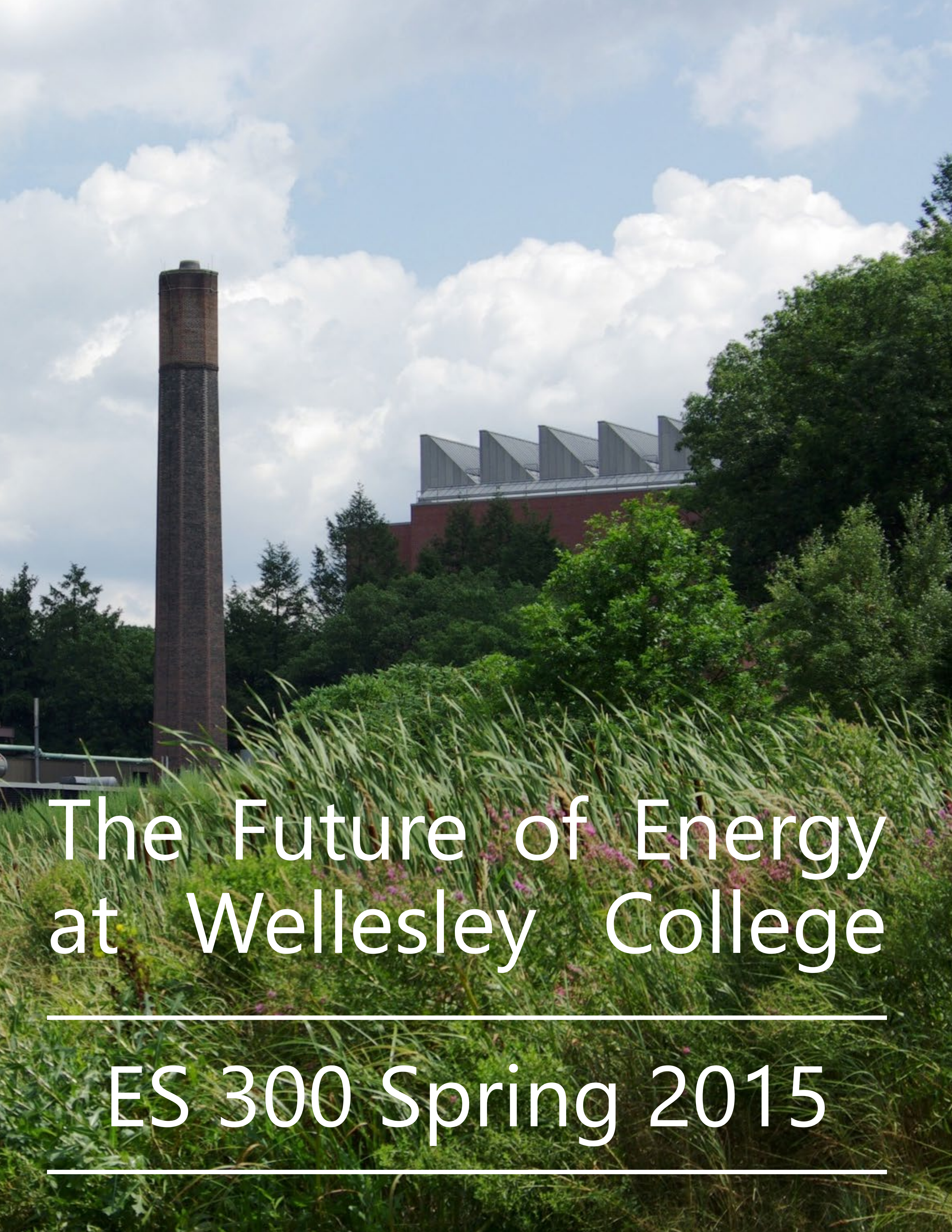

The Future of Energy at Wellesley College

ES 300 Spring 2015

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Executive Summary

In Spring 2015, the Environmental Studies capstone course, ES300: Environmental Decisionmaking, was tasked with researching the state of energy on campus and providing recommendations for Wellesley College's energy future. The cogeneration plant, which provides electricity and heat for the campus, is reaching obsolescence and needs replacement. The necessity of an updated campus energy plan coupled with continuing campus renovations makes now an opportune time to investigate and make recommendations for the future of energy at Wellesley College.

In this report, ES300 presents our research and recommendations for the five most relevant heat and electricity options that could potentially be used by the college. For heat, these options are natural gas, No. 6 fuel oil, No. 2 fuel oil, solar hot water and geothermal; for electricity they are natural gas, green grid electricity purchased from the town of Wellesley, purchased grid electricity, wind, and solar PV.

All energy sources have a variety of different social and environmental impacts over their lifecycles. We evaluate these potential energy options using eight metrics: cost, reliability, educational advantage, greenhouse gas emissions, ecotoxicity, ecosystem disruption, human health, and environmental justice. In our report, we present information on energy options, rate the options using metrics, and provide metric comparisons in order to draw conclusions regarding energy options over their entire lifecycle.

We recommend that the College consider renewable forms of energy—solar hot water and geothermal as heat options, and wind and solar PV for electricity. Although these sources would likely only provide a fraction of our total energy usage, the college should consider these options as they are relatively low cost, lessen the social and environmental externalities created by fossil fuels, and provide an educational advantage. In addition, we caution against viewing natural gas as an ideal energy source of heat and electricity. Due to the negative environmental and social consequences of natural gas extraction and use, we encourage diversification of energy sources. We also expect the price of natural gas to rise in the future as negative externalities of fracking are realized, making renewable energy options even more competitive.

There is no single perfect energy source; through our analysis we determined that even renewables have negative social and environmental externalities associated with their lifecycles. To this end, we recommend a range of conservation tools that can be enacted on a variety of scales, including college-wide policies and individual actions.

These recommendations represent what the ES300 class deems essential in energy procurement at Wellesley. Our transparency and data also allow others to draw their own conclusions regarding trade-offs of different forms of energy. The information, comparisons, and recommendations provided in this report are useful in informing future decisions regarding energy for the College and in helping guide Wellesley towards a sustainable energy future.

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Baltazar, Catherine. *ES 300 Spring 2015. May, 2015.*

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We would also like to thank **Monica Higgins** for advising us on the use of SimaPro 7, a LCA software, and Environmental Studies Professor **Jay Turner**, who provided assistance in understanding solar PV energy, RECS, and geothermal energy.

Our biggest thank you goes out to **Trina Learned**, the Director of Operations at Wellesley College who has been such an invaluable resource throughout the semester.

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- **Trevor Criswell**, Energy Services and Planning Manager of Wellesley Municipal Light and Power
- **ES Program**
- **Ruhlman Committee**
- **Previous ES300 Classes**

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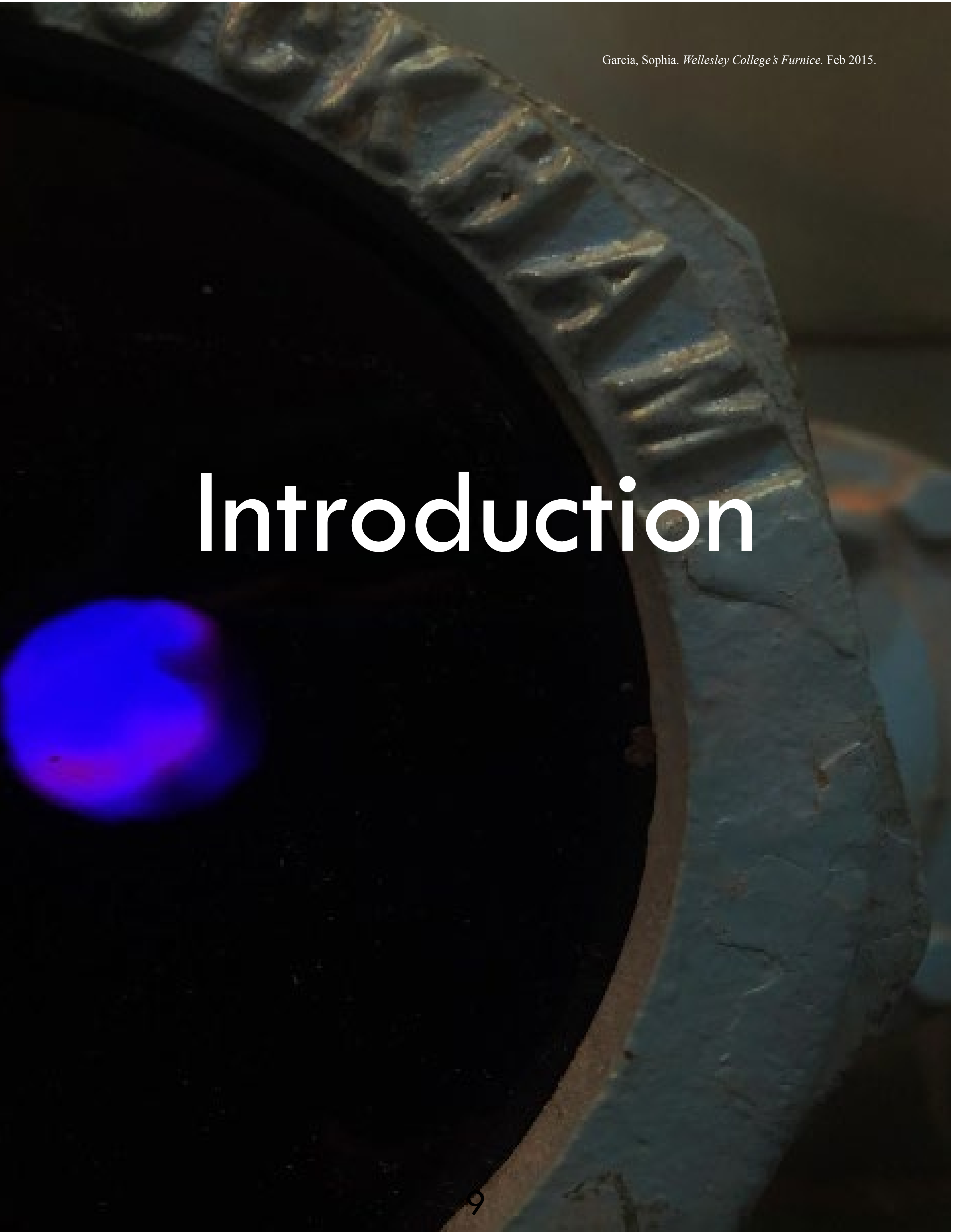
Abbreviations

2,4-D- 2,4-Dichlorophenoxyacetic
BTU- British Thermal Unit
BWRs- Boiling Water Reactors
CH4- Methane
CHP- Combined Heat and Power
CO2- Carbon Dioxide
Cogen- Cogeneration - Combined heat and power plants
CSP- Concentrated Solar Power (plant)
CTUe- Comparative toxicity unit for aquatic ecotoxicity
CTUh- Comparative toxicity unit for human toxicity
DC- Direct Current
DE 209- Bentonite
DEQ- Department of Environmental Quality
DOER- Department of Energy Resources
EJ- Environmental Justice
EPA- Environmental Protection Agency
eq- Equivalent
ES 220- Wellesley College Environmental Studies course: Environmental Limits and Conservation
ES 300- Wellesley College Environmental Studies capstone course: Environmental Decisionmaking
Fracking- Hydraulic Fracturing
GB- Allocation energy/electricity production
GHGs - Greenhouse Gases
GSHP- Ground Source Heat Pump
HAPs- Hazardous Air Pollutants
HD- High Definition
HRSG- Heat Recovery Steam Generator
kg- Kilogram
KSC- Wellesley College Keohane Sports Center
kW- Kilowatt
kWh- Kilowatt hour
LCA- Life Cycle Analysis
LCOE- Levelized Cost of Energy
LEDs- Light Emitting Dioxides
LEED- Leadership in Energy and Environmental Design
MA- Massachusetts
MATLAB- Matrix Laboratory
MMBTU- One Million British Thermal Units
MW- Megawatt
Mwh- Megawatt hour
N/A- Not Available
NM- New Mexico
No. 2 fuel oil- Number 2 fuel oil
No. 6 fuel oil - Number 6 fuel oil
NOx- Nitrogen Dioxide
N-type- Phosphorus-doped silicon
OpenEI- Open Energy Information
PCBs- Polychlorinated Biphenyls
PM 2.5- Fine Particulate Matter 2.5
PM- Particulate Matter
PM10- Coarse Particulate Matter 10
P-N junction- Boundary or interface between two types of semiconductor material
P-type- Boron-doped silicon
PV- Photovoltaic
PWRs- Pressurized Water Reactors
RECs- Renewable Energy Credits
RER 108- Reinforcing Steel
SimaPro 7- Sustainability Life Cycle Assessment Carbon Footprinting version 7
SO2- Sulfur Dioxide
Solar HW- Solar Hot Water
Solar PV- Solar Photovoltaic
SRECII- Solar Carve Out Policy
SRECs- Solar Renewable Energy Certificates
TRACI2- Tool for the Reduction and Assessment of Chemical and other environmental impacts
UK- United Kingdom
VOC- Volatile Organic Compounds
WMLP- Wellesley Municipal Light Plant



Garcia, Sophia. *Wellesley College's Furnice.* Feb 2015.

Introduction

Energy at Wellesley

Background to Wellesley

Wellesley College, an undergraduate institution founded in 1875, was created on the principle of providing an excellent liberal arts education for young women. The values of diversity, collaboration, and interdisciplinary learning are core components of the College and are core components for tackling sustainability issues. Wellesley College sits on 500 acres of land located 40 minutes south of the city of Boston and has a population of 2,400 students. The campus has been praised for its beautiful landscape and its ability to foster creative learning. Driven by its core mission, Wellesley fosters an environment in which students can take on real-world challenges of sustainability, including how to evaluate and propose new energy sources for campus use.

Background to ES 300

Each spring, students in the Environmental Decisionmaking capstone course for the Environmental Studies (ES) major at Wellesley act as environmental consultants for the College. Through this course, ES juniors and seniors conduct an interdisciplinary analysis about a topic of relevance to Wellesley's campus. The students not only present a final paper and presentation to the College but also have a semester-long job that they each apply for at the beginning of the course. This class is a unique opportunity for ES majors to utilize the skills that they have learned throughout their time in ES classes at Wellesley and surrounding colleges. Ultimately, the completed paper will be used to make a final decision regarding the future energy sources used to satisfy Wellesley's future energy needs. Our assessment comes at a time at which the campus is experiencing campus-wide renewal projects for which the students in the ES department have the opportunity to voice their opinions.

While buildings on campus are being renovated at various degrees, our campus cogeneration power plant is nearing the end of its lifetime. The plant was purchased in 1994 by an Austrian company named Jenbacher and is still in operation today, despite being labeled as outdated. Because cogeneration systems provide both heat and electricity, it is vital that we evaluate the current energy situation on Wellesley's campus and address it as we feel is best. We hope that our assessment extends beyond Wellesley and is used by other colleges that are overlooking similar renovations for their schools.

Energy at the College: Wellesley's Cogeneration Plant

The cogen plant runs on natural gas and began operations in 1994 with four 1,400 kW high-efficiency natural gas engines; a fifth engine was added in 1999.[1] During the day, the power plant is used to provide heat and energy to the College. At night, the power plant is shut off and the College purchases power from the town of Wellesley. In 2013, the College consumed 27,211,329 kWh of electricity. 19,222,944 kWh were produced on campus while 7,988,385 kWh were imported from the town of Wellesley. [2] 97.9% of electricity comes from natural gas that is burned in the cogeneration plant, .001% from solar panels in the field house, and 2% from Hydro power.[3] The College made a deal with the town of Wellesley to purchase electricity during off-peak hours (at night) and during the weekends[4] in order to help maintain a lower price of power for their residents and to keep the cost of energy down for the college; It is less expensive to pay the town of Wellesley $111,000 than it is to keep the power plant running over night. This contract with the

1 "High-tech Cogen plant saves money for Wellesley College, " *Power Engineering,* last modified September, 01,1995, http://www.power-eng.com/articles/print/volume-99/issue-9/field-notes/high-tech-cogen-plant-saves-money-for-wellesley-college.html.

2 Wellesley College Sustainability Committee, Energy, *Wellesley College Homepage,* accessed May 15, 2015, http://www.wellesley.edu/sustainability/energy.

3 3. Director of Sustainability Patrick Willoughby, "Coolest Schools," *Sierra Magazine Online Questionnaire,* last modified April 13, 2011, http://vault.sierraclub.org/sierra/201109/coolschools/pdfs/Wellesley/Sierra%20Club%202011%20Final.pdf.

4 Shivani Kuckreja Notes from Wellesley College Cogeneration Power Plant Tour March 23, 2015.

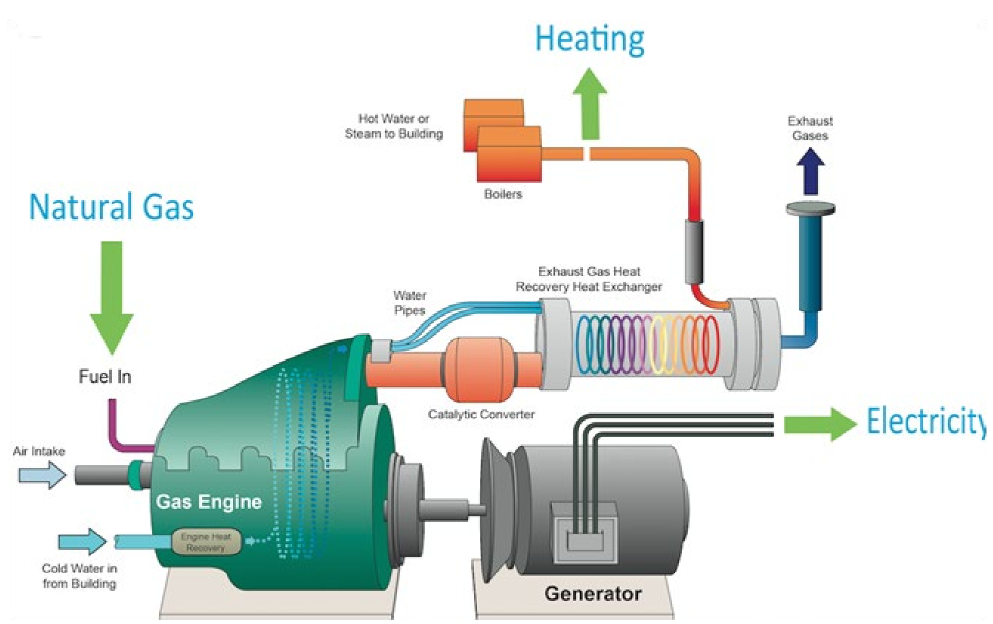


Figure 30: Cogeneration diagram on how a combined heat and power system works. [12]

town terminates in May of 2015. [5]

In addition, the College also has 4 steam boilers on campus for heat, hot water and air conditioning. The boilers at Wellesley were installed in 1981, 1983, and 1991.[6] In order to ensure the boilers are properly cleaned, every year one boiler is taken offline, cleaned and then put back online. Two of the boilers run on natural gas, one runs on No. 6 fuel oil and the other boiler runs on waste oil from the motor pool but can also be used to run on other fuels.[7] In 2013, the consumption of thermal energy was 236,316 MMBTU.[8] On average, 97% of heating comes from natural gas and 3% from fuel oil. [9]

Our current cogen plant is reaching obsolescence. For example, generator engine #4 only has 200 hours of run time (as of February 2015) left before it has to be taken offline. The lifespan of a cogeneration plant is usually 20 years maximum, but the College's engines have run for 21 years already. These types of engines have a specific maintenance program every few thousand operating hours. In order to maintain operations, the College has found service providers that have given up their older machines which the College has then re-machined into our plant. While this does buy us time, it is not a long term solution.[10]

One possible solution is to buy brand new engines and have them installed. When the College changes the engines, however, it is also required to replace its use of No. 6 fuel with No. 2 fuel oil. The main consideration when switching from No. 6 to No. 2 fuel oil is the increased price of the fuel. According to the US Energy Information Administration, No. 6 fuel oil comes in at $201/barrel and No. 2 $323/barrel.[11] These additional costs (beyond changing the engines) are important to take into consideration, especially when plans to renew the plant are not on the College's campus renewal budget.

5 Independent Auditor Report "Wellesley College Financial Statements," *Wellesley College,* last modified June 30, 2014, http://www.wellesley.edu/sites/default/files/assets/departments/controller/files/wellesley_college_fy14_fs.pdf.

6 Shivani Kuckreja Notes from Wellesley College Cogeneration Power Plant Tour March 23, 2015.

7 Shivani Kuckreja Notes from Wellesley College Cogeneration Power Plant Tour March 23, 2015.

8 Wellesley College Sustainability Committee "Energy." *Wellesley College Homepage,* http://www.wellesley.edu/sustainability/energy

9 3. Director of Sustainability Patrick Willoughby, "Coolest Schools," *Sierra Magazine Online Questionnaire,* last modified April 13, 2011, http://vault.sierraclub.org/sierra/201109/coolschools/pdfs/Wellesley/Sierra%20Club%202011%20Final.pdf.

Background on Cogeneration Plants

How Cogeneration works

10 Shivani Kuckreja Notes from Wellesley College Cogeneration Power Plant Tour March 23, 2015

11 Shivani Kuckreja Notes from Wellesley College Cogeneration Power Plant Tour March 23, 2015.

Combined heat and power (CHP), also known as cogeneration, is the simultaneous production and generation of electricity and heat from a single fuel source, often natural gas.[12] The ability to create two forms of energy from a single source requires an integrated energy system modified to suit the needs of the energy end user.[13] There are various components to cogeneration including onsite generation, waste-heat recovery, and seamless system integration. A fundamental part of the system includes an internal combustion, reciprocating engine that drives an electric generator. The natural gas fired engine spins a generator to produce electricity and the natural byproduct of this process is usually heat. This heat is then captured and used to supply space and water heating. Cogeneration is a highly efficient form of energy conversion and can lead to higher savings in energy production in comparison to purchasing electricity off of the national grid.[14] The fuel efficiency of a combined heat and power system can be approximately 90%. It is important to note that cogeneration is not actually an energy source, but rather an energy multiplier or a way of acquiring more usable energy from any one energy source.[15]

Advantages of Cogeneration

Because cogeneration provides high efficiency, there are various other considerable energy, environmental, and economic benefits. By using cogeneration power plants, there is less dependency on the usage of a centralized energy network, which also reduces vulnerability to power outages and system failures.[16] Economic losses due to power outages can be avoided or made less frequent by having cogeneration on site. Moreover, cogeneration requires less fuel to produce a given energy output, while avoiding transmission and distribution losses that usually occur when electricity travels over power lines.[17] The cogeneration plant will also only be generating the energy demanded by the end-users and would, therefore, avoid overproduction. By switching to cogeneration power plants, older, more polluting, and less efficient modes of heat supply are replaced. Environmental benefits associated with cogeneration include less air pollution and greenhouse gas emissions. There is also a thermal efficiency associated with cogeneration power plants that does not exist with single process plants that usually source their power and thermal energy separately. In a cogeneration plant, thermal loads are supplied by boilers existent in the system.[18]

12 "Combined Heat and Power Partnership," *EPA,* last modified February 03, 2015, http://www.epa.gov/chp/basic/

13 "Cogeneration & CHP Engineer Install Maintain," *Clarke Energy,* accessed May 15, 2015, http://www.clarke-energy.com/chp-cogeneration/.

14 Siegel. RP "Combined Heat and Power: Pros and Cons," *Triple Pundit people, planet, profit,* last modified April 30, 2012, http://www.triplepundit.com/special/combined-heat-power-pros-cons/.

15 Woodford, Chris, Combined heat and power (CHP) cogeneration, *Explain That Stuff,* last modified March 29, 2015, http://www.explainthatstuff.com/combinedheatpower_cogeneration.html.

16 "Combined Heat and Power Partnership," *EPA,* last modified February 13, 2015, http://www.epa.gov/chp/basic/.

Disadvantages of Cogeneration

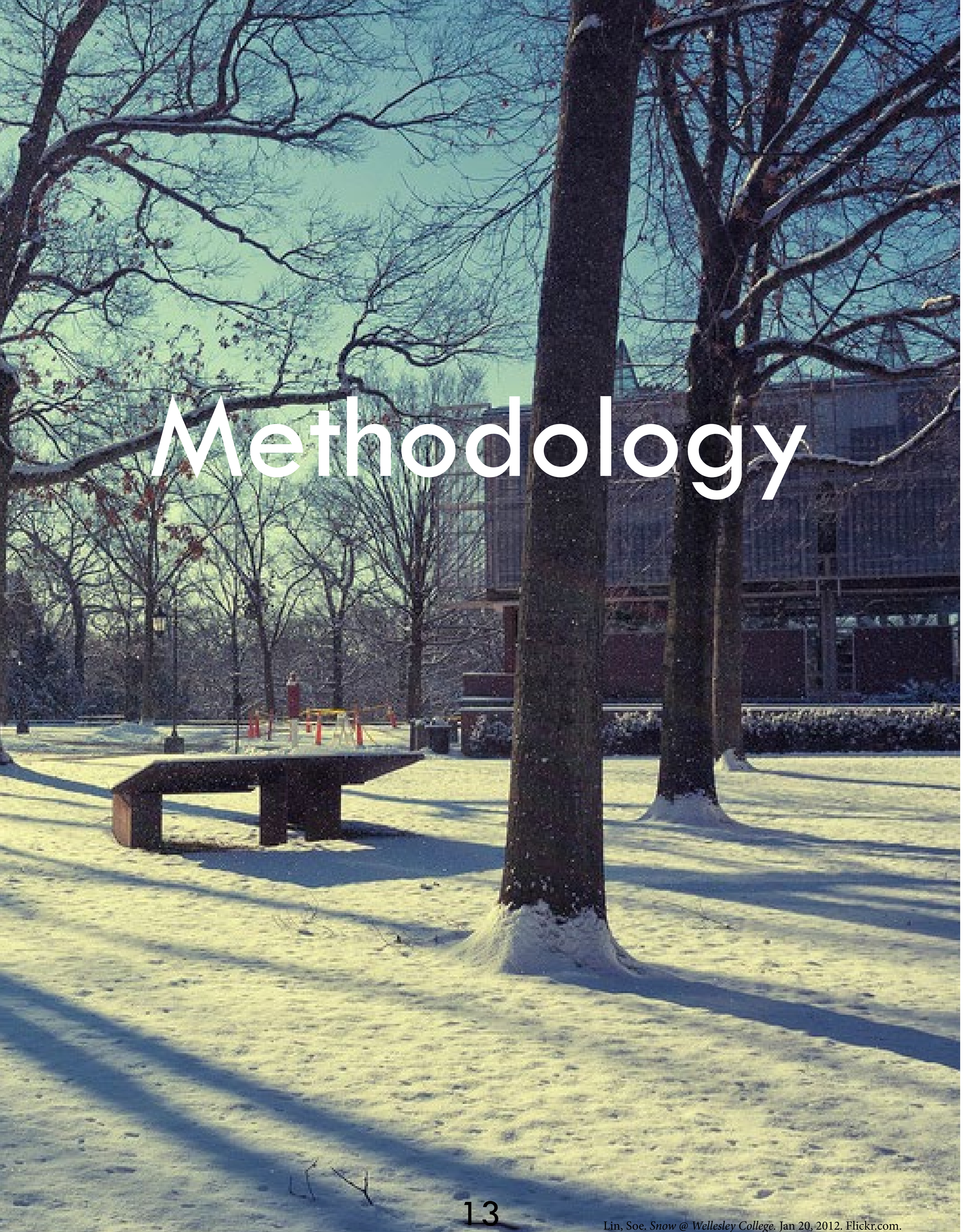
A common problem with building cogeneration plants is the high initial investment for the plant. Maintenance can also be costly for cogeneration plants. Furthermore, cogeneration is only suitable when there is a need for both electricity and heat on site, and the demand for both must remain fairly consistent. Lastly, cogeneration tends to make us depend on potentially unstable energy sources such as natural gas. [19]

In this report we evaluate the ability of various energy options to meet Wellesley College's energy needs.

17 "Cogeneration & Trigeneration," *Origin,* http://www.originenergy.com.au/4040/Benefits.

18 Woodford. Chris " Combined heat and power (CHP) cogeneration," *Explain That Stuff,* last modified March 29, 2015, http://www.explainthatstuff.com/combinedheatpower_cogeneration.html.

19 Siegel. RP "Combined Heat and Power: Pros and Cons," *Triple Pundit people, planet, profit*, last modified April 30, 2012, http://www.triplepundit.com/special/combined-heat-power-pros-cons/.



Methodology

Lin, Soe. *Snow @ Wellesley College.* Jan 20, 2012. Flickr.com.

Research Design

In order to evaluate energy options, we gathered both qualitative and quantitative data. Our class focused on 5 different energy options for both heat and electricity generation. For heat generation, we chose to focus on No. 2 fuel oil, No. 6 fuel oil, natural gas, solar hot water, and geothermal energy. We chose these energy sources because they are the most practical sources to use on campus, as they have either been used on our campus or on similar college campuses. For electricity, we chose to look at natural gas, purchased grid electricity, purchased green grid electricity, wind power, and solar photovoltaic energy. All of the energy sources for both heat and electricity generation will be explained in detail in latter sections of this report.

In order to thoroughly assess each energy source, we evaluated each energy source on eight metrics: cost, reliability, educational advantages, climate change (greenhouse gas emissions), ecotoxicity, ecosystem disruption, human health impacts, and environmental justice impacts.

The goal when using metrics is to be able to fully analyze the impact that each energy source has throughout its lifetime, particularly for the extraction, manufacturing, transport, and operation phases.

Lifecycle Assessment

A lifecycle assessment (LCA) is a technique that looks at the relevant impacts associated at every stage of a product or service's lifetime. Looking at the LCA of each energy generation operation establishes a systematic measurement of the environmental, social, and economic impacts of each energy source, and thus helps determine which energy sources are the best. The elements in the LCA include mapping, classification, characterization, and interpretation/improvement, all of which are illustrated in figure 2.[1]

In our analysis, we assess the various characteristics at each stage by creating an inventory of all

1 Life Cycle Data for Hydroelectric Generation at Embretsfoss 4 (E4) Power Station, *Ostfoldforskning,* accessed April 4, 15, http://ostfoldforskning.no/uploads/dokumenter/publikasjoner/703.pdf.

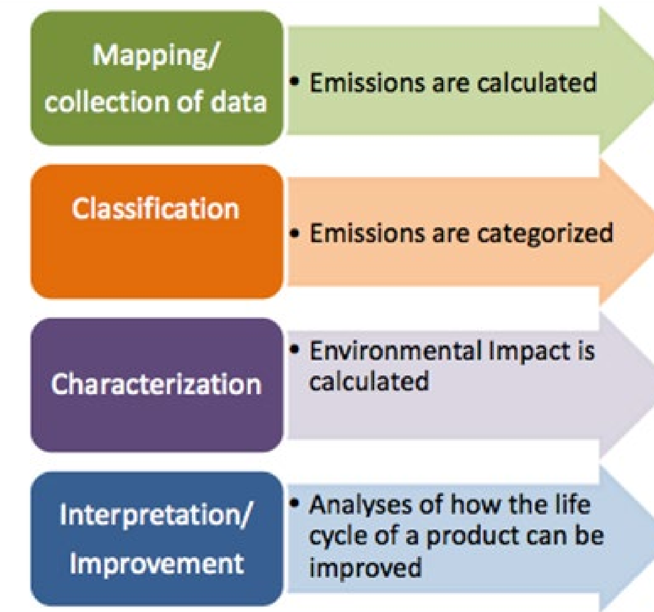


Figure 31: Main stages of a Life Cycle Assessment

relevant inputs and outputs, and evaluating the potential impacts on the environment and on human health. Because it creates common units for comparison, an LCA allows us to compare and contrast energy sources. Furthermore, by completing an LCA, we will be able to have a clear breakdown of each stage of the process, which will help us identify the processes with the greatest impact, thus allowing us to examine how to reduce or avoid those impacts.

A disadvantage of using a lifecycle assessment is that the lifecycle analysis process requires us to input distinct parameters that may generalize and disregard certain information, regardless of how thorough our processes are.

Our LCA attempts to quantify the total costs, benefits and justice impacts of each source, as well as each source's human health impacts, climate change impacts, and ecotoxicity levels. Other metrics were assessed by using a software program, SimaPro 7, which will be detailed in a later section.

A few metrics, like environmental justice and energy source reliability, were measured using relevant points or questions that the class determined to be crucial. The specifics for these, too, will be discussed in later sections. It is important to note that it was difficult to establish quantitative measures for some of the environmental and social impacts, as they can be relative and their magnitudes can differ drastically between individual opinions.

An LCA delivers clear documentation of the total environmental impacts related to a product or service, so it provides an easy format for Wellesley to compare the different performance options. Our ability to use lifecycle assessments for each energy source's lifetime- from extraction to disposal- allows us to present the various factors necessary for consideration. Although Wellesley does not have the means to directly influence the manufacturing processes of energy sources, the college does, indeed, have the ability to weigh the significance and trade-offs of each energy option's impacts at every stage of its life cycle.

SimaPro 7

In addition to using lifecycle assessments, we also used a software program called SimaPro 7 to quantify the total benefits for health, ecotoxicity, and climate change impacts. SimaPro 7 aggregates data for each lifecycle stage in order to determine the impacts of each energy source at different stages of the lifecycle assessment. It is important to note that we exclude the effects of all disposal phases in our analysis of energy sources because we cannot determine how the products will be disposed of in the future. Moreover, it is important to recognize that Wellesley College is committed to a high standard of waste disposal, thus the effects of any disposal should be relatively low.[2]

Within SimaPro 7, we also analyzed data using the EPA Tools for the Reduction and Assessment of Chemical and Other Environmental Impacts, often referred to as a TRACI2 test. Our functional unit for this analysis was 1 kWh- the input needed to produce one kilowatt-hour of heat or electricity. While heat is typically measured in BTUs, we chose to have a consistent functional unit across our energy production sources for consistency and clarity.[3] We also believe that the kilowatt-hour is the most understandable energy unit across all audiences, as it is used on electricity bills, in chemistry courses, and is used to describe basic power plant capacity. Furthermore, because we will be using the unit of kilowatt-hour, our cost units will be USD per kWh ($/kWh), another unit most commonly used.

Summing up the environmental and health effects is difficult because the effects have different units. In order to overcome this problem, TRACI2 normalizes our results by creating its own unit of measurement.[4] Health impacts are thus measured in a comparative toxic unit for human toxicity impacts (CTUh), which calculates the number of disease cases per kWh of energy produced. Ecotoxicity is measured in comparative toxic units for aquatic ecotoxicity impacts (CTUe), which calculates the number of potentially affected species per cubic meter per day for every kWh produced of energy. For global warming potential, TRACI2 converts all greenhouse gases (like carbon dioxide and methane) into kilograms of carbon dioxide equivalent units by factoring in each gas' greenhouse gas potential.

Once the units have been normalized and summed, the TRACI2 analysis provides a table output and graphical representation of the health and environmental impacts for each kilowatt-hour of energy produced.

The following sections provide insight into the processes used to decide which aspects of each of the aforementioned metrics we would be focusing on and how we came to these conclusions.

Metrics

Cost Analysis

The metric of cost analysis provides insight into the financial burden each energy source will have on Wellesley College. The results of this metric will inform the decisions of the college's administrators when assessing the feasibility of each energy source for Wellesley's campus.

Levelized Cost of Energy

The Levelized Cost of Energy (LCOE) facilitates cost comparisons across energy generation sources for the entire lifetime of each generator. It aggregates the capital cost, capacity factor, fixed costs of operation and management, variable costs of operations and management, heat rate, fuel costs, electricity price, and cost escalation rate. It then factors in how many years the generator will function, as well as a discount rate.[5] Its final computation results in a number that embodies the total costs to the energy user throughout the lifetime of the generator, adjusted for the number of kWh of energy it will produce.

2 For more information on Wellesley College waste management policies, visit their website at http://www.wellesley.edu/safety/waste

3 Since co-generation plants produce both heat and electrical energy, it is clearer to use a single functional unit to describe its output capacity.

4 Frequently Asked Questions– How to Use USEtox Characterization Factors, *USEtox,* accessed March 28, 2015.

Equation 1: Levelized Cost of Energy Calculation

$$sLCOE^{26} = \frac{(\textit{overnight capital cost}) * (\textit{capital recovery factor}) + (\textit{fixed O\&M cost})}{(8760 * \textit{capacity factor})\} + (\textit{fuel cost} * \textit{heat rate}) + \textit{variable O\&M cost}}$$

The equation to compute LCOE is Equation 1.

To make this calculation, we use the Levelized Cost of Energy calculator that was created by the National Renewable Energy Laboratory, a subsector of the U.S. Department of Energy's the Office of Energy Efficiency and Renewable Energy.[6] In order to obtain an LCOE, the following input values were required:

Inputs to the Levelized Cost of Energy Calculator:

- Period (Years): Number of years the energy source will function
- Discount Rate (%): How much less we value money in the future compared to our value of money in the present
- Capital Cost ($/kW): Upfront costs of purchasing this energy generator
- Capacity Factor (%): The amount of time the energy generator will run each year, i.e. if it ran at 100% capacity for half of the year, then Capacity Factor = 50%
- Fixed Operations and Maintenance ($/kW-yr): The definite costs per year of using the generator, i.e. hiring staff to operate the generator
- Variable Operations and Maintenance ($/kWh): The fluctuating costs per year of using the generator, i.e. every few years the generator may need a new part
- Fuel Cost ($/MMBTU): The costs of fuel inputs used to produce 1 million British Thermal Units of energy , i.e. the average cost of No. 6 fuel oil in 2014 = $ 2.044/gallon. The gallons to MMBTU conversion for No. 6 fuel oil = 0.15.[7] So the Fuel Cost for No. 6 fuel oil = ($2.044/gallon)(0.15 gallons of No. 6 fuel oil/MMBTU) = $13.63/MMBTU
- Today's Electricity Price (cents/kWh): The cost of buying electricity from the grid in order to run the basic functions of the power plant
- Cost Escalation Rate (%): The expected change in grid electricity prices
- Heat Rate: The amount of energy expended to obtain a unit of useful energy

Each of these data pieces is necessary in order to have a complete analysis of the total expenses for each energy generation option.

Additionally, as mentioned above, we decided that the most practical unit to use for our cost assessment would be the USD per kilowatt-hour. As we mentioned earlier, while heat is typically measured in BTUs, we chose to have a more uniform functional unit across our energy production sources for consistency and clarity.[8] We also believe that using kilowatt-hour is the most understandable unit across all audiences. Moreover, because we will be using kilowatt-hour, our cost units will be USD per kWh ($/kWh), another unit most commonly used. It is important to note that two metrics, kWh and BTU, are interconvertible, as long as we keep in mind that we used kWh as a unit for our outputs.

5 Levelized Cost of Energy Calculator, *National Renewable Energy Laboratory,* accessed on April 19, 2015, http://www.nrel.gov/analysis/tech_lcoe.html.

6 Levelized Cost of Energy Calculator, *National Renewable Energy Laboratory,* accessed on April 19, 2015, http://www.nrel.gov/analysis/tech_lcoe.html.

7 Energy Units, *Think Energy Management,* accessed on April 19, 2015, http://www.think-energy.net/energy_units.htm.

8 Since co-generation plants produce both heat and electrical energy, it is clearer to use a single functional unit to describe its output capacity.

Kilowatt hours (kWh) is one kilowatt amount of power delivered in one hour. A British Thermal Unit (BTU) is the amount of energy required to heat one pound of water to 1 Fahrenheit degree. Use the following table to convert between the two:

1 kWh =	3,412.14163 BTU
1 BTU =	0.00029307107 kWh

Furthermore, for our cost analysis of both our heat and electricity options, we would have benefited from having had more information regarding upfront costs. With the available information, we analyzed our costs with the following assumptions:

<u>Assumptions for All Energy Sources</u>

- In order to imagine the energy to be scaled to meet Wellesley's demand, we assume that every energy source has 100% capacity, which means the energy is being used year- round at full capacity.
- We use a discount rate of 3% to normalize the comparisons across time.
- Based on our conversation with the Wellesley Municipal Light Plant, we assume that grid electricity costs 5 cents per kWh.[9]

<u>Assumptions for No. 2 and No. 6 Fuel Oil (Heat)</u>

- Wellesley already has boilers that burn No. 6 fuel oil and natural gas. Those boilers can easily be retrofitted to burn No. 2 fuel oil. We assumed the overnight capital cost is $0 since the infrastructure already exists.
- No. 2 fuel oil, No. 6 fuel oil, and natural gas all generate heat from the same boilers and cogeneration plant, so we assume the operating costs are the same ($0.0035/kW-yr).[10]
- For our LCOE calculation, we estimated the lifespan of the cogeneration plant is 5 years.[11] Within the next 5 years we will have to replace or retrofit the current cogeneration plant to run No. 2 fuel oil or another energy source. If we run No. 2 fuel oil, the re-permitting process will require Wellesley College to disuse No. 6 fuel oil.
- Please note we did not consider the re-permitting cost.
- The fuel cost for non-renewables also impacts the annual cost.
- We assume the cost of No. 6 fuel oil is fixed at the average 2014-2015 cost: $13.63/MMBTU.[12]
- We assume the cost of No. 2 fuel oil is fixed at the average 2014-2015 cost: $13.00/MMBTU.[13]
- The heat rate for No. 2 fuel oil and No. 6 fuel oil is 10,710.[14]

<u>Assumptions for Natural Gas (Heat)</u>

- In order to imagine the energy to be scaled to meet Wellesley's demand, we assume that every energy source has 100% capacity, which means the energy is being used year-round at full capacity.
- We use a discount rate of 3% to normalize the comparisons across time.
- Based on our conversation with the Wellesley Municipal Light Plant, we assume that grid electricity costs 5 cents per kWh.[15]
- We will assume the generator is a combined cycle electricity generator because that is what we currently use on campus.[16]
- The fuel cost is fixed at $3.73/MMBTU.[17]
- The heat rate is 6,900.[18]
- The overall overnight capital cost ($/kW) is $1318/kWh.
- Fixed Operating Cost ($/kW-yr): $6.20
- Variable Operating Cost ($/kW-yr): $0.0035
- Fuel Cost: $26.67/MMBTU
- Years that the cogen plant will function: 30

<u>Assumptions for Solar Hot Water (Heat)</u>

- We used values for capital costs, fixed operating costs, and variable operating costs from OpenEl.[19]
- The heat rate is 10,000.

<u>Assumptions for Geothermal (Heat)</u>

- We used values for capital costs, fixed operating costs, and variable operating costs from OpenEl.[20]
- We made fixed operating cost assumptions for geothermal energy based on data from OpenEI. The website indicated that the fixed operating cost for blind geothermal was an outlier in the dataset. With no credible alternatives, we chose to use the supplied data.
- The variable operating cost for geothermal energy was also labeled an outlier. Upon closer inspection, we noticed a calculation error in the dataset. The "outlier" was actually a value that had not been converted from megawatts to kilowatts. We used our calculated value of $0.0017/kW-yr.
- The heat rate for geothermal is 10,000.[21]

<u>Assumptions for Natural Gas (Electricity)</u>

- We will assume the generator is a combined cycle electricity generator because that is what we currently use on campus.[22]
- The fuel cost is fixed at $3.73/MMBTU.[23]
- The heat rate is 6,900.[24]

<u>Assumptions for Solar Photovoltaic (Electricity)</u>

- In order to imagine the energy to be scaled to meet Wellesley's demand, we assumed that every energy had 100% capacity, which means the energy is being used year round at full capacity.
- We use a discount rate of 3% to normalize the comparisons across time.
- Based on our conversation with the Wellesley Municipal Light Plant we assume grid electricity costs 5 cents per kWh .[25]
- The heat rate is 10,000.[26]
- Overnight Capital Cost ($/kW): $4303
- Fixed Operating Cost ($/kW-yr): $30
- Variable Operating Cost ($/kW-yr): $0
- Number of years the solar panels will generate electricity: 30

9 Conversation with WMLP on April 10th, 2015.

10 "Transparent Cost Database," *OpenEl,* accessed on April 20, 2015, http://en.openei.org/apps/TCDB/.

11 We gathered this from our conversation with Wellesley College's Director of Operations, Trina Learned, when we discovered the cogeneration plant has reached its lifespan.

12 U.S. Residual Fuel Oil Wholesale/Resale Price by Refiner, *U.S. Energy Information Administration,* accessed on April 19, 2015, http://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=EMA_EPPR_PWG_NUS_DPG&f=M.

13 U.S. Residual Fuel Oil Wholesale/Resale Price by Refiner, *U.S. Energy Information Administration,* accessed on April 19, 2015, http://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=EMA_EPPR_PWG_NUS_DPG&f=M.

14 U.S. Residual Fuel Oil Wholesale/Resale Price by Refiner, *U.S. Energy Information Administration,* accessed on April 19, 2015, http://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=EMA_EPPR_PWG_NUS_DPG&f=M.

15 Conversation with WMLP on April 10th, 2015.

16 Need to download the dataset to see this information, Transparent Cost Database, *OpenEl,* accessed on April 19, 2015, http://en.openei.org/apps/TCDB/.

17 Henry Hub Natural Gas Spot Rate, *U.S. Energy Information Administration,* accessed on April 19, 2015, http://www.eia.gov/dnav/ng/hist/rngwhhdA.htm.

18 Need to download the dataset to see this information, Transparent Cost Database, *OpenEl,* accessed on April 19, 2015, http://en.openei.org/apps/TCDB/.

19 Need to download the dataset to see this information, Transparent Cost Database, *OpenEl,* accessed on April 19, 2015, http://en.openei.org/apps/TCDB/.

20 Need to download the dataset to see this information, Transparent Cost Database, *OpenEl,* accessed on April 19, 2015, http://en.openei.org/apps/TCDB/.

21 Need to download the dataset to see this information, Transparent Cost Database, *OpenEl,* accessed on April 19, 2015, http://en.openei.org/apps/TCDB/.

22 Need to download the dataset to see this information, Transparent Cost Database, *OpenEl,* accessed on April 19, 2015, http://en.openei.org/apps/TCDB/.

23 "Henry Hub Natural Gas Spot Rate," *U.S. Energy Information Administration,* accessed on April 19, 2015, http://www.eia.gov/dnav/ng/hist/rngwhhdA.htm.

24 Need to download the dataset to see this information, Transparent Cost Database, *OpenEl,* accessed on April 19, 2015, http://en.openei.org/apps/TCDB/.

25 Conversation with WMLP on April 10th, 2015.

26 Need to download the dataset to see this information, Transparent Cost Database, *OpenEl,* accessed on April 19, 2015, http://en.openei.org/apps/TCDB/.

Assumptions for Purchased Grid (Electricity)

- In order to imagine the energy to be scaled to meet Wellesley's demand, we assumed that every energy had 100% capacity, which means the energy is being used year round at full capacity.
- We use a discount rate of 3% to normalize the comparisons across time.
- Based on our conversation with the Wellesley Municipal Light Plant, we assume that grid electricity costs 5 cents per kWh .[27]
- We assume that the price of green grid electricity is fixed at its current average price (9 cents/kWh).[28]
- There are no fixed costs since we will import from the Wellesley Town's Power Plant.
- The variable costs are the same as natural gas to maintain electricity distribution on campus.

Assumptions for Purchased Green Grid (Electricity)

- In order to imagine the energy to be scaled to meet Wellesley's demand, we assumed that every energy source has 100% capacity, which means that the energy is being used year- round at full capacity.
- We use a discount rate of 3% to normalize the comparisons across time.
- Based on our conversation with the Wellesley Municipal Light Plant, we assume that grid electricity costs 5 cents per kWh .[29]
- We assume that the price of grid electricity is fixed at its current average price (5 cents/kWh).[30]
- We assume that the price of green grid electricity is fixed at its current average price (9 cents/kWh).[31]
- There are no fixed costs since we will import from the Wellesley town's power plant.
- The variable costs are the same as natural gas to maintain electricity distribution on campus.

Assumptions for Wind (Electricity)

- In order to imagine the energy to be scaled to meet Wellesley's demand, we assume that every energy has 100% capacity, which means that the energy is being used year-round at full capacity.
- We use a discount rate of 3% to normalize the comparisons across time.
- Based on our conversation with the Wellesley Municipal Light Plant, we assume that grid electricity costs 5 cents per kWh .[32]
- In order to imagine the energy to be scaled to meet Wellesley's demand, we assume that every energy source has 100% capacity, which means that the energy is being used year- round at full capacity.
- We use a discount rate of 3% to normalize the comparisons across time.
- Based on our conversation with the Wellesley Municipal Light Plant, we assume that grid electricity costs 5 cents per kWh .[33]
- Similar to the problem of outliers we confronted working with the geothermal data in OpenEl, the variable operating cost was an outlier. Again, we found that the value had not been converted from megawatts to kilowatts. We recalculated the given value and used the updated cost of $0.006/kW-yr for our calculations.
- The heat rate for wind is $10,000.[34]
- Overnight Capital Cost ($/kW): $1800
- Fixed Operating Cost ($/kW-yr): $18
- Variable Operating Cost ($/kW-yr): $0.01
- Lifetime of a wind turbine: 20 years

Reliability

Reliability focuses on how dependent each energy- generating option is after implementation.

27 Conversation with WMLP on April 10th, 2015.
28 Conversation with WMLP on April 10th, 2015.
29 Conversation with WMLP on April 10th, 2015.
30 Conversation with WMLP on April 10th, 2015.
31 Conversation with WMLP on April 10th, 2015.

32 Conversation with WMLP on April 10th, 2015.
33 Conversation with WMLP on April 10th, 2015.
34 Need to download the dataset to see this information. "Transparent Cost Database," *OpenEl,* accessed on April 19, 2015, http://en.openei.org/apps/TCDB/.

Table 75: Composition of the aforementioned assumptions for each energy option for both heat and electricity generation. Footnotes at the end of methodology section.

Source (Data from 2009-2014)	Lifetime	Discount Rate	Capital Cost ($/kW)	Capacity Factor (%)	Fixed O&M Cost ($/kW-yr)	Variable O&M Cost ($/kWh)	Heat Rate (Btu/kWh)	Fuel Cost Input ($/MMBtu)	Electricity Price (cents/kWh)[1]	Cost Escalation Rate (%)
No.6 Fuel Oil	5	3%	$0.00	100%	$6.20	$0.0035	10,713[2]	$26.67/MMBTU[3]	5	3
No.2 Fuel Oil	5	3%	$0.00	100%	$6.20	$0.0035	10,713[4]	$37.07/MMBTU[5]	5	3
Natural Gas[6]	20	3%	$ 1,318	100%	$6.20	$0.0035	6,900	$3.73/MMBTU[7]	5	3
Geothermal[8]	20	3%	$6,846	100%	$222.98	$0.0170	3,412	0	5	3
Solar Hot Water (flat plate & evacuated tube)[9]	30	3%	$9,800	100%	$71.00	$0.003	3,412[10]	0	5	3
Purchased Grid Energy	20	3%	$0.00	100%	$0.00	$0.0035	10,000[11]	0.05	5	3
Purchased Green Energy	20	3%	$0.00	100%	$0.00	$0.0035	10,000[12]	0	5	3
Natural Gas	20	3%	$1,318	100%	$6.20	$0.0035	6,900	0	5	3
Wind (100-1000kW)[13]	30	3%	$1,800	100%	$18	$0.01	0	0	5	3
Solar PV (100-1000kW)[14]	30	3%	$4,303	100%	$30	$0.00	0	0	5	3

The metric of reliability refers to whether an energy source can be provided uninterrupted, whether is it available in both the long-term and the short-term, the degree to which it is independent of weather, and its ability to provide energy based on demand.

Wellesley College, like most places, requires reliable energy 24 hours a day, 7 days a week, 365 days a year. With this in mind, we gave each energy source a score of 0 for "No" or a 1 for "Yes" based on whether it fulfills these six qualities of a reliable energy source:

- Can it be provided uninterrupted?
- Can it be stored?
- Is it available short-term (until 2025)?
- Is procurement stable (not volatile) in the long term?
- Is it independent of weather?
- Can you ramp it up/down to meet fluctuating energy demand?

We also choose not to include questions for energy sources when they are not applicable for that particular source by labeling that category as "N/A." A score of "N/A" is given when the answer is unclear or unpredictable, as is the case when assessing long-term availability for some energy sources.

For example, to calculate the reliability of Natural Gas:

1 Can it be provided uninterrupted? Yes. Natural gas is available uninterrupted at a premium.

0 Can it be stored? No. Natural gas can't be stored for future use.

1 Is it available short term (until 2025)? Yes. Our natural gas reserves are currently abundant and we are confident in its relatively cheap supply for the next 10 years.

0 Is procurement stable (not volatile) in the long term? No. Regulation of fracking practices is trending towards becoming more stringent, making it possible that natural gas is too costly or too sparsely extracted and may be unavailable in 35 years.

1 Is it independent of weather? Yes. Weather variations won't affect the energy source's ability to harness energy.

1 Can you ramp it up/down to meet fluctuating energy demand? Yes. We have the power to increase natural gas flow into the combustion turbine, thus increasing energy generated.

Total Score: **4** out of 6

The higher the score, the more reliable that energy source is, based on the qualities of reliability as we have previously defined it.

Educational Advantages

Educational advantages measures how much more of an educational boost Wellesley College will receive after implementation of the energy options chosen.

The metric of educational advantages refers to whether an energy sources provides an educational boost to the campus based on several different categories. Each category was chosen to be representative of an aspect of education that Wellesley College considers a priority.

Wellesley College relies on energy to fulfill its basic mission: to educate. Energy allows for the basic functions of the college, but has the additional potential to teach the community about energy generation. There are many ways to generate electrical and thermal energy, each with a varying capacity to engage the community in energy-related learning. Energy generation is an interdisciplinary field and may be especially beneficial for the Environmental Studies, Geosciences, Engineering, Chemistry, Physics, Computer Science, and Architecture programs during lectures, labs, and research.

We will rate energy generation options based on their ability to promote the education of Wellesley College community members. This metric measures the range of educational advantages each energy source provides for the Wellesley College community.

We assess the educational benefits of five different educational categories. These categories are scored on a 3-point scale: 0,1, and 2, where 0 represents low educational benefit, 2 represents high educational benefit, and 1 represents medium educational benefit.

We will add up the scores across the five categories to determine if that method of energy generation has a cumulative positive, neutral, or negative effect on the education of the Wellesley College community.

The categories are in-class interaction, outside of class energy awareness, career development, administrative model, and model for others, and the definition for each is as follows:

- **In-Class Interactions**

Students can learn from the energy source and use data from it to understand energy generation.

Generator options will be scored positively if they create opportunities for those of the Wellesley community to safely visit and interact with the power generator, and to collect and analyze data for use in class or lab.

- **Outside of Class**

There is visibility on-campus and the energy source raises awareness about sustainability.

Visibility is an effective way to educate others and encourage environmentalism. The power generator would be rated positively if it is visible every day to the majority of the Wellesley community.

- **Career Development**

The energy source's ability to be a research opportunity to further the interests of students and professors.

The power generator would be rated positively if it creates opportunities for students and professors to conduct research.

- **Administrative Model**

The energy source's ability to inform administrative decisions on scaling up energy production, which is most relevant for new technologies.

The implementation of a certain energy source may also be educational for the college's administration. The generator is rated positively if use of the technology can inform the administrators as to whether or not the use of certain energy sources can be feasibly scaled up on campus.

- **Model for Others**

The energy source provides insight and encourages external organizations to replicate forms of uncommon energy production.

Wellesley College is a distinguished college and is a model for other colleges around the world. Generators will be rated positively if their implementation reflects a bold decision that may further distinguish Wellesley from other similar or surrounding colleges.

For example, if we were to look at the education advantages for Solar Panels:

2 In Class Interactions. For example, in ES 220, students develop MATLAB code that uses data collected from the solar panels at the KSC.

1 Outside of Class. The solar photovoltaic system is highly visible to students because they will be able to see where the energy they are consuming is coming from.

2 Career Development. If student conducts research on campus regarding the solar panel system, then it could be shared with others at Tanner, Ruhlman, and other conferences.

1 Administrative Model. Solar PV cells are common on other college campuses and solar PV is difficult to scale up to provide for a large portion of the campus, as it requires land and money.

1 Model for Others. For example, our unique choices, like the solar panel system, can provide an example for other colleges and may attract press, which could educate people outside of the academic community.

Total score: **7** out of 8

A higher score means that an energy source has more of a positive effect for education on campus, based on the qualities of the metric of educational advantage as we have defined it.

Greenhouse Gas Emissions

The following metric of greenhouse gas emissions measures how much impact an energy source has based on the amount of greenhouse gas emissions emitted per each stage of the lifecycle. This metric is measured using SimaPro 7.

The metric of greenhouse gas emissions refers to the environmental impact each energy source has on climate change. Climate change occurs when large amounts of greenhouse gases, such as carbon dioxide (CO2) and methane (CH4), are released into the atmosphere. Human activities, primarily burning fossil fuels, emit greenhouse gases into the earth's atmosphere. The greenhouse gases trap heat, which causes the planet to warm or cool to extreme temperatures. In general, global climate change can lead to higher temperatures, ocean acidification, sea level rise, and the increased likelihood of extreme weather. These processes are already affecting the lives of millions of people all around the world economically, environmentally, and socially.

Multiple college campuses, Wellesley among them, have made commitments to reduce their net greenhouse gas emissions with campus goals, projects, and purchases, which is why it is important to look at greenhouse gas as a metric to assess the environmental impact each energy source has at each stage in its life cycle.

We use SimaPro 7 to measure our energy inputs, processes, and carbon dioxide emissions as a measure of climate change. SimaPro 7 quantifies emissions of different greenhouse gases as carbon dioxide equivalents.

Ecotoxicity

The following metric, ecotoxicity, measures the amount of exposure to toxic chemicals communities around the energy source are subjected to when the source emits toxic chemicals in surrounding ecosystems at the different stages of its lifecycle. This metric is measured using SimaPro 7.

The metric, ecotoxicity, is the measure of the potential biological, chemical or physical stressors that affect ecosystems and determines the overall environmental impact of using an energy source. Ecotoxicity quantifies the effects of contaminants on the natural environment. This metric is important in the life cycle, since many stages have effects with long lasting impacts.

Ecotoxicity considers the impacts of contaminants, including pesticides, on individuals, populations, natural communities, and ecosystems. Contaminants can include mercury, lead, pesticides, PCBs, VOCs, heavy metals, dioxins, mold, chlorine, and asbestos. Ecotoxicity also affects the larger ecosystems since many organisms are dependent upon each other and organisms that are lower on the food chain can cause higher toxic accumulations at the top of the food chain.

Exposure to toxic chemicals can be found at many stages throughout the life cycles of our electricity and heat options. For example, the process of extracting natural gas introduces thousands of hazardous chemicals into the earth's soil, water and air. These toxic chemicals stay in the environment for long periods of time because once the fracking is finished the toxic fluids remain deep in the ground. Another example, both No. 2 and No. 6 Fuel Oil production processes use a wide array of chemicals to extract and refine oil, and toxic substances are released into the atmosphere and in wastewater from refineries. Toxic chemical including arsenic and lead, are also used in the manufacturing of PV solar panels.

For our report, we used SimaPro 7 to measure ecotoxicity impacts. The software uses the TRACI2 test, and normalizes the impacts of these various chemicals by quantifying ecotoxicity as an herbicide. By using TRACI2, we are able to assign ecotoxicity a unit of analysis that will remain consistent for the comparison of our energy sources. As previously mentioned, SimaPro 7 uses the functional unit of CTUe, which is a measurement of comparative toxic units for aquatic ecotoxicity impacts (CTUe), for ecotoxicity. This unit calculates the number of potentially affected species per cubic meter per day for every kWh produced of energy.

Furthermore, the unit is an herbicide, kg 2,4-dichlorophenoxyacetic acid (2,4-D) equivalent. 2,4-D is one of the most widely used herbicides in the world. As a chemical herbicide, 2,4-D has low toxicity for humans, but is moderately toxic to birds and mammals and slightly toxic to fish. Acute oral exposure for pigeons occurs at 668 mg/kg in pigeons and acute exposure of the dimethyl amine salt form of 2,4-D to rainbow trout is 100 mg/L which is considered to be slightly toxic. 2,4-D is not cancer-inducing in humans and the reference dose is 0.01 mg/kg/day.

Ecosystem Disruption

Ecosystem disruption measures the potential stressors that affect different parts of ecosystems that are not measured in SimaPro 7. This metric considers the environmental impacts overlooked in other metrics we consider.

The aspects of ecosystem disruption that were considered include biodiversity loss, land disruption, water use, and water contamination. For example, burning natural gas releases much less pollution into the air when it is burned, but the process of extracting natural gas is very energy intensive. In order to drill for the oil, large tracts of land must be cleared of forests, and thousands of chemicals are pumped into the ground to bring the natural gas to the surface. Not only do these production methods cause soil erosion and water pollution, but also natural habitats are fragmented and ecosystems destroyed.

Another example is solar PV cells, for which the creation process is energy intensive because mining for the rare earth metals also involves moving large tracts of land and drilling deep into the earth to create huge pits. The metals have to be further refined before being put into the solar panels. Aside from the production of solar panels, the use of solar panels on a large scale can lead to land degradation and habitat loss.

For each energy option, we look at the three main phases of the lifecycle: extraction, manufacturing, and use, and we consider the impacts of the aforementioned aspects with the following criteria:

- Land Disruption is the temporary and permanent destruction of an area of land resulting from processes including mining and deforestation.
- Water Use is the amount of water used and/or contaminated during the life cycle of an energy source.
- Biodiversity Disruption refers to a negative impact on the number of species within an area and is a general measure of species loss.
- Water Use refers to the amount of water an energy option uses and does not return back to the original system. This does not refer to the water used as part of the system, like in geothermal closed-loop systems or in solar hot water systems.

When looking at each aspect of ecosystem disruption, a number was designated based on a scale of 0 to 2. The number 0 for "No" or a 1 for "Yes" based on whether it fulfills these six qualities of a reliable energy source. A higher number is worse for the environment, with a maximum of 8 possible points.

Human Health Impacts

The following metric, human health impacts, measures the various impacts the lifecycle stages of each energy source have on human health. This metric is similar to that of ecotoxicity and ecosystem disruption, but captures the impact on humans rather than on the environment.

The metric of human health impacts is measured in SimaPro 7 as 3 different categories: carcinogens, non-carcinogens, and particulate matter.

According to the World Health Organization, human health is defined as "a state of complete physical, social and mental well-being, and not merely the absence of disease or infirmity."[35] Human health is a telling metric of personal well-being.

Each category is defined as follows:

- Carcinogens

One of the sub categories of human health is carcinogens, substances that are directly involved in causing cancer. They can disrupt cellular processes all over the body and ultimately change a cell's DNA. While there are a host of carcinogenic chemicals associated with an energy source's lifecycle, SimaPro 7 normalizes these impacts and reports carcinogenic potential in kilograms of benzene-equivalent released for each unit of energy produced. Benzene is a volatile organic chemical that is often released as a byproduct of burning gasoline or smoking a cigarette.

The energy sources that we looked at expose humans to carcinogens throughout their lifecycles. For example, during oil drilling, hydrocarbons are released into waterways. Similarly, solar panels and wind turbines require rare-earth metals which, when mined, discharge carcinogens like the radioactive ele-

35 World Health Organization: Trade, foreign policy, diplomacy and health, accessed March 8, 2015, http://www.who.int/trade/glossary/story046/en/.

ment thorium into water supplies.

- Non-Carcinogens

The second subcategory, non-carcinogens, are substances that are also toxic to human health, but do not necessarily cause cancers. A wide array of substances falls under this category including heavy metals, dioxins, and some organic chemicals. SimaPro 7 normalizes this wide array in kilograms of toluene-equivalent released for each unit of energy produced. Toluene is an important organic solvent with intoxicating properties. If ingested, toluene has the potential to cause severe neurological harm and death.

Non-carcinogens can be produced in all stages of an energy source's lifecycle. For example, people who live next to fracking sites have reported suffering from neurological problems, skin rashes, and digestive disorders. Furthermore, crystalline silica dust is a potentially harmful by-product associated with the mining and processing of silica and is associated with silicosis, a lung disease in which scar tissue forms in the lungs and reduces the ability to breath.

- Particulate Matter

Our third health subset metric, particulate matter, is comprised of sulfate, nitrates, ammonia, sodium chloride, black carbon, mineral dust and water, and has the potential to harm respiratory organs. Long exposure to small particulate matter also has the potential to cause structural damage to the lungs. Most health damaging particles have a diameter of 10 microns or less (PM10), but particulate matter, with a diameter smaller than 2.5 microns (PM 2.5), heightens the risk of lung disease by lodging deep inside one's lungs. Thus, SimaPro 7 normalizes the impacts of all particulate matter emissions by reporting emissions in terms of kilograms of particulate matter size PM2.5-equivalent per unit of energy produced.

Energy sources emit particulate matter in all phases of the lifecycle, but particulate matter is most heavily emitted during the transportation and energy generation phase. For example, transportation by fossil fuels emits particulate matter that can cause heightened risk of asthma and respiratory illness.

Environmental Justice Impacts

The metric, environmental justice impacts, measures the various impacts the lifecycle stages of each energy source has on human communities, particularly those of minorities (people of color), low socioeconomic status, or those consisting predominantly of women.

The metric of environmental justice impacts measures the potential impacts to minority communities at each of the lifecycle stages of our energy options. This metric is especially relevant because, for Wellesley, the environmental justice impacts of our energy sources occur off-campus, thus creating a disconnect between the Wellesley community and those affected by our energy sources.

Environmental justice involves the fair treatment of all people, regardless of their race, color, nationality, and origin, and embodies the belief that everyone receives equal levels of environmental protection. The communities most commonly affected by environmental injustices are those in which residents are predominantly people of color or of low income. Moreover, these communities are also often excluded from environmental policy and decision-making processes, even though they are subject to a disproportionate impact from numerous environmental hazards.

Furthermore, residents from these communities also experience negative externalities as a result of disparate implementation of environmental regulations, requirements, practices, and activities. Environmental justice efforts attempt to address the various inequities and injustices of environmental issues affecting said marginalized communities.

When considering alternative energy sources for the Wellesley College campus, we believe it is of crucial importance to include the environmental impacts both visibly harmful to the environment and to humans. As end users of the electricity and heating, our goal is to address the importance of the negative externality—environmental justice— that is often ignored throughout the lifecycle of all energy sources. While cultural impacts are difficult to calculate, there are various ways to do so. One of the ways to assess cultural impacts is to look at the destruction of cultural resources in areas undergoing surface disturbance, including the unauthorized removal of artifacts or vandalism of local spaces, which includes destruction

of sacred landscapes or historic trails. Other issues include noise disturbances and visual impacts, which could have an adverse effect on local sites.

Environmental justice was calculated on a scale of 0 to 2, where 0 is the least amount of impact and 2 is the greatest amount of impact.

<u>We looked at 4 different lifecycle phases:</u>

- Raw Material Extraction
- Manufacturing & Production (refining of fuels, manufacturing of equipment)
- Transport (all transport phases prior to reaching Wellesley)
- Generation (at Wellesley or wherever the electricity is generated)

<u>For each phase of the life cycle, in determining a score, we consider the following factors:</u>

- How large is the population being affected?
- To what extent is this happening in disadvantaged (low-income/minority) communities? (Rank by median income, community composition)
- To what extent are the affected communities displaced or divided by this facility?
- To what extent are communities negatively affected?

The total possible score available is 8. The greater the score, the greater the injustice.

Table 1 Footnotes

1 Conversation with WMLP on April 10th, 2015.

2 "Average Operating Heat Rate for Selected Energy Sources," SAS Output, accessed May 10, 2015, http://www.eia.gov/electricity/annual/html/epa_08_01.html.

3 "U.S. Residual Fuel Oil Wholesale/Resale Price by Refiners," U.S. Energy Information Administration, accessed May 10, 2015, http://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=EMA_EPPR_PWG_NUS_DPG&f=M.

4 "Average Operating Heat Rate for Selected Energy Sources," SAS Output, accessed May 10, 2015, http://www.eia.gov/electricity/annual/html/epa_08_01.html.

5 "U.S. Residual Fuel Oil Wholesale/Resale Price by Refiners," U.S. Energy Information Administration, accessed May 10, 2015, http://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=EMA_EPPR_PWG_NUS_DPG&f=M.

6 "Lazard's Levelized Cost of Energy Analysis," Lazard, last modified September 1, 2014, accessed May 10, 2015, http://www.lazard.com/PDF/Levelized Cost of Energy - Version 8.0.pdf.

7 "Henry Hub Natural Gas Spot Price (Dollars per Million Btu)," U.S. Energy Information Administration, May 6, 2015, accessed May 10, 2015, http://www.eia.gov/dnav/ng/hist/rngwhhdA.htm.

8 "Renewable Energy Technology," accessed December 10, 1997, http://www.nrel.gov/docs/gen/fy98/24496.pdf.

9 "Lazard's Levelized Cost of Energy Analysis," Lazard, last modified September 1, 2014, accessed May 10, 2015, http://www.lazard.com/PDF/Levelized Cost of Energy - Version 8.0.pdf.

10 "Distributed Generation Renewable Energy Estimate of Costs," NREL: Energy Analysis, accessed May 10, 2015, http://www.nrel.gov/analysis/tech_lcoe_re_cost_est.html.

11 "Levelized Cost of Energy Calculator," NREL: Energy Analysis, accessed May 10, 2015, http://www.nrel.gov/analysis/tech_lcoe.html.

12 "Levelized Cost of Energy Calculator," NREL: Energy Analysis, accessed May 10, 2015, http://www.nrel.gov/analysis/tech_lcoe.html.

13 "Lazard's Levelized Cost of Energy Analysis," Lazard, September 1, 2014, accessed May 10, 2015, http://www.lazard.com/PDF/Levelized Cost of Energy - Version 8.0.pdf.

14 "Tracking the Sun VII: An Historical Summary of the Installed Price of Photovoltaics in the United States from 1998-2013," Tracking the Sun VII: An Historical Summary of the Installed Price of Photovoltaics in the United States from 1998-2013, accessed May 10, 2015, http://emp.lbl.gov/publications/tracking-sun-vii-historical-summary-installed-price-photovoltaics-united-states-1998-20.

Evaluating Heat Energy Options

Note on units: We use the same unit of analysis when discussing heat and electricity, as it better facilitates comparison of effects. Additionally, kWh is a measure that is more intuitive to a general audience, although we recognize that heat is more traditionally measured in BTUs. BTUs and kWh are fully inter-convertible.

Lin, Soe. *Snow@ Wellesley College.* Jan 20, 2012. Flickr.com

Natural Gas

Introduction to Natural Gas Heat Energy

Natural gas, commonly used for heat energy, is the fuel used by Wellesley College's current cogeneration plant. Cogeneration, or "combined heat and power," simultaneously produces two forms of energy from a single source. A cogeneration plant consists of a combustion turbine that produces electricity and a unit that recovers the steam from electricity generation to provide thermal energy. Consider how a combustion turbine functioning normally to generate electricity produces excess exhaust heat, released as steam. A cogeneration system is simply a combustion turbine with the addition of a heat recovery steam generator, a condenser, and possible additional parts to convert the excess thermal energy into heat.

To understand how to get energy from natural gas, one must consider the beginning of the natural gas lifecycle. The raw materials extraction and acquisition phase is first. This phase includes well site investigation, which is exploration through seismic testing. During exploration, some companies drill wells to evaluate whether a certain reservoir has sufficient hydrocarbons to make development economically viable. Some companies have reported that before a drill touches a particular area, a variety of processes are done to pinpoint where exactly drilling should occur. These processes help mitigate the damage caused to the surrounding vegetation, land, water, air, natural habitats, and communities.[1] The first phase also includes site preparation (drill pad construction and preparation for drilling rig), well drilling (vertical and horizontal drilling), and hydraulic fracturing (also known as fracking).

Once the materials are acquired, the manufacturing and production phase begins. In this phase, the well begins production, processed either on or off-site. Processing is done through processing plants, centrifugal compressors, acid gas removal vents, and blowdown vents. After the natural gas is processed, it is moved and stored using reciprocating and centrifugal compressors, dehydrator vents, and pneumatic devices. After the natural gas is ready to be sent out to the energy conversion facilities, it is moved using miles of pipes, called mains. These mains are usually made of iron, steel, or copper. Depending on the source of acquisition for the natural gas, natural gas can also be shipped over land or water, although not a common practice for the United States.[2]

Acquiring natural gas is only one part of the entire energy cycle. Cogeneration plants use combined cycles, which use both a gas and a steam turbine together to produce up to 50% more electricity from the same fuel than a traditional simple-cycle plant. The waste heat from the gas turbine is routed to the nearby steam turbine, which generates extra power. The heat recovery system, formally known as the Heat Recovery Steam Generator (HRSG), captures exhaust from the gas turbine, which delivers the heat to the steam turbine. Some of the heat on campus comes from this process.

For natural gas heat energy we chose "natural gas, burned in power plant/ASCC S" in SimaPro 7.

Cost

Taking into account initial or capital costs, fixed operating costs, and variable operating costs, the cost of a natural gas system is $0.09/kWh.

Reliability

Table 76: Reliability assessment for natural gas heat option

	Yes (1), No (0), or N/A
Can it be provided uninterrupted?	*1*
Can it be stored?	*0*
Is it available short-term (until 2025)?	*1*

1 David Biello, "Fracking Can Be Done Safely, But Will it Be?" *Scientific American* 17 May 2013, accessed May 10, 2010, http://www.scientificamerican.com/article/can-fracking-be-done-without-impacting-water/.

2 GE Power, "Combined Cycle Power Plant - How It Works?," accessed April 30, 2015, https://powergen.gepower.com/plan-build/tools-resources/power-generation-basics/combined-cycle-power-plants.html.

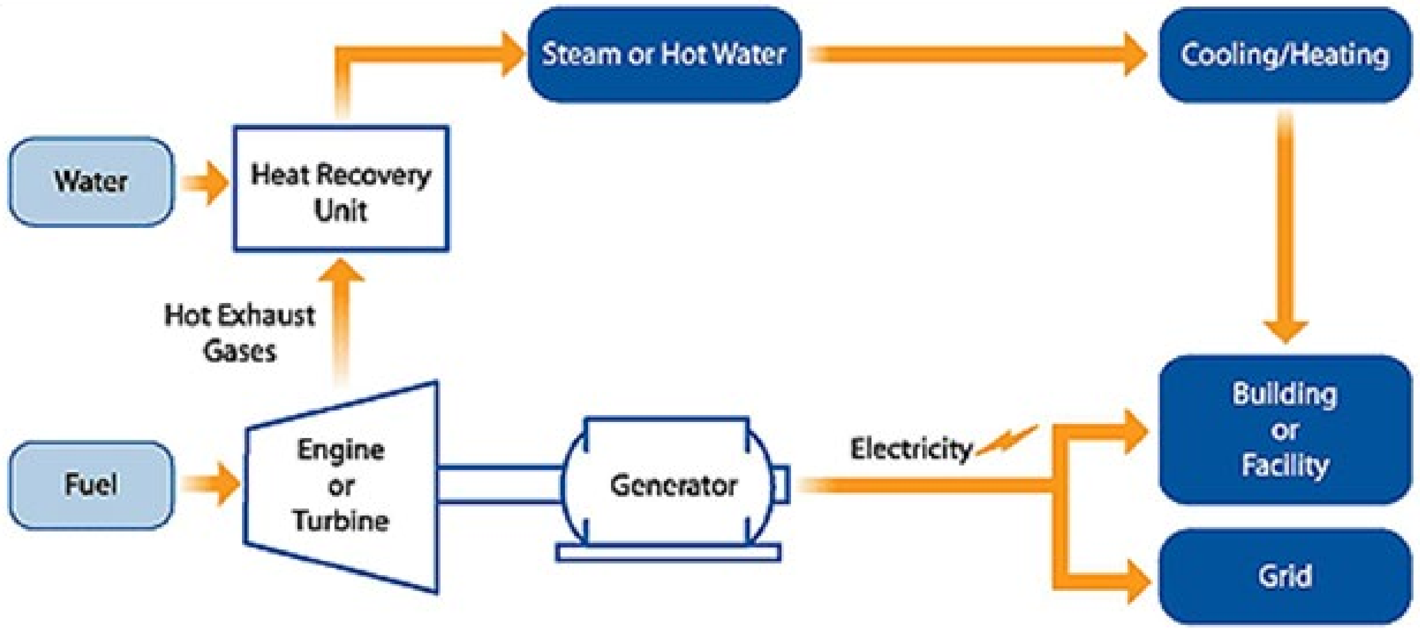


Figure 32:Cogeneration plant powered by natural gas. [1]

EPA, "Gas Turbine or Engine With Heat Recovery Unit," accessed May 10, 2015, http://www.epa.gov/chp/basic/.

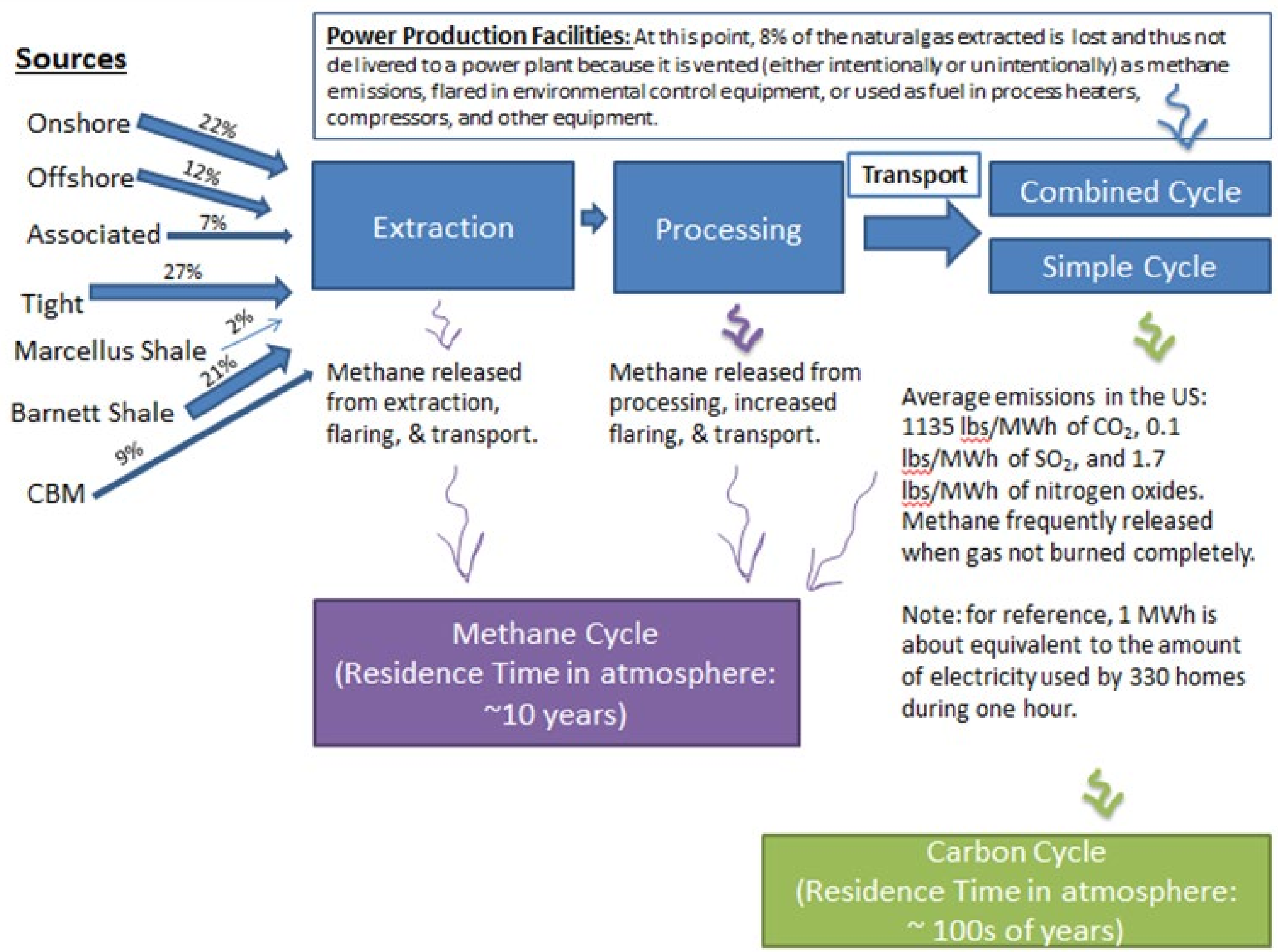


Figure 33: Lifecycle of Natural Gas

Is procurement stable (not volatile) in the long term?	*0*
Is it independent of weather?	*1*
Can you ramp it up/down to meet fluctuating heat demand?	*1*
Total:	*4*

Natural gas is a very reliable heat source, at least in the short term. Although natural gas cannot be stored, we have direct access to pipes that transport natural gas to the power plant and we can thus have uninterrupted access to the gas, ramp it up and down, and use it in any weather. Like other fossil fuels, our confidence in natural gas availability is high in the short term, as there is an abundance of known reservoirs being tapped and left to tap. Natural gas is only renewed on a geologic time scale, so for our purposes it is nonrenewable and this means its supply is finite. As the supply becomes more scarce - whether it be more stringent regulations, fewer reservoirs in existence, or higher costs - it is possible, although not certain, that natural gas will not be as available in the future as it is today.[3] Thus, its procurement is unstable, and, as a long-term fuel source, natural gas may not be reliable.

Educational Advantage

Table 77: Educational advantage assessment for natural gas heat option

High (2), Medium (1), Low (0)	*Score*
Students can learn from this energy source and use data from it to understand energy generation.	*1*
There is visibility on campus and this energy source raises awareness about sustainability.	*0*
Ability to be a research opportunity to further the interests of students and professors.	*1*
Informs administrative decisions on scaling up energy production in new technologies	*0*
Provides insight and encourages external organizations to replicate forms of uncommon energy production.	*0*
Total:	*2*

The cogeneration plant already serves an educational purpose on campus. While cogeneration is not a new technology, it is worthwhile for professors to teach students about such a widely-used and efficient energy generation process. The cogeneration plant already exists and is visible on campus, centrally located with a noticeable smokestack, yet many students do not know what the building is, let alone what type of fuel it is using, and other significant details about the plant's purpose and function. Its visibility has no benefits for raising awareness about sustainability. Although novel when first constructed, today it is unlikely to inform other school administrators about how to use cogeneration technology because cogeneration is already common, and does not provoke discussion of new technologies or uncommon energy production possibilities.

Greenhouse Gas Emissions

Table 78: Greenhouse gas emissions assessment for natural gas heat option

Impact Category	*Total*
Greenhouse Gas Emissions	*1.53E-5 kg CO2 eq*

The primary chemical component of natural gas is methane, which has a global warming potential of 25 (over 100 years time), meaning it is 25 times as potent as CO_2. Methane is released during extraction, flaring, transport, and processing, resulting in an 8 percent loss of natural gas by the time it is delivered to power plants. When natural gas is burned, 1135 lb/MWH CO_2 are released. Furthermore, methane is frequently released when natural gas is not burned completely. Losses of methane to the atmosphere during the extraction, transmission, and delivery of natural gas to end users made up 25 percent of U.S. 2011 total methane emissions and 2.2 percent of all GHGs when comparing GHGs on a 100yr time frame.[4]

In our life cycle assessment, we also consider the greenhouse gas emissions required to produce

3 Davenport, Coral, "New Federal Rules Are Set for Fracking," *New York Times*, accessed May 15, 2015.

4 National Energy Technology Laboratory, U.S. Department of Energy, "Life Cycle Greenhouse Gas Inventory of Natural Gas Extraction, Delivery and Electricity Production," DOE/NETL-2011/1522, October 24, 2011.

the cogeneration system in which the natural gas is burned.

Ecotoxicity

Table 79: Ecotoxicity assessment for natural gas heat option

Impact Category	***Total***
Ecotoxicity	*0.000124 CTUe*

Ecotoxicity of natural gas is highest during the extraction phase, with a variety of chemicals needed to pump the gas leaching into the environment. This occurs mainly through water contamination, a pathway that has been expanded on in the ecosystem disruption metric analysis. Additionally, studies have shown dangerous levels of toxic air pollution and smog near fracking sites, another pathway for ecotoxicity.

Ecosystem Disruption

Table 80: Ecosystem disruption assessment for natural gas heat option

Low (0), Medium (1), High (2)	*Score*
Land Disruption - permanent or temporary	*1*
Water Use	*2*
Water Contamination	*0*
Biodiversity disruption (consider both the number of species and the extent of the disruption for species)	*2*
Total:	***5***

<u>Extraction</u>

Natural gas is extracted by the disruptive process of hydraulic fracturing (fracking). During fracking, chemicals are mixed with large quantities of water (or other base fluid) and sand, and injected into wells at extremely high pressure. These sand particles cause tiny fractures in geologic formations that allow natural gas to seep out and be pumped up out of the ground through wells. Fracking has also been linked to sinkholes and seismic activity near extraction sites.

Surface disturbances and habitat fragmentation are ecological impacts made to areas of natural gas extraction.[5] Drilling muds are used to drill the well, and, in order to access these muds, millions of gallons of fluids, usually loaded with toxic chemicals, are injected into the ground. This process helps facilitate fracking.[6] Moreover, most of the well pads have drilling or reserve pits that hold these drilling muds. The land on which all of these processes takes place contains these hazardous wastes, and often times has the potential to become a Superfund site.[7]

A study of fracking in Michigan found that there are potential environmental impacts from fracking, including erosion and sedimentation, increased risk of contamination of water sources from chemical spills or sediment runoff, habitat fragmentation, and the reduction of surface waters from the lowering of groundwater levels.[8] The amount of water used in fracking varies upon formation geology of the site, well construction, and the type of fracking process used. In 2011, the EPA estimated that approximately 70 to 140 billion gallons of water were used nationwide for the fracking of 35,000 wells.[9]

Wastewater leftover from the fracking process is most often stored in a large above-ground holding container, or in an artificial holding lake. The water is eventually cleaned and recycled on-site or transported away from the extraction site. Ideally, both aforementioned wastewater storage methods provide a leak-free holding site until wastewater is dealt with, but this is not always the case. The wastewater leakage during the extraction phase of natural gas thus poses a high threat of aquatic contamination, and is compounded by the risk of chemical spills and equipment runoff on site.

5 Office of Indian Energy and Economic Development, "Oil and Gas Drilling/Development Impacts," *Tribal Energy and Environmental Information*, accessed May 1, 2015, http://teeic.indianaffairs.gov/er/oilgas/impact/drilldev/index.htm.

6 The Endocrine Disruption Exchange, Inc., "Chemicals in Natural Gas Operations," accessed May 1, 2015, http://endocrinedisruption.org/chemicals-in-natural-gas-operations/introduction.

7 The Endocrine Disruption Exchange, "Chemicals in Natural Gas Operations," accessed May 1, 2015, http://endocrinedisruption.org/chemicals-in-natural-gas-operations/introduction.

8 Union of Concerned Scientists, "Environmental Impacts of Natural Gas," accessed May 1, 2015, http://www.ucsusa.org/clean_energy/our-energy-choices/coal-and-other-fossil-fuels/environmental-impacts-of-natural-gas.html#.VTW4qNxBs0s.

9 Union of Concerned Scientists, "Environmental Impacts of Natural Gas," accessed May 1, 2015, http://www.ucsusa.org/clean_energy/our-energy-choices/coal-and-other-fossil-fuels/environmental-impacts-of-natural-gas.html#.VTW4qNxBs0s.

The recovery periods of wildlife species disturbed by natural gas extraction varies by community. Indirect impacts to vegetation could also include increased deposition of dust, the spread of invasive and noxious weeds, and the increased potential of other natural occurrences, such as wildfires. Furthermore, dust settling from land disturbance on vegetation could alter or limit any surrounding plants' ability to photosynthesize or reproduce.[10] The adverse impacts from the extraction phase that could occur to the surrounding biodiversity and habitats include erosion and runoff, dust cover, introduction and spread of nonnative species, modification or the reduction of habitat, mortality of biota, exposure to contaminants from various sources, and interference with behavioral activities, among other effects.[11]

<u>*Manufacturing, Transport, and Use*</u>

The ecosystem disruptions from the manufacturing of natural gas are very similar to the extraction phase. In addition, as part of the manufacturing phase, companies occasionally use seismic effects to pull natural gas from the ground for manufacturing. These seismic occurrences may induce earthquakes.[12]

In many cases, vegetation and topsoil are removed for the development of well pads, access roads, pipelines and other ancillary facilities. These lead to the destruction of wildlife habitat, which also has secondary effects, including an increase in erosion. Surface disturbance does not only involve site preparation and well pad construction, but also requires road, pipeline and other infrastructure modifications for transport.

During the manufacturing process, some naturally occurring radioactive chemicals used for the processing and refining of gas can leak into groundwater, posing flammability concerns for the surrounding ecosystems. Most--if not all--surface water contamination risks from natural gas production are related to the land management in the on-and-off site chemical and wastewater management.[13]

10 Office of Indian Energy and Economic Development, "Oil and Gas Drilling/Development Impacts," *Tribal Energy and Environmental Information*, accessed May 1, 2015, http://teeic.indianaffairs.gov/er/oilgas/impact/drilldev/index.htm.

11 Erik Liviat and Karent Schneller-McDonald, "Fracking and Biodiversity: Unaddressed Issues in the New York Debate," *New from Hudsonia*, vol 24, no. 2, Fall 2011, 1-10.

12 Leighton Kille, "The Environmental Costs and Benefits of Fracking: The State of Research," *Journalist's Resource*, last modified October 26, 2014, accessed May 1, 2015, http://journalistsresource.org/studies/environment/climate-change/environmental-costs-benefits-fracking#.

Large quantities, usually between the tens of thousands of gallons for each well, of chemical additives are trucked to and stored on a well pad. If not managed properly, these chemicals could leak or spill out of faulty containers and shipments during transport.[14]

In many cases, potable and arable water resources subject to natural gas extraction and manufacturing sites are extremely vulnerable to contamination. For example, various mountain watersheds in the western United States that provide drinking and irrigation water for vast numbers are at risk for contamination from the toxic chemicals used.[15] This is one of the biggest issues of fracking: there is no accountability for what happens to the source from which the water is taken or what happens to the water once it is used.

For many natural gas processing facilities, it is a common practice to use "water trucks" to haul the produced water from sites to large, central evaporation sites. There is a large possibility that many of these chemicals will leak onto the road and contaminate surrounding ecosystems.[16]

During manufacturing processes, some companies resort to using seismic effects as a method of locating fracking zones to increase gas production. They also dispose of wastewater by injecting it into the locations where natural gas has been removed. Some of these seismic methods induce earthquakes

13 Union of Concerned Scientists, "Environmental Impacts of Natural Gas, accessed May 1, 2015, http://www.ucsusa.org/clean_energy/our-energy-choices/coal-and-other-fossil-fuels/environmental-impacts-of-natural-gas.html#.VTW4qNxBs0s.

14 Union of Concerned Scientists, "Environmental Impacts of Natural Gas," accessed May 1, 2015, http://www.ucsusa.org/clean_energy/our-energy-choices/coal-and-other-fossil-fuels/environmental-impacts-of-natural-gas.html#.VTW4qNxBs0s.

15 The Endocrine Disruption Exchange, "Chemicals in Natural Gas Operations," accessed May 1, 2015, http://endocrinedisruption.org/chemicals-in-natural-gas-operations/introduction.

16 The Endocrine Disruption Exchange, "Chemicals in Natural Gas Operations," accessed May 1, 2015, http://endocrinedisruption.org/chemicals-in-natural-gas-operations/introduction.

strong enough to be felt by humans;[17] the effects on the surrounding biodiversity is unknown at this time.[18]

By increasing human and outside traffic activities, the potential for invasive, noxious, or introduced species increases in these areas during the reclamation phase. In addition to the land and water contamination issues, tons of toxic volatile compounds can escape and mix with nitrogen oxides from transport vehicle exhaust and cause ground level ozone at the delivery and transport stages of natural gas production. Gas field-produced ozone creates the same extent of air pollution as those from large urban areas, and also has the potential to spread up to 200 miles from the gas production site.[19] The cumulative impacts of surface disturbances that extend over large areas result in the habitat fragmentation of both plant and animal species that can be sensitive to changes, affecting population sizes.

Natural gas-fired power plants emit sulfur dioxide and nitrogen oxides, both of which contribute to acid rain and ground-level ozone. For example, methane is a potent greenhouse gas, more than 20 times more powerful in terms of its heat-trapping ability than is carbon dioxide.[20] Moreover, because the use of natural gas still emits greenhouse gases, even if it is at lower quantities than other fossil fuels, the process still contributes to climate change. The indirect effects of climate change on biodiversity, ecosystems, water sources, etc., is another factor to take into consideration.

Health

17 K. M. Keranen, M. Weingarten, G. A. Abers, B. A. Bekins, S. Ge, "Sharp Increase in Central Oklahoma Seismicity since 2008 Induced by Massive Wastewater Injection," *Science* Vol. 345 no. 6195 (July 2014), pp. 448-451.

18 Leighton Kille, "The Environmental Costs and Benefits of Fracking: The state of Research," *Journalist's Resource*, last modified October 26, 2014, accessed May 1, 2015, http://journalistsresource.org/studies/environment/climate-change/environmental-costs-benefits-fracking#.

19 The Endocrine Disruption Exchange, "Chemicals in Natural Gas Operations," accessed May 1, 2015, http://endocrinedisruption.org/chemicals-in-natural-gas-operations/introduction.

20 Center for Climate and Energy Solutions, "Natural Gas," accessed May 1, 2015, http://www.c2es.org/energy/source/natural-gas.

Table 81: Health assessment for natural gas heat option

Impact Category	***Total***
Respiratory effects	*2.12 E-5 kg PM2.5 eq*
Carcinogenics	*9.11E-05 CTUh*
Non-carcinogenics	*5.14E-05 CTUh*

Natural gas production causes a variety of health effects, primarily in communities surrounding extraction sites. The health issues associated with natural gas extraction are respiratory difficulties, skin rashes, digestive disorders, and neurological problems.[21] Many of the complaints regarding health issues include foul odors, water pollution or leaching, incessant noise, and production that occurs 24 hours a day. Furthermore, natural gas production facilities emit pollutants called hazardous air pollutants (HAPs) and volatile organic compounds (VOC), which can also harm facility employees. Depending on the chemicals emitted, natural gas production facilities can be linked to skin irritation, blisters, blood disorders, reproductive and developmental disorders, nervous system disorders, chest constriction, and respiratory diseases and disorders, among other impacts.[22] While little is known about the direct public health impacts of fracking, many of the previously mentioned impacts are very much present and visible in communities near natural gas extraction sites, with respiratory impacts being the most prevalent.

Environmental Justice

Table 82: Environmental justice assessment for natural gas heat option

Low (0), Medium (1), High (2)	*Score*
Raw material extraction	*2*
Manufacturing & Production (refining of fuels, manufacturing of equipment)	*2*
Transport (all transport phases prior to reaching Wellesley)	*2*
Generation (at Wellesley or wherever the heat is generated)	*0*
Total:	***6***

21 Stephen Lester, "Building Strong, Healthy, and Safe Communities," *Center for Health Environment Justice*, November 2, 2012, accessed May 1, 2015, http://chej.org/2012/11/health-effects-associated-with-natural-gas-extraction-using-hydraulic-fracturing-or-fracking/.

22 EPA, "Improving Air Quality in Your Community," accessed May 1, 2015, http://www.epa.gov/oaqps001/community/details/oil-gas_addl_info.html.

Raw Materials Extraction and Acquisition

The use of advanced fracking methods has resulted in threats to water, air, land and the health of various communities. Studies have shown there to be dangerous levels of toxic air pollution near fracking sites due to an excess amount of smog from gas extraction with levels higher than those in Los Angeles.[23] Deep drilling technologies from fracking has led to various cases of groundwater pollution, which threatens various water sources for many communities located near the fracking source. The groundwater contamination from drilling and improper wastewater disposal is a major concern for many. This wastewater can contain various radioactive materials, such as arsenic and benzene, which are harmful to humans and other forms of life.[24]

Other activities that may cause environmental justice issues include ground clearing, grading, drilling, waste management, vehicular and pedestrian traffic and the construction and installation of facilities.[25] There have been various arguments in favor of fracking, one of which includes the creation of new jobs for those in the affected communities. For example, in 2011, Ohio public officials spoke of the creation of more than 200,000 jobs to the state as a positive economic impact from the natural gas extraction.[26] The problem with this argument is that most of these jobs are temporary and, once wells are in production, the need for workers decreases.

Cultural impacts are difficult to calculate when addressing the ecological impacts throughout the lifecycle of natural gas. One of the ways to assess cultural impacts is to look at the destruction of cultural resources in areas undergoing surface disturbance, including the unauthorized removal of artifacts or vandalism of local spaces, which includes destruction of sacred landscapes or historic trails.[27] Other issues include noise disturbances and visual impacts, which create adverse effects on local sites. Development of a gas field could potentially negatively affect the property values of those in close proximity to the gas field.

Manufacturing and Production

During the manufacturing and production of natural gas, improper waste management can lead to solid and industrial waste generation. Solid waste can consist of containers and packaging materials, miscellaneous wastes from equipment assembly and presence of construction crews. Industrial wastes can include minor amounts of paints, coatings and spent solvents, which would most likely be transported off-site for disposal. Some drilling wastes include hydraulic fluids, used oils and oil filters, spilled fuel, drill cuttings, drums and containers, etc. Produced water, water that coexists with oil and gas formations and is recovered during well development, can be an issue over the long-term operation of a gas field.[28] Although there are existing regulations for the disposal of produced water, water is usually disposed of by underground injection in disposal wells. In some locations, the produced water can carry naturally occurring radioactive materials (NORM) to the surface. The chemicals that are leaked can then be hazardous to both occupational and public environments.

Transportation

The development of a gas site would result in the need to construct or improve access roads or mains. This construction could lead to an increase in industrial traffic in sites not usually accustomed to high traffic loads. Overweight or oversized loads could cause tem-

23 Natural Resources Defense Council, "Unchecked Fracking Threatens Health, Water Supplies," accessed May 1, 2015, http://www.nrdc.org/energy/gasdrilling/.

24 Energy Justice Network, "Natural Gas Health and Environmental Hazards," accessed May 1, 2015, http://www.energyjustice.net/naturalgas.

25 Oil and Gas Drilling/Development Impacts, Trial Energy and Environmental Information, accessed May 1, 2015, http://teeic.indianaffairs.gov/er/oilgas/impact/drilldev/index.htm.

26 Environmental Justice, Hydraulic Fracturing and Appalachia, Triple Pundit People Planet Profit, last modified August 12, 2013, accessed May 1, 2015, http://www.triplepundit.com/special/environmental-justice-hydraulic-fracturing-appalachia/.

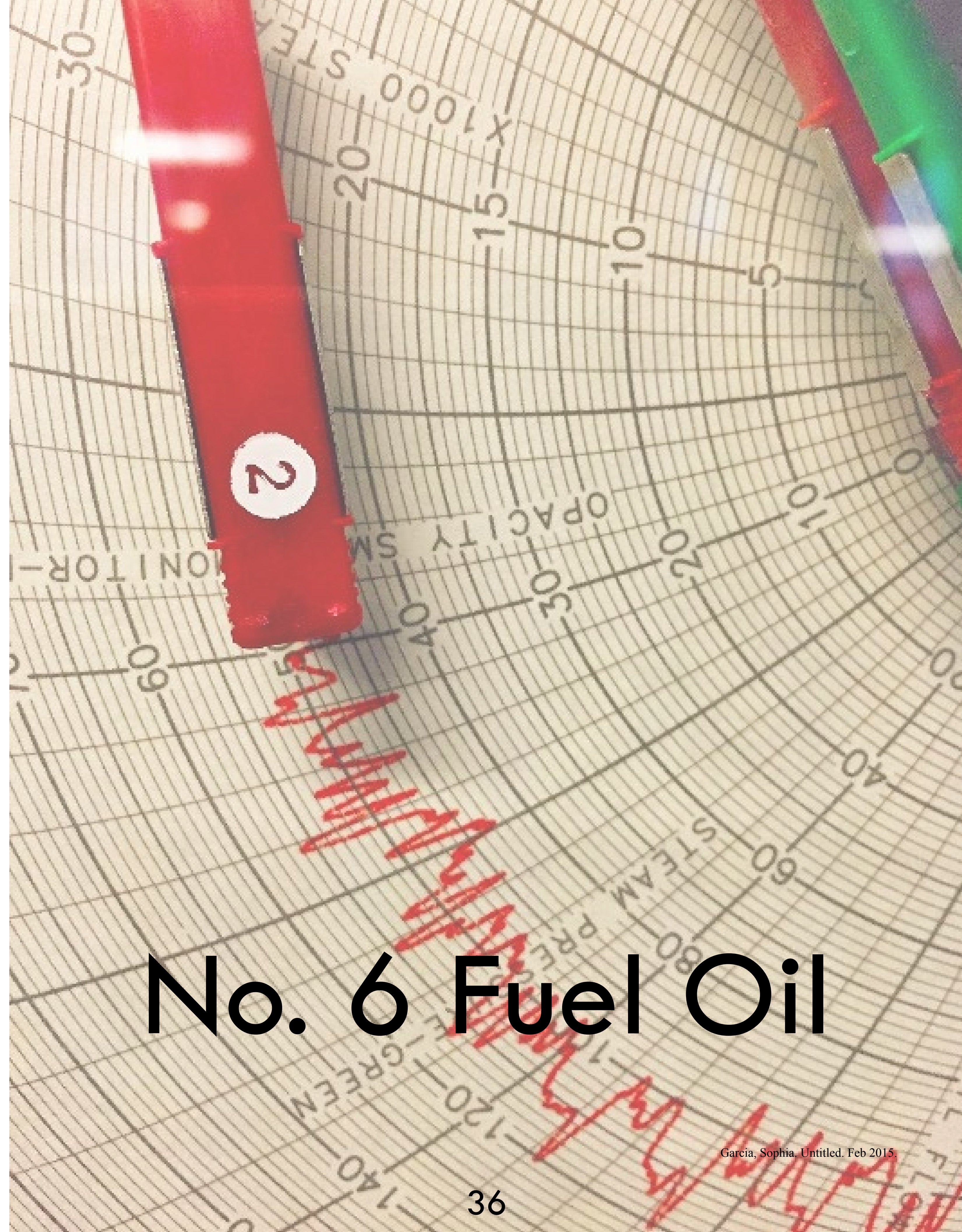
27 Office of Indian Energy and Economic Development, "Oil and Gas Drilling/Development Impacts," *Tribal Energy and Environmental Information*, accessed May 1, 2015, http://teeic.indianaffairs.gov/er/oilgas/impact/drilldev/index.htm.

28 Office of Indian Energy and Economic Development, "Oil and Gas Drilling/Development Impacts," *Tribal Energy and Environmental Information*, accessed May 1, 2015, http://teeic.indianaffairs.gov/er/oilgas/impact/drilldev/index.htm.

porary disruptions and could require extensive modifications of various roads links and bridges. In many situations, natural gas produced from a particular well site has to travel a great distance to reach its point of use and the transportation system consists of a complex network of pipelines designed for quick and efficient transport.[29] Transportation problems include dangers with the pipeline system such as leakages, pipe bursts, and land displacement for the creation of pipeline systems. When constructing a pipeline, everything in the path is cleared and displaced, including communities of people. There have been various methods put in place, like Leak detections, pipeline markers, and gas sampling have been used to prevent or mitigate these environmental justice problems,[30] though they are unlikely to fully succeed.

29 "The Transportation of Natural Gas," last modified September 23, 2013, accessed May 1, 2015, http://naturalgas.org/naturalgas/transport/.

30 "The Transportation of Natural Gas," last modified September 23, 2013, accessed May 1, 2015, http://naturalgas.org/naturalgas/transport/.



No. 6 Fuel Oil

Garcia, Sophia. Untitled. Feb 2015.

Introduction to No. 6 Fuel Oil Heat Energy

No. 6 fuel oil is a residual fuel that is burned in a boiler to create heat. It is thicker than No. 2 fuel oil and is solid at room temperature. It must be kept in a heated storage container of about 100°F and must be heated an additional 50-100°F to be burned for energy. Of the six grades of fuel oils, it is the most impure. When it is burned, it releases the highest particulate matter content of the six fuel oils. This has led to No. 6 being banned by local or state governments in many contexts.[31]

For No. 6 fuel oil, we chose "heavy fuel oil, burned in industrial furnace 1MW, non-modulating/ CH S" in SimaPro 7.

Cost

Taking into account initial or capital costs, fixed operating costs, and variable operating costs, the cost of No. 6 fuel oil is $0.29/kWh.

Reliability

Table 83: Reliability assessment for No.6 fuel oil

Yes (1), No (0), or N/A	*Score*
Can it be provided uninterrupted?	*1*
Can it be stored?	*1*
Is it available short-term (until 2025)?	*1*
Is procurement stable (not volatile) in the long term?	*1*
Is it independent of weather?	*1*
Can you ramp it up/down to meet fluctuating heat demand?	*1*
Total:	***6***

Fuel oil, whether No. 2 or No. 6, comes in a steady supply and can be available in an uninterruptible format. Fuel oil can be easily procured and provide steam regardless of weather conditions, as long as the fuel is on hand. Fuel oils can be also stored for long periods of time, though, in the case of No. 6 fuel oil, it needs to be heated while in storage. Because No. 6 fuel oil is usually used in large commercial and industrial boilers, facilities need to be able to maintain a reasonable supply of oil to the boiler, and large storage tanks must be kept as full as possible to minimize any accumulation of moisture build-up within the tanks.[32] In the short term, fuel oil is readily available in the market and use of fuel oil can also be increased quickly to meet demands. We cannot, however, anticipate how the price of No. 2 fuel oil will fluctuate in the future. Additionally, it should be noted that, although the oil supply is unlikely to run out in the future, the supply chain may be fragile and unable to respond quickly during adverse weather conditions or when demand is high in the winter season in New England.[33] Because the supply of oil is available and stable, and we anticipate it will continue to be so in the future, we rate No. 2 and No. 6 fuel oils as being highly reliable.

Educational Advantage

Table 84: Educational advantage assessment for No.6 fuel oil

High (2), Medium (1), Low (0)	*Score*
Students can learn from this energy source and use data from it to understand energy generation.	*1*
There is visibility on campus and this energy source raises awareness about sustainability.	*0*
Ability to be a research opportunity to further the interests of students and professors.	*1*
Informs administrative decisions on scaling up energy production in new technologies (this is most relevant for new technologies).	*0*
Provides insight and encourages external organizations to replicate forms of uncommon energy production.	*0*
Total:	***2***

No. 6 fuel oil has few educational advantages. Students have opportunities to tour the power plant in environmental studies courses. They could potentially do research on the energy procurement process on campus and could even pursue research using data from the fuel oil-burning boilers, although the data is not very accessible due to its being kept on paper files within the power plant facility. The fuel oil-powered boiler data is not unique to Wellesley, nor has the field been understudied. Furthermore, having oil-powered boilers in the power plant does not raise awareness about sustainability issues on campus. In fact, using no. 6 fuel oil could brand Wellesley College as a college that is using a fuel source that is the antithesis to sustainability, as no. 6 has been shown to be a particularly dirty fuel and has already been banned in many cities. No. 6 fuel oil does not provide insights for the administration about how this fuel source could be scaled up because this fuel is already implemented in the power plant on campus, so that knowledge already exists. Along similar lines, using this fossil fuel does not provide other institutions with insights about the usage of uncommon energy sources.

Greenhouse Gas Emissions

Table 85: Greenhouse gas emissions assessment for No.6 fuel oil

Impact Category	***Total***
Greenhouse Gas Emissions	*1.61E-05 kg CO2 eq*

The greenhouse gas emissions potential for No. 6 fuel oil is calculated to be 1.61E-05 kg CO2 equivalent. 92% of greenhouse gas emissions takes place in the "use" phase, while the remaining 8% is attributed to the production and refining of the oil.

Ecotoxicity

Table 86: Ecotoxicity assessment for No.6 fuel oil

Impact Category	***Total***
Ecotoxicity	*3.25E-05 CTUe*

The ecotoxicity of No. 6 fuel oil was calculated to be 3.25E-05 CTUe equivalent. 94% of ecotoxicity is attributed to the boiler manufacturing, transportation and use of the No.6 fuel oil, while the other 6% of ecotoxicity is accounted for during the extraction and refining of the oil.

Ecosystem Disruption

Table 87: Ecosystem disruption assessment for No.6 fuel oil

Low (0), Medium (1), High (2)	*Score*
Land Disruption - permanent or temporary	*1*
Water Use	*2*
Water Contamination	*2*
Biodiversity disruption (consider both the number of species and the extent of the disruption for species)	*2*
Total:	*7*

Extraction

Land disruption is inherent to the exploration and extraction processes of fuel oils. Swathes of land are cleared and graded to create roads leading to on-site wells, pipelines from the site to refineries, on-site buildings, and the drilling site itself.[34] Rural land transforms into an industrial site with constant noisy, dirty activity and an influx of extra-community workers.[35] During the extraction process, drilling brings underground materials to the Earth's surface. Tons of non-native materials including radioactive minerals change the original makeup of the aboveground envi-

31 The Bottom of the Barrel: How the Dirtiest Heating Oil Pollutes Our Air and Harms Our Health, December 2009, *Environmental Defense Fund*, Chapter 3, pp. 1, http://www.edf.org/sites/default/files/10085_EDF_Heating_Oil_Report.pdf.

32 The True Cost of #6 Oil, *National Fuel,* accessed on March 18, 2015, http://www.natfuel.com/ForBusiness/publications/oil_6_techline.htm.

33 Managing the Reliability of the Electric Grid While the Power Industry Undergoes Rapid Transformation, *ISO New England,* last modified September 19, 2014, Boston, MA. pp. 10, accessed on March 18, 2015, http://iso-ne.com/static-assets/documents/2014/09/ma_roundtable_9_19_14_gvw_final.pdf.

34 Oil and Gas Drilling/Development Impacts, *Tribal Energy and Environmental Information Clearhouse,* accessed March 18, 2015, http://teeic.indianaffairs.gov/er/oilgas/impact/drilldev/index.htm.

35 Oil and Gas Drilling/Development Impacts, *Tribal Energy and Environmental Information Clearhouse,* accessed March 18, 2015, http://teeic.indianaffairs.gov/er/oilgas/impact/drilldev/index.htm.


Bridges, Derek. *Mississippi River Oil Spill.* July 29, 2008. Flickr.com/

ronment.[36] Oil and gas create more waste than municipal, agricultural, mining, and industrial waste combined; about 20% of the total non-hazardous waste created annually in the U.S. comes from oil exploration and extraction.[37]

Negative effects of water use are significant in the extraction of fuel oils. Produced water, water extracted from underground during the drilling process, is forced back underground under high pressure to bring more oil to the surface. Produced water that is not re-injected into the wells is released into surface water sources even though it is four times saltier than seawater and often includes toxics and metals like benzene, xylene, toluene, ethyl benzene, barium, arsenic, cadmium, chromium, and mercury.[38]

There are significant amounts of water contamination during the extraction phase of fuel oil. When land is cleared for construction, the deforestation can lead to significant erosion, which contaminates the waterways. The drilling process brings waste–including toxic waste–to the Earth's surface.[39] These contaminants, in turn, wash into the local watershed.

The exploration and extraction phase of No. 6 fuel oil's lifecycle creates significant damage to biodiversity. As previously noted, there are significant land disruptions from creating an extraction site. These disruptions displace native flora and fauna. There are also foreign minerals brought to the surface environment during the drilling process.[40] Radioactive material or the accumulation of mercury, lead, or other materials can be toxic to local organisms.[41] Produced water released into local water sources can threaten local aquaculture.[42] Bottom-dwelling animals, migratory birds, and marine mammals are particularly affected by water contamination.[43]

Manufacturing, Transport and Use

36 O'Rouke, Dara, and Sarah Connolly, Just Oil? The Distribution of Environmental and Social Impacts of Oil Production and Consumption, Annual Review of Environment and Resources 28 (2003): 595, accessed April 11, 2015, http://www.annualreviews.org/doi/abs/10.1146/annurev.energy.28.050302.105617.

37 O'Rouke, Dara, and Sarah Connolly, Just Oil? The Distribution of Environmental and Social Impacts of Oil Production and Consumption, Annual Review of Environment and Resources 28 (2003): 595, accessed April 11, 2015, http://www.annualreviews.org/doi/abs/10.1146/annurev.energy.28.050302.105617.

38 O'Rouke, Dara, and Sarah Connolly, Just Oil? The Distribution of Environmental and Social Impacts of Oil Production and Consumption, Annual Review of Environment and Resources 28 (2003): 595, accessed April 11, 2015, http://www.annualreviews.org/doi/abs/10.1146/annurev.energy.28.050302.105617.

39 O'Rouke, Dara, and Sarah Connolly, Just Oil? The Distribution of Environmental and Social Impacts of Oil Production and Consumption, Annual Review of Environment and Resources 28 (2003): 595, accessed April 11, 2015, http://www.annualreviews.org/doi/abs/10.1146/annurev.energy.28.050302.105617.

40 Oil and Gas Drilling/Development Impacts, *Tribal Energy and Environmental Information Clearhouse,* accessed March 18, 2015, http://teeic.indianaffairs.gov/er/oilgas/impact/drilldev/index.htm.

41 O'Rouke, Dara, and Sarah Connolly, Just Oil? The Distribution of Environmental and Social Impacts of Oil Production and Consumption, Annual Review of Environment and Resources 28 (2003): 595, accessed April 11, 2015, http://www.annualreviews.org/doi/abs/10.1146/annurev.energy.28.050302.105617.

42 O'Rouke, Dara, and Sarah Connolly, Just Oil? The Distribution of Environmental and Social Impacts of Oil Production and Consumption, Annual Review of Environment and Resources 28 (2003): 595, accessed April 11, 2015, http://www.annualreviews.org/doi/abs/10.1146/annurev.energy.28.050302.105617.

43 O'Rouke, Dara, and Sarah Connolly, Just Oil? The Distribution of Environmental and Social Impacts of Oil Production and Consumption, Annual Review of Environment and Resources 28 (2003): 595, accessed April 11, 2015, http://www.annualreviews.org/doi/abs/10.1146/annurev.energy.28.050302.105617.

The manufacturing, transport and use phases do not pose major threats to long-term or short-term land disruption. Oil manufacturing does not cause long-term land disruption aside from the initial construction of the facility. Oil is transported by sea and on-land transportation occurs on infrastructure that is already in place.[44] While power plants must be built before fuel oil is burned, the amount of land disruption is low, particularly when compared to the extraction phase.

Refineries use thousands of gallons of water per day for production and cooling processes.[45] On average, 3.4–6.6 gallons of fresh water are needed to produce one gallon of gasoline.[46] Transportation of fuel oil and oil products does not have a significant impact on water use, particularly when compared to other life stages. Fuel oil is transported across countries and worlds via fuel tanker and pipelines, without using significant amounts of water.[47] During the usage stage, steam is used for oil tank heating, atomization and soot blowing. To create steam, water is continuously pumped into the boiler.[48]

In the refining stage, hazardous waste is released as effluent into lakes and rivers near the refineries. Water used in the refining process must be treated to remove traces of heavy metals, noxious chemicals, solvents and residual aromatic hydrocarbons before this water can be released into disposal wells or waterways. Often times the oil, or oil waste products, leach into groundwater from ground containment facilities or are discharged directly into water. Oil refineries and transport efforts account for approximately 46% of the estimated 3.2 million tons of oil entering the oceans each year. [49]

There is a significant risk of pollution from the transport of oil via oil tankers or trucks. Emissions from trucks and oil tankers, such as nitrous oxides, contribute to acid rain which has widespread effects on both water and ecosystems. There is also potential for oil spills during the transport phase. Major spills have long-lasting and serious consequences for water quality, as well as effects on an ecosystem as a whole.

The burning of no. 6 fuel oil releases air pollutants, such as sulfur dioxide and nitrogen oxides, that can ultimately contaminate water systems and cause problems such as acid rain. The use phase, however, does not directly contaminate water as significantly as the extraction and manufacturing stages.

During manufacturing, the treatment of liquid effluent does not always eliminate all contaminants that enter waterways used by humans, fish, and wildlife. These chemicals can lead to differences in the diversity and abundance of fish located up- and downstream from refineries. Aside from water pollution, thermal pollution makes the surrounding waters warmer, disrupting marine ecosystems.[50] Many studies

44 Transporting Oil and Natural Gas, *American Petroleum Institute,* accessed on April 11, 2015, http://www.api.org/oil-and-natural-gas-overview/transporting-oil-and-natural-gas.

45 O'Rouke, Dara, and Sarah Connolly, Just Oil? The Distribution of Environmental and Social Impacts of Oil Production and Consumption, Annual Review of Environment and Resources 28 (2003): 595, accessed April 11, 2015, http://www.annualreviews.org/doi/abs/10.1146/annurev.energy.28.050302.105617.

46 Wu, Mintz, Wang, and Arora, Consumptive Water Use in the Production of Bioethanol and Petroleum Gasoline (2008), pp 5, https://www.acs.org/content/dam/acsorg/policy/acsonthehill/briefings/energywaternexus/12-08-anl-water-use-in-bioethanol-gas.pdf.

47 Transporting Oil and Natural Gas, *American Petroleum Institute,* accessed on April 11, 2015, http://www.api.org/oil-and-natural-gas-overview/transporting-oil-and-natural-gas.

48 The True Cost of #6 Oil, *National Fuel,* accessed on March 18, 2015, http://www.natfuel.com/ForBusiness/publications/oil_6_techline.htm.

49 Borasin et al, Oil: A Lifecycle Analysis of its Health and Environmental Impacts, 2002 http://priceofoil.org/content/uploads/2006/05/OILHarvardMedfullreport.pdf.

50 O'Rouke, Dara, and Sarah Connolly, Just Oil? The

have found that streams that received effluent from oil refineries have high levels of benzene which changed the diversity and abundance of fish downstream from the refinery.[51]

There is a potential for oil contamination during the process of transport. Spills can have serious consequences for an area's wildlife and biodiversity. In the Exxon Valdez spill in 1989, for example, there was damage to the ecosystem and species within it. The spill endangered ten million migratory shorebirds and waterfowl, as well as hundreds of sea otters, whales, harbor seals, sea lions and other species. Seal pup breeding grounds and fish hatcheries were particularly affected by this spill, and, although clean-up efforts targeted these areas first, there was still irreparable damage.[52]

The burning of fuel oil does not pose a significant threat to biodiversity loss. Although greenhouse gases and other pollutants are released as air pollution during the use phase, this does not directly target species. (It should be noted, however, that long term effects as a result of continuous use such as global warming will harm species and biodiversity around the world.)

Human Health

Table 88: Human health assessment for No.6 fuel oil

Impact Category	*Total*
Respiratory effects	*6.33E-06 kg PM2.5 eq*
Carcinogenics	*6.02E-05 CTUh*
Non-carcinogenics	*1.89E-05 CTUh*

There are many human health impacts associated with the lifecycle of No. 6 fuel oil. Workers in refineries and plants burning No. 6 are exposed to a host of health impacts, both carcinogenic and non-carcinogenic, including skin and eye irritation, bronchitis, chemically-induced pneumonia, chronic lung disease, psychosis and peripheral neuropathies, and increased cancer risks.[53] No. 6 fuel oil is noted for being particularly bad in particulate matter emissions, which cause issues with air quality and lung health.

Environmental Justice

Table 89: Environmental justice assessment for No.6 fuel oil

Low (0), Medium (1), High (2)	*Score*
Raw material extraction	*2*
Manufacturing & Production (refining of fuels, manufacturing of equipment)	*2*
Transport (all transport phases prior to reaching Wellesley)	*2*
Generation (at Wellesley or wherever the heat is generated)	*0*
Total:	***6***

<u>Raw Materials/Extraction</u>

A careful look at the chosen locations of drilling sites reveals industry-wide environmental injustices. Oil exploration sites are located in low income, sparsely-populated areas since the industrial work is so intrusive. Impoverished, rural communities have neither the financial resources nor the political clout to prevent large oil companies from using their land as extraction sites.

There are significant environmental injustices that occur in the extraction process for fuel oil. The following are examples of worldwide environmental injustices. In 1999 in Bolivia and Brazil, an Enrol-Shell oil pipeline was created through indigenous land.[54] Road construction followed the pipeline's creation and foreign companies began exploiting oil reserves on traditionally indigenous land,[55] destroying

Distribution of Environmental and Social Impacts of Oil Production and Consumption, Annual Review of Environment and Resources 28 (2003): 595, accessed April 11, 2015, http://www.annualreviews.org/doi/abs/10.1146/annurev.energy.28.050302.105617.

51 Borasin et al, Oil: A Lifecycle Analysis of its Health and Environmental Impacts, 2002 http://priceofoil.org/content/uploads/2006/05/OILHarvardMedfullreport.pdf.

52 Exxon Valdex Spill Profile, *U. S. Environmental Protection Agency,* accessed on March 18, 2015, http://www2.epa.gov/emergency-response/exxon-valdez-spill-profile.

53 O'Rouke, Dara, and Sarah Connolly, Just Oil? The Distribution of Environmental and Social Impacts of Oil Production and Consumption, Annual Review of Environment and Resources 28 (2003): 596, accessed April 11, 2015, http://www.annualreviews.org/doi/abs/10.1146/annurev.energy.28.050302.105617.

54 Hindrey, Derek, (2004) Social and Environmental Impacts of World Bank/IMF-Funded Economic Restructuring in Bolivia: An Analysis of Enron and Shell's Hydrocarbons Projects, *Singapore Journal of Tropical Geography* 25(3): 284.

55 Hindrey, Derek, (2004) Social and Environmental Impacts of World Bank/IMF-Funded Economic Restructuring

the people's land and their ways of life.[56] In the mid-1990s in Chile, indigenous groups were met with violence after they protested the harm done to their land, lifestyles, and livelihoods when the federal government granted permits and privileges for oil companies to drill on their land.[57] This is an example of a government prioritizing its national economic interests over the rights of minority groups. The ironic part is that the biggest economic winners are the foreign corporations who take their profits and invest them abroad.[58] In Bolivia, leaking pipelines that ran through the high elevation altiplano indigenous land contaminated about 18,000 hectares of indigenous land. Federal fines were imposed on the violating companies–Enron, Shell, and Transredes–but it was only after local indigenous communities put further pressure on the companies that they made any effort to compensate the people whose lives they had permanently altered.

Cases of indigenous, or otherwise marginalized, communities being disproportionately affected by the environmental "bads" of oil extraction are not isolated to South America. A report by Kretzmann and Wright found that oil exploration threatens indigenous livelihoods on six continents.[59] Oil exploration threatens the territory of indigenous groups by diminishing, segmenting, and degrading the land through road construction, deforestation, and resource contamination. It creates economic incentives for people and companies from outside of the community to exploit the land for resources, with little chance for politically underserved indigenous peoples to prevent unwanted development.[60]

<u>Extraction</u>

Environmental justice focuses on the distribution of social impacts. Extracting fuel oil is a hazardous job. There is the constant presence of highly explosive materials, toxic chemicals, large machinery, and the frequent isolation of drilling sites.[61] The risks associated with working at oil extraction sites have driven up the wages of workers in this industry in the U.S.,[62] but that is not necessarily the case in other countries. In Saudi Arabia, workers are prohibited to collectively bargain and Human Rights Watch reports oil-workers working under oppressive conditions where compensation may be denied.[63]

<u>Manufacturing and Production</u>

Oil refining sites are given the highest score in the manufacturing stage of environmental justice because many of these sites are located in minority or poor communities. 56% of the people living near a refinery are minorities, double the national average. Communities of color and low income families are disproportionately affected, and this issue also extends to developing nations.[64] For example, the people of Richmond, California live within a ring of five oil refineries, three chemical plants, eight Superfund sites, dozens of other toxic waste sites, highways, two rail yards, ports and marine terminals.[65] The median

in Bolivia: An Analysis of Enron and Shell's Hydrocarbons Projects, *Singapore Journal of Tropical Geography* 25(3): 284.

56 Hindrey, Derek, (2004) Social and Environmental Impacts of World Bank/IMF-Funded Economic Restructuring in Bolivia: An Analysis of Enron and Shell's Hydrocarbons Projects, *Singapore Journal of Tropical Geography* 25(3): 284.

57 Hindrey, Derek, (2004) Social and Environmental Impacts of World Bank/IMF-Funded Economic Restructuring in Bolivia: An Analysis of Enron and Shell's Hydrocarbons Projects, *Singapore Journal of Tropical Geography* 25(3): 284.

58 Hindrey, Derek, (2004) Social and Environmental Impacts of World Bank/IMF-Funded Economic Restructuring in Bolivia: An Analysis of Enron and Shell's Hydrocarbons Projects, *Singapore Journal of Tropical Geography* 25(3): 284.

59 O'Rouke, Dara, and Sarah Connolly, Just Oil? The Distribution of Environmental and Social Impacts of Oil Production and Consumption, Annual Review of Environment and Resources 28 (2003): 596, accessed April 11, 2015, http://www.annualreviews.org/doi/abs/10.1146/annurev.energy.28.050302.105617.

60 O'Rouke, Dara, and Sarah Connolly, Just Oil? The Distribution of Environmental and Social Impacts of Oil Production and Consumption, Annual Review of Environment and Resources 28 (2003): 596, accessed April 11, 2015, http://www.annualreviews.org/doi/abs/10.1146/annurev.energy.28.050302.105617.

61 Webley, Kayla, Just How Dangerous Are Oil Rigs, Anyway?, *Time Magazine*, Apr. 24, 2010, accessed on March 17, 2015, http://content.time.com/time/nation/article/0,8599,1984296,00.html.

62 Hargreaves, Steve, Oil Rig Workers Make Nearly $100,000 a Year, *CNN Money*, May 10, 2012, accessed on March 17, 2015, http://money.cnn.com/2012/05/10/news/economy/oil_workers/.

63 O'Rouke, Dara, and Sarah Connolly, Just Oil? The Distribution of Environmental and Social Impacts of Oil Production and Consumption, Annual Review of Environment and Resources 28 (2003): 596, accessed April 11, 2015. http://www.annualreviews.org/doi/abs/10.1146/annurev.energy.28.050302.105617.

64 O'Rouke, Dara, and Sarah Connolly, Just Oil? The Distribution of Environmental and Social Impacts of Oil Production and Consumption, Annual Review of Environment and Resources 28 (2003): 596, accessed April 11, 2015. http://www.annualreviews.org/doi/abs/10.1146/annurev.energy.28.050302.105617.

65 Kay, Jane, and Cheryl Katz, Pollution, Poverty, People of Color: The Factory on the Hill, Environmental Health News,

income in North Richmond, $36,875 in 2010, is less than Richmond's modest $54,012 and less than half of Contra Costa County's $78,385.[66]

Oil refineries affect large populations because they produce large amounts of toxic air and water emissions as well as solid and hazardous waste such as benzene, heavy metals, hydrogen sulfide, acid gases, mercury, and dioxins. Other environmental injustices include thermal pollution and noise pollution. Petroleum refining facilities release 75% of its toxic emissions to the air, 24% to the water, and 1% to the land.[67]

Hazardous-waste disposal is also a major issue of environmental justice. Oil refinery disposal methods for toxic refinery wastes tend to take advantage of wide open spaces instead of environmentally sound waste management techniques.[68] The wastes from the oil refineries cause health risks to facility workers and surrounding communities. Facility workers are at high risk of accidents such as fires, explosions, and chemical leaks and spills. Health impacts can include severe burns or skin and eye irritation, bronchitis, chemically-induced pneumonia, chronic lung disease, psychosis and peripheral neuropathies, and increased cancer risks. Health impacts extend outside the walls of refineries, where studies have demonstrated the relationship between proximity of communities to refineries and cancer.[69]

<u>*Transportation*</u>

Transportation of both crude oil and no. 6 fuel oil presents serious implications for environmental justice. Oil spills are a potential hazard of the transportation stage of fuel oil, and transportation of crude oil by water–specifically large oil tankers–are a likely source of spills. Oil spills severely harm coastal and subsistence communities. The Exxon Valdez spill in 1989, the second biggest oil spill in U.S. history, resulted from the transportation of oil on a large tanker. It spilled more than 11 million gallons of crude oil and had long-lasting consequences for the communities of Prince William Sound, Alaska, particularly those who depended on commercial fisheries and the coastline used for subsistence hunting, fishing and gathering.[70]

Additionally, emissions from transportation–both crude oil in oil tankers and no. 6 in heated trucks–are concentrated around large cities, often with high numbers of minority and low-income communities. Pollution from these transportation sources may cause respiratory or health issues, and communities clustered around oil tanker ports or highways are disproportionately affected.

<u>*Generation/Use*</u>

The burning and use of No. 6 fuel oil releases large amounts of pollutants into the nearby area. While we recognize that the use of this fuel could have major ramifications for environmental justice if it were to be burned in disadvantaged communities where power plants are often placed, we do not feel that this is the case for Wellesley, because we do not consider the Wellesley College community or surrounding communities to be minority or low-income communities.

June 4, 2012, accessed April 11, 2015, http://www.environmentalhealthnews.org/ehs/news/2012/pollution-poverty-and-people-of-color-richmond-day-1/.

66 Kay, Jane, and Cheryl Katz, Pollution, Poverty, People of Color: The Factory on the Hill, Environmental Health News, June 4, 2012, accessed April 11, 2015, http://www.environmentalhealthnews.org/ehs/news/2012/pollution-poverty-and-people-of-color-richmond-day-1/.

67 O'Rouke, Dara, and Sarah Connolly, Just Oil? The Distribution of Environmental and Social Impacts of Oil Production and Consumption, Annual Review of Environment and Resources 28 (2003): 596, accessed April 11, 2015, http://www.annualreviews.org/doi/abs/10.1146/annurev.energy.28.050302.105617.

68 O'Rouke, Dara, and Sarah Connolly, Just Oil? The Distribution of Environmental and Social Impacts of Oil Production and Consumption, Annual Review of Environment and Resources 28 (2003): 596, accessed April 11, 2015. http://www.annualreviews.org/doi/abs/10.1146/annurev.energy.28.050302.105617.

69 O'Rouke, Dara, and Sarah Connolly, Just Oil? The Distribution of Environmental and Social Impacts of Oil Production and Consumption, Annual Review of Environment and Resources 28 (2003): 596, accessed April 11, 2015, http://www.annualreviews.org/doi/abs/10.1146/annurev.energy.28.050302.105617.

70 Exxon Valdex Spill Profile, *U. S. Environmental Protection Agency,* accessed on March 18, 2015, http://www2.epa.gov/emergency-response/exxon-valdez-spill-profile.

Grey, CGP. *California-Oil Pumps.* August 16, 2006. Flickr.com.

No. 2 Fuel Oil

Introduction to No. 2 Fuel Oil Heat Energy

No. 2 fuel oil is a distillate fuel oil that flows easily at room temperature, as it is less sludgy than is No. 6 fuel oil.[71] No. 2 is also known as heating oil and is frequently used for heating homes in the Northeast U.S.[72] The energy content of No. 2 is approximately 140,000 Btu/gal, or 41 kWh/gal, and the flash point, or lowest temperature needed to form a combustible concentration of gas, is 100 degrees Fahrenheit. Because No. 2 is a light fuel oil that releases fewer emissions of particulate matter, sulfur dioxide and nitrogen oxide than do heavier fuel oils such as No. 6, many cities that currently burn No. 6 have advocated switching to No. 2 for dramatic benefits to public health.[73] Although No. 2 fuel oil is more expensive than its No. 6 counterpart, reduced boiler maintenance and lower costs by avoiding heating of oil and pollution control compared to No. 6 helps to offset higher fuel costs.[74]

Note: No. 2 fuel oil has comparable CO_2 emissions to No. 6 fuel oil, but has significantly less NO_x, SO_2 and particulate matter.[75]

For No. 2 fuel oil we chose "light fuel oil, burned in industrial furnace 1MW, non-modulating/ CH S" in SimaPro 7.

Cost

Taking into account initial or capital costs, fixed operating costs, and variable operating costs, the cost of No. 2 fuel oil is $0.41/kWh.

Reliability

Table 90: Reliability assessment for No.2 fuel oil

Yes (1), No (0), or N/A	*Score*
Can it be provided uninterrupted?	*1*
Can it be stored?	*1*
Is it available short-term (until 2025)?	*1*
Is procurement stable (not volatile) in the long term?	*1*
Is it independent of weather?	*1*
Can you ramp it up/down to meet fluctuating heat demand?	*1*
Total:	***6***

Fuel oil, whether No. 2 or No. 6, comes in a steady supply and can be available in an uninterruptible format. Fuel oil can be easily procured and provide steam regardless of weather conditions, as long as the fuel is on hand. Fuel oils can be also stored for long periods of time, though, in the case of No. 6, it needs to be heated while in storage. Because No. 6 fuel oil is usually used in large commercial and industrial boilers, facilities need to be able to maintain a reasonable supply of oil to the boiler, and large storage tanks must be kept as full as possible to minimize any accumulation of moisture build-up within the tanks.[76] In the short term, fuel oil is readily available in the market and use of fuel oil can also be increased quickly to meet demands. We cannot, however, anticipate how the price of No. 2 fuel oil will fluctuate in the future. Additionally, it should be noted that, although the oil supply is unlikely to run out in the future, the supply chain may be fragile and unable to respond quickly during adverse weather conditions or when demand is high in the winter season in New England.[77] Because the supply of oil is available and stable, and we anticipate it will continue to be so in the future, we rated No. 2 and No. 6 fuel oils as having a high reliability.

71 Types of Refined Petroleum Products, *EPA*, accessed March 18, 2015, http://www2.epa.gov/emergency-response/types-refined-petroleum-products.

72 Beyond Natural Gas and Electricity, *U.S. Energy Information Administration*, accessed March 18, 2015, http://www.eia.gov/todayinenergy/detail.cfm?id=4070.

73 The Bottom of the Barrel: How the Dirtiest Heating Oil Pollutes Our Air and Harms Our Health, (Dec. 2009) *Environmental Defense Fund*, Chapter 3, pp. 1-2.

74 The Bottom of the Barrel: How the Dirtiest Heating Oil Pollutes Our Air and Harms Our Health, (Dec. 2009) *Environmental Defense Fund*, Chapter 3, pp. 4.

75 The Bottom of the Barrel: How the Dirtiest Heating Oil Pollutes Our Air and Harms Our Health, (Dec. 2009) *Environmental Defense Fund*, Chapter 3, pp. 4.

76 The True Cost of #6 Oil, *National Fuel,* accessed on March 18, 2015, http://www.natfuel.com/ForBusiness/publications/oil_6_techline.htm.

77 Managing the Reliability of the Electric Grid While the Power Industry Undergoes Rapid Transformation, *ISO New England,* last modified September 19, 2014, Boston, MA. pp. 10, accessed on March 18, 2015, http://iso-ne.com/static-assets/documents/2014/09/ma_roundtable_9_19_14_gvw_final.pdf.

Educational Advantage

Table 91: Educational advantage assessment for No.2 fuel oil

High (2), Medium (1), Low (0)	*Score*
Students can learn from this energy source and use data from it to understand energy generation.	*1*
There is visibility on campus and this energy source raises awareness about sustainability.	*0*
Ability to be a research opportunity to further the interests of students and professors.	*1*
Informs administrative decisions on scaling up energy production in new technologies (this is most relevant for new technologies).	*1*
Provides insight and encourages external organizations to replicate forms of uncommon energy production.	*0*
Total:	***3***

In general, No. 2 fuel oil is more educationally advantageous than No. 6 fuel oil, but not remarkably educational. Like No. 6 Fuel oil, it is possible for classes to tour a No. 2 fuel oil-powered boiler in the power plant. Interested students can even pursue research using data from the fuel oil-burning boilers, but there is not very much data available for students to analyze because of poor data collection systems. Administrators could also learn something about the benefits and costs of using No. 2 fuel oil by introducing its usage on-campus, even though it is not a new sustainable technology.

Having a No. 2 fuel oil boiler does not raise awareness about sustainability issues on campus. Using No. 2 fuel oil does not provide other institutions with insights about the usage of uncommon energy sources because fuel oils are already widely used.

Greenhouse Gas Emissions

Table 92: Greenhouse gas emissions assessment for No.2 fuel oil

Impact Category	***Total***
Greenhouse Gas Emissions	*1.54E-05 kg CO2 eq*

The climate change potential for No. 2 fuel oil was calculated to be 1.54E-5 kg CO_2 equivalent. 85% of the climate change potential is attributed to the boiler materials, manufacturing, transportation and use of the No. 2 fuel oil. The other 15% is accounted for during the extraction and refining of the oil.

Ecotoxicity

Table 93: Ecotoxicity assessment for No.2 fuel oil

Impact Category	***Total***
Ecotoxicity	*2.77E-05 CTUe*

The ecotoxicity of No. 2 fuel oil was calculated to be 2.77E-05 CTUe equivalent. 78% of ecotoxicity is attributed to the boiler manufacturing, transportation and use of the No.2 fuel oil, while the other 22% of ecotoxicity is accounted for during the extraction and refining of the oil.

Ecosystem Disruption

Table 94: Ecosystem disruption assessment for No.2 fuel oil

Low (0), Medium (1), High (2)	*Score*
Land Disruption - permanent or temporary	*1*
Water Use	*2*
Water Contamination	*2*
Biodiversity disruption (consider both the number of species and the extent of the disruption for species)	*2*
Total:	*7*

Extraction

There is significant land disruption during the exploration and extraction phases of fuel oil. Significant amounts of land clearing, grading, mineral upheaval, and solid waste during this lifecycle phase contribute to the high ranking of No. 2 fuel oil in ecosystem disruptions. See page 38 for further discussion of land disruptions issues related to fuel oil exploration and extraction.

There is significant water use in extracting fuel oils, as water is extracted from below the surface during the oil drilling process. Like No. 6 fuel oil, we ranked No. 2 highly for 'water use' after considering the extensive usage of water in the creation of produced water. See page 39 for further discussion of water disruptions issues related to fuel oil exploration and extraction. Water contamination is significant in extracting fuel oils. Water contamination ranked highly for No. 2 fuel oil during extraction because of erosion effects and contamination from produced water released into waterways during this lifecycle phase. See page 39 for further discussion of water contamination issues related to fuel oil exploration and extraction.

The exploration and extraction phase of No. 2 fuel oil's lifecycle creates significant damage to biodiversity. We rated No. 2 fuel oil highly as damaging biodiversity after considering the habitat disruptions and environmental contamination that occur during this lifecycle stage. See page 39 for further discussion of biodiversity issues related to fuel oil exploration and extraction.

<u>*Manufacturing, Transport and Use*</u>

Aside from the initial construction of the facility, the manufacturing, transport and use phases of No. 2 fuel oil do not pose major threats to long-term or short-term land disruption. Oil is transported by sea and on-land transportation occurs on infrastructure that is already in place. While power plants have to be built before fuel oil is burned, the amount of land disruption is low, particularly when compared to the extraction phase.

Like No. 6 Fuel oil, No. 2 refinery also utilize millions of gallons of water. On average 3.4–6.6 gallons of fresh water are needed to produce one gallon of gasoline. See page 40 for further discussion of water use issues related to fuel oil manufacturing. Transportation does not involve significant water use, nor does the burning of No. 2, especially when compared to the extraction and manufacturing phases.

Water contamination during the refinery process is very high. Many chemicals that are used to refine crude oil are leaked into water sources nearby. See page 40 for further discussion of water disruptions issues related to fuel oil manufacturing. The transportation of crude oil and refined products has the potential for oil spills, which can have serious ramifications for water contamination. See page 40 for further discussion of water contamination issues related to fuel oil transport. The burning of No. 2 can exacerbate water contamination problems such as acid rain. Water is more often directly contaminated in the extraction and manufacturing phases.

During the oil refinery process, chemicals that are used to distill the crude oil create large amounts of waste that are often leaked into the land, air and water near refineries, causing huge ecosystem disruptions. See page 40 for further discussion of biodiversity issues related to fuel oil manufacturing. There is a potential for oil spills during the transport of oil with potential major ramifications for wildlife and biodiversity. See page 41 for further discussion of biodiversity issues related to fuel oil transport. The burning of fuel oil does not pose a significant threat to biodiversity loss. Although greenhouse gases and other pollutants are released as air pollution during the use phase, this does not directly target species. (It should be noted, however, that long-term effects as a result of continuous use such as global warming will harm species and biodiversity around the world.)

Human Health

Table 95: Human health assessment for No.2 fuel oil

Impact Category	***Total***
Respiratory effects	*2.61E-06 kg PM2.5 eq*
Carcinogenics	*7.30E-05 CTUh*
Non-carcinogenics	*4.90E-05 CTUh*

75% of carcinogens is attributed to the boiler manufacturing, transportation and use of the No. 2 fuel oil while the other 25% is accounted for during the extraction and refining of the oil. 91% of non-carcinogens is attributed to the boiler manufacturing, transportation and use of the No. 2 fuel oil while the other 9% is accounted for during the extraction and refining of the oil. 68% of particulate matter is attributed to the boiler manufacturing, transportation and use of the

No. 2 fuel oil while the other 32% is accounted for during the extraction and refining of the oil.

Environmental Justice

Table 96: Environmental justice assessment for No.2 fuel oil

Low (0), Medium (1), High (2)	*Score*
Raw material extraction	*2*
Manufacturing & Production (refining of fuels, manufacturing of equipment)	*2*
Transport (all transport phases prior to reaching Wellesley)	*2*
Generation (at Wellesley or wherever the heat is generated)	*0*
Total:	***6***

<u>*Raw Material Extraction*</u>

Oil exploration and extraction sites are not present in wealthy, populated centers; they exist in areas in which the locals are politically disenfranchised. This misdistribution of environmental degradation is an environmental injustice. This industry-wide phenomenon led us to rate No. 2 fuel oil with the worse rating for environmental justice in the extraction lifecycle stage. See page 41 for further discussion of environmental justice issues related to fuel oil exploration and extraction.

<u>*Manufacturing*</u>

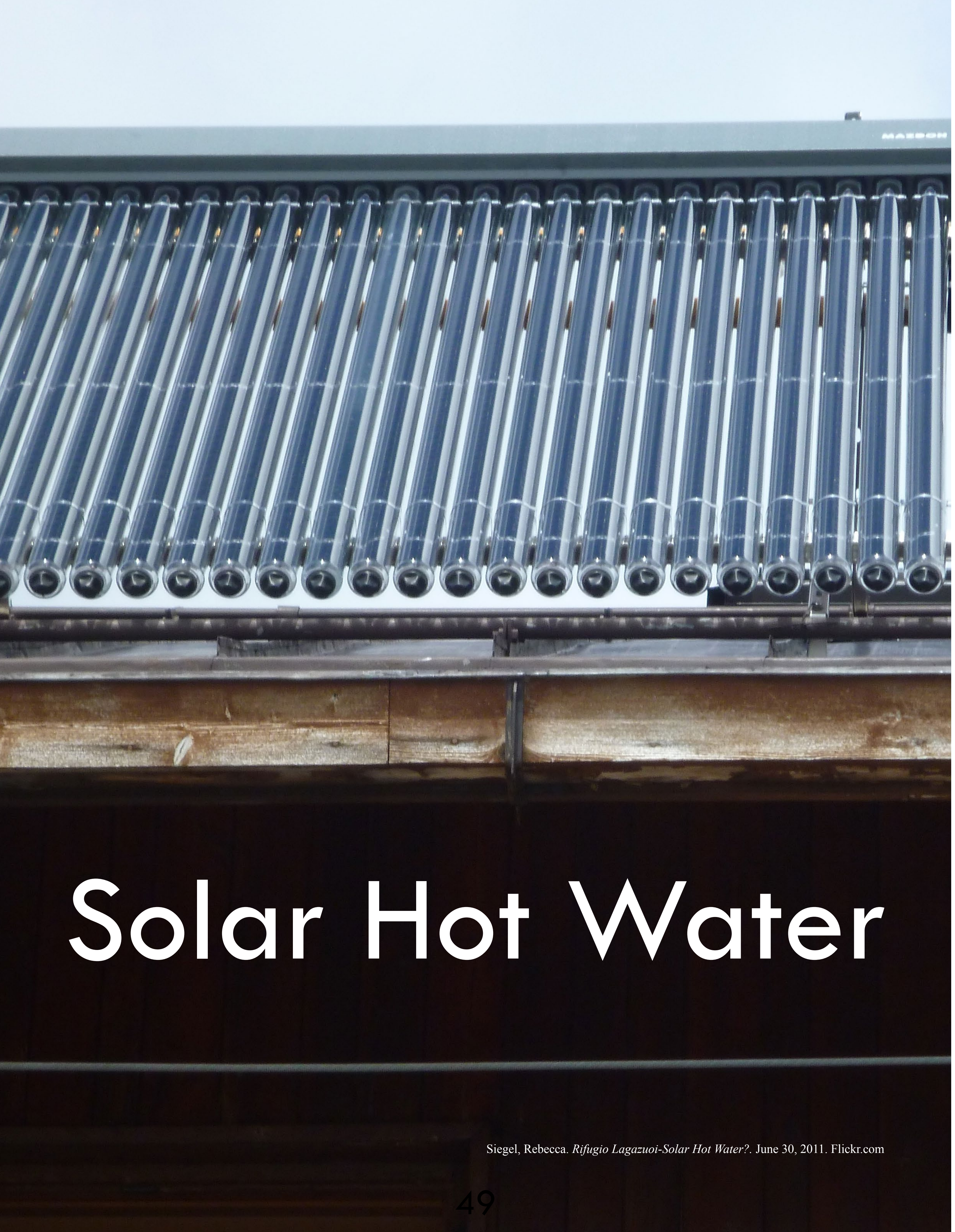
Similar to No. 6 Fuel oil, refining No. 2 Fuel oil has many local environmental impacts such as toxic air and water emissions, accidental releases of chemicals, hazardous waste disposal, thermal pollution, and noise pollution. These effects are detrimental to the communities located near refineries. The communities near refineries are commonly poor and minorities or people of color. See page 42 for further discussion of environmental justice issues related to fuel manufacturing.

<u>*Transportation*</u>

The transportation of No. 2 fuel oil, both as a crude oil and a refined product, is problematic in terms of environmental justice. The transport of No. 2 fuel oil, similar to that of No. 6 fuel oil, has the potential for oil spills that could be disproportionately devastating for minority communities, as well as for air pollution from oil tankers and other transport vehicles. Because of this, No. 2 fuel oil ranked high on the environmental justice scale for the transport stage. See page 43 for further discussion of environmental justice issues related to fuel oil transportation.

<u>*Use*</u>

Similar to No. 6 fuel oil, the burning and use of No. 2 fuel oil releases large amounts of pollutants, yet, because we do not classify Wellesley as a disadvantaged community, we gave the use phase of No. 2 a ranking of 0, or low, on the environmental justice scale.



Solar Hot Water

Siegel, Rebecca. *Rifugio Lagazuoi-Solar Hot Water?*. June 30, 2011. Flickr.com

Introduction to Solar Hot Water Heat Energy

A solar hot water system captures the sun's rays in order to produce heat or electricity. The system utilizes photovoltaic panels to collect thermal energy from the sun. It then transfers this thermal energy to a series of technologies that convert the sun's rays to usable energy such as heat. A solar hot water system can be used to heat air or to heat water which is then transferred to a space heating boiler or directly plumbed through radiators throughout the house.[78] Solar hot water systems operate at the same temperatures as most hot water distribution systems in buildings: about 120°F.[79] There are two types of systems: active, which have circulating pumps and controls, and passive, which do not.[80]

Solar hot water systems usually use solar energy for either space heating or water heating. Most college campuses use it for the latter. For example, at the University of Maryland, 30% of dining hall heating is done via a solar hot water system. The system includes 20 panels with 3 solar storage tanks, pumps, temperature sensors, and controls.[81] Harvard University, an institution closer to home, also installed solar hot water systems on the dormitory buildings that make up Canaday Hall. These solar hot water systems account for 60% of the domestic hot water needs for all 13 dorms in Harvard Yard.[82] Some other campuses that use the energy from solar hot water systems for domestic hot water include Eastern Mennonite University,[83] Williams College,[84] and Governors State University, which boasts the largest solar installation in Illinois- one that heats their Olympic-sized pool as well.[85] Dickinson College is another example of a school that uses the energy generated from solar hot water to heat an entire greenhouse.[86] Guilford College has one of the largest solar-thermal systems ever installed on a U.S. college or university campus (200 solar thermal collector panels).[87]

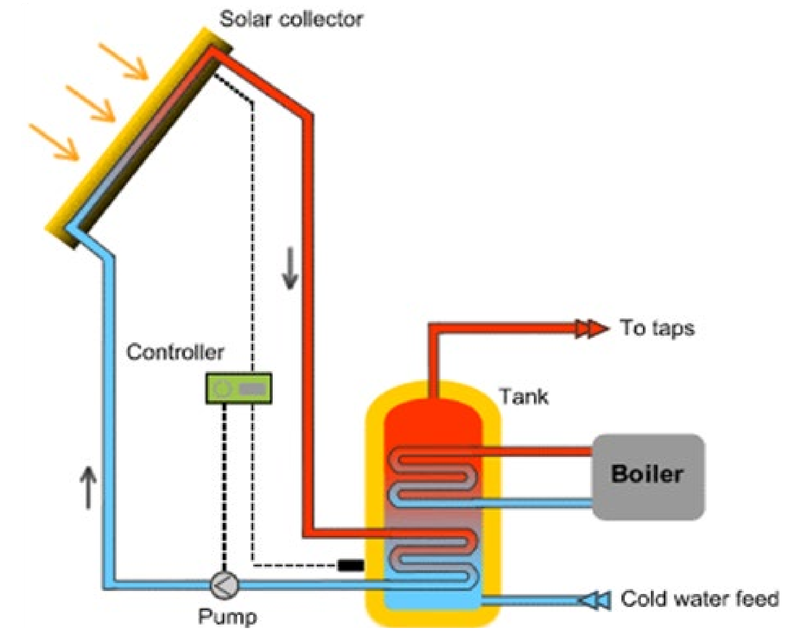


Figure 34: Solar hot water system.[1]

1 Solar Hot Water Systems, Pro Enviro, accessed May 7, 2015, http://www.proenviro.com/UK/services/renewables/solar_hot_water_systems.htm.

It would most likely be difficult for Wellesley College to implement a solar hot water system that would allow the college to completely rely on solar hot water as its main source of heating on campus, primarily due to scale and space issues. That being said, it is very likely that the school could generate enough solar-heated water to sustain the heat demand of the campus' dining halls. It would be easiest to implement a water heating system in the meadow near the East Side dorms where there is a large piece of open and flat land that would provide a good space for panels and storage tanks. This location would also catch the

78 Solar Power for Hot Water and Heating, Solar Server, accessed April 5, 2015, http://www.solarserver.com/knowledge/basic-knowledge/solar-heating.html.

79 Solar Thermal, National Renewable Energy Laboratory, accessed April 5, 2015, http://www.nrel.gov/tech_deployment/climate_neutral/solar_thermal.html#options.

80 How Solar Water Heaters Work, How Stuff Works, accessed April 5, 2015, http://science.howstuffworks.com/environmental/green-tech/sustainable/solar-water-heater.htm.

81 Energy, University of Maryland, accessed April 5, 2015, http://www.sustainability.umd.edu/content/campus/energy.php#Solar Diner.

82 Creating Power by the Yard, Harvard Gazette, accessed April 5, 2015, http://news.harvard.edu/gazette/story/2010/10/creating-power-by-the-yard/.

83 Secure Futures Resilient Solar Solutions, Eastern Mennonite University, accessed April 5, 2015, http://securefutures.us/case-studies/eastern-mennonite-university/.

84 The College Sustainability Report Card, Williams College: Report Card 2011, accessed April 5, 2015, http://www.greenreportcard.org/report-card-2011/schools/williams-college.html.

85 Welcome Message from Dr. Elaine P. Maimon, Governors State University, accessed April 5, 2015, http://www.energysystemsgroup.com/gsu/welcome.html.

86 About the Hosts: Dickinson College, Seeding the Future Conference, accessed April 5, 2015, http://blogs.dickinson.edu/seedingthefuture/about-the-hosts/.

87 Column Highlights Solar Power at Guilford, Guilford College, accessed April 5, 2015, http://www.guilford.edu/news/item/index.aspx?pageaction=ViewSinglePublic&LinkID=449&ModuleID=54.

attention of visitors such as prospective students and their families, leading them to realize one of Wellesley's sustainable measures.

For solar hot water energy we chose "hot water tank 600l, at plant/CH/I S" in SimaPro 7 because it is similar to systems we looked at for Wellesley College, and "ethylene glycol, at plat/RER S" as the antifreeze that would be used in such a system.

Cost

Taking into account initial or capital costs, fixed operating costs, and variable operating costs, the cost of a solar hot water system is $0.07/kWh.

If we purchase the solar hot water system from one of the manufactures listed below, the College will be eligible to receive a rebate:

- EverStore= Everstor, Inc., Duxbury, MA (41.8 miles from Wellesley College)
- HeatFlo= Uxbridge, MA (28.3 miles from Wellesley College)
- HTP= East Freetown, MA (48.9 miles from Wellesley College)
- Stiebel Eltron= West Hatfield, MA (94.5 miles from Wellesley College)
- SunDrum Solar= Hudson, MA (24.8 miles from Wellesley College)
- Vaughn Corp= Salisbury, MA (53.6 miles from Wellesley College)
- Wagner= Cambridge, MA (13.8 miles from Wellesley College)[88]

Reliability

88 Eligible Massachusetts Manufacturers of Solar Hot Water Components, Massachusetts Clean Energy Center, accessed on May 7, 2015, http://www.masscec.com/content/eligible-massachusetts-manufacturers-solar-hot-water-components.

Table 97: Reliability assessment for solar hot water

Yes (1), No (0), or N/A	*Score*
Can it be provided uninterrupted?	*0*
Can it be stored?	*0.5*
Is it available short-term (until 2025)?	*1*
Is procurement stable (not volatile) in the long term?	*1*
Is it independent of weather?	*0*
Can you ramp it up/down to meet fluctuating heat demand?	*0.5*
Total:	***3***

Because a solar hot water system relies solely on the sun as its source of fuel, energy from solar hot water will be available in both the short-term and the long-term. That being said, on a daily basis, the amount of energy produced by a solar hot water system may fluctuate due to changes in weather. For example, on a stormy day, less heat may be produced as less sun is fueling the solar hot water energy system.[89] This does not mean that the water will be colder that day; most solar storage tanks in solar hot water systems have a secondary way of obtaining heat, often through electricity.[90] Furthermore, heat collected during the day can remain stored in the system's storage tanks until it is needed. Students tend to shower in the mornings and the evenings, two times that do not coincide with peak sunlight, however students could tap into the heat supply stored in solar hot water storage tanks in order to take a hot shower.[91]

Educational Advantage

Table 98: Educational advantage assessment for solar hot water

High (2), Medium (1), Low (0)	*Score*
Students can learn from this energy source and use data from it to understand energy generation.	*2*
There is visibility on campus and this energy source raises awareness about sustainability.	*1*
Ability to be a research opportunity to further the interests of students and professors.	*2*
Informs administrative decisions on scaling up energy production in new technologies (this is most relevant for new technologies).	*1*
Provides insight and encourages external organizations to replicate forms of uncommon energy production.	*2*
Total:	***8***

89 FAQs: Solar Hot Water, EarthNet Energy, accessed March 12, 2015, http://www.earthnetenergy.com/faqs-solar-hot-water/.

90 FAQ: Solar Hot Water, New England Clean Energy, accessed March 12, 2015, http://newenglandcleanenergy.com/home-solar-hot-water/faq/.

91 Solar Hot Water Storage, Home Power, accessed March 12, 2015, http://www.homepower.com/articles/solar-water-heating/equipment-products/solar-hot-water-storage.

If Wellesley College installs a solar hot water system to provide heat on campus, it would need a large plain area. Thus it would be unlikely to be installed near the center of campus, visible and available for students and pedestrians to interact with, and most likely be located near the campus sports fields or on the meadow near the East Side dormitories. If located near the East Side dorms, the solar hot water system will at least catch the attention of prospective students and their families when they visit the college. The school can also plan more events around or near the solar hot water system to raise awareness about it.

Furthermore, students can have the opportunity to conduct research. In addition, installing a solar hot water heating system on Wellesley College's campus may also prove a great way to distinguish the college and its mission from those of surrounding colleges. Although Harvard University utilizes a solar hot water system to heat 60% of the hot water in Harvard Yard's 28 buildings[92], Wellesley College, a smaller institution, may be able to boast a larger impact of installing solar panels as the system could heat more of Wellesley's Campus than the solar hot water system does Harvard's campus. Perhaps Wellesley College can have a goal of supplying all of the campus' heat needs with the solar hot water system over some time.

Overall, at a score of 8, solar hot water would be an educational asset for Wellesley College and Wellesley town communities.

92 Canaday Hall Solar Thermal and Heat Recovery System, Harvard University: Sustainability, accessed March 14, 2015, http://www.green.harvard.edu/tools-resources/video/canaday-hall-solar-thermal-and-heat-recovery-system.

Greenhouse Gas Emissions

Table 99: Greenhouse gas emissions assessment for solar hot water

Impact Category	***Total***
Greenhouse Gas Emissions	*5.33E-08 kg CO2 eq*

The effects of global warming are felt heavily by the transport of solar hot water materials to the destination site.

Ecotoxicity

Table 100: Ecotoxicity assessment for solar hot water

Impact Category	***Total***
Ecotoxicity	*2.34E-06CTUe*

Ecotoxicity is highest during the raw materials extraction portion of the solar hot water life cycle. Throughout the life cycle of the solar hot water energy system, ecotoxicity has an impact value of 2.34E-06 CTUe.

Ecosystem Disruption

Table 101: Ecosystem disruption assessment for solar hot water

Low (0), Medium (1), High (2)	*Score*
Land Disruption - permanent or temporary	*1*
Water Use	*1*
Water Contamination	*1*
Biodiversity disruption (consider both the number of species and the extent of the disruption for species)	*1*
Total:	***4***

Extraction

The solar collectors require raw materials such as quartzite gravel or crushed quartz and land disruption is inherent to the exploration and extraction processes. The extraction process of materials require space for infrastructure and roads thus land clearing occurs which removes vegetation and creates ecological impacts. Another typical activity during the solar energy facility construction phase is drilling. Drilling is necessary to uncover the raw materials, such as silica, need to be mined from the earth. Other types of land disruption include vehicular and pedestrian traffic and trenching. Trenching is when ditches are dug into the ground in order to create space for transmission lines or pipelines.[93] Also, an indirect effect may be that certain roads will be blocked off and traffic would be redirected onto unpaved roads.

The exploration and extraction phase of the solar collector's resources poses significant biodiversity damage. Land clearing and other forms of land disruptions have a huge impact on ecological systems. These disruptions introduce foreign species of invasive plants and displace the current types of vegetation.

During these processes, there is water used in the process, primarily as a form of coolant to make sure the machines do not overheat. The amount of water used is dependent on how large the system is but because solar panels require extraction of raw earth materials, the process is on a pretty large scale and therefore gets a relatively score between medium-high.

Manufacturing, Transport and Use

The manufacturing, transport and use phases do not pose major threats to long-term or short-term land disruption. While solar hot water systems are commonly assembled on cleared land, it is more common to install systems on building roofs. Having the system implemented on an already man-constructed setting would not disrupt the land anymore, so it would receive a low rating for land disruption.

Transportation of the system is usually done through vehicles like trucks, which release gas into the air. While there is rarely potential for biodiversity disruption from the process of transportation, minor spillage during its travel, and unloading stages can cause direct ecosystem disruption. Energy generated through solar power does not pose a significant threat to biodiversity loss. Particularly, it wouldn't be an issue because it is installed on a manmade environment (roofs) so the system's installation would not have a direct impact on ecological processes. In addition, there isn't a huge threat posed against aquaculture during the actual usage stage of the solar hot water system because the system is self-contained and everything occurs within the system.

Because the water used to sustain a solar hot water system often serves as the source of heat energy used by consumers, there is no high detrimental value of water use when using a solar hot water system. The only times water may be used in greater scales is during the production period. Similarly to the extraction phases, manufacturing the solar hot water system requires water usage. The cooling towers typically withdraw between 600 and 650 gallons of water per megawatt-hour of electricity produced. CSP plants with once-through cooling technology have higher levels of water withdrawal, but lower total water consumption (because water is not lost as steam). [94]

When water is used as a cooling device, water contamination may occur during the production and manufacturing phase. Any water that is not steamed has the potential to be contaminated, although the percentage of water that is not used for steam is small.

93 **Solar Energy Construction Impacts, Tribal Energy and Environmental Information Clearhouse, accessed March 30, 2015, http://teeic.indianaffairs.gov/er/solar/impact/construct/index.htm.**

94 Water Use, *UCUSA*, accessed April 5, 2015, http://www.ucsusa.org/clean_energy/our-energy-choices/renewable-energy/environmental-impacts-solar-power.html#bf-toc-1.

Health

Table 102: Health assessment for solar hot water

Impact Category	*Total*
Respiratory effects	*8.81E-08 kg PM2.5 eq*
Carcinogenics	*2.04E-05 CTUh*
Non-carcinogenics	*9.67E-07 CTUh*

In the lifecycle of a solar hot water system, the raw material extraction phase has the greatest impact on health. Based on the above table, it is clear that carcinogens have a higher impact value for a 1,000L solar hot water system at 2.04E-05 CTUh than do non-carcinogens at 9.67E-07 CTUh. The 8.81E-08 kg PM2.5eq worth of respiratory effects are likely due to the transportation of the solar hot water system.

Environmental Justice

Table 103: Environmental justice assessment for solar hot water

Low (0), Medium (1), High (2)	*Score*
Raw material extraction	*1*
Manufacturing & Production (refining of fuels, manufacturing of equipment)	*2*
Transport (all transport phases prior to reaching Wellesley)	*0.5*
Generation (at Wellesley or wherever the heat is generated)	*0*
Total:	***3.5***

Raw Material Extraction

The extraction and manufacturing related to solar hot water take the greatest environmental justice toll, as the extraction of these materials causes significant environmental, health and safety hazard. A potentially harmful by-product associated with the extraction stages (mining and processing of silica sand) is crystalline silica dust. Silica dust has been associated with silicosis, a lung disease in which scar tissue forms in the lungs and reduces the ability to breath. Furthermore, crystalline silica dust is classified as a known human carcinogen by the International Agency for Research on Cancer,[95] and studies show an increased risk of developing lung cancer through regular exposure to crystalline silica dust. The crystalline silica dust, however, does not carry across long distances, thus the dust primarily affects those working directly with it. While there is a chance that the dust will be blown into nearby communities, it is difficult to calculate the certainty of this happening, the amount of dust that would travel, and the population it would affect.

Manufacturing & Production

For the manufacturing and production stages of solar hot water, the heightened exposure route of vapor or dust inhalation is the greatest environmental justice risk, although, as we mentioned earlier, it is difficult to determine if the heightened exposure route of vapor or dust inhalation has a higher impact on nearby communities or on those working in close proximity to the dust. There is also a risk of spills that release gases, and fires. It is important to note, however, that there have not been any catastrophic spills or fires related to solar hot water in United States due to strict regulations: solar hot water manufacturing facilities are not required to have extensive occupational ventilation systems, accident prevention and planning programs, and emergency confinement and absorption units.[96]

While people can undoubtedly be negatively affected by solar hot water systems, there are social benefits to adopting this alternative energy source, such as job creation. Between November 2013 and November 2014, 31,000 solar jobs were added in the U.S., opening up more opportunities for economic growth, which can eventually lead to people and communities having more decision-making power, and can thus allow for their relocation to safer neighborhoods and access to better health care in the long-run.[97]

Transportation

The transportation of solar hot water systems via diesel trucks can also affect communities. As the trucks travel from the manufacturing facility to their destinations, they are polluting our air with carbon monoxide, lead, and sulfur dioxide. The carbon monoxide in fuel emissions can prevent oxygen from reaching one's brain and heart, and the lead found in gasoline can damage organs and significantly decrease mental ability. Furthermore, when fuel containing sulfur is inputted into diesel engines, sulfur dioxide generation can occur, causing a constriction of air passages and exacerbating asthma-related health problems. [98]

Generation

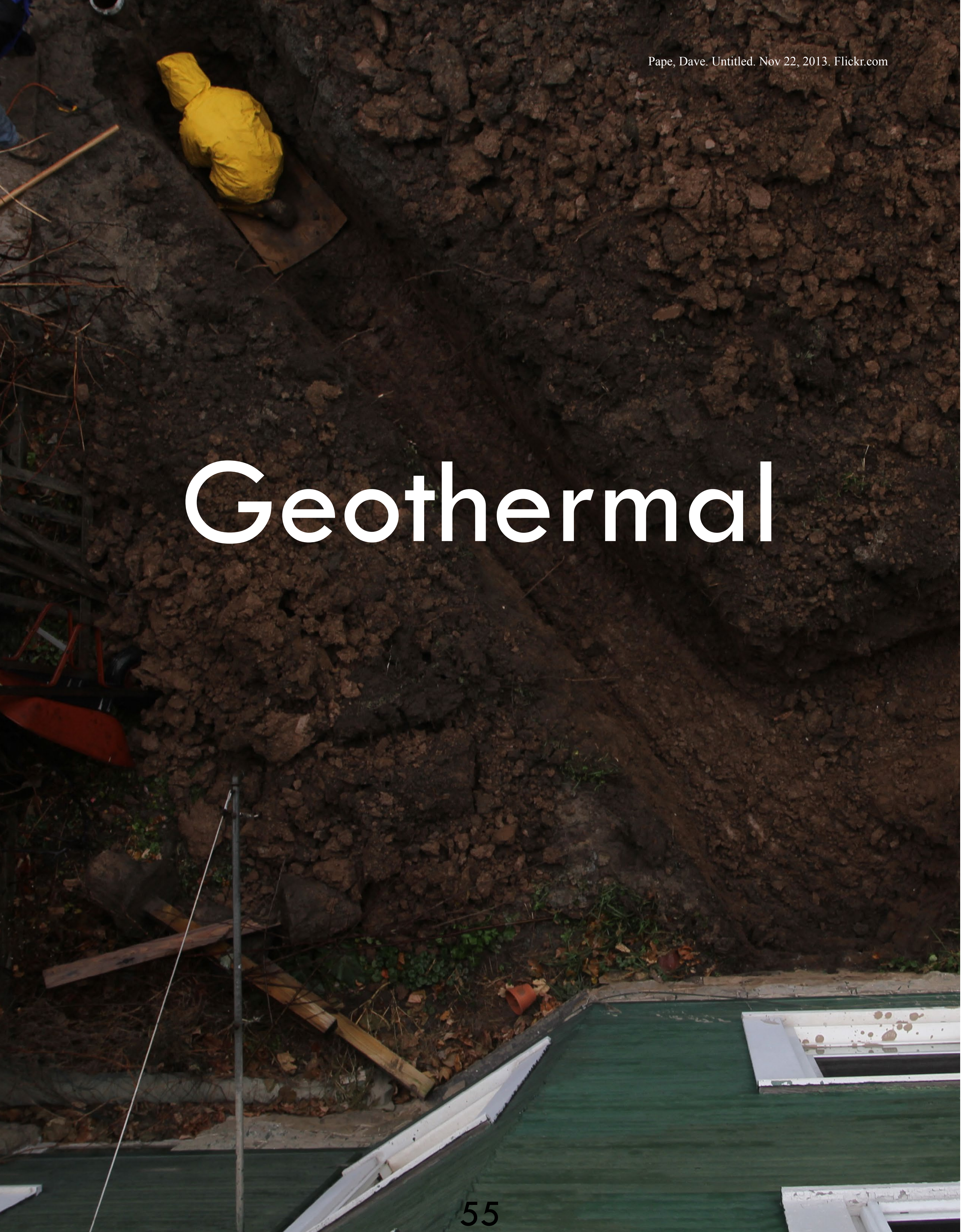
Because solar hot water systems are fueled by the sun's rays, the generation phase of the energy source lacks environmental justice implications.

95 Health and Safety Concerns of Photovoltaic Solar Panels, Oregon Government, accessed April 5, 2015, http://www.oregon.gov/odot/hwy/oipp/docs/life-cyclehealthandsafetyconcerns.pdf.

96 Health and Safety Concerns of Photovoltaic Solar Panels, Oregon Government, accessed April 5, 2015, http://www.oregon.gov/odot/hwy/oipp/docs/life-cyclehealthandsafetyconcerns.pdf.

97 The Solar Industry Created More Jobs In 2014 Than Oil and Gas Extraction, Climate Progress, accessed April 5, 2015, http://thinkprogress.org/climate/2015/01/15/3611522/solar-jobs-report-2014/.

98 Health Effects from Automobile Emissions, Washington State Department of Ecology, accessed April 1, 2015, https://fortress.wa.gov/ecy/publications/publications/0002008.pdf.


Pape, Dave. Untitled. Nov 22, 2013. Flickr.com

Geothermal

Introduction to Geothermal Heat Energy

Geothermal energy, which is the heat energy generated from the earth's core can be utilized to provide heating and cooling using a geothermal heat pump. While there are numerous geothermal technologies available, the most feasible technology for Wellesley College's campus is a ground source heat pump or GSHP. The key to GSHP is that, several feet below the frost line, the ground has a year round constant temperature of 55ºF. To heat or cool a building, antifreeze liquid is circulated through a closed-loop network of underground tubing. While the liquid moves through the tubes underground, it gradually captures the underground heat and the antifreeze fluid is brought up to a heat exchanger at the surface. There are three major components in a heat exchanger: the evaporator, the compressor, and the condenser.[99] The diagram above displays these three components.

The GSHP process can be explained by a short video called, "How a Ground Source Heat Pump Works (HD)" created by Kensa Heat Pump, a major GSHP supplier in the UK. Starting from the right side of the diagram, the antifreeze fluid first enters a container called the evaporator, which is filled with a refrigerant solution. The antifreeze fluid and the refrigerant never come in physical contact. The refrigerant captures the heat, evaporates, and then enters the compressor. The gas fed into the compressor increases the pressure, which increases the temperature. The gas is then transported to another container called the condenser. After the refrigerant gas transfers its heat to water, it condenses and becomes a liquid again. The heated water is hot enough to meet the demands of the residents. Once the refrigerant condenses, it is moved through an expansion valve that reduces its pressure and temperature, and the cycle is repeated.

The benefit of geothermal technology is that is that it can be scaled up or down depending on the heating or cooling demand. The underground tubes can expand out or down or into a body of water. The system can last up to 50 years, however the internal components need to be replaced every 20 to 25 years. Once installed, the system has low maintenance and operation costs, apart from the refrigerant liquid that needs replacement several times a year.

This system is not passive and depends on electricity to power the heat pump, which has a high environmental impact during the lifecycle of the GSHP. The lifecycle of the GSHP is comprised of the material extraction, manufacture, and operation phases.

99 How A Ground Source Heat Pump Works (HD), YouTube, last modified 2011, accessed May 3, 2015, https://www.youtube.com/watch?v=KE3SvNRmwcQ&feature=youtube_gdata_player.

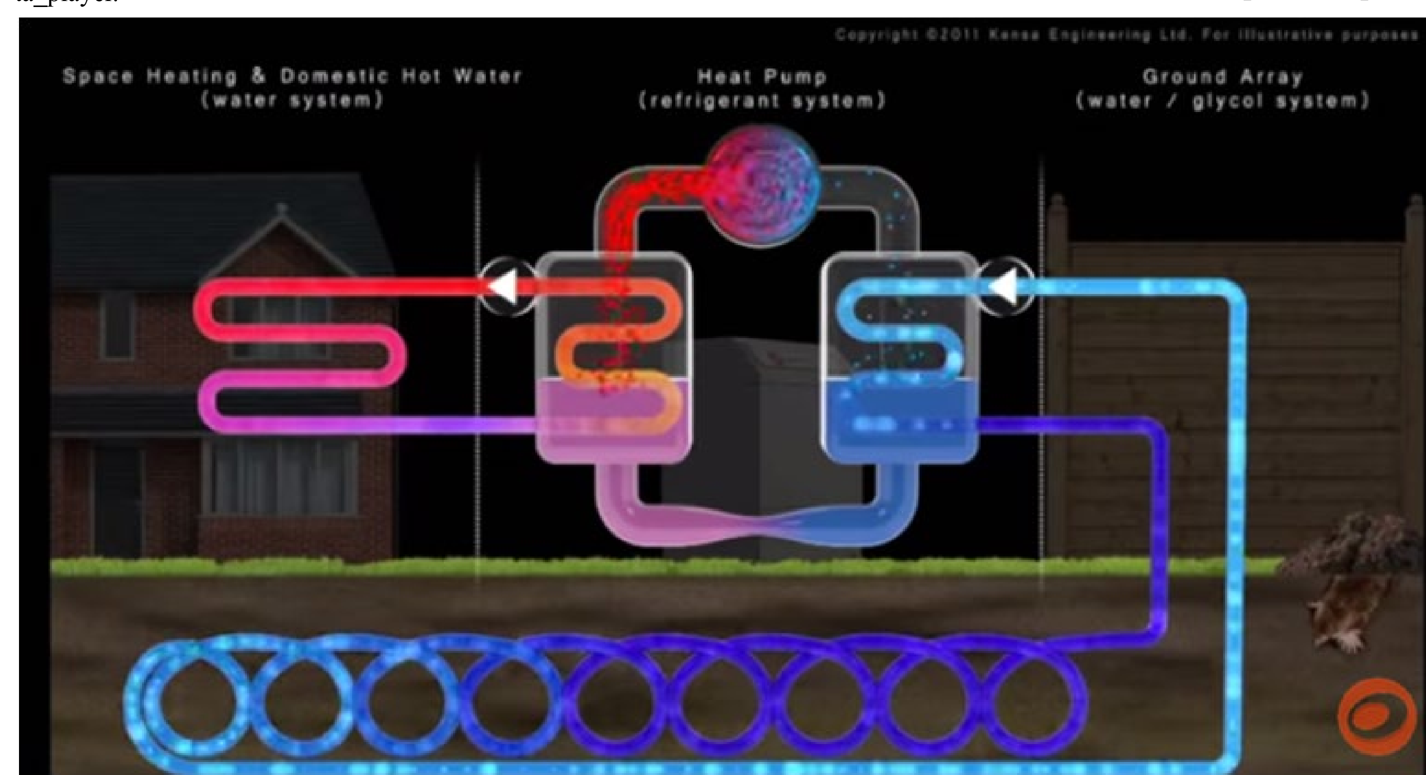


Figure 35:Geothermal ground source heat pump system. From the left to right is the evaporator, heat pump, and condenser.[1]

1 How A Ground Source Heat Pump Works (HD), YouTube, last modified 2011, accessed May 3, 2015, https://www.youtube.com/watch?v=KE3SvNRmwcQ&feature=youtube_gdata_player.

According to Saner et al.[100], the chief materials for a GSHP are steel and plastic; electricity, natural gas, and diesel for manufacturing, and electricity for operation of the geothermal system. For this study, it is assumed that the materials and energy for manufacture are similar, however, electricity to operate is solely fueled by natural gas.

Skidmore College a private liberal arts college has a student population of 2,300 and is located in Saratoga Spring, New York. Skidmore College will be the first in the Northeast to implement a district geothermal system. A district system is a system for distributing heat generated in a centralized location, either for residential or commercial use. The College began with the implementation of geothermal heating at residential apartments and then expanded to include a dining hall and music center, within the span of four years. The three buildings account for 16 percent of the total square footage of the college's campus.[101] Projects to install geothermal units for other buildings are currently underway. Skidmore set a goal by 2020 50% of the campus will be heated and cooled by geothermal energy, so far they have reached 36%. By making the commitment to geothermal heating and cooling, Skidmore is illustrating that the College wants to deepen its connection to the community and enhance their environmental responsibility as a campus community[102]. The College's commitment to sustainability has not gone without notice. In 2012 Skidmore College received a Sustainability Leadership Award from the Association for the Advancement of Sustainability in Higher Education.

Ball State is a public coeducational research University located in Muncie, Indiana, with a student population of 20,503 students. Ball State University is creating the nation's ground-source, closed-loop district geothermal energy system[103]. The system will have positive economic and environmental effects for the University and surrounding communities. The University currently relies on the operation of four coal-fired boilers. The new Geothermal System will heat and cool 47 buildings, save $2 million in annual savings, create 2,300 jobs and cut the campuses carbon footprint in half. Ball State geothermal system demonstrates that geothermal energy coupled with ground source heat pump technology can be used on a large-scale district distribution system[104]. The commitment to the geothermal technology is a good representation of the university's overall commitment to sustainability.

For geothermal heat we chose "heat, at heat pump 30kW, allocation electricity/CH S" in SimaPro 7 because it was similar to the type of system we would incrementally expect to install at Wellesley College.

To better understand the geothermal potential and the bedrock for Wellesley's campus, please visit: http://wellesley.maps.arcgis.com/home/webmap/viewer.html?useExisting=1.

Cost

Taking into account initial or capital costs, fixed operating costs, and variable operating costs, the cost of a geothermal system is $0.10/kWh.

Reliability

Table 104: Reliability assessment for geothermal

Yes (1), No (0), or N/A	*Score*
Can it be provided uninterrupted?	*1*
Can it be stored?	*0*
Is it available short-term (until 2025)?	*1*
Is procurement stable (not volatile) in the long term?	*1*
Is it independent of weather?	*1*
Can you ramp it up/down to meet fluctuating heat demand?	*1*
Total:	***5***

The Ground Source Heat Pump can be con-

100 Dominik Saner et al., "Is It Only CO2 That Matters? A Life Cycle Perspective on Shallow Geothermal Systems," *Renewable and Sustainable Energy Reviews* 14, no. 7 (September 2010): 1798–1813, doi:10.1016/j.rser.2010.04.002.

101 Skidmore honored for campus sustainability innovation, Skidmore College, accessed May 2, 2015, http://www.skidmore.edu/home/121105-sustainability.php.

102 Bob Kimmerle, Skidmore College Goes Geothermal: Skidmore College received honor for campus sustainability innovation, Skidmore College: Trends in Green Sustainable Innovations on Campus, accessed May 3, 2015, http://college-planning.epubxp.com/i/103663-jan-2013/73.

103 Going Geothermal: Nation's Largest Project of Its Kind Goes Live, Ball State University, accessed May 3, 2015, http://cms.bsu.edu/about/geothermal.

104 Going Geothermal: Nation's Largest Project of Its Kind Goes Live, Ball State University, accessed May 3, 2015, http://cms.bsu.edu/about/geothermal.

sidered a reliable energy producer. For starters, it can provide uninterrupted energy because it is dependent on the ground's thermal energy, which is constant, although it is important to note that a GSHP is dependent on the electricity to power the heat pump. For this very reason, geothermal will be readily available in both the short-term and the long-term; hence, storage is also not an issue. Another positive feature of GSHPs is that they are independent of weather since the majority of the device is stored underground. Lastly, the pump can be easily shut down if residents no longer need hot water or heat. This allows the systems to be scaled up or down to meet the demands of the users. While shallow ground source heat pumps are accessible for most locations, factors such as hydrology, geology, and soil content do need to be considered when constructing the infrastructure.

Educational Advantage

Table 105: Educational advantage assessment for geothermal

High (2), Medium (1), Low (0)	*Score*
Students can learn from this energy source and use data from it to understand energy generation.	*2*
There is visibility on campus and this energy source raises awareness about sustainability.	*0*
Ability to be a research opportunity to further the interests of students and professors.	*2*
Informs administrative decisions on scaling up energy production in new technologies (this is most relevant for new technologies).	*2*
Provides insight and encourages external organizations to replicate forms of uncommon energy production.	*2*
Total:	***8***

The geothermal heating and cooling system would have a system to collect the numbers and other data related to the buildings system. There is a National Geothermal Data System that is set in place and can offer an opportunity for students and faculty members to interact with other companies' and universities' data and compare our numbers to theirs. Since the system will always have numbers to report, and the Wellesley's data would be reported on the National Geothermal Data System, geothermal energy would be a highly educational heat energy system.

The majority of the geothermal unit would be underground and have little visibility to students and members of the community. The low visibility is also a part of the appeal of the geothermal system. You receive a reliable source of heat and cooling with a minimal eye sore.

Wellesley College is in a unique stage in its history. The first time since its opening, the College is experiencing a campus wide renovation, and thus we feel there is no better time to look at heat and electrical energy than now. A geothermal unit could be installed to run a few buildings and then could be reevaluated in order to scale up the system. With the end renovations lasting at least 10 years, a trial run for some geothermal buildings is a possibility.

Wellesley is one of the original 7 sisters, a group of women's colleges founded in the late 19th century. Other schools around the country take notice when a prestigious school from New England takes a stand in sustainable initiatives, so, if Wellesley were to implement a geothermal unit, other universities would take notice, illustrating that Wellesley has power and pull outside of the campus community.

National Geothermal Data System [105]

The college could put the data acquired from the geothermal units onto the National System website to contribute to the national database. The National Data base system contains online data regarding wells, temperature and heat flows, hot springs, water chemistry, and geochemistry, and core and cuttings. Wellesley Colleges geothermal well data can be added to the National Database to allow for a shared system allowing students to interact with the National Database. Digital geologic maps can also be added to the site. Each state has their own rules and regulations for data collection on geothermal wells and some states, including Massachusetts, are looking to place all data sets on one coherent system, thus ensuring that the data is easy to read and learn from throughout the state.

105 Geothermal Data Repository, National Geothermal Data System: YOUR PORTAL TO GEOTHERMAL DATA, accessed May 3, 2015, http://geothermaldata.org/.

Greenhouse Gas Emissions

Table 106: Greenhouse gas emissions assessment for geothermal

Impact Category	***Total***
Greenhouse Gas Emissions	*9.05E-06 kg CO2 eq*

99.99% of the impact is due to electricity provided by natural gas, and 0.08% is due to GSHP Manufacturing.

Ecotoxicity

Table 107: Ecotoxicity assessment for geothermal

Impact Category	***Total***
Ecotoxicity	*7.75E-06 CTUe*

The majority of the ecotoxicity of geothermal energy is due to the electricity consumption necessary to operate the GSHP. We initially hypothesized that mining of metals for GSHP would have the greatest impact on Ecotoxicity, especially since is it replaced twice over 20 years, however, according to the table above, using fossil fuels to operate the renewable energy source releases the most toxins into the environment.

Ecosystem Disruption

Table 108: Ecosystem disruption assessment for geothermal

Low (0), Medium (1), High (2)	*Score*
Land Disruption - permanent or temporary	*1*
Water Use	*0*
Water Contamination	*1*
Biodiversity disruption (consider both the number of species and the extent of the disruption for species)	*0*
Total:	***2***

Extraction

While the extraction of materials for production is never good for the environment, geothermal system parts only need to be replaced every 20 or 50 years. The amount of land required for a geothermal plant varies depending on the power capacity, location, building needs, and other needs of the client. Geothermal reservoirs can sometimes cause land subsidence to occur. Land subsidence occurs when large amounts of groundwater have been withdrawn from certain types of rock. Hydrothermal plants are sited on geological "hot spots" which have a higher levels of earthquake risks. Enhanced geothermal systems, or hot dry rock, can also increase small earthquakes because water is pumped at high pressures to fracture underground hot rock reservoirs. Enhanced geothermal systems mimic the processes of hydraulic fracturing.

Manufacturing, Transport, and Use

Hot water pumped from underground reservoirs often contains high levels of sulfur, salt, and other minerals. Most facilities are closed-loop water systems where the extracted water is returned directly back to the geothermal reservoir. There have been no reported cases of water contamination from geothermal sites in the United States. Water has to be re-injected into the reservoir because of water lost downstream. However the water used in the reservoir is dirty and can be non-potable water.

There are two ways to install the geothermal unit: vertically, which has less damage to the soil, and horizontally, which requires more space. However, once the installation process is complete, other land damage will only occur if something needs to be replaced in the system. Although the installation process is extensive and results in a temporary disruption of the local environment, the geothermal unit will result in minimal disruption to its surroundings overtime.

Health

Table 109: Health assessment for geothermal

Impact Category	***Total***
Respiratory effects	*4.62E-07 kg PM2.5 eq*
Carcinogenics	*3.40E-05 CTUh*
Non-carcinogenics	*4.07E-06 CTUh*

In the lifecycle of a GSHP, the operation of the GSHP has the greatest impact on health. Based on the above table, it is clear that carcinogens have the greatest impact value due to electricity generation to power the GSHP.

Environmental Justice

Table 110: Environmental justice assessment for geothermal

Low (0), Medium (1), High (2)	*Score*
Raw material extraction	*1*
Manufacturing & Production (refining of fuels, manufacturing of equipment)	*1*
Transport (all transport phases prior to reaching Wellesley)	*1*
Generation (at Wellesley or wherever the heat is generated)	*0*
Total:	***3***

Raw Material

In the area of Raw Material extraction we looked at the four most common materials used for geothermal parts: steel, bentonite, ethylene, and copper. RER 108 otherwise known as reinforcing steel results in a large amount of waste rock during extraction. Large particles circulate through the air during underground extraction. The conditions for workers during surface mining also remain poor. Bentonite, otherwise known as DE 209, has many uses, including cat litter and ground water barriers. The mining of Bentonite includes the usage of drilling mud, or liquid fluids that have to be put into the ground to reduce damage and corrosion. Since ethylene glycol is a form of plastic, the extraction stage begins with the extraction of oil. The material extraction of oil damages communities near the site by polluting the air, land and water. Ethylene glycol is manufactured to produce coolants, antifreeze, and plastic bottles. The extraction of copper requires a lot of work for few pieces of copper. There are also large quantities of discarded rock that must be taken into account.

Manufacture and Production

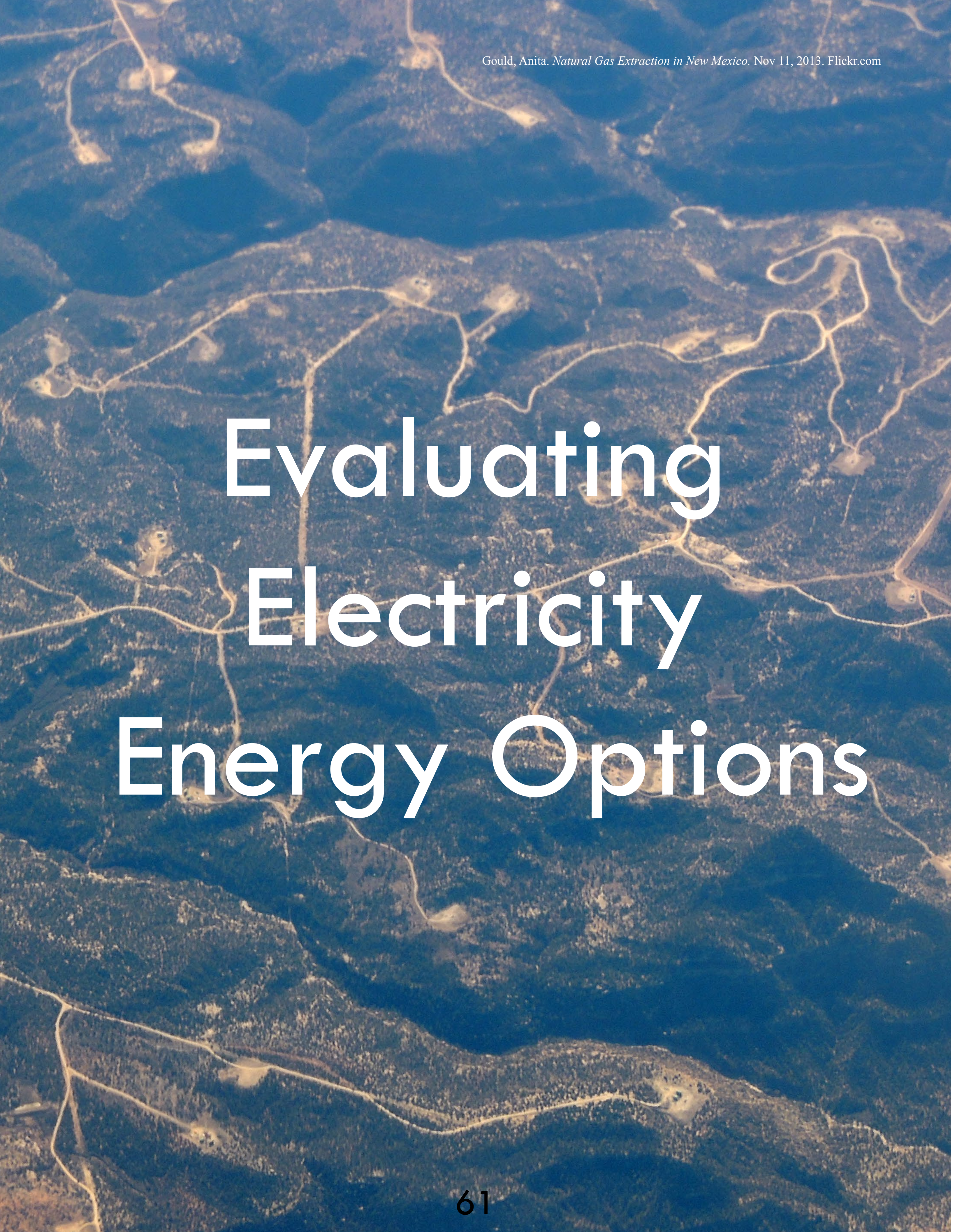
The manufacturing and production phases of geothermal energy commonly occur in small towns in America. Since geothermal technology is a renewable energy, the sector is growing steady but still requires skill for production. Plants are commonly located in small American towns or in Europe with large populations of white residents. But we cannot ignore the electricity needed to manufacture and produce the product. Electricity most commonly uses natural gas for production which negatively affects marginalized groups of color.

Transportation

A single geothermal unit for one 200 square building could fit in one or two truck loads. Since the unit will be installed once and only needs replacement parts every 20 and 50 years the impact on marginalized communities by geothermal transport is less than is the impact of conventional energy sources.

Generation at Wellesley

The geothermal unit would have the largest impact to the community at Wellesley during installation, as the area of installation would need to be dug up entirely. While the installation process is extensive, the impacts to the Wellesley community after installation are minimal. A few pipes roughly three feet above ground and two box units will be the only remnants of an energy system.


Gould, Anita. *Natural Gas Extraction in New Mexico.* Nov 11, 2013. Flickr.com

Evaluating Electricity Energy Options

Natural Gas

Introduction to Natural Gas Electrical Energy

Natural gas, commonly used for heat energy, is the fuel used by Wellesley College's current cogeneration plant. Cogeneration, or "combined heat and power," simultaneously produces two forms of energy from a single source. A cogeneration plant consists of a combustion turbine that produces electricity and a unit that recovers the steam from electricity generation to provide thermal energy. Consider how a combustion turbine functioning normally to generate electricity produces excess exhaust heat, released as steam. A cogeneration system is simply a combustion turbine with the addition of a heat recovery steam generator, a condenser, and possible additional parts to convert the excess thermal energy into heat.

To understand how to get energy from natural gas, one must consider the beginning of the natural gas lifecycle. The raw materials extraction and acquisition phase is first. This phase includes well site investigation, which is exploration through seismic testing. During exploration, some companies drill wells to evaluate whether a certain reservoir has sufficient hydrocarbons to make development economically viable. Some companies have reported that before a drill touches a particular area, a variety of processes are done to pinpoint where exactly drilling should occur. These processes help mitigate the damage caused to the surrounding vegetation, land, water, air, natural habitats, and communities.[1] The first phase also includes site preparation (drill pad construction and preparation for drilling rig), well drilling (vertical and horizontal drilling), and hydraulic fracturing (also known as fracking).

Once the materials are acquired, the manufacturing and production phase begins. In this phase, the well begins production, processed either on or off-site. Processing is done through processing plants, centrifugal compressors, acid gas removal vents, and blowdown vents. After the natural gas is processed, it is moved and stored using reciprocating and centrifugal compressors, dehydrator vents, and pneumatic devices. After the natural gas is ready to be sent out to the energy conversion facilities, it is moved using miles of pipes, called mains. These mains are usually made of iron, steel, or copper. Depending on the source of acquisition for the natural gas, natural gas can also be shipped over land or water, although not a common practice for the United States.[2]

Acquiring natural gas is only one part of the entire energy cycle. Cogeneration plants use combined cycles, which use both a gas and a steam turbine together to produce up to 50% more electricity from the same fuel than a traditional simple-cycle plant. The waste heat from the gas turbine is routed to the nearby steam turbine, which generates extra power. The heat recovery system, formally known as the Heat Recovery Steam Generator (HRSG), captures exhaust from the gas turbine, which delivers the heat to the steam turbine. Some of the heat on campus comes from this process.

For natural gas heat energy we chose "natural gas, burned in power plant/ASCC S" in SimaPro 7.

Cost

Taking into account initial or capital costs, fixed operating costs, and variable operating costs, the cost of a natural gas system is $0.09/kWh.

Reliability

Table 111: Reliability assessment for natural gas electricity option

Yes (1) or No (0) or N/A	Score
Can it be provided uninterrupted?	1
Can it be stored?	0
Is it available short-term (until 2025)?	1
Is procurement stable (not volatile) in the long term?	0
Is it independent of weather?	1
Can you ramp it up/down to meet fluctuating energy demand?	1
Total:	**4**

1 David Biello, "Fracking Can Be Done Safely, But Will it Be?" *Scientific American* 17 May 2013, accessed May 10, 2010, http://www.scientificamerican.com/article/can-fracking-be-done-without-impacting-water/.

2 GE Power, "Combined Cycle Power Plant - How It Works?" accessed April 30, 2015, https://powergen.gepower.com/plan-build/tools-resources/power-generation-basics/combined-cycle-power-plants.html.

Natural gas is a very reliable electricity source, at least in the short term. Although natural gas cannot be stored, we have direct access to pipes that transport natural gas to the power plant and we can thus have uninterrupted access to the gas, ramp it up and down, and use it in any weather. Like other fossil fuels, our confidence in natural gas availability is high in the short term, as there is an abundance of known reservoirs being tapped and left to tap. Natural gas is only renewed on a geologic time scale, so for our purposes it is nonrenewable and this means its supply is finite. As the supply becomes more scarce - whether it be more stringent regulations, fewer reservoirs in existence, or higher costs - it is possible, although not certain, that natural gas will not be as available in the future as it is today.[3] Thus, its procurement is unstable, and, as a long-term fuel source, it may not be reliable.

Educational Advantage

Table 112: Educational advantage assessment for natural gas electricity option

High (2), Medium (1), Low (0)	Score
Students can learn from this energy source and use data from it to understand energy generation.	1
There is visibility on campus and this energy source raises awareness about sustainability.	0
Ability to be a research opportunity to further the interests of students and professors.	1
Informs administrative decisions on scaling up energy production in new technologies	0
Provides insight and encourages external organizations to replicate forms of uncommon energy production.	0
Total:	**2**

The cogeneration plant already serves an educational purpose on campus. While cogeneration is not a new technology, it is worthwhile for professors to teach students about such a widely-used and efficient energy generation process. The cogeneration plant already exists and is visible on campus, centrally located with a noticeable smokestack, yet many students do not know what the building is, let alone what type of fuel it is using, and other significant details about the plant's purpose and function. Its visibility has no benefits for raising awareness about sustainability. Although novel when first constructed, today it is unlikely to inform other school administrators about how to use cogeneration technology because cogeneration is already common, and does not provoke discussion of new technologies or uncommon energy production possibilities.

3 Davenport, Coral, "New Federal Rules Are Set for Fracking," *New York Times*, accessed May 15, 2015.

Greenhouse Gas Emissions

Table 113: Greenhouse gas emissions assessment for natural gas electricity option

Impact Category	Total
Global Warming	1.57E-5 kg CO2 eq

The primary chemical component of natural gas is methane, which has a global warming potential of 25 (over 100 years time), meaning it is 25 times as potent as CO_2. Methane is released during extraction, flaring, transport, and processing, resulting in an 8 percent loss of natural gas by the time it is delivered to power plants. When natural gas is burned, 1135 lb/MWH CO_2 are released. Furthermore, methane is frequently released when natural gas is not burned completely. Losses of methane to the atmosphere during the extraction, transmission, and delivery of natural gas to end users made up 25 percent of U.S. 2011 total methane emissions and 2.2 percent of all GHGs when comparing GHGs on a 100yr time frame.[4]

In our life cycle assessment, we also consider the greenhouse gas emissions required to produce the cogeneration system in which the natural gas is burned.

Ecotoxicity

Table 114: Ecotoxicity assessment for natural gas electricity option

Impact Category	Total
Ecotoxicity	9.7E-05 CTUe

4 National Energy Technology Laboratory, U.S. Department of Energy, "Life Cycle Greenhouse Gas Inventory of Natural Gas Extraction, Delivery and Electricity Production," DOE/NETL-2011/1522, October 24, 2011.

Ecotoxicity of natural gas is highest during the extraction phase, with a variety of chemicals needed to pump the gas leaching into the environment. This occurs mainly through water contamination, a pathway that has been expanded on in the ecosystem disruption metric analysis. Additionally, studies have shown dangerous levels of toxic air pollution and smog near fracking sites, another pathway for ecotoxicity.

Ecosystem Disruption

Table 115: Ecosystem disruption assessment for natural gas electricity option

Low (0), Medium (1), High (2)	Score
Land Disruption - permanent or temporary	1
Water Use	2
Water Contamination	0
Biodiversity disruption (consider both the number of species and the extent of the disruption for species)	2
Total:	**5**

<u>Extraction</u>

Natural gas is extracted by the disruptive process of hydraulic fracturing (fracking). During fracking, chemicals are mixed with large quantities of water (or other base fluid) and sand, and injected into wells at extremely high pressure. These sand particles cause tiny fractures in geologic formations that allow natural gas to seep out and be pumped up out of the ground through wells. Fracking has also been linked to sinkholes and seismic activity near extraction sites.

Surface disturbances and habitat fragmentation are ecological impacts made to areas of natural gas extraction.[5] Drilling muds are used to drill the well, and, in order to access these muds, millions of gallons of fluids, usually loaded with toxic chemicals, are injected into the ground. This process helps facilitate fracking.[6] Moreover, most of the well pads have drilling or reserve pits that hold these drilling muds. The land on which all of these processes takes place contains these hazardous wastes, and often times has the potential to become a Superfund site.[7]

A study of fracking in Michigan found that there are potential environmental impacts from fracking, including erosion and sedimentation, increased risk of contamination of water sources from chemical spills or sediment runoff, habitat fragmentation, and the reduction of surface waters from the lowering of groundwater levels.[8] The amount of water used in fracking varies upon formation geology of the site, well construction, and the type of fracking process used. In 2011, the EPA estimated that approximately 70 to 140 billion gallons of water were used nationwide for the fracking of 35,000 wells.[9]

Wastewater leftover from the fracking process is most often stored in a large above-ground holding container, or in an artificial holding lake. The water is eventually cleaned and recycled on-site or transported away from the extraction site. Ideally, both aforementioned wastewater storage methods provide a leak-free holding site until wastewater is dealt with, but this is not always the case. The wastewater leakage during the extraction phase of natural gas thus poses a high threat of aquatic contamination, and is compounded by the risk of chemical spills and equipment runoff on site.

The recovery periods of wildlife species disturbed by natural gas extraction varies by community. Indirect impacts to vegetation could also include increased deposition of dust, the spread of invasive and noxious weeds, and the increased potential of other natural occurrences, such as wildfires. Furthermore, dust settling from land disturbance on vegetation could alter or limit any surrounding plants' ability to photosynthesize or reproduce.[10] The adverse impacts

5 Office of Indian Energy and Economic Development, "Oil and Gas Drilling/Development Impacts," *Tribal Energy and Environmental Information*, accessed May 1, 2015, http://teeic.indianaffairs.gov/er/oilgas/impact/drilldev/index.htm.

6 The Endocrine Disruption Exchange, Inc., "Chemicals in Natural Gas Operations," accessed May 1, 2015, http://endocrinedisruption.org/chemicals-in-natural-gas-operations/introduction.

7 The Endocrine Disruption Exchange, "Chemicals in Natural Gas Operations," accessed May 1, 2015, http://endocrinedisruption.org/chemicals-in-natural-gas-operations/introduction.

8 Union of Concerned Scientists, "Environmental Impacts of Natural Gas," accessed May 1, 2015, http://www.ucsusa.org/clean_energy/our-energy-choices/coal-and-other-fossil-fuels/environmental-impacts-of-natural-gas.html#.VTW4qNxBs0s.

9 Union of Concerned Scientists, "Environmental Impacts of Natural Gas," accessed May 1, 2015, http://www.ucsusa.org/clean_energy/our-energy-choices/coal-and-other-fossil-fuels/environmental-impacts-of-natural-gas.html#.VTW4qNxBs0s.

10 Office of Indian Energy and Economic Development,

from the extraction phase that could occur to the surrounding biodiversity and habitats include erosion and runoff, dust cover, introduction and spread of nonnative species, modification or the reduction of habitat, mortality of biota, exposure to contaminants from various sources, and interference with behavioral activities, among other effects.[11]

Manufacturing, Transport, and Use

The ecosystem disruptions from the manufacturing of natural gas are very similar to the extraction phase. In addition, as part of the manufacturing phase, companies occasionally use seismic effects to pull natural gas from the ground for manufacturing. These seismic occurrences may induce earthquakes.[12]

In many cases, vegetation and topsoil are removed for the development of well pads, access roads, pipelines and other ancillary facilities. These lead to the destruction of wildlife habitat, which also has secondary effects, including an increase in erosion. Surface disturbance does not only involve site preparation and well pad construction, but also requires road, pipeline and other infrastructure modifications for transport.

During the manufacturing process, some naturally occurring radioactive chemicals used for the processing and refining of gas can leak into groundwater, posing flammability concerns for the surrounding ecosystems. Most--if not all--surface water contamination risks from natural gas production are related to the land management in the on-and-off site chemical and wastewater management.[13]

Large quantities, usually between the tens of thousands of gallons for each well, of chemical additives are trucked to and stored on a well pad. If not managed properly, these chemicals could leak or spill out of faulty containers and shipments during transport.[14]

In many cases, potable and arable water resources subject to natural gas extraction and manufacturing sites are extremely vulnerable to contamination. For example, various mountain watersheds in the western United States that provide drinking and irrigation water for vast numbers are at risk for contamination from the toxic chemicals used.[15] This is one of the biggest issues of fracking: there is no accountability for what happens to the source from which the water is taken or what happens to the water once it is used.

For many natural gas processing facilities, it is a common practice to use “water trucks” to haul the produced water from sites to large, central evaporation sites. There is a large possibility that many of these chemicals will leak onto the road and contaminate surrounding ecosystems.[16]

During manufacturing processes, some companies resort to using seismic effects as a method of locating fracking zones to increase gas production. They also dispose of wastewater by injecting it into the locations where natural gas has been removed. Some of these seismic methods induce earthquakes strong enough to be felt by humans;[17] the effects on the surrounding biodiversity is unknown at this time.[18]

By increasing human and outside traffic activ-

“Oil and Gas Drilling/Development Impacts,” *Tribal Energy and Environmental Information*, accessed May 1, 2015, http://teeic.indianaffairs.gov/er/oilgas/impact/drilldev/index.htm.

11 Erik Liviat and Karent Schneller-McDonald, “Fracking and Biodiversity: Unaddressed Issues in the New York Debate,” *New from Hudsonia*, vol 24, no. 2, Fall 2011, 1-10.

12 Leighton Kille, “The Environmental Costs and Benefits of Fracking: The State of Research,” *Journalist’s Resource*, last modified October 26, 2014, accessed May 1, 2015, http://journalistsresource.org/studies/environment/climate-change/environmental-costs-benefits-fracking#.

13 Union of Concerned Scientists, “Environmental Impacts of Natural Gas, accessed May 1, 2015, http://www.ucsusa.org/clean_energy/our-energy-choices/coal-and-other-fossil-fuels/environmental-impacts-of-natural-gas.html#.VTW4qNxBs0s.

14 Union of Concerned Scientists , “Environmental Impacts of Natural Gas,” accessed May 1, 2015, http://www.ucsusa.org/clean_energy/our-energy-choices/coal-and-other-fossil-fuels/environmental-impacts-of-natural-gas.html#.VTW4qNxBs0s.

15 The Endocrine Disruption Exchange, “Chemicals in Natural Gas Operations,” accessed May 1, 2015, http://endocrinedisruption.org/chemicals-in-natural-gas-operations/introduction.

16 The Endocrine Disruption Exchange, “Chemicals in Natural Gas Operations,” accessed May 1, 2015, http://endocrinedisruption.org/chemicals-in-natural-gas-operations/introduction.

17 K. M. Keranen, M. Weingarten, G. A. Abers, B. A. Bekins, S. Ge, “Sharp Increase in Central Oklahoma Seismicity since 2008 Induced by Massive Wastewater Injection,” *Science* Vol. 345 no. 6195 (July 2014), pp. 448-451.

18 Leighton Kille, “The Environmental Costs and Benefits of Fracking: The state of Research,” *Journalist’s Resource*, last modified October 26, 2014, accessed May 1, 2015, http://journalistsresource.org/studies/environment/climate-change/environmental-costs-benefits-fracking#.

ities, the potential for invasive, noxious, or introduced species increases in these areas during the reclamation phase. In addition to the land and water contamination issues, tons of toxic volatile compounds can escape and mix with nitrogen oxides from transport vehicle exhaust and cause ground level ozone at the delivery and transport stages of natural gas production. Gas field-produced ozone creates the same extent of air pollution as those from large urban areas, and also has the potential to spread up to 200 miles from the gas production site.[19] The cumulative impacts of surface disturbances that extend over large areas result in the habitat fragmentation of both plant and animal species that can be sensitive to changes, affecting population sizes.

Natural gas-fired power plants emit sulfur dioxide and nitrogen oxides, both of which contribute to acid rain and ground-level ozone. For example, methane is a potent greenhouse gas, more than 20 times more powerful in terms of its heat-trapping ability than is carbon dioxide.[20] Moreover, because the use of natural gas still emits greenhouse gases, even if it is at lower quantities than other fossil fuels, the process still contributes to climate change. The indirect effects of climate change on biodiversity, ecosystems, water sources, etc., is another factor to take into consideration.

Health

Table 116: Health assessment for natural gas electricity option

Category	Total
Respiratory effects	1.64E-5 kg PM2.5 eq
Carcinogenics	8.25E-05 CTUh
Non-carcinogenics	6.00E-07 CTUh

Natural gas production causes a variety of health effects, primarily in communities surrounding extraction sites. The health issues associated with natural gas extraction are respiratory difficulties, skin rashes, digestive disorders, and neurological problems.[21] Many of the complaints regarding health issues include foul odors, water pollution or leaching, incessant noise, and production that occurs 24 hours a day. Furthermore, natural gas production facilities emit pollutants called hazardous air pollutants (HAPs) and volatile organic compounds (VOC), which can also harm facility employees. Depending on the chemicals emitted, natural gas production facilities can be linked to skin irritation, blisters, blood disorders, reproductive and developmental disorders, nervous system disorders, chest constriction, and respiratory diseases and disorders, among other impacts.[22] While little is known about the direct public health impacts of fracking, many of the previously mentioned impacts are very much present and visible in communities near natural gas extraction sites, with respiratory impacts being the most prevalent.

Environmental Justice

Table 117: Environmental justice assessment for natural gas electricity option

Low (0), Medium (1), High (2)	Score
Raw material extraction	2
Manufacturing & Production (refining of fuels, manufacturing of equipment)	2
Transport (all transport phases prior to reaching Wellesley)	2
Generation (at Wellesley or wherever the electricity is generated.)	0
Total:	**6**

Raw Materials Extraction and Acquisition

The use of advanced fracking methods has resulted in threats to water, air, land and the health of various communities. Studies have shown there to be dangerous levels of toxic air pollution near fracking sites due to an excess amount of smog from gas extraction with levels higher than those in Los Angeles.[23] Deep drilling technologies from fracking has led to various cases of groundwater pollution, which

19 The Endocrine Disruption Exchange, “Chemicals in Natural Gas Operations,” accessed May 1, 2015, http://endocrinedisruption.org/chemicals-in-natural-gas-operations/introduction.

20 Center for Climate and Energy Solutions, “Natural Gas,” accessed May 1, 2015, http://www.c2es.org/energy/source/natural-gas.

21 Stephen Lester, “Building Strong, Healthy, and Safe Communities,” *Center for Health Environment Justice*, November 2, 2012, accessed May 1, 2015, http://chej.org/2012/11/health-effects-associated-with-natural-gas-extraction-using-hydraulic-fracturing-or-fracking/.

22 EPA, “Improving Air Quality in Your Community,” accessed May 1, 2015, http://www.epa.gov/oaqps001/community/details/oil-gas_addl_info.html.

23 Natural Resources Defense Council, “Unchecked Fracking Threatens Health, Water Supplies,” accessed May 1, 2015, http://www.nrdc.org/energy/gasdrilling/.

threatens various water sources for many communities located near the fracking source. The groundwater contamination from drilling and improper wastewater disposal is a major concern for many. This wastewater can contain various radioactive materials, such as arsenic and benzene, which are harmful to humans and other forms of life.[24]

Other activities that may cause environmental justice issues include ground clearing, grading, drilling, waste management, vehicular and pedestrian traffic and the construction and installation of facilities.[25] There have been various arguments in favor of fracking, one of which includes the creation of new jobs for those in the affected communities. For example, in 2011, Ohio public officials spoke of the creation of more than 200,000 jobs to the state as a positive economic impact from the natural gas extraction.[26] The problem with this argument is that most of these jobs are temporary and, once wells are in production, the need for workers decreases.

Cultural impacts are difficult to calculate when addressing the ecological impacts throughout the lifecycle of natural gas. One of the ways to assess cultural impacts is to look at the destruction of cultural resources in areas undergoing surface disturbance, including the unauthorized removal of artifacts or vandalism of local spaces, which includes destruction of sacred landscapes or historic trails.[27] Other issues include noise disturbances and visual impacts, which create adverse effects on local sites. Development of a gas field could potentially negatively affect the property values of those in close proximity to the gas field.

Manufacturing and Production

During the manufacturing and production of natural gas, improper waste management can lead to solid and industrial waste generation. Solid waste can consist of containers and packaging materials, miscellaneous wastes from equipment assembly and presence of construction crews. Industrial wastes can include minor amounts of paints, coatings and spent solvents, which would most likely be transported off-site for disposal. Some drilling wastes include hydraulic fluids, used oils and oil filters, spilled fuel, drill cuttings, drums and containers, etc. Produced water, water that coexists with oil and gas formations and is recovered during well development, can be an issue over the long-term operation of a gas field.[28] Although there are existing regulations for the disposal of produced water, water is usually disposed of by underground injection in disposal wells. In some locations, the produced water can carry naturally occurring radioactive materials (NORM) to the surface. The chemicals that are leaked can then be hazardous to both occupational and public environments.

Transportation

The development of a gas site would result in the need to construct or improve access roads or mains. This construction could lead to an increase in industrial traffic in sites not usually accustomed to high traffic loads. Overweight or oversized loads could cause temporary disruptions and could require extensive modifications of various roads links and bridges. In many situations, natural gas produced from a particular well site has to travel a great distance to reach its point of use and the transportation system consists of a complex network of pipelines designed for quick and efficient transport.[29] Transportation problems include dangers with the pipeline system such as leakages, pipe bursts, and land displacement for the creation of pipeline systems. When constructing a pipeline, everything in the path is cleared and displaced, including communities of people. There have been various methods put in place, like Leak detections, pipeline markers, and gas sampling have been used to prevent or mitigate these environmental justice problems,[30] though they are unlikely to fully succeed.

24 Energy Justice Network, "Natural Gas Health and Environmental Hazards," accessed May 1, 2015, http://www.energyjustice.net/naturalgas.

25 Oil and Gas Drilling/Development Impacts, Trial Energy and Environmental Information, accessed May 1, 2015, http://teeic.indianaffairs.gov/er/oilgas/impact/drilldev/index.htm.

26 Environmental Justice, Hydraulic Fracturing and Appalachia, Triple Pundit People Planet Profit, last modified August 12, 2013, accessed May 1, 2015, http://www.triplepundit.com/special/environmental-justice-hydraulic-fracturing-appalachia/.

27 Office of Indian Energy and Economic Development, "Oil and Gas Drilling/Development Impacts," *Tribal Energy and Environmental Information*, accessed May 1, 2015, http://teeic.indianaffairs.gov/er/oilgas/impact/drilldev/index.htm.

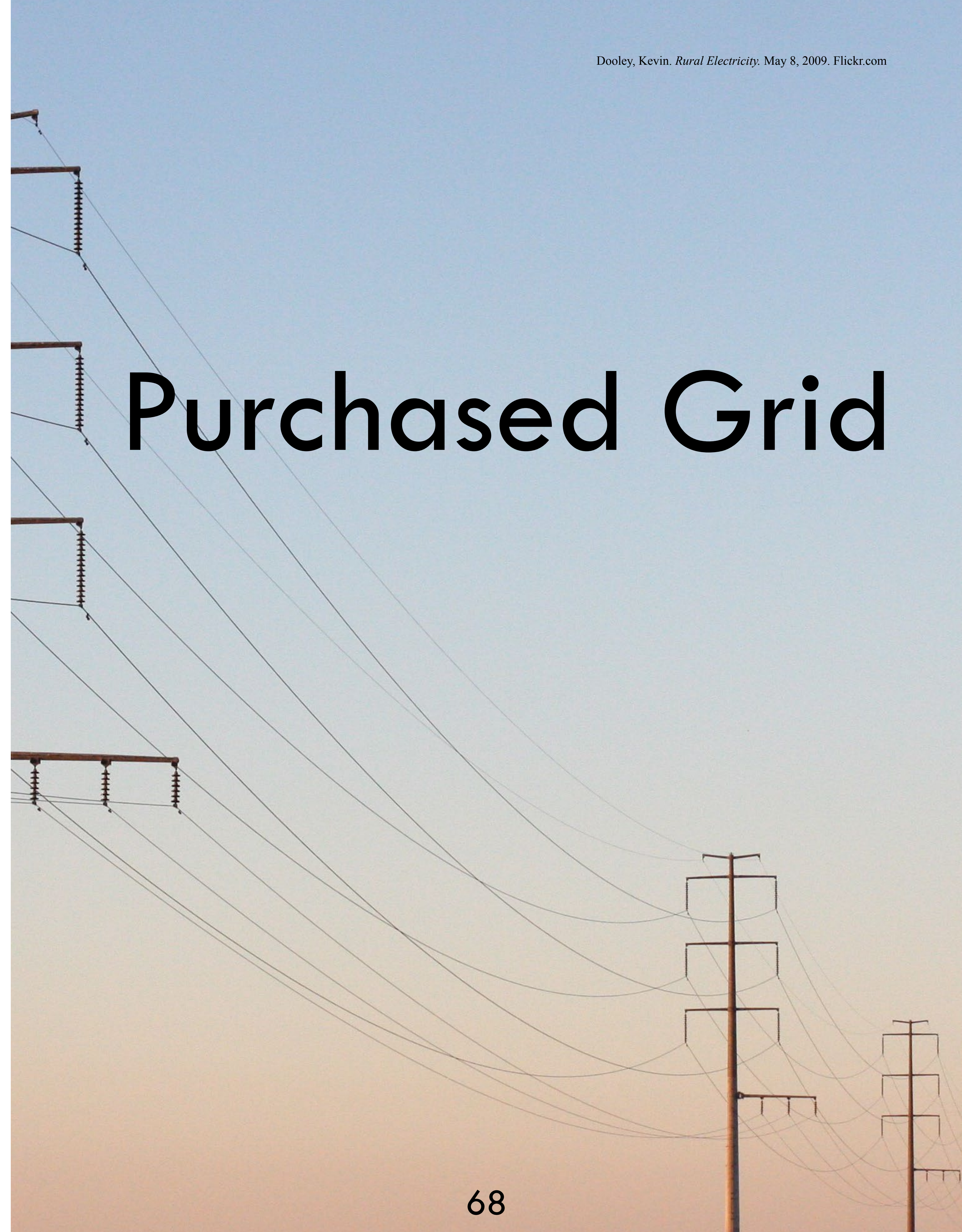
28 Office of Indian Energy and Economic Development, "Oil and Gas Drilling/Development Impacts," *Tribal Energy and Environmental Information*, accessed May 1, 2015, http://teeic.indianaffairs.gov/er/oilgas/impact/drilldev/index.htm.

29 "The Transportation of Natural Gas," last modified September 23, 2013, accessed May 1, 2015, http://naturalgas.org/naturalgas/transport/.

30 "The Transportation of Natural Gas," last modified September 23, 2013, accessed May 1, 2015, http://naturalgas.org/naturalgas/transport/.

Dooley, Kevin. *Rural Electricity.* May 8, 2009. Flickr.com

Purchased Grid



Introduction on Purchased Grid

The power grid is one of the most extensive networks in the United States. The town of Wellesley is part of the Eastern power grid which connects every state east of the Rocky Mountains.[31] Throughout the East, power plants produce electricity and add it to the grid. The grid transports electricity to storage facilities and end users for consumption.

Even though Wellesley College has its own power plant running 24/7, the College purchases energy from the town grid daily. The Wellesley Municipal Light Plant serves customers ranging from residential, commercial, to industrial. There are two primary reasons why we purchase electricity from the grid: the first is that, during off-peak hours, town electricity is cheaper than the electricity that Wellesley College generates itself. Secondly, the College is part of the town and, in purchasing town electricity, it is contributing to the town's local economy. For the Fiscal Year 2014 (July 2013-June 2014), Wellesley College bought 6,825,068kWh of imported energy from the local power company, Wellesley Municipal Light Plant (WMLP).[32] In 2013, Wellesley College obtained 29% of its consumed electricity from the grid through WMLP.[33] Wellesley Municipal Light Plant exports electricity to the grid from its local power plant, but is also the "middle man" for all electricity purchased from the grid within the town of Wellesley. Electricity in the grid can come from any form of energy generation. The electricity in the our local grid has the following source breakdown:[34]

- Natural Gas: 51.94%
- Nuclear: 29.15%
- Hydro: 6.77%
- Wind: 5.64%
- Coal: 5.37%
- Landfill: 1.13%
- Oil: 0%[35]

Since there are many sources of energy in the grid, we analyze each source individually and then weigh the averages based on their prevalence in the grid. We analyze electricity sourced from coal, nuclear energy, landfill gas, and hydropower here. Analysis of natural gas and wind can be found on pages 62 and 84 respectively. The ratings of natural gas and wind determined in their sections are included in our final weighted calculations for each metric.

SimaPro 7

We chose electricity generated from natural gas, bituminous coal, nuclear, biomass, wind, and hydro energy as our input processes to reflect the proportional amount of each type of electricity that is in the Wellesley Town electricity grid.

<u>*Natural Gas:*</u>

- For natural gas we chose to use "electricity, natural gas, at power plant/US" because it is the life cycle measurement for electricity produced by natural gas in the United States. It makes up 51.94% of the grid electricity so we weighed it as 0.5194 of our total kWh inputs.

<u>*Coal:*</u>

- For coal our input was "electricity, bituminous coal, at power plant/US" because it is the most common type of coal used in the U.S.[36] It makes up 5.37% of the grid electricity so we weighed it as 0.0537 of our total kWh inputs.

<u>*Nuclear:*</u>

- For nuclear energy, we used "electricity, nuclear, at power plant/US" because it is the option specific for the United States. It makes up 29.15% of the grid electricity so we weighed it as 0.2915 of our total kWh inputs.

31 Eastern Interconnection, Wikipedia, accessed on 4/5/2015, http://en.wikipedia.org/wiki/Eastern_Interconnection

32 We obtained this data from conversations with the WMLP.

33 Energy, *Wellesley College Sustainability,* accessed on 4/5/2015, http://www.wellesley.edu/sustainability/energy

34 We obtained this data from conversations with the WMLP.

35 This percentage was rounded down from 0.0068%.

36 Bituminous Coal, *About,* accessed on 4/4/2015, http://energy.about.com/od/Coal/a/Bituminous-Coal.htm.

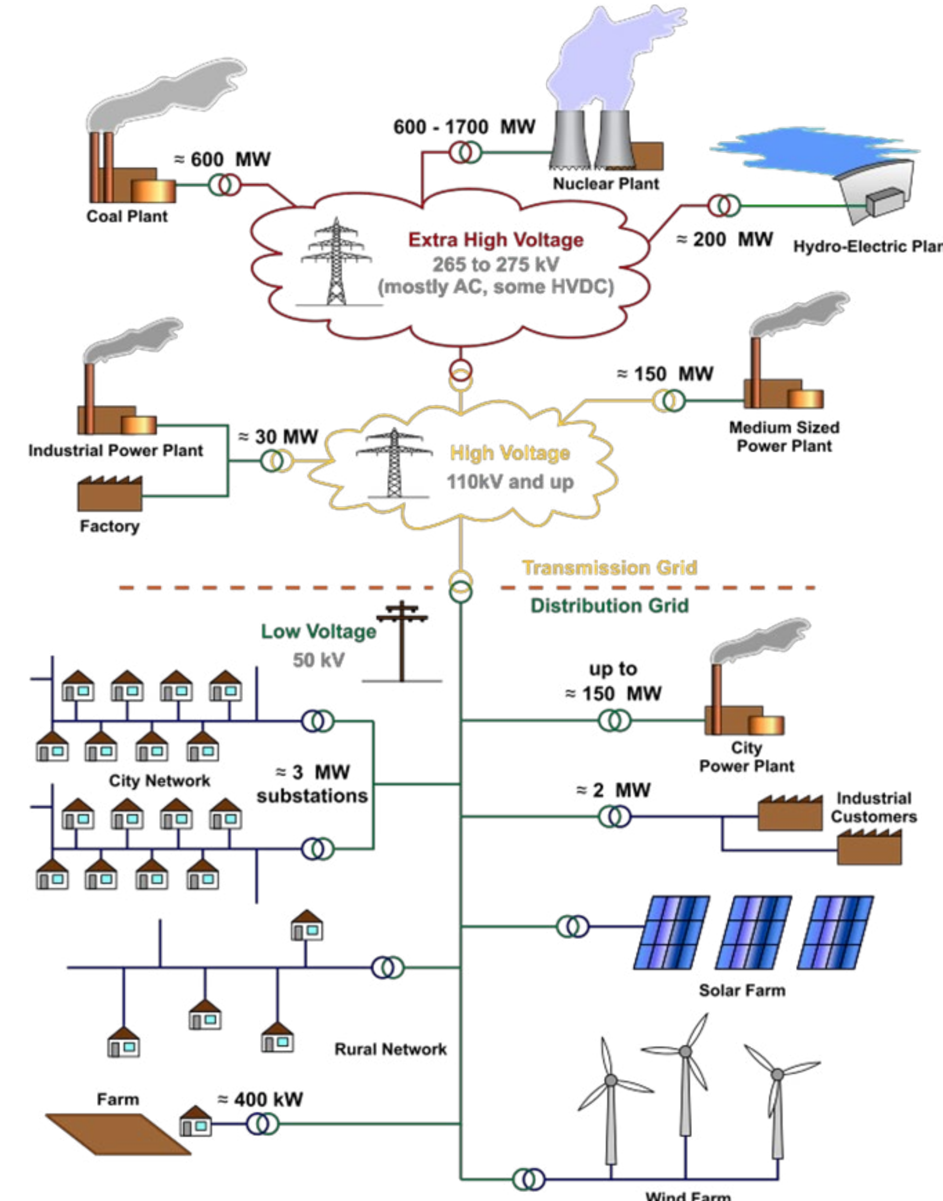


Figure 36: Purchased electricity grid diagram[1]

1 MBizon, Wikimedia Commons, accessed April 12th, 2015, http://commons.wikimedia.org/wiki/File:Electricity_Grid_Schematic_English.svg.

Landfill Gas:

- For landfill gas, which is 1.13% of the electricity in our grid we used biogas as a proxy because life cycle data for landfill gas was not available within the SimaPro 7 database. We chose "electricity, at cogen with biogas engine, allocation exergy/GB" biogas option because it was the non-agricultural usage of biogas energy in a region, Great Britain, that we deemed most energy-similar to the United States.[37] It makes up 1.13% of the grid electricity so we weighed it as 0.113 of our total kWh inputs.

Wind Energy:

- For wind energy we chose "electricity, high voltage, {GB}|electricity production, wind, 1-3 MW turbine, onshore | Alloc Def, U" because it is similar to the energy the Wellesley Municipal Light Plant supports.[38] Our wind en-

37 The other regional options were Switzerland, Brazil, and China.

38 "Wellesley Renewable Energy FAQs," *Wellesley*

ergy is created on 2mW turbines in a similar environment and climate to the UK.[39] It makes up 5.64% of the grid electricity so we weighed it as 0.0564 of our total kWh inputs.

Hydropower:

- For hydro, we chose "electricity, hydropower, at power plant/GB U" because Great Britain hydropower model is similar to that used in New England.[40] It makes up 6.77% of the grid electricity so we weighed it as 0.0677 of our total kWh inputs.

Cost

Taking into account initial or capital costs, fixed operating costs, and variable operating costs, the cost of purchased grid energy is $0.05/kWh.

Reliability

Table 118: Reliability assessment for purchased grid

Yes (1), No (0), or N/A	Score
Can it be provided uninterrupted?	1
Can it be stored?	1
Is it available short-term (until 2025)?	1
Is procurement stable (not volatile) in the long term?	1
Is it independent of weather?	0
Can you ramp it up/down to meet fluctuating energy demand?	1
Total:	**5**

Electricity from the grid is always available. It can be controlled and increased and decreased at will to meet the demands of Wellesley College during peak electricity-consumption hours. That being said, it cannot be stored, but that is an unnecessary quality as it can always be accessed. In the short run, Wellesley College could run solely on electricity provided by the Town of Wellesley because the Town has the capacity to supply us with sufficient amounts of energy. They could transfer more grid energy to the College, or ramp up their power plant's electricity production. In the long run, there is a possibility that the Wellesley Municipal Light Plant (WMLP) could go out of business, but regardless of WMLP's future, Wellesley College could still purchase electricity from the grid through a different power company. A downside of town energy is that it is more unstable than electricity produced on campus. WMPL electricity is more prone to power interruptions which presents a greater likelihood of power outages. In the past, Wellesley College has purchased 100% of their electricity from the town. Because the provided power was unreliable, especially during extreme weather conditions, Wellesley decided to transition to generating our own electricity.

Town, accessed on 4/4/2015, http://www.wellesleyma.gov/pages/wellesleyma_sustenergy/WellesleyRenewableEnergy-FAQs-2-29-2012.pdf.

39 About the Spruce Mountain Wind Project, *Patriot Renewables,* accessed 4/4/2015, http://patriotrenewables.com/SpruceMountainWind.html.

40 Flynn, Kerry, Renewing Industry with Ancient Tech: A Return to Hydropower, *Forbes.com,* last modified June, 25 2014, accessed on 4/4/2015.

Educational Advantage

Table 119: Educational advantage assessment for purchased grid

High (2), Medium (1), Low (0)	Score
Students can learn from this energy source and use data from it to understand energy generation.	1
There is visibility on campus and this energy source raises awareness about sustainability.	0
Ability to be a research opportunity to further the interests of students and professors.	0
Informs administrative decisions on scaling up energy production in new technologies (this is most relevant for new technologies).	0
Provides insight and encourages external organizations to replicate forms of uncommon energy production.	0
Total:	**1**

Purchasing grid energy is not likely to enhance community learning significantly, as derived from the table above. People can learn about the energy source because it is a very common implementation. The town keeps thorough reports of electricity consumption and is a good reference. Also, as the town is close to the College, the Wellesley College community can easily interact with the town to understand and clarify thoughts on energy generation.

The grid is not a visible nor a tangible product/service, which is why it receives a low visibility rating. Since the grid is not a power generation with a physical structure, this affects students' opportunity to be proactively curious and attempt to research more about something they might have fortuitously come across in their path.

There is a lot of data generated from the grid. It is available for any inquisitive students or professors to use regardless of Wellesley College purchasing grid energy. We do not think that Wellesley College using more grid energy would provide additional opportunity for research.

Using different electricity procurement provides the College administration with new information. The administration can learn about student and alumni reactions, greenhouse gas emissions, costs, and other important metrics that could have only been estimated before implementation provided real data. Since grid data is being used, using grid electricity does not provide the college with any additional insight.

Grid energy is the most common form of obtaining energy. This does not provide any new information for outside decision makers to consider new electricity procurement methods.

Greenhouse Gas Emissions

Table 120: Greenhouse gas emissions for purchased grid

Impact Category	Total
Global Warming	1.81E-05 CTUe

Grid electricity has the potential to release 1.81e-5 lbs of CO_2 per kWh of electricity. Most of the greenhouse gas emissions can be traced to electricity coming from natural gas. The global warming implications of natural gas can be found on page 63 of the global warming analysis of natural gas. Other CO2 emissions come from burning coal, which is what produces 5% of grid electricity. Coal combustion is the leading contributor to climate change and carbon dioxide emissions, which disrupts ecosystems locally and globally.[41]

Ecotoxicity

Table 121: Ecotoxicity assessment for purchased grid

Impact Category	Total
Ecotoxicity	6.54E-05 CTUe

The ecotoxicity of using grid energy is 6.53828e-5 CTUe. The ecotoxicity analysis of natural gas can be found on page 63. Other energy sources such as coal, release many heavy metals such as lead, mercury, nickel, tin, cadmium, antimony, and arsenic lead during burning and can lead to acute or chronic toxicity (poisoning). Other compounds released during combustion, such as sulfur dioxide, contribute to acid rain. The waste from combustion contains toxic metals that leech into the local environment. Landfill gas capture can leach toxic waste into soil and water, affecting human health and aquatic life.

41 Environmental Impacts of Coal, SourceWatch, accessed April 11, 2015, http://www.sourcewatch.org/index.php/Environmental_impacts_of_coal.

Kaufmann, Bert. *Open coal min Garzweiler II.* Feb 8, 2009. Flickr.com

Ecosystem Disruption

Table 122: Breakdown of ecosystem disruption assessment for purchased grid

Purchased	% of Grid	Land Disruption	Water Use	Water Contamination	Biodiversity Loss	Sum	Ind. Weighted sum	Total Weighted Sum
Natural gas	0.5194	2	2	2	1	7	3.6358	**7.08565**
Coal	0.0537	2	2	2	2	8	0.4296	
Nuclear	0.2915	2	2	2	2	8	2.332	
Landfill	0.0113	2	0	1	1	4	0.0452	
Hydro	0.0677	1	1	0.5	2	4.5	0.30465	
Wind	0.0564	2	2	1	1	6	0.3384	
Weighted sum		1.9323	1.9097	1.83075	1.4129			

Table 123: Ecosystem disruption assessment for purchased grid

Low (0), Medium (1), High (2)	Score
Land Disruption - permanent or temporary	1.9323
Water Use	1.9097
Water Contamination	1.83075
Biodiversity disruption (consider both the number of species and the extent of the disruption for species)	1.4129
Total:	**6.8**

Energy Sources

Nuclear

Nuclear reactors generating electricity in the United States fall into two main categories: boiling water reactors (BWRs) and pressurized water reactors (PWRs). Both systems boil water to make steam, which is then cooled and run through a turbine to produce electricity.[42] Perhaps the impact that is easiest to notice is the effect on the environment, particularly in terms of flora and fauna. Setting up of a nuclear plant requires a large area, preferably situated near a natural water body which means land clearing is necessary. Land clearing encompasses removing vegetative cover as well as deforestation, which disturbs and upsets the balance of ecological habitats. In order to keep the system cool, the nuclear plant requires water. However, when nuclear plants draw water from natural water sources, fish and other wildlife get caught in the cooling system water intake structures and are often killed.[43]

In addition, heat from the plants are often rejected into nearby bodies of water and disturb aquaculture.[44] Studies have shown that the there have been significant drops in the populations of several species of fish in certain regions of US.[45] Another significant effect is the increased levels chance of acid rain created from the high releases of sulfur dioxide. Acid rain is particularly damaging to surface water bodies (lakes, streams), affects land productivity (forest soil), infrastructure (decays building materials and paints), and the particulate matter takes a toll on human health.[46]

Hydropower

Hydropower is praised for having little air quality impacts, water pollution, and solid waste generation, however there are various environmental impacts, especially with the construction and operation of hydropower dams. During the construction phase, large portions of land are altered to construct the hydropower plant, flooding wildlife habitat or farmlands. Dams also result in sedimentation and erosion. Sedimentation occurs because the dam's physical barrier traps organic and inorganic materials, which leads to habitat decline at the bottom of the waterway and causes the supply of oxygen in the reservoir to be depleted.[47] Erosion occurs because the dams have changing water levels and the vegetation along the banks are removed.[48]

Dams affect the flow of natural waterways; for instance, some dams release withheld water all at once, which disrupts plant and wildlife habitat downstream.[49] Furthermore, water at the bottom of the dam is colder and oxygen-poor compared to the water at the top, making it inhospitable to fish.[50] When this colder water is discharged into the waterway, it can kill fish living downstream that are accustomed to oxygen-rich water.[51] Salmon is a well-known example of a species that has declined due to the construction of nearby dams.[52]

42 "Energy and Water Use", *UCSUSA*, accessed on 4/4/2015, http://www.ucsusa.org/clean_energy/our-energy-choices/energy-and-water-use/water-energy-electricity-nuclear.html#.VSJ8oWRoTqs.

43 "Licensed to Kill," *NIRS,* accessed on 4/4/2015. http://www.nirs.org/reactorwatch/licensedtokill/LiscencedtoKill.pdf.

44 "Impact of Nuclear Power Plants," *Stanford University,* accessed 4/4/2015, http://large.stanford.edu/courses/2011/ph241/jaffer2/.

45 Fukushima: The Ticking Nuclear Bomb, Over 800 Tons of Radioactive Material Pouring into Pacific Ocean, *Global Research,* accessed on 4/4/2015, http://www.globalresearch.ca/fukushima-the-ticking-nuclear-bomb-over-800-tons-of-radioactive-material-pouring-into-pacific-ocean/5356276.

46 "Effects of Acid Rain," *EPA,* accessed 4/4/2015, http://www.epa.gov/acidrain/effects/index.html.

47 "Environmental Racism and Environmental Justice," The Manitoban, last modified March 27, 2010, accessed April 11, 2015.

48 "Environmental Racism and Environmental Justice," The Manitoban, last modified March 27, 2010, accessed April 11, 2015.

49 "Hydroelectricity," EPA, accessed April 11, 2015, http://www.epa.gov/cleanenergy/energy-and-you/affect/hydro.html.

50 "Hydroelectricity," EPA, accessed April 11, 2015, http://www.epa.gov/cleanenergy/energy-and-you/affect/hydro.html.

51 "Hydroelectricity," EPA, accessed April 11, 2015, http://www.epa.gov/cleanenergy/energy-and-you/affect/hydro.html.

52 "How a Hydroelectric Project Can Affect a River," accessed April 11, 2015, http://fwee.org/environment/how-a-

Lastly, many emission calculations for hydropower dams ignore turbine pressure that produces greenhouse gas emissions and tree decay from the above-water surrounding trees by the reservoir, and have incomplete assessments for downstream emissions.[53] Calculations also underestimate methane concentrations or use outdated global warming potentials for methane.[54]

Coal

There are immeasurable effects from coal. According to "Environmental impacts of coal" by Sourcewatch, coal combustion is the leading contributor to climate change and carbon dioxide emissions, which has disrupts ecosystems locally and globally.[55] In the beginning lifecycle of coal, coal mines permanently disturb the land by exploding entire mountaintops to obtain ores. This destroys the landscape, habitat, alters water supplies, and pollutes the air. The acid mine drainage from the outflow of acidic water from the coal mines washes into nearby streams and waterways, affecting photosynthesis and smothering animal life. Furthermore, the thermal pollution from coal plants impacts organisms by decreasing oxygen supply in the waterway. Coal sludge is liquid from washing coal, which leaches into underground and surface water. The heavy metals released when burning coal, such as lead, mercury, nickel, tin, cadmium, antimony, and arsenic lead to acute or chronic toxicity (poisoning). Other compounds released during combustion, such as sulfur dioxide, contributes to acid rain. The waste from combustion contains toxic metals that leech into the local environment. There are many more impacts from coal production, and as you can see, the energy source negatively impacts the environment.

Landfill

hydroelectric-project-can-affect-a-river/how-a-hydro-project-affects-a-river-print/.

53 Fearnside, Philip M, "Emissions from Tropical Hydropower and the IPCC," accessed April 11, 2015, http://philip.inpa.gov.br/publ_livres/Preprints/2015/Hydro_emissions_and_the_IPCC-Preprint.pdf.

54 Fearnside, Philip M, "Emissions from Tropical Hydropower and the IPCC," accessed April 11, 2015, http://philip.inpa.gov.br/publ_livres/Preprints/2015/Hydro_emissions_and_the_IPCC-Preprint.pdf.

55 "Environmental Impacts of Coal," SourceWatch, accessed April 11, 2015, http://www.sourcewatch.org/index.php/Environmental_impacts_of_coal.

We rate landfill with a 'medium' or '1' for its land disruption, water contamination, and biological disruption effects because during the initial stage of creating landfill gas there are lots of ecological effects. We rate it 'low' or '0' for water usage because it doesn't directly require water. The worst ecosystem effects associated with landfill gas occur at the landfill site.[56] Land changes are the most obvious ecosystem disruption effect of landfills. The land has to be cleared to make space for new buildings and large open spaces that will be filled with garbage. Land that might have been filled with a grassland ecosystem is replaced with a landfill ecosystem of scavengers like rats and seagulls.

The most studied ecosystem disruptions associated with landfill are the water and soil contamination. Landfills are lined with clay or plastic to prevent the garbage from leaking out of the landfill, but the liners often leak. The leakage, called leachate, is water that has percolated through the garbage in the landfill and then seeps through the liner into the surrounding land. While moving through the garbage, it picks up toxins from organic matter, plastics, metals, drugs, and more.[57] When leachate escapes it not only contaminates the soil ecosystems, it can also travel to the groundwater and affect aquatic life.

Landfill gas is not harmful to the ecosystem during its manufacturing, transportation, and usage phases. It is usually manufactured at the landfill site, from where it then enters the grid before being transported to its end use sites.

Health

Table 124: Health assessment for purchased grid

Impact Category	Total
Respiratory effects	9.01E-06 kg PM2.5 eq
Carcinogens	4.26E-05 CTUh
Non-carcinogenics	2.21E-05 CTUh

56 Tim Raud, "Impacts of Landfills on the Ecosystem," *eHow,* accessed 4/4/2015, http://www.ehow.com/info_8411740_impacts-landfills-ecosystem.html.

57 Peter Kjeldsen, Morton A. Barlaz, Alix P. Rooker, Anders Baun, Anna Ledin and Thomas H. Christensen, "Present and Long-Term Composition of MSW Landfill Leachate: A Review," *Critical Reviews in Environmental Science and Technology 32(4)*, 2002: pp. 297-336.

Health is divided into carcinogenic, non-carcinogenic, and respiratory health effects. We calculated the total life cycle health effects per kWh of electricity produced as 4.26e-5, 2.21e-5 CTUh for carcinogens and non-carcinogens respectively, and 9.01e-6 PM2.5 eq of respiratory effects. Natural gas makes up the biggest portion of purchased grid electricity. Many of the human health effects are found on page 66 of the Natural Gas human health analysis. Nuclear energy also makes up a big portion and has many cancer causing and respiratory effects that are detailed in the nuclear portion of the purchased grid analysis under environmental justice on page 76. Likewise, the human health impacts of coal can be found on page 77, hydro on page 77, wind on page 88, and landfill gas capture on page 78.

Environmental Justice

Table 125: Environmental justice assessment for purchased grid

Low (0), Medium (1), High (2)	Score
Raw material extraction	1.8759
Manufacturing & Production (refining of fuels, manufacturing of equipment)	1.6755
Transport (all transport phases prior to reaching Wellesley)	1.704375
Generation (at Wellesley or wherever the electricity is generated.)	0.7186
Total:	**5.974375**

To determine the environmental justice ramifications of using grid electricity, we need to identify all of the electricity sources that contribute to the grid. These include natural gas, wind, coal, nuclear, landfill gas, and hydro energy. We will analyze and score the environmental justice effects at the relevant life cycle stages of each energy source. Then we will weigh the environmental justice effects from each energy source based on each source's proportion in the grid to get a final environmental justice rating. Extensive discussions of the environmental justice effects of creating electricity with natural gas and wind power can be found on pages 66 and 89 respectively. Here we will explore the environmental justice effects of nuclear energy, hydropower, coal energy, and landfill gas.

Nuclear

Raw material extraction

The process of extracting plutonium requires using irradiated reactor fuel rods, one of the most radioactive materials on earth, both of which result in massive amounts of radioactive gases and other substances being released into the air[58]. The stored radioactive waste also poses issues of leakage. Leakage then leads to runoff and water contamination, which creates the need for cleanup remediation. Workers and locals are exposed to these hazardous radioactive releases via liquids, gaseous, and particulates. Public health studies depict that miners and residents of mining regions are largely historically American Indian tribes, such as the Navajos, and other minority groups in the United States.[59] In addition, uranium mining threatens to contaminate the Navajo communities' source of drinking water, affecting 10,000 to 15,000 people living in the Eastern Navajo Agency in northwestern New Mexico.

Nuclear energy requires enriched uranium. In terms of both short and long-term environmental impact, uranium mining is by far the most environmentally problematic of any mining activity because radioactivity of the ore cannot be chemically mitigated. Even after the mining activities ceased on the Navajo Nation, environmental harm continued from events like that of 1979 in Church Rock, NM. There, one of the largest accidental releases of radioactive material in U.S. history on American soil occurred. A tailing dam burst, sending eleven hundred tons of radioactive mill wastes and ninety million gallons of contaminated liquid pouring toward Arizona into the Rio Puerco River.[60] To this day, the Navajo cannot use this water. The process of enriching uranium also targets marginalized people. In 1990, the Louisiana Energy Services company tried to build a uranium enrichment plant in a location in which the community within a 1-mile radius of the plant was 97% African American.[61]

58 "Nuclear Power Plant Fuel--a source of Plutonium for Weapons?" *Nuclear Information and Resource Service,* accessed 4/5/2015, http://www.nirs.org/factsheets/plutbomb.htm.

59 Why Should We Be Concerned With Environmental Ethics in Nuclear Energy?, Nuclear Energy, accessed May 15, 2015, https://sites.google.com/a/ncsu.edu/nuclear-energy/ethics.

60 "Uranium Milling and the Church Rock Disaster, *Ratical,* accessed on April 11, 2015, http://www.ratical.com/radiation/KillingOurOwn/KOO9.html.

61 "Louisiana Energy Services: Uranium and Environmental Racism," *EJnet.org,* accessed on April 12, 2015, http://www.ejnet.org/ej/les.html.

Manufacturing/Production

Living near a nuclear power plant has been shown to raise the chance of infant mortality, cancer, and leukemia because of the exposure to radiation.[62] A study done by Alldred and Shrader-Frechette analyzes the locations of nuclear power plant sites and predominance of households living below the poverty line found in the area. They found that there is a 0.1% chance that the sites were all located in areas that had such a large proportion of low-income households.[63]

Transport

Nuclear generation of electricity poses several concerns for environmental justice because it creates nuclear waste. Exposure to nuclear waste, or radiation, can cause acute health effects like burns, hair loss, nausea, or diminished organ function and long-term effects like increasing risk of cancer.[64] According to national regulations, nuclear waste has to be stored in steel and concrete lined containers until it can be safely deposited in nuclear waste site.[65] This poses an environmental justice problem because the temporary waste containers are usually stored in places with cheap land and little political opposition–areas that are usually inhabited by impoverished or minority communities.[66] Thus far, the U.S. does not have such a site, but has begun the construction of such a site in Yucca Mountain in Nevada.[67] The probability of this site being completed and utilized is unknown as it has encountered many delays. The land has historical significance to the Southern Paiute, Western Shoshone, and Owens Valley Pauite and Shoshone people who historically inhabited the area.[68] It is even considered sacred by the Western Shoshone.[69] The mountain was

Hydropower

The greatest impact for dams is the displacement of communities living by the waterways either on-site or downstream. The construction of dams may flood agricultural lands, natural landscape, or even homes. Once the dam is in use, the negative environmental impacts on the local habitat and aquatic species may have harmful repercussions for the livelihood of communities downstream.[70] For example, according to the "Menominee River Fish Passage Environmental Assessment" report by N.E.W. Hydro Inc., Menominee River dams have hindered the migration and spawning of the lake sturgeon, a threatened species in Michigan. The dam has also hindered the growth of other fish species, making fishing communities in the region anxious.

Another example of the harms caused by dams is the Grand Rapids hydroelectric dam, which caused the relocation of the Chemawawin and Moose lake Cree Native American tribe.[71] The project to redirect the adjacent river destroyed commercial fishing in the area, flooded numerous Cree burial sites, and contaminated fish with mercury. The construction of the reservoir polluted the waters and habitat which permanently altered an entire community.[72]

62 Alldred, Mary, and Kristin Shrader-Frechette, "Environmental Injustice in Siting Nuclear Plants," *Environmental Justice* 2 (2009): 85-96.

63 Alldred, Mary, and Kristin Shrader-Frechette, "Environmental Injustice in Siting Nuclear Plants," *Environmental Justice* 2 (2009): 85-96.

64 "Radiation Protection," *United States Environmental Protection Agency,* accessed on April 12, 2015, http://www.epa.gov/radiation/understand/health_effects.html.

65 "Nuclear Waste Management," *Nuclear Energy Institute,* accessed on April 12, 2015, http://www.nei.org/Issues-Policy/Nuclear-Waste-Management.

66 "Environmental Justice and Nuclear Power," *Nuclear Information and Resource Service,* accessed on April 12, 2015, http://www.nirs.org/ejustice/ejustice.htm.

67 "Nuclear Waste Management," *Nuclear Energy Institute,* accessed on April 12, 2015, http://www.nei.org/Issues-Policy/Nuclear-Waste-Management.

68 "Environmental Racism, Tribal Sovereignty, and Nuclear Waste," *Nuclear Information and Resource Service,* accessed on April 12, 2015, http://www.nirs.org/factsheets/pfsej-factsheet.htm.

69 "Environmental Justice Case Study: The Yucca Mountain High-Level Nuclear Waste Repository and the Western Shoshone," *University of Michigan,* accessed on April 12, 2015, http://www.umich.edu/~snre492/kendziuk.html.

70 "Menominee River Fish Passage Environmental Assessment," November 30, 2011, accessed April 11, 2015, http://www.fws.gov/midwest/greenbay/hydropower/pdf/Menominee-RiverFishPassageEA.pdf.

71 "Environmental Racism and Environmental Justice - The Manitoban," The Manitoban, March 27, 2010, accessed April 11, 2015, http://www.themanitoban.com/2010/03/environmental-racism-and-environmental-justice/1121/.

72 "Environmental Racism and Environmental Justice - The Manitoban," The Manitoban, March 27, 2010, accessed April 11, 2015, http://www.themanitoban.com/2010/03/environmental-racism-and-environmental-justice/1121/.

Coal

Most coal mining take place on reservations home to both low-income and minority populations. Coal mining on tribal lands will bring both positive and negative impacts to these communities. These communities can benefit from more job opportunities, since there is a chance these industries want to aim at employing the local population[73]. However there are a lot of negative characteristics of environmental and health impacts that coal mining presents to the local community.

If the plant doesn't solely employ members from the proximity, the increase in job opportunities could lead to rapid population growth. As more outsiders move in, this could create imbalance in the local governance and culture due to different beliefs and traditions. Outsiders perhaps would not have the same respect for the community and this could lead to negative events such as cases of greater crime rates.

The extraction of coal has a great impact on air quality and human health. During the stages such as clearing, excavating, backfilling, compacting, or grading, and during blasting, airborne dust hit the air in great amounts and especially in areas where land is unpaved. This could lead to chronic respiratory problems. In addition, there are significant amounts of water contamination during the extraction phase of coal. When land is cleared for construction, deforestation occurs, affecting biodiversity, increasing soil erosion, and water pollution. The drilling process brings up contaminants, which likely infiltrates the local watershed and contaminate the water.

Acoustics are an issue since proponents of a coal mine project heightens existing background noise levels from equipment use during drilling, blasting, and other forms of construction. This may have indirect effects local communities and may lead to issues like devaluing real estate. If the property rate are lower, not only would this target lower-income communities but can also instigate more industries to move in (assuming there are resources available) and cause greater incidence for socio-economic injustices.

During the generation of coal, communities living near the production plant are at a higher health risk. For instance, the Delaware Division of Public Health conducted a study that confirmed that the residents in the six zip codes areas surrounding the region's coal plant had a 17% higher cancer rate in comparison to the national average.[74] Furthermore, communities downwind of that smokestack is also in danger of developing asthma, cardiovascular disease, and premature births.[75] Most importantly, these effects are generally targeted to minorities. 68% percent of African Americans live within 30 miles of a coal plant, as opposed to 56% of whites.[76] The generation of coal is various implication of communities, particularly affecting their health.

Landfill

Landfill gas has the most environmental justice ramifications in the location of the landfill, or its raw material/extraction phase. There is an extensive literature addressing the disproportionate placement of environmentally undesirable developments in marginalized communities. This includes smelly sewage treatment plants, air polluting factories, landfills (hazardous and non-hazardous), and other industries whose presence decreases the property value of the surrounding neighborhoods. Pastor, Sadd, and Hipp research Los Angeles waste disposal centers in 1990.[77] Their research forms a snapshot of landfill placement in the L.A. area during the time period and finds that the properties that are within a ¼ mile radius landfill have on average 25% higher minority populations than the county average.

Given the high environmental injustice of landfills in this stage, we give landfill gas a 'high' or '2' ranking for the EJ effects during its raw material extraction phase. It ranks 'low' or '0' for its manufacturing, transportation, and use phases. Landfill gas manufacturing has few negative impacts and there isn't data that claims that these jobs are unfairly designated to minorities. Transportation happens in unobtrusive underground pipelines, and landfill gas burns cleanly during its usage phase.

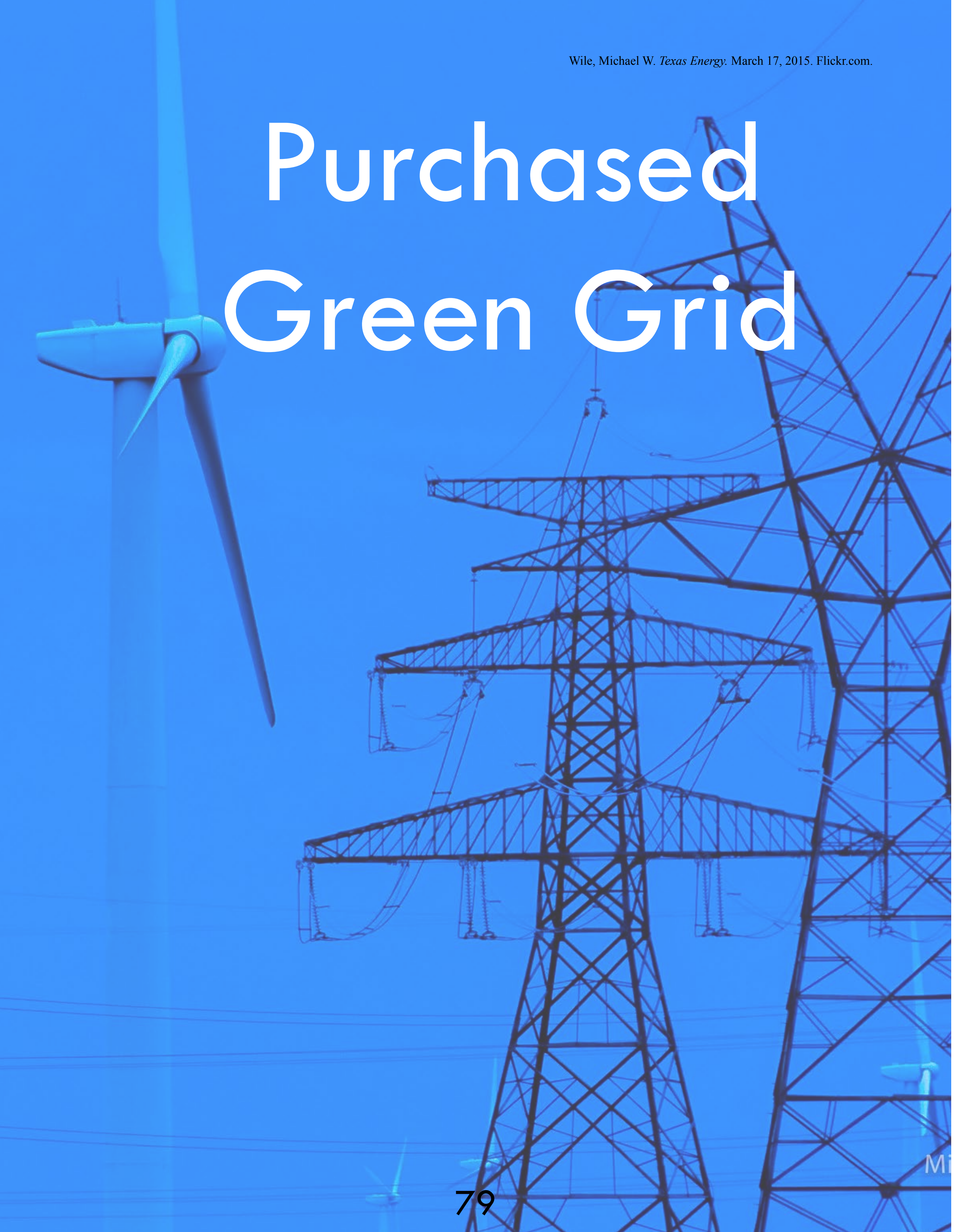
73 "Environmental Justice Mitigation methods," *Trial Energy and Environmental Information,* accessed 4/4/2015, http://teeic.indianaffairs.gov/er/coal/mitigation/justice/index.htm.

74 Coal: Dangerous Power, Energy Justice Network, accessed April 13, 2015, http://www.energyjustice.net/coal.

75 Coal: Dangerous Power, Energy Justice Network, accessed April 13, 2015, http://www.energyjustice.net/coal.

76 Coal: Dangerous Power, Energy Justice Network, accessed April 13, 2015, http://www.energyjustice.net/coal.

77 Miguel Pastor Jr., Jim Sadd, and John Hipp, "Which Came First? Toxic Facilities, Minority Move-In, and Environmental Justice," *Journal of Urban Affairs 23.1* (2001): 1-21.



Wile, Michael W. *Texas Energy.* March 17, 2015. Flickr.com.

Purchased Green Grid

Introduction to Purchased Green

Purchasing green grid energy is a more complicated than it sounds because purchasing green electricity does not mean that you are using green electricity. When consumers pay for green energy, they are paying for that quantity of green energy to enter somewhere in the grid. If they do not pay for that amount of green energy, it would not have been created and, collectively, consumers using the grid would be using that much less green energy. But the key idea is that it is not the consumer who is paying for green energy, but who is consuming it.

Wellesley College is committed to consuming 5% green electricity. The town of Wellesley was awarded the EPA Green Power Community certification from purchasing 3% of its total electrical consumption from renewable sources, and overall currently purchases 4.2% renewable energy. Since the College's power plant does not create green energy, it relies on purchasing green energy from the Wellesley Municipal Light Plant to meet its goal.[78] In 2014, Wellesley College purchased 873,839 kWh of green electricity from the town.[79] By purchasing green energy, the College is supporting the creation of green wind energy, hydropower, and landfill gas in the following proportions:[80]

- Hydro: 50%
- Wind: 41.67%
- Landfill: 8.33%

Since there are three sources of green energy that WMLP creates in the grid, we will analyze each source individually and then weigh the averages based on their prevalence in the grid.[81]

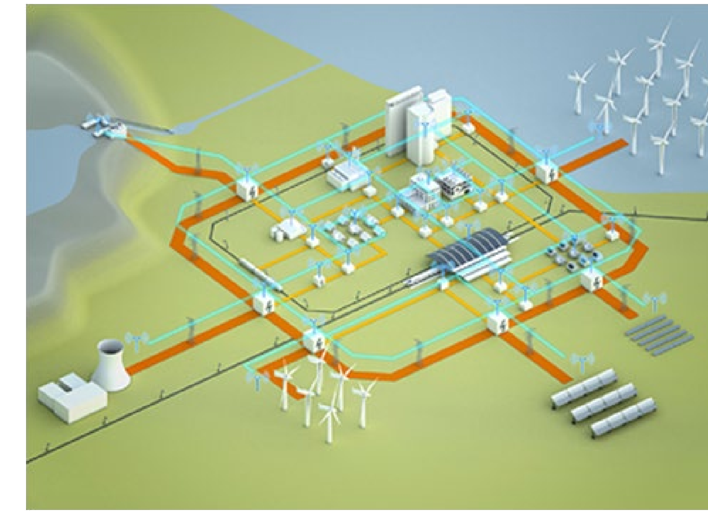


Figure 37:Example of purchased green grid system[1]

1"Looking to the Future – The Smart Grids of Tomorrow," Siemens Global Website, accessed April 11, 2015.

SimaPro 7

Wind:

- For wind energy we chose "electricity, high voltage, {GB}|electricity production, wind, 1-3 MW turbine, onshore | Alloc Def, U" because it was similar to the energy the Wellesley Municipal Light Plant supports.[82] Our wind energy is created on 2mW turbines in a similar environment and climate to the UK.[83] It makes up 41.57% of the RECs the town purchases so we weighed it as 0.4157 of our total kWh inputs.

Hydropower:

- For hydro, we chose "electricity, hydropower, at power plant/GB U" because Great Britain hydropower model is similar to that used in

78 Wellesley College has several solar panels that create a nominal amount of green energy. They contribute about 0.03% to the College's total annual electricity usage. "Energy," Wellesley College Sustainability, accessed on 4/5/2015, http://www.wellesley.edu/sustainability/energy.

79 We obtained this data from conversations with the WMLP in March 2015.

80 These percentages are extrapolated from the data provided by the WMLP.

81 In this section we report the total ratings that we give purchased green energy based on weighing the individual scores of hydropower, landfill gas, and wind power. For further analysis of each of the three electricity sources we cite previous discussions in the hydropower or landfill gas sections of purchased grid electricity or the wind power section.

82 "Wellesley Renewable Energy FAQs," *Wellesley Town,* accessed 4/4/2015, http://www.wellesleyma.gov/pages/wellesleyma_sustenergy/WellesleyRenewableEnergy-FAQs-2-29-2012.pdf.

83 "About the Spruce Mountain Wind Project," *Patriot Renewables,* accessed 4/4/2015, http://patriotrenewables.com/SpruceMountainWind.html.

New England.[84] It makes up 50% of the RECs the town purchases, so we weighed it as 0.50 of our total kWh inputs.

Landfill Gas:

- For landfill gas, we used biogas as a proxy because life cycle data for landfill gas was not available within the SimaPro 7 database. We chose "electricity, at cogen with biogas engine, allocation exergy/GB" biogas option because it was the non-agricultural usage of biogas energy in a region, Great Britain, that we deemed most energy-similar to the United States.[85] It makes up 8.33% of the RECs the town purchases, so we weighed it as 0.0833 of our total kWh inputs.

Cost

Taking into account initial or capital costs, fixed operating costs, and variable operating costs, the cost of green grid energy is $0.09/kWh.

Reliability

Table 126: Reliability assessment for purchased green grid

Yes (1), No (0), or N/A	Score
Can it be provided uninterrupted?	1
Can it be stored?	1
Is it available short-term (until 2025)?	1
Is procurement stable (not volatile) in the long term?	1
Is it independent of weather?	0
Can you ramp it up/down to meet fluctuating energy demand?	1
Total:	**5**

The question is whether the green town grid electricity is reliable or not. This misinterprets what green grid energy is. Green grid electricity means the consumer is purchasing grid energy at a premium to ensure that somewhere in the grid, that quantity of green energy is being produced. It does not necessitate that the electricity used by the customer is completely generated from a green source. Therefore, the reliability of green grid electricity is the exact same as purchasing grid electricity because the consumer is actually using regular grid electricity. The generation of the different types of green energy like wind, hydro, landfill in the grid may vary, but nonetheless the aggregate of all the types will be reliably generated. For further analysis on the reliability of grid electricity see page 68.

Educational Advantage

Table 127: Educational advantage assessment for purchased green grid

High (2), Medium (1), Low (0)	Score
Students can learn from this energy source and use data from it to understand energy generation.	1
There is visibility on campus and this energy source raises awareness about sustainability.	0
Ability to be a research opportunity to further the interests of students and professors.	0
Informs administrative decisions on scaling up energy production in new technologies (this is most relevant for new technologies).	1
Provides insight and encourages external organizations to replicate forms of uncommon energy production.	1
Total:	**3**

The green grid provides relatively little educational advantage for the College. There is an opportunity for students, administration, and outsiders to learn from Wellesley College purchasing green energy, but the effect of making this change would be relatively invisible to those stakeholders.

Since most electricity users buy primarily regular grid energy, purchasing green grid energy would enable students to become more aware of the green grid purchasing options. They could learn about how paying a premium for green energy does not necessarily mean that your electricity is coming from a green source, but instead is enabling the production of more green energy somewhere in the system. While this learning is constructive, there is no hands-on portion to it and students could learn this information even if Wellesley didn't buy green grid electricity by visiting the WMLP website.

Using green grid energy would be an invisible change on campus. This invisibility does not discourage, but neither encourages awareness of sustainable energy for Wellesley College community members.

Wellesley College's purchasing of green energy would not create new data that would be especially insightful in the field of electricity purchasing. If Wellesley College purchased all green grid energy there would be data available for professors and students to analyze. That data already exists in the system from other schools, institutions, and households so those curious minds could get that same data from elsewhere.

When Wellesley College institutes new policies, the administration are able to see the impacts on the school and learn from those effects. The College has already purchased some green grid electricity, so some of this information is already available for the administration. Currently the electricity is not all green grid energy, so if the College purchased 100% green electricity they could inform future decisions about purchasing electricity.

Similarly, most other institutions purchase some but not 100% green grid electricity. They would be able to learn from Wellesley College if we were to switch to all green energy. It is unlikely that Wellesley College would run on 100% green energy in the near-future. It is possible that with changing norms and incentives within Massachusetts and nationally, we will move towards 100% renewable energy in the long-term.

Greenhouse Gas Emissions

Table 128: Greenhouse gas emissions assessment for purchased green grid

Impact Category	Total
Global Warming	1.17e-6 CTUe

Grid electricity has the potential to release 1.17e-6 lbs of CO_2 per kWh of electricity.

What might be contributing most to climate change? A further discussion of global warming impacts of wind can be found on page 86 and for hydro can be found on page 74.

Ecotoxicity

Table 129: Ecotoxicity assessment for purchased green grid

Impact Category	Total
Ecotoxicity	1.36e-4 CTUe

The ecotoxicity of using green grid energy is 1.36e-4 CTUe. What might be contributing most to ecotoxicity? A further discussion of Ecotoxicity impacts of wind can be found on page 86 and for hydro can be found on page 74.

Ecosystem Disruption

Table 130: Ecosystem disruption assessment for purchased green grid

Low (0), Medium (1), High (2)	Score
Land Disruption - permanent or temporary	1.5
Water Use	1.3334
Water Contamination	0.75
Biodiversity disruption (consider both the number of species and the extent of the disruption for species)	1.5
Total:	**5.0834**

84 Flynn, Kerry, "Renewing Industry with Ancient Tech: A Return to Hydropower," *Forbes.com,* last modified June 25, 2014, accessed on 4/4/2015.

85 The other regional options are Switzerland, Brazil, and China.

Table 131: Breakdown of ecosystem disruption assessment for purchased green grid

Purchased	% of Grid	Land Disruption	Water Use	Water Contamination	Biodiversity Loss	Sum	Ind. Weighted Sum	Total Weighted Sum
Hydro	0.5	1	1	0.5	2	4.5	2.25	
Wind	0.4167	2	2	1	1	6	2.5002	**5.0834**
Landfill	0.0833	2	0	1	1	4	0.3332	

<u>Energy Source</u>

<u>Hydropower</u>

Refer to page 74 for the Hydropower portion of the Purchased Grid analysis portion in our report.

<u>Wind</u>

Refer to page 87 of the Wind Ecosystem Disruption analysis portion of our report.

<u>Landfill</u>

Landfill gas earned a 3 on ecosystem disruptions based on the land clearing, leachate leakage, and habitat loss associated with creating landfills. For the discussion of these effects that led to this rating, please read the ecosystem disruption effects of landfills in the grid analysis on page 75.

Health

Table 132: Health assessment for purchased green grid

	Total
Respiratory effects	6.44E-07 PM2.5 eq
Carcinogens	7.94E-05 CTUh
Non carcinogens	8.77E-06 CTUh

Health is divided into carcinogenic, non-carcinogenic, and respiratory health effects. We calculated the life cycle health effects per kWh of electricity produced as 7.94e-5 and 8.77e-6 CTUh for carcinogens and non-carcinogens respectively, and 6.44E-07 PM2.5 eq of respiratory effects. The carcinogenic effects are much higher than non-carcinogens which are much higher than particulate matter. A further discussion of human impacts of wind can be found on page 88 and for hydro can be found on page 77.

Environmental Justice

Low (0), Medium (1), High (2)	Score
Raw material extraction	1.0833
Manufacturing & Production (refining of fuels, manufacturing of equipment)	0
Transport (all transport phases prior to reaching Wellesley)	0.312525
Generation (at Wellesley or wherever the electricity is generated.)	0.20835
Total:	**1.604175**

<u>Energy Source</u>

<u>Hydropower</u>

Please refer to page 77 for the Hydropower portion of the Purchased Grid analysis portion in our report.

<u>Wind</u>

Please refer to page 89 of our Wind Environmental Justice Assessment portion of our report.

<u>Landfill</u>

Landfill gas earned a 2 on environmental justice based on the disproportionate placement of landfills in minority and low-income neighborhoods. For a discussion of the phenomenon that led to this rating, please read the environmental justice effects of landfills found in the grid analysis on page 78.

Hawley, Richard G. *Turbines.* Sept 12, 2009. Flickr.com

Wind

Introduction to Wind

A wind turbine is a system that converts winds into electricity. Each turbine consists of a foundation, a tower, rotor and rotor blades, a nacelle with a drive train, a gearbox, a generator, a coupling and brake, fire extinguishing equipment, sensors, and a system used to feed the wind energy into the electricity grid.[86] If Wellesley purchases a wind turbine, the College would likely choose to purchase a 1.5 megawatt (MW) turbine, as campus of similar sizes have chosen to purchase 1.5 MW wind turbines.[87,88] The materials that go into constructing a 1.5 MW wind turbine include 132,561 kg of steel, 8,629kg of fiberglass, 2,380kg of copper, 1,934kg of concrete, 1,637kg of adhesives, 1,190kg of aluminum, and 595.112kg of foam, plastic, and wood.[89]

As pictured above, wind turbines are extremely tall, as faster and less turbulent wind is found at higher elevations. Today, most wind turbines have two to three blades. As the wind blows, each blade collects low-pressure air. This low-pressure air then pulls the blade towards it, causing the blades to spin like a propeller, thus generating energy. In order to convert wind energy into electricity, one must connect the wind turbine to an electrical grid.[90]

In 2013, Wellesley College used 27,211,329 kWh (27,211.329 MW) of electricity to power its campus.[91] Assuming that Wellesley College is using the same amount of electricity today, a 1.5 megawatt wind turbine could provide up to 1.5 MW of the annual 27,211.329 MW that the school needs. In general, wind turbines need about 13 mile per hour winds[92] to serve their purpose, and Framingham, Massachusetts has an average wind speed of 13.6 miles per hour.[93]

For wind energy we chose "electricity, high voltage, {ASCC}|electricity production, wind, <1MW turbine, onshore | Alloc Def, S" in SimaPro 7 because it was similar to the type of turbine we would expect to install at Wellesley College.

Cost

Taking into account initial or capital costs, fixed operating costs, and variable operating costs, the cost of a wind energy system is $0.02/kWh.

Reliability

Table 133: Reliability assessment for wind

Yes (1), No (0), or N/A	Score
Can it be provided uninterrupted?	0
Can it be stored?	0.1
Is it available short-term (until 2025)?	1
Is procurement stable (not volatile) in the long term?	1
Is it independent of weather?	0
Can you ramp it up/down to meet fluctuating energy demand?	0
Total:	**2.1**

Unsurprisingly, wind turbine-generated electricity is heavily dependent on wind availability, although Stanford University has found that wind turbines are efficient enough to produce three days' worth of battery or geological storage, which means that wind-generated electricity can be accessed after up to three days of no wind.[94] Unfortunately, after up to three days without wind, the wind turbine does not have any generated or stored energy, making wind energy difficult to rely on. In contrast, the advantage of relying on a weather-dependent energy source is that wind-generated electricity will be available in the long-term, in varying capacities, as wind will always be present to varying extents.

Educational Advantage

Table 134: Educational advantage assessment for wind

High (2), Medium (1), Low (0)	Score
Students can learn from this energy source and use data from it to understand energy generation.	2
There is visibility on campus and this energy source raises awareness about sustainability.	2
Ability to be a research opportunity to further the interests of students and professors.	2
Informs administrative decisions on scaling up energy production in new technologies (this is most relevant for new technologies).	2
Provides insight and encourages external organizations to replicate forms of uncommon energy production.	1
Total:	**9**

Installing a wind turbine on Wellesley's campus increases visibility about alternative wind energy options. Students can see the turbine and contribute to a conversation about energy use and sustainability on campus. In addition, each turbine has a computer interface which tracks and relays the wind speeds at each moment, the amount of energy being generated, and the capacity of the turbine. Students in the environmental studies program can study the greenhouse gas emissions of the wind turbine and the physics department can study the mechanical aspects of the turbine and the generation of energy with the power of the wind. [95]

The tracking system can translate the kWh of energy into greenhouse gas reductions and these emissions can be observed overtime. Students can use the data to learn more about how wind turbines function and why wind power is important to Wellesley and the region. Faculty may also offer a summer research opportunity to continue research about green energy and the efficiency of different methods of green energy. Each type could be compared and contrasted as to their effectiveness and environmental footprint.[96]

In addition, although Wellesley could provide an example to other liberal arts institutions or Colleges in the geographical region to install turbines since an uncommon source of energy production, Babson College, which is also in the town of Wellesley, already has a wind turbine so it gets a rating of 1. Wellesley's administration can also decide to include more wind turbines to scale up energy production if it can produce enough energy.

Greenhouse Gas Emissions

Table 135: Greenhouse gas emissions assessment for wind

Impact Category	Total
Global warming	0.01 kgCO2 eq

The effects of global warming are felt evenly between the material extraction as well as the transport of materials to the site. Extraction of Materials releases a lot of carbon dioxide and sulfur dioxides into the atmosphere that increase overall CO2 emissions even though wind usage has very low emissions. The other factor that contributes to global warming is the transportation of raw materials to Wellesley College for assembly. Trucks have to travel around 28,079.5km to deliver all of the materials to build the turbine.

Ecotoxicity

86 BWE Bundesverband WindEnergie e.V.: German Wind Energy Association, The Structure of a Modern Wind Turbine: An Overview, accessed on April 2, 2015, http://www.wwindea.org/technology/ch01/en/1_2.html.

87 Heinz, Gloria, The History of Carleton's First Wind Turbine, Carleton College, last modified March 20, 2014, accessed April 4, 2015. https://apps.carleton.edu/campus/facilities/sustainability/wind_turbine/.

88 Jensen, Jon, Sustainability: Wind Turbine. March 2, 2015, Luther College, accessed April 4, 2015, http://www.luther.edu/sustainability/campus/energy-climate/renewable/wind-turbine/.

89 Wilburn, D.R., 2011, Wind energy in the United States and materials required for the land-based wind turbine industry from 2010 through 2030: U.S. Geological Survey Scientific Investigations Report 2011–5036, 22 p. http://pubs.usgs.gov/sir/2011/5036/sir2011-5036.pdf

90 Wind Power, accessed Renewable Energy World.Com, April 4, 2015, http://www.renewableenergyworld.com/rea/tech/wind-power.

91 Energy, Wellesley College, accessed April 4, 2015, http://www.wellesley.edu/sustainability/energy.

92 Wind Energy Basics, Wind Energy Development, accessed April 4, 2015, http://windeis.anl.gov/guide/basics/.

93 **Top 101 cities with the highest average wind speeds (population 50,000+), City-Data.Com, accessed April 4, 2015, http://www.city-data.com/top2/c467.html.**

94 Schwartz, Mark, "Wind Farms Can Provide a Surplus of Reliable Clean Energy to Society, Stanford Study Finds," Stanford University, last modified March 20, 2014, accessed April 4, 2015.

95 Heinz, Gloria,The History of Carleton's First Wind Turbine, Carleton College, last modified March 20, 2014, Accessed April 4, 2015, https://apps.carleton.edu/campus/facilities/sustainability/wind_turbine/.

96 Heinz, Gloria,The History of Carleton's First Wind Turbine, Carleton College, last modified March 20, 2014, Accessed April 4, 2015, https://apps.carleton.edu/campus/facilities/sustainability/wind_turbine/.

Table 136: Table 61: Ecotoxicity assessment for wind

Impact Category	Total
Ecotoxicity	0.08 CTUe

Ecotoxicity is highest during the raw materials extraction portion of the wind turbine life cycle. Materials account for almost 85% of total ecotoxicity. Extraction of raw materials for steel, copper, and concrete release a lot of toxins into the land air and water. For example, heavy metals enter into rivers from open pit mines and cause decreases in fish populations. [97]

Ecosystem Disruption

Table 137: Ecosystem disruption assessment for wind

Low (0), Medium (1), High (2)	Score
Land Disruption - permanent or temporary	1
Water Use	1
Water Contamination	0
Biodiversity disruption (consider both the number of species and the extent of the disruption for species)	1
Total Sum:	**3**

<u>Extraction of Materials</u>

Land disruption during the extraction phase of materials is high. The top 3 materials use in wind turbines: concrete, iron for steel, and copper all cause extensive permanent and temporary land disruption.

Surface mining to extract iron and copper ore from surface deposits overburden the soil and rock material. Large tracts of land and the vegetation are removed in order to mine for the minerals. The ground is drilled, blasted, and the minerals are extracted before they are taken to a plant for refinery. [98] In order to create concrete, we need to mine for aggregates. Creating the pits or quarries requires the removal of virtually all natural vegetation, topsoil and subsoil to reach the aggregate underneath. Often, these disturbed lands are permanent since the entire landscape is destroyed. Companies sometimes leave the pits and quarries open and don't rehabilitate the land.[99]

At a given facility, extraction of iron ores require between 600 and 7,000 gallons of water per ton of iron concentrate produced, depending on the specific refinery process used. [100] Copper requires 46,000 gallons of water per ton[101] Mining for iron, copper or aggregates require the creation of pits and quarries which can disrupt the existing movement of surface water and groundwater. Mining operations interrupt natural water recharge and reduce the quantity and quality of drinking water and wildlife near or downstream from a mining site.[102]

As noted above, extracting copper, iron, and aggregates have negative impacts on biodiversity as a result of vegetation removal. Lack of vegetation alters the availability of food and shelter for local wildlife. For an overall ecosystem, mining affects biodiversity by changing species composition and structure. On examples is when acid and heavy metals enter into rivers from open pit mines and cause decreases in fish populations. [103]

<u>Manufacturing, Transportation, and Use</u>

Manufacturing of wind turbines has low land disruption asides from the initial construction of the plant to assemble the turbine. There are minimal land disruptions during transportation because materials are transported via trucks which will travel along paths that have already been paved.

As in all manufacturing processes, water is used to manufacture steel and cement for wind turbines.[104] 62,000 gallons of water are need to produce one ton of steel, 1,360 gallons of water are needed to produce one ton of cement[105], and 403-942 gallons of water are need to process one ton of copper ore. [106] The manufacturing of one 1.5MW wind turbine would require 1,052,000 gallons of water for steel, 2449 gallons for copper, and 2,897 gallons for cement.

Transportation of the wind turbine from the manufacturers to the installation site and operation of wind turbines does not have a significant impact on water use. [107] The manufacturing and transportation phase of wind turbines have minimal impacts on biodiversity.

Large areas of land are required for wind power plants. The land often cannot be utilized productively during construction or decommissioning[108]. Approximately 1-2 hectares of land need to be cleared per MW of wind turbine in order to build the platform, access to roads, and construction. Turbine construction and operation require large machinery like cranes to assemble all of the parts which can lead to removal of vegetation, disturbance, and compaction of soil, soil erosion, and changes in hydrologic features. Although, these practices are relatively short term there are still detrimental effects on habitat quality for local ecosystems. [109] If more than one wind turbine is erected they must be placed approximately 5 to 10 rotor diameters apart (a rotor diameter is the diameter of the wind turbine blades). [110]

Once a wind turbine is installed, the main concern is that birds and bats will be killed when they fly into the towers or blades. These large structures could also fragment habitats. Studies have revealed that approximately 145,000 birds are killed by the U.S. wind industry each year. Comparatively, 550 million birds die each year from colliding with buildings according to the U.S. Forest Service.[111]

Health

Table 138: Health assessment for wind

Impact Category	Total
Respiratory effects	2.92E-06 kg PM2.5eq
Carcinogenics	2.71 E-10 CTUh
Non-carcinogenics	4.08 E-09 CTUh

Health is a composite of carcinogenic, non-carcinogenic, and respiratory effects. In the lifecycle of a wind turbine, the raw material extraction phase has the greatest impact on health. Based on the above table, it is clear that carcinogens have a lower impact value than do non-carcinogens, although cancer rates have seen increases in areas in which rare earth minerals are mined for wind turbines.[112] Most of the non-carcinogens are related to the mining of raw materials like steel, concrete and copper which contribute to noise and air pollution, emitting carbon monoxide, carbon

97 "Appendix 2: Environmental and Social Impacts of Mining," accessed April 4, 2015, http://pdf.wri.org/mining_background_literature_review.pdf.

98 "Technical Resource Document Extraction and Benefection of Ores and Minerals," U.S. Environmental Protection Agency, last modified August 1, 1994, accessed April 4, 2015, http://www.epa.gov/osw/nonhaz/industrial/special/mining/techdocs/iron.pdf.

99 "3. The Environmental Impacts of Aggregate Extraction," Toronto Environmental Alliance, accessed April 4, 2015, http://www.torontoenvironment.org/gravel/impacts.

100 "Technical Resource Document Extraction and Benefection of Ores and Minerals," U.S. Environmental Protection Agency, last modified August 1, 1994, accessed April 4, 2015, http://www.epa.gov/osw/nonhaz/industrial/special/mining/techdocs/iron.pdf.

101 Singh, Madan, "Water Consumption at Copper Mines in Arizona," State of Arizona Department of Mines & Mineral Resources, last modified December 1, 2010, accessed April 5, 2015, http://www.patagoniaalliance.org/wp-content/uploads/2014/08/Water-Consumption-at-Copper-Mines-in-Arizona.pdf.

102 "3. The Environmental Impacts of Aggregate Extraction," Toronto Environmental Alliance, accessed April 4, 2015, http://www.torontoenvironment.org/gravel/impacts.

103 "Appendix 2: Environmental and Social Impacts of Mining," accessed April 4, 2015, http://pdf.wri.org/mining_background_literature_review.pdf.

104 "Environmental Impacts of Wind Power," Union of Concerned Scientists, accessed April 5, 2015, http://www.ucsusa.org/clean_energy/our-energy-choices/renewable-energy/environmental-impacts-wind-power.html#bf-toc-0.

105 Merchant, Brian, "How Many Gallons of Water Does It Take to Make . . ." Tree Hugger, last modified June 24, 2009, accessed April 5, 2015, http://www.treehugger.com/clean-technology/how-many-gallons-of-water-does-it-take-to-make.html.

106 Wilburn, D.R., 2011, Wind energy in the United States and materials required for the land-based wind turbine industry from 2010 through 2030: U.S. Geological Survey Scientific Investigations Report 2011–5036, 22 p. http://pubs.usgs.gov/sir/2011/5036/sir2011-5036.pdf.

107 "Environmental Impacts of Wind Power," Union of Concerned Scientists, accessed April 5, 2015, http://www.ucsusa.org/clean_energy/our-energy-choices/renewable-energy/environmental-impacts-wind-power.html#bf-toc-0.

108 Wilburn, D.R., 2011, Wind energy in the United States and materials required for the land-based wind turbine industry from 2010 through 2030: U.S. Geological Survey Scientific Investigations Report 2011–5036, 22 p., accessed May 15, 2015, http://pubs.usgs.gov/sir/2011/5036/sir2011-5036.pdf.

109 National Research Council. *Environmental Impacts of Wind-Energy Projects*. Washington, DC: The National Academies Press, 2007. Accessed April 5, 2015. http://www.nap.edu/openbook.php?record_id=11935&page=69

110 "Environmental Impacts of Wind Power," Union of Concerned Scientists, accessed April 5, 2015, http://www.ucsusa.org/clean_energy/our-energy-choices/renewable-energy/environmental-impacts-wind-power.html#bf-toc-0.

111 Jensen, Jon, Sustainability: Wind Turbine, Luther College, accessed April 4, 2015, http://www.luther.edu/sustainability/campus/energy-climate/renewable/wind-turbine/.

112 Daily Mail Online-UK, In China, the true cost of Britain's clean, green wind power experiment: Pollution on a disastrous scale, accessed April 4, 2015, http://www.dailymail.co.uk/home/moslive/article-1350811/In-China-true-cost-Britains-clean-green-wind-power-experiment-Pollution-disastrous-scale.html.

dioxide, and sulfur dioxide into the air. [113] Carbon monoxide can prevent oxygen from reaching the heart and blood, and can cause death in extreme cases. Also from SimaPro 7 we can see that Respiratory effects are much higher than both carcinogens and non-carcinogens. Sulfur dioxide can cause irritation of the skin and the respiratory system, which could lead to coughing and breathing difficulties, and can exacerbate asthma and heart disease.[114]

Environmental Justice

Table 139: Environmental justice assessment for wind

Low (0), Medium (1), High (2)	Score
Raw material extraction	1.00
Manufacturing & Production (refining of fuels, manufacturing of equipment)	0.00
Transport (all transport phases prior to reaching Wellesley)	0.75
Generation (at Wellesley or wherever the electricity is generated.)	0.50
Total:	**2.25**

Raw Materials Extraction

Wind turbines consist of steel, fiberglass, copper, concrete, adhesives, and aluminum. Steel is created by extracting iron from iron ore and converting this iron into steel. Ore mining is associated with noise and air pollution, emitting carbon monoxide, carbon dioxide, and sulfur dioxide into the air. [115] Carbon monoxide can prevent oxygen from reaching the heart and blood, and can cause death in extreme cases.[116] Carbon dioxide can prevent proper breathing and can cause unconsciousness or death under certain circumstances.[117] Lastly, sulfur dioxide can cause irritation of the skin and the respiratory system, which could lead to coughing and breathing difficulties, and can exacerbate asthma and heart disease.[118] According to an analysis compiled by the World Association of Technology Teachers, the place in which iron ore is most often mined is China, followed by Australia, Brazil, and India, respectively.[119]

In 2011, an article in the Daily Mail discussed the trade-offs of converting to green technology by looking at the poisoned and polluted lakes of China, where many raw materials used to construct wind turbines are extracted.[120] The lake, which is referred to as a "hissing cauldron of chemicals",[121] is home to seven million tons of acid and chemical-doused mined rare earth per year. It has also caused illnesses and deaths among humans and animals alike. Young villagers living near the lake described their hair turning white and their teeth falling out. Furthermore, villagers are suffering from higher rates of cancer, severe skin diseases, and respiratory diseases. Because of the raw material extraction of wind turbine materials, the lake in China has 10 times higher radiation levels than its surrounding lakes, and has caused severe health and psychological issues.[122]

Copper mining is also associated with two distinct genetic disorders in copper mine workers: Wilson's Disease and Menkes Disease. Furthermore, copper mining and extraction is associated with lung cancer and coronary heart disease.[123] In addition, although there are no significant adverse health effects found in obtaining aluminum, there are correlations found between aluminum extractors and heat stress and hearing loss.[124]

Manufacturing, Transport, and Use

Although the environmental justice implications of manufacturing a wind turbine are not significant, those employed in the wind farm industry do face dangers associated with constructing wind turbines. For starters, carrying heavy loads of wind turbine parts can cause strained, twisted, and broken body parts. Furthermore, dealing with high voltage equipment puts workers in danger of being electrocuted or permanently disabled. [125]

When wind turbines are transported, they are done so in parts via truck. Because of the size of turbines, trucks must often make close to a dozen trips from the manufacturers to the desired site in order to fully transport all parts necessary to assemble a functioning wind turbine on site. This being said, those along the transportation route of wind turbines are being hit harder by fuel emissions and traffic than are those distant from the route of wind turbine transportation. The carbon monoxide in fuel emissions can prevent oxygen from reaching one's brain and heart, and the lead found in gasoline can damage organs and significantly decrease mental ability. Furthermore, when fuel containing sulfur is inputted into diesel engines, sulfur dioxide generation can occur, causing a constriction of air passages and exacerbating asthma-related health problems. [126]

Furthermore, there have been instances of wind turbines falling from transport trucks. In Ontario in February of 2014, a part of a large wind turbine being transported by truck rolled onto the road, putting peoples' live in danger and causing traffic around Ontario.[127]

Because of the size of wind turbines, accidents associated with the energy source are often fatal. There have been instances in which wind turbines have fallen or electrocuted handlers. In Minnesota in 1994, a chunk of ice sitting on a wind turbine fell, killing a passerby. Wind turbine blades have flown out of place while in motion and fires have erupted at the tops of turbines.[128] Although accidents like these are rare, they are often fatal when they do occur.

113 ChemGuide, Iron and Steel, accessed April 2, 2015, http://www.chemguide.co.uk/inorganic/extraction/iron.html.

114 National Park Service, Sulfur Dioxide Effects on Health, accessed April 2, 2015, http://www.nature.nps.gov/air/AQBasics/understand_so2.cfm.

115 ChemGuide, Iron and Steel, accessed April 2, 2015, http://www.chemguide.co.uk/inorganic/extraction/iron.html.

116 United States Environmental Protection Agency, Carbon Monoxide: Health, accessed April 2, 2015, http://www.epa.gov/airquality/carbonmonoxide/health.html.

117 U.S. National Library of Medicine, Carbon Dioxide, accessed April 2, 2015, http://toxtown.nlm.nih.gov/text_version/chemicals.php?id=6.

118 National Park Service, Sulfur Dioxide Effects on Health, accessed April 2, 2015, http://www.nature.nps.gov/air/AQBasics/understand_so2.cfm.

119 World Association of Technology Teachers, Where is Iron Ore Mined?, accessed April 2, 2015, http://www.technologystudent.com/pdf7/iron2.pdf.

120 Daily Mail Online-UK, In China, the true cost of Britain's clean, green wind power experiment: Pollution on a disastrous scale, accessed April 4, 2015, http://www.dailymail.co.uk/home/moslive/article-1350811/In-China-true-cost-Britains-clean-green-wind-power-experiment-Pollution-disastrous-scale.html.

121 Daily Mail Online-UK, In China, the true cost of Britain's clean, green wind power experiment: Pollution on a disastrous scale, accessed April 4, 2015, http://www.dailymail.co.uk/home/moslive/article-1350811/In-China-true-cost-Britains-clean-green-wind-power-experiment-Pollution-disastrous-scale.html.

122 Daily Mail Online-UK, In China, the true cost of Britain's clean, green wind power experiment: Pollution on a disastrous scale, accessed April 4, 2015, http://www.dailymail.co.uk/home/moslive/article-1350811/In-China-true-cost-Britains-clean-green-wind-power-experiment-Pollution-disastrous-scale.html.

123 University of Virginia, Copper Mining: From the Ground Up, accessed April 2, 2015, http://faculty.virginia.edu/metals/cases/dudgeon3.html.

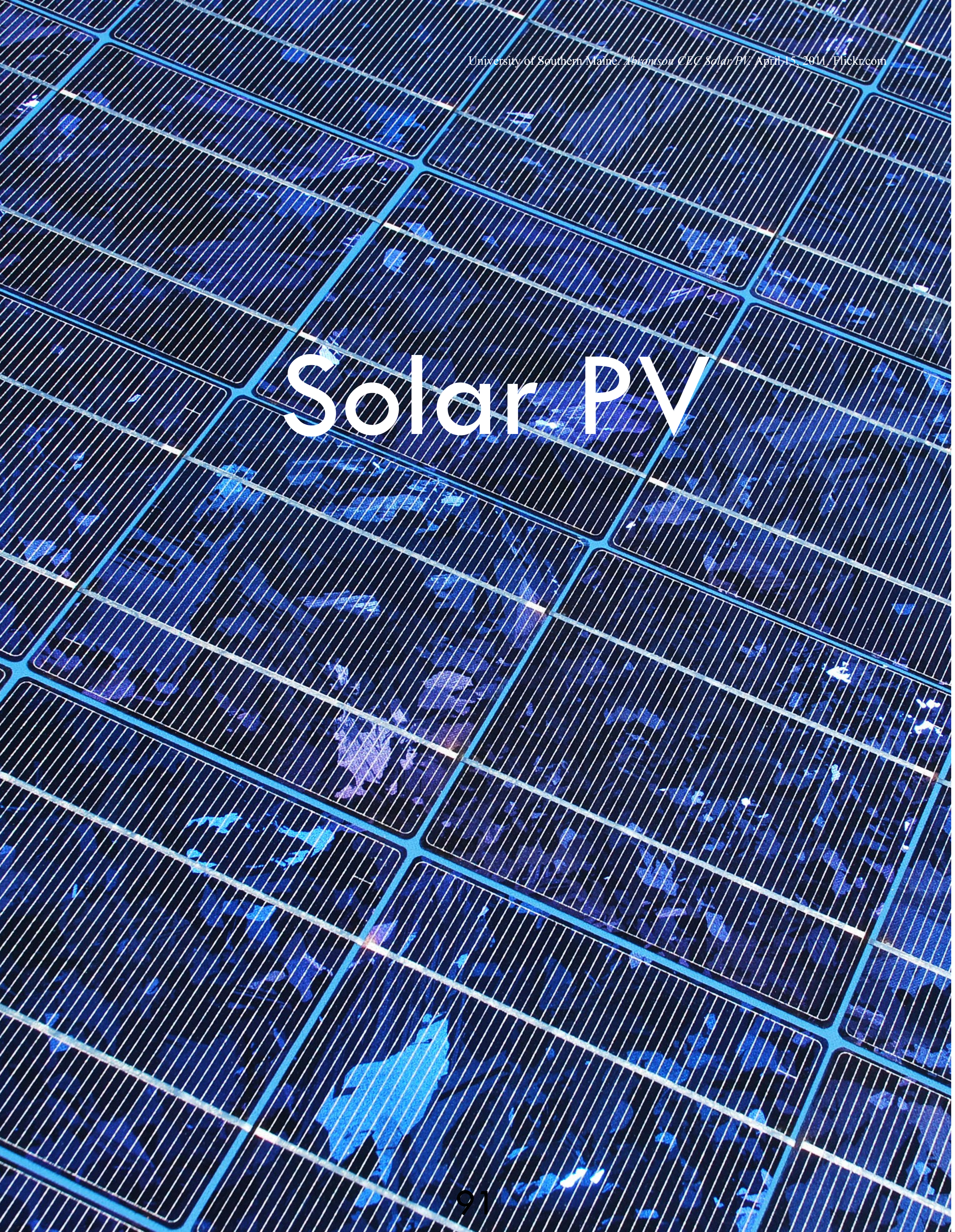
124 Journal of Occupational and Environmental Medicine, Occupational and Environmental Health in the Aluminum Industry: Key Points for Health Practitioners, accessed April 3, 2015, http://journals.lww.com/joem/Fulltext/2014/05001/Occupational_and_Environmental_Health_in_the.3.aspx.

125 Renewable Energy World.Com, Keeping Safe When Working with Wind Power, accessed April 4, 2015, http://www.renewableenergyworld.com/rea/news/article/2014/01/keeping-safe-when-working-with-wind-power.

126 Washington State Department of Ecology, Health Effects from Automobile Emissions, accessed April 1, 2015, https://fortress.wa.gov/ecy/publications/publications/0002008.pdf.

127 CBS News, Charges laid after wind turbine rolls off transport truck, accessed April 1, 2015, http://www.cbc.ca/news/canada/windsor/charges-laid-after-wind-turbine-rolls-off-transport-truck-1.2537814.

128 East County Magazine, The Dark Side of "Green": Wind Turbine Accidents, Injuries, and Fatalities, Raise Serious Safety Concerns, accessed on April 1, 2015, http://www.eastcountymagazine.org/dark-side-%E2%80%9C-green%E2%80%9D-wind-turbine-accidents-injuries-and-fatalities-raise-serious-safety-concerns.



University of Southern Maine. *Abromson CEC Solar PV*. April 15, 2011. Flickr.com

Solar PV

Introduction to Solar PV

A solar photovoltaic (solar PV) system converts energy from the sun to electricity. Photovoltaic is the direct conversion of light into electricity at the atomic level. Certain materials can absorb photons of light and release electrons, generating an electric current that can be used as electricity.[129] Solar PV systems can be mounted on rooftops or installed closer to the ground, angled appropriately for the sun.[130]

Solar PV gets its name from the process of converting light (photons) to electricity (voltage), which is called the PV effect.[131] A typical silicon PV cell is composed of a thin wafer consisting of an ultra-thin layer of phosphorus-doped (N-type) silicon on top of a thicker layer of boron-doped (P-type) silicon. An electrical field is created near the top surface of the cell where these two materials are in contact, called the P-N junction. When sunlight strikes the surface of a PV cell, this electrical field provides momentum and direction to light-stimulated electrons, resulting in a flow of current when the solar cell is connected to an electrical load.[132] Regardless of size, a typical silicon PV cell produces about 0.5 – 0.6 volt DC under open-circuit, no-load conditions. The current (and power) output of a PV cell depends on its efficiency and size (surface area), and is proportional to the intensity of sunlight striking the surface of the cell. For example, under peak sunlight conditions, a typical commercial PV cell with a surface area of 160 cm^2 (~25 in^2) will produce about 2 watts peak power. If the sunlight intensity were 40 percent of peak, this cell would produce about 0.8 watts[133].

Right now, Wellesley has a 10kW system of PV solar panels installed near the athletic fields. This system generates approximately 12,000 kWh of electricity annually, about 0.044% of Wellesley's yearly consumption of about 27 million kWh. The cost of this system was $64,000 and it saves Wellesley an estimated $1,450 annually.[134]

129 Gil Knier, "How Do Photovoltaics Work?" NASA Science, last modified August 6, 2008, http://science.nasa.gov/science-news/science-at-nasa/2002/solarcells/.

130 "Solar PV," *Dictionary of Environmental Science and Technology* (Hoboken: Wiley, 2000), accessed May 15, 2015.

131 Solar Photovoltaic Technology Basics, National Renewable Energy Laboratory, accessed April 15, 2015, http://www.nrel.gov/learning/re_photovoltaics.html.

132 How PV Cells Work, Florida Solar Energy Center: Creating Energy Independence, accessed April 15, 2015 http://www.fsec.ucf.edu/En/consumer/solar_electricity/basics/how_pv_cells_work.htm.

133 How PV Cells Work, Florida Solar Energy Center: Creating Energy Independence, accessed April 15, 2015 http://www.fsec.ucf.edu/En/consumer/solar_electricity/basics/how_pv_cells_work.htm.

134 "Solar Photovoltaic Installation at Wellesley College," The Association for the Advancement of Sustainability in Higher Education, accessed April 3, 2015, http://www.aashe.org/resources/campus-solar-photovoltaic-installations/detail/wellesley-college-2010/.

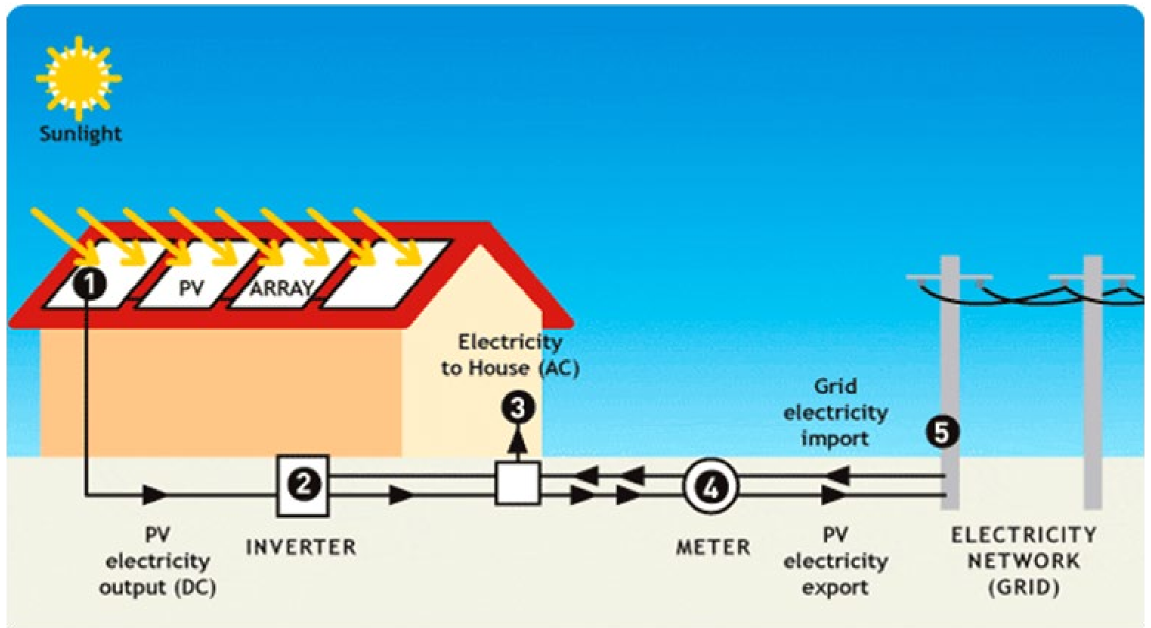


Figure 38:Diagram of a solar PV system[1]

1Solar Photovoltaic, Ste Cliffe, accessed May 15, 2015, http://stecliffe.com/solar-photovoltaic.php.

For solar to be a significant part of Wellesley' electricity portfolio, Wellesley would need to install a much bigger PV system. Harvard University, for example, has a number of different PV system installed across campus including a 600 kW system on the roof of the athletics center and a 500 kW system at the Arsenal Mall, as well as many other smaller systems on individual buildings.[135] While it could be difficult for Wellesley to generate all of its electricity from solar PV on campus, Wellesley could install PV systems on rooftops of buildings or on certain places around campus. A 1200 kW system could generate about 5% of Wellesley's annual energy consumption.[136]

For solar PV we chose "electricity, low voltage {AT}|electricity production, photovoltaic, 3kWp slanted-roof installation, multi-Si, panel, mounted | Alloc Def, S" in SimaPro 7 because it was similar to the type of system we would incrementally expect to install at Wellesley College.

Cost

Taking into account initial or capital costs, fixed operating costs, and variable operating costs, the cost of a solar PV system is $0.03/kWh.

Reliability

Table 140: Reliability assessment for solar PV

Yes (1), No (0), or N/A	Score
Can it be provided uninterrupted?	0
Can it be stored?	.5
Is it available short-term (until 2025)?	1
Is procurement stable (not volatile) in the long term?	1
Is it independent of weather?	0
Can you ramp it up/down to meet fluctuating energy demand?	0.5
Total:	**3.0**

While solar PV is an exciting and promising form of energy generation, there are often concerns over the reliability of a system that depends entirely on the sun for generation. Although solar cells only need daylight, as opposed to direct sunlight, to create electricity, PV systems do rely entirely on the sun. Days of bright, direct sunlight produce more electricity than cloudy days. Although generation is independent of temperature, solar cells actually function better on cold, clear days than scorching hot days.[137] Similarly, solar cells cannot generate electricity during the nighttime and there will be greater generation in seasons with more hours of daylight.

Electricity generated by solar panels can be transmitted immediately and used by an end user, but special equipment is needed to store electricity for later use. (For electricity use at night, for example, when solar panels cannot generate any electricity.) Many users, particularly those who have solar PV on their own residence, opt for "net metering." This means that their electricity meter runs both forwards and backwards; excess electricity generated by panels during the day is credited to the producer returns to the grid to serve other customers, while the producer is able to draw on grid electricity at night.[138] Options for storing electricity include batteries or supercapacitors, energy that is stored in an electric field due to spatial separation of positive and negative charges.[139] Because these options are expensive, net metering is often a more logical choice. For a situation where solar PV is combined with other forms of electricity, it would not make sense to store electricity, but rather draw from other sources of electricity during times when solar generation is inactive or stalled.

As a promising source of renewable energy, there has been a lot of research devoted to solar PV technology and it will continue to improve in the years to come, making solar PV a strong candidate both now and in the future. While solar is rated as less reliable because of its completely reliance on the sun and weather, it ranked well for stable procurement now and in the future for a total ranking of 3.0.

135 Renewable Energy, Harvard University Sustainability, accessed April 4, 2015, http://green.harvard.edu/topics/energy-emissions/renewable-energy.

136 See SimaPro 7 calculations

137 Cindy Hill, The Effects of Temperature on Solar Panel Power Production, accessed April 4, 2015, http://homeguides.sfgate.com/effects-temperature-solar-panel-power-production-79764.html.

138 Net Metering, Solar Energy Industry Associates, accessed April 5, 2015, http://www.seia.org/policy/distributed-solar/net-metering.

139 Matthew Panzer, "How can we effectively store solar energy?" *Tufts Now,* last modified May 13, 2013, http://now.tufts.edu/articles/how-can-we-effectively-store-solar-energy.

Educational Advantage

Table 141: Educational advantage assessment for solar PV

High (2), Medium (1), Low (0)	Score
Students can learn from this energy source and use data from it to understand energy generation.	2
There is visibility on campus and this energy source raises awareness about sustainability.	1
Ability to be a research opportunity to further the interests of students and professors.	2
Informs administrative decisions on scaling up energy production in new technologies (this is most relevant for new technologies).	1
Provides insight and encourages external organizations to replicate forms of uncommon energy production.	1
Total:	**7**

The array of solar panels installed near the athletic fields are already providing a host of educational benefits to the Wellesley College community, and implementing additional solar panels in more prominent locations on campus would further these educational benefits. The 10 kW system that is currently in-use on campus provides real-time data which can be used and viewed publicly. Students have already been able to make use of this data. In the ES220 course, Environmental Limits and Conservation, students use collected data to develop a MATLAB (computing programming language) and model solar generation scenarios on various Wellesley buildings as well as various types of efficiencies. Solar panels could be integrated into the curriculums of many different academic departments focusing on design, sustainability, mathematical models etc.

Additionally, visibility of the panels would raise awareness about issues of sustainability and interest in the sources from which Wellesley generates its power. A larger solar PV array in a visible location on campus could even encourage other schools, business and nonprofits, particularly those in the Boston area, to adopt similar systems. Solar PV cells are common on other college campuses and solar PV is hard to scale-up. Even if Wellesley College covers every building with solar panels, it would only provide a minimal percentage of total electricity. Because of the significant educational benefits provided by solar PV, this electricity generation option scored a total of 7, a high educational advantage.

Greenhouse Gas Emissions

Table 142: Greenhouse gas emissions assessment for solar PV

Impact Category	**Total**
Global Warming	3.57E-6 kg CO2 eq

Global warming was calculated at 3.57E-6 kg CO2 equivalent, with manufacturing and installation contributing at 52% and 47% respectively, along with a small amount of transport. Diesel and energy consumption in the manufacturing phase are also contributors. The need to use fossil fuels to make renewable energies is unavoidable.

Ecotoxicity

Table 143: Ecotoxicity assessment for solar PV

Impact Category	**Total**
Ecotoxicity	0.000989 CTUe

Ecotoxicity was calculated at 0.000989 CTUe, with installation as a major contributor to ecotoxicity (about 70%), followed by manufacturing.

Ecosystem Disruption

Table 144: Ecosystem disruption assessment for solar PV

Low (0), Medium (1), High (2)	Score
Land Disruption - permanent or temporary	1
Water Use	1
Water Contamination	0

Biodiversity disruption (consider both the number of species and the extent of the disruption for species)	1
Total:	**3**

Extraction

Material inputs have a major impact on the surrounding ecosystem. Extraction of natural resources, such as quartz, silicon carbide, glass and aluminum can cause habitat disturbances analogous to sand and gravel pit mining but there is no leaching or precipitation process involving acids.[140]

Manufacturing, Transportation and Use

During the manufacturing and production of solar panels the solid waste production is minimal. However the fabrication of silicon solar cells does require large volumes of high purity water for silicon wafer cleaning. Many plants are designed to minimize water consumption through recycling and all wastewater is treated and monitored prior to discharge under a Department of Environmental Quality (DEQ) water permit.[141]

The ecosystem disruption during use can be minimal depending on where the solar panels are located. Utility scale solar farms, on the other hand, do require large amounts to produce electricity on a commercial scale.[142] For example In the Mojave desert in California, the large solar farm is having a large impact on migratory birds and the desert area that the farm occupies.[143] This fact concerns about the potential impact of such projects on natural habitats, concerns the EPA is working to address by sitting renewable energy projects on contaminated sites and mines.[144] However when panels are located on existing structures or in urban areas, solar panels can have a minimal impact.[145]

The disposal of solar panels can be classified as hazardous due to the lead content from soldering or from glass encapsulation, which has the potential to leach. Since the industry is relatively new the amount of waste generated is currently small but there are initiatives to develop an industry to deal with growing PV waste stream.[146]

140 Life-Cycle Environmental Performance of Silicon Solar Panels, last modified August 2008, http://www.oregon.gov/ODOT/HWY/OIPP/docs/solar_panel_lifecycle.pdf.

141 Life-Cycle Environmental Performance of Silicon Solar Panels, last modified August 2008, http://www.oregon.gov/ODOT/HWY/OIPP/docs/solar_panel_lifecycle.pdf.

142 Positive and Negative Effects of Solar Energy, SFGate, accessed May 15, 2015, http://homeguides.sfgate.com/positive-negative-effects-solar-energy-79619.html.

143 Take a Look at the World's Largest Solar Thermal Farm: When completed in 2013, this series of 170,000 mirrors will power 140,000 California homes, Smithsonian, accessed May 15, 2015, http://www.smithsonianmag.com/science-nature/take-a-look-at-the-worlds-largest-solar-thermal-farm-91577483/?no-ist.

Health

Table 145: Health assessment for solar PV

Impact Category	Total
Respiratory effects	4.18 E-6 kg PM2.5 eq
Carcinogenics	2.5E-4 CTUh
Non-carcinogenics	1.11E-4 CTUh

Carcinogens was calculated as 2.5E-4 CTUh and non-carcinogens was calculated 1.11E-4 CTUh, with the highest impacts in the manufacturing and system installation phases. Respiratory effects was calculated to be 4.18 E-6 kg PM2.5 equivalent. While manufacturing and installation are the most significant contributors to particulate matter, transportation also has a small effect. Most of the causes of human health effects are explained in the section below about Environmental Justice.

Environmental Justice

Table 146: Environmental justice assessment for solar PV

144 Positive and Negative Effects of Solar Energy, SFGate, accessed May 15, 2015, http://homeguides.sfgate.com/positive-negative-effects-solar-energy-79619.html.

145 Life-Cycle Environmental Performance of Silicon Solar Panels, last modified August 2008, http://www.oregon.gov/ODOT/HWY/OIPP/docs/solar_panel_lifecycle.pdf.

146 Life-Cycle Environmental Performance of Silicon Solar Panels, last modified August 2008, http://www.oregon.gov/ODOT/HWY/OIPP/docs/solar_panel_lifecycle.pdf.

Low (0), Medium (1), High (2)	Score
Raw material extraction	2
Manufacturing & Production (refining of fuels, manufacturing of equipment)	1
Transport (all transport phases prior to reaching Wellesley)	1
Generation (at Wellesley or wherever the electricity is generated.)	0
Total:	**4**

The main lifecycle environmental impacts of silicon solar panels come from the production phase and include. Energy consumed during panel production and emissions associated with that energy generation. Water consumption, which is cleaned and returned to the watershed can still produce some hazardous byproducts which are released to the air or recycled and reused in further production processes. Air emissions are routed to pollution control equipment and covered under a department of environmental quality. Wastewater is treated and monitored prior to discharge, both are regulated by the Department of Environmental Quality and the positive impact during panel use and energy generation displaces carbon intensive energy.[147]

In the raw material extraction phase, heavy metal emissions such as sulfur dioxide, nitrogen oxide, and lead are emitted into the local air. Diesel and energy consumption in the manufacturing phase are also contributors. The need to use fossil fuels to make renewable energies is unavoidable.[148]

The main raw silicon cannot be found in a pure state. It must be mined and extracted. From an abundant resource, sand. The majority of silica produced in the US is produced East of the Mississippi River and in the Northwest. We also import silicon from Norway, Russia, Brazil, Canada and other countries.[149] Silica sand is the new gold but residents who live near sand extraction sites are being exposed to silica dust. Dust that can cause lung diseases, including cancer. In Chippewa Falls, Wisconsin residents are worried about silica water in their drinking water and in Midland Texas a silica manufacturing company has bought 155 acres above a creek.[150] Not only is Midland know for its beautiful landscape but having a sand mine near a creek and a town is concerning. Silica exposure in the workplace occurs but the silica dust are the most potent in producing pulmonary inflammation compared with other forms of silica.[151]

Electronic parts are required for solar panel production and they consist mostly of copper. Copper mining waste constitutes the largest quantity of metal mining and processing in the USA. Mining is located mostly in the arid west, with Arizona mining 61% of the domestic copper. Because of the large waste volumes associated with copper extraction, the production and processing facilities are located near one another. Leaching into groundwater, surface water, and soils remain a constant source of stress. For economic and environmental reasons the byproducts of extraction are reclaimed, such as sulfur dioxide gas which is turned into sulfuric acid.[152]

Silicon disks are shiny and require an antireflective coating, usually titanium dioxide. The protective material for the silicon disks consists of encasement of transparent silicon rubber or butyryl plastic (commonly used in automobile windshields) bonded around the cells, which are then embedded in ethylene vinyl acetate. Butyryl plastic, otherwise known as orthophthalates, have been classified as potential endocrine disruptors with developmental toxicity reported. The structure that solar panels need to stand on usually consist of concrete and also contribute to greenhouse gas emissions.

The main manufactures of solar panels in the United States occur in small towns with populations no larger than 40,000 residents. In the majority of towns white residents hold the highest percentage of the population followed by Hispanics, Blacks and Asians.

147 Life-Cycle Environmental Performance of Silicon Solar Panels, last modified August 2008, http://www.oregon.gov/ODOT/HWY/OIPP/docs/solar_panel_lifecycle.pdf.

148 Life-Cycle Environmental Performance of Silicon Solar Panels, last modified August 2008, http://www.oregon.gov/ODOT/HWY/OIPP/docs/solar_panel_lifecycle.pdf.

149 How Products Are Made: Solar Cell, *Madehow.com*, accessed April 15, 2015, http://www.madehow.com/Volume-1/Solar-Cell.html.

150 Josephine Marcotty, "Silica sand is the new gold," *StarTribune*, last modified June 11, 2011, http://www.startribune.com/local/123670439.html.

151 "Silica, Crystalline Forms," Texas Commission on Environmental Quality, last modified October 8, 2009, http://www.tceq.com/assets/public/implementation/tox/dsd/final/october09/silica_crystalline_forms.pdf.

152 Copper Mining and Production Wastes, EPA, last modified December 4, 2014, http://www.epa.gov/radiation/tenorm/copper.html.

The energy and climate payback is significant. The crystalline silicon solar panels generate 9-17x the energy required to produce them and the clean energy payback of a PV system ranges from 1-4yrs. 100% of solar electricity is produced emission free, factoring in emissions due to production 87-97% of the energy is free of pollution and greenhouse gases. Replacing conventionally produced electricity with solar panels results in a 89% reduction in greenhouse gases to the grid. With the production of 1000 kWh of solar electricity the reduction of emissions is 8 lbs or sulfur dioxide, 5 lbs of nitrogen oxide, and 1,4000 lbs of co2.[153]

End of life management of materials, such as recycling technologies for reusing silicon from solar cells, are not commercially available in the US. It would take roughly ⅓ of the energy to make a solar panel with recyclable materials versus using new materials. There are currently strategies being put in place to recover reusable materials from previous solar panels. Currently these practices are not widely used.

Renewable Energy Credits

What is a REC?

Colleges have the option to buy renewable energy credits or certificates ("RECs") as a means of investing in green energy. A REC represents 1,000 kWh, or 1 megawatt hour, of electricity produced by green sources, including solar PV, wind, geothermal, and certain types of hydropower, biomass and hydrogen fuel cell-derived electricity.[154] Although the actual electricity is produced and consumed remotely, purchasers of RECs get the credit for environmentally-friendly generation. Some of the main advantages to buying RECs include contributing to the development of additional green power, demonstrating a commitment to sustainability, protecting against fluctuating energy prices by entering into a long-term contract, providing educational benefits and lowering institutional GHG emissions.

Selling RECs is another possibility for green energy produced on college campuses. Selling RECs is a way to defray the costs of producing green power, and increases the payback time of costly installations and systems; people/institutions often turn to RECs to finance green power initiatives, particularly when starting out. Selling RECs, as the opposite of buying, means that producers of green power, who consume the green electricity directly, receive money but waive the right to any of "environmental good" produced by the system. While selling RECs means that a college could not count their green electricity as a reduction in GHG emissions, for example, green energy on campuses still provides educational benefits for students, demonstrates a school's' commitment towards sustainability and provides an overall net increase in the capacity of green power.

Generating electricity via solar PV brings about the option of selling SRECs, or Solar Renewable Energy Credits. Each SREC acts as a certificate that represents the environmental benefits of producing one megawatt-hour of electricity using solar PV and can be bought and sold.[155] Selling SRECs may help finance a solar PV system or help with payback.

How does it work?

There are two main markets for RECs: the voluntary market and compliance market. The voluntary market is for customers--such as colleges--who choose to buy RECs out of a desire to support renewable energy. The compliance market, where customers are mandated to purchase a particular amount of RECs, is usually determined on a state-by-state basis.

Some states have programs dealing with RECs, and Massachusetts is among these. The Massachusetts Renewable Energy Portfolio Standard mandates that power companies either use a certain percentage of renewable energy on-site or deliver it to the grid, or, alternatively, purchase RECs. In 2014, for example, power suppliers were required to purchase RECs totaling to 9% of their overall load in Massachusetts in order to comply with the standard, and this percentage is set to increase by one percent each year.[156]

153 Life-Cycle Environmental Performance of Silicon Solar Panels, Oregon Government, last modified August 2008, http://www.oregon.gov/ODOT/HWY/OIPP/docs/solar_panel_lifecycle.pdf.

154 Buy Green Power, Association for the Advancement of Sustainability in Higher Education, accessed April 19, 2015, http://www.aashe.org/wiki/cool-campus-how-guide-college-and-university-climate-action-planning/54-buy-green-power.

155 Solar Renewable Energy Credits or SRECs, SunBug Solar, accessed April 5, 2015, http://sunbugsolar.com/why-solar/srecs.

156 RPS and APS Program Summaries, *EPA*, accessed April 30, 2015, http://www.mass.gov/eea/energy-utilities-clean-tech/renewable-energy/rps-aps/rps-and-aps-program-summaries.html.

Massachusetts has created a specific program/market for solar RECs or SRECs with the SRECII program. This program represents a second phase of MA's solar carve-out program and is designed to support a market for SRECs in Massachusetts until 1,600 MW of PV capacity have been reached statewide. This program is actively accepting new applications for new solar PV facilities and their sales of SRECs.[157] SRECs are sold on the market, with the price influenced by the rate of "Alternative Compliance Payments," or the cost per megawatt hour that a power company must pay if they do not achieve their obligation to the portfolio standard.[158] The price for SRECs is set under by the Massachusetts Department of Energy Resources (DOER), the department in charge of administering the marketplace. Under the Alternative Compliance Payment for utilities in 2015, each SREC is currently set at $375. (Note that these rates are set to drop each year.)[159]

Advantages and Disadvantages of RECs

The University of Pennsylvania is one of the largest purchasers of RECs among institutes of higher education. In 2013, UPenn signed a five-year contract to purchase 200 million kWh worth of wind RECs annually, offsetting over 50% of their total electricity consumption.[160] UPenn's heavy investment in the wind power sector helped to finance the construction of a new 12-turbine, 20-MW wind farm in Pennsylvania, thus increasing the production capacity of the green energy sector.[161] Georgetown University, too, buys RECs--over 150 million kWh per year--and does so from a variety of sources, not simply in the wind sector.

Princeton University is an example of a school who sells RECs, specifically solar or SRECs. In 2011, Princeton began the construction of a 5.3 megawatt PV system that has the potential to provide 5.5% of Princeton's total electricity. The 16,500 panels comprise one of the largest solar installations at a U.S. college or university, and the system is expected to reduce Princeton's spending on electricity by about 8%.[162]

The university is leasing the system for the first eight years in order to take full advantage of both federal incentives and New Jersey's SREC program. During this time, Princeton plans to sell SRECs in order to pay for the lease. Princeton will not claim any greenhouse gas emission reductions until 2020 when the school plans to stop selling SRECs and retire them instead, allowing the university to use the PV system to claim greenhouse gas reductions to meet its Sustainability Plan and greenhouse gas emission standards adopted by the College in 2008.[163] Similarly, another college that is selling SRECs is Stonehill College, a college outside of Boston. The school is leasing a 2.7 MW PV system that will provide 20% total electricity for the College, taking advantage of both federal tax incentives and the SRECII program in MA.[164]

Some critics, however, are skeptical about the usefulness of RECs and argue that the purchase of RECs in particular provides little other than bragging rights. Ideally, the purchase of RECs would allow for or cause an increase in the production capacity of the green energy sector, rather than simply paying for the bragging rights for greenhouse gas emission reductions that would have occurred regardless of the purchase.[165] This may be difficult to discern when buying

summaries.html.

157 RPS and APS Program Summaries, *EPA*, accessed April 30, 2015, http://www.mass.gov/eea/energy-utilities-clean-tech/renewable-energy/rps-aps/rps-and-aps-program-summaries.html.

158 "Current Status of the Solar Carve-Out II Program," Energy and Environmental Affairs, *MA Office of Energy and Environmental Affairs,* accessed April 5, 2015, http://www.mass.gov/eea/energy-utilities-clean-tech/renewable-energy/solar/rps-solar-carve-out-2/current-statis-solar-carve-out-ii.html.

159 "Current Status of the Solar Carve-Out II Program," Energy and Environmental Affairs, *MA Office of Energy and Environmental Affairs,* accessed April 5, 2015, http://www.mass.gov/eea/energy-utilities-clean-tech/renewable-energy/solar/rps-solar-carve-out-2/current-statis-solar-carve-out-ii.html.

160 Conserving Energy, University of Pennsylvania, accessed April 20, 2015, http://www.upenn.edu/sustainability/sustainability-themes/conserving-energy.

161 Partner Profile, EPA, accessed May 15, 2015, http://www.epa.gov/greenpower/partners/partners/universityofpennsylvania.htm.

162 Ruth Stevens, "Princeton to install powerful solar collector field," *News at Princeton*, last modified Feb. 2, 2011, accessed May 15, 2015, http://www.princeton.edu/main/news/archive/S29/66/01I62/index.xml?section=topstories.

163 Ruth Stevens, "Princeton to install powerful solar collector field," *News at Princeton*, last modified Feb. 2, 2011, accessed May 15, 2015, http://www.princeton.edu/main/news/archive/S29/66/01I62/index.xml?section=topstories.

164 One of Nation's Largest College Campus Solar Fields Being Built at Stonehill, Stonehill College, accessed April 30, 2015, http://www.stonehill.edu/news-media/news/details/one-of-nations-largest-college-campus-solar-fields-being-built-at-stonehill/.

165 Buy Green Power, Association for the Advancement

RECs through the marketplace, and the process may prove more transparent when entering into contracts with green power companies directly.

Jay Turner, a professor of Environmental Studies at Wellesley, mentioned the difficulties, in general, of justifying purchases of RECs because it is money that is spent off campus; rather, there is a preference for money that is invested in on-campus sustainability measures, including infrastructure upgrades and conservation efforts. Bowdoin College previously purchased RECs through an investment in a wind project, but decided to discontinue their purchase of RECs for a similar reason, stating that the money previously used to purchase renewable energy credits would instead be put towards expanding on-campus efficiency and renewable energy projects.[166]

of Sustainability in Higher Education, accessed April 19, 2015, http://www.aashe.org/wiki/cool-campus-how-guide-college-and-university-climate-action-planning/54-buy-green-power.

166 Annual Greenhouse Gas Emission Inventory, Bowdoin College, last modified November 7, 2014, accessed May 15, 2015, http://www.bowdoin.edu/sustainability/pdf/2014-ghg-emissions-update.pdf.

Lin, Soe. *Wellesley College, Waban Lake, Sigma DP2s.* April 2, 2010. Flickr.com

Metrics Across Options Comparisons

Cost

Financial considerations will always be prominent in the College's decision-making processes. Investing in energy generation technology is very costly. We used a life cycle cost calculation called Levelized Cost of Energy (LCOE) to weigh the costs an energy generation method would incur over its lifetime. The total cost is then divided by the amount of kilowatt-hours of energy the generator would produce in its lifetime. The unit of our cost comparison is cost/kWh.

To calculate LCOE we made a series of assumptions based on information we gathered from OpenEI, an open source energy database, and the U.S. Energy Information Administration. These assumptions are detailed in the explanation of the cross metric on page 15.

<u>Heat Cost Analysis</u>

Our LCOE calculations show that heat from No. 2 fuel oil is the most expensive at $0.41/kWh. No. 6 is the second most expensive heat source at $0.29/kWh, followed by geothermal heat at $0.10/kWh. The second cheapest of our options is natural gas at $0.09/kWh. Our cheapest heating option is solar hot water at $0.07/kWh.

Even with the non-existent overnight capital cost, No. 2 and No. 6 fuel oil are more expensive than both renewable energies. This is due to the high fuel costs of No. 2 and No. 6. Natural gas is comparatively inexpensive because not only are the overnight capital costs non-existent, but natural gas as fuel is currently very inexpensive. Renewables have no fuel costs.

Given our assumptions of the longevity of our current power plant, after five years the college will have to buy a new cogeneration plant. If the power plant is improved in any way then it will need to be completely re-permitted. The College will not be able to use no. 6 fuel oil after the re-permitting process. In order to use No. 2 fuel oil, the boilers would need to be retrofitted. This process will increase the overnight capital cost of No. 2 and natural gas from zero. The cost of natural gas is likely to increase in the future as regulations on hydraulic fracturing become more stringent.[1] These considerations make the cost of No. 6 less relevant in the long term and suggest that the LCOE of No. 2 and natural gas are probably negatively biased in our estimates.

In this scenario natural gas is cheaper than geothermal energy. In five years, when overnight capital costs and fuel costs of natural gas increase, geothermal night become the more economical option. Our other renewable option, solar hot water, has the lowest LCOE. Its cost would decrease further if government tax incentives were included in our LCOE calculations. While it is unrealistic that solar hot water could be scaled up to 100% on our campus, it is possible to implement it incrementally all over campus as a supplementary heat source.

<u>Electricity Cost Analysis</u>

We calculated the LCOE for purchasing grid electricity to be $0.05/kWh, $0.09/kWh for purchased green grid energy, $0.04/kWh for natural gas, $0.02/kWh for wind , and $0.03/kWh for solar PV. Our calculations tell us that the lifetime costs of electricity for wind are cheapest, followed by solar PV and natural gas. Purchasing grid electricity is the second most expensive option, and purchasing green grid electricity is the most expensive option. While purchasing our energy demands little in terms of our on-campus resources, it dramatically increases the cost of energy per kWh. Wind and solar electricity generation requires the highest upfront costs, but ends up having lower a LCOE because of relatively low fixed and variable operating costs.

We also want to note that the cost of purchasing grid or green grid energy would be more expensive if we scaled it up to 100% because we would have to pay on-peak prices. Natural gas will become more expensive in the future because the upfront costs will increase when we need to buy a new cogen plant. Natural gas will likely become a more expensive option if fuel prices increase because of increased government regulation of hydraulic fracturing. The costs of wind and solar PV per kWh would decrease even more from these LCOE calculations if government tax incentives

1 Davenport, Coral, "New Federal Rules Are Set for Fracking," New York Times, March 20, 2015.

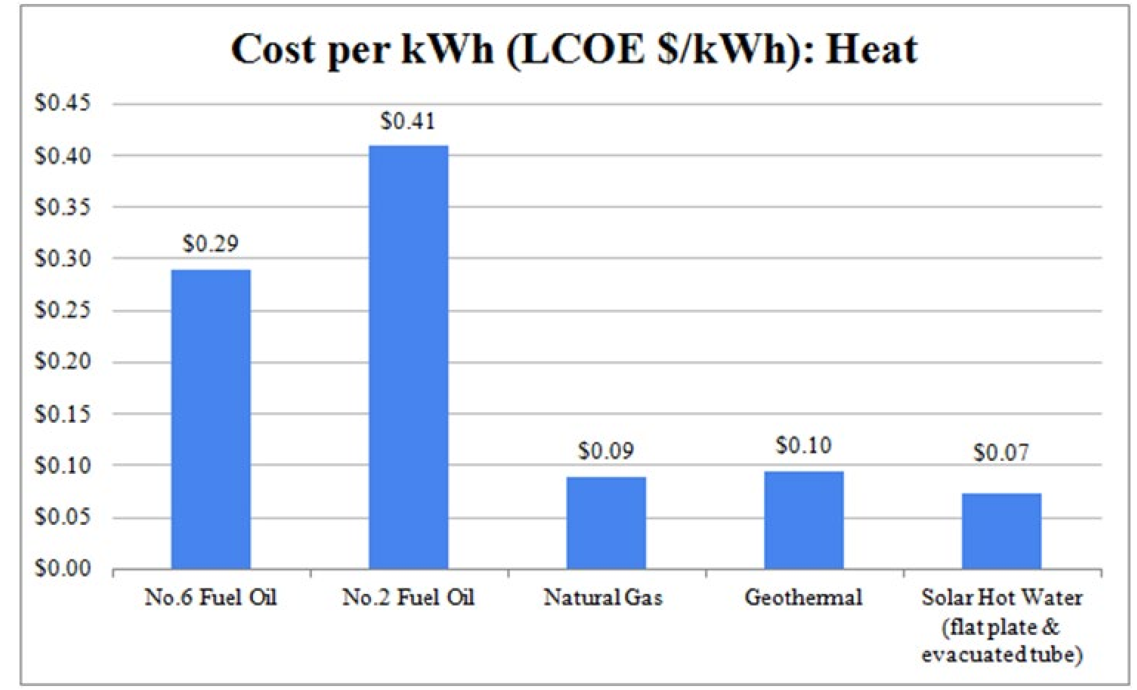


Figure 39:Levelized Cost of Energy for Heat Options

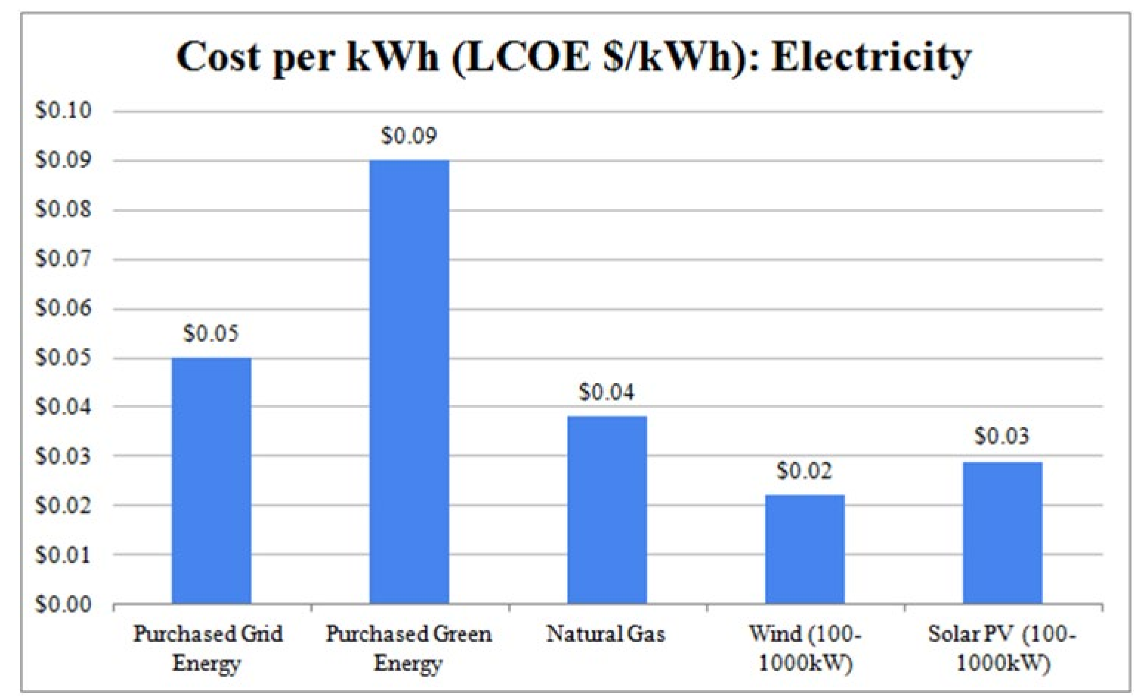


Figure 40:Levelized Cost of Energy for Electricity Options

were included. The college has agreed to use at least 5% renewable energy to help the Town of Wellesley meet its Green Power Community goal. By producing wind and solar energy on campus we would be meeting our 5% obligation to the town, but would not have to purchase the expensive green grid energy we are currently buying from the Wellesley Municipal Light Plant.

Table 147: Levelized Cost of Energy for Heat Options Breakdown for overnight capital cost, fixed operating cost, and variable operating cost.

Source (Data from 2009-2014)	Overnight Capital Cost ($/kW)	Fixed Operating Cost ($/kW-yr)	Variable Operating Cost ($/kW-yr)
No.6 Fuel Oil	$0.00	$6.20	$0.0035
No.2 Fuel Oil	$0.00	$6.20	$0.0035
Natural Gas	$0.00	$6.20	$0.0035
Geothermal	$6,846	$222.98	$0.0170
Solar Hot Water (flat plate & evacuated tube)	$9,800	$71.00	$0.003

Table 148: Levelized Cost of Energy for Electricity Options Breakdown of overnight capital cost, fixed operating cost, and variable operating cost.

Source (Data from 2009-2014)	Overnight Capital Cost ($/kW)	Fixed Operating Cost ($/kW-yr)	Variable Operating Cost ($/kW-yr)
Purchased Grid Energy	$0.00	$0.00	$0.0035
Purchased Green Energy	$0.00	$0.00	$0.0035
Natural Gas	$1,318	$6.20	$0.0035
Wind (100-1000kW)	$1,800	$18	$0.01
Solar PV (100-1000kW)	$4,303	$30	$0.00

Reliability

Reliability

Reliability is important for Wellesley College because variable energy supply is undesirable for students, faculty, and staff. ES 300 scored reliability for each energy generation by answering yes or no questions listed below.

- Can it be provided uninterrupted?
- Can it be stored?
- Is it available short-term (until 2025)?
- Is procurement stable (not volatile) in the long term?
- Is it independent of weather?
- Can you ramp it up/down to meet fluctuating energy demand?

Heat Reliability Analysis

Our scoreboard reveal that no.6 fuel oil, one of the heat options we are currently using on campus, is the most reliable. In terms of technology, no.6 fuel oil will only be available to us as long we don't upgrade the power plant. We must upgrade the power plant soon, as it is quickly approaching its lifetime. So while it produces heat reliably, we cannot use it in the future. No.2 fuel oil is very reliable. Natural gas is less reliable because it may not be readily available in the long term due to increasing fracking regulations. Natural gas also cannot not stored.

Geothermal is ranked second most reliable energy source because the energy comes from the earth's core heat energy, which exists at a constant gradient year round. The main component it lacks is storage. Solar Hot Water is the least reliable due to weather dependency, so we recommend using it supplementally to another heat source.

Electricity Reliability Analysis

Overall, the grid options are the most reliable. Natural Gas is less reliable because, as stated previously, it may not be readily available in the long term and cannot be stored. Wind is the least reliable because it is weather dependent, cannot be ramped up to meet fluctuating demands, and the electricity cannot be stored. Wind would be used to supplement other electricity sources. Like Wind, Solar PV is also weather dependent, so it would be interrupted. Solar PV can be stored, but for only maximum three days.

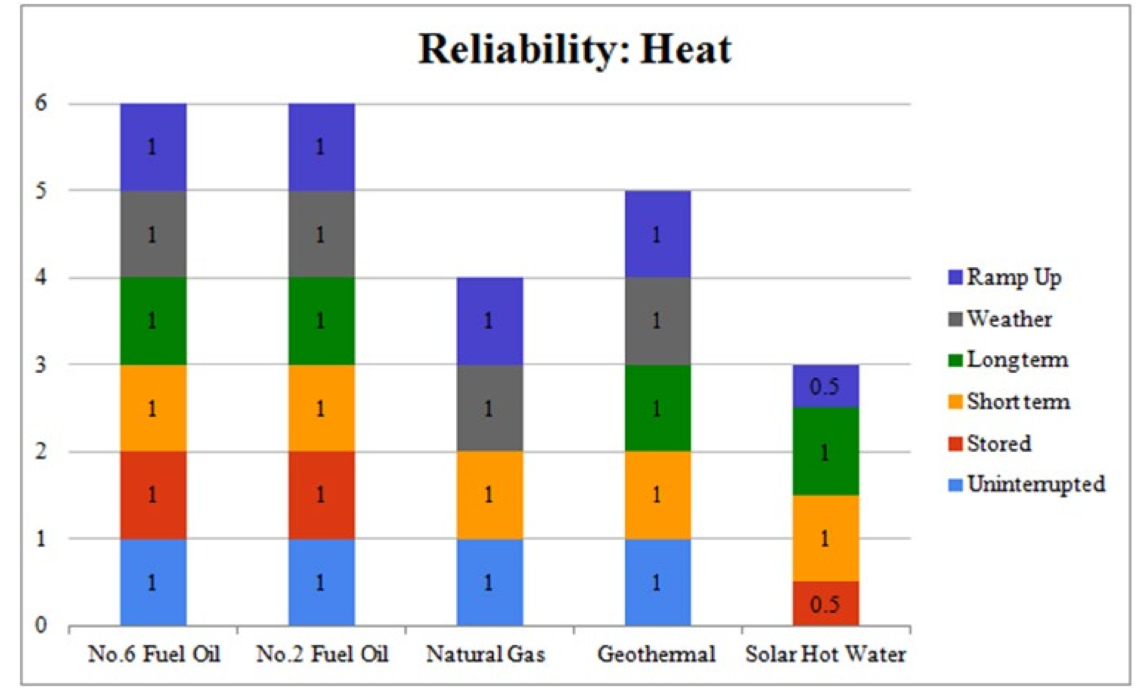


Figure 41: Reliability for Heat Options

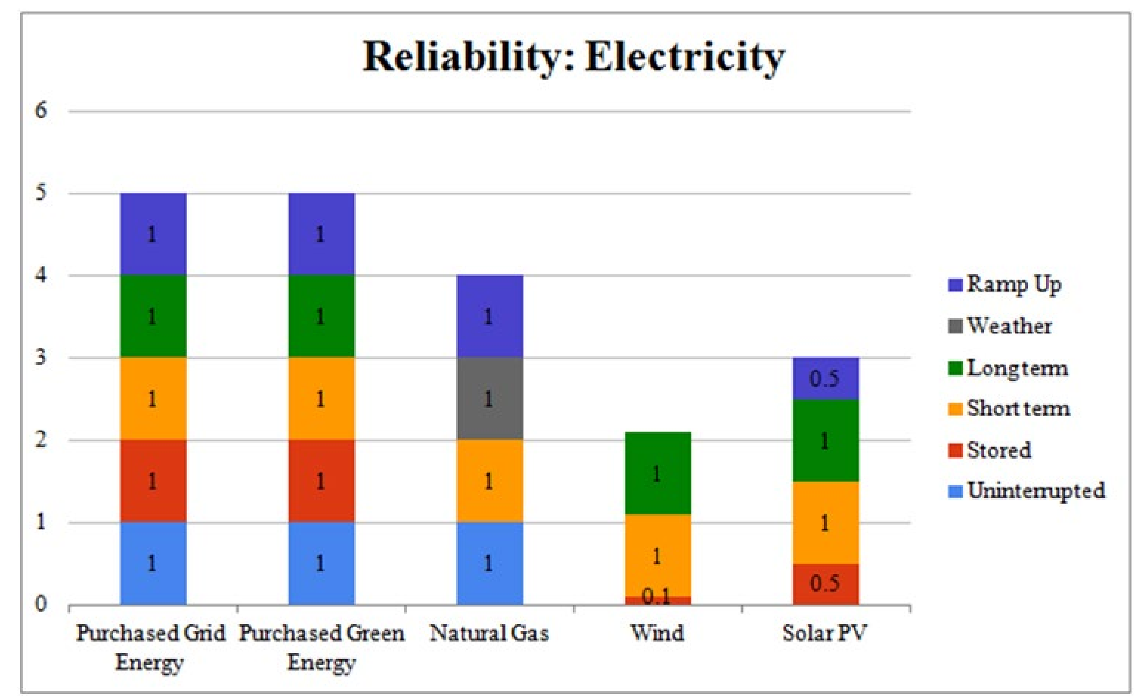


Figure 42:Reliability for Electricity Options

Educational Advantage

Since the establishment of Wellesley College, the institution's purpose is to educate. The energy options we choose will provide means to educate students, staff, and faculty. We ranked the education advantage of each energy option with a point-scale method. For each option, we asked the questions listed below.

- Can students learn from the energy source and use data from it to understand energy generation?
- Is there visibility on-campus and raises awareness about sustainability?
- Does it have the ability to be a research opportunity to further the interests of students and professors?
- Does it inform administrative decisions on scaling up energy production in new technologies?
- Does it provides insight and encourages external organizations to replicate forms of uncommon energy production?

Heat Educational Advantage Analysis

No. 6 fuel oil, no.2 fuel oil, and natural gas are all ranked similarly for educational advantage because the energy generation system is currently used on campus, so these fuel sources do not provide a new model or other college campuses, are not informative for the administration, and are not highly visible. Geothermal is ranked high for educational advantage because it is a unconventional system which would be a model for others, provide information for the administration, and allow for abundant student and faculty learning. However, the geothermal ground source heat pump system would mostly be underground, so it is not visible to the student body. Lastly, solar hot water is also ranked well on the educational advantage score sheet because like geothermal, it is different and informative. Unlike geothermal, solar hot water would be more visible if placed on rooftops.

Electricity Educational Advantage Analysis

Purchased grid and natural gas are ranked low for educational advantage because these are conventional electricity generation systems. Purchased green grid is ranked slightly higher because Wellesley College has never relied solely on green grid electricity would provide information for the administration. Wind is ranked the most educational advantageous for the electricity options because it answers all the questions with a yes. Solar PV also meets most of the categories, but since we already have solar on campus, it does not bring new information to the administration.

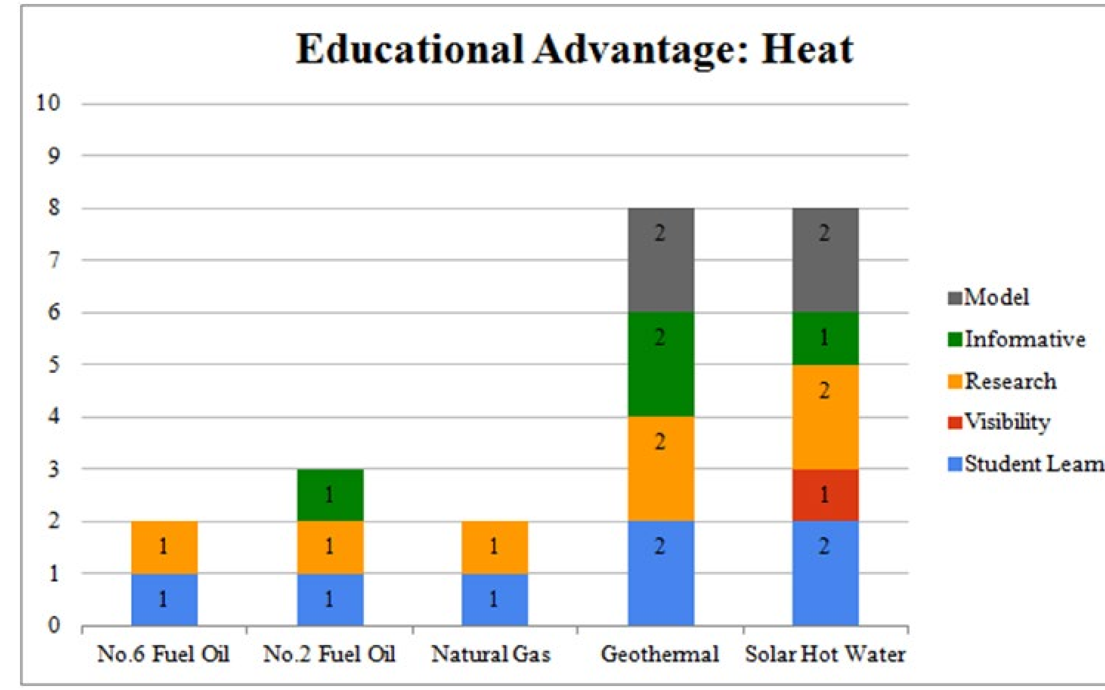


Figure 43: Educational Advantage for Heat Options

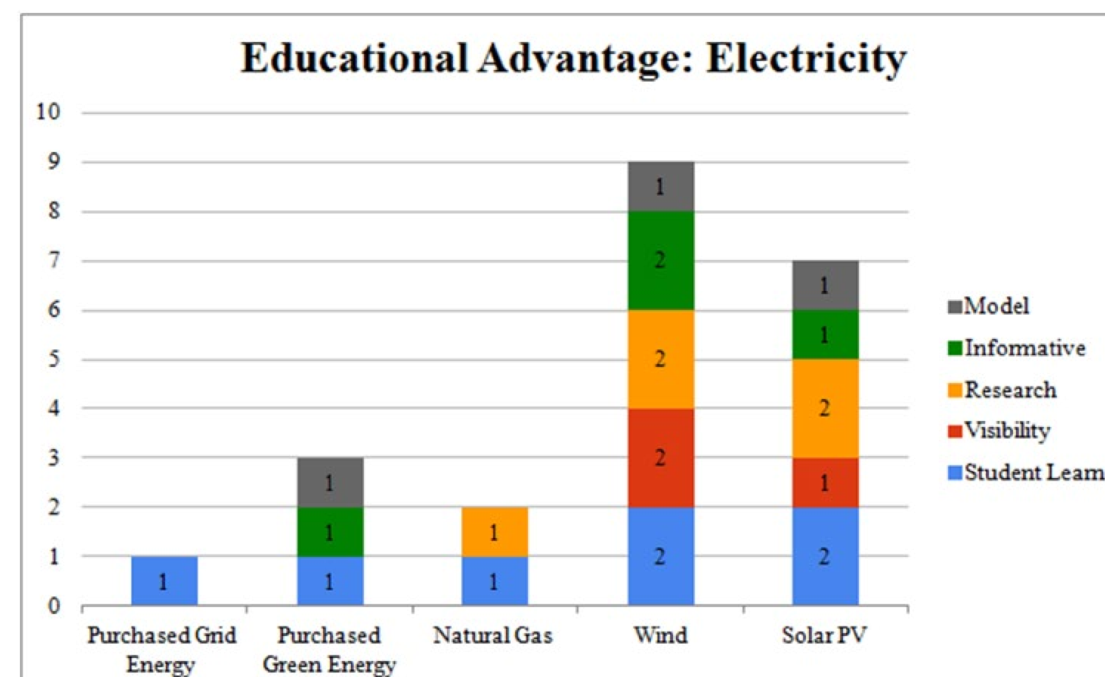


Figure 44: Educational Advantage for Electricity Options

Greenhouse Gas Emissions

Greenhouse Gas

As the College and the world become more concerned with climate change it is important to take the greenhouse gas emissions of energy into consideration. We measured greenhouse gas emissions on the life cycle analysis software SimaPro 7. We specified the energy generation type, and the software estimated the tons of CO_2 equivalent emissions per kWh of consumed energy.

Greenhouse Gas Heat Analysis

The greenhouse gas emissions of producing heat are highest when the college uses no. 6 fuel oil, no. 2 fuel oil, and natural gas. Geothermal produced heat only uses about 60% of the other options. Solar hot water generates very few greenhouse gas emissions.

No. 6 fuel oil and no. 2 fuel oil are both energy intensive in the extraction, refining, and transporting processes. They both emit CO_2 when burned. no. 6 fuel oil requires more energy than no. 2 fuel oil because it is so more sludgy and it needs to be heated when it is in storage.

Natural gas is usually considered a fairly clean method of generating energy because it burns cleanly. When considering the entire lifecycle of natural gas, however, this fuel type does not fare well. Natural gas extraction is a very energy intensive process that involves drilling miles underground and pumping highly pressurized water and chemicals into the well. Methane, the primary component of natural gas, is also a very strong greenhouse gas. It has four times the greenhouse gas potential of CO_2.[2] When methane is being transported via pipeline to power plants there are leaks where methane escapes into the atmosphere. Once the entire life cycle of natural gas is taken into consideration it turns out to be a less clean option than people typically imagine; in fact, using natural gas involves nearly as much greenhouse gas emissions as using fuel oil.

Geothermal energy is renewable but scores relatively less well than our other renewable energy source. It takes electricity to pump fluid throughout system. SimaPro 7 assumes that the electricity used to run the system is produced at a cogeneration plant that runs on either no. 2 or natural gas fuel, both of which emit greenhouse gases.

Solar hot water scores extremely well, with very little emissions associated with heat production. All in all, it is unsurprising that the renewable energy sources scored so much better than the fossil fuel sources. Reducing greenhouse gas emissions of energy generators are one of the primary drivers of developing new technologies.

Electricity Greenhouse Gas Analysis

The greenhouse gas (GHG) emissions are highest for purchased grid energy, then natural gas, solar PV, purchased green energy, and wind power. Purchased grid energy is highest because it is made up of over 50% natural gas and includes even more greenhouse gas polluting electricity sources like coal. Natural gas closely follows as the second most greenhouse gas emitting option because of the energy intensive extraction process and the frequent gas pipe leaks that allow methane to escape into the atmosphere.

The greenhouse gases associated with solar PV and wind come from the extraction and manufacturing states of the panels and turbines. Purchased green energy is made up of landfill gas, hydropower, and wind energy. Its greenhouse gas emissions are proportional to the emissions in each of those sectors. Hydropower has high upfront emissions in the building of dams, but low throughout the lifecycle of a dam. Landfill gas is similarly energy intensive during the manufacturing stage of the landfill, but is actually considered GHG negative during its use phase because by converting the landfill gas into electricity it is averting methane emissions that would have been released into the atmosphere.

Solar PV, purchased green energy, and wind power all have relatively low levels of greenhouse gas emissions. Similar to our analysis in the heat section, this is largely due to the fact that these renewables are created in part with the intention of lowering greenhouse gas emissions.

2 Natural Gas, U.S. Environmental Protection Agency, accessed on May 3, 2015, http://www.epa.gov/cleanenergy/energy-and-you/affect/natural-gas.html.

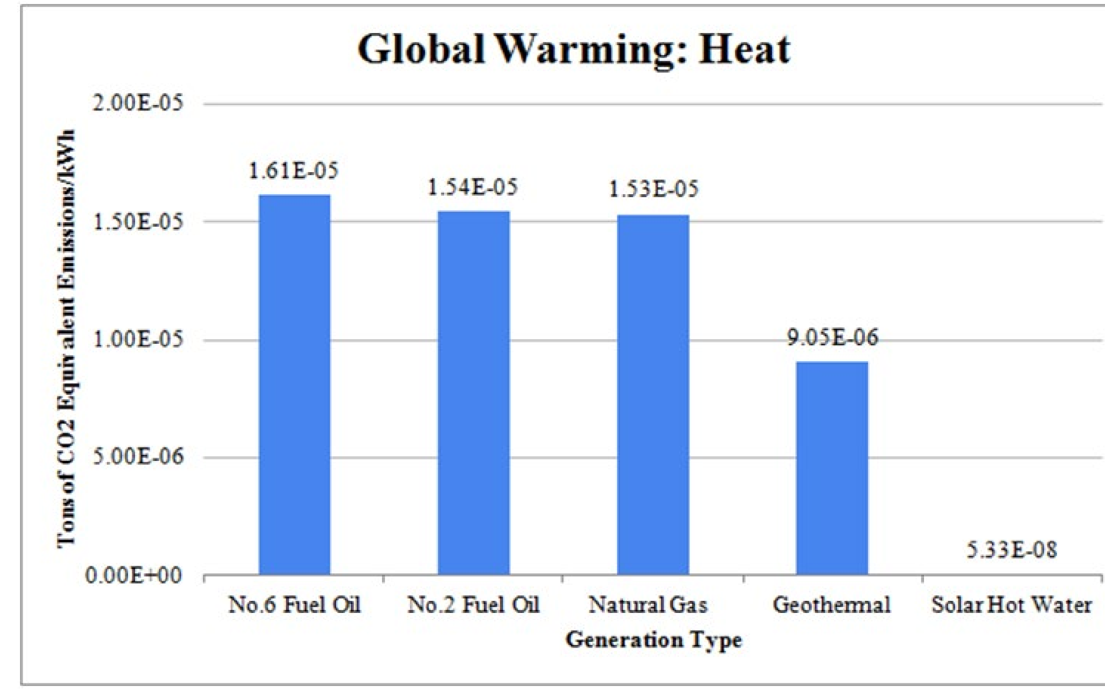


Figure 45: Greenhouse Gas Emissions for Heat Options

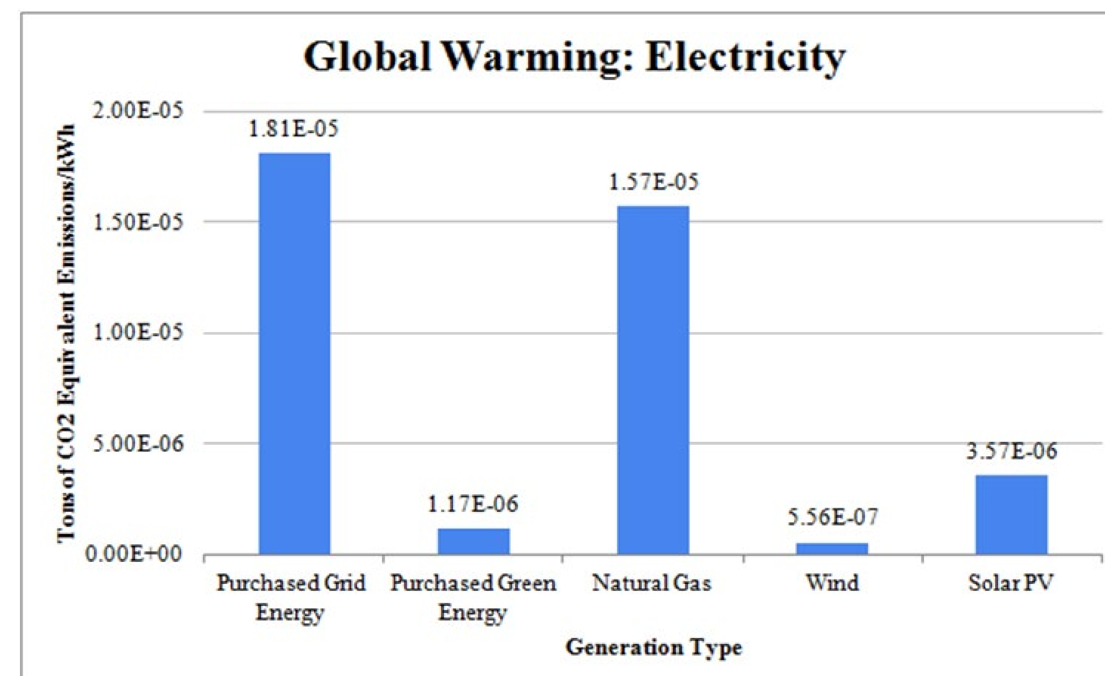


Figure 46: Greenhouse Gas Emissions for Electricity Options

Ecotoxicity

Ecotoxicity measures the potential biological, chemical, or physical stressors on a ecosystem due to the generation of an energy source. It is important to measure ecotoxicity because the effects of contaminants may have long-lasting effects on an environment. We measured ecotoxicity with SimaPro 7 which a software that normalizes the impacts of various chemicals using TRACI2, and quantifies ecotoxicity as an herbicide. It is measured in CTUe or Comparative Toxic Units. It is an estimate of the potentially affected fraction of specifies.

Heat Ecotoxicity Analysis

The SimaPro 7 results reveal that natural gas is the biggest ecotoxicity contributor. We expect that fracking for extraction and wastewater leakages throughout the lifecycle provide a far-reaching exposure pathway, through waterways out into the environment. No.6 fuel oil and no.2 fuel oil are the next highest, respectively, followed by geothermal, and finally solar hot water, which is 16 times less ecotoxic than natural gas.

Electricity Ecotoxicity Analysis

Solar PV is the most ecotoxic of the electricity options. The majority of this ecotoxicity mostly likely comes from the extraction and manufacturing phases where silica and various metals are mined and refined using a host of chemicals. Many chemicals leach out from the extraction site and manufacturing plant into surrounding areas, including into soil and water sources.

Solar PV is followed by wind. Similar to Solar PV, the majority of ecotoxicity probably occurs with the extraction of raw materials and manufacturing phases. Wind turbines are made of various materials, including steel, fiberglass, copper, concrete, adhesives, and aluminum, all of which require extraction, processing and refining. The mining of metals is an environmentally-destructive process where exotoxic chemicals can be released. Purchased Green Energy, Natural Gas and Purchased Grid Energy have comparatively low ecotoxicity.

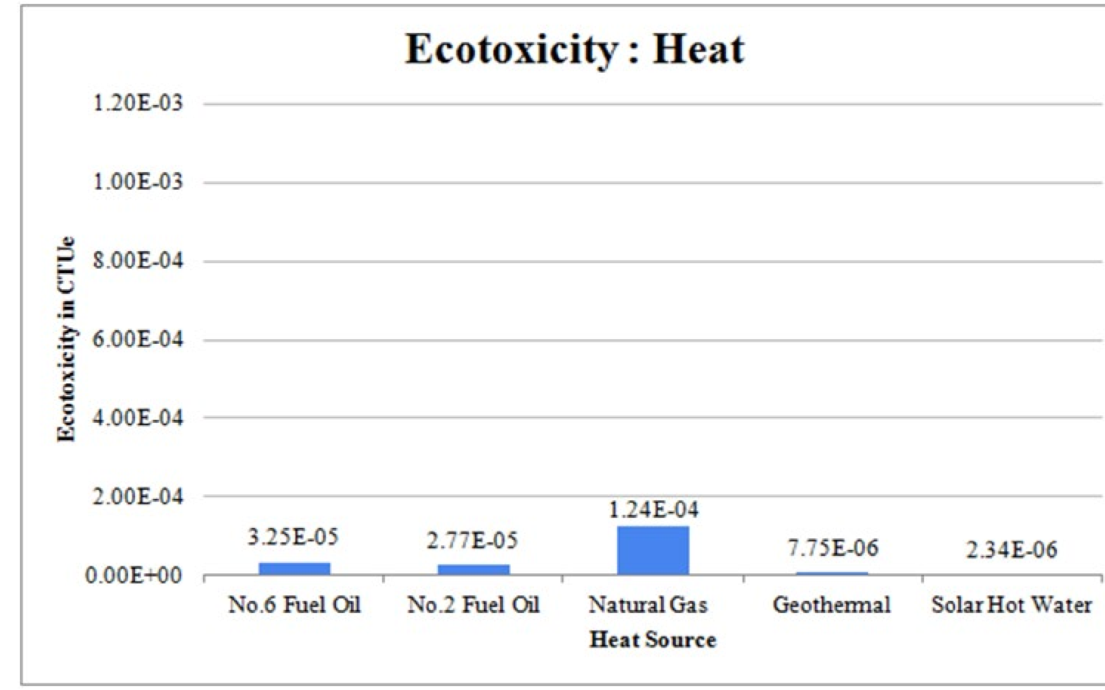


Figure 47:Ecotoxicity for Heat Options

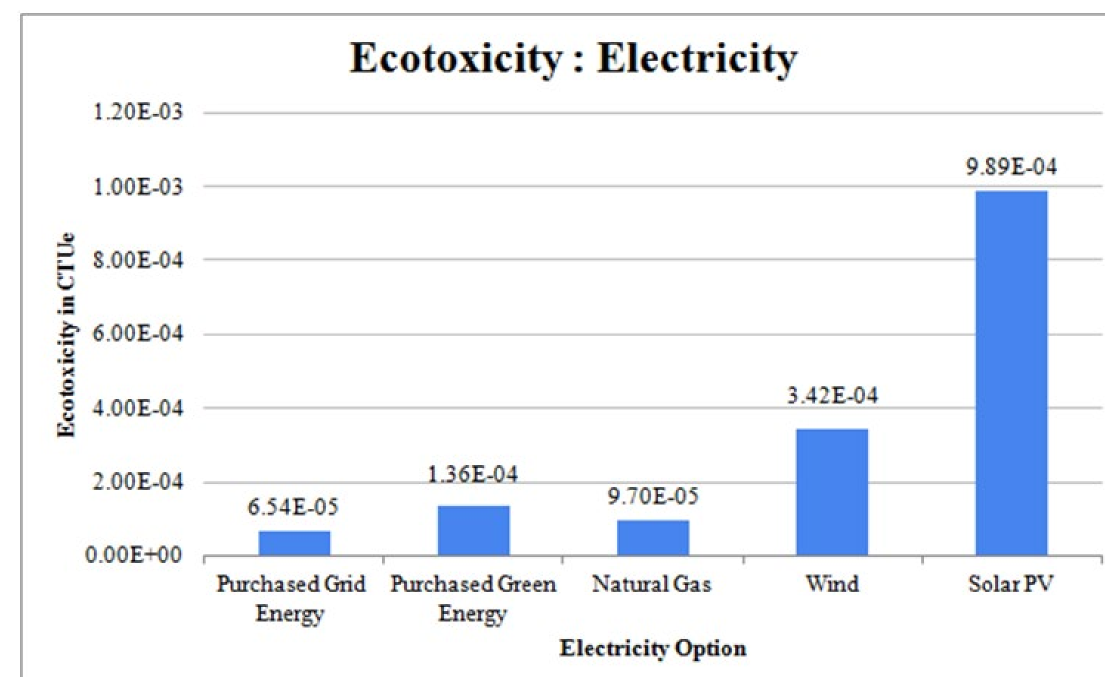


Figure 48: Ecotoxicity for Electricity Options

Ecosystem Disruptions

In order to analyze environmental harms that were occurring outside of the realm measured in SimaPro 7, we created our own metric to quantify other environmental problems. We measured land disruption, water use, water contamination, and biodiversity loss across the entire life cycle. We did research for each energy source and then rated on a low (0), medium (1), high (2) scale for each of the four ecosystem disruption areas of interest. Then we summed the numbers to determine the level of ecosystem disruptions associated with that energy source. We consider all life cycle phases, but then weigh the disruption based on its severity, prevalence across life cycle phases, and recurrence in the creation of heat. For example no. 6 fuel oil and geothermal both contaminate water during extraction phases. No. 6 fuel oil, however, scores worse because the extraction phase is persistent throughout the use of no. 6 fuel oil, whereas mining for geothermal happens once (to manufacture pipes) in the entire lifetime of the geothermal infrastructure.

The definitions for each ecosystem impact are listed below.

- Biodiversity disruptions defined as: negative shocks on the total number of species or the number of organisms within species in an affected area
- Water contamination defined as: contamination to neighboring bodies of water that are not being directly used. This often occurs because of chemical leaks or runoff.
- Water use defined as: use of water to the point that it is changed from its natural quality
- Land-use defined as: permanent or temporary changes in the natural land
- We consider all life cycle phases, but then weigh the disruption based on its severity, prevalence across life cycle phases, and recurrence in the creation of heat. For example No. 6 Fuel Oil and Geothermal both contaminate water during extraction phases. No. 6 Fuel Oil, however, scores worse because the extraction phase is persistent throughout the use of No. 6 Fuel Oil, whereas mining for geothermal happens once (to manufacture pipes) in the entire lifetime of the geothermal infrastructure.

Heat Ecosystem Disruptions Analysis

There are the most ecosystem disruptions in the life cycles of no. 6 fuel oil and no. 2 fuel oil. Natural gas causes the next most ecosystem disruptions. Solar hot water causes the fourth most ecosystem disruptions. Geothermal heat causes the least ecosystem disruptions.

No. 6 and no. 2 fuel oil are disruptive to land because of the drilling, extraction, and transportation processes. Oil wells and oil refineries rely heavily upon water to force oil from underground to the surface. The water is infused with chemicals and, once used, is discarded into neighboring bodies of water. Water contamination is highly prevalent during the extraction phase and transportation phases for the fuel oils because chemical waste or oil itself have the potential to contaminate bodies of water. Water contamination can also happen because of acid rain caused by the SO_2 released from burning no. 6 fuel oil. The habitat loss, oil spills, and climate change also pose serious threats to biodiversity.

The gravest ecosystem disruption associated with natural gas is the hydraulic fracturing process. It disrupts land at the extraction site. It uses significant amounts of pressurized water to release the gas. Large underground water sources can and have been extremely contaminated due to chemicals leaking through well walls and waste water holding facilities.

Solar hot water requires solar cells. The cells are made from mined materials like silica that necessitate intensive land and water use. There is potential for water contamination at the extraction and refining sites for these minerals. Biodiversity is threatened during the mining and refining phases because of habitat loss.

Geothermal energy requires a pipe-based circulatory system on campus that necessitates mined materials and disrupting the campus to bury the lines. Both processes are limited to once in the lifetime of the system, so they score relatively low on ecosystem disruptions.

Electricity Ecosystem Disruption Analysis

Purchased grid energy has the most ecosystem disruptions, followed by purchased green energy and natural gas. The electricity generating options with the fewest ecosystem disruptions are wind and solar PV.

Natural gas poses the most ecosystem disruptions during the hydraulic fracturing stage with significant water use, biodiversity threats, and poor land use practices. Purchased grid Energy is composed of over 50% natural gas. It also includes electricity from more disruptive sources like hydropower and coal.

Purchased green energy is comprised of hydropower, landfill gas, and wind energy. The land use practices of hydropower entail significant land and water alternations and threaten the native biodiversity in those areas. Extracting the resources for wind turbines relies heavily on water. Water contamination happens frequently in landfills when the lining around the landfill leaks into the surrounding soil and groundwater.

Similar to solar hot water, solar PV requires the mining of earth minerals. There are harmful land use implications of mining, as well as a heavy reliance of water, and high frequencies of contamination. Since these harms are limited to the one-time production of the solar cells, they do not score as highly as the harmful fuel extracting options that are maintained throughout the use of those options.

Figure 49: Ecosystem Disruption for Heat Options

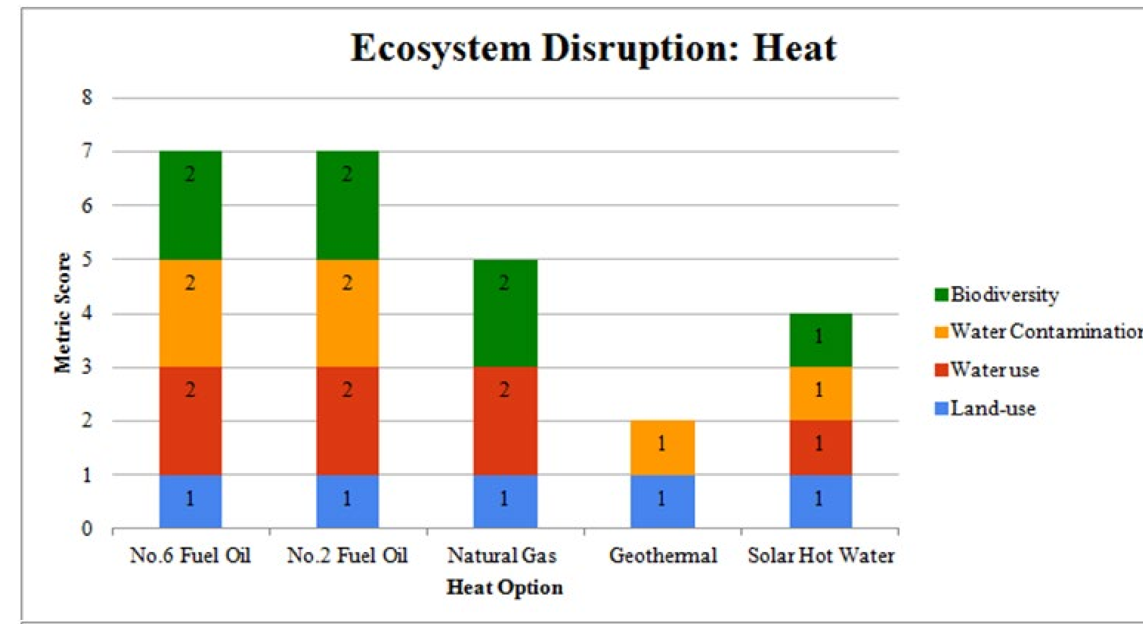
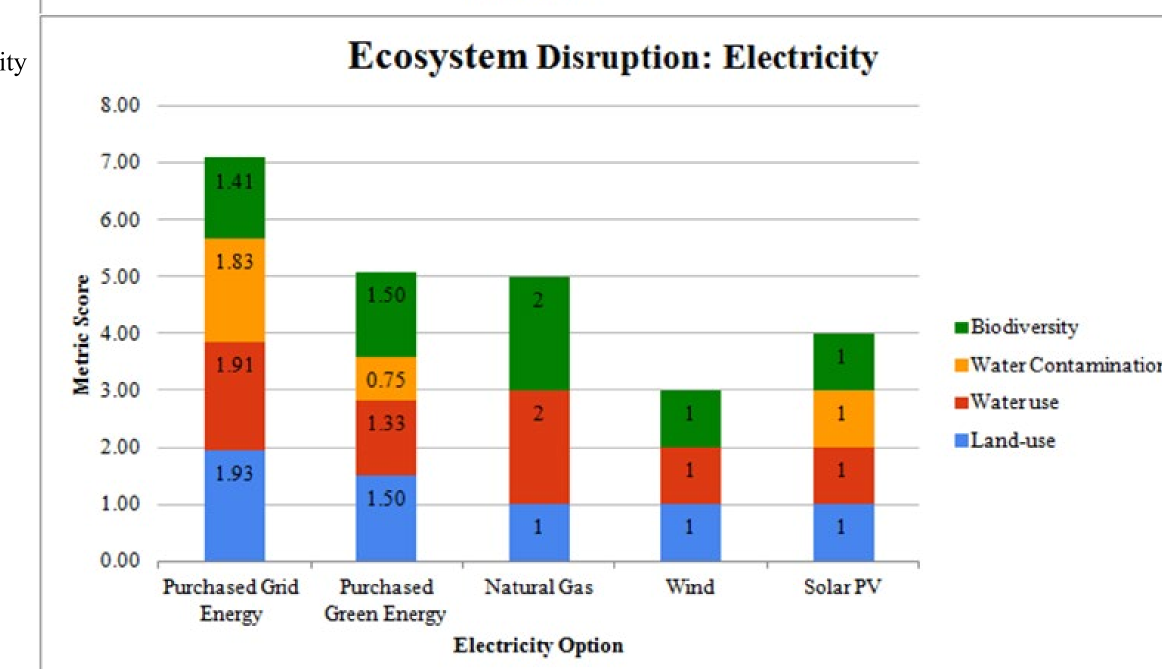


Figure 50: Ecosystem Disruption for Electricity Options



Respiratory Effects

One of the categories modeled on SimaPro 7 is potential respiratory effects from particulate matter. This is important because long exposure to small sized particulate matter can cause structural damage to the lungs. SimaPro 7 measures particulate matter in 2.5 microns (PM 2.5) which has heightens the risk of lung disease in comparison to typical damaging particles with PM 10. SimaPro 7 normalizes the impacts of all particulate matter emissions by reporting emissions in terms of kilograms of particulate matter size PM2.5

<u>Heat Respiratory Effects Analysis</u>

No.6 fuel oil has substantially worse respiratory effects than other heat options at 6.33E-06 kg PM2.5 eq/kWh, as combustion of No.6 fuel oil releases many particulates into the air. The next highest heat option is No.2 fuel oil with 2.61E-06 kg PM2.5 eq/kWh. Natural gas has the next highest respiratory effects at 2.12E-06 kg PM2.5 eq/kWh, followed by geothermal (4.62E-07), and solar hot water (8.81E-08). Particulate matter is released during the extraction phase of natural gas with the burning of fossil fuels for machinery and the release of dusts and other PM released during the process of fracking. There may also be small amounts of PM released during the combustion of natural gas. The extraction and manufacturing of geothermal infrastructure and solar hot water tanks releases PM in small amounts.

<u>Electricity Respiratory Effects Analysis</u>

Natural gas has the highest respiratory effects at 1.64E-04 kg PM2.5 eq/kWh, followed by purchased grid and green energy (9.01E-06), solar PV (4.18E-06) and wind (6.94E-07). Particulate matter is released during the extraction phase of natural gas with the burning of fossil fuels for machinery and the release of dusts and other PM released during the process of fracking. There may also be small amounts of PM released during the combustion of natural gas. PM is most likely released during the extraction and burning phases for the grid energy, and the extraction and manufacturing of green technologies for the green energy. The extraction and manufacturing of solar PV panels releases large amounts of PM in the form of silica dust, a harmful material that is a byproduct of silicon extraction and manufacturing that is a primary material in solar cells.

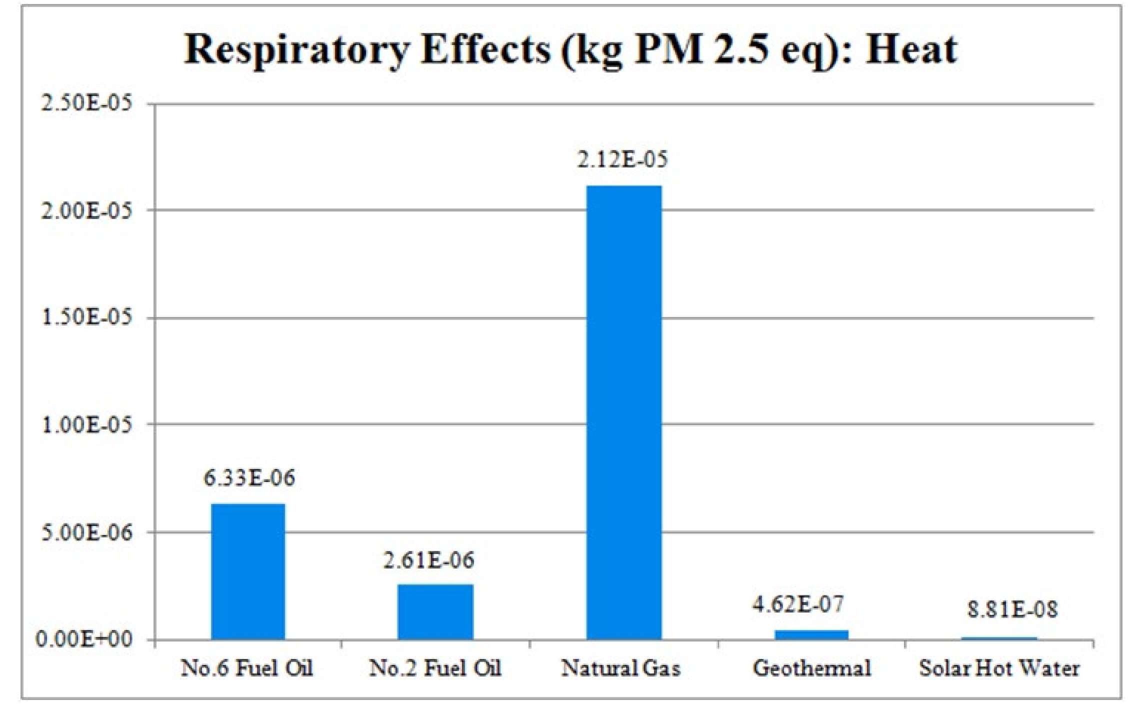


Figure 51: Respiratory Effects for Heat Options

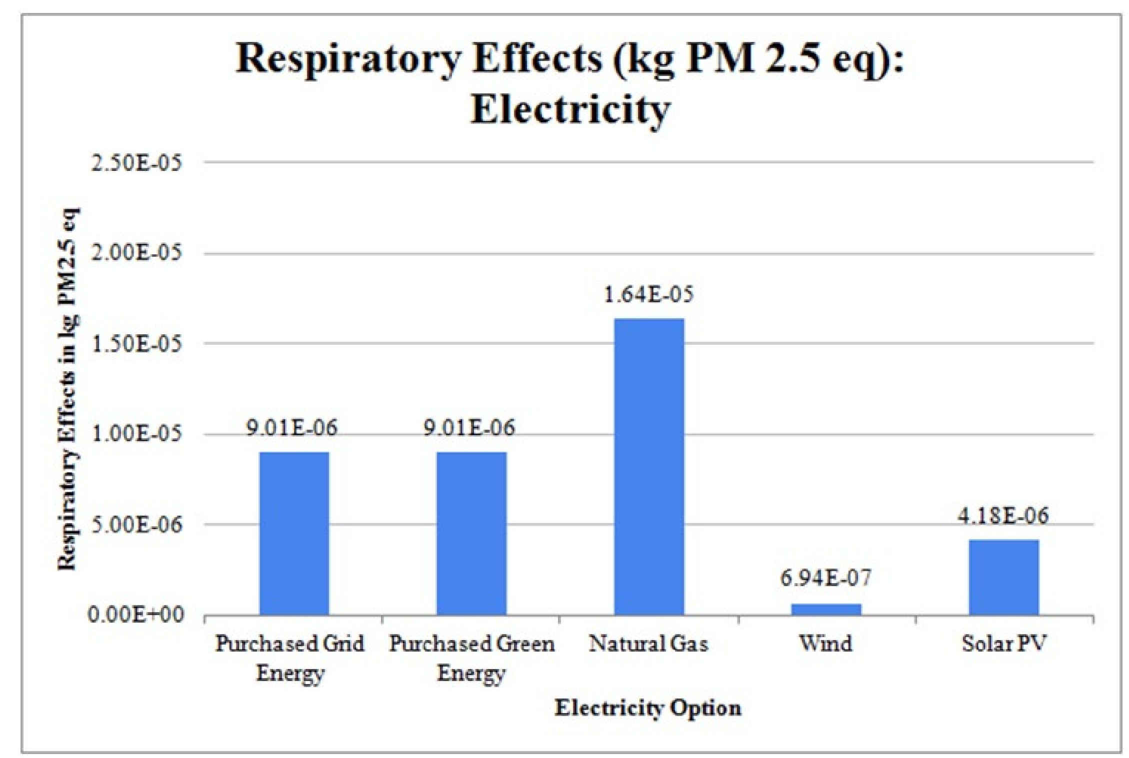


Figure 52: Respiratory Effects for Electricity Options

Carcinogens and Non-Carcinogens Effects

Another SimaPro 7 health measurement is carcinogens, or substances that cause cancer. SimaPro 7 normalizes the impacts of various substances impacts and reports carcinogenic potential in kilograms of benzene equivalent released for each unit of energy produced. Benzene is a volatile organic chemical that is often released as a byproduct of burning gasoline or smoking a cigarette. Carcinogens are measured in CTUh or Comparative Toxic Units for humans, which estimate the increase in morbidity in the human population. For example, natural gas a value of 9.1E-05, so for every kWh produced by natural gas, there is the potential for 9.1E-05th of a human decease.

The other SimaPro 7 health category is non-carcinogens, or substances that are also toxic to human health. A wide array of substances falls under this category and SimaPro 7 normalizes this wide array in kilograms of toluene equivalent released for each unit of energy produced. Toluene is an important organic solvent with intoxicating properties that, if ingested, has the potential to cause severe neurological harm and death. Non-carcinogens are measured in CTUh as well.

Heat Carcinogens Analysis

The heat option with the highest carcinogenic potential is natural gas, followed by No.6 fuel oil, No.2 fuel oil, geothermal, and solar hot water. For natural gas carcinogens were found to be 9.11 E-05 CTUh, with cancer-causing agents most likely involved in the extraction and manufacturing phases. Fracking to extract natural gas may lead to possible water contamination, mainly caused by leakages in the storage and transportation of waste water. This water contamination is a direct exposure pathway to humans. No.2 and No.6 fuel oil release most carcinogens in the boiler manufacture phase. Geothermal and solar hot water release less than half of the carcinogens as natural gas and No.6 fuel oil.

Heat Non-Carcinogens Analysis

Natural gas has the highest amount of non carcinogens at 5.14E-05 CTUh/kWh, followed very closely by No.2 fuel oil at 4.90E-05, and by smaller amounts of non carcinogens from No.6 fuel oil (1.89E-05 CTUh/kWh), geothermal (4.07E-06 CTUh/kWh), and solar hot water (9.67E-07CTUh.kWh). Non carcinogens are substances that are harmful, though non-cancerous, to human health, including heavy metals, dioxins and some organic chemicals. Many heavy metals are produced during the extraction of natural gas and fuel oil that could account for the high non carcinogenic potential relative to other electricity options. Releases of toxic chemicals during geothermal system installation and solar hot water tank manufacture account for the small non carcinogen releases.

Electricity Carcinogens Analysis

The electricity option with the highest carcinogenic potential is solar PV, followed by wind, natural gas, purchased green energy and purchased grid energy. For solar PV carcinogens were found to be 2.5E-04 CTUh/kWh, with cancer-causing agents most likely involved in the extraction and manufacturing phases. Mining for raw materials, such as rare earth metals for solar panels, releases radioactive chemicals like thorium into nearby sites, affecting workers and those nearby. Other hazardous byproducts of extraction and refining of materials also contribute to solar's release of carcinogens. Wind, at 1.4E04 CTUh/kWh, also releases carcinogenic materials during similar processes of extraction and refining, including mining of rare earth elements. Natural gas and purchased grid and green energy have similar amounts of carcinogens; chemicals are most likely released during the extraction phase of raw materials.

Electricity Non-Carcinogens Analysis

Natural gas has the highest amount of non carcinogens at 5.14E-05 CTUh/kWh, followed very closely by No.2 fuel oil at 4.90E-05, and by smaller amounts of non carcinogens from No.6 fuel oil (1.89E-05 CTUh/kWh), geothermal (4.07E-06 CTUh/kWh), and solar hot water (9.67E-07CTUh.kWh). Non carcinogens are substances that are harmful, though non-cancerous, to human health, including heavy metals, dioxins and some organic chemicals. Many heavy metals are produced during the extraction of natural gas and fuel oil that could account for the high non carcinogenic potential relative to other electricity options. Releases of toxic chemicals during geothermal system installation and solar hot water tank manufacture account for the small non carcinogen releases.

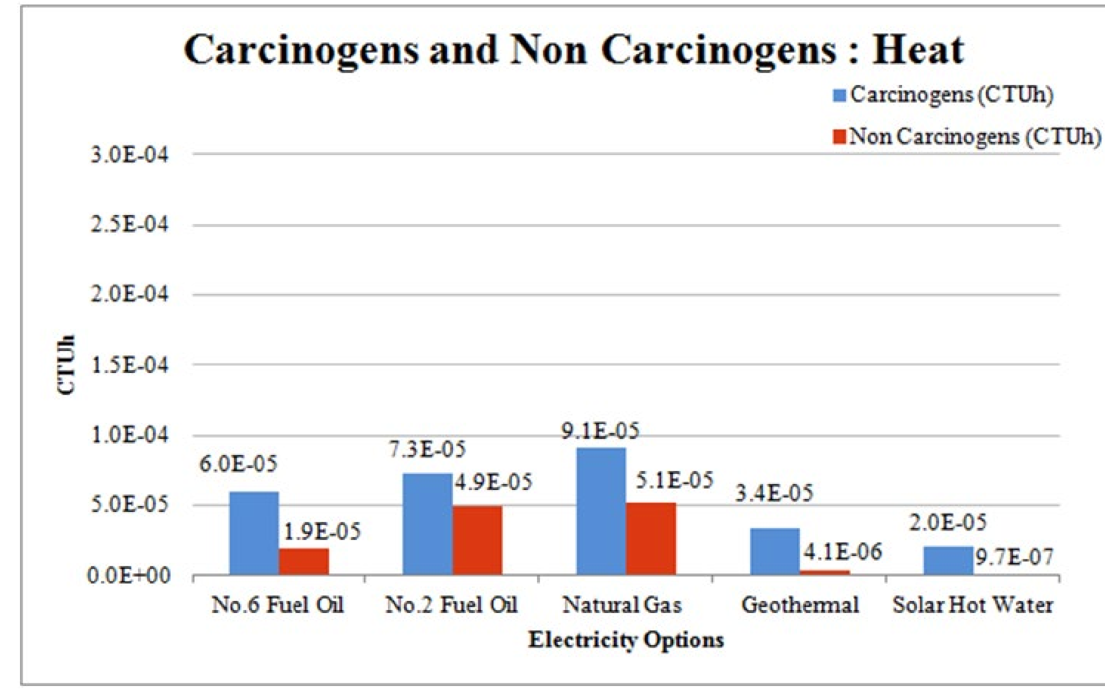


Figure 53: Carcinogens and Non-Carcinogens Effects for Heat Options

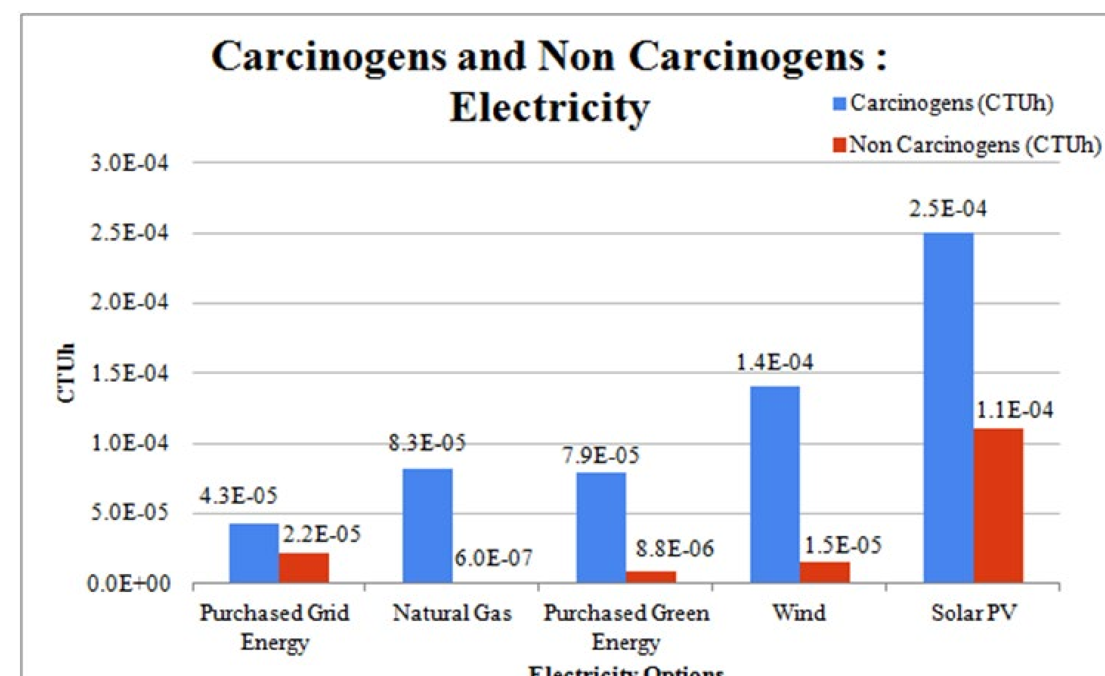


Figure 54: Carcinogens and Non-Carcinogens Effects for Electricity Options

Environmental Justice

Environmental justice involves the fair treatment of all people and to regard the communities commonly affected by environmental injustices. In general, cultural impacts are difficult to calculate, but we must not ignore the existence of them. Impacts on cultural identity are just as relevant as other calculable metrics and should receive the same kind of consideration, even when most of these issues occur off campus. It is crucial for Wellesley College to consider environmental justice in order to assess the environmental, social, and economic impacts derived from each energy source. As end users of the electricity and heating, our goal is to assess the negative environmental injustice externalities associated with the lifecycle of all energy sources.

ES 300 defined this metric and scored each option against a series of questions. The research process was composed of looking at the injustices for each part of the lifecycle stage: raw material extraction, manufacturing and production, transport, and generation. One of the ways to look at cultural impact is the destruction of cultural resources in areas undergoing surface disturbance, including the unauthorized removal of artifacts or vandalism of local spaces, which includes destruction of sacred landscapes or historic trails. Other issues include noise disturbance and visual impacts, which could create an adverse effect on local sites, creation of transportation methods and infrastructure that could divide or displace communities at extraction at manufacturing sites. For example, the development of a gas or oil field could potentially negatively affect the property values of those in close proximity to the field.

For each stage, we analyzed the questions listed below.

- How large is the population being affected?
- To what extent is this happening in disadvantaged (low-income/minority) communities? (Rank by median income, community composition)
- To what extent are the affected communities displaced or divided by this facility?
- To what extent are communities negatively affected?

Heat Analysis

For all heat options, environmental injustices related to the generation of the energy source does not exist. No. 6 fuel oil, No. 2 fuel oil, and natural gas rank equally bad for environmental justice, followed by solar hot water, and then geothermal. For No. 6 fuel oil, No. 2 fuel oil, and natural gas, all have negative externalities associated with the extraction, manufacture, and transportation of the fuel. For example, the extraction methods for natural gas release dangerous levels of toxic air pollutants near fracking. The biggest externality for solar hot water is the manufacturing of the equipment. Geothermal also has negative impacts from the extraction, manufacture, and transport of the equipment.

Electricity Analysis

Overall, natural gas has the greatest potential for environmental injustice, followed by purchased grid energy, solar PV, wind, and purchased green grid. Natural gas has negative implications from extraction, manufacture, and transportation phases. Purchased grid energy is ranked worst in the extraction of the fuel sources. When considering our purchased green and grid electricity , we considered that the energy sources include natural gas, wind, hydropower, and nuclear. For these sources, the main environmental injustice issues occur at the early stages of the lifecycle. These include many human health problems, which are explained in the health metric analysis. Solar PV also has the biggest negative implication during the extraction phase, and the same for wind and purchases green grid.

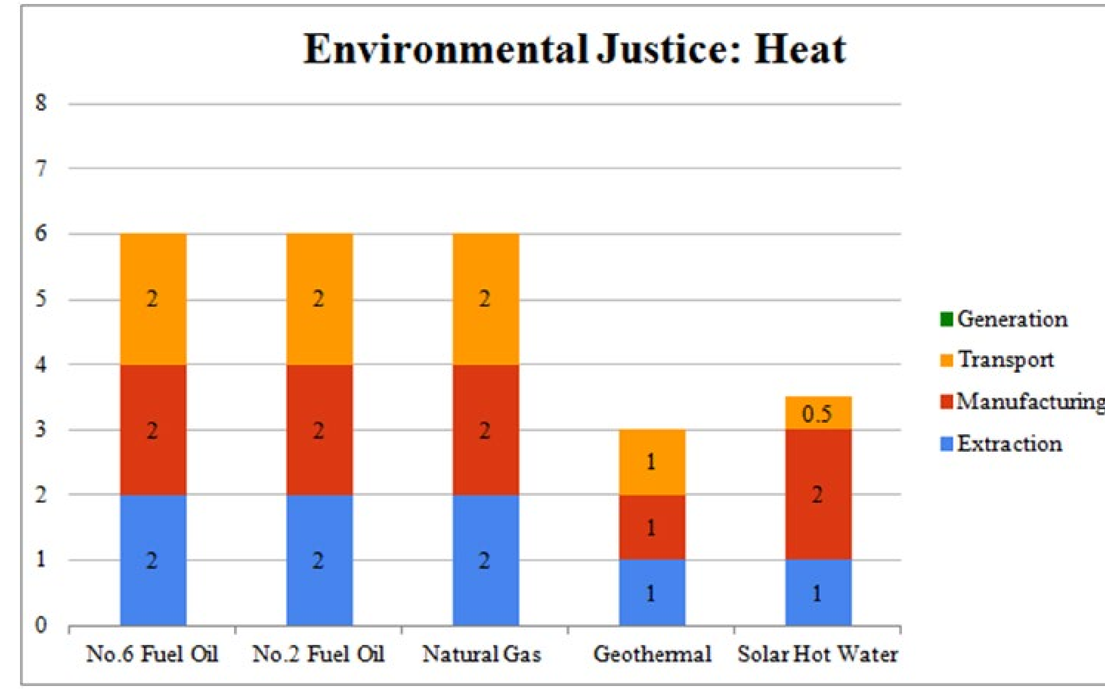


Figure 55: Environmental Justice Impacts for Heat Options

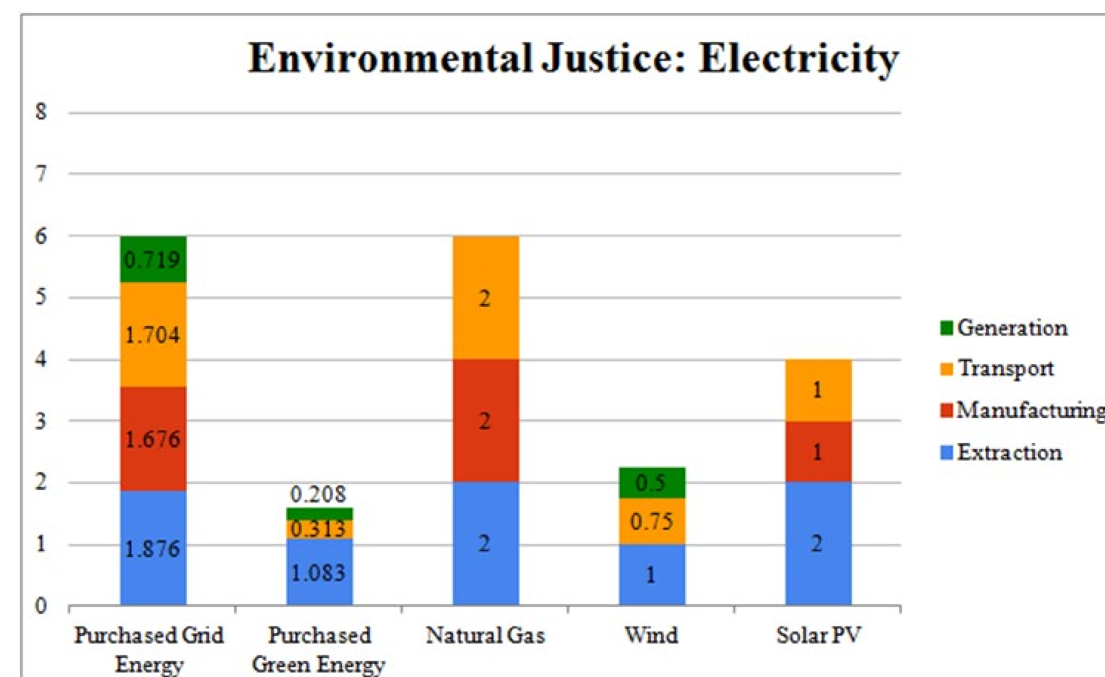


Figure 56: Environmental Justice Impacts for Electricity Options

Metrics Conclusions

We took a holistic approach to evaluating the impacts and benefits of utilizing five heat sources and five energy sources to fulfill Wellesley College's heat and energy demands. Having seen how each energy source compares in each of our eight metrics, we look to see how each energy source performs across them. This is difficult as the metrics set out to evaluate categories of very different types of measurements. In order to do a cross-metric analysis, we first looked at all of the data we had for one metric across all energy sources. Then we determined what the numerical cutoff is for us to consider that an energy source had fared "better" in that metric, "worse" in that metric, or "in-between". These cutoffs were not determined comparatively, but rather absolutely. For example, all of our heat energy sources cause environmental injustices, and, although technically one will cause the least environmental injustice, that injustice was still determined to be too high to qualify that energy source as having "better" environmental injustice. In this way, our analysis reflects how these energy sources compare in the grand scheme of things and is not contingent on the particular energy sources we chose to analyze. In the figures that follow, green means "better", red means "worse", and yellow means "in-between". All of the metrics have been broken down into these categories with the exception of cost, which remains in dollars/kWh. These figures help to summarize and contextualize all of the data given thus far in the report, but they do not represent the final results and findings of our analysis. They simply provide a way to better visualize the impacts of energy sources in a more holistic way. Interpretations and conclusions drawn from these figures will be based on which metrics each reader values the most, and we would like to emphasize that there is no silver bullet solution.

Heat

As stated before, conclusions from this figure will differ based on which metrics the reader values most, yet there are some trends and comprehensive conclusions that are important to recognize.

The least costly options are the renewable options, geothermal and solar hot water, and natural gas, our current heat source. Thus, the best options for the environment are also the cheapest. The fuel oils are significantly more costly than any of these options. Additionally, No. 2 fuel oil is significantly more costly than No. 6 fuel oil, yet across the other metrics there was very little difference between the two. There is not a benefit from using No..2 fuel oil versus No. 6 fuel oil, yet No. 2 fuel oil comes at a much higher price and will be required to replace No. 6 fuel oil if our power plant is renovated in any way.

Geothermal and solar hot water are better than or equal to the non-renewable options in all metrics except for reliability. Yet, as these heat sources will not stand alone in providing heat on campus, diversifying our heat sources is an option that will increase the overall reliability of our heat supply and allow us to benefit from the many advantages of geothermal and solar hot water we can identify in the figure above, especially educational advantage. Additionally, these heat sources can be implemented incrementally, so they could provide heating for one building first, then more if the college desired to expand them.

Natural gas, our current heat option of choice on campus, is low cost, but comes with a host of negative environmental health impacts, human health impacts, and social impacts. If the cost rises, as we expect to see with increased fracking regulation in the future, the campus would be more and more justified in relying less on natural gas and more on the lower-cost heat options which also are less environmentally and socially harmful.[1]

Global warming and environmental justice are especially important metrics. While all of our heat options cause some environmental injustices to someone, we favor geothermal and solar hot water because they are better on the environmental justice metric than natural gas and the fuel oils, which have extraction and refining phases that disrupt people's water supply, air, environment, and cultural community and heritage - all environmental injustices. Using natural gas and the fuel oils also cause more global warming than use of geothermal, and use of geothermal causes more global warming than use of solar hot water. Therefore, again, we favor geothermal and solar hot water for heat production because they cause less global warming than

1 Davenport, Coral, "New Federal Rules Are Set for Fracking," New York Times, March 20, 2015.

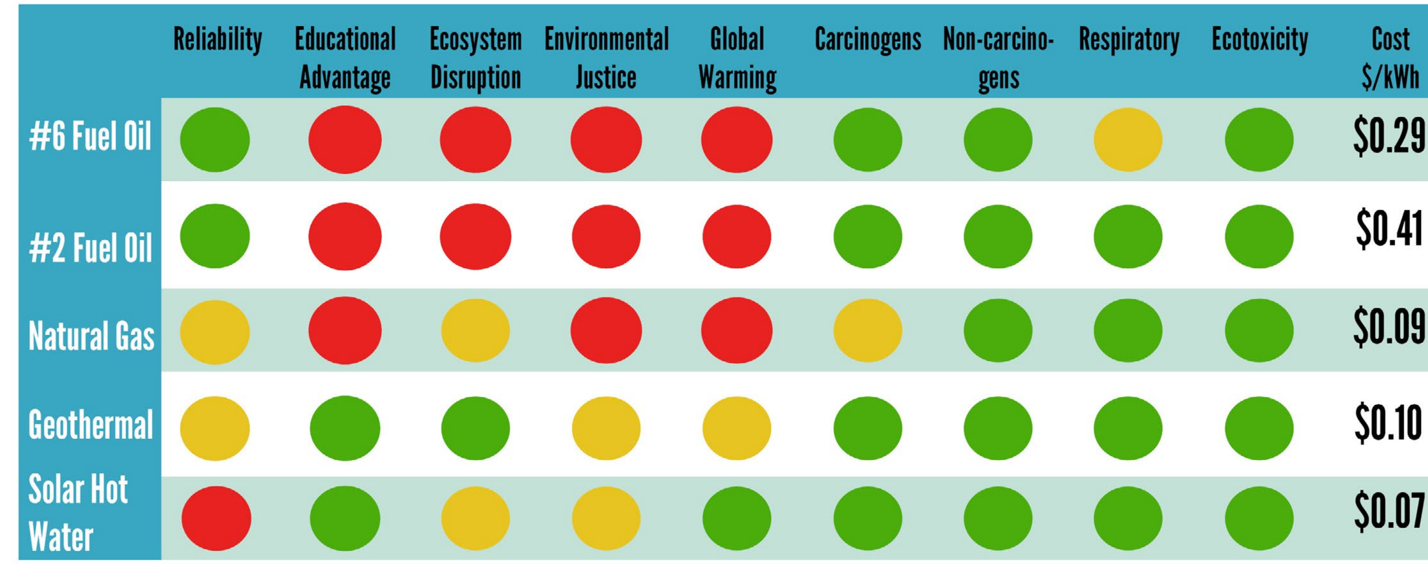


Figure 57:Color-based scoreboard for comparing heat energy options

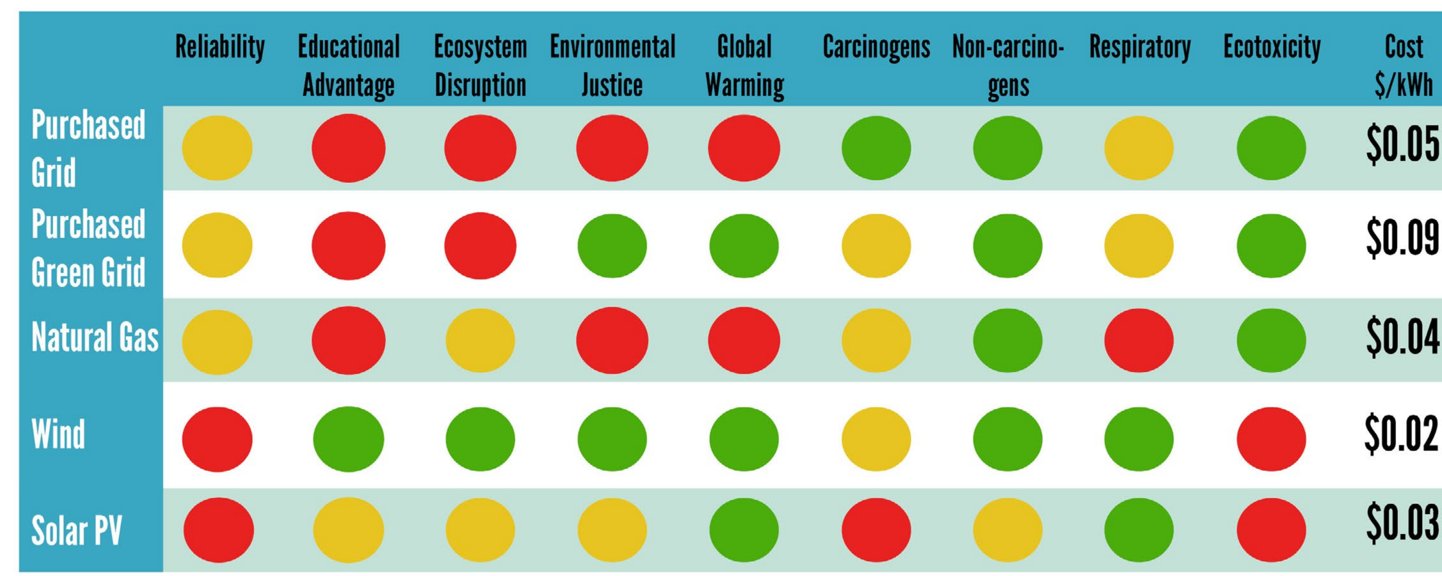


Figure 58:Color-based scoreboard for comparing electricity energy options

natural gas and the fuel oils, which are not only releasing greenhouse gasses when they are burned to produce energy, but also have high-intensity greenhouse gas extraction and refining phases.

Electricity

Before trends and comprehensive conclusions are recognized, it is important to note that the costs given for wind and solar PV in this figure will be lower for Wellesley College because the costs given do not represent the impact of solar renewable energy credits (SRECs), nor do they include the impact of government incentives for new wind and solar projects in place by the government of Massachusetts. Additionally, the grid costs are higher than is shown, as the costs given above are for less-expensive non-peak hours.

That being said, wind and solar PV are already the lowest cost electricity options we have analyzed. They both also do better than or equal to all of our other energy options across the majority of metrics. However, they are both definitively worse in reliability. Being weather dependent, this comes as no surprise. Yet, again, diversification must be considered. Neither of these two electricity sources will stand alone in providing electricity on campus, and diversifying our electricity sources will increase the overall reliability of our electricity supply and allow us to benefit from the many advantages of wind and solar PV we can identify in the figure above, especially educational advantage.

Purchasing energy from the green town grid is the most costly electricity option we analyze. We purchase this green energy to attain the green energy requirements that the town needs to fulfill. Yet, we see our green energy generation options, wind and solar PV, are not only cheaper than purchasing green grid energy, they also yield many more benefits. We thus question the decision to fulfill the green energy quota by purchasing town green energy when generating our own would be at lower cost, with many more benefits.

Natural gas, our current electricity generation option of choice on campus, is low cost, but comes with a host of negative environmental health impacts, human health impacts, and social impacts. If the cost rises, as we expect to see with increased fracking regulation in the future, it will start to be a less and less justifiable option. Purchased grid energy, also composed of non-renewables, is currently worse than natural gas across many of our metrics, and comes at a slightly higher cost, making it a non-viable energy option.

Global warming and environmental justice are especially important metrics. Across both metrics, using purchased green grid, wind, and solar PV is better than using regular purchased grid electricity or natural gas. Wind is particularly good, getting a green dot in both of these metrics, while solar PV gets yellow dots for being somewhere in between.

Conservation

In terms of increasing conservation measures at the college, both the administration and students can take steps to make an impact. We want to focus on conservation because nothing is cleaner than the BTU or kilowatt-hour of energy that you don't need, don't consume, and therefore that doesn't need to be produced or generated. Conservation allows us to change incentives, goals and habits for the better because it means cutting down on the energy practices that are wasteful. Even if we have the cleanest energy source installed on campus, there are still social and environmental impacts. The only way to prevent these effects is to conserve. ES 300 has split this section into 2 different sections: regulatory conservation efforts versus voluntary conservation efforts. Regulatory conservation measures would be suggestions Wellesley College should implement. To make a large impact, it would be advantageous to change on greater systemic level. In addition to these mandatory changes, everyone else too could make slight adjustments to their daily routine and the aggregate would result in a greater impact as well.

Regulatory Conservation

Auditing

Auditing is an assessment that surveys and inspects the energy flow in a building.

A professional energy audit will help the College understand where and how it loses energy, thus implying by how much we can reduce our carbon footprint, and how we can decrease energy costs.

LEED Certification

Wellesley is currently in the process of making every building LEED certified. Wellesley College should attempt to achieve Platinum certification, which could be obtained through more stringent green building policies and requirements, such as ensuring that all new construction and renovation work to be at least 36% below code. We can learn from Babson, which aims to have all energy performance at least 20% below code and, by 2020, it aims to obtain LEED Platinum certification. With such a large energy decrease, Babson would save $100,000 annually.[2]

Weather/infiltration sealing

Wellesley should establish a strict standard about sealing. Because there is an extreme range in weather conditions here, students rely on both air conditioning and heating, thus some form of heating or cooling energy is almost always on. Facilities or professional auditors should go around and check for any leaks in these windows and doors. Any inefficient windows or doors should be replaced.

College Energy Efficiency Goals

Many colleges, like Middlebury College and Emory University, have a clear statement and mission about their energy efficiency goals on their sustainability websites. Wellesley should also have a goal that is transparent and accessible to everyone.

Technology

Conservation can also be achieved through improvements of current technologies. Wellesley College should aim for more efficient shower heads, shower timers, new windows in the old dormitories, metering, and resetting the temperature to be cooler in the winter and warmer in the summer months.

Set Temperature Points

One of the easiest ways Wellesley College can make a big impact on energy use would be to alter the set temperature settings. Lowering the base temperature during the winter greatly reduced the heating

2 "Babson College Sustainability and Climate Action Plan," The American College & University Presidents' Climate Commitment, last modified 2011, accessed April 20, 2015, http://rs.acupcc.org/site_media/uploads/cap/831-cap.pdf.

costs and increasing the base temperature during the summer cuts back on cooling costs. Wellesley College could set the base temperature to 68 degrees during the summer and 76 degrees in the winter. Emory University already implemented this energy saving technique back in 2011.[3] When Emory reduced its energy consumption during the holidays by turning down the thermostats over two four-day periods, the University saved approximately $30,000. This reduction saved as much energy as used by 24 typical American houses for one year (12,733kWh/house/year), and reduced emissions of CO2 equivalent to taking 57 vehicles off the road for a year (11,260lb CO2/vehicle/year).

Motion sensor lights

Lighting accounts for a great amount of a campus' energy budget. Anywhere between 330 Wh and 1400 Wh of electricity are wasted per day. Installing motion sensor lights in all buildings on campus can greatly help lessen the amount of time the lights are on at all times. The motion sensor lights will turn on whenever there is movement in the room and will turn off after a period of inactivity. Setting a timer on the motion sensors so that the light will turn off after 20 minutes of no movement would also help reduce energy consumption. Wellesley has already installed motion sensor lights in some rooms in the Lulu Chow Wang Campus Center as well as in dormitory bathrooms, but they should be installed in all buildings and hallways. In 2001, Tufts decided to invest heavily in these lighting upgrades. Several buildings were equipped with motion sensors and saved both energy and money, 876,024 kWh and $91,930 respectively. The payback rate was within 2.5 years, so this is a regulation Wellesley should take into consideration.

Ban all incandescent bulbs and halogen lamps

Wellesley should consider converting all exit lighting to LEDs or switch to photoluminescent signs that require no electricity. Babson upgraded to high-efficiency fluorescent lighting throughout the campus. Working with the EPA, Stanford University has signed a commitment under the Green Lights Program to retrofit 90 percent of its fluorescent lighting to more efficient T8 lamps with electronic ballasts, which produce better light and last longer, within 5 years. Stanford replaced over 90 percent of its fixtures in academic, residential, and administrative buildings on campus in only 4 years. In less than 10 years' time, Stanford University was able to save 13,782,798 kWh of energy.[4]

Timers for Showers

Wellesley should install timers for showers in all of the dormitories. Currently, Wellesley has installed these shower timers in one of the Tower Complex dormitory halls, but expanding this program around campus would raise awareness about the amount of water used during showers. Every student can learn to shower within 5 minutes and, once they gain this skill, it may become habit.

Pool

Wellesley College has an indoor pool on campus, Chandler Pool, which includes an eight-lane competitive pool and a one and three-meter diving well, and is open to the public. As it is an indoor pool, it is largely dependent on heat energy. It would be interesting to see if the pool can be converted to be solely dependent on solar hot water generation. For example, Babson College has evaluated installing a solar heating system for their Webster athletic Center pool, and the approximated savings would be 42 mtCo2e per year and about $11,800 annual savings.

Education- Behavioral change

Being a student in college allows for luxuries, as students do not have to worry about electricity or water bills. It is never too early to start creating sustainable habits, and doing it now will help into adulthood. We would like the label of "environmentalist" to be as readily accepted as is the term "feminist" on campus today. The term "feminist" was largely contested years ago because people did not understand what it meant and a similar anxiety has been placed on the term "environmentalist". We would like to change that.

During orientation, student coordinators can start discussing with incoming students what they can do to save energy in their dorm. The environmentally focused student organizations on campus as well as the Office of Sustainability have made lengths on encouraging students to be more sustainable, but need to reach an even greater percentage of the population. There can be more open club meetings, workshops and resources available for the student body.

Self-monitoring

While we now have compost bins in all the dining halls, the next step is to work on the amount of food waste going into the bins

· During the winter months students can learn to wear sweaters, pants, and additional layers indoors, instead of simply cranking up the heater to a higher setting.

· Change habit of long showers

· Turn off your lights when exiting the room

· There are recycling bins on every dorm floor, and student should learn to separate waste accordingly

Commitment and certification

Following the change in habit we would like to use goals, pledges, or certifications. This method can be used as a personal challenge to be held accountable by the honor code and personal commitment.

The Office of Sustainability is promoting a sustainable certificate for students who can reduce their energy usage throughout the year. They encourage the use of power strips, taking advantage of the natural light, and discouraging the use of personal refrigerators.

While the honor code is in full effect throughout the year, audits by other students can also be a way to keep students accountable. Those students or staff members will be trained in what to look for and also potentially help students find ways to improve their personal sustainability.

Incentives

Another conservation method we are proposing is incentive-based methods. Examples of this method are contests and rewards. Incentives will especially motivate students to conserve energy because of the chance of winning and gaining rewards for their effort. There could be monthly awards, such as bus tokens and snacks, and awards for Halls if a student in the Hall was able to conserve the most energy on campus in that month.

Sustainable Living Certificate

The Sustainable Living Certification Program is a way to inspire the Wellesley students to have sustainable living practices and contribute to the college's commitment to the environment, as sustainability is one of our college core values. Through gaining the different levels of certification, room residents will collect prizes and show off their achievements and their own commitment to the environment. Each student is certified individually and will be rewarded individually.

Interested students/residents will participate in a simple audit process in which they will have to comply with a list of sustainable standards. Your building's Eco-Rep or a Wellesley Sustainability staff member, a resource for environmental knowledge and provide helpful advice in achieving your goals, will give your audit. This manual/package will also be a useful resource in answering most if not all of your questions on how to be more sustainable in your daily living habits.

The audit itself will be based on your everyday habits. The idea is to reduce the amount of energy used, waste created, and chemicals put into the environment through these sustainable habits. While each action seems small, collectively, they make a significant difference.

3 Campus News- Setting Temperatures Will save Energy, Emory University, accessed April 19, 2015, http://www.emory.edu/EMORY_REPORT/stories/2011/03/campus_new_temperature_policy.html.

4 Energy Retrofit Program, Stanford University, accessed April 19, 2015, http://lbre.stanford.edu/sem/energy_retrofit_program#lighting.

Final Conclusion

Wellesley College is a liberal arts college committed to education and is also a college that "considers sustainability as a factor in all institutional decisions."[5] As the College takes up campus renewable plans and the cogeneration plant nears obsolescence, the College has reached a crossroad at which it must determine an energy plan for the future. Now is the perfect time for the College to demonstrate its commitment to sustainability with a new campus energy plan that includes renewable sources and exhibits concern for factors such as greenhouse gas emissions and environmental justice.

Over the course of our research of a range of heat and electricity energy sources, it becomes clear that there was no single perfect energy option, and so we suggest a number of recommendations based on trends from our metric analysis. First, we encourage the College to consider renewable forms of energy. While solar hot water, geothermal, and wind have been largely overlooked, our analysis shows that these options have significant advantages over fossil fuel-derived energy options in both social and environmental metrics. Although these systems can only provide a fraction of the campus' total heat or electricity consumption, the College should consider installing these systems, perhaps for specific areas or buildings on campus. In terms of renewable energy, generation on campus—through wind or solar PV, for example—is cheaper and yields more educational benefits than investing in off-campus renewables through the town of Wellesley's green grid option.

We caution against over-reliance on natural gas as our sole provider of heat and electricity. While natural gas has advantages over fuel oils in terms of cost and certain health and environmental factors, there are still many environmental and social harms associated with natural gas and the method of fracking in particular. Although natural gas is inexpensive now, we anticipate an increase in the price of natural gas in the future and encourage investment in other alternate forms of heat and electricity generation. In researching the lifecycles of energy options, we discover that the majority of the negative environmental and social externalities—measured through environmental justice or ecosystem disruption, for example—occur not during the on-campus generation phase, but rather during material extraction or transport phases. We stress the danger of an "out of sight, out of mind" mentality in dealing with our energy on campus, and the need for greater visibility and awareness for the negative effects that occur off-campus.

Regardless of the option or options the College chooses to pursue, we strongly recommend accurate data collection and data transparency. Real-time, accessible data available to the members of the community is vital for the future. These data will enable smarter future uses of energy on campus and can provide insight into the most effective forms of conservation.

Using less energy through conservation is a way to reduce the environmental and social externalities that occur as a result of our energy consumption as a campus, and will also save money. We encourage conservation in a variety of forms, from voluntary conservation on the individual level to administrative policies that can be implemented campus-wide. Although individuals have the power to be more sustainable in their everyday lives, institution-driven conservation is effective in scaling up conservation efforts and attaining significant reductions in energy use.

While our recommendations embody the values of the ES300 class as whole, we hope that the transparency in our data and metric evaluations allows for others to easily draw their own conclusions. Energy at Wellesley is essential for powering powerful women. We hope this report will be used to facilitate discussion among the campus community regarding energy on campus, and will be useful in informing administrative decisions about the future of energy at Wellesley College.

5 Mission and Values: Sustainability, Wellesley College, accessed May 4, 2015, http://www.wellesley.edu/about/missionandvalues/sustainability.