[xxxii] Middlebury bought approximately 175,000 gallons of B20 fuel in 2008.[xxxiii]

Although several other universities have implemented biodiesel on their campuses, most of these fuels are blends of less than 30% biodiesel and are used primarily in universities' transportation sectors, rather than in heating plants. Thus, Dartmouth has the potential of becoming a leader in the biofuels industry by burning a mixture of greater than 30% biofuel in one of its boilers.

Amenico has already shown its BioFuel to be successful during a test burn at a New Hampshire paper mill. They ran the burn in an unmodified No. 6 boiler, and the BioFuel was more efficient than No. 6 fuel oil because it burned cleaner, leaving less residue in the boiler. Amenico and Dartmouth power plant employees are in the process of scheduling a test burn in

Dartmouth's boilers in the coming months, which will provide more concrete information to predict how BioFuel would perform at Dartmouth.

*Pros*

- ✓ May be instituted almost immediately pending a finalized agreement with Amenico and the purchase of BioFuel
- ✓ Requires little if any equipment change; comparable test burns have shown changes are not needed, and the upcoming test burn at Dartmouth should confirm this
- ✓ Requires little protocol change; protocol for burning biofuel is nearly the same as for burning No. 6 fuel oil
- ✓ Yields a 90% reduction in net *fossil* carbon dioxide emissions,[7] when considering the life cycle analyses of fossil fuels and waste vegetable oils
- ✓ Reduces emissions of capped GHG (NOx, SOx, PM); Reduces SOx emissions by at least 96% from No. 6 fuel oil; Reduces NOx emissions by at least 67% from No. 6 fuel oil; PM emissions are 0[8]
- ✓ WVO does not lead to deforestation because the vegetable oil is inevitably produced for restaurants and otherwise; WVO is a waste product and there is no land use change from producing it
- ✓ Reduces use of No. 6 fuel oil, the biggest source of Dartmouth's emissions; must attack biggest problem to have a significant impact

*Cons*:

- ✓ Noticeably more expensive than oil (for now); beginning price: NYMEX[9] heating oil price [currently $2.05], which is currently about $0.50 more than the price Dartmouth pays for 0.5% No. 6 oil [currently $1.58]
- ✓ BioFuel is not entirely carbon neutral; it still produces modern carbon emissions. (See Appendix D for discussion of modern versus fossil carbon)
- ✓ Price could increase as demand for alternative energy and WVO increases; demand could increase and supply likely would not because the amount of WVO produced is dependent on the restaurants that use it
- ✓ More trucks and fuel needed because it has a lower energy content than oil; greater volume of biofuel must be burned to obtain the same amount of energy as a volume of oil
- ✓ Increased demand on a large scale could lead to deforestation if source spread beyond WVO (land use change); higher demand for vegetable oil could lead to higher supply and deforestation
- ✓ Not a guaranteed supply; Amenico is the only known supplier of BioFuel in the NorthEast Region. Amenico would supply 1.2 million gallons of biofuel/year while Dartmouth uses 5 million gallons of No. 6 fuel oil currently; if demand increases drastically, Amenico may not be able to supply this much in the future

---

[7] EPA determined biodiesel burns with 80% reduction of emissions; biofuel has less direct emissions from burning and does not undergo transesterification, so it would reduce carbon dioxide emissions by at least 90% from No.6 fuel oil.

[8] From communications with Tony Giunta, CEO of Amenico

[9] New York Mercantile Exchange (NYMEX) makes price predictions for the cost of oil, and BioFuels sets their price predictions for number 2 oil.

*2.6c Costs and Savings*

The price of producing BioFuel is somewhat contingent on the price of oil. Petroleum-based oil is used to produce the vegetable oil that becomes WVO and to transport and potentially refine the WVO. Although Dartmouth currently locks in the cost of oil for a six-month period with its provider Hess, Amenico would not lock in a price. Instead the price would be contingent on the NYMEX petroleum exchange's price for No. 2 distillate fuel oil, or heating oil. According to the CEO of Amenico, though the price could change with negotiations, it would be about the same price as the price as No. 2 home heating oil. Thus, we used EIA price predictions for heating oil in our calculations. This creates a significant range of possible prices and relationships between the price of No. 6 and No. 2 oil fuel, making costs and savings relatively uncertain.

*2.6d Life Cycle Analysis (LCA)*

The total carbon dioxide emissions resulting from the processing, transportation, and burning of BioFuel are 0.009838 metric tons of carbon dioxide per gallon of BioFuel.[xxxiv] (For full LCA examination, see biofuel section of Appendix B; for discussion of modern carbon versus fossil carbon, see Appendix D.)

*2.6e Calculations*

For our calculations, we considered fossil carbon emissions, as opposed to fossil and modern carbon emissions combined. This is standard practice for the US EPA as well as the International Panel on Climate Change (IPCC). Some disagree with this methodology, particularly if land use is involved, but that is not the case with BioFuel.[x] Therefore for carbon dioxide emissions from BioFuel in our graphs, we used the 90% life cycle $CO_2$ reductions compared to No. 6 extrapolated from the EPA figure[xxxv] as opposed to our 0.009838 mt/gal BioFuel figure that includes modern carbon.

## 2.7 BIOMASS: WOODFUELS

Biomass is a renewable energy often burned in the form of woodchips or woodpellets and formed from organic matter such as virgin wood, energy crops, agricultural residues, food waste, or industrial waste and co-products.[xxxvi] It is burned in boilers that are generally different from liquid fuel-burning boilers, so oftentimes an entirely new plant is built when switching from petroleum to biomass. Dartmouth would only obtain a single new boiler, and it would use wood pellets because of their decreased water content (and therefore higher efficiency and fewer deliveries of fuel) and decreased emissions and ash remains after burning.

*2.7a Precedents*

The University of South Carolina powers the co-generation plant on its Columbia Campus with “locally-sourced wood fuel.” Using this biomass energy, USC produces 72 MMBTU/hr for heating and 1.3 MW of electric power. This will reduce its annual greenhouse gas emissions by 18,150 metric tons (McNamerra, J. personal communication). At the College of the Atlantic in

Bar Harbor, Maine, approximately 20% of the campus is heated by a new central wood pellet boiler installed in January 2009.[xxxvii]

Last February, Middlebury opened a biomass gasification plant, which burns wood chips from sources within a 75-mile radius. According to Middlebury's Sustainability webpage, by replacing one million gallons of No. 6 fuel oil with biomass energy, the college will save 12,500 metric tons of $CO_2$ annually.[xxxviii] Initially they intended to fuel it using a single supplier, ideally certified by the Forest Stewardship Council (FSC). However, "they quickly learned that no such supplier exists; in fact, virtually no FSC-certified chips can be found anywhere near the College."[xxxix] Now the sources of Middlebury's woodchips are unclear. The college purchases its woodchips through a broker who in turn purchases woodchips from loggers and millers within a 75-mile radius. Unfortunately, the broker does not have records of the actual sources of this biomass, as the woodchips bought from any given logger could actually come from multiple different forests. While it's possible that these woodchips are procured through sustainable forestry techniques, it is just as likely that they are not. To mitigate the potential threat of "exhausting local resources," Middlebury has started a project with the help of SUNY-ESF to cultivate nine acres of willow trees as a "potential source for steadier and more sustainable fuel."[xl]

*2.7b Biomass at Dartmouth*

Because of the limited space on Dartmouth's campus, the use of biomass would involve a boiler within the heating plant specifically designed for burning wood pellets., which would replace an old petroleum-burning boiler. The two storage silos would likely be 45 feet tall and placed on the north side of the power plant, which is now a parking lot. The new boiler would be supplied by a company called WoodFuels.

WoodFuels presently offers ten-year contracts to a limited number of businesses and universities in Maine, Massachusetts, New Hampshire and Vermont, and they claim that they could supply all of Dartmouth's heating demand if necessary. They are currently constructing a woodpellet plant in Maine and have a fifteen-year contracted supply of whole logs. They are also currently installing their first boilers, which will work for the heating season of 2009-2010. One of their first large-scale installations is at Franklin Pierce University, whose new heating systems became operational in November 2009.[xli]

Most importantly, WoodFuels provides their services without any capital cost investments. They construct their facilities on their own dollar and only bill their customers by the amount of BTU they consumed. They also grant ownership of their pellet facility to the consumers for the contract period and cover all maintenance costs.

Pros

- ✓ A no-capital switch to renewable energy
- ✓ A free biomass boiler -- completely installed and maintained by WoodFuels (including needed engineering, design, permits and construction)
- ✓ Measured heat that is billed upon consumption (by BTU), not delivery
- ✓ Supposedly guaranteed biomass fuel supply using sustainably harvested wood
- ✓ Preemptive mitigation from possible future regulations/taxes regarding fossil fuel usage -- as well as volatile price fluctuations
- ✓ WoodFuels installs and maintains new boilers

Cons

- ✓ Though a potential location for the pellet storage facility has been identified adjacent to the power plant, it would displace a parking lot and add the sight of two 45-foot silos
- ✓ WoodFuels is a young company and therefore does not have a long record of proven successes
- ✓ Forestry impacts and overall life cycle analysis is still relatively unclear[xlii]
- ✓ Biomass may not be a solution that many other institutions can follow sustainably

*2.7c Costs and Savings*

According to WoodFuels Renewable Energy Director Mike Mooney, WoodFuels would start to generate savings for Dartmouth once No. 6 fuel oil rises about $1.63/gallon, assuming a 75% overall efficiency in Dartmouth's heating system. In 2011, the EIA predicts the price of No. 6 fuel oil/gallon to range from $1.83 to $2.92. We found that installing a WoodFuels 1,000 HP boiler producing 291,708 million BTU per year would start generating savings within 0-5 years and generate a net present value between $2 million and $14.5 million, with a 5.5% rate of discount.

*2.7d Biomass Production*

Woodfuels purchases its woodchips from suppliers in Maine that are Sustainable Forestry certified. The Sustainable Forestry Initiative requires that its participants implement methods to monitor and preserve water bodies and watersheds affected by the certified region. Effects on biodiversity and habitat must also be monitored and participants must reforest harvested areas immediately.[10] The certification requires the "use of least-toxic and narrowest-spectrum pesticides," "designation of streamside and other needed buffer strips," and the "use of integrated pest management where feasible."[xliii]

WoodFuels uses a manufacturing facility to convert whole logs into ultra-low emission wood pellets. According to Mike Mooney, the entire conversion process, from forests, to pellet manufacturing, to each customer's boilers and back to the earth is contained within roughly a 200-mile radius. WoodFuels does not use any landfill sourced biomass or construction debris, and the pellets are additive-free. WoodFuels also collects the ash produced in combustion and offers it to organic composting companies for free.

It is important to note above that Middlebury was also guaranteed FSC certified wood which was not delivered as promised and that WoodFuels is a young company and therefore does not have a long record of proven successes.

*2.7e Carbon Dioxide from Biomass*

Our analysis makes biomass seem very attractive for $CO_2$ reductions, but we are only taking into account fossil carbon (as discussed in Section 2.6), in which case biomass is close to carbon neutral. Yet whether one includes not just fossil carbon but "modern carbon" as well is currently

[10] Introduction to the SFI Standard, Sustainable Forestry Initiative, Accessed 20 November 2009 http://www.sfiprogram.org/sfi-standard/sfi-standard.php

a point of contention in the environmental world. Some environmentalists are concerned since fuel is still burned, and carbon is still released. When this "modern carbon" is included, the total carbon emissions of biomass are close to those the emissions of No. 6 fuel oil. The biomass numbers in this section are only one side of the debate and should be accepted cautiously. It should also be noted that the fuel from Woodfuels would be transported by truck from Maine adding to its carbon footprint.

### *2.7f Biofuels Versus Biomass*

For our energy mix, the ENVS 80 class selected biofuels over biomass for two main reasons. First, both of these technologies are seen as temporary stopgaps rather than permanent solutions. The class found biofuels more appealing since for biofuels, no infrastructural change would be necessary. Thereby it would be more likely biofuels would not be seen as a permanent solution over cleaner, renewable technologies. Second, BioFuel derives from a waste product, thereby avoiding land use change, while biomass converts forests into harvested forests, the latter of which absorbs less carbon dioxide from the atmosphere than the former. The supply of WVO is not guaranteed, but after developing renewable energy sources, Dartmouth's demand for BioFuel would be drastically reduced. This would make it more likely that the BioFuel supply would be sufficient for Dartmouth.

## 3 CONCLUSION

### *3a Proposed Measures*

The following tables compare the best individual projects for different technologies. Both assume energy cost projections from the EIA. The first two tables are the 20 projects with the shortest simple payback periods. 'LE' stands low efficiency and refers to only implementing the Strategic Energy Conservation Plan (SECP); 'HE' stands for high efficiency and refers to implementing the Strategic Energy Conservation Plan campus–wide (SECP-CW).

| Top 20 Payback Periods for High Energy Costs | | | | |
|---|---|---|---|---|
| Scenario Description | Payback Period (yrs) | Net Present Value ($) | Cost per CO2 Reduced ($/metric ton) | Total Net CO2 Emissions Reduced (metric tons) |
| Energy Efficiency 2) Campus-Wide Implementation (Phases 1 & 2) | 0.79 | 121,934,014 | -149 | 819,108 |
| Energy Efficiency 1) Phase 1 (25 Buildings) | 1.25 | 82,772,665 | -149 | 556,204 |
| Geothermal LE 6) New Science Building | 2 | 1,520,816 | -82 | 18,495 |
| Geothermal LE 5) New Academic Building | 2 | 36,520 | -136 | 268 |
| Geothermal LE 1) Visual Arts Center | 2 | 699,328 | -137 | 5,100 |
| Geothermal HE 5) New Academic Building | 2 | 36,520 | -136 | 268 |
| Geothermal HE 6) New Science Building | 3 | 1,520,816 | -136 | 11,201 |
| Geothermal LE 3) Kemeny Haldeman Moore | 5 | 2,791,315 | -99 | 28,120 |
| Geothermal LE 2) McLaughlin, DMS, Life Sciences Center | 5 | 8,979,301 | -98 | 91,619 |
| Geothermal HE 3) Kemeny, Haldeman, Moore | 5 | 2,791,315 | -99 | 28,120 |
| Geothermal HE 2) McLaughlin, DMS, Life Sciences Center | 5 | 8,979,301 | -98 | 91,619 |
| Geothermal HE 1) Visual Arts Center | 5 | 657,254 | -136 | 4,825 |
| Wind 3) 20-MW Capacity Ownership | 5 | 88,727,625 | -404 | 490,920 |
| Wind 2) 12-MW Capacity Ownership | 5 | 52,907,625 | -402 | 294,552 |
| Solarthermal 2) McKenzie | 5 | 429,175 | -151 | 2,835 |
| Geothermal HE 4) Burke, Steele, Wilder, Fairchild | 8 | 1,244,233 | -48 | 25,717 |
| Geothermal LE 4) Burke, Steele, Wilder, Fairchild | 9 | 1,244,233 | -48 | 25,717 |
| Solarthermal 1) SLC | 11 | 3,361 | -20 | 167 |
| Solarthermal 3) Visual Arts Center | 11 | 25,772 | -10 | 2,629 |
| Solarthermal 4) Rest of Campus, Phase 1 | 13 | -473,638 | 17 | 27,484 |

Figure 9: Top 20 payback periods for proposed projects.

| Payback Period for Low Energy Costs | | | | |
|---|---|---|---|---|
| Scenario Description | Payback Period (yrs) | Net Present Value ($) | Cost per CO2 Reduced ($/metric ton) | Total Net CO2 Emissions Reduced (metric tons) |
| Energy Efficiency 2) Campus-Wide Implementation (Phases 1 & 2) | 1.29 | 69,717,584 | -85 | 819,108 |
| Energy Efficiency 1) Phase 1 (25 Buildings) | 2.02 | 48,877,401 | -88 | 556,204 |
| Geothermal LE 1) Visual Arts Center | 4 | 434,140 | -85 | 5,100 |
| Geothermal LE 6) New Science Building | 5 | 944,484 | -51 | 18,495 |
| Geothermal LE 5) New Academic Building | 5 | 22,684 | -85 | 268 |
| Geothermal HE 5) New Academic Building | 5 | 22,684 | -85 | 268 |
| Geothermal HE 1) Visual Arts Center | 5 | 408,252 | -85 | 4,825 |
| Geothermal HE 6) New Science Building | 6 | 944,484 | -84 | 11,201 |
| Geothermal HE 4) Burke, Steele, Wilder, Fairchild | 8 | 1,244,233 | -48 | 25,717 |
| Wind 3) 20-MW Capacity Ownership | 9 | 20,023,611 | -93 | 490,920 |
| Wind 2) 12-MW Capacity Ownership | 9 | 11,685,325 | -91 | 294,552 |
| Geothermal LE 3) Kemeny Haldeman Moore | 9 | 1,348,734 | -48 | 28,120 |
| Geothermal LE 2) McLaughlin, DMS, Life Sciences Center | 9 | 4,276,404 | -47 | 91,619 |
| Geothermal HE 3) Kemeny, Haldeman, Moore | 9 | 1,348,734 | -48 | 28,120 |
| Geothermal HE 2) McLaughlin, DMS, Life Sciences Center | 9 | 4,276,404 | -47 | 91,619 |
| Geothermal LE 4) Burke, Steele, Wilder, Fairchild | 9 | 1,244,233 | -48 | 25,717 |
| Solarthermal 1) SLC | 11 | 3,361 | -20 | 167 |
| Solarthermal 2) McKenzie | 11 | 13,977 | -5 | 2,835 |
| Solarthermal 3) Visual Arts Center | 11 | 25,772 | -10 | 2,629 |
| Solarthermal 4) Rest of Campus, Phase 1 | 13 | -473,638 | 17 | 27,484 |

Figure 10: Top 20 payback periods for proposed projects

Energy efficiency improvements and geothermal installations have some of the shortest paybacks. Investments in wind projects and one of the solar thermal installations also have short paybacks.

This next table displays the 20 projects with the highest net present values (NPV) after 20 years from the date of installation.

| Top 20 Net Present Values for High Energy Costs | | | | |
|---|---|---|---|---|
| Scenario Description | Payback Period (yrs) | Net Present Value ($) | Cost per CO2 Reduced ($/metric ton) | Total Net CO2 Emissions Reduced (metric tons) |
| Energy Efficiency 2) Campus-Wide Implementation (Phases 1 & 2) | 0.79 | 121,934,014 | -149 | 819,108 |
| Wind 3) 20-MW Capacity Ownership | 5 | 88,312,094 | -408 | 490,920 |
| Energy Efficiency 1) Phase 1 (25 Buildings) | 1.25 | 82,772,665 | -149 | 556,204 |
| Wind 2) 12-MW Capacity Ownership | 5 | 52,658,415 | -407 | 294,552 |
| WInd 1) Power Purchase Agreement | N/A | 33,706,506 | -264 | 294,552 |
| Biomass - Woodfuels 5) 1000 HP Boiler = 291,708 mmBTU/year | N/A | 14,429,555 | -30 | 480,183 |
| Geothermal LE 2) McLaughlin, DMS, Life Sciences Center | 5 | 8,979,301 | -98 | 91,619 |
| Geothermal HE 2) McLaughlin, DMS, Life Sciences Center | 5 | 8,979,301 | -98 | 91,619 |
| Biomass - Woodfuels 4) 500 HP Boiler = 145,854 mmBTU/year | N/A | 7,214,777 | -30 | 240,091 |
| Biomass - Woodfuels 3) 250 HP Boiler = 72,927 mmBTU/year | N/A | 6,416,111 | -53 | 120,046 |
| Biomass - Woodfuels 2) LE Remaining Demand = 65,083 mmBTU/year | N/A | 3,219,379 | -30 | 107,134 |
| Geothermal LE 3) Kemeny Haldeman Moore | 5 | 2,791,315 | -99 | 28,120 |
| Geothermal HE 3) Kemeny, Haldeman, Moore | 5 | 2,791,315 | -99 | 28,120 |
| Biomass - Woodfuels 1) HE Remaining Demand = 12,685 mmBTU/year | N/A | 2,018,371 | -97 | 20,881 |
| Geothermal LE 6) New Science Building | 2 | 1,520,816 | -82 | 18,495 |
| Geothermal HE 6) New Science Building | 3 | 1,520,816 | -136 | 11,201 |
| Geothermal LE 4) Burke, Steele, Wilder, Fairchild | 9 | 1,244,233 | -48 | 25,717 |
| Geothermal HE 4) Burke, Steele, Wilder, Fairchild | 8 | 1,244,233 | -48 | 25,717 |
| Geothermal LE 1) Visual Arts Center | 2 | 699,328 | -137 | 5,100 |
| Geothermal HE 1) Visual Arts Center | 5 | 657,254 | -136 | 4,825 |

Figure 11: Top 20 NPV's for proposed projects

| Net Present Value for Low Energy Costs | | | | |
|---|---|---|---|---|
| Scenario Description | Payback Period (yrs) | Net Present Value ($) | Cost per CO2 Reduced ($/metric ton) | Total Net CO2 Emissions Reduced (metric tons) |
| Energy Efficiency 2) Campus-Wide Implementation (Phases 1 & 2) | 1.29 | 69,717,584 | -85 | 819,108 |
| Energy Efficiency 1) Phase 1 (25 Buildings) | 2.02 | 48,877,401 | -88 | 556,204 |
| WInd 1) Power Purchase Agreement | N/A | 33,706,506 | -264 | 294,552 |
| Wind 3) 20-MW Capacity Ownership | 9 | 20,023,611 | -93 | 490,920 |
| Wind 2) 12-MW Capacity Ownership | 9 | 11,685,325 | -91 | 294,552 |
| Geothermal LE 2) McLaughlin, DMS, Life Sciences Center | 9 | 4,276,404 | -47 | 91,619 |
| Geothermal HE 2) McLaughlin, DMS, Life Sciences Center | 9 | 4,276,404 | -47 | 91,619 |
| Biomass - Woodfuels 5) 1000 HP Boiler = 291,708 mmBTU/year | N/A | 2,321,144 | -5 | 480,183 |
| Biomass - Woodfuels 3) 250 HP Boiler = 72,927 mmBTU/year | N/A | 2,107,060 | -18 | 120,046 |
| Geothermal LE 3) Kemeny Haldeman Moore | 9 | 1,348,734 | -48 | 28,120 |
| Geothermal HE 3) Kemeny, Haldeman, Moore | 9 | 1,348,734 | -48 | 28,120 |
| Geothermal LE 4) Burke, Steele, Wilder, Fairchild | 9 | 1,244,233 | -48 | 25,717 |
| Geothermal HE 4) Burke, Steele, Wilder, Fairchild | 8 | 1,244,233 | -48 | 25,717 |
| Biomass - Woodfuels 4) 500 HP Boiler = 145,854 mmBTU/year | 5 | 1,160,572 | -5 | 240,091 |
| Geothermal LE 6) New Science Building | 5 | 944,484 | -51 | 18,495 |
| Geothermal HE 6) New Science Building | 6 | 944,484 | -84 | 11,201 |
| Biomass - Woodfuels 2) LE Remaining Demand = 65,083 mmBTU/year | 5 | 517,871 | -5 | 107,134 |
| Geothermal LE 1) Visual Arts Center | 4 | 434,140 | -85 | 5,100 |
| Geothermal HE 1) Visual Arts Center | 5 | 408,252 | -85 | 4,825 |
| Biomass - Woodfuels 1) HE Remaining Demand = 12,685 mmBTU/year | 4 | 260,981 | -12 | 20,881 |

Figure 12: Top 20 NPV's for proposed projects

Again energy efficiency is the best investment, yielding large returns. Wind appears strong as well, ranking directly under energy efficiency. Geothermal also seems like a better investment based on NPV than it did from payback. Therefore, though geothermal may have a comparatively longer payback period, it has the potential to save the college significant amounts of money over the next 20 years.

Tables showing all projects with high and low energy costs sorted by a variety of criteria are available in Appendix C.

*3b Take-Home Message*

Dartmouth has a long and proud history of environmental stewardship and innovation. In 1904, Dartmouth took a risk and was one of the first institutions in the country to cogenerate steam and electricity. In 1970, Dartmouth created one of the first environmental studies programs in the nation, and environmental studies continues to be cited as one of the strongest departments at the College.[xliv] Recently, Dartmouth has celebrated a number of environmental accomplishments. Steve Shadford is in the midst of implementing $12.5 million of efficiency upgrades to the 25 most energy intensive buildings on campus, the Energy Task Force recently passed a commitment to carbon reductions, and last spring Kathy Lambert and Marissa Knodel launched the 'I Am Green' energy pledge campaign to promote sustainable behavioral changes.

In order to continue environmental leadership and to become "the greenest college in the world," Dartmouth must continue to take steps forward. Pursuing a carbon neutral campus is not only environmentally and socially responsible, it is also economically viable and profitable. The analysis presented in this report suggests that Dartmouth must reconsider its current supply of energy. We believe this report represents the foundation for a comprehensive energy plan for Dartmouth, which will allow the college to achieve independence from No. 6 fuel oil by implementing cost-effective efficiency measures and alternative technologies. Due to the broad scope of our study, more detailed professional studies will be necessary to move forward. (See Appendix E for further considerations).

Though a full overhaul of Dartmouth's energy production and consumption would set a profound precedent for other institutions worldwide, none of the measures we propose are revolutionary. Overall, we propose proven technologies with high returns on investment. The precedents for each piece of our proposed mix have been set, therefore it would be Dartmouth's full-scale commitment to cost-effective carbon neutrality that would put Dartmouth at the forefront of green institutions. We believe that Dartmouth College should seriously reconsider the way in which it is using enegy due to environmental, social, and financial considerations.

This class has created the foundation for further meaningful research into the feasibility of specific projects towards achieving carbon neutrality.

*3c Recommendations*

- ✓ Seriously consider energy efficiency and renewable energy measures with short payback periods, high net present values, and large GHG reductions
- ✓ Expand the scope of the Resource Working Group.
- ✓ Form an Energy Research and Advisory Committee made up of alumni, faculty, current students, and public and private partners to consider in more depth some of the projects mentioned in this report.
- ✓ Provide more staff support for implementing energy efficiency and renewable projects through the Sustainability Office, FO&M, Faculty, and the College. We believe that implementing numerous "green" projects will require increased oversight and resources.
- ✓ See Appendix C for rankings of individual projects

## 4 ACKNOWLEDGEMENTS

We would like to thank the following people for their support and assistance:

- Professor Karolina Kawiaka, Dartmouth College
- President Kim, Dartmouth College
- Steve Shadford, Energy Engineer, Dartmouth College
- Kathy Lambert, Office of Sustainability, Dartmouth College
- Lynda Snyder, Chief Facilities Officer, Dartmouth College
- Andrew J. Friedland, The Richard and Jane Pearl Professor in Environmental Studies Chair, Environmental Studies Program, Dartmouth College
- Marissa Knodel, Sustainability Programs Specialist, Dartmouth College
- Steve Kadish, Senior Vice President and Strategic Advisor, Dartmouth College
- Adam Keller, Senior Advisor to the President and Provost, Dartmouth College
- Brett Tofel, Principal, ReKnew Energy Systems, Inc., South Royalton, VT
- David Madigan, Van Zelm Engineers
- David Kaufman, Energy Solutions, Waldoboro ME
- Michael Mooney, Renewable Energy director of International Woodfuels
- Bill Riehl, Chief Operating Engineer, Dartmouth College Power Plant
- Will Carroll, Special Projects Coordinator, International Woodfuels
- Colin High, Resource Groups Systems, Inc.
- Ken Packard, FO&M, Dartmouth College
- Tony Giunta, CEO, AMENICO
- John Wiles, Wind Developer, CWE
- Peter Fontaine, Wind Developer, CWE
- Wedge Bramhall, Wind Developer, CWE
- Tony Giunta, President and CEO, American Energy Independence Company
- Michael F. Mooney, Renewable Energy Director, International WoodFuels
- Will Carroll, Special Projects Coordinator, International WoodFuels
- Jim McNamara, Nexterra Systems Corporation
- Stephen Doig, RMI
- Ken Packard, Assistant Director of Engineering and Utilities, co-chair Facilities, Operations and Management, Dartmouth College
- Jack Wilson, Dartmouth College
- Nathan Harvey, Office of Petroleum Reserves, United States Department of Energy
- James Lowe, Head Engineer, Ball State University
- Ken Seibert, President CMTA Consulting Engineers, Inc
- Jerry Hill, Head Engineer, Yale University
- Jeff Smith, Head Engineering Operations, Harvard University

## 5 References

See end of Appendices

i Kim, J. Y. (2009, October 22). *Green groups meeting*. Personal communication.

ii Harwood, J. (2009, May 3). Link to the Economic Crisis Is Vital to Obama Agenda. *The New York Times.* Retrieved from http://www.nytimes.com/2009/05/04/us/politics/04caucus.html?_r=1

iii Kim, J. Y. (2009, November 7) *Budget message from president Kim*. Email to the Dartmouth community.

iv Intergovernmental Panel on Climate Change. (2007): *Climate Change 2007: Synthesis Report*. Geneva, Switzerland: Watson, R.T. and the Core Writing Team Eds.

v Hansen, J., Sato, Mki., Kharecha, P., Beerling, D., Berner, R., Masson-Delmotte, V., et al. (2008). Target atmospheric CO2: Where should humanity aim? *Open Atmos. Sci. J.*, 2, 217-231.

vi Intergovernmental Panel on Climate Change. (2007): *Climate change 2007: The physical science basis. Contribution of Working Group I to the fourth assessment report of the Intergovernmental Panel on Climate Change*. Geneva, Switzerland: Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., et al., Eds.

vii Intergovernmental Panel on Climate Change. (2007): *Climate change 2007: Impacts, adaptation and vulnerability. Contribution of Working Group II to the fourth assessment report of the Intergovernmental Panel on Climate Change*. Geneva, Switzerland: Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J., and Hanson, C.E. Eds.

viii Intergovernmental Panel on Climate Change. (2007): *Climate change 2007: Mitigation of climate change. Contribution of Working Group III to the fourth assessment report of the Intergovernmental Panel on Climate Change*. Geneva, Switzerland: Metz, B., Davidson, O.R., Bosch, P.R., Dave, R., Meyer L.A. Eds.

ix Rosenzweig, C., Karoly, d., Vicarelli, M., Neofotis, P., Wu, Q., Casassa, G., et al. (2009) Attributing physical and biological impacts to anthropogenic climate change. *Nature,* 453, 353-357.

x Dartmouth College Energy Task Force. (2008, Summer). *Summary of findings and recommendations.* Hanover, NH: Packard, K., Purcell, M., Cushman Roisin, B., Dolan, J., Friedland, A., Gorman, M., et al.

xi Dartmouth College Facilities Operations & Management. (2008, February 20). *Strategic energy conservation plan highlights*. Hanover, NH: .

xii American College and Universities President Climate Commitment. (2009, November 20). *Home*. Retrieved from http://www.presidentsclimatecommitment.org/

xiii Berger, G. (2009, October 12). Dartmouth's endowment drops 23 percent. *The Dartmouth*. Retrieved from http://thedartmouth.com/content/2009/10/12/cover-original.pdf

xiv Madigan, D., Schadford, S. (2009, October). Sustaining campus utility load growth. Presented at *ERAPPA 2009.* Portland, ME.

xv The Committee On Energy And Commerce. (2009, June 1). *The American Clean Energy and Security Act (H.R. 2454)*. Retrieved from: http://energycommerce.house.gov/index.php?option=com_content&view=article&id=1633&catid=155&Itemid=55 accessed 15 Nov. 200

[xvi] Office of the Press Secretary of the White House. (2009, November 25). *Administration Announces U.S. Emission Target for Copenhagen*. Retrieved from http://www.whitehouse.gov/the-press-office/president-attend-copenhagen-climate-talks

[xvii] Energy Information Administration. (March 2009). *Annual Energy Outlook 2009*.

Retrieved from http://www.eia.doe.gov/oiaf/aeo/index.html

[xviii] Johnson, W. (2009, November). Personal communication (email).

[xix] Madigan, D. (2009, November). Personal communication (email).

[xx] American Wind Energy Association. (2009, October 20). *U.S. wind energy industry installs over 1,6000 MW in third quarter*. Retrieved from http://www.awea.org/newsroom/releases/10-20-09_AWEA_Q3_market_report.html

[xxi] Database of State Incentives for Renewables and Efficiency. (2009, May 17). *New Hampshire: Incentives/Policies for Renewables & Efficiency*. Retrieved from http://www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=NH09R&re=1&ee=1

[xxii] Granite Viewpoint. (2009, July 6). Electricity in NH - Wind power. Posted to http://www.graniteviewpoint.com/2009/07/electricity-in-nh-wind-power.html

[xxiii] Environmental Protection Agency Green Power Partnership. (2009, October 26). *2009-2010 College & University Green Power Challenge*. Retrieved from http://www.epa.gov/grnpower/initiatives/cu_challenge.htm

[xxiv] Harvard News Office. (2009, November 2). *Harvard to be largest buyer of wind power in N.E.* Retrieved from http://www.greencampus.harvard.edu/node/507

[xxv] MWUR. (2008, October 7). *Lempster Wind Farm To Come Online By Year's End*. Retrieved from http://www.wmur.com/money/17646467/detail.html

[xxvi] Database of Federal Incentives for Renewables and Efficiency. (2009, May 17). *Federal incentives/policies for renewables & efficiency*. Retrieved from http://www.dsireusa.org/incentives/index.cfm?state=us&re=1&EE=1

[xxvii] Fleischer, C. (2009, October 11). Symbol or solution? *Valley News*. Retrieved from http://www.vnews.com/10112009/6066487.htm

[xxviii] University Office Of Sustainability: University of New Hampshire. (2009). *ECOLine and selling RECS*. Retrieved from http://www.sustainableunh.unh.edu/climate_ed/recs.html

[xxix] Smith, J. (2009, November). Personal communication (email).

[xxx] National Renewable Energy Grants. Department of Energy. Retrieved from http://www.dsireusa.org/incentives/.

[xxxi] National Center for Environmental Economics. (2009, November 29). *Economics of biofuels*. Retrieved from http://yosemite.epa.gov/ee/epa/eed.nsf/pages/Biofuels.html

[xxxii] Middlebury College Sustainability Integration Office. (2009, October 29). *Biofuel use for heat and transport*. Retrieved from http://www.middlebury.edu/administration/enviro/initiatives/energy/biofuel_use.htm

[xxxiii] The College Sustainability Report Card. (2009, July 23). *Middlebury College: Campus survey.* Retrieved from http://www.greenreportcard.org/report-card-2010/schools/middlebury-college/surveys/campus-survey

[xxxiv] Office of Transportation and Air Quality. (2009, May). *EPA lifecycle analysis of greenhouse gas emissions from renewable fuels*. Retrieved from http://www.epa.gov/oms/renewablefuels/420f09024.htm

[xxxv] Environmental Protection Agency Office of Transportation and Air Quality. (2009, May). *EPA lifecycle analysis of greenhouse gas emissions from renewable fuels*. Retrieved from http://www.epa.gov/oms/renewablefuels/420f09024.htm

[xxxvi] Biomass Energy Centre. (2009, November 24). *Sources of biomass*. Retrieved from http://www.biomassenergycentre.org.uk/portal/page?_pageid=75,15174&_dad=portal&_schema=PORTAL

[xxxvii] The College Sustainability Report Card. (n.d.) *College of the Atlantic.* Retrieved from http://www.greenreportcard.org/report-card-2010/schools/college-of-the-atlantic

[xxxviii] Biomass at Middlebury. (Accessed 2009, October 29). *FAQs*. Retrieved from http://blogs.middlebury.edu/biomass/about/faqs/

[xxxix] Shurmantine, K. (2009, November 18). College unsure of biofuel's origins. *The Middlebury Campus*. Retrieved from http://middleburycampus.com/?p=190

[xl] Shurmantine, K. (2009, November 18). College unsure of biofuel's origins. *The Middlebury Campus*. Retrieved from http://middleburycampus.com/?p=190

[xli] Franklin Pierce University News. (2009, October 6). Franklin Pierce University installs new wood pellet boilers on Rindge campus. *Franklin Pierce University News*. Retrieved from http://beta.franklinpierce.edu/about/news/pr_woodpelletinstall.htm

[xlii] Searchinger, T. D., Hamburg, S. P., Melillo, J., Chameides, W., Havlik, P., Kammen, D. M., et al. (2009, October 23). Fixing a critical climate accounting error. *Science,* 326, 527.

[xliii] Sustainable Forestry Initiative. (n.d.). *2005-2009 Standard.* Retrieved from http://www.sfiprogram.org/files/pdf/sfi-standard-2005-2009-sept%2008%20update.pdf

[xliv] Fiske, Edward (2009). *Fiske Guide to Colleges 2010, 26E.* Sourcebooks College.

## APPENDICES: TABLE OF CONTENTS

**Page Number…..Title**

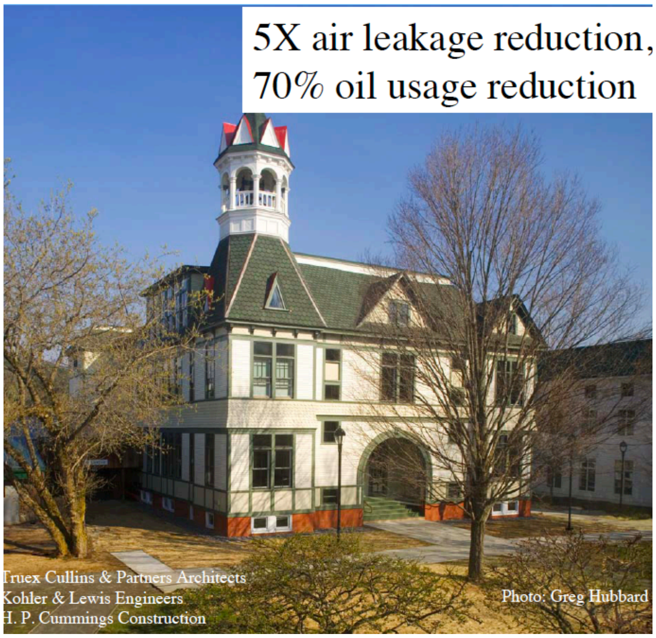
**APPENDIX A: Precedents**

**Table I: Noteworthy Examples of Academic Institutions Exploring Building Retrofits for Efficiency**

| College, Location | Retrofits | Projected Outcomes |
|---|---|---|
| Lee College, Baytown, TX | • The addition of a new building management system<br>• The installation of energy efficient HVAC and lighting products | • Reduce energy usage by 35 percent<br>• Reduce energy and water costs by 32 percent |
| Portland Community College, Portland, OR | • The installation of a 1.1-megawatt natural gas generator<br>• The monitoring of heating and air conditioning systems | • A "net zero" site, where all energy is generated on site and all carbon emissions are offset<br>• Reduce the campus's carbon output by 57 percent<br>• Reduce energy spending from \$1.6 million a year to \$440,000 |
| Allegheny College, Meadville, PA | • Upgrades to boilers, chillers, major HVAC equipment, water, thermal improvements, building lighting and system controls will net significant energy saving | • Achieve better energy efficiency as well as emissions reduction across all facilities at the college<br>• Long-term goal of zero growth of global warming emissions on its member campuses |
| University of Vermont, Burlington, VT | • Centralized Building Controls<br>• Efficient Hockey Rink<br>• IPAC™ Cooling System<br>• Efficient Washing Machines<br>• Light Emitting Diode (LED) Exit Signs<br>• Campus Lighting Upgrades<br>• Energy Efficient Mini-Fridges<br>• Motor Upgrades<br>• Occupancy Sensors<br>• Sleep Mode™<br>• Thermostat Setbacks<br>• Vending Miser<br>• Used Motor Oil Reuse | |

**Efficiency Precedents: Deep Energy Retrofits**
[As presented in *Affordable Comfort Home Performance 2008*, Marc Rosenbaum, P.E. Energysmiths]

Debevoise Hall at VT Law School:




This historic 1893 Vermont schoolhouse, owned by VLS since the 1970s, was completely renovated. Sometimes competing goals of historic preservation and energy efficiency were challenging to reconcile. The building grew from ~24,000 sf. to almost 28,000 sf.

- Windows:
  - Historic wooden windows rehabbed
  - Open cell foam was used to fill the remaining depth of the sash weight cavity to allow it to be removed in the future for servicing the window hardware
  - New fiberglass Accurate Dorwin windows with double low-e argon-filled glazing are inside the historic single pane windows

---

Union Mill, West Peterborough, NH:


This 25,000 sf mill was built in 1824. It has been rehabilitated into 10 housing units and several thousand square feet of commercial space. Windows were replaced and the walls and roof were fully insulated with soy-based foam products. Heat and DHW are produced by two residential pellet boilers.

---

Mike Rogers' 1920s house in Burlington, VT

Before
- 1,320 sf
- Heat: 198 MMBTU/year
- Electricity: 6,000 kWh/year

After
- 2,060 sf
- Heat: 85 MMBTU/year
- Electricity: 3,000 kWh/year

General:
- 60% heating energy reduction, with modest envelope improvements – cellulose + 1.5" foam, dbl low-e Arwindows, ~1,000 CFM50, furnace
- 50% electricity reduction – lighting, Energy Star appliances
- Today – more R, better windows, airtightness, point source heat, SDHW

---

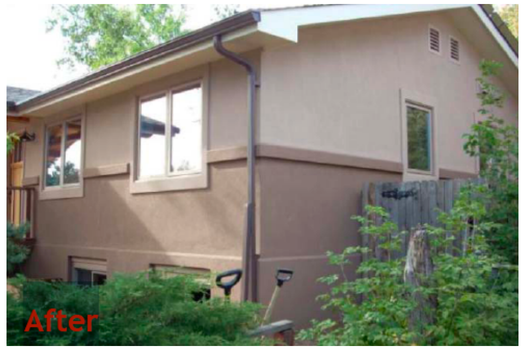
Bill Asdal's Cottage in Califon, NJ



- 74% energy reduction for heating and cooling, with modest envelope improvements – cellulose + foam-filled siding, dbl low-e Arwindows
- 2 ton GSHP, SDHW with instantaneous DHW back-up, 7.2 kW PV
- Base case upgrade estimated at $23K, yields $500/year energy savings
- Upgrade as built, w/o PV, cost $37K, yields $2,800/year energy savings
- More aggressive envelope strategies combined with mini-split HP and less PV may be a better overall investment

---

Ecofutures 1247 Scrub Oak in Boulder, CO


Before:
- 1,000 sf + 1,000 sf basement

After:
- 2,700 sf, incl. conditioned basement

Retrofits:
- Basement: 1” XPS + 2x4 w/batts, walls new 2x4 with open cell SPF, attic 8” open cell SPF + 12” cellulose, fiberglass windows quad glazed low-e, 750 CFM50
- Gas line disconnected, active solar thermal 180 evacuated tubes + 360 gallons water storage, back-up 9 kW modulating electric boiler, ERV
- 6.6 kW PV installed

PV details:
- A non-ideal solar site with almost no passive gain opportunities has been creatively adapted to create a solar-driven, all-electric home
- House loads are estimated at 6,300 kWh/year
- PV output is estimated at 9,600 kWh/year –a surplus of 3,300 kWh/year in order to power an electric vehicle

---

1970s Ranch in northern MA

Before:
- 2,430 sf
- Heat: 75 MMBTU/year
- DHW: 20 MMBTU/year
- Electric: 6,000 kWh/year
- Currently 1150 CFM50
- Existing HVAC upgrade to gas boiler and fan coil -~15% of existing electrical use

After (projected):
- 2,430 sf
- Heat: 24 MMBTU/year
- DHW: 6 MMBTU/year
- 3,600 kWh/year
- Budget is $50K

Proposed:
- Attic air sealing and R-65 cellulose (existing)
- Exterior Larsen truss and 4.5” closed cell SPF

- New windows U=0.20 or better
- Basement interior R-25 rigid foam
- Goal of 300 CFM50
- SDHW
- 3 kW renewable electricity: PV (+ maybe wind –site is coastal)

After retrofit:

- Peak heating load drops from 37,000 BTU/hour to 15,000 BTU/hour
- A central distribution duct runs the length of the house and serves all rooms
- A new 400 CFM fan and a "hood" over the wood stove will permit heat from the stove to be distributed to all rooms

---

Principles of Deep Energy Retrofits

- Envelope and load reduction first
- Don't spend the money on mechanicals –radiant floors, GSHPs- think micro and point source
- It's OK to phase these improvements within a master planned approach
- Hit the renovation market hard –the energy improvements become a marginal additional cost when siding, windows, roofs are replaced
- Solar can be planned for and arrive later
- Reducing electrical loads is crucial –occupant choices predominate

## Table II: Precedents for GHG emissions measures in American Universities

| **College**<br><br>**Location**<br><br>**Metric tons CO2/student** | **Efficiency Measures** | **Energy Generation** | **Purchased Electricity from renewable sources** | **Fuel Mix** | **Reduction targets** |
|---|---|---|---|---|---|
| Amherst College<br><br>Amherst, MA<br><br>2008: 13.7 metric tons/student | Temperature controls, vending misers, variable frequency drives, dining hall hood controls, building control algorithm and calibration program, lighting control retrofits, hot water hydronic loop temperature reset to match ambient air temperature differential | Cogen. plant provides 67% of annual electricity use and 50% of its peak use, steam from plant satisfies 30% of heating needs; The college has four buildings that have **solar hot water system, some photovoltaics, and a wind turbine** | Agreement to purchase REC credits for 3% of its electricity, 33% of electricity from the grid from Trans. Canada which generations 40% of the grid from renewables | Natural Gas- 49%<br><br>Oil- 51% | Active member in the Cities for Climate Protection organization and working through the Town of Amherst Energy Task Force Reduction level: 35% target Baseline year: 1997 Target date: 2009 |
| Brown University<br><br>Providence, RI<br><br>2008: **8.5** metric tons/student | Building energy use competitions, morning mails and splash screens keep student body aware of energy consumption | 5% of electricity from co-gen. heating plant run on oil and natural gas, runs natural gas in central heat plant | No renewable energy purchased or generated | n/a<br><br>(probably not a good school to highlight for our purposes?) | Reduction level: 42 percent Baseline year: 2007 (equivalent to 15 percent below 1990 levels) Target date: 2020 |
| College of the Atlantic<br><br>Bar Harbor, ME<br><br>2008: **4.8** metric tons/student | **New boiler controls and temperature sensors were installed and programmed to run boiler to match load,** heat recovery system over stoves in the kitchen, ask people to enter through doors that less impact energy use, CFLs instead of incandescent bulbs | 20% of campus heated by a new wood pellet boiler | Purchases 100% of its electricity from a renewable source, a hydroelectric project in Maine | Oil- 69%<br><br>Propane- 31% | To be determined |
| Columbia University<br><br>New York, NY<br><br>CO2 emissions not | | | | | 30% below 2005 levels by 2017 |

| | | | | | |
|---|---|---|---|---|---|
| University of New Hampshire<br><br>Durham, NH | Efficient lighting, efficiency retrofits, electric hand dryers | Will receives up to 85% of energy used by campus by the landfill gas project, but sells associate RECs to help finance the capital costs of the project | No, will sell back RECs from landfill gas project to make $ | 10% landfill gas<br><br>55% natural gas<br><br>Natural gas- 90.16% | Climate Action Plan – WildCAP - UNH will cut its greenhouse gas emissions: 50% by 2020 |
| Harvard University<br><br>Cambridge, MA<br><br>2008: 15.5 metric tons/student | Broad educational campaign, Green office and lab certification programs, building energy competitions, Smartpower strips, CFL bulbs, plug timers | **PV and solar hot water projects**, currently testing winds for potential wind projects | 8.7% of electric usage from renewables | #2 Oil- 2.02%<br><br>#4 Oil- 0.88%<br><br>#6 Oil- 6.76%<br><br>Propane- 0.02%<br><br>Wood- 0.18% | Reduction level: 30% including growth<br><br>Baseline year: 2006<br><br>Target date: 2016 |
| Middlebury College<br><br>Middlebury, VT<br><br>metric tons/student | | | | | Carbon neutral by 2016 |
| Princeton University<br><br>Princeton, NJ<br><br>metric tons/student | | 443-kilowatt photovoltaic array on ReCAP library storage facility | | | 1990 levels by 2020 |
| Smith College<br><br>Northampton, MA<br><br>2008: **8.2** metric tons/student | Building metering and dashboard, cooler efficiency retrofits to save electricity in walk in coolers and freezers, power strips | Natural gas run cogen. plant | 3% from RECs | #6 oil- 0.20%<br><br>#2 Oil- 0.59%<br><br>Natural gas- 99.2% | Smith has made a commitment to be carbon neutral, consistent with the ACUPCC, timeline of plan TBD |
| University of New Hampshire | Efficient lighting, efficiency retrofits, | Will receives up to 85% of energy used | No, will sell back RECs from | 10% landfill gas | Climate Action Plan – WildCAP - UNH |

University Precedents: Green Power- Inspirational Building Designs

**Figure I: Wood Chip Burner Made into a Public Display.** "Middlebury Colleges Turn to Wood Chips for Heat — and Education" (New York Times, January 15, 2009, 9:03 AM)

<http://graphics8.nytimes.com/images/blogs/greeninc/vermont.jpeg&imgrefurl=http://greeninc.blogs.nytimes.com/2009/01/15/colleges-turn-to-wood-chips-for-heat-and- education/&usg=__qzUFunXK25PJsZlN-e5OnnMJAlI=&h=364&w=480&sz=84&hl=en&start=1&um=1&tbnid=AqlARyRsR6wgLM:&tbnh=98&tbnw=129&prev=/images%3Fq%3Dmiddlebury%2Bcollege%2Bwood%2Bchip%2Bplant%26hl%3Den%26client%3Dsafari%26rls%3Den-us%26sa%3DN%26

**Figure II: The Pompiou Center.** The original "inside out" building where the steel structure, external elevators, and duct work, all color coded by function, are visible on the exterior.

<http://www.galinsky.com/buildings/pompidou/pompidou1.jpg&imgrefurl=http://www.galinsky.com/buildings/pompidou/index.htm&usg=__ylGnMq8jFh7QPsy6WZWIoo3sn9A=&h=323&w=430&sz=90&hl=en&start=1&um=1&tbnid=d9Z7U3OAXWjiM:&tbnh=95&tbnw=126&prev=/images%3Fq%3DPompidou%2Bcenter%26hl%3Den%26client%3Dsafari%26rls%3Den-us%26sa%3DN%26um%3D1>

**Figure III: University of Pennsylvania Gateway Complex, Philadelphia, PA.**

"Faced with a clunky chiller plant that sat right next to a baseball field at the University of Pennsylvania, LWA wrapped it gracefully in a mesh that cloaks it during the day but actually shows off the machinery at night."

Peter Aaron/Esto <http://www.metropolismag.com/story/20080220/mission-impossible-architecture>

**Figure IV: UMass Amherst Dedicates $133 Million Central Heating Plant, Showcasing Green Energy Achievements on Campus.**“WGBY-TV's "Making It Here" features the new, award-winning Central Heating Plant at the University of Massachusetts Amherst. Ten years in the planning, the facility replaces a coal-fired plant built more than 80 years ago.”

<http://www.umass.edu/newsoffice/newsreleases/articles/87784.php&usg=__WZwvyKXFldafdWsktjGt01DiSYQ=&h=600&w=900&sz=501&hl=en&start=18&um=1&tbnid=Y5_Bi91a4PWeuM:&tbnh=97&tbnw=146&prev=/images%3Fq%3Dheating%2Bplant%26hl%3Den%26client%3Dsafari%26rls%3Den-us%26sa%3DN%26um%3D1>

**Figure V: Vermont I-89 Rest Area.** Inside the rest area's wastewater treatment system, plants and animals clean the waste from the water through a series of engineered ecosystems in a visible display of sustainability. (Photo by Living Technologies)

**Figure VI: Oberlin College.** A highly visible and interactive building, "The Adam Joseph Lewis Center for Environmental Studies is an ongoing green building experiment, as its energy performance is studied and adjusted as green technologies continue to evolve."

http://www.inhabitat.com/wp-content/uploads/ob2.jpg&imgrefurl=http://www.inhabitat.com/2008/07/03/oberlin-college-setting-a-sustainable-example-in-ohio/&usg=__eyEbQCkoHLlD0MDPIlRCvdyAaYs=&h=415&w=537&sz=50&hl=en&start=16&um=1&tbnid=RQD-J0gDZ5eVsM:&tbnh=102&tbnw=132&prev=/images%3Fq%3DOberlin%2BLewis%26hl%3Den%26client%3Dsafari%26rls%3Den-us%26um%3D1

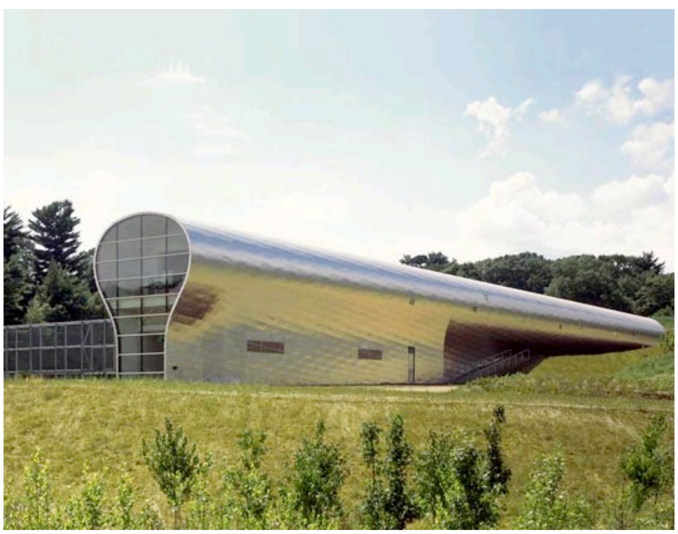


**Figure VII: Steven Holl's Whitney Water Purification Plant.**
"The integration of education, architecture, and landscaping in the project for a facility, which in most cases, would be hidden, or worse, badly designed, is what makes this one of the top ten green projects of 2007, and one worthy of the attention that it is getting."

<http://www.inhabitat.com/wp-content/uploads/whitney-water-purification-2.jpg&imgrefurl=http://www.inhabitat.com/2007/05/03/steven-holls-whitney-water-purification-plant/&usg=__u-Fw2nSl4XbJu0Atl9263i0NSf8=&h=416&w=537&sz=59&hl=en&start=1&um=1&tbnid=SPCCi7DNC_JwRM:&tbnh=102&tbnw=132&prev=/images%3Fq%3DSteven%2BHoll,%2Bwater%2Btreatment%26hl%3Den%26client%3Dsafari%26rls%3Den-us%26sa%3DN%26um%3D1>

**Figure VIII: Wastewater Treatment at Sidwell College.**
Wastewater treatment is turned into an attractive and interactive experience in the form of a wetland terrace.

<http://pruned.blogspot.com/2009/06/wetland-machine-of-sidwell.html&usg=__1JKv88g_Ce89PK2FUyn1GySXeJM=&h=400&w=550&sz=97&hl=en&start=3&um=1&tbnid=GspS8k8nrFGqTM:&tbnh=97&tbnw=133&prev=/images%3Fq%3Dsidwell%2Bfriends,%2Binfrastructure%26hl%3Den%26client%3Dsafari%26rls%3Den-us%26sa%3DN%26um%3D1>

**APPENDIX B: Assumptions**

## *General Assumptions*

### Cost Projections

1. We used EIA published price predictions for the low estimate of the price of #6 residual fuel oil, and EIA “High Price” predictions for the high estimate.

2. Since we currently have no data for projected electricity costs, we project that the low price for electricity will stay constant at current levels of $0.13/KWH. We projected high energy costs with a price increase of 5%/KWH/year [as per a conversation with Linda Snyder]

| Fiscal Year | EIA price predictions (dollars/gallon #6 fuel)- High | EIA price predictions (dollars/gallon #6 fuel)- Low ("updated" EIA reference case) | Price per million BTU - High | Price per million BTU - Low | Electricity Price Per KWH rising at 5% | Electricity Price Per KWH constant-Low |
|---|---|---|---|---|---|---|
| 2006 | 1.38 | 1.38 | | | | |
| 2007 | 1.57 | 1.59 | | | | |
| 2008 | 2.05 | 2.06 | | | | |
| 2009 | 1.05 | 1.04 | | | 0.13 | 0.13 |
| 2010 | 2.58 | 1.47 | 17.23 | 9.83 | 0.14 | 0.13 |
| 2011 | 2.92 | 1.83 | 19.47 | 12.23 | 0.14 | 0.13 |
| 2012 | 3.28 | 2.09 | 21.86 | 13.91 | 0.15 | 0.13 |
| 2013 | 3.60 | 2.31 | 24.03 | 15.40 | 0.16 | 0.13 |
| 2014 | 3.93 | 2.49 | 26.18 | 16.61 | 0.17 | 0.13 |
| 2015 | 4.19 | 2.70 | 27.93 | 18.00 | 0.17 | 0.13 |
| 2016 | 4.36 | 2.82 | 29.07 | 18.78 | 0.18 | 0.13 |
| 2017 | 4.55 | 2.91 | 30.33 | 19.39 | 0.19 | 0.13 |
| 2018 | 4.66 | 3.01 | 31.07 | 20.07 | 0.20 | 0.13 |
| 2019 | 4.73 | 3.06 | 31.51 | 20.41 | 0.21 | 0.13 |
| 2020 | 4.80 | 3.10 | 31.97 | 20.69 | 0.22 | 0.13 |
| 2021 | 4.79 | 3.14 | 31.93 | 20.93 | 0.23 | 0.13 |
| 2022 | 4.83 | 3.16 | 32.18 | 21.06 | 0.25 | 0.13 |
| 2023 | 4.87 | 3.19 | 32.44 | 21.26 | 0.26 | 0.13 |
| 2024 | 4.89 | 3.20 | 32.59 | 21.35 | 0.27 | 0.13 |
| 2025 | 4.93 | 3.15 | 32.89 | 20.97 | 0.28 | 0.13 |
| 2026 | 4.98 | 3.17 | 33.23 | 21.13 | 0.30 | 0.13 |
| 2027 | 5.02 | 3.19 | 33.47 | 21.29 | 0.31 | 0.13 |
| 2028 | 5.08 | 3.24 | 33.87 | 21.61 | 0.33 | 0.13 |
| 2029 | 5.14 | 3.26 | 34.25 | 21.75 | 0.34 | 0.13 |
| 2030 | 5.16 | 3.31 | 34.41 | 22.03 | 0.36 | 0.13 |

## *Business As Usual Assumptions & Projections*

To calculate total campus energy rates, we used total electricity and steam usage rates for the 2009 Fiscal Year and the total campus square footage to find average electricity and steam usage rates per square foot per year, and then used campus growth projections to estimate energy usage from 2010 to 2030.

Total campus square footage is **4,637,395** sq.ft. This number is based on the sum of the total sq.ft. of every campus building, as outlined in the "Building Square Footage Listing" spreadsheet (Karolina Kawiaka).

Total electricity usage and steam usage were determined from the "Year to Year Summaries" for campus energy usage (Steve Shadford).

- For the 2009 Fiscal Year, Total Electricity Usage (purchased + co-generated) = 64,611,843 kWh / yr.
- For the 2009 Fiscal Year, total steam Usage = 781,472 MMBTU/yr.
  - Total Fuel Oil Gallons consumed (#2 and #6 Fuel Oil) = 5,209,817 Gal.
  - Conversion factor: 0.15 MMBTU per Gal Residual Fuel Oil (EIA)
  - Accounts for 75% efficiency of boilers

**Energy Rates** (total usage / campus sq. ft.)
- Electricity = 13.9 kWh/sq.ft./yr.
- Steam = 0.126 MMBTU/sq.ft./yr.

**GHG Emissions**

- We used EIA conversion factors to calculate emissions from purchased electricity, #6 fuel oil, and non-#6 fuel oil energy sources.
- For non-#6 fuel oil, we assumed the majority was #2 fuel oil and used that conversion factor.
- We did not calculate for GHG emissions associated with transport and other indirect emissions
- GHG from electricity
  - Assume 0.000420789 MT $CO_2$ / kWh electricity (from EPA eGrid data)
- GHG from steam
  - Assume 0.011757907 MT $CO_2$ / gal residual fuel oil (Clean Air Cool Plant calculator)

**Projected Campus Growth**

- New construction (space additions)
  - 2008, Tuck Living/Learning Center (100,000 sq. ft.)
  - 2012, Visual Arts Center (99,000 sq.ft.)
  - 2012, Life Sciences Building (175,000 sq.ft.)
  - 2019, Academic Building, (60,000 sq. ft.)

- 2020, Science Building, (120,000 sq.ft.)
- 2021, Potential new building*, (80,000 sq.ft.)
- 2029, Potential Growth*, (20,000 sq.ft.)
- 2030, Potential Growth*, (20,000 sq. ft.)

- Demolitions: (space deletions)
    - 2010, Clement Hall, (-25,100 sq.ft.)
- *Assumed a general ten-year cycle of building growth; put hypothetical buildings online in 2022, 2029, and 2030 to reflect future potential growth of the college. )

**To project Energy Usage to 2030**

- Assume rate of 2% increase in electricity usage per year (See “Energy Rates”) (Steve Shadford)
- Assume constant steam usage rate in future (see “Energy rates”)
- Assume 75% boiler efficiency (Steve Shadford)

## *Efficiency Measurements: Sources & Assumptions*

Table I: Used the net savings of electricity, steam usage, and GHG emissions from the VanZelm Report (Strategic Energy Conservation Plan) to determine average energy and GHG emissions reduced per square foot.

| | **VANZELM Steam Savings (MMBTU/yr)** | **VANZELM Electricity Savings (kWH/yr)** | **VANZELM GHG Emissions Savings (MTCE/Yr)** | **VANZELM Investment Cost ($)** |
|---|---|---|---|---|
| Conservation & Efficiency Projects | 117,172 | 7,373,998 | 12,638 | $10,579,942 |
| Chiller Replacements | 71,132 | -1,442,511 | 4,849 | $5,295,000 |
| Steam Trap Maintenance Program | 26,728 | 0 | 2,080 | |
| **TOTALS** | **215,031** | **5,931,487** | **19,567** | |

Table II: Total square footage of buildings in VanZelm study = 2,248,800 sq. ft.

| | **AVERAGE Steam Savings (MMBTU/sq.ft./yr)** | **AVERAGE Electricity Savings (kWH/sq.ft./yr)** | **AVERAGE GHG Emissions Savings (MTCE/sq.ft./Yr)** | **AVERAGE Investment Cost ($/sq.ft.)** |
|---|---|---|---|---|
| Conservation & Efficiency Projects | 0.052 | 3.279 | .0056198 | 4.705 |

Table III: Total campus square footage: 4,637,395 sq.ft

| | **CAMPUS Steam Savings (MMBTU/sq.ft./yr)** | **CAMPUS Electricity Savings (kWH/sq.ft./yr)** | **CAMPUS GHG Emissions Savings (MTCE/sq.ft./Yr)** | **CAMPUS Investment Cost** |
|---|---|---|---|---|
| Conservation & Efficiency Projects | 241627 | 15206394 | 26061 | 21817578 |

High Performance Design Assumptions:

- Reduce Steam Usage by 50% (=0.630 MMBTU/sq.ft./yr) [Steve Shadford]
- Reduce Electricity Usage by 30% of 2010 levels, keep constant instead of increase by 2% per year (9.3 kWh/sq.ft./yr.) [Steve Shadford]
- Not accounting for increased construction costs for HPD
- Reduction factors may change

Implementation:

- All remaining absorption chillers can be replaced within 5 years, 2010-2014 (linear projection of the 5 years)
- 25 Bldg Efficiency (SECP) installed in 5 years: 2010-2014 (linear projection over the 5 years)
- Remaining campus buildings (SECP-CW) retrofitted in next 5 years: 2015-2019 (linear projection over the 5 years)
- HPD incorporated in every new building project

Chiller replacements

- Assuming geothermal can account for all cooling needs, we will assume that replacing absorption chillers with electric chillers is unnecessary. In our final energy mix, we are assuming that geothermal steam and electricity savings account for the replacement of absorption chillers with geothermal installations.
- Currently we have electric chillers installed at the following locations (one at each):
    - Gilman
    - Murdough
    - Cummings
    - MacLean ESC

*Wind Project Assumptions*

**Electricity produced per year (kWh)** **35,000,000 kWh** from 12 MW wind farm
**58,333,333 kWh** from 20 MW wind farm

This figure was provided is estimated from wind surveys completed on Tug Mountain in 2006 (CWE)

**Years of production** **20 years**

Common lifespan for a wind farm although turbines could last longer (CWE)

**Total cost of predevelopment ($)** **$500,000**

Costs include permitting, scientific surveys, interconnection studies, and site preparation (CWE)

**Total cost installation ($)** **$24,000,000** for 12 MW wind farm
**$40,000,000** for 20 MW wind farm

Total for purchasing, transporting, and installing turbines as well as road and electrical maintenance (CWE, Lempster Wind Farm- http://www.graniteviewpoint.com/2009/07/electricity-in-nh-wind-power.html)

**Amount of principal paid up front in loan scenario (%)** **20%**

One possible payment plan

**Time period of paying back loan** **18 years**

One possible payment plan—eighteen years represents 90% of expected lifetime of turbines

**Estimated rate for electricity with Power Purchase Agreement ($/kWh)** **0.15 $/kWh**

As estimated by CWE

**Estimated PSNH rate for electricity with full ownership ($/kWh)** **0.04 $/kWh**

Estimates for how much PSNH would charge (CWE)

**Current price of electricity ($/kWh)** **0.13 $/kWh**

From Steve Shadford

**Projected annual rate of increase in the price of electricity for "high cost" estimate** **5%**

Rate used by Dartmouth College in five-year projections for electricity prices (Linda Snyder). We extrapolated this 5% increase for all twenty years.

**Projected annual rate of increase in the price of electricity for "low cost" estimate** **0%**

This represents a low range for electricity prices, although we expect there to be variability in the price of electricity in the future.

**Annual Interest Rate** **5.5%**

Typical rate for Dartmouth College (Adam Keller)

**Annual Discount Rate (%)** **5.5%**

Typical rate used by Dartmouth College (Adam Keller)

**Life Cycle Analysis for wind turbines (g-CO2/kWh)** **11**

Bhat, Varun and Ravi Prakash. "LCA of renewable energy for electricity generation systems—A review." *Renewable and Sustainable Energy Reviews* 13 (2009) 1067–1073.

**$CO_2$ rate is PSNH (lb/MWh)** **927.68**

EPA eGRID data (http://cfpub.epa.gov/egridweb/view_srl.cfm)

**Annual Lease Payment for land** **$30,000**

As estimated by CWE

**Total Energy Savings**

To calculate total energy savings, we multiplied total electricity produced by the project and market price of electricity. For the price of electricity, we had a low cost estimate (with a 0% increase per year from $0.13/kWh) and a high cost estimate (5% annual increase). See assumptions above for the amount of electricity produced by the project. Total Energy Savings represent the avoided cost from a "business as usual" scenario.

**Net Financial Savings**

To calculate net financial savings, we began with the energy savings, subtracted the annual leasing cost ($30,000/year), the cost of electricity that the College would have to pay ($0.04/kWh multiplied by kWh produced by the wind farm), the annual loan payment, and the annual leasing cost. The annual loan payment was calculated in Microsoft Excel using the PMT function (provided by CWE).

**Net CO2 Reductions**

To calculate net reductions, we subtracted the total CO2 emissions of the wind farm from the total emissions avoided. The total CO2 emission of the wind farm was calculated using a life cycle analysis (see assumptions). We calculated total avoided emissions using the EPA eGRID data (see assumptions).

**Economic Profit**

The economic profit represents the total savings over the 20-year period. To calculate that number, we summed each year's "Net Financial Savings" over the course of the 20 years.

**Simple Payback**

To calculate simple payback, we added up the all the payments of the project (initial down-payment and each annual loan payment). We then divided that figure by the average annual energy savings (calculated by subtracting the amount the College would have to pay for the electricity from the wind farm from the total cost avoided).

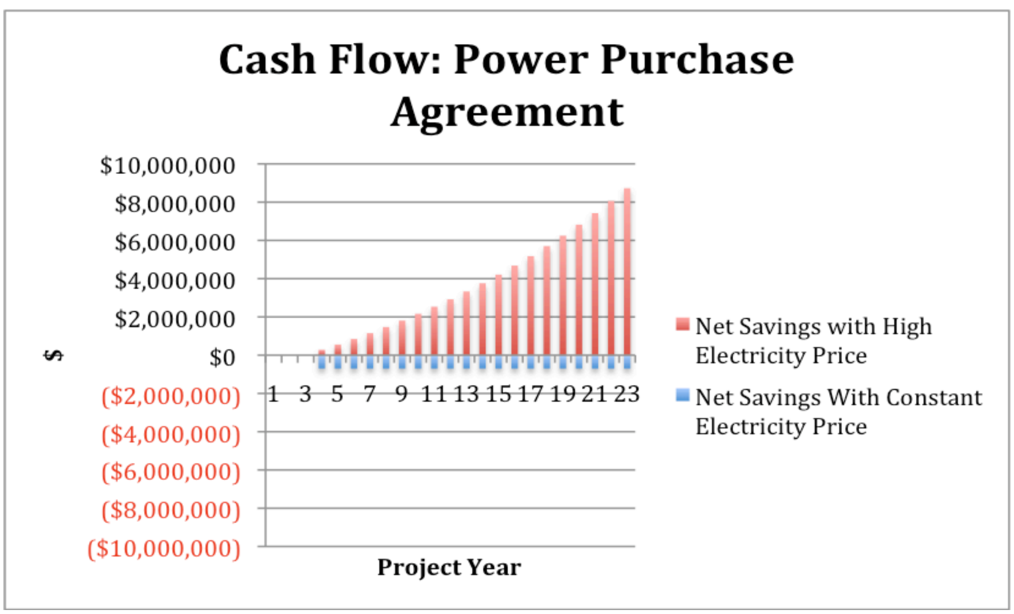
**Net Present Value:**

To calculate the project's net present value, we first calculated the net present value of the annual financial savings (this was done by taking each annual net savings and dividing it by (1 + discount rate of 5.5%) and raising the denominator by the year of the project). For the total net present value, we added up each discounted annual savings over the 20-year period.

## Calculations and Net Savings Graphs:

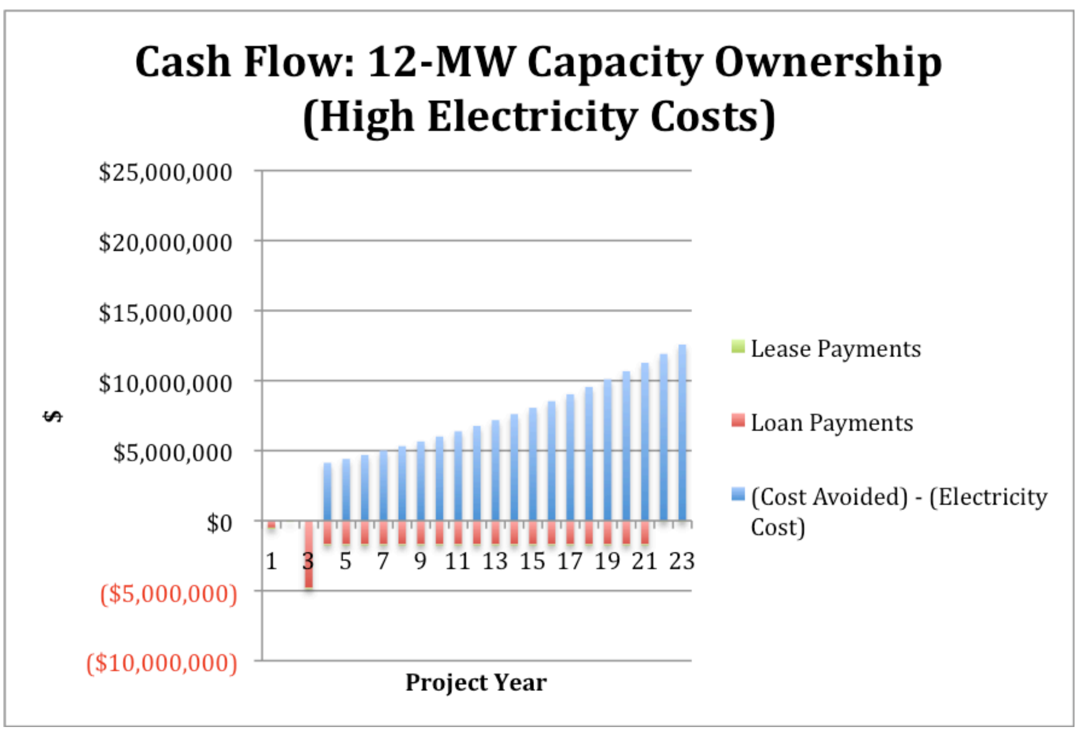
### Power Purchase Agreement

| Year | Cost avoided (high cost) ($) | Cost avoided (low cost) ($) | Cost of elect-ricity from project ($) | Invest-ment Cost ($) | Net Savings (high cost) ($) | Net Savings (low cost) ($) | Net Savings Dis-counted (high cost) ($) | Net Savings Dis-counted (low cost) ($) | $CO_2$ reduced (metric ton/ |
|---|---|---|---|---|---|---|---|---|---|
| 2010 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2011 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2012 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2013 | 5,530,553 | 4,550,000 | 5,250,000 | 0 | 280,553 | -700,000 | 238,923 | -596,130 | 14,343 |
| 2014 | 5,807,081 | 4,550,000 | 5,250,000 | 0 | 557,081 | -700,000 | 449,685 | -565,052 | 14,343 |
| 2015 | 6,097,435 | 4,550,000 | 5,250,000 | 0 | 847,435 | -700,000 | 648,402 | -535,594 | 14,343 |
| 2016 | 6,402,307 | 4,550,000 | 5,250,000 | 0 | 1,152,307 | -700,000 | 835,706 | -507,672 | 14,343 |
| 2017 | 6,722,422 | 4,550,000 | 5,250,000 | 0 | 1,472,422 | -700,000 | 1,012,197 | -481,206 | 14,343 |
| 2018 | 7,058,543 | 4,550,000 | 5,250,000 | 0 | 1,808,543 | -700,000 | 1,178,445 | -456,119 | 14,343 |
| 2019 | 7,411,471 | 4,550,000 | 5,250,000 | 0 | 2,161,471 | -700,000 | 1,334,987 | -432,340 | 14,343 |
| 2020 | 7,782,044 | 4,550,000 | 5,250,000 | 0 | 2,532,044 | -700,000 | 1,482,336 | -409,801 | 14,343 |
| 2021 | 8,171,146 | 4,550,000 | 5,250,000 | 0 | 2,921,146 | -700,000 | 1,620,975 | -388,437 | 14,343 |
| 2022 | 8,579,704 | 4,550,000 | 5,250,000 | 0 | 3,329,704 | -700,000 | 1,751,363 | -368,187 | 14,343 |
| 2023 | 9,008,689 | 4,550,000 | 5,250,000 | 0 | 3,758,689 | -700,000 | 1,873,934 | -348,992 | 14,343 |
| 2024 | 9,459,123 | 4,550,000 | 5,250,000 | 0 | 4,209,123 | -700,000 | 1,989,103 | -330,799 | 14,343 |
| 2025 | 9,932,079 | 4,550,000 | 5,250,000 | 0 | 4,682,079 | -700,000 | 2,097,258 | -313,553 | 14,343 |
| 2026 | 10,428,683 | 4,550,000 | 5,250,000 | 0 | 5,178,683 | -700,000 | 2,198,771 | -297,207 | 14,343 |
| 2027 | 10,950,118 | 4,550,000 | 5,250,000 | 0 | 5,700,118 | -700,000 | 2,293,993 | -281,713 | 14,343 |
| 2028 | 11,497,623 | 4,550,000 | 5,250,000 | 0 | 6,247,623 | -700,000 | 2,383,255 | -267,026 | 14,343 |
| 2029 | 12,072,505 | 4,550,000 | 5,250,000 | 0 | 6,822,505 | -700,000 | 2,466,875 | -253,105 | 14,343 |
| 2030 | 12,676,130 | 4,550,000 | 5,250,000 | 0 | 7,426,130 | -700,000 | 2,545,150 | -239,910 | 14,343 |
| 2031 | 13,309,936 | 4,550,000 | 5,250,000 | 0 | 8,059,936 | -700,000 | 2,618,364 | -227,403 | 14,343 |
| 2032 | 13,975,433 | 4,550,000 | 5,250,000 | 0 | 8,725,433 | -700,000 | 2,686,785 | -215,548 | 14,343 |
| **Total** | **182,873,026** | **91,000,000** | **105,000,000** | **0** | **77,873,026** | **-14,000,000** | **33,706,506** | **-7,515,795** | **286,852** |



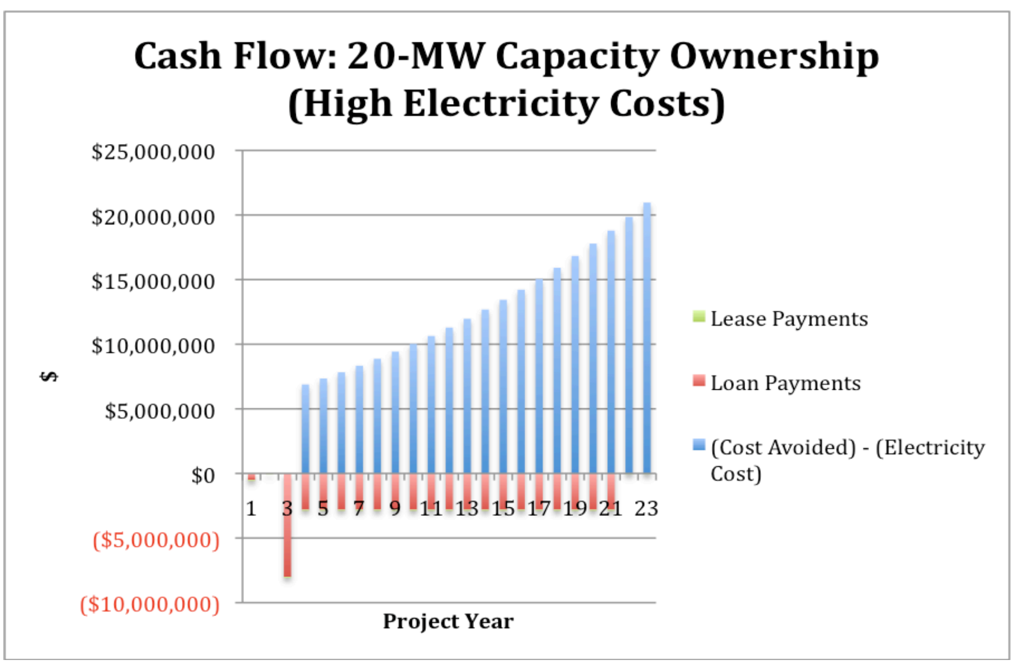
**12-MW Capacity Ownership**

| Year | Cost avoided (high cost) ($) | Cost avoided (low cost) ($) | Cost of electricity from project ($) | Investment Cost ($) | Net Savings (high cost ($) | Net Savings (low cost ($) | Net Savings Discounted (high) cost ($) | Net Savings Discounted (low) cost ($) | $CO_2$ reduced (metric ton) |
|---|---|---|---|---|---|---|---|---|---|
| 2010 | 0 | 0 | 0 | 500,000 | -500,000 | -500,000 | -500,000 | -500,000 | 0 |
| 2011 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2012 | 0 | 0 | 0 | 4,800,000 | -4,800,000 | -4,800,000 | -4,312,572 | -4,312,572 | 14,343 |
| 2013 | 5,530,553 | 4,550,000 | 1,400,000 | 1,712,598 | 2,417,955 | 1,437,402 | 2,059,164 | 1,224,111 | 14,343 |
| 2014 | 5,807,081 | 4,550,000 | 1,400,000 | 1,712,598 | 2,694,483 | 1,437,402 | 2,175,032 | 1,160,295 | 14,343 |
| 2015 | 6,097,435 | 4,550,000 | 1,400,000 | 1,712,598 | 2,984,837 | 1,437,402 | 2,283,801 | 1,099,806 | 14,343 |
| 2016 | 6,402,307 | 4,550,000 | 1,400,000 | 1,712,598 | 3,289,709 | 1,437,402 | 2,385,848 | 1,042,470 | 14,343 |
| 2017 | 6,722,422 | 4,550,000 | 1,400,000 | 1,712,598 | 3,609,824 | 1,437,402 | 2,481,526 | 988,123 | 14,343 |
| 2018 | 7,058,543 | 4,550,000 | 1,400,000 | 1,712,598 | 3,945,945 | 1,437,402 | 2,571,174 | 936,610 | 14,343 |
| 2019 | 7,411,471 | 4,550,000 | 1,400,000 | 1,712,598 | 4,298,873 | 1,437,402 | 2,655,109 | 887,782 | 14,343 |
| 2020 | 7,782,044 | 4,550,000 | 1,400,000 | 1,712,598 | 4,669,446 | 1,437,402 | 2,733,637 | 841,499 | 14,343 |
| 2021 | 8,171,146 | 4,550,000 | 1,400,000 | 1,712,598 | 5,058,548 | 1,437,402 | 2,807,042 | 797,629 | 14,343 |
| 2022 | 8,579,704 | 4,550,000 | 1,400,000 | 1,712,598 | 5,467,106 | 1,437,402 | 2,875,597 | 756,047 | 14,343 |
| 2023 | 9,008,689 | 4,550,000 | 1,400,000 | 1,712,598 | 5,896,091 | 1,437,402 | 2,939,559 | 716,632 | 14,343 |
| 2024 | 9,459,123 | 4,550,000 | 1,400,000 | 1,712,598 | 6,346,525 | 1,437,402 | 2,999,173 | 679,272 | 14,343 |
| 2025 | 9,932,079 | 4,550,000 | 1,400,000 | 1,712,598 | 6,819,481 | 1,437,402 | 3,054,671 | 643,860 | 14,343 |
| 2026 | 10,428,683 | 4,550,000 | 1,400,000 | 1,712,598 | 7,316,085 | 1,437,402 | 3,106,271 | 610,294 | 14,343 |
| 2027 | 10,950,118 | 4,550,000 | 1,400,000 | 1,712,598 | 7,837,520 | 1,437,402 | 3,154,183 | 578,477 | 14,343 |
| 2028 | 11,497,623 | 4,550,000 | 1,400,000 | 1,712,598 | 8,385,025 | 1,437,402 | 3,198,601 | 548,320 | 14,343 |
| 2029 | 12,072,505 | 4,550,000 | 1,400,000 | 1,712,598 | 8,959,907 | 1,437,402 | 3,239,715 | 519,734 | 14,343 |
| 2030 | 12,676,130 | 4,550,000 | 1,400,000 | 1,712,598 | 9,563,532 | 1,437,402 | 3,277,699 | 492,639 | 14,343 |
| 2031 | 13,309,936 | 4,550,000 | 1,400,000 | 30,000 | 11,879,936 | 3,120,000 | 3,859,335 | 1,013,568 | 14,343 |
| 2032 | 13,975,433 | 4,550,000 | 1,400,000 | 30,000 | 12,545,433 | 3,120,000 | 3,863,061 | 960,728 | 14,343 |
| **Total** | **182,873,026** | **91,000,000** | **28,000,000** | **36,186,764** | **118,686,262** | **26,813,236** | **52,907,625** | **11,685,325** | **286,852** |



## 20-MW Capacity Ownership

| Year | Cost avoided (high cost ($) | Cost avoided (low cost ($) | Cost of electricity from project ($) | Invest-ment Cost ($) | Net Savings (high cost) ($) | Net Savings (low cost) ($) | Net Savings Dis-counted (high cost) ($) | Net Savings Dis-counted (low cost) ($) | $CO_2$ reduced (met-ric ton) |
|---|---|---|---|---|---|---|---|---|---|
| 2010 | 0 | 0 | 0 | 500,000 | -500,000 | -500,000 | -500,000 | -500,000 | 23,904 |
| 2011 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 23,904 |
| 2012 | 0 | 0 | 0 | 8,000,000 | -8,000,000 | -8,000,000 | -7,187,619 | -7,187,619 | 23,904 |
| 2013 | 9,217,589 | 7,583,333 | 2,333,333 | 2,834,330 | 4,049,926 | 2,415,670 | 3,448,972 | 2,057,218 | 23,904 |
| 2014 | 9,678,469 | 7,583,333 | 2,333,333 | 2,834,330 | 4,510,805 | 2,415,670 | 3,641,197 | 1,949,969 | 23,904 |
| 2015 | 10,162,392 | 7,583,333 | 2,333,333 | 2,834,330 | 4,994,729 | 2,415,670 | 3,821,638 | 1,848,312 | 23,904 |
| 2016 | 10,670,512 | 7,583,333 | 2,333,333 | 2,834,330 | 5,502,848 | 2,415,670 | 3,990,918 | 1,751,955 | 23,904 |
| 2017 | 11,204,037 | 7,583,333 | 2,333,333 | 2,834,330 | 6,036,374 | 2,415,670 | 4,149,625 | 1,660,620 | 23,904 |
| 2018 | 11,764,239 | 7,583,333 | 2,333,333 | 2,834,330 | 6,596,576 | 2,415,670 | 4,298,321 | 1,574,048 | 23,904 |
| 2019 | 12,352,451 | 7,583,333 | 2,333,333 | 2,834,330 | 7,184,788 | 2,415,670 | 4,437,535 | 1,491,988 | 23,904 |
| 2020 | 12,970,073 | 7,583,333 | 2,333,333 | 2,834,330 | 7,802,410 | 2,415,670 | 4,567,769 | 1,414,207 | 23,904 |
| 2021 | 13,618,577 | 7,583,333 | 2,333,333 | 2,834,330 | 8,450,914 | 2,415,670 | 4,689,501 | 1,340,481 | 23,904 |
| 2022 | 14,299,506 | 7,583,333 | 2,333,333 | 2,834,330 | 9,131,843 | 2,415,670 | 4,803,180 | 1,270,598 | 23,904 |
| 2023 | 15,014,481 | 7,583,333 | 2,333,333 | 2,834,330 | 9,846,818 | 2,415,670 | 4,909,236 | 1,204,358 | 23,904 |
| 2024 | 15,765,205 | 7,583,333 | 2,333,333 | 2,834,330 | 10,597,542 | 2,415,670 | 5,008,074 | 1,141,572 | 23,904 |
| 2025 | 16,553,466 | 7,583,333 | 2,333,333 | 2,834,330 | 11,385,802 | 2,415,670 | 5,100,077 | 1,082,058 | 23,904 |
| 2026 | 17,381,139 | 7,583,333 | 2,333,333 | 2,834,330 | 12,213,475 | 2,415,670 | 5,185,611 | 1,025,648 | 23,904 |
| 2027 | 18,250,196 | 7,583,333 | 2,333,333 | 2,834,330 | 13,082,532 | 2,415,670 | 5,265,020 | 972,178 | 23,904 |
| 2028 | 19,162,706 | 7,583,333 | 2,333,333 | 2,834,330 | 13,995,042 | 2,415,670 | 5,338,631 | 921,496 | 23,904 |
| 2029 | 20,120,841 | 7,583,333 | 2,333,333 | 2,834,330 | 14,953,177 | 2,415,670 | 5,406,756 | 873,456 | 23,904 |
| 2030 | 21,126,883 | 7,583,333 | 2,333,333 | 2,834,330 | 15,959,220 | 2,415,670 | 5,469,687 | 827,920 | 23,904 |
| 2031 | 22,183,227 | 7,583,333 | 2,333,333 | 0 | 19,819,894 | 2,415,670 | 6,438,722 | 1,695,777 | 23,904 |
| 2032 | 23,292,388 | 7,583,333 | 2,333,333 | 0 | 20,929,055 | 2,415,670 | 6,444,593 | 1,607,372 | 23,904 |
| **Total** | **304,788,377** | **151,666,667** | **46,666,666** | **59,577,940** | **88,634,201** | **45,422,059** | **88,727,445** | **20,023,611** | **478,087** |



## *Biofuel Assumptions*

**GHG Emissions**

1. Modern carbon emissions are not included in emissions figures because modern carbon is taken out of the atmosphere by plants and becomes the oil, which is then burned. This carbon cycle ensures that all carbon that is emitted through burning of the biofuel was recently taken out of the atmosphere by the crops used to produce it.

2. Biofuel emits 90% less carbon dioxide than #6 fuel oil over the life cycle of the fuel using the EPA report, EPA emissions statistics, and comparing the processes of producing biodiesel versus biofuel.

3. Data predictions (primarily EIA Price Projections) are accurate enough to give a sense of future costs of different options. It is very hard to predict the price of oil in the future, and though the EIA is likely to have some of the most thoroughly-researched statistics, even they are likely to be inaccurate. Most important is the relative cost of #6 oil to #2 oil (which is also the cost of biofuel); #2 must become closer to #6 to make biofuel viable.

4. Biofuel will run smoothly in the power plant equipment into the future without unforeseen difficulties. This will be judged by the power plant operators. Test burns at other facilities have shown that the biofuel runs smoothly, but we need to conduct tests on Dartmouth's equipment.

**Calculation Assumptions**

| | |
|---|---|
| 1. Gallons of #6 burned per year (gallons) | 5,000,000 |
| 2. Years of production | 20 years |
| | |
| 3. Total cost installation ($) | $0 (no alterations needed) |
| 4. Time period of paying back loan | No payback for biofuel |
| | |
| 5. Current price of AMENICO biofuel ($/mmBTU) based on # 2 prices | $2.302 (high); $1.969 (low) |
| 6. Current price of #6 fuel oil ($/mmBTU) | $1.048 (high); $1.035 (low) |
| 7. Current price of #2 fuel oil ($/mmBTU) | $2.302 (high); $1.969 (low) |
| 8. Projected annual rate of increase in the price of #2 oil/biofuel for "high cost" estimate (%) | 3.5% |
| 9. Projected annual rate of increase in the price of #2 oil/biofuel for "low cost" estimate (%) | 1.8% |
| 10. Projected annual rate of increase in the price of #6 oil for | 5.3% |

| | |
|---|---|
| "high cost" estimate (%) | |
| 11. Projected annual rate of increase in the price of #6 oil for "low cost" estimate (%) | 3.5% |
| | |
| 12. Life Cycle Analysis for Biofuel emissions (mt CO2/mmBtu) | 0.07425 |

**Assumption 1:**
From "ANNUAL TOTALS 2007/2008," Dartmouth College Cogeneration Plant
-Boiler Plant Oil Consumption Totals:

-2007: 5,047,334
-2008: 4,862,543

**Assumption 2:**
Production duration limited solely by need (assume the supply of biofuel does not run out).

**Assumption 3:**
The CEO of Amenico states that no changes will need to be to the cogeneration plant boilers. Test burns on boilers that burn #6 oil demonstrate this. A test burn at Dartmouth in early December will likely confirm this.

**Assumption 5, 6, 7, 8, 9, 10, 11:**
EIA Annual Energy Outlook 2009. "High Price Case" and "Published Reference Case" Projection Tables use for "high cost" and "low cost" respectively. Current prices used in calculations are these projected figures, though actual prices are:

-#2 oil: $1.96 (as of Nov. 29 from NYMEX exchange)
-#6 oil: 0.5% sulfur content - $1.577; 1.0% sulfur content - $1.324 (from Bill Riehl)

These actual prices were not used because their sources did not provide price projections. Since we decided to use price projections from the EIA, we decided to use the current prices that they projected for consistency (which are in fact close to the true prices).

**Assumption 12:**
Figures used provided by Tony Giunta of Amenico. This takes into account transportation of WVO from restaurants and other suppliers to Amenico, the electricity and BioFuel that goes into processing BioFuel, transportation to Dartmouth, and burning of the BioFuel. See calculations below.

## Life Cycle Analysis Calculations:

| | | |
|---|---|---|
| Looking at the Life Cycle Analysis of One Gallon of Biofuel | | |
| TRANSPORTATION TO AMENICO | | |
| Miles their 2 transportation trucks drive in a year | 52000 | miles/year |
| Gallons diesel used for that distance (assume 15 mpg/truck) | 3466.67 | gal/yr |
| $CO_2$ emissions from that amount of diesel used | 30506.67 | kg CO2/yr |
| $CO_2$ emissions per gallon biofuel (assume 3,500,000 gal biofuel produced by Amenico per year) | 0.008716 | kg CO2/gal |
| $CO_2$ emissions per gallon biofuel | 8.71619E-06 | mt CO2/gal |
| | | |
| PROCESSING USING AMENICO BIOFUEL | | |
| Gallons used to produce one gallon of biofuel | 0.007 | gal |
| $CO_2$ emissions per gallon biofuel | 0.06784 | kg CO2/gal |
| $CO_2$ emissions per gallon biofuel | 6.7846E-05 | mt CO2/gal |
| | | |
| PROCESSING USING ELECTRICITY FROM THE GRID | | |
| Dollars spent on one gallon of finished biofuel | $0.01 | $/gallon |
| Kilowatts consumed per gallon of fuel, where cost is $.12/kWh | 0.08 kw | kW |
| $CO_2$ Emissions: assume .000420789 metric ton/kwh | 3.3663E-05 | mt CO2/gal |
| | | |
| FUEL DELIVERY TO HANOVER | | |
| Distance Travelled from Pittsfield to Hanover | 82 | mi |
| Roundtrip Distance to Hanover and back to Pittsfield | 164 | mi |
| Gallons diesel/biofuel mix used: assume 5 mpg for transport rig | 32.8 | gal |
| $CO_2$ emissions: assume 9.6924 kg $CO_2$/gallon | 317.91 | kg |
| $CO_2$ emissions (metric tons) | 0.31791 | mt |
| $CO_2$ emissions per gallon biofuel (assume transportation rig delivers 9000 gallons of biofuel) | 3.5323E-05 | mt CO2/gal |
| | | |
| FUEL COMBUSTION | | |
| $CO_2$ Emissions (kg): assume 9.6924 kg $CO_2$/gallon of biofuel | 9.6924 | kg CO2/gal |
| $CO_2$ emissions per gallon biofuel | 0.0096924 | mt CO2/gal |
| | | |
| TOTAL | | |
| Total $CO_2$ Emissions Attributable to One Gallon of Biofuel (mt) | 0.009838 | mt CO2/gal |
| Total $CO_2$ Emissions Attributable to One BTU of biofuel energy (mt) (assume 132,500 BTUs/gallon) | 7.4249E-08 | mt CO2/btu |
| Total $CO_2$ Emissions Attributable to 1 mmBTU of biofuel energy (mt) | 0.07425 | mt CO2/mBtu |

*Geothermal Assumptions*

1. COP of ground source heat pumps = 3

2. All closed-loop wells (standing columns are cheaper per btu, but more dependent on variable geology)

3. Each closed-loop well requires a spacing of 30 feet

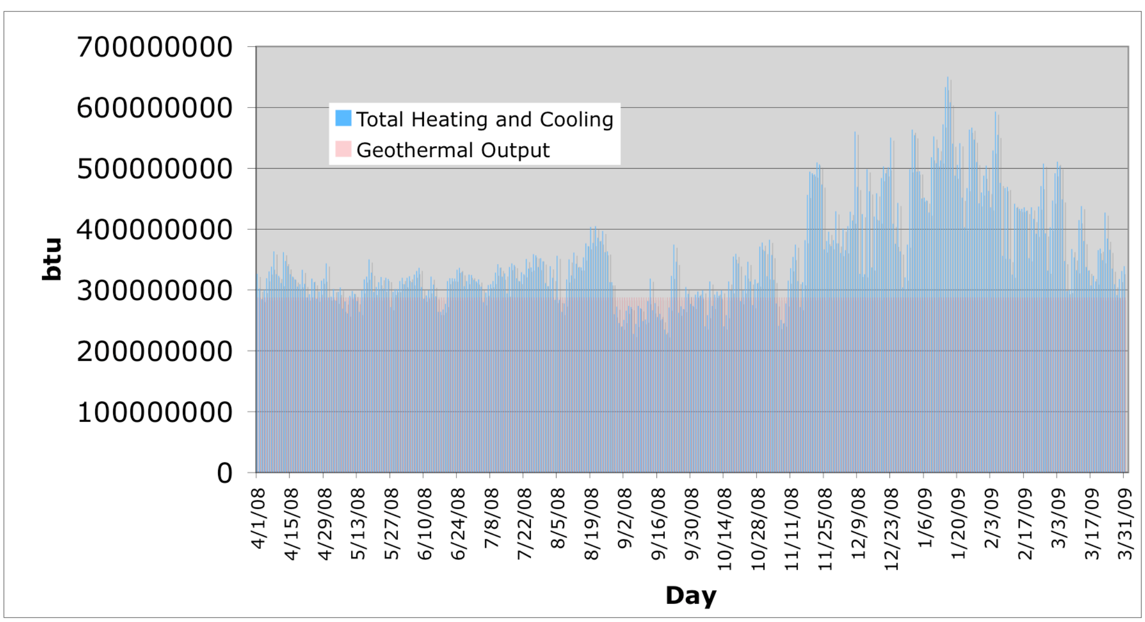
4. Each well has a constant output of 24,000 btus/hr.

5. Wells are estimated to cost $5,500 each (based on Ball State University costs)

6. Costs for converting buildings to low temperature hot water system: $5/sqft for new buildings. $8/sqft for buildings that will be majorly retrofitted under the efficiency scenario. $12/sqft is used for converting the rest of campus (a mid point between a very high cost of $15 for very old buildings and 10$ for more recent buildings). Based on communications with Ball State University and Bill Johnson.

7. Heating and cooling data from "Utility Billing History," FY 2009, Steve Shadford

8. Installation sizes were based on an industry standard of supplying 80% of combined heating and cooling load. Heating and cooling loads were determine using daily heating and cooling data from Steve Shadford (above) to account for the distribution of peak loads. Where the goethermal output is higher than demand, the excess was not counted as savings. An example of a graph is provided below:



*Solar Thermal Assumptions*

1. We assume that hot water produced by installations on Berry Sports Center, Leverone Field House, Thompson Arena, and the Central Chilled Water Plant can be pumped back to the central boiler with 75% efficiency and therefore DHW load is unlimited for these buildings.

2. We assume that DHW consumption can be divided into rough categories of hot water consumption estimated from the Hopkins Center (a public building with food establishment = 5000 BTU spent on hot water/$ft^3$ cold water consumed) and North Hall data (sustainability dormitory = 2500 BTU/$ft^3$), the only available campus data on hot water consumption. The categories we use for hot water consumption are library (~2000BTU/$ft^3$), public space (~2000/$ft^3$), dormitory (~3000/$ft^3$), laboratory (~5000/$ft^3$) and other unique buildings for which we did rough estimates. The dormitory numbers were rounded up from north hall data produced by a student as part of a honors thesis. The numbers were rounded up approximately 30%, which is on average what washing machines and extended showers contribute to a hot water bill, both things which have been eliminated in the SLC (north hall).

3. We assume that annual cold water usage can be reasonably estimated by multiplying quarterly water usage by 4.

4. We assume that of available roof space with direct sunlight, 65% of that surface area would be covered by solar thermal. The loss in space reflects the framing of the solar thermal panels, the necessary tilt of the panels, and maintenance space between the panels. This number was attained through S.O.L.I.D. solar estimates and other quotes held on record by Steve Shadford.

5. We assume that 675 therms can be produced annually for every 360 square feet of solar panel (about 35% efficiency). This is from experimental data from a study done in Canaan, NH. The Study was quoted by ReKnew solar as a reliable measure of overall system BTU production.

6. We assume roughly $59 per square feet of installation initial cost. This figure was obtained from the S.O.L.I.D. solar estimate for McKenzie hall.

7. We assume that there is about 75% efficient production and transmission of steam by the central boiler plant, on average. This number was attained from Steve Shadford.

8. Maintenance costs were divided into parts costs and labor sots and then subdivided into costs per panel, and costs that are independent of the number of panels. The annual price of each type of maintenance was estimated by ReKnew solar. It was assumed that maintenance warranty would be similar to that of the S.O.L.I.D. McKenzie

installation with labor being covered fully for the first 5 years and parts being covered fully for the first 15 years.

9. For calculating BTU production that can be mapped out over the course of the year (takes into account the seasonality of solar thermal hot water production), we used SRCC ratings for the gluatmugl 212' solar panels which S.O.L.I.D. reported it would use on a campus wide installation. The relative efficiency of the panels had to be adjusted so that the average annual efficiency matched that of the experimental data from the Canaan, NJ study. These numbers were used in conjunction with both Hanover records of sun irradiance and temperature on a monthly basis.

10. It was assumed that kWh of energy used to pump glycol through the system was a number that varied directly with square footage of the panels, because it was assumed htat square footage of the panels directly correlated to the volume of propylene gycol in the system. The numbers for kWh of energy consumed were therefore extrapolated from product data on the heliopak, the system proposed for use by ReKnew solar on the Sustainable Living Center.

**Assumptions For Campus-Wide Installation**

1. Annual average BTU output of the solar panels are used and maximum BTU output is capped at the average annual domestic hot water load of each building.

**Assumptions For Combination With Geothermal**

1. Current calculations do not take into consideration the seasonality of the domestic hot water load. (see explanation in main section of report)

**APPENDIX C: Cost Projections and Energy Production**

| | 2030 Projections with SECP Measures (MMBTU) | % of total demand- SECP measures | 2030 Projections with SECP-CW Measures (MMBTU) | % of total demand-SECP-CW |
|---|---|---|---|---|
| *Steam Demand in 2030* | *458,856* | | *315,507* | |
| | | | | |
| Energy made through Geothermal | 277,380 | 60% | 277,380 | 88% |
| Energy made through Solar Thermal | 27,310 | 6% | 27,310 | 9% |
| **TOTAL MMBTU NEEDED (from biomass, biofuels, or electric boilers)** | 154,166 | 34% | 10,817 | 3% |
| | | | | |
| | | | | |
| | | | | |
| | **2030 Projections with SECP Measures (kWh)** | **% of total demand- SECP measures** | **2030 Projections with SECP-CW Measures (kWh)** | **% of total demand-SECP-CW** |
| *Total Electricity Demand:* | *54,590,174* | | *45,568,766* | |
| | | | | |
| Geothermal | -20,435,895 | | -20,435,895 | |
| ST | -338,058 | | -338,058 | |
| Wind-full ownership | 58,333,333 | 77% | 58,333,333 | 88% |
| Electricity Co-Generated | 8,973,723 | 12% | 629,664 | 1% |
| **TOTAL ELECTRICITY TO PURCHASE** | 8,057,071 | 11% | 7,379,722 | 11% |

**Table IV: Meeting energy demand in 2030:** energy is broken down into steam and electricity. The italicized numbers take into account the projected demand with SECP measures and SECP-campus wide measures. After considering steam, we will need 3-34% from biomass, biofuels or electric boilers, plus additional capacity for backup. Geothermal and solar thermal systems require electricity, so that is taken into account for the total electricity demand, and some electricity will be co-generated if we pursue biofuels or biomass.

Solar Thermal, Geothermal and Wind Installations

**2010**
ST: SLC
Wind: Pre-development
Efficiency: Phase 1
**2011**
ST: McKenzie, President Kim's House
Wind: Prevelopment
**2012**
ST + GT: Visual Arts Center
Wind: Project goes live
**2013**
ST: Berry Sports Center, Leverone, Thompson, Alumni Hall
GT: Life Sciences, DMS
ST + GT: McLaughlin Cluster
**2014**
ST: Fahey McLane
GT: Central Well Field
**2015**
ST: Baker Library, Tuck, Phase 1 Dorms
Efficiency: Phase 2
**2016**
ST + GT: Kemeny/Haldemann, Moore
**2017**
**2018**
ST + GT: Burke Fairchild, Steele
GT: Wilder
**2019**
ST: Remsen, Maclean, Central Chilled water plant, rest of Phase 2 buildings
GT: New Academic Building
**2020**
GT: New Science Building

**Figure IX: Proposed plan of installations**

| | | | | | | |
|---|---|---|---|---|---|---|
| Technology: 2010-2030 | Geothermal | | | | | |
| Scenario Description | Total Investment Costs | % Total Heating Demand in 2030 w/High Energy efficiency plan | Total Net CO2 Emissions Reduced | | | |
| All installations | $41,764,187 | 88% | 685,481 | | | |
| | High Energy Costs | | | Low Energy Costs | | |
| | SIMPLE PAYBACK (yrs) | Net Present Value | Cost per CO2 Reduced ($/metric ton) | SIMPLE PAYBACK (yrs) | Net Present Value | Cost per CO2 Reduced ($/metric ton) |
| All installations | 12 | $365,095 | -$0.53 | 16 | -$6,914,595 | $10.09 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Technology: 2010-2030 | Solar Thermal | | | | | |
| Scenario Description | Total Costs over 20 years | % Total Heating Demand in 2030 w/High Energy efficiency plan | Total Net CO2 Emissions Reduced | | | |
| Entire Project | $10,205,135 | 9% | 81,474 | | | |
| | High Energy Costs | | | Low Energy Costs | | |
| | SIMPLE PAYBACK (yrs) | Net Present Value | Cost per CO2 Reduced (/metric ton) | SIMPLE PAYBACK (yrs) | Net Present Value | Cost per CO2 Reduced (/metric ton) |
| Entire Project | 13 | $1,667,755 | -$20.47 | over 20 years | -$3,161,767 | $38.81 |

**Table V: Costs, Payback Period, NPV, Cost per CO2 Reduced, and Total New $CO_2$ Emissions for geothermal and solar thermal projects**

| | | | | | | |
|---|---|---|---|---|---|---|
| Technology: 2010-2030 | Wind | | | | | |
| Scenario Description | Total Costs over 20 years | % of Total Electricity Demand w/ High Efficiency Plan | Total Net CO2e Reduced | | | |
| 1) Power Purchase Agreement | $105,000,000 | 36% | 286,852 | | | |
| 2) 12-MW Capacity Ownership | $64,186,764 | 36% | 286,852 | | | |
| 3) 20-MW Capacity Ownership | $106,244,606 | 60% | 483,220 | | | |
| | High Energy Costs | | | Low Energy Costs | | |
| | SIMPLE PAYBACK (yrs) | Net Present Value | Cost per CO2 Reduced ($/metric ton) | SIMPLE PAYBACK (yrs) | Net Present Value | Cost per CO2 Reduced ($/metric ton) |
| 1) Power Purchase Agreement | n/a | $33,706,506 | -$264.38 | n/a | -$7,515,795 | $47.53 |
| 2) 12-MW Capacity Ownership | 5 | $52,907,626 | -$402.94 | 9 | $11,685,325 | -$91.03 |
| 3) 20-MW Capacity Ownership | 5 | $88,727,455 | -$404.43 | 9 | $20,023,611 | -$92.52 |

**Table VI: Costs, Payback Period, NPV, Cost per CO2 reduced, and Total New $CO_2$ Emissions for different approaches to the wind project.**

| Technology: 2010-2030 | Efficiency -- from Strategic Energy Highlights Plan | | | | | |
|---|---|---|---|---|---|---|
| Scenario Description | Total Investment Costs | % Reduction of Total Heating Demand in 2030 | % Reduction of Total Electricity Demand in 2030 | Total Net CO2 Emissions Reduced | | |
| 1) Phase 1 Only (25 bldgs) | $10,579,942 | 35% | 15% | 556,204 | | |
| 2) Campus-Wide Implementation (Phase 1 & Phase 2) | $23,523,528 | 56% | 29% | 819,108 | | |
| | High Energy Costs | | | Low Energy Costs | | |
| | SIMPLE PAYBACK (yrs) | Net Present Value | Cost per CO2 Reduced ($/metric ton) | SIMPLE PAYBACK (yrs) | Net Present Value | Cost per CO2 Reduced ($/metric ton) |
| 1) Phase 1 Only (25 bldgs) | 1.00 | 106,412,225 | -$191.32 | 1.59 | 64,249,519 | -$115.51 |
| 2) Campus-Wide Implementation (Phase 1 & Phase 2) | 0.65 | 152,802,633 | -$186.55 | 1.05 | 89,537,454 | -$109.31 |

**Table VII: Costs, Payback Period, NPV, Cost per CO2 Reduced, and Total New $CO_2$ Emissions for efficiency**

The following tables compare all possible projects we considered of all of the technologies we researched. Each is sorted by a different criterion (one of the columns). The scenarios that perform best in this criterion appear at the top of the table. The data is divided into *High Energy Costs* and *Low Energy Costs*. Low costs are taken from the EIA "published" energy cost predictions. High costs are based on the EIA "high" projections. This is explained in the "Assumptions" section of the report. *LE* stands for low efficiency and indicates that the scenario assumes that campus remains as it is; *HE* stands for high efficiency and describes the installation in the hypothetical circumstance of improved campus energy efficiency.

## Essential note: Caution regarding biomass figures

Though the following tables make biomass seem very appealing, the carbon dioxide emissions numbers are only taking into account fossil carbon, in which case biomass is close to carbon neutral. Yet there is strong opposition in the environmental world against looking only at fossil carbon because fuel is still burned, and carbon is still released. Even though the EPA and IPCC look primarily at fossil carbon, the true total carbon emissions of biomass-modern carbon included-are as high if not higher than No. 6 fuel oil. Whether one includes modern carbon is currently a point of debate in the environmental world. The following biomass numbers are only one side of the debate and should not be accepted blindly.

**Table VIII:**

| Sorted by Payback for High Energy Costs | | | | | | | |
|---|---|---|---|---|---|---|---|
| | High Energy Costs | | | Low Energy Costs | | | |
| Scenario Description | Payback Period (yrs) | Net Present Value ($) | Cost per CO2 Reduced ($/metric ton) | Payback Period (yrs) | Net Present Value ($) | Cost per CO2 Reduced ($/metric ton) | Total Net CO2 Emissions Reduced (metric tons) |
| Energy Efficiency 2) Campus-Wide Implementation (Phases 1 & 2) | **0.79** | 121,934,014 | -149 | 1.29 | 69,717,584 | -85 | 819,108 |
| Energy Efficiency 1) Phase 1 (25 Buildings) | **1.25** | 82,772,665 | -149 | 2.02 | 48,877,401 | -88 | 556,204 |
| Geothermal LE 1) Visual Arts Center | **2** | 699,328 | -137 | 4 | 434,140 | -85 | 5,100 |
| Geothermal LE 5) New Academic Building | **2** | 36,520 | -136 | 5 | 22,684 | -85 | 268 |
| Geothermal HE 5) New Academic Building | **2** | 36,520 | -136 | 5 | 22,684 | -85 | 268 |
| Geothermal LE 6) New Science Building | **2** | 1,520,816 | -82 | 5 | 944,484 | -51 | 18,495 |
| Geothermal HE 6) New Science Building | **3** | 1,520,816 | -136 | 6 | 944,484 | -84 | 11,201 |
| Geothermal HE 1) Visual Arts Center | **5** | 657,254 | -136 | 5 | 408,252 | -85 | 4,825 |
| Geothermal LE 3) Kemeny Haldeman Moore | **5** | 2,791,315 | -99 | 9 | 1,348,734 | -48 | 28,120 |
| Geothermal HE 3) Kemeny, Haldeman, Moore | **5** | 2,791,315 | -99 | 9 | 1,348,734 | -48 | 28,120 |
| Geothermal LE 2) McLaughlin, DMS, Life Sciences Center | **5** | 8,979,301 | -98 | 9 | 4,276,404 | -47 | 91,619 |
| Geothermal HE 2) McLaughlin, DMS, Life Sciences Center | **5** | 8,979,301 | -98 | 9 | 4,276,404 | -47 | 91,619 |
| Wind 3) 20-MW Capacity Ownership | **5** | 88,727,445 | -404 | 9 | 20,023,611 | -93 | 490,920 |
| Wind 2) 12-MW Capacity Ownership | **5** | 52,907,625 | -403 | 9 | 11,685,325 | -91 | 294,552 |
| Solarthermal 2) McKenzie | **5** | 429,175 | -151 | 11 | 13,977 | -5 | 2,835 |
| Geothermal HE 4) Burke, Steele, Wilder, Fairchild | **8** | 1,244,233 | -48 | 13 | -74,630 | 3 | 25,717 |
| Geothermal LE 4) Burke, Steele, Wilder, Fairchild | **9** | 1,244,233 | -48 | 13 | -74,630 | 3 | 25,717 |
| Solarthermal 1) SLC | **11** | 3,361 | -20 | 17 | -9,142 | 55 | 167 |
| Solarthermal 3) Visual Arts Center | **11** | 25,772 | -10 | 18 | -238,843 | 91 | 2,629 |
| Solarthermal 4) Rest of Campus, Phase 1 | **13** | -473,638 | 17 | 20 | -2,496,368 | 91 | 27,484 |
| Solarthermal 5) Rest of Campus, Phase 2 | **17** | -1,535,038 | 81 | 26 | -2,922,216 | 154 | 18,995 |
| Geothermal LE 7) Rest of Campus | **17** | -13,553,485 | 80 | 23 | -24,048,863 | 142 | 169,319 |
| Geothermal HE 7) Rest of Campus | **21** | -9,143,000 | 69 | 24 | -15,960,792 | 120 | 132,807 |
| Solarthermal 6) Rest of Campus with GWSHPs | **26** | -6,218,283 | 240 | 41 | -8,126,076 | 314 | 25,879 |
| Solar PV 1) Parking Lot Installations | **31** | -27,766,224 | 471 | 53 | -33,629,827 | 570 | 58,971 |
| Biomass - Woodfuels 1) HE Remaining Demand = 12,685 mmBTU/year | **N/A** | 2,018,371 | -97 | N/A | 260,981 | -12 | 20,881 |
| Biomass - Woodfuels 3) 250 HP Boiler = 72,927 mmBTU/year | **N/A** | 6,416,111 | -53 | N/A | 2,107,060 | -18 | 120,046 |
| Biomass - Woodfuels 7) LE Total Load = 458856 mmBTU/year | **N/A** | 22,697,656 | -30 | N/A | 2,510,506 | -3 | 755,326 |
| Biomass - Woodfuels 6) HE Total Load = 315506 mmBTU/year | **N/A** | 15,606,741 | -30 | N/A | 4,395,515 | -8 | 519,357 |
| Biomass - Woodfuels 5) 1000 HP Boiler = 291,708 mmBTU/year | **N/A** | 14,429,555 | -30 | N/A | 2,321,144 | -5 | 480,183 |
| Biomass - Woodfuels 4) 500 HP Boiler = 145,854 mmBTU/year | **N/A** | 7,214,777 | -30 | N/A | 1,160,572 | -5 | 240,091 |
| Biomass - Woodfuels 2) LE Remaining Demand = 65,083 mmBTU/year | **N/A** | 3,219,379 | -30 | N/A | 517,871 | -5 | 107,134 |
| WInd 1) Power Purchase Agreement | **N/A** | 33,706,506 | -264 | N/A | -7,515,795 | 48 | 294,552 |
| Biofuel LE 3) 100% of Energy Demand | **N/A** | 0 | 0 | N/A | -249,874 | 5 | 96,420 |
| Biofuel LE 2) 67% of Energy Demand | **N/A** | 0 | 0 | N/A | -167,416 | 5 | 64,602 |
| Biofuel LE 1) 33% of Energy Demand | **N/A** | 0 | 0 | N/A | -82,458 | 5 | 31,819 |
| Biofuel HE 3) 100% of Energy Demand | **N/A** | 0 | 0 | N/A | -48,702 | 5 | 18,793 |
| Biofuel HE 2) 67% of Energy Demand | **N/A** | 0 | 0 | N/A | -32,630 | 5 | 12,591 |
| Biofuel HE 1) 33% of Energy Demand | **N/A** | 0 | 0 | N/A | -16,072 | 5 | 6,202 |

**Table IX:**

## Sorted by Net Present Value for High Energy Costs

| | High Energy Costs | | | Low Energy Costs | | | |
|---|---|---|---|---|---|---|---|
| Scenario Description | Payback Period (yrs) | Net Present Value ($) | Cost per CO2 Reduced ($/metric ton) | Payback Period (yrs) | Net Present Value ($) | Cost per CO2 Reduced ($/metric ton) | Total Net CO2 Emissions Reduced (metric tons) |
| Energy Efficiency 2) Campus-Wide Implementation (Phases 1 & 2) | 0.79 | **121,934,014** | -149 | 1.29 | 69,717,584 | -85 | 819,108 |
| Wind 3) 20-MW Capacity Ownership | 5 | **88,727,445** | -404 | 9 | 20,023,611 | -93 | 490,920 |
| Energy Efficiency 1) Phase 1 (25 Buildings) | 1.25 | **82,772,665** | -149 | 2.02 | 48,877,401 | -88 | 556,204 |
| Wind 2) 12-MW Capacity Ownership | 5 | **52,907,625** | -403 | 9 | 11,685,325 | -91 | 294,552 |
| WInd 1) Power Purchase Agreement | N/A | **33,706,506** | -264 | N/A | -7,515,795 | 48 | 294,552 |
| Biomass - Woodfuels 7) LE Total Load = 458856 mmBTU/year | N/A | **22,697,656** | -30 | N/A | 2,510,506 | -3 | 755,326 |
| Biomass - Woodfuels 6) HE Total Load = 315506 mmBTU/year | N/A | **15,606,741** | -30 | N/A | 4,395,515 | -8 | 519,357 |
| Biomass - Woodfuels 5) 1000 HP Boiler = 291,708 mmBTU/year | N/A | **14,429,555** | -30 | N/A | 2,321,144 | -5 | 480,183 |
| Geothermal LE 2) McLaughlin, DMS, Life Sciences Center | 5 | **8,979,301** | -98 | 9 | 4,276,404 | -47 | 91,619 |
| Geothermal HE 2) McLaughlin, DMS, Life Sciences Center | 5 | **8,979,301** | -98 | 9 | 4,276,404 | -47 | 91,619 |
| Biomass - Woodfuels 4) 500 HP Boiler = 145,854 mmBTU/year | N/A | **7,214,777** | -30 | N/A | 1,160,572 | -5 | 240,091 |
| Biomass - Woodfuels 3) 250 HP Boiler = 72,927 mmBTU/year | N/A | **6,416,111** | -53 | N/A | 2,107,060 | -18 | 120,046 |
| Biomass - Woodfuels 2) LE Remaining Demand = 65,083 mmBTU/year | N/A | **3,219,379** | -30 | N/A | 517,871 | -5 | 107,134 |
| Geothermal LE 3) Kemeny Haldeman Moore | 5 | **2,791,315** | -99 | 9 | 1,348,734 | -48 | 28,120 |
| Geothermal HE 3) Kemeny, Haldeman, Moore | 5 | **2,791,315** | -99 | 9 | 1,348,734 | -48 | 28,120 |
| Biomass - Woodfuels 1) HE Remaining Demand = 12,685 mmBTU/year | N/A | **2,018,371** | -97 | N/A | 260,981 | -12 | 20,881 |
| Geothermal LE 6) New Science Building | 2 | **1,520,816** | -82 | 5 | 944,484 | -51 | 18,495 |
| Geothermal HE 6) New Science Building | 3 | **1,520,816** | -136 | 6 | 944,484 | -84 | 11,201 |
| Geothermal HE 4) Burke, Steele, Wilder, Fairchild | 8 | **1,244,233** | -48 | 13 | -74,630 | 3 | 25,717 |
| Geothermal LE 4) Burke, Steele, Wilder, Fairchild | 9 | **1,244,233** | -48 | 13 | -74,630 | 3 | 25,717 |
| Geothermal LE 1) Visual Arts Center | 2 | **699,328** | -137 | 4 | 434,140 | -85 | 5,100 |
| Geothermal HE 1) Visual Arts Center | 5 | **657,254** | -136 | 5 | 408,252 | -85 | 4,825 |
| Solarthermal 2) McKenzie | 5 | **429,175** | -151 | 11 | 13,977 | -5 | 2,835 |
| Geothermal LE 5) New Academic Building | 2 | **36,520** | -136 | 5 | 22,684 | -85 | 268 |
| Geothermal HE 5) New Academic Building | 2 | **36,520** | -136 | 5 | 22,684 | -85 | 268 |
| Solarthermal 3) Visual Arts Center | 11 | **25,772** | -10 | 18 | -238,843 | 91 | 2,629 |
| Solarthermal 1) SLC | 11 | **3,361** | -20 | 17 | -9,142 | 55 | 167 |
| Biofuel LE 3) 100% of Energy Demand | N/A | **0** | 0 | N/A | -249,874 | 5 | 96,420 |
| Biofuel LE 2) 67% of Energy Demand | N/A | **0** | 0 | N/A | -167,416 | 5 | 64,602 |
| Biofuel LE 1) 33% of Energy Demand | N/A | **0** | 0 | N/A | -82,458 | 5 | 31,819 |
| Biofuel HE 3) 100% of Energy Demand | N/A | **0** | 0 | N/A | -48,702 | 5 | 18,793 |
| Biofuel HE 2) 67% of Energy Demand | N/A | **0** | 0 | N/A | -32,630 | 5 | 12,591 |
| Biofuel HE 1) 33% of Energy Demand | N/A | **0** | 0 | N/A | -16,072 | 5 | 6,202 |
| Solarthermal 4) Rest of Campus, Phase 1 | 13 | **-473,638** | 17 | 20 | -2,496,368 | 91 | 27,484 |
| Solarthermal 5) Rest of Campus, Phase 2 | 17 | **-1,535,038** | 81 | 26 | -2,922,216 | 154 | 18,995 |
| Solarthermal 6) Rest of Campus with GWSHPs | 26 | **-6,218,283** | 240 | 41 | -8,126,076 | 314 | 25,879 |
| Geothermal HE 7) Rest of Campus | 21 | **-9,143,000** | 69 | 24 | -15,960,792 | 120 | 132,807 |
| Geothermal LE 7) Rest of Campus | 17 | **-13,553,485** | 80 | 23 | -24,048,863 | 142 | 169,319 |
| Solar PV 1) Parking Lot Installations | 31 | **-27,766,224** | 471 | 53 | -33,629,827 | 570 | 58,971 |

**Table X:**

## Sorted by Cost per CO2 Reduced for High Energy Costs

| | High Energy Costs | | | Low Energy Costs | | | |
|---|---|---|---|---|---|---|---|
| Scenario Description | Payback Period (yrs) | Net Present Value ($) | Cost per CO2 Reduced ($/metric ton) | Payback Period (yrs) | Net Present Value ($) | Cost per CO2 Reduced ($/metric ton) | Total Net CO2 Emissions Reduced (metric tons) |
| Wind 3) 20-MW Capacity Ownership | 5 | 88,727,445 | **-404** | 9 | 20,023,611 | -93 | 490,920 |
| Wind 2) 12-MW Capacity Ownership | 5 | 52,907,625 | **-403** | 9 | 11,685,325 | -91 | 294,552 |
| WInd 1) Power Purchase Agreement | N/A | 33,706,506 | **-264** | N/A | -7,515,795 | 48 | 294,552 |
| Solarthermal 2) McKenzie | 5 | 429,175 | **-151** | 11 | 13,977 | -5 | 2,835 |
| Energy Efficiency 2) Campus-Wide Implementation (Phases 1 & 2) | 0.79 | 121,934,014 | **-149** | 1.29 | 69,717,584 | -85 | 819,108 |
| Energy Efficiency 1) Phase 1 (25 Buildings) | 1.25 | 82,772,665 | **-149** | 2.02 | 48,877,401 | -88 | 556,204 |
| Geothermal LE 1) Visual Arts Center | 2 | 699,328 | **-137** | 4 | 434,140 | -85 | 5,100 |
| Geothermal LE 5) New Academic Building | 2 | 36,520 | **-136** | 5 | 22,684 | -85 | 268 |
| Geothermal HE 5) New Academic Building | 2 | 36,520 | **-136** | 5 | 22,684 | -85 | 268 |
| Geothermal HE 1) Visual Arts Center | 5 | 657,254 | **-136** | 5 | 408,252 | -85 | 4,825 |
| Geothermal HE 6) New Science Building | 3 | 1,520,816 | **-136** | 6 | 944,484 | -84 | 11,201 |
| Geothermal LE 3) Kemeny Haldeman Moore | 5 | 2,791,315 | **-99** | 9 | 1,348,734 | -48 | 28,120 |
| Geothermal HE 3) Kemeny, Haldeman, Moore | 5 | 2,791,315 | **-99** | 9 | 1,348,734 | -48 | 28,120 |
| Geothermal LE 2) McLaughlin, DMS, Life Sciences Center | 5 | 8,979,301 | **-98** | 9 | 4,276,404 | -47 | 91,619 |
| Geothermal HE 2) McLaughlin, DMS, Life Sciences Center | 5 | 8,979,301 | **-98** | 9 | 4,276,404 | -47 | 91,619 |
| Biomass - Woodfuels 1) HE Remaining Demand = 12,685 mmBTU/year | N/A | 2,018,371 | **-97** | N/A | 260,981 | -12 | 20,881 |
| Geothermal LE 6) New Science Building | 2 | 1,520,816 | **-82** | 5 | 944,484 | -51 | 18,495 |
| Biomass - Woodfuels 3) 250 HP Boiler = 72,927 mmBTU/year | N/A | 6,416,111 | **-53** | N/A | 2,107,060 | -18 | 120,046 |
| Geothermal HE 4) Burke, Steele, Wilder, Fairchild | 8 | 1,244,233 | **-48** | 13 | -74,630 | 3 | 25,717 |
| Geothermal LE 4) Burke, Steele, Wilder, Fairchild | 9 | 1,244,233 | **-48** | 13 | -74,630 | 3 | 25,717 |
| Biomass - Woodfuels 7) LE Total Load = 458856 mmBTU/year | N/A | 22,697,656 | **-30** | N/A | 2,510,506 | -3 | 755,326 |
| Biomass - Woodfuels 6) HE Total Load = 315506 mmBTU/year | N/A | 15,606,741 | **-30** | N/A | 4,395,515 | -8 | 519,357 |
| Biomass - Woodfuels 5) 1000 HP Boiler = 291,708 mmBTU/year | N/A | 14,429,555 | **-30** | N/A | 2,321,144 | -5 | 480,183 |
| Biomass - Woodfuels 4) 500 HP Boiler = 145,854 mmBTU/year | N/A | 7,214,777 | **-30** | N/A | 1,160,572 | -5 | 240,091 |
| Biomass - Woodfuels 2) LE Remaining Demand = 65,083 mmBTU/year | N/A | 3,219,379 | **-30** | N/A | 517,871 | -5 | 107,134 |
| Solarthermal 1) SLC | 11 | 3,361 | **-20** | 17 | -9,142 | 55 | 167 |
| Solarthermal 3) Visual Arts Center | 11 | 25,772 | **-10** | 18 | -238,843 | 91 | 2,629 |
| Biofuel LE 3) 100% of Energy Demand | N/A | 0 | **0** | N/A | -249,874 | 5 | 96,420 |
| Biofuel LE 2) 67% of Energy Demand | N/A | 0 | **0** | N/A | -167,416 | 5 | 64,602 |
| Biofuel LE 1) 33% of Energy Demand | N/A | 0 | **0** | N/A | -82,458 | 5 | 31,819 |
| Biofuel HE 3) 100% of Energy Demand | N/A | 0 | **0** | N/A | -48,702 | 5 | 18,793 |
| Biofuel HE 2) 67% of Energy Demand | N/A | 0 | **0** | N/A | -32,630 | 5 | 12,591 |
| Biofuel HE 1) 33% of Energy Demand | N/A | 0 | **0** | N/A | -16,072 | 5 | 6,202 |
| Solarthermal 4) Rest of Campus, Phase 1 | 13 | -473,638 | **17** | 20 | -2,496,368 | 91 | 27,484 |
| Geothermal HE 7) Rest of Campus | 21 | -9,143,000 | **69** | 24 | -15,960,792 | 120 | 132,807 |
| Geothermal LE 7) Rest of Campus | 17 | -13,553,485 | **80** | 23 | -24,048,863 | 142 | 169,319 |
| Solarthermal 5) Rest of Campus, Phase 2 | 17 | -1,535,038 | **81** | 26 | -2,922,216 | 154 | 18,995 |
| Solarthermal 6) Rest of Campus with GWSHPs | 26 | -6,218,283 | **240** | 41 | -8,126,076 | 314 | 25,879 |
| Solar PV 1) Parking Lot Installations | 31 | -27,766,224 | **471** | 53 | -33,629,827 | 570 | 58,971 |

**Table XI:**

| Sorted by Payback for Low Energy Costs | | | | | | | |
|---|---|---|---|---|---|---|---|
| | High Energy Costs | | | Low Energy Costs | | | |
| Scenario Description | Payback Period (yrs) | Net Present Value ($) | Cost per CO2 Reduced ($/metric ton) | Payback Period (yrs) | Net Present Value ($) | Cost per CO2 Reduced ($/metric ton) | Total Net CO2 Emissions Reduced (metric tons) |
| Energy Efficiency 2) Campus-Wide Implementation (Phases 1 & 2) | 0.79 | 121,934,014 | -149 | **1.29** | 69,717,584 | -85 | 819,108 |
| Energy Efficiency 1) Phase 1 (25 Buildings) | 1.25 | 82,772,665 | -149 | **2.02** | 48,877,401 | -88 | 556,204 |
| Geothermal LE 1) Visual Arts Center | 2 | 699,328 | -137 | **4** | 434,140 | -85 | 5,100 |
| Geothermal LE 5) New Academic Building | 2 | 36,520 | -136 | **5** | 22,684 | -85 | 268 |
| Geothermal HE 5) New Academic Building | 2 | 36,520 | -136 | **5** | 22,684 | -85 | 268 |
| Geothermal HE 1) Visual Arts Center | 5 | 657,254 | -136 | **5** | 408,252 | -85 | 4,825 |
| Geothermal LE 6) New Science Building | 2 | 1,520,816 | -82 | **5** | 944,484 | -51 | 18,495 |
| Geothermal HE 6) New Science Building | 3 | 1,520,816 | -136 | **6** | 944,484 | -84 | 11,201 |
| Wind 3) 20-MW Capacity Ownership | 5 | 88,727,445 | -404 | **9** | 20,023,611 | -93 | 490,920 |
| Geothermal LE 3) Kemeny Haldeman Moore | 5 | 2,791,315 | -99 | **9** | 1,348,734 | -48 | 28,120 |
| Geothermal HE 3) Kemeny, Haldeman, Moore | 5 | 2,791,315 | -99 | **9** | 1,348,734 | -48 | 28,120 |
| Geothermal LE 2) McLaughlin, DMS, Life Sciences Center | 5 | 8,979,301 | -98 | **9** | 4,276,404 | -47 | 91,619 |
| Geothermal HE 2) McLaughlin, DMS, Life Sciences Center | 5 | 8,979,301 | -98 | **9** | 4,276,404 | -47 | 91,619 |
| Wind 2) 12-MW Capacity Ownership | 5 | 52,907,625 | -403 | **9** | 11,685,325 | -91 | 294,552 |
| Solarthermal 2) McKenzie | 5 | 429,175 | -151 | **11** | 13,977 | -5 | 2,835 |
| Geothermal HE 4) Burke, Steele, Wilder, Fairchild | 8 | 1,244,233 | -48 | **13** | -74,630 | 3 | 25,717 |
| Geothermal LE 4) Burke, Steele, Wilder, Fairchild | 9 | 1,244,233 | -48 | **13** | -74,630 | 3 | 25,717 |
| Solarthermal 1) SLC | 11 | 3,361 | -20 | **17** | -9,142 | 55 | 167 |
| Solarthermal 3) Visual Arts Center | 11 | 25,772 | -10 | **18** | -238,843 | 91 | 2,629 |
| Solarthermal 4) Rest of Campus, Phase 1 | 13 | -473,638 | 17 | **20** | -2,496,368 | 91 | 27,484 |
| Geothermal LE 7) Rest of Campus | 17 | -13,553,485 | 80 | **23** | -24,048,863 | 142 | 169,319 |
| Geothermal HE 7) Rest of Campus | 21 | -9,143,000 | 69 | **24** | -15,960,792 | 120 | 132,807 |
| Solarthermal 5) Rest of Campus, Phase 2 | 17 | -1,535,038 | 81 | **26** | -2,922,216 | 154 | 18,995 |
| Solarthermal 6) Rest of Campus with GWSHPs | 26 | -6,218,283 | 240 | **41** | -8,126,076 | 314 | 25,879 |
| Solar PV 1) Parking Lot Installations | 31 | -27,766,224 | 471 | **53** | -33,629,827 | 570 | 58,971 |
| Biomass - Woodfuels 1) HE Remaining Demand = 12,685 mmBTU/year | N/A | 2,018,371 | -97 | **N/A** | 260,981 | -12 | 20,881 |
| Biomass - Woodfuels 3) 250 HP Boiler = 72,927 mmBTU/year | N/A | 6,416,111 | -53 | **N/A** | 2,107,060 | -18 | 120,046 |
| Biomass - Woodfuels 7) LE Total Load = 458856 mmBTU/year | N/A | 22,697,656 | -30 | **N/A** | 2,510,506 | -3 | 755,326 |
| Biomass - Woodfuels 6) HE Total Load = 315506 mmBTU/year | N/A | 15,606,741 | -30 | **N/A** | 4,395,515 | -8 | 519,357 |
| Biomass - Woodfuels 5) 1000 HP Boiler = 291,708 mmBTU/year | N/A | 14,429,555 | -30 | **N/A** | 2,321,144 | -5 | 480,183 |
| Biomass - Woodfuels 4) 500 HP Boiler = 145,854 mmBTU/year | N/A | 7,214,777 | -30 | **N/A** | 1,160,572 | -5 | 240,091 |
| Biomass - Woodfuels 2) LE Remaining Demand = 65,083 mmBTU/year | N/A | 3,219,379 | -30 | **N/A** | 517,871 | -5 | 107,134 |
| WInd 1) Power Purchase Agreement | N/A | 33,706,506 | -264 | **N/A** | -7,515,795 | 48 | 294,552 |
| Biofuel LE 3) 100% of Energy Demand | N/A | 0 | 0 | **N/A** | -249,874 | 5 | 96,420 |
| Biofuel LE 2) 67% of Energy Demand | N/A | 0 | 0 | **N/A** | -167,416 | 5 | 64,602 |
| Biofuel LE 1) 33% of Energy Demand | N/A | 0 | 0 | **N/A** | -82,458 | 5 | 31,819 |
| Biofuel HE 3) 100% of Energy Demand | N/A | 0 | 0 | **N/A** | -48,702 | 5 | 18,793 |
| Biofuel HE 2) 67% of Energy Demand | N/A | 0 | 0 | **N/A** | -32,630 | 5 | 12,591 |
| Biofuel HE 1) 33% of Energy Demand | N/A | 0 | 0 | **N/A** | -16,072 | 5 | 6,202 |

**Table XII:**

## Sorted by Net Present Value for Low Energy Costs

| Scenario Description | High Energy Costs: Payback Period (yrs) | High Energy Costs: Net Present Value ($) | High Energy Costs: Cost per CO2 Reduced ($/metric ton) | Low Energy Costs: Payback Period (yrs) | Low Energy Costs: Net Present Value ($) | Low Energy Costs: Cost per CO2 Reduced ($/metric ton) | Total Net CO2 Emissions Reduced (metric tons) |
|---|---|---|---|---|---|---|---|
| Energy Efficiency 2) Campus-Wide Implementation (Phases 1 & 2) | 0.79 | 121,934,014 | -149 | 1.29 | **69,717,584** | -85 | 819,108 |
| Energy Efficiency 1) Phase 1 (25 Buildings) | 1.25 | 82,772,665 | -149 | 2.02 | **48,877,401** | -88 | 556,204 |
| Wind 3) 20-MW Capacity Ownership | 5 | 88,727,445 | -404 | 9 | **20,023,611** | -93 | 490,920 |
| Wind 2) 12-MW Capacity Ownership | 5 | 52,907,625 | -403 | 9 | **11,685,325** | -91 | 294,552 |
| Biomass - Woodfuels 6) HE Total Load = 315506 mmBTU/year | N/A | 15,606,741 | -30 | N/A | **4,395,515** | -8 | 519,357 |
| Geothermal LE 2) McLaughlin, DMS, Life Sciences Center | 5 | 8,979,301 | -98 | 9 | **4,276,404** | -47 | 91,619 |
| Geothermal HE 2) McLaughlin, DMS, Life Sciences Center | 5 | 8,979,301 | -98 | 9 | **4,276,404** | -47 | 91,619 |
| Biomass - Woodfuels 7) LE Total Load = 458856 mmBTU/year | N/A | 22,697,656 | -30 | N/A | **2,510,506** | -3 | 755,326 |
| Biomass - Woodfuels 5) 1000 HP Boiler = 291,708 mmBTU/year | N/A | 14,429,555 | -30 | N/A | **2,321,144** | -5 | 480,183 |
| Biomass - Woodfuels 3) 250 HP Boiler = 72,927 mmBTU/year | N/A | 6,416,111 | -53 | N/A | **2,107,060** | -18 | 120,046 |
| Geothermal LE 3) Kemeny Haldeman Moore | 5 | 2,791,315 | -99 | 9 | **1,348,734** | -48 | 28,120 |
| Geothermal HE 3) Kemeny, Haldeman, Moore | 5 | 2,791,315 | -99 | 9 | **1,348,734** | -48 | 28,120 |
| Biomass - Woodfuels 4) 500 HP Boiler = 145,854 mmBTU/year | N/A | 7,214,777 | -30 | N/A | **1,160,572** | -5 | 240,091 |
| Geothermal HE 6) New Science Building | 3 | 1,520,816 | -136 | 6 | **944,484** | -84 | 11,201 |
| Geothermal LE 6) New Science Building | 2 | 1,520,816 | -82 | 5 | **944,484** | -51 | 18,495 |
| Biomass - Woodfuels 2) LE Remaining Demand = 65,083 mmBTU/year | N/A | 3,219,379 | -30 | N/A | **517,871** | -5 | 107,134 |
| Geothermal LE 1) Visual Arts Center | 2 | 699,328 | -137 | 4 | **434,140** | -85 | 5,100 |
| Geothermal HE 1) Visual Arts Center | 5 | 657,254 | -136 | 5 | **408,252** | -85 | 4,825 |
| Biomass - Woodfuels 1) HE Remaining Demand = 12,685 mmBTU/year | N/A | 2,018,371 | -97 | N/A | **260,981** | -12 | 20,881 |
| Geothermal LE 5) New Academic Building | 2 | 36,520 | -136 | 5 | **22,684** | -85 | 268 |
| Geothermal HE 5) New Academic Building | 2 | 36,520 | -136 | 5 | **22,684** | -85 | 268 |
| Solarthermal 2) McKenzie | 5 | 429,175 | -151 | 11 | **13,977** | -5 | 2,835 |
| Solarthermal 1) SLC | 11 | 3,361 | -20 | 17 | **-9,142** | 55 | 167 |
| Biofuel HE 1) 33% of Energy Demand | N/A | 0 | 0 | N/A | **-16,072** | 5 | 6,202 |
| Biofuel HE 2) 67% of Energy Demand | N/A | 0 | 0 | N/A | **-32,630** | 5 | 12,591 |
| Biofuel HE 3) 100% of Energy Demand | N/A | 0 | 0 | N/A | **-48,702** | 5 | 18,793 |
| Geothermal HE 4) Burke, Steele, Wilder, Fairchild | 8 | 1,244,233 | -48 | 13 | **-74,630** | 3 | 25,717 |
| Geothermal LE 4) Burke, Steele, Wilder, Fairchild | 9 | 1,244,233 | -48 | 13 | **-74,630** | 3 | 25,717 |
| Biofuel LE 1) 33% of Energy Demand | N/A | 0 | 0 | N/A | **-82,458** | 5 | 31,819 |
| Biofuel LE 2) 67% of Energy Demand | N/A | 0 | 0 | N/A | **-167,416** | 5 | 64,602 |
| Solarthermal 3) Visual Arts Center | 11 | 25,772 | -10 | 18 | **-238,843** | 91 | 2,629 |
| Biofuel LE 3) 100% of Energy Demand | N/A | 0 | 0 | N/A | **-249,874** | 5 | 96,420 |
| Solarthermal 4) Rest of Campus, Phase 1 | 13 | -473,638 | 17 | 20 | **-2,496,368** | 91 | 27,484 |
| Solarthermal 5) Rest of Campus, Phase 2 | 17 | -1,535,038 | 81 | 26 | **-2,922,216** | 154 | 18,995 |
| WInd 1) Power Purchase Agreement | N/A | 33,706,506 | -264 | N/A | **-7,515,795** | 48 | 294,552 |
| Solarthermal 6) Rest of Campus with GWSHPs | 26 | -6,218,283 | 240 | 41 | **-8,126,076** | 314 | 25,879 |
| Geothermal HE 7) Rest of Campus | 21 | -9,143,000 | 69 | 24 | **-15,960,792** | 120 | 132,807 |
| Geothermal LE 7) Rest of Campus | 17 | -13,553,485 | 80 | 23 | **-24,048,863** | 142 | 169,319 |
| Solar PV 1) Parking Lot Installations | 31 | -27,766,224 | 471 | 53 | **-33,629,827** | 570 | 58,971 |

**Table XIII:**

| Sorted by Cost Per CO2 Reduced for Low Energy Costs | | | | | | | |
|---|---|---|---|---|---|---|---|
| | High Energy Costs | | | Low Energy Costs | | | |
| Scenario Description | Payback Period (yrs) | Net Present Value ($) | Cost per CO2 Reduced ($/metric ton) | Payback Period (yrs) | Net Present Value ($) | Cost per CO2 Reduced ($/metric ton) | Total Net CO2 Emissions Reduced (metric tons) |
| Wind 3) 20-MW Capacity Ownership | 5 | 88,727,445 | -404 | 9 | 20,023,611 | **-93** | 490,920 |
| Wind 2) 12-MW Capacity Ownership | 5 | 52,907,625 | -403 | 9 | 11,685,325 | **-91** | 294,552 |
| Energy Efficiency 1) Phase 1 (25 Buildings) | 1.25 | 82,772,665 | -149 | 2.02 | 48,877,401 | **-88** | 556,204 |
| Geothermal LE 1) Visual Arts Center | 2 | 699,328 | -137 | 4 | 434,140 | **-85** | 5,100 |
| Energy Efficiency 2) Campus-Wide Implementation (Phases 1 & 2) | 0.79 | 121,934,014 | -149 | 1.29 | 69,717,584 | **-85** | 819,108 |
| Geothermal LE 5) New Academic Building | 2 | 36,520 | -136 | 5 | 22,684 | **-85** | 268 |
| Geothermal HE 5) New Academic Building | 2 | 36,520 | -136 | 5 | 22,684 | **-85** | 268 |
| Geothermal HE 1) Visual Arts Center | 5 | 657,254 | -136 | 5 | 408,252 | **-85** | 4,825 |
| Geothermal HE 6) New Science Building | 3 | 1,520,816 | -136 | 6 | 944,484 | **-84** | 11,201 |
| Geothermal LE 6) New Science Building | 2 | 1,520,816 | -82 | 5 | 944,484 | **-51** | 18,495 |
| Geothermal LE 3) Kemeny Haldeman Moore | 5 | 2,791,315 | -99 | 9 | 1,348,734 | **-48** | 28,120 |
| Geothermal HE 3) Kemeny, Haldeman, Moore | 5 | 2,791,315 | -99 | 9 | 1,348,734 | **-48** | 28,120 |
| Geothermal LE 2) McLaughlin, DMS, Life Sciences Center | 5 | 8,979,301 | -98 | 9 | 4,276,404 | **-47** | 91,619 |
| Geothermal HE 2) McLaughlin, DMS, Life Sciences Center | 5 | 8,979,301 | -98 | 9 | 4,276,404 | **-47** | 91,619 |
| Biomass - Woodfuels 3) 250 HP Boiler = 72,927 mmBTU/year | N/A | 6,416,111 | -53 | N/A | 2,107,060 | **-18** | 120,046 |
| Biomass - Woodfuels 1) HE Remaining Demand = 12,685 mmBTU/year | N/A | 2,018,371 | -97 | N/A | 260,981 | **-12** | 20,881 |
| Biomass - Woodfuels 6) HE Total Load = 315506 mmBTU/year | N/A | 15,606,741 | -30 | N/A | 4,395,515 | **-8** | 519,357 |
| Solarthermal 2) McKenzie | 5 | 429,175 | -151 | 11 | 13,977 | **-5** | 2,835 |
| Biomass - Woodfuels 5) 1000 HP Boiler = 291,708 mmBTU/year | N/A | 14,429,555 | -30 | N/A | 2,321,144 | **-5** | 480,183 |
| Biomass - Woodfuels 4) 500 HP Boiler = 145,854 mmBTU/year | N/A | 7,214,777 | -30 | N/A | 1,160,572 | **-5** | 240,091 |
| Biomass - Woodfuels 2) LE Remaining Demand = 65,083 mmBTU/year | N/A | 3,219,379 | -30 | N/A | 517,871 | **-5** | 107,134 |
| Biomass - Woodfuels 7) LE Total Load = 458856 mmBTU/year | N/A | 22,697,656 | -30 | N/A | 2,510,506 | **-3** | 755,326 |
| Geothermal HE 4) Burke, Steele, Wilder, Fairchild | 8 | 1,244,233 | -48 | 13 | -74,630 | **3** | 25,717 |
| Geothermal LE 4) Burke, Steele, Wilder, Fairchild | 9 | 1,244,233 | -48 | 13 | -74,630 | **3** | 25,717 |
| Biofuel HE 1) 33% of Energy Demand | N/A | 0 | 0 | N/A | -16,072 | **5** | 6,202 |
| Biofuel LE 1) 33% of Energy Demand | N/A | 0 | 0 | N/A | -82,458 | **5** | 31,819 |
| Biofuel LE 2) 67% of Energy Demand | N/A | 0 | 0 | N/A | -167,416 | **5** | 64,602 |
| Biofuel HE 2) 67% of Energy Demand | N/A | 0 | 0 | N/A | -32,630 | **5** | 12,591 |
| Biofuel HE 3) 100% of Energy Demand | N/A | 0 | 0 | N/A | -48,702 | **5** | 18,793 |
| Biofuel LE 3) 100% of Energy Demand | N/A | 0 | 0 | N/A | -249,874 | **5** | 96,420 |
| WInd 1) Power Purchase Agreement | N/A | 33,706,506 | -264 | N/A | -7,515,795 | **48** | 294,552 |
| Solarthermal 1) SLC | 11 | 3,361 | -20 | 17 | -9,142 | **55** | 167 |
| Solarthermal 4) Rest of Campus, Phase 1 | 13 | -473,638 | 17 | 20 | -2,496,368 | **91** | 27,484 |
| Solarthermal 3) Visual Arts Center | 11 | 25,772 | -10 | 18 | -238,843 | **91** | 2,629 |
| Geothermal HE 7) Rest of Campus | 21 | -9,143,000 | 69 | 24 | -15,960,792 | **120** | 132,807 |
| Geothermal LE 7) Rest of Campus | 17 | -13,553,485 | 80 | 23 | -24,048,863 | **142** | 169,319 |
| Solarthermal 5) Rest of Campus, Phase 2 | 17 | -1,535,038 | 81 | 26 | -2,922,216 | **154** | 18,995 |
| Solarthermal 6) Rest of Campus with GWSHPs | 26 | -6,218,283 | 240 | 41 | -8,126,076 | **314** | 25,879 |
| Solar PV 1) Parking Lot Installations | 31 | -27,766,224 | 471 | 53 | -33,629,827 | **570** | 58,971 |

**Table XIV:**

| Sorted by Net CO2 Emissions Reduced | | | | | | | |
|---|---|---|---|---|---|---|---|
| | High Energy Costs | | | Low Energy Costs | | | |
| Scenario Description | Payback Period (yrs) | Net Present Value ($) | Cost per CO2 Reduced ($/metric ton) | Payback Period (yrs) | Net Present Value ($) | Cost per CO2 Reduced ($/metric ton) | Total Net CO2 Emissions Reduced (metric tons) |
| Energy Efficiency 2) Campus-Wide Implementation (Phases 1 & 2) | 0.79 | 121,934,014 | -149 | 1.29 | 69,717,584 | -85 | **819,108** |
| Biomass - Woodfuels 7) LE Total Load = 458856 mmBTU/year | N/A | 22,697,656 | -30 | N/A | 2,510,506 | -3 | **755,326** |
| Energy Efficiency 1) Phase 1 (25 Buildings) | 1.25 | 82,772,665 | -149 | 2.02 | 48,877,401 | -88 | **556,204** |
| Biomass - Woodfuels 6) HE Total Load = 315506 mmBTU/year | N/A | 15,606,741 | -30 | N/A | 4,395,515 | -8 | **519,357** |
| Wind 3) 20-MW Capacity Ownership | 5 | 88,727,445 | -404 | 9 | 20,023,611 | -93 | **490,920** |
| Biomass - Woodfuels 5) 1000 HP Boiler = 291,708 mmBTU/year | N/A | 14,429,555 | -30 | N/A | 2,321,144 | -5 | **480,183** |
| Wind 2) 12-MW Capacity Ownership | 5 | 52,907,625 | -403 | 9 | 11,685,325 | -91 | **294,552** |
| WInd 1) Power Purchase Agreement | N/A | 33,706,506 | -264 | N/A | -7,515,795 | 48 | **294,552** |
| Biomass - Woodfuels 4) 500 HP Boiler = 145,854 mmBTU/year | N/A | 7,214,777 | -30 | N/A | 1,160,572 | -5 | **240,091** |
| Geothermal LE 7) Rest of Campus | 17 | -13,553,485 | 80 | 23 | -24,048,863 | 142 | **169,319** |
| Geothermal HE 7) Rest of Campus | 21 | -9,143,000 | 69 | 24 | -15,960,792 | 120 | **132,807** |
| Biomass - Woodfuels 3) 250 HP Boiler = 72,927 mmBTU/year | N/A | 6,416,111 | -53 | N/A | 2,107,060 | -18 | **120,046** |
| Biomass - Woodfuels 2) LE Remaining Demand = 65,083 mmBTU/year | N/A | 3,219,379 | -30 | N/A | 517,871 | -5 | **107,134** |
| Biofuel LE 3) 100% of Energy Demand | N/A | 0 | 0 | N/A | -249,874 | 5 | **96,420** |
| Geothermal LE 2) McLaughlin, DMS, Life Sciences Center | 5 | 8,979,301 | -98 | 9 | 4,276,404 | -47 | **91,619** |
| Geothermal HE 2) McLaughlin, DMS, Life Sciences Center | 5 | 8,979,301 | -98 | 9 | 4,276,404 | -47 | **91,619** |
| Biofuel LE 2) 67% of Energy Demand | N/A | 0 | 0 | N/A | -167,416 | 5 | **64,602** |
| Solar PV 1) Parking Lot Installations | 31 | -27,766,224 | 471 | 53 | -33,629,827 | 570 | **58,971** |
| Biofuel LE 1) 33% of Energy Demand | N/A | 0 | 0 | N/A | -82,458 | 5 | **31,819** |
| Geothermal LE 3) Kemeny Haldeman Moore | 5 | 2,791,315 | -99 | 9 | 1,348,734 | -48 | **28,120** |
| Geothermal HE 3) Kemeny, Haldeman, Moore | 5 | 2,791,315 | -99 | 9 | 1,348,734 | -48 | **28,120** |
| Solarthermal 4) Rest of Campus, Phase 1 | 13 | -473,638 | 17 | 20 | -2,496,368 | 91 | **27,484** |
| Solarthermal 6) Rest of Campus with GWSHPs | 26 | -6,218,283 | 240 | 41 | -8,126,076 | 314 | **25,879** |
| Geothermal HE 4) Burke, Steele, Wilder, Fairchild | 8 | 1,244,233 | -48 | 13 | -74,630 | 3 | **25,717** |
| Geothermal LE 4) Burke, Steele, Wilder, Fairchild | 9 | 1,244,233 | -48 | 13 | -74,630 | 3 | **25,717** |
| Biomass - Woodfuels 1) HE Remaining Demand = 12,685 mmBTU/year | N/A | 2,018,371 | -97 | N/A | 260,981 | -12 | **20,881** |
| Solarthermal 5) Rest of Campus, Phase 2 | 17 | -1,535,038 | 81 | 26 | -2,922,216 | 154 | **18,995** |
| Biofuel HE 3) 100% of Energy Demand | N/A | 0 | 0 | N/A | -48,702 | 5 | **18,793** |
| Geothermal LE 6) New Science Building | 2 | 1,520,816 | -82 | 5 | 944,484 | -51 | **18,495** |
| Biofuel HE 2) 67% of Energy Demand | N/A | 0 | 0 | N/A | -32,630 | 5 | **12,591** |
| Geothermal HE 6) New Science Building | 3 | 1,520,816 | -136 | 6 | 944,484 | -84 | **11,201** |
| Biofuel HE 1) 33% of Energy Demand | N/A | 0 | 0 | N/A | -16,072 | 5 | **6,202** |
| Geothermal LE 1) Visual Arts Center | 2 | 699,328 | -137 | 4 | 434,140 | -85 | **5,100** |
| Geothermal HE 1) Visual Arts Center | 5 | 657,254 | -136 | 5 | 408,252 | -85 | **4,825** |
| Solarthermal 2) McKenzie | 5 | 429,175 | -151 | 11 | 13,977 | -5 | **2,835** |
| Solarthermal 3) Visual Arts Center | 11 | 25,772 | -10 | 18 | -238,843 | 91 | **2,629** |
| Geothermal LE 5) New Academic Building | 2 | 36,520 | -136 | 5 | 22,684 | -85 | **268** |
| Geothermal HE 5) New Academic Building | 2 | 36,520 | -136 | 5 | 22,684 | -85 | **268** |
| Solarthermal 1) SLC | 11 | 3,361 | -20 | 17 | -9,142 | 55 | **167** |

**APPENDIX D: BioFuel**

## *Modern Carbon Versus Fossil Carbon*

The net carbon dioxide emissions from biofuels are heavily debated. The distinction lies between the implications of releasing fossil carbon versus modern carbon. Fossil carbon is from underground, such as oil, which would not be released into the atmosphere if not for humans. Modern carbon is part of the carbon cycle in the atmosphere, plants, and environment in general. Biofuels emit only modern carbon because the emissions contain carbon that was once part of the structure of a plant, which the plant removed from the atmosphere. Therefore modern carbon in biofuel emissions is returned to the atmosphere from which it came only a short while ago. The US Environmental Protection Agency and Kyoto Protocol only include fossil carbon in their analyses of emissions. Using these guidelines, though BioFuel physically emits about 7% less CO2 out of the smokestack than #6 oil (fossil carbon)[i], its net CO2 emissions are about 90% less than emissions from #6 oil due to the oil involved in transportation and processing the WVO (modern carbon)[ii].

This formula does not is not accurate for biofuels that involve land use changes. For example, harvesting wood from a forest removes a source of carbon absorption. Though trees are planted to replace those harvested, they do not absorb as much during their growth as does a mature forest. This leads to a greater amount of carbon in the atmosphere. Alternately, BioFuel does not involve land use change because the land is already farmed in order to produce the vegetable oil for the industries. Therefore the lifecycle of the fuel begins when it is discarded from the industries. This means that the only energy that goes into its production is transportation and processing, the latter of which is done with energy from BioFuel.

Yet the price of BioFuel in the future is not certain. The supply of WVO is limited. If the government implements a cap and trade bill to mitigate GHG emissions, institutions will look for renewable energy sources, meaning there could be increased demand for WVO. This would drive up the price. Fortunately WVO is a niche market for now; Amenico produces a product that others have not been able to produce from WVO. In our calculations of BioFuel versus #6 oil prices, we assume the price remains equivalent to that of #2 heating oil. In addition, Amenico supplies all of its sources of WVO with the straight vegetable oil (SVO) those sources use. Therefore the sources have interest in continuing to sell WVO to Amenico so they can continue buying the SVO, and potential competing WVO-based fuel suppliers would have difficulty interfering with Amenico's WVO supply.

**APPENDIX E: Further Considerations**

The following list is comprised of further considerations that the class acknowledges but was unable to fully research. It is broken into three categories: economic, practical, and general.

## *1. Economic*

• Grants: Government grants may be available to fund some of the projects suggested in this report, lowering the initial investment costs.

• Payback Post 2030: We deliberately chose projects that will pay back in 20 years or less. After their relatively short payback periods they will continue to save the college money as opposed to the business as usual scenario. This fact is not accounted for in the net present value calculations, but is a critical concept to bear in mind in thinking these projects as investments.

• Maintenance: Though the technologies we chose are well established, they are inherently more maintenance-intensive than our existing heating system. There is no way to know exactly what maintenance will be required in the 20 year period we looked at, though it is safe to assume that there will be some. We did not account for these predicted maintenance costs, though they would most likely be marginal.

• See Appendix G for in-depth discussion of further possible economic impacts

## *2. Practical*

• Construction Protocol: We recognize that moving forward on a complete energy restructuring may seem overwhelming or daunting. However, we would like to emphasize that with proper building protocol, a reconstruction can happen smoothly and in phases that safeguard against technology failure. More specifically, the easiest buildings will be renovated and retrofitted first, and new technologies can be tested where installation will be the simplest. As more complicated projects come up later in the timeline, we predict that the technologies will have been further refined, protecting against possible lost investments on failed technologies.

• Restructuring of Operations and Management: These projects will require a reorganization of the current system of buildings management. A new protocol needs to be put in place for all future buildings. Though this represents a bureaucratic challenge it is an opportunity to create new jobs within the college.

• Deployment: We did not address the specifics of deploying the suggested technologies. However, we have been in direct contact with a number of professionals, from companies who are currently ready to perform installations, to consultants who would be able to give comprehensive advice to the College and form professional recommendations. We suggest that the College take up where this class left off in maintaining these relationships and entering into professional agreements with some, if not many, of these well-respected companies.

• Staff: Every phase of this energy overhaul will necessitate a full-time staff devoted to these projects. Though our project recommendations are ambitious, they are crucial for the College's economic future and reputation, and a staff who can be devoted entirely to these measures will be fundamental to implement these technologies].

• Backup Systems: In the event that any of our proposed technologies were unable to carry the load of the College for any reason, Dartmouth would have numerous options to ensure that systems would continue running. We could burn biofuel or biomass (biofuel doesn't require an infrastructure change, biomass would) or we could simply revert to burning #6 fuel oil until the technology failure could be addressed.

### *3. General*

• Continuation With VanZelm: We suggest following up the work of this class with the VanZelm engineers to verify our calculations, look forward at next steps, and begin renovations for efficiency as soon as possible.

• Mark Rosenbaum: As a trusted architect that Dartmouth has employed in the past, Mr. Rosenbaum could do great work towards actualizing the proposed efficiency renovations necessary on campus.

•Building Renovations and Construction Guidelines: all future campus building and renovation projects should adhere to new, stricter energy use and sustainable design guidelines, even beyond current specifications for High Performance Design, and be powered by renewable energy and be net zero energy users or even net energy exporting.

• Opportunity for Collaboration: This class is an innovative example of the way students can engage with the administration as well as outside parties and gain experiences and knowledge rooted in real-world problems. Continued work towards decreasing Dartmouth's carbon emissions would offer further opportunities for this kind of fruitful (at least for us!) collaboration.

• Further GHG Reduction Measures: True carbon neutrality will come not only from a firm commitment from the administration, but from a commitment from the faculty, staff and students as well. There are far more measures to be taken than the ones outlined in this report to make this campus a more environmentally responsible one. Though we focused on only one front of this complicated and multi-faceted problem, we are both aware of the other fronts from which the problem of Dartmouth's GHG emissions needs to be attacked and committed to moving forward from these other fronts as well.

**APPENDIX F: Implications of Climate Legislation:**

## *Background*

On 26 June 2009, the US House of Representatives passed the American Clean Energy and Security Act of 2009, H.R. 2454, by a vote of 219 to 212.[iii,iv] The bill aims to "create millions of new clean energy jobs, enhance America's energy independence, and protect the environment."[v] Some key provisions include: "1) require electric utilities to meet 20 per cent of their electricity demand through renewable energy sources and energy efficiency by 2020; 2) invest in new clean energy technologies and energy efficiency, including energy efficiency and renewable energy (US$90 billion in new investments by 2025), carbon capture and sequestration (US$60 billion), electric and other advanced technology vehicles (US$20 billion), and basic scientific research and development (US$20 billion); 3) establish new energy-saving standards for new buildings and appliances; 4) reduce carbon emissions from major U.S. sources by 17 per cent by 2020 and over 80 per cent by 2050 compared to 2005 levels. Complementary measures in the legislation, such as investments in preventing tropical deforestation, will achieve significant additional reductions in carbon emissions; 5) protect consumers from energy price increases."[vi] Estimates made by the Environmental Protection Agency claim that carbon reductions designated by the legislation will "cost American families less than a postage stamp per day."[1,vii] However, in order for the bill to come into force, it must be passed by the Senate and then signed by the President.

On 30 September 2009, Senators John Kerry (D-Mass.) and Barbara Boxer (D-Calif.) introduced the Senate version of H.R. 2454 called the Clean Energy Jobs and American Power Act.[viii] The Kerry-Boxer bill aims to "create clean energy jobs, reduce pollution, and protect American security by enhancing domestic energy production and combating global climate change."[ix] The Senate bill is similar to the House climate bill; however, there are some differences. For instance, the Senate version of the bill aims to reduce GHG emissions by 20 per cent by 2020 and 80 per cent by 2050 from 2005 levels.[x]

On 25 November 2009, the US administration announced that President Obama was prepared to "put on the table" a greenhouse gas reduction target at the UN climate conference in Copenhagen.[xi] The target aims to reduce GHG emissions 17 per cent below 2005 levels in 2020 and ultimately be in line with "final U.S. energy and climate legislation." Furthermore, "In light of the President's goal to reduce emissions 83% by 2050, the expected pathway set forth in this pending legislation would entail a 30% reduction below 2005 levels in 2025 and a 42% reduction below 2005 in 2030."[xii]

## *Increases in fossil fuel prices*

The analysis of Parker et al. (2009) describes models from numerous different organizations and government agencies.[xiii] However, it is important to recognize that "long-term cost projections are at best speculative, and should be viewed with attentive skepticism….In the words of the late Dr. Lincoln Moses, the first Administrator of the

---

[1] The Congressional Budget Office (CBO) estimates that the bill will cost the average household less than 50 cents each day.

Energy Information Administration: 'There are no facts about the future.' " However, it is still possible to predict general trends such as rising energy costs for carbon intensive energy.[xiv]

The crucial variables that will change the cost of carbon will be: 1) if climate legislation actually gets passed; 2) whether there is an overriding global legislation target set at Copenhagen; and 3) the availability of offsets (particularly international offsets). Although H.R. 2454 limits the availability of domestic and international offsets to two billion tons of emissions annually—divided equally between domestic and international pools—the pricing of international markets is extremely uncertain. The overview of the bill makes it clear how extremely complicated the legislation processes are. In order to make the bill politically feasible, there are a lot of allocations of allowances, often with the intention of benefiting energy consumers and low-income households, which makes sense.[xv]

However, there is definitely uncertainty on how quickly the market will establish a reasonable price for carbon. It is uncertain whether H.R. 2454's allocation scheme's attempt "to smooth the economy's transition to a less carbon- intensive future through free allowance allocations to energy-intensive, trade-exposed industries, merchant coal-fired electric generators, and petroleum refiners" will result in a low price of carbon for a significant time—which is shown to a certain extent in the models. There are also serious concerns for "potential allowance market abuse and manipulation" since the market will involve all of the financial instruments, particularly derivatives, that any other commodity market includes.[xvi]

It will be up to the Federal Energy Regulatory Commission (FERC) to have clear oversight of the cash allowance market, and for the Commodity Futures Trading Commission (CFTC) to have clear oversight of allowance derivatives. The legislation "addresses cost control through five main mechanisms: (1) unlimited banking and limited borrowing, (2) a two- year compliance period, (3) a strategic reserve auction with a pool of allowances available at a minimum reserve price, (4) periodic auctions with a reserve price, and (5) broad limits on the use of offsets." The bill also does establish a price floor for the reserve price of regular auctions, which are set at "$10 (in 2009 dollars) in 2012, increasing at 5% real annually." The allowance price projections predicted by the various models seem to start from around $10-22 per allowance in 2010 to $25-125 per allowance in 2030. The complicated thing to consider is that these are costs per allowance and are not equivalent to a carbon tax. Each energy supplier will have a specific "cap" for their emissions and they will have to meet that cap either by reducing their emissions or purchasing allowances.[xvii]

Overall, the US climate legislation is likely to evolve overtime to the point where carbon pricing accounts for the social cost of carbon. If carbon is accurately priced, then the EIA high cost projections are much more likely for fossil fuel energy like #6 fuel oil.

REFERENCES

---

[i] Giunta, T. (2009). Personal communication.

[ii] Environmental Prtotction Agency's Office of Transportation and Air Quality. (2009, May). *EPA lifecycle analysis of greenhouse gas emissions from renewable fuels.* Retrieved from http://www.epa.gov/oms/renewablefuels/420f09024.htm

[iii] 'The American Clean Energy and Security Act (H.R. 2454)' *Committee On Energy And Commerce* [website], (updated Jun. 2009) http://energycommerce.house.gov/index.php?option=com_content&view=article&id=1633&catid=155&Itemid=55 accessed 15 Nov. 2009

[iv] 'The American Clean Energy and Security Act (H.R. 2454)' *Committee on Energy and Commerce* [pdf], (published Jul. 2009) http://energycommerce.house.gov/Press_111/20090701/hr2454_house.pdf accessed 15 Nov. 2009

[v] 'The American Clean Energy and Security Act (H.R. 2454)' *Committee on Energy and Commerce* [pdf], (published Jul. 2009) http://energycommerce.house.gov/Press_111/20090701/hr2454_house.pdf accessed 15 Nov. 2009

[vi] 'The American Clean Energy and Security Act (H.R. 2454)' *Committee on Energy and Commerce* [pdf], (published Jul. 2009) http://energycommerce.house.gov/Press_111/20090701/hr2454_house.pdf accessed 15 Nov. 2009

[vii] 'The American Clean Energy and Security Act (H.R. 2454)' *Committee on Energy and Commerce* [pdf], (published Jul. 2009) http://energycommerce.house.gov/Press_111/20090701/hr2454_house.pdf accessed 15 Nov. 2009

[viii] 'Kerry, Boxer Introduce Clean Energy Jobs and American Power Act' *U.S. Senate Committee on Environment & Public Works* [website], (published online Sep. 2009) http://epw.senate.gov/public/index.cfm?FuseAction=Majority.PressReleases&ContentRecord_id=0c00344c-802a-23ad-4f4d-edb0c9408d2e&Region_id=&Issue_id= accessed 15 Nov. 2009

[ix] 'Kerry, Boxer Introduce Clean Energy Jobs and American Power Act' *U.S. Senate Committee on Environment & Public Works* [website], (published online Sep. 2009) http://epw.senate.gov/public/index.cfm?FuseAction=Majority.PressReleases&ContentRecord_id=0c00344c-802a-23ad-4f4d-edb0c9408d2e&Region_id=&Issue_id= accessed 15 Nov. 2009

[x] 'Clean Energy Jobs and American Power Act: Summary of Provisions' *U.S. Senate Committee on Environment & Public Works* [pdf], (updated Sep. 2009) http://epw.senate.gov/public/index.cfm?FuseAction=Files.View&FileStore_id=eb1619a8-2b2f-4750-8aec-779726be03dc accessed 15 Nov. 2009

[xi] 'Administration Announces U.S. Emission Target for Copenhagen' *The White House* [website], (published Nov. 2009) <http://www.whitehouse.gov/the-press-office/president-attend-copenhagen-climate-talks> accessed 25 Nov. 2009

[xii] 'Administration Announces U.S. Emission Target for Copenhagen' *The White House* [website], (published Nov. 2009) <http://www.whitehouse.gov/the-press-office/president-attend-copenhagen-climate-talks> accessed 25 Nov. 2009

[xiii] Larry Parker. Yacobucci, Brent. 'Climate Change: Costs and Benefits of the Cap-and-Trade Provisions of H.R. 2454' *Congressional Research Service*

[xiv] Larry Parker. Yacobucci, Brent. 'Climate Change: Costs and Benefits of the Cap-and-Trade Provisions of H.R. 2454' *Congressional Research Service*

[xv] Larry Parker. Yacobucci, Brent. 'Climate Change: Costs and Benefits of the Cap-and-Trade Provisions of H.R. 2454' *Congressional Research Service*

[xvi] Larry Parker. Yacobucci, Brent. 'Climate Change: Costs and Benefits of the Cap-and-Trade Provisions of H.R. 2454' *Congressional Research Service*

[xvii] Larry Parker. Yacobucci, Brent. 'Climate Change: Costs and Benefits of the Cap-and-Trade Provisions of H.R. 2454' *Congressional Research Service*