Options for Improved Energy Systems in Health Care Facilities

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Introduction

The following report is the culmination of a semester-long project carried out to understand options for improving energy consumption in health care facilities. A team of M.Eng students identified technologies and practices, and modeled various energy efficiency and renewable energy systems that a health care facility operator might consider for the site to reduce cost and emissions.

In the Engineering Management team projects (course code CEE 5910) that I advise in the School of Civil & Environmental Engineering at Cornell University, I frame the broad goals of the project and presented them to the student team. Thereafter, the team defines a specific scope of work and progressed toward project deliverables, culminating in the final report that you are about to read. In this case, the team consisted of 10 Master of Engineering students, 7 from engineering management, 2 from mechanical engineering, and 1 from environmental engineering.

The report covers several major areas of technologies, such as conversion from steam to hot water heating to reduce losses and improve energy efficiency. Another technique is combined heat and power (CHP), where byproduct heat from making electricity is used for space heating and service hot water, increasing the overall utilization of combusted natural gas. Various improved efficiency technologies come into play as well, including variable frequency drives for ventilation, improved chillers, and more efficient backup diesel generation. Lastly, solar photovoltaic (PV) panels can be installed, for example over parking spaces where they also provide shading and cover from the elements.

In closing, I wish to thank the following for their insights contributed to the project: John Graves, member of Ithaca Community Energy; Kara Brookes, American Society for Healthcare Engineering; John Gaetano, Assistant Vice President for Facilities Management at Cayuga Medical Center; Terry Holmes, Facilities Manager at CMC; John Moynihan, Cogen Power Technologies, Latham, NY; and Lauren Ray, GEM Energy, Rudolph Libbe Group, Ithaca, NY[1]. While this assistance is gratefully acknowledged, responsibility for all errors and omissions rests with the team and with me as advisor, and the findings in this report do not represent the official position of Cayuga Medical Center, Ithaca Community Energy, or Cornell University.

Yours in sustainability,

Francis M Vanek, PhD

Senior Lecturer and Research Associate

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Team Member Backgrounds

Emma Burke: Emma graduated with a Bachelor of Science in Operations Research and Information Engineering and a minor in Business from Cornell University in December 2016. She then began pursuing the Master of Engineering Management degree, also at Cornell, with a specialization in Manufacturing and Operations. She has a strong interest in sustainability and has been involved with the Cornell chapter of Engineers for a Sustainable World for several years.

Edward Crocker: Edward graduated with with a Bachelor of Science in Environmental Engineering from Cornell University in May 2017. He is currently pursuing a Master of Engineering degree, also in Environmental Engineering, planning to graduate in December 2017.

Peter Ferenz: Peter graduated with a Bachelor of Science in Mechanical Engineering from Cornell University in May 2017. He is currently pursuing a Master of Engineering degree, also in Mechanical Engineering.

Titus Maritim: Titus graduated with a Bachelor of Science in Civil Engineering from Cornell University in May 2017. He is currently pursuing a Master of Engineering in Engineering Management at Cornell and plans to graduate in December 2017.

Makayla Mellas: Makayla graduated with a Bachelor of Science in Chemical Engineering from Cornell University in May 2017. She began the Master of Engineering Management program at Cornell immediately after and plans to graduate in December 2017. She has background and experience in sustainability and energy consulting through her internship and undergraduate engineering project team Engineers for a Sustainable World.

Mario Saldana: Mario is currently a candidate for a Bachelor of Science in Civil Engineering at Cornell University. Concurrently, he is working towards earning a Master of Engineering Management, and a minor on Real Estate. His anticipated graduation is December 2017 for his Bachelor, and May 2018 for his Master and graduate minor. Mario's background on projects including sustainable structural design and construction management bring a diverse point of view to the team. Furthermore, his involvement and leadership in organizations such as Engineers Without Borders and the American Society of Civil Engineering facilitate the acquisition of intellectual resources that could aid on the development of the project.

Prajnavaro Selamet: Prajnavaro a.k.a. Varo graduated with a Bachelor of Science in Industrial and System Engineering from San Jose State University in May 2015. He began his Master of Engineering Management program at Cornell with specialization in system engineering in January 2017 and plans to graduate in December 2017. He has background in lean manufacturing certification, high interest in sustainability and experience in project management as previously worked for Apple Inc. in Cupertino, CA.

Vincent Sheppard: Vincent graduated from Cornell University with a Bachelor of Science in Mechanical Engineering in May 2017. He is currently pursuing as Master of Engineering in Mechanical Engineering also at Cornell, and will graduate in December 2017. He specializes in structural analysis and mechanical design, and has some project management experience.

Rosa Won: Rosa graduated with a Bachelor of Science in Mechanical Engineering from Cornell University in May 2017. She is currently pursuing a Master of Engineering in Engineering Management at Cornell and plans to graduate in December 2017.

Jessica Yuan: Jessica graduated with a Bachelor of Science in Operations Research and Information Engineering with a minor in Business from Cornell University in May 2017. She is currently pursuing a Master of Engineering in Engineering Management and plans to graduate in December 2017. She developed an interest in improving performance and processes, completing her green belt in lean six sigma, as well as an interest and background in finance, steering her the last couple of summers to Wall Street.

Goals and Project Scope

Continuous Energy Efficiency Measures

Energy efficiency has emerged as one of the most critical short-term goals of healthcare facilities. MYSTERY Consulting Group is motivated to explore different solutions for healthcare facilities that could help achieve an improved overall energy efficiency. Energy efficiency can be an inexpensive opportunity to reduce emissions and other pollutants. Moreover, given that energy is so expensive, hospitals can slash their overall operating costs by using energy more efficiently.

There is an opportunity to explore the option of adding to the existing systems in lieu of introducing new systems. For example, suppose a facility has three 500-kW diesel generators that are used to provide back up in case of power failure, which can meet partial demand, but not the full demand. One of the suggestions is to add a 1500-kW diesel generator to allow the system to meet close to the full demand of the facility. We examined the capital cost of adding a new generator combined with its operating cost vis-a-vis other alternatives.

In addition, we examined other methods that similar facilities have been implementing to enhance energy efficiency. For instance, Cornell University completed a feasibility report on replacing building heating from using steam to hot water. The report established that hot water heating minimizes energy losses during transmission and promises significant energy cost savings in the long term. In other words, converting the steam heating system to hot water distribution could be more economically and environmentally beneficial. Facilities that currently have steam systems can explore whether this procedure is a viable option and if so, develop critical recommendations on how they could possibly incorporate this option to upgrade the overall facility.

Peak Shaving Energy Efficiency Measures

Peak shaving efficiency measures represent any measures that can reduce peak energy consumption so as to reduce energy charges associated with having highly peaked energy profiles. By way of background, a major healthcare facility such as a hospital may have on the order of tens of millions of kWh/year of electricity use and tens of thousands of dekatherms per year of natural gas use. The average load factor is the ratio of the average load to the maximum load, for example, if the average load is 1 MW across a period of time, and the maximum is 2 MW, then the average load factor is 50%. Maximum natural gas consumption occurs in the winter months in a temperate climate. From June through September, the natural gas usage remains at a relatively constant value, but electricity consumption may be highly peaked if summer temperatures require significant indoor cooling. Total utility billing for electricity and gas may be on the order of one to several million dollars per year, depending on the size of the facility.

MYSTERY Consulting Group analyzed a variety of energy efficiency measures that may be recommended for implementation to reduce peak demand, which could lead to significant reductions in demand charges annually. These measures would be in addition to the continuous or total energy use reduction measures detailed previously. Some of the peak shaving methods MYSTERY evaluated include downsizing potentially oversized equipment to fit their job functions, rescheduling energy intensive activities to low-demand times to balance out load throughout the day, minimizing the need for AC through modern cool roofing technologies and window efficiency measures, and controlled and metered subsystems or variable frequency drives (VFDs) on fans to modulate flow and ramp down use during low-consumption periods. Additionally, MYSTERY explored demand-side options such as battery storage opportunities and efficiency measures surrounding mechanical equipment such as chillers, boilers, air handling units, and other HVAC systems. Furthermore, lighting, window AC, and perimeter heating may be examined to determine if occupancy sensors and programmable thermostats could be significant cost savers and energy efficiency measures for the hospital.

Since it is already being implemented elsewhere in some hospitals, such as the University of Massachusetts teaching hospital in Worcester, MA, the possible integration of Smart Grid technology was also considered. Smart grids would allow users to manage demand in line with available electricity production.

Energy Star Rating

Most of the measures discussed in this analysis would have some impact on a healthcare facility’s Energy Star rating. The Energy Star rating compares a facility’s energy use to other hospitals, and assigns a rating on a 1 – 100 scale, with 50 representing median performance. The calculation of energy usage normalized by facility size, or Energy Use Intensity (EUI), is based on the consumption of electricity and natural gas. The values of energy consumption are weighted such that purchasing electricity from the grid results in a higher EUI, whereas purchasing natural gas and generating an equivalent amount of energy results in a lower EUI. The value of EUI is compared against the expected value for a hospital of similar size, and the resulting ratio is called the energy efficiency ratio. A lookup table can be used to find the resulting Energy Star rating for a given efficiency ratio.

Although the Energy Star rating typically requires data on existing hospitals to find the reference EUI, it is possible to approximate the reference using the known Energy Star rating and known consumption values. New values of the hospital’s actual EUI can then be computed for different scenarios of changing demand and on-site generation, and compared to the reference EUI in order to approximate the new Energy Star Rating.

Market Analysis

Background

In recent years some hospitals have opted to adapt their electricity supply systems into an electricity microgrid. For example, St. Luke's Hospital in Utica, NY, has built a microgrid with 3.6-MW nameplate capacity that supplies its campus as well as some adjacent commercial customers. Possible downsides to being involved in a microgrid include the logistical costs associated with providing energy to the surrounding area. There is also the large initial investment required in the equipment to generate sufficient energy to operate a microgrid. However, the following sections address microgrids in detail as they are potentially a useful solution for the future.

Hospital Microgrids

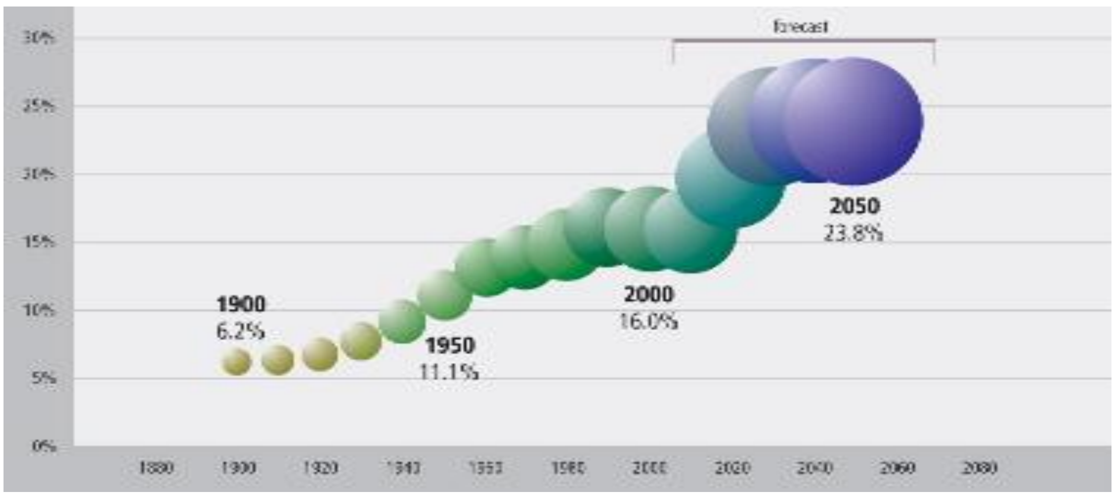


Figure 1: Forecast of Senior Population

Hospitals are in greater demand than ever before. According to the US Census Bureau as shown in Figure 1, the US senior population is projected to more than double by 2060. Coupled with the rate at which medical advances are accelerating, hospital expansions are inevitable to keep up with the state of the world. A survey of 3,125 hospital executives in 2016 showed that 70% of US hospitals were planned to undergo construction in the near future (<3 years) (Wood, 2017). With hospitals on average utilizing 2.5 times more energy than other commercial buildings, the need for more efficient distributions of existing infrastructure or newly improved systems is growing rapidly. Microgrids optimize energy usage, leveraging multiple different energy assets that could include traditional generators and renewable energy sources. Interestingly, the next generation of microgrids are even able to predict the nature of the weather, and further, the probabilities of power disturbances, effectively isolating the grid to achieve uninterrupted power regardless of the weather. Often, microgrids use some combination of solar, energy storage, and CHP. The controller can then allocate the most efficient uses at different points in time under the primary objective of the hospital, whether it be cost-budgeting, sustainability targets, or its endurance to increasing volatility in weather.

Trends

The microgrid market is growing faster than ever before, as microgrids are being more widely used around the world to provide reliable electricity and to help fight climate change. In the past, microgrids were prohibitively expensive, but they are now more financially feasible because renewable energy costs are going down and microgrid technology is improving. This increases the profitability and creates a larger market for microgrids. In the past, microgrids were known for resiliency, but now there are more benefits. Using microgrids is both financially and environmentally beneficial. The cost savings are favorable for both the utilities and end-customers. Moreover, carbon-reduction targets can be reached reliably with microgrids. The microgrid market also yields various opportunities for investment and business cases by providing customization.

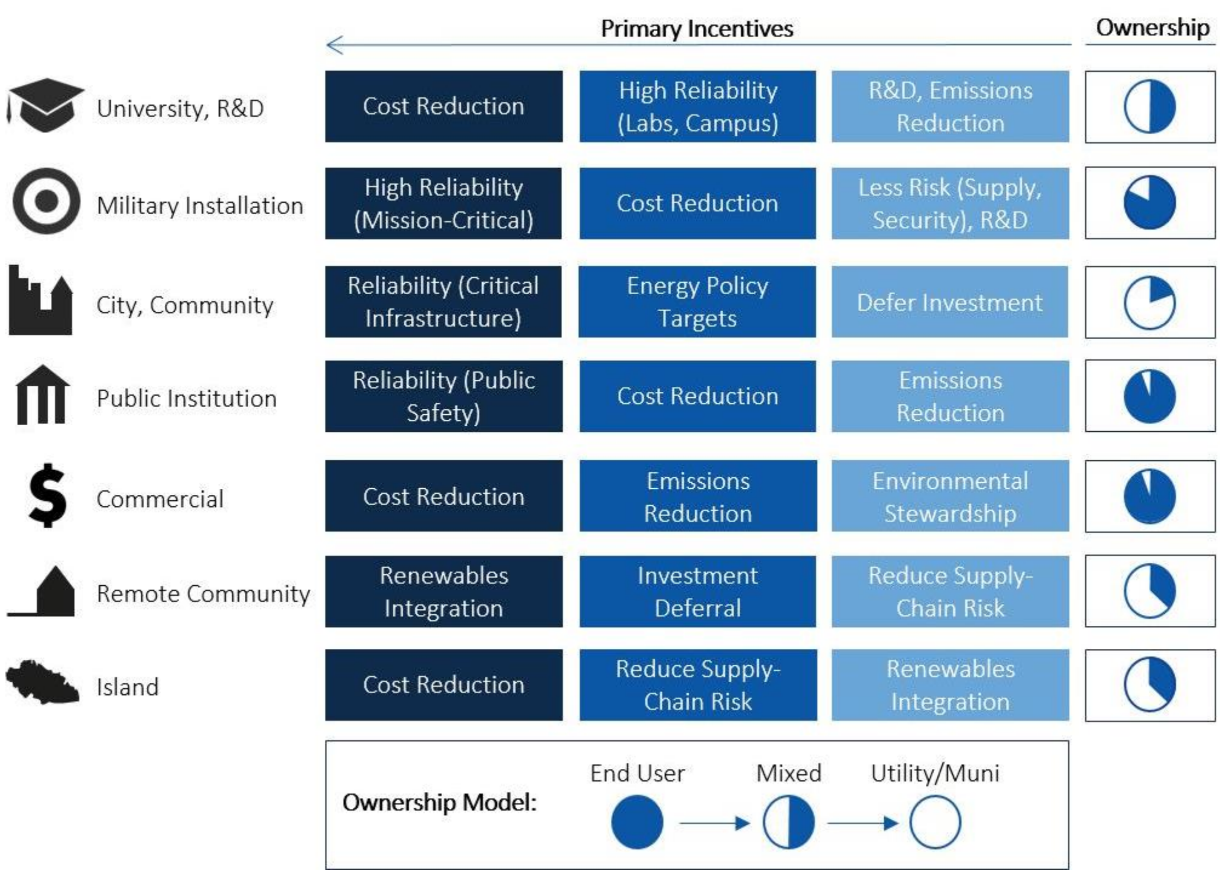


Figure 2: Ranking of Microgrid Implementation Drivers by End-customer Type

Another trend is that microgrids are helping to electrify rural areas and developing regions of the world. In these areas, the grid either cannot reach the area or is unreliable. Therefore, people rely on diesel generators or lead acid batteries, which pose health risks through exposure to pollutants or toxic chemicals. Microgrids are a solution to these problems, enabling systems in rural areas to become distributed, smart, and clean.

The future of microgrid technology lies in sustainability and climate change. Installing microgrids reduces emissions from diesel and costs from fuel transportation. For instance, Tesla's solar power system in American Samoa prevents the use of 100,000 gallons of diesel per year (Mearian, 2016). The environment can also be significantly impacted by installing solar microgrids, as over 240 million tons of CO_2 emissions per year from the fuel-based lighting can be avoided by utilizing microgrids (Juozitis, 2016). In addition, emergency situations caused by climate fluctuations and natural disasters, including power outages, can be prevented by using microgrids. This can be extremely important for facilities like hospitals, as well as other emergency services, that cannot risk losing power.

Comparison

Installing a CHP system in conjunction with a microgrid provides multiple advantages, including reduced energy operating costs, increased energy efficiency, and reduced greenhouse gas emissions. The Shands Cancer Hospital at the University of Florida, a level 1 trauma center is an example of a successful microgrid based around a hospital. Multiple aspects of this plan are comparable to this project, one being that the project was in partnership with its local utility company GRU, who built and operated its energy center on campus. An interesting note about this microgrid setup is that though it uses both a combustion turbine generator and diesel generator, CHP solutions were implemented to maximize efficiency by capturing waste heat and converting it to steam that the hospital can use. This is a pivotal point in their design, as >5% of energy produced in US is wasted, resulting in huge losses. In the case of excess generated electricity, the GRU is able to routinely export the power to other parts of the grid, rather than having to separately use packaged boilers to account for the excess steam load. Bolstering the success of this microgrid is the added isolation of the system derived from CHP operation that is in parallel with utility. That is, if a significant storm were to hit the campus, GRU could island the campus without any effect to the end-users. Because the energy distribution is underground with 0 outside influences, power outages are minimized, with an automatic re-connection to the re-stabilized utility grid after the storm has passed. Lastly, the added benefit of this microgrid system is that it is able to withstand testing to the emergency generator without power interruption. This is again due to the generator being parallel to the utility grid, thereby being able to do work while being fully loaded, vs. a traditional hospital where generator load tests must be connected to resistor load banks that turn the generators' outputs into heat, that are not utilized for any further work.

The success of the Shands Cancer Hospital microgrid has been largely recognized as one of the few US institutions that are Gold certified under LEED (US Green Building Council's Leadership in Energy and Environmental Design). More than just its personal financial savings, its increased efficiency has sparked the project to consider expanding to incorporate even more customers within the system. (Burns, 2016)

Energy Efficiency Measures and Peak Demand Savings

As the second highest energy-intensive industry, and with increasing energy costs and required usage, including a 20% increase in costs and 36% increase in energy use since 1995, hospitals have been focusing on efforts to reduce their costs and usage as well as minimize CO_2 emissions and climate change effects (Schneider Electric, 2010). Many hospitals tend to focus on traditional cost-cutting measures, such as new equipment and technologies, reducing staff numbers and work benefits, improving processes, or removing services, and they tend to overlook reduction in energy costs, as they only account for 2-5% of total hospital operating budgets (Schneider Electric, 2010). However, utilities can have a significant impact on profitability in an already low-margin industry. Energy efficiency measures are easy to quantify; the data is easy to collect and analyze and it can be filtered based on a wide range of variables, including hospital sector/areas, utility, time of day, or seasonal variations (Schneider Electric, 2010). They incur low risk to patient care, productivity of doctors and staff, and customer service, and they can typically be completed without disruption of operations (Schneider Electric, 2010).

There are three main types of energy efficiency projects: entry, medium, and advanced. Entry projects are typically a small investment with a fast payback period (less than two years). They include building optimization, utility rate reviews, and placing variable frequency drives on fans and pumps to regulate flow (Schneider Electric, 2010). Medium investment projects have paybacks between two and five years, and typically include building recommissioning, HVAC optimization, and lighting retrofits (Schneider Electric, 2010). Finally, advanced projects typically include third party financing and have extensive paybacks over 5 years. They involve building upgrades, HVAC improvements, building envelope improvements, and more innovative measures (Schneider Electric, 2010). Depending on the project, energy costs can be reduced by 10%, 20%, or 30%, respectively (Schneider Electric, 2010).

In the case of healthcare facilities with peaked demand, significant costs could be saved through the reduction of annual and monthly peak demand as well as through overall energy reduction measures to bring the average demand down. Some common and successful peak shaving methods are downsizing or replacing oversized or old/inefficiency equipment to better fit their job functions, rescheduling energy intensive activities to low-demand times, and minimizing AC requirements through roof and window efficiency measures. Additionally, the installation of variable frequency drives on fans to modulate flow is a simple and easy measure to reduce peak demand and average usage. Some other total energy reduction measures include replacing steam heating with hot water throughout the building, which reduces consumption from boilers and increases efficiency of heating per unit energy.

A handful of hospitals have successfully implemented these measures and significantly reduced costs. The Medical University of South Carolina installed 13 energy saving measures, including lighting upgrades, toilet and flow restrictors, steam traps, and shower heads (Ameresco - MUSC, 2017). The capital cost was roughly $14.5 million, and the project showed annual savings of $2.5 million (Ameresco - MUSC, 2017). Children’s Hospital Boston also completed a project that involved the installation of intelligent energy services that improved operations and maintenance through indoor air quality upgrades, LED light upgrades, plumbing and water conservation measures, ventilation system and control upgrades, and efficiency building equipment (Ameresco - CHB, 2017). The project cost $5.6 million, and they are seeing annual savings of 9.6 million kWh electricity and 12 million gallons of water for cost savings of $1.5 million each year (Ameresco - CHB, 2017).

Macro grid Exchange

Macro grid exchange can be viewed as a complementary and building block to the centralized grid. We conducted some market research to identify what are some of the ways that microgrids exchange power with the central grid and came up with the list below.

1. Power exchange using modular-isolated bidirectional DC-DC converter

This converter is composed of two modular bridges in primary and secondary sides. High-frequency transformers are located between two modular bridges to implement the galvanic isolation between two DC sides and serve as instantaneous energy storage components. Primary windings of transformers are placed in the primary side bridge, and secondary windings are placed in the secondary side bridge. The switches in the modular bridges can conduct current in both directions. The basic modules of bridges contain one of the transformer windings and two power switches, connected to the ends of the winding. In each module, the sum of the transformer leakage inductance and external auxiliary inductance is considered as an equivalent inductance in the secondary side of the transformer.
The primary or low-voltage sides of the input parallel and output parallel (IPOP) modular converter consist of a low-voltage DC-link and a modular parallel bridge, and the secondary or high-voltage side of the converter consists of a high-voltage DC-link and a modular parallel bridge. The modular parallel bridges are based on the parallel connection of modules, as magnetic flux directions of two adjacent parallel modules are reverse. This converter provides the advantages of electric isolation between two DC sides and the capability of easy extension for power capacity increment. This converter is proposed as an interface between a DC microgrid and a DC distribution network.

2. Power exchange from buildings using a DC bus (the DC-BUS is a physical layer that allows transmission of data over the power line and receiving that signal even if attenuated to the noise level of the power line)

This configuration facilitates the cooperation of buildings that are fed by different distribution transformers. The majority of the studies in the literature consider that all buildings (or loads) are located at the low voltage of the same distribution transformer, and hence they can exchange power through the PCC. However, for buildings that are willing to cooperate, and they are neither connected to the same transformer nor to a common DC bus, the only way for exchanging power is through the medium voltage distribution line. In that case, the decisions for the optimal power flows are taken by the distribution system operator (DSO). The configuration proposed in this work removes the aforementioned restriction, while it guarantees the self-management of the MG, and ensures that power exchanges take place only among the MG participants. The evaluation of the performance of the proposed cooperative approach is realized by considering a representative Superblock in the city of Barcelona that comprises of buildings with diverse power consumption patterns. The results of the proposed approach indicate a significant reduction of the operational cost by 34.6% compared to the baseline scenario (where buildings obtain energy by the main grid only) and by 15.7% compared to a MG case where no power exchange occurs, as well as a reduction of the carbon emissions by 65.3%.

3. Power exchange by using microgrid inverter with high voltage gain for photovoltaic applications

The proposed system consists of novel DC-DC converter cascaded with nine-switch inverter. The DC-DC converter has the advantage of high-voltage gain. The DC voltage generated from a single PV module has small value. These small DC values are not suitable to be used alone to produce the required ac voltage. Increasing the DC-AC conversion gain ratio by increasing the DC-DC conversion gain ratio is one solution to overcome this problem. High efficiency is achieved by having a portion of the input PV power directly fed forward to the output without being processed by the converter. The boost converter switch T1 is designed to operate at high frequency to decrease the inductor values and the overall system size.
Operation of DC-DC converter is the same as conventional boost converter. This converter has two modes of operations. The output voltage is controlled by duty cycle of T1 switch. T1 switch has two states and by notice to switching state of T1 switch, modes of operations are described as two modes.

Energy Options, Barriers, and Challenges

Combined Heat and Power

CHP systems, also known as cogeneration systems, generate electricity with a fuel-powered turbine and utilize the waste heat that is generated due to inefficiencies to heat a structure. The most common type of CHP system is the reciprocating engine, accounting for 54% of CHP systems installed in the US. Individual reciprocating engines can range in size from 100-kW capacity engines to as large as 9.3-MW systems when multiple units are used in combination, and have electrical efficiencies ranging from approximately 30% to 42%, increasing with the size of the system. The overall efficiencies, including the utilization of waste heat, range from 77% to 83%, decreasing as system size increases. Installation costs range from $2,900/kW for smaller systems to $1,430/kW for large systems. Average emissions for natural gas CHP plants range from 452-536 lbs. of CO_2/MWh. These values include a thermal credit for fuel that would otherwise be used in a boiler to generate heat (DOE/EE, 2016).

CHP systems run primarily on natural gas, though the use of biomass fuel is expected to increase over the next decade (GMI, 2017). Natural gas prices, excluding the cost of delivery, have been steadily increasing in price in recent years, and are currently estimated at $3.30 per thousand cubic feet. This number is projected to increase annually and reach $3.59 per thousand cubic feet by 2023 (IBIS World, 2017). A plot of annual natural gas prices, including delivery costs, is shown in Figure 3. The price in 2016 was $7.28 per thousand cubic feet, and the trend in recent years does not appear to increase, unlike the price of natural gas alone (U.S. EIA, 2017).

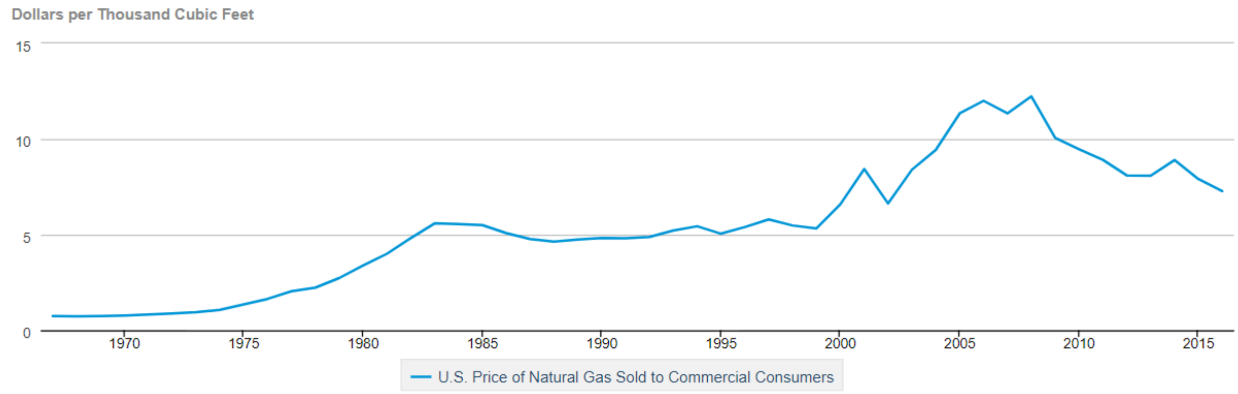


Figure 3: Natural Gas Price for Commercial Consumers

Prices fluctuate seasonally with demand, tending to increase in the winter and decrease in the summer. Some utilities purchase gas when prices are low and keep an inventory for colder months.

The Bank of America Tower in New York City serves as a precedent for utilizing a CHP plant to meet most or all of a large facility's needs. The building was designed to run a 4.6 MW CHP plant, which provides more than two thirds of the building's energy. Because CHP plants operate more efficiently when they are run continuously, the system remains on during the night and generates ice to cool the building the following day, reducing energy usage during peak hours. The system was projected to greatly reduce energy costs for the building, but the building incurred other unexpected costs. When the facility became operational, the building's utility company, Consolidated Edison, increased electric and steam standby charges by 50% and 125%, respectively. As a result, Bank of America Tower pays nearly $2.5 million per year for a connection to the grid in case the on-site system fails. This charge almost completely nullifies the economic benefits of the CHP plant for Bank of America Tower (Durst, 2015).

A 2011 report by the American Council for an Energy-Efficient Economy documents some of the major barriers for CHP plants (Chittum, 2011). One major barrier comes from regulatory bodies. Though natural gas CHP plants have much lower emissions than coal plants, they still emit greenhouse gases and pollutants, and are therefore subject to regulation. Another major barrier is utility company cooperation. CHP plants can greatly reduce utility costs for the consumer, which means that the utility company receives less business. Utilities can reduce the effectiveness of CHP projects in many ways, such as creating convoluted interconnection requirements, failing to adhere to the spirit of laws governing behaviors regarding the project, or demanding ownership of their clients' CHP projects, thus reducing the economic benefit. Utility companies can also increase a client's standby rates, paid by the CHP system's host for additional or backup power. Standby rates are calculated on the assumption that the utility must be prepared for every CHP system in its service region to fail simultaneously, but the report suggests that this is an extremely unlikely occurrence. High standby charges can result in exorbitant costs for a client that uses utility power for only a few minutes in a year, negatively affecting the economics of some projects, as seen with the Bank of America Tower.

Solar Photovoltaic

The development of energy through sustainable technologies is more than ever a more achievable solution for residential as well as commercial infrastructures. At the forefront of these sustainable technologies is solar photovoltaic energy.

Photovoltaic solar energy directly transforms solar light into electricity using a technology based on the photovoltaic effect. The panel as described in Figure 5 is the main component that allows this technology to produce its green energy. By influencing the radiation of the sun on one of the faces of a photocell, there is a difference of electrical potential between both sides that causes the electrons to jump from one place to another, thus generating electrical current. Using the diagram from GeoGreenPower.com in Figure 4, one can see the components outlined in the process mentioned before. The electricity production process for once single panel, and an array of panels in a house is shown through a diagram in Figures 6 and 7 provided by alternative-energy news.

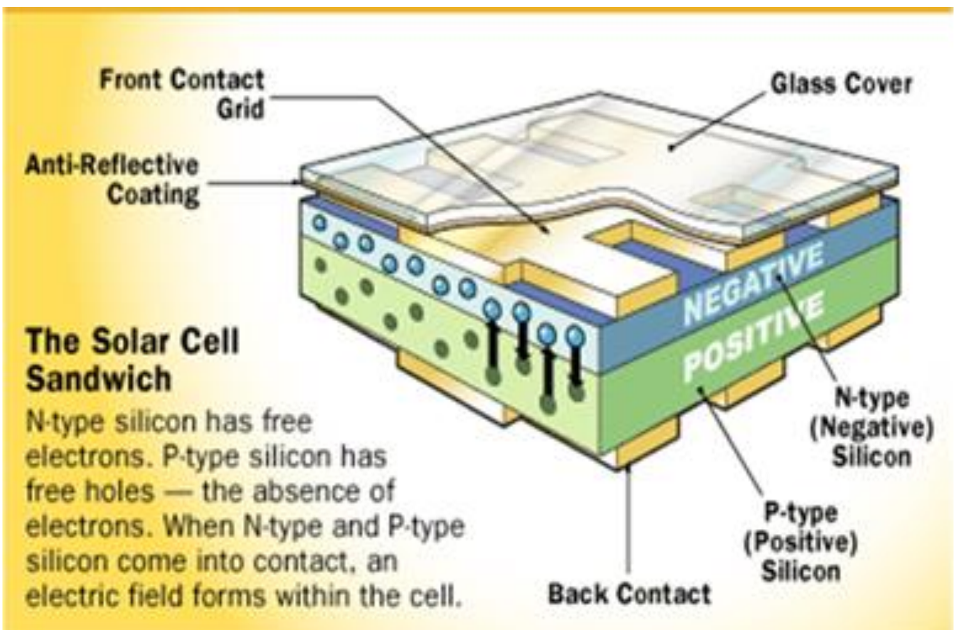


Figure 4: How Solar Arrays Work

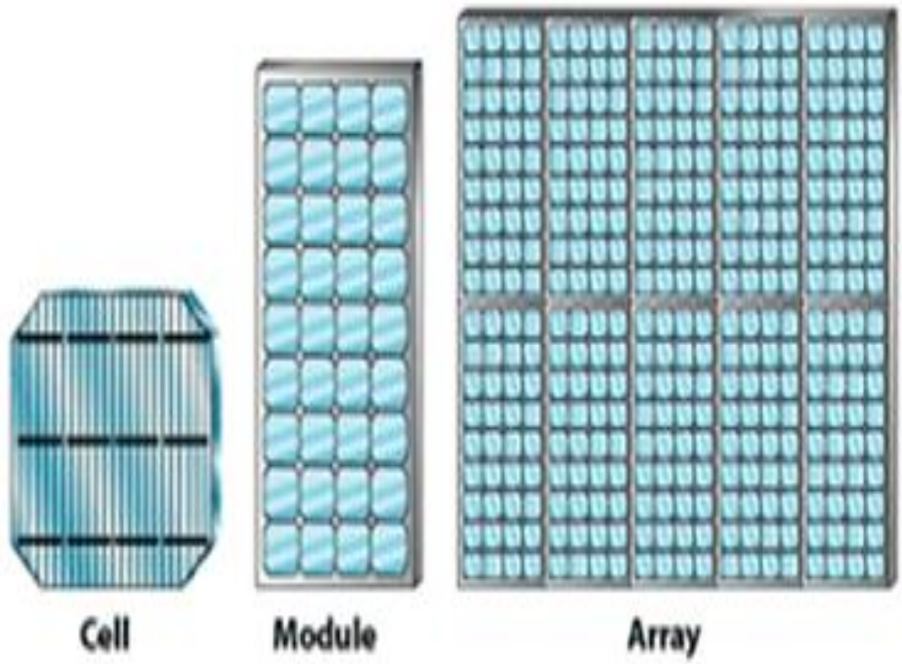


Figure 5: Cell, Module, and Array Representation of Solar Cells

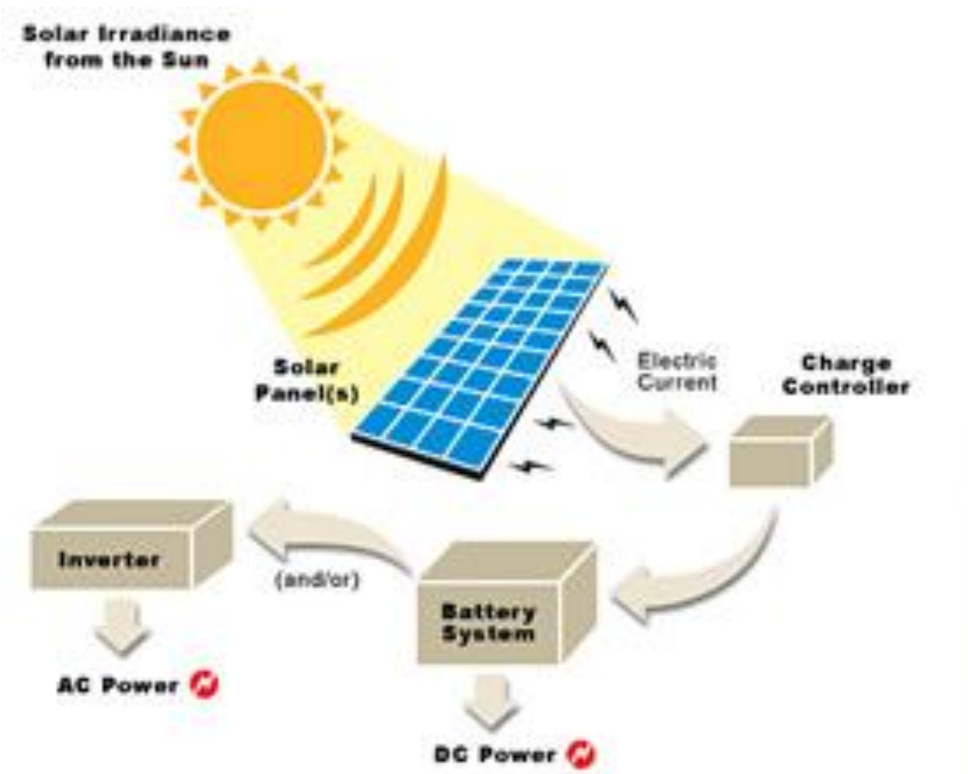


Figure 6: Solar System Process

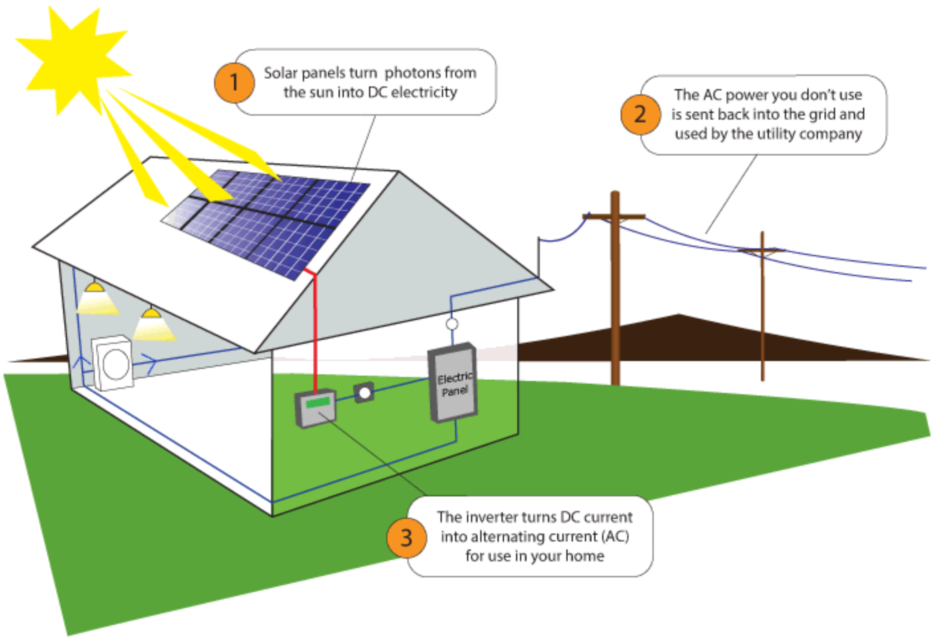


Figure 7: Solar Array Connection to Residence

Solar insolation is the measure of solar radiation received per day at a given location on earth in $kWh/m^2/day$. Figure 8 from AltEstore shows this amount of solar energy in hours, received per day on the worst month of the year based on accumulated worldwide solar insolation data. This is also known as "Peak sun hours." As an example, Ithaca NY has around 9 hours of sunlight,

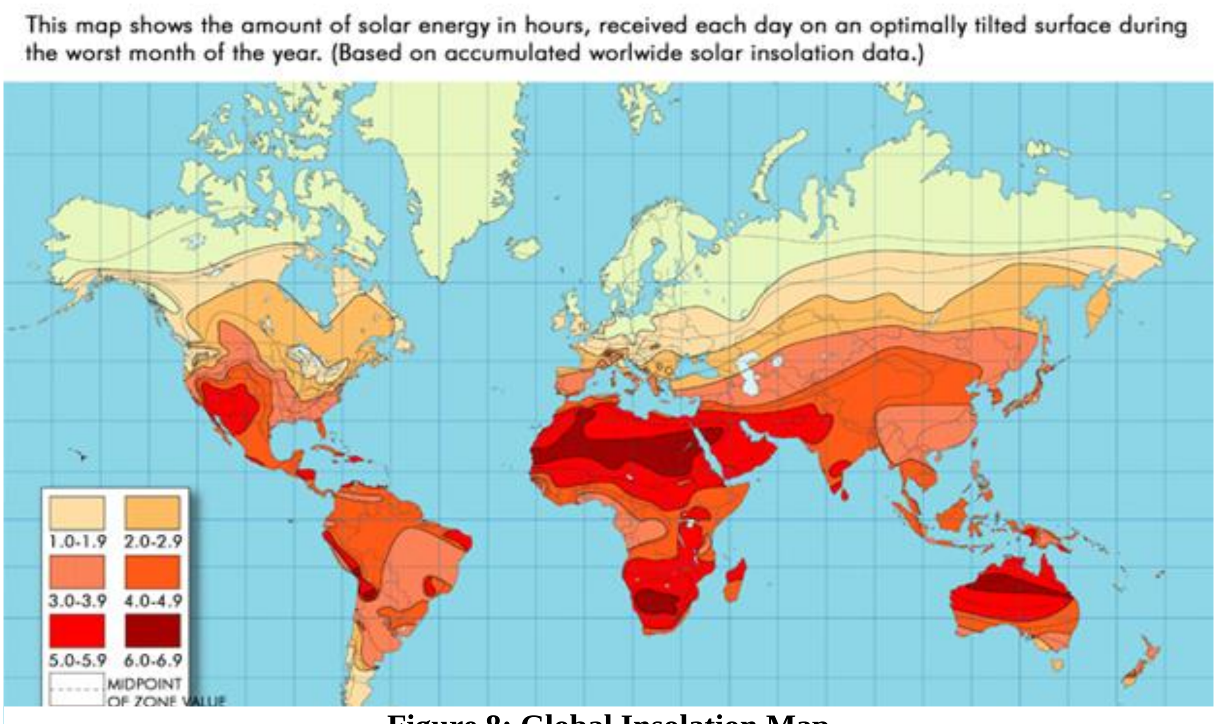


Figure 8: Global Insolation Map

but only 3-4 peak sun hours (depending on the time of year). As an illustration of model reliability, the observed actual production from a local PV array and the modeled data from National Renewable Energy Labs for that array are provided in Appendix A.

The electrical output of a Photovoltaic (PV) Solar Array is defined by the equation below.

$$Electrical\ Output = PV\ array\ area \cdot efficiency\ of\ the\ panel \cdot peak\ Sun\ hours$$

From the National Solar Database (NSRBD), 2012 Ithaca, NY had an average peak Sun hours of 3.79 $kWh/m^2/day$.

Solar is only expected to become more efficient, cheaper, and have a better energy output in the future. However, there are some factors that need to be considered when making the decision whether it is in fact economically viable to make the transition to solar PV energy. Some of these factors include but are not limited to:

- Insolation as shown in Figure 8
- Temperature
- Effects of shading for string inverters
- Land availability
- Size of batteries being used to store the electricity
- Support structure
- Spacing of ground mounted solar arrays

Meeting 100% of average electricity demand for a major healthcare facility with available space for solar PV is prohibitive. Nonetheless this energy could be used to provide assistance to the other energy resources on a daily basis, supply energy to a backup stationary battery system in case of emergencies, or even provide energy to a future microgrid.

Geothermal Heating

Geothermal heating can be a useful resource in supplying a heating system for the medical facility. A paper studying geothermal possibilities around Canada can be used to help assess the possibility of using geothermal heat to assist in heating the hospital and associated buildings (Majorowicz, Grasby, and Skinner 2009). This paper was chosen due to the proximity to Canada, and the similar heating demands of Ithaca to Canada. The study focused on the available shallow depth geothermal in Canada, where shallow depth is defined as being less than 250 m. The study breaks up the depths into 50 m levels, and defines the available heat in these levels. In the upper 50 m near New York, there is a large amount of heat compared to the rest of Canada.

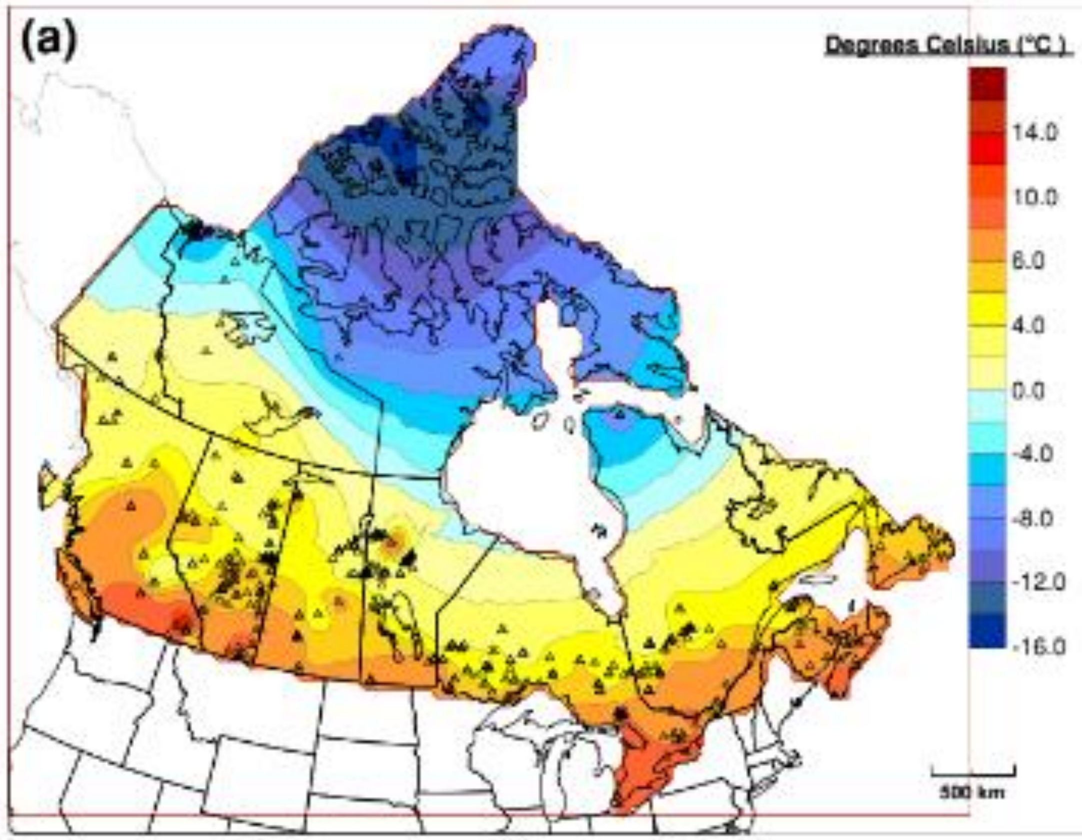


Figure 9: Temperature Profile of Canada at 50 m below the surface

Conservatively approximating, the mean average temperature at 50 m below the surface is approximately 10° C. At this level, during the winter the air would require less energy to heat up. For example, if the outside air is at 0° C, the difference between heating 1 m^3 of air is 13.01 Wh. This heat savings is under the assumption that the air entering into the system is at 0° C and the air can be heated up to the full 10° C. Depending on the number of air changes and the size of the hospital, this could make the geothermal system viable due to the lessened heating demand reducing operating costs.

This shallow geothermal source is important due to the costs associated with geothermal. The cost of the system relies on both the depth of the system and the horizontal size of the system. Due to the cost of excavation, vertical systems will typically cost more because of the specialized equipment required for deep boring. A shallow system minimizes the drilling depth, trading it out for either horizontal drilling equipment or a larger excavation area. Either system could be less expensive, but the deciding factor to this discussion depends on the underlying rock and the water table depth. If the bedrock is low enough and soft, the vertical system could be less expensive while still providing the same amount of heat as the horizontal system. These two systems can be decided between based upon further examination of possible locations for the systems. While it is likely that the full heating load cannot be achieved from just geothermal, it can alleviate the need to burn some amount of fossil fuels and make the system economically viable.

A way that this can be done is through a GIS system. A study in Germany focused on urban planning of a geothermal system that could be used for this heating demand (Schiel et al. 2016). A GIS system for an approximation would be extremely helpful in a feasibility study due to the lack of direct soil information. This GIS approximation will give us a way to see if the system is fully feasible and a more in-depth study should be done to fully scale the project. The study itself focused on a vertical system, but the same approach can be done for a horizontal system. Both systems can be researched with some minor alterations.

Another interesting point that the paper brings up is the seasonal variability could be used to our advantage. Due to the depth, there is a delay of the temperature reaching the geothermal depth of the system. This can be seen in the temperature profile of the soil as shown in Figure 10 (Schiel).

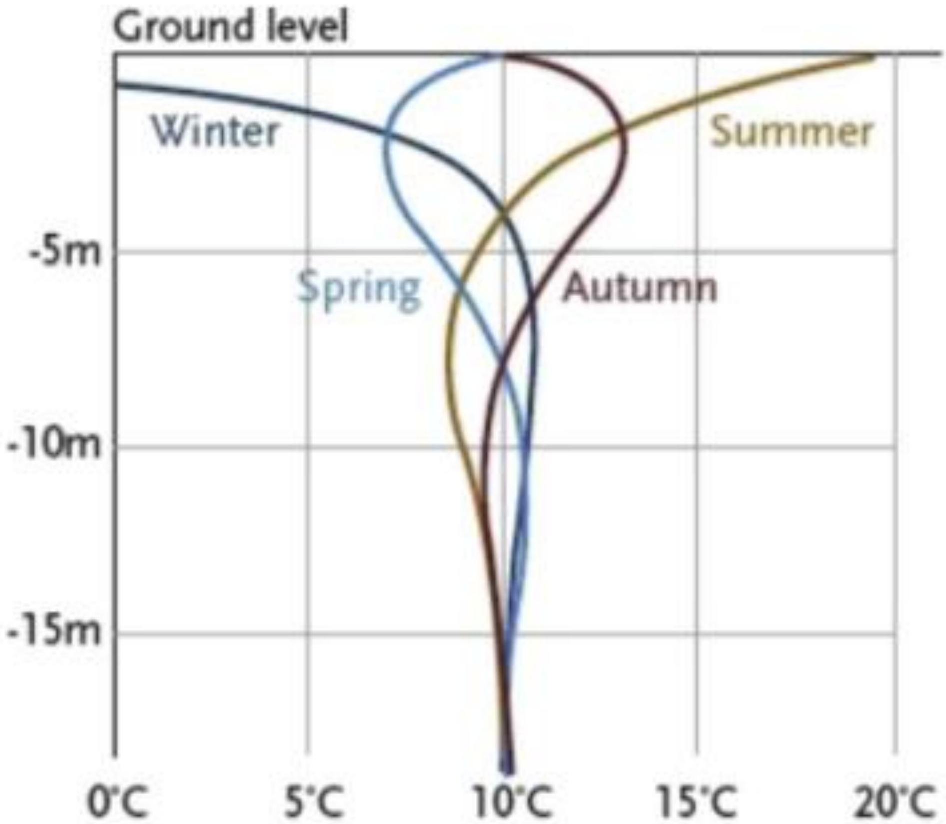


Figure 10: Temperature profile in a soil throughout the year in Britain

The average temperature of the area is 10° C, and the heat from the different seasons is delayed by 6 months. This is extremely beneficial due to additional heat being needed in the winter, and this also creates the possibility to use to soil to cool the air during the summer. This additional efficiency could also make the system have a better return on investment.

A geothermal system would not be solely efficient enough to heat a major healthcare facility without using deep geothermal. Geothermal itself can be used to assist a secondary system that heats up the air to a point of usefulness to the center. Power generation is extremely unlikely, but a boost from the geothermal source is worth looking further research.

Wind Source

Wind power has been the one of the cleanest and more efficient renewable energy resources available to date. According to Global Wind Energy Council (GWEC) United States is ranked 2nd place in the world in wind power energy generated. In the US, wind turbines have a total nameplate capacity of 82,184 MW, and 8,203 MW of that was just added in last year, meeting a total of 5.5% of the entire United States' electricity demand. Based on the operating and installation trend observed year by year, these numbers are only going to increase with time. This phenomenon is partly due to tax incentive that companies get when an organization invests in wind power renewable energy resource.

Based on 2016 data, only one state has wind energy penetration as high as 36.6%, while New York State did not even make the rank in the top 20 and falls below the 1% range. See Figure 11 for more details.

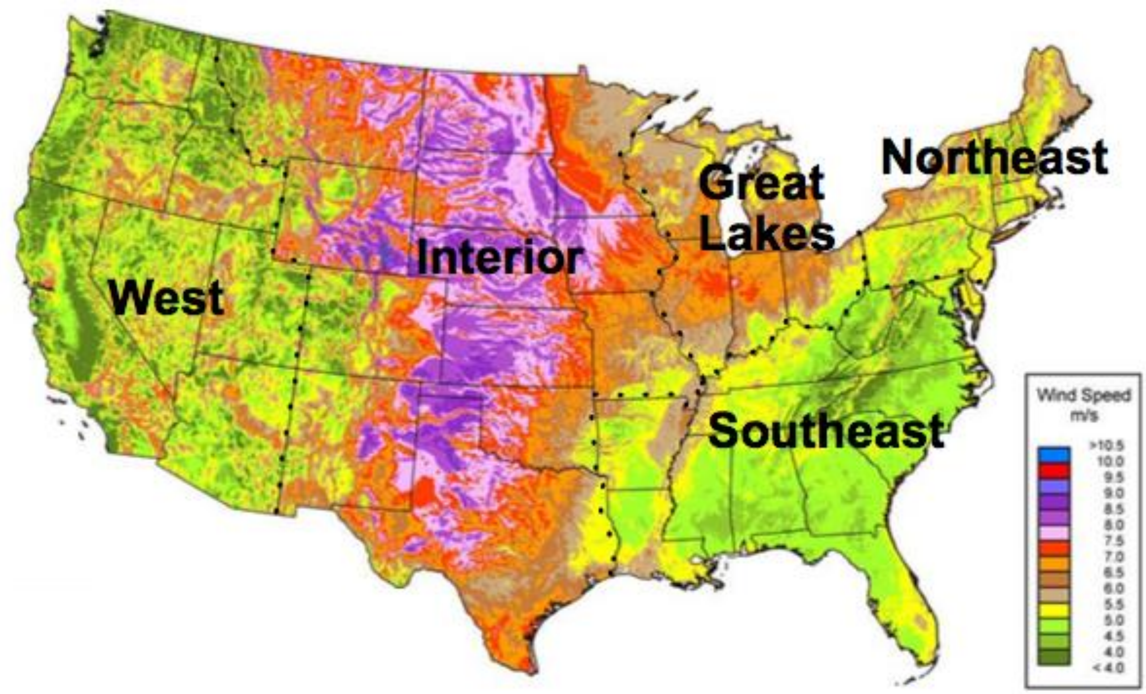
Installed Capacity (MW)				Percentage of In-State Generation	
Annual (2016)		Cumulative (end of 2016)		Actual (2016)*	
Texas	2,611	Texas	20,320	Iowa	36.6%
Oklahoma	1,462	Iowa	6,911	South Dakota	30.3%
Iowa	707	Oklahoma	6,645	Kansas	29.6%
Kansas	687	California	5,656	Oklahoma	25.1%
North Dakota	603	Kansas	4,451	North Dakota	21.5%
Nebraska	438	Illinois	4,026	Minnesota	17.7%
Minnesota	291	Minnesota	3,499	Colorado	17.3%
Maine	288	Oregon	3,163	Vermont	15.4%
Missouri	201	Washington	3,075	Idaho	15.2%
Illinois	184	Colorado	3,026	Maine	13.9%
West Virginia	103	North Dakota	2,746	Texas	12.6%
Ohio	102	Indiana	1,897	Oregon	12.1%
Michigan	80	New York	1,827	New Mexico	10.9%
Wyoming	80	Michigan	1,611	Nebraska	10.1%
New York	78	Wyoming	1,489	Wyoming	9.4%
Utah	64	Pennsylvania	1,369	Montana	7.6%
Colorado	61	Nebraska	1,328	Washington	7.1%
Rhode Island	45	New Mexico	1,112	California	6.9%
Pennsylvania	40	South Dakota	977	Hawaii	6.7%
New Mexico	32	Idaho	973	Illinois	5.7%
Rest of U.S.	48	*Rest of U.S.*	6,041	*Rest of U.S.*	1.0%
TOTAL	**8,203**	**TOTAL**	**82,143**	**TOTAL**	**5.6%**

* Based on 2016 wind and total generation by state from EIA's *Electric Power Monthly*.

Source: AWEA project database, EIA

Figure 11: U.S. Wind Power Rankings for the Top 20 US States. Source: U.S. Energy Information Administration

There are a several variables that needed to be considered when dealing with wind power energy. The first element that needs to be considered is the location. The location affects the power output of a wind turbine significantly. Figure 12 shows the average wind speed in m/s for the entire span of United States.



Source: AWS Truepower, National Renewable Energy Laboratory

Figure 12: Average Wind Speeds Across the United States

As shown in Figure 12, the coastal area of United States has a relatively lower wind speed than the area in the Interior. Elevation is a major key factor in wind speed data discrepancy. The higher elevation tends to yield a higher wind speed. Geographically the center region of the United States is located significantly higher above sea level than the coasts, further supporting this claim.

In New York State area, especially near the Finger Lakes, it seems the average wind speed is notably lower than the rest of its surroundings (green color). However, there are also some ridges with higher average wind speeds (brown color).

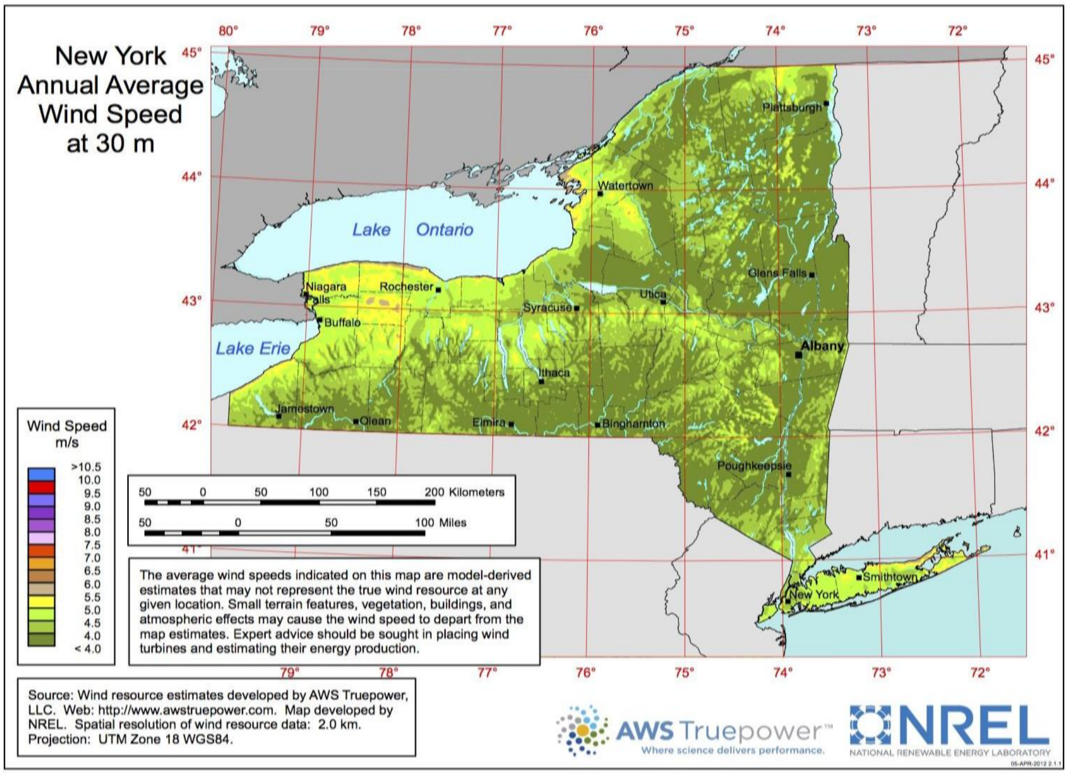


Figure 13: New York State Wind Speed Map at 30 m

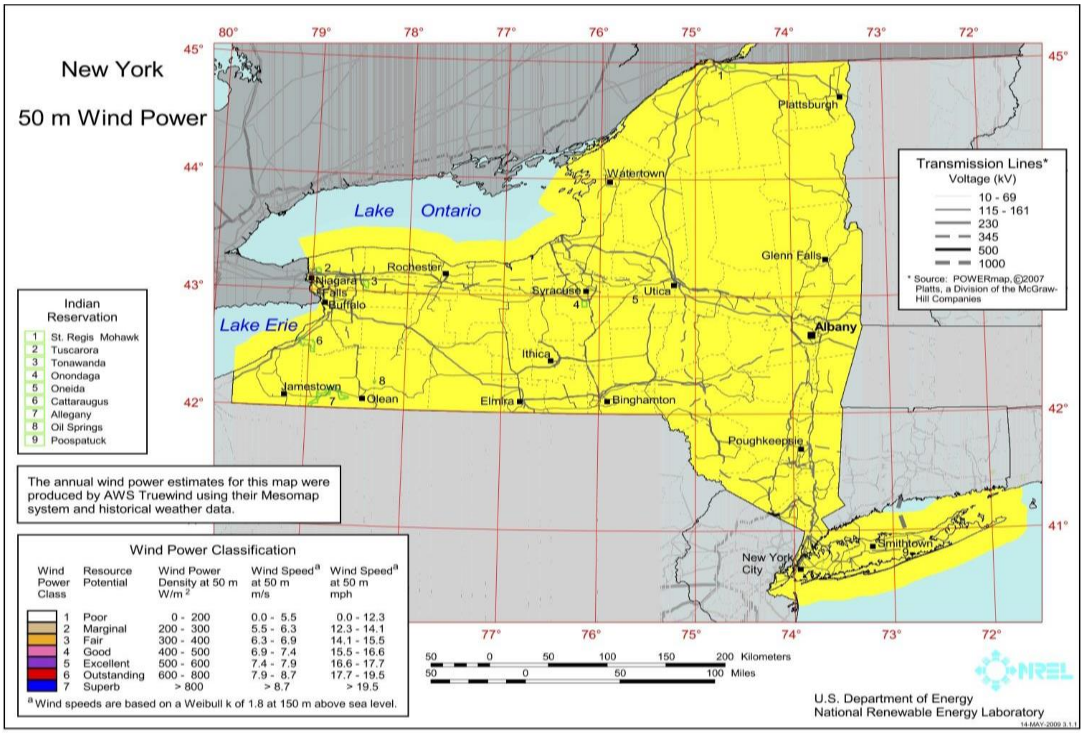


Figure 14: New York State Wind Speed Map at 50 m

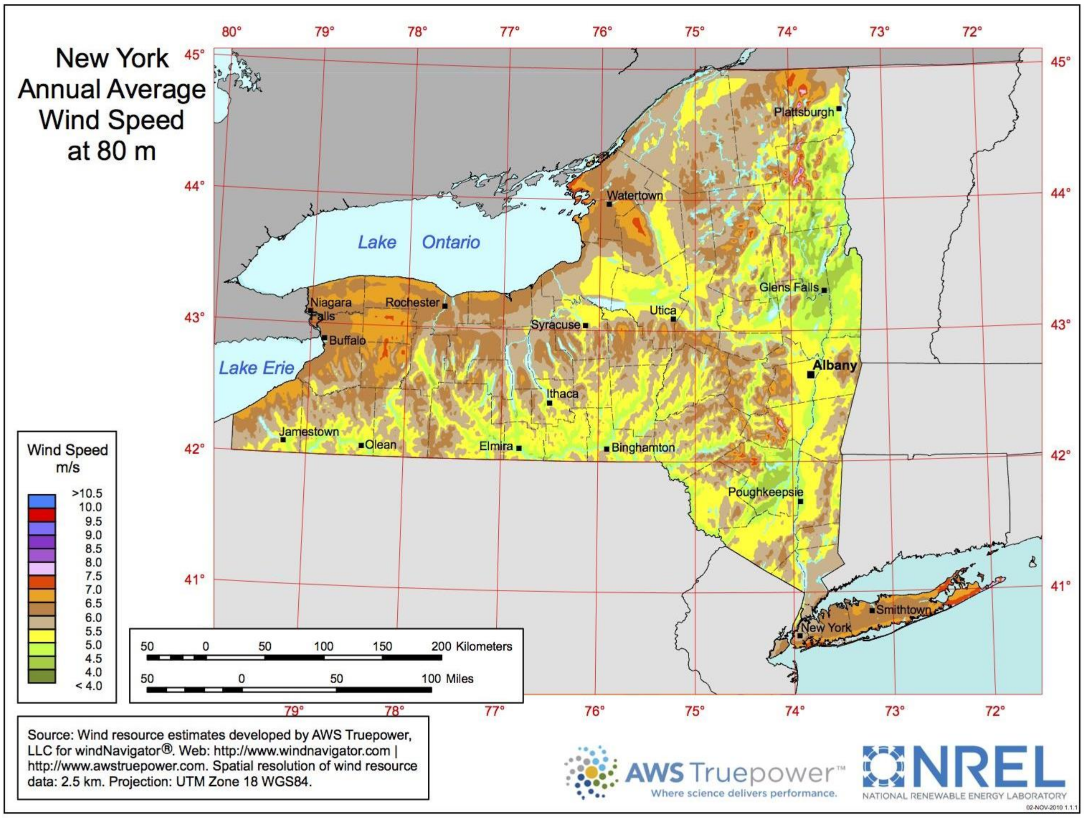


Figure 15: New York State Wind Speed Map at 80 m

Figure 13, Figure 14, and Figure 15 above all show different wind speeds, in meter per second, at different elevations, 30m, 50m and 80m. At almost any typical wind turbine elevation we can see that Ithaca's wind speed is located on the lower end of the scale.

Another factor to consider is the power generation of each wind turbine design and specification. The design of a wind turbine is something that we don't control. The majority of wind turbines are being contracted to an independent contractor that is running the energy generation such as General Electric or Siemens. However, the main importance of selecting wind turbine design is based on location's wind speed and the amount of energy needed for the service area.

Cost is another major decision element. Some wind turbine designs' initial cost varies between brand to brand; however, the deciding factor of this component is mainly maintenance cost and life cycle. A certain design of wind turbine could have a lower initial cost but cost more over its entire lifecycle when maintenance is considered. One other possible element to cost reduction is tax incentive from the government. Some states have a higher tax break than others, which could potentially make wind energy the cheapest option.

Like any other energy source there are barriers and challenges that can be found with wind power. Firstly, the environmental impact. Some local nature environmentalist might oppose of implementing wind turbines in a location where there are wildlife inhabitants. It is not only considered damaging to the natural habitat of those animals but also disturbing to the natural scenery of a particular location. Secondly, wind turbines require a lot of space. Finding a suitably large area of land on which to construct a wind farm may prove challenging, and there is an opportunity cost associated with making the land unusable for other purposes. Third is the location of turbine itself. It is highly possible that the idea location for the wind turbine is not close to where the actual energy consumers are located. Cities and tight suburban areas are places that typically have high energy demand but are poor locations for wind turbines. There is a limitation on the transmission of electricity from the wind power generation site. The further the energy generator is from the consumer, the more electricity is lost during transmission.

Lake Source Cooling

Lake Source Cooling (LSC) is a method for cooling buildings pioneered at Cornell University. It replaces chillers with the naturally cold water at the bottom of Cayuga Lake, a renewable resource that is replenished in the winter months. Due to the fact that water is densest at around 4° C, and the water at the bottom of the lake is the most dense, it is approximately the same temperature year round. In LSC, this cold water is pumped from the bottom of the lake to a series of heat exchangers located in a heat exchange facility on the shore, where it is used to cool off warm water from Cornell's campus. After the warm water is cooled, it is pumped up to the campus where it is used to cool campus buildings. The water is then cycled back to the heat exchangers. Having separate water loops on either side of the heat exchange facility reduces pumping requirements since the closed loop between the lake and the campus is sealed and therefore requires less energy to circulate. After cooling off the campus supply, the water from Cayuga Lake is returned to the lake, but at a shallower depth (Energyandsustainability.fs.cornell.edu, 2005). This process can be seen in Figure 16.

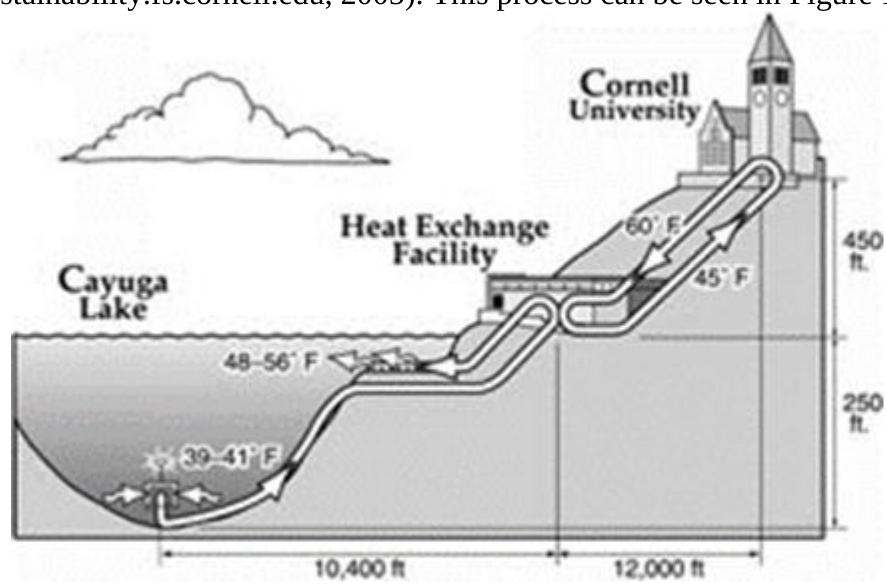


Figure 16: Overview of Lake Source Cooling System at Cornell University

Cornell's LSC system finished construction in 2000, and at the time cost $58.5 million dollars to construct (approximately $83 million in 2017 dollars). It was built to replace an aging and outdated chiller system. The system was more expensive than a chiller upgrade, but is expected to have a much longer service life. The LSC system is expected to have a service life of 75-100 years, which is twice that of current chiller systems. The LSC provides an 86% reduction in energy consumption associated with cooling Cornell's campus, which equates to about 25,000,000 kWh per year in energy savings. Cornell's energy savings from the LSC system in kWh is shown in Figure 17 on a monthly basis (Energyandsustainability.fs.cornell.edu, 2005). Pumps and heat exchangers in the system can be turned on and off to match campus demand.

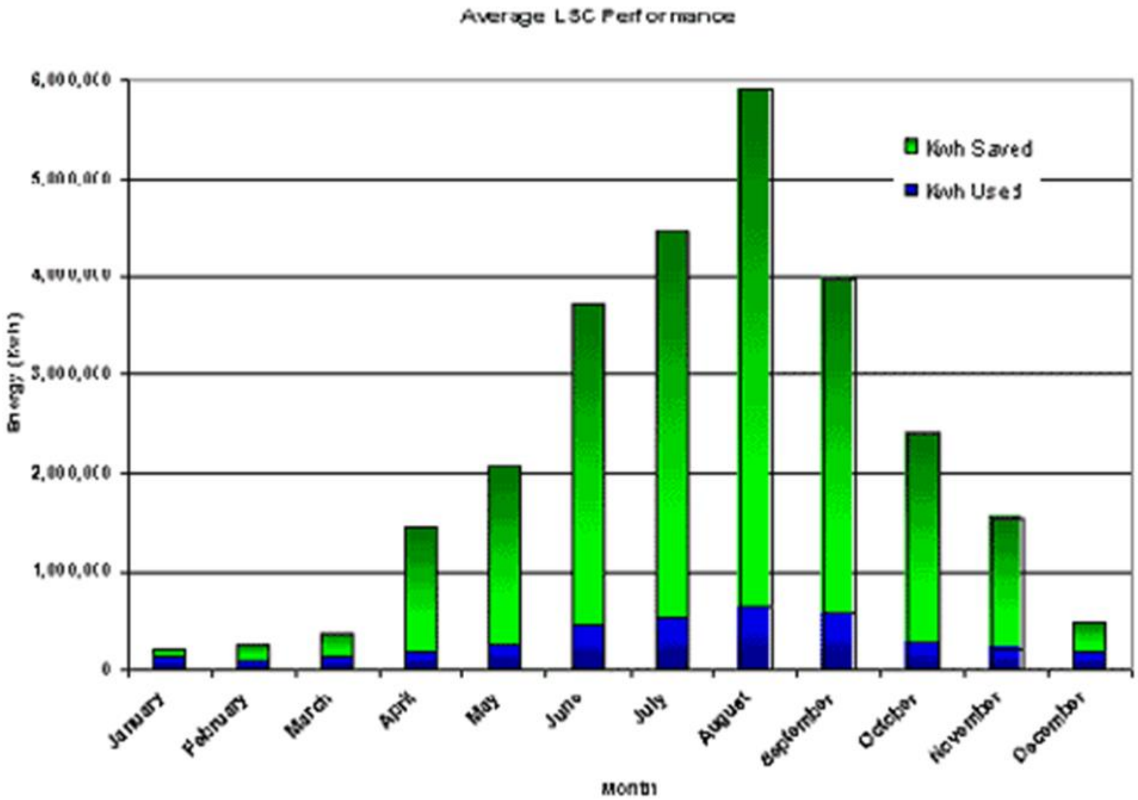


Figure 17: Energy Consumption With (Blue) and Without (Green) Lake Source Cooling.
Source: Cornell office of energy and sustainability, 2005.

A potential risk of the system is returned warmed water to Cayuga Lake. While it is believed that there is no environmental risk posed to the lake, Cornell is obligated to monitor the lake, and submit a yearly report addressing any possible effects of the LSC system (Energyandsustainability.fs.cornell.edu, 2005). This monitoring may be a deterrent for other groups seeking to have a similar system.

LSC is still a relatively unexplored market. There is only one other LSC system of note in the world, located in Toronto. This system was built in 2004, and uses Lake Ontario to cool 30 million ft^2 of office space. At the time of construction, the system cost $100 million to build (approximately $129.5 million in 2017 dollars). The Toronto system is substantially larger than Cornell's, and provides a 90% reduction in energy costs associated with cooling. This equates to 85,000,000 kWh per year (Acciona.us, 2017). The system has been a large success, and demand for cool lake water has increased to the point where a 25% capacity increase is currently under discussion (Best Practice: Deep Lake Water Cooling System, 2009). One major difference between the Cornell and Toronto systems is where the lake water goes after passing through the heat exchangers. The Cornell systems returns the water to the lake, but the Toronto system adds the water to the municipal water supply. Since the water is not being returned to the lake, continuous environmental monitoring is not needed. Systems are also being considered in Honolulu and Stockholm.

Areas for Opportunity

Corporate push for microgrid technology

There are a variety of companies available to assist with the implementation and control of energy microgrids. Many companies, such as Microgrid Energy, act primarily in a consulting capacity to institutions, with minimal implementation or follow-up work. These companies provide guidance as to what mixture of energy sources to use and how to set up the institution's microgrid. Microgrid Energy emphasizes renewable energy in the development of microgrids, and recently helped install an energy microgrid at a fire station. Other companies, such as Pareto Energy, Spirae, and Schneider, all offer products that assist with energy microgrid control and management. All three emphasize the resilience and independence that microgrids offer institutions in lieu of traditional utility providers. Several also emphasize that, in some cases, institutions can even leverage their microgrids to generate new revenue streams. Yet another company, Siemens, offers Microgrid Software as a Service (MSaaS), which provides end users with a dashboard and ability to control their own microgrid without the information technology work and maintenance. This product was rather disruptive to the microgrid management industry, and opened up a new market opportunity for companies involved in microgrid technology, such as those previously mentioned.

All of these companies' models, though they are effective in controlling the microgrid to minimize both costs and emissions, require that the hosting institution play a very active role in control and management. Even Siemens' MSaaS model, while eliminating the hassle related to maintaining the control system, still puts the onus of controlling the grid on the institution.

Though they do provide a simple interface for the user, the product still requires a user to make choices about the operation of the microgrid. In doing research, it is difficult to identify companies or services that will operate a microgrid on another institution's behalf. Many instead choose to outsource actual management of the system to end users, who are empowered by the control and management products available. It is expected that the market for services similar to MSaaS will continue to grow as both utilities and consumers search for more environmentally and cost-efficient ways to manage energy usage. At this time, it does not appear that utilities services are looking to take over the management of microgrids. Indeed, much of the appeal of the microgrid services listed above is that they provide some freedom from traditional utilities providers, thus gaining better resiliency and more autonomy.

Local push for energy use transparency

In Ithaca, two initiatives are underway to improve energy usage for both the community and individuals. The first is real-time energy monitoring of commercial buildings, and the second is the development of energy "nanogrids." For a relatively low cost of $500-$600, an energy monitoring device can be installed in a commercial location, from which data will be pushed outward to a simple user interface for monitoring. This allows owners or tenants to see their energy usage or consumption in real time, which can correspondingly help influence or change their behavior. Ithaca Bakery, which has several solar panels on its roof, will be used as a test location for a solar "nanogrid," which similarly helps owners regulate and make informed decisions about energy usage. The "nanogrid" can act as an energy backup for Ithaca Bakery and provide some energy during peak demand, when rates can be higher, thus helping the establishment save money. This can serve as an interesting small-scale implementation example.

Risks

Overall, the implementation of an energy microgrid should help to mitigate several risks at the facility, most especially power outages. A microgrid will also help to reduce fluctuations in energy costs through "peak shaving," by avoiding the purchase of some energy at surge rates during high demand periods. However, this project will likely be capital intensive, and thus it may be a challenge to procure sufficient funds and support. Opposition from neighboring institutions and residential homes could also halt the development and construction of different parts of the microgrid. Once the microgrid is established, there is a chance that it will not operate as expected, leading to reduced energy output and higher energy costs. Additionally, the machinery could malfunction, leading to increased maintenance costs and user dissatisfaction. Within the healthcare facility, it may be difficult to identify an employee, or employees, who would be willing and able to effectively monitor the microgrid, rendering it less efficient than desired or raising salary expenses.

These risks could render the use of alternative energy sources or implementation of energy efficiency measures better solutions to the facility's current energy needs. However, similar risks regarding capital expenditure, community opposition, and staffing requirements will likely exist for these strategies, as well.

Energy Efficiency

Diesel Generator

One of the most crucial main requirements in a healthcare system is the ability to self-sufficiently power itself when power is lost from the grid. These issues could impede healthcare operations, affecting patients' medical conditions, which may be in a critical state. According to a New York Government Report published in 2013, many hospitals in the state of New York currently do not have a reliable backup power generator for power failures. This further emphasize the criticality of having a reliable back up system in place.

In some cases, the backup system capacity is less than adequate to sustain today's energy demand that is required to fully operate the hospital. Therefore, when electrical outages occur, non-critical systems power down to limit the demand. Increasing the size of the backup system allows for greater coverage.

Upgrading or increasing backup power capacity can also improve efficiency. A 2500 kW is the value for required demand used for calculations in the following examples.

The team proposes a series of potential changes in the diesel power generator arrangement to meet with the current and short-term future demand. One suggestion is to swap to a larger power generator to meet the predicted demand. Another alternative is to cannibalize the current layout by keeping the existing generator and adding or replacing some of the current diesel power generators with a larger capacity unit. To further increase efficiency we analyze different types of diesel power configurations, subject to minimizing capital and running cost while maintaining high level of utility and meeting energy demand.

To ensure that the healthcare facility gets the most utility out of each diesel generator option available, we conducted a simple objective function to maximize output with the least capital cost and operating cost. Based on our research we have gathered a variety of diesel power generator name brands such as John Deere, Perkins, Cummins, MTU, Broadcrown, and Caterpillar. The output of each generator with respect to cost was then computed. Table 1 shows the breakdown of 25 different models from various name brands based on their manufacturer specification along with different capacities. To make a control comparison our calculations included the capacity factor of each diesel generator, in other words the true power output suggested by the manufacturer.

No.	Brand	Model / Type	Dimension (LxWxH)	Capacity (W)	Continuous Output (W)	Price ($)	Price / W	Consumption (gal/hr)			Consumption gal/hr/kWh	Running Cost kWh
1	John Deere	4045TDF Diesel	62x34x25 inches	52500-50000	50,000	$11,599.00	$0.231980	at load	0.5	1.9	0.07600	$0.217
								at load	0.75	2.8	0.07467	$0.213
								at load	1	3.6	0.07200	$0.205
2	John Deere	4045HF285	86x35x56 inches	105000-100000	100,000	$16,999.00	$0.169990	at load	0.5	3.9	0.07800	$0.223
								at load	0.75	5.1	0.06800	$0.194
								at load	1	6.1	0.06100	$0.174
3	Perkins	1104-C2	88x34x60 inches	105000-100000	100,000	$15,749.00	$0.157490	at load	0.5	3.9	0.07800	$0.223
								at load	0.75	5.1	0.06800	$0.194
								at load	1	6.1	0.06100	$0.174
4	John Deere	6068HF285	130x45x65 inches	127500-125000	125,000	$20,999.00	$0.167992	at load	0.5	4.7	0.07520	$0.215
								at load	0.75	6.15	0.06560	$0.187
								at load	1	7.35	0.05880	$0.168
5	Perkins	1106D-E66TA	98x37x62 inches	152000-150000	150,000	$22,475.00	$0.149833	at load	0.5	5.3	0.07067	$0.202
								at load	0.75	6.9	0.06133	$0.175
								at load	1	8.7	0.05800	$0.166
6	John Deere	6068HF285	130x45x65 inches	150000-140000	145,000	$22,475.00	$0.155000	at load	0.5	5.1	0.07034	$0.201
								at load	0.75	6.8	0.06253	$0.178
								at load	1	8.2	0.05655	$0.161
7	Perkins	1106D-E66TA	113x41x66 inches	175000-173500	173,500	$23,999.00	$0.138323	at load	0.5	5.9	0.06801	$0.194
								at load	0.75	8.3	0.06378	$0.182
								at load	1	10.5	0.06052	$0.173
8	John Deere	6068HF485	135x45x69 inches	210000-200000	200,000	$26,299.00	$0.131495	at load	0.5	6.8	0.06800	$0.194
								at load	0.75	9.8	0.06533	$0.186
								at load	1	12.9	0.06450	$0.184
9	Cummins	QST30-G4	80x56x65 inches	1000000-910000	1,000,000	$171,600.00	$0.171600	at load	0.5	28.798	0.05760	$0.164
								at load	0.75	44.385	0.05918	$0.169
								at load	1	60.23	0.06023	$0.172
10	Cummins	QST30-G3	2621x1448x2021 mm	800,000-728,000	910,000	$186,500.00	$0.204945	at load	0.5	24.835	0.05458	$0.156
								at load	0.75	36.724	0.05381	$0.154
								at load	1	48.613	0.05342	$0.152
11	MTU	16V2000G85	194.9x63.1x96.3 inche	1000000-900000(	900,000	$159,100.00	$0.176778	at load	0.5	34.13	0.07584	$0.216
								at load	0.75	45.5	0.06741	$0.192
								at load	1	60.67	0.06741	$0.192
12	Cummins	QST 30 G4	4737x1760x2337mm	925000-1000000	1000000	$150,970.00	$0.150970	at load	0.5	31.4399	0.06288	$0.179
								at load	0.75	46.7635	0.06235	$0.178
								at load	1	63.408	0.06341	$0.181
13	Perkins	4008-TAG2A	3852x2046x2067mm	880000-800000	800,000	$161,200.00	$0.201500	at load	0.5	28.798	0.07200	$0.205
								at load	0.75	43.065	0.07178	$0.205
								at load	1	59.709	0.07464	$0.213
14	Perkins	4012-46TWG2A	3714x1780x2255mm	1100000-100000(	1,100,000	$220,100.00	$0.200091	at load	0.5	39.63	0.07205	$0.206
								at load	0.75	53.633	0.06501	$0.186
								at load	1	70.2774	0.06389	$0.182
15	Cummins	KTA50-G9	3498x2000x2703mm	1500000-129500(	1,500,000	$301,400.00	$0.200933	at load	0.5	47.556	0.06341	$0.181
								at load	0.75	67.9	0.06036	$0.172
								at load	1	87.186	0.05812	$0.166
16	Broadcrown	QSK 50 G4	232X79X115 Inches	1500000-136500(	1,500,000	$260,430.00	$0.173620	at load	0.5	61.6	0.08213	$0.234
								at load	0.75	87.4	0.07769	$0.222
								at load	1	109.6	0.07307	$0.209
17	Broadcrown	QSK50G6	232x79x115 inches	1600000-145400(	1600000	$280,215.00	$0.175134	at load	0.5	65	0.08125	$0.232
								at load	0.75	88	0.07333	$0.209
								at load	1	113.9	0.07119	$0.203
18	Cummins	KTA 50 G9	5560x2000x2431mm	1500000-128000(	1,500,000	$223,230.00	$0.148820	at load	0.5	47.556	0.06341	$0.181
								at load	0.75	67.9	0.06036	$0.172
								at load	1	87.786	0.05852	$0.167
19	Broadcrown	QSK 60 G10	245x100x130 inches	2000000-182500(	2,000,000	$386,130.00	$0.193065	at load	0.5	73	0.07300	$0.208
								at load	0.75	99	0.06600	$0.188
								at load	1	131	0.06550	$0.187
20	Perkins	4012-46TAG3A	3915x2198x2259mm	1500000-136800(	1,500,000	$279,800.00	$0.186533	at load	0.5	49.4055	0.06587	$0.188
								at load	0.75	72.655	0.06458	$0.184
								at load	1	97.754	0.06517	$0.186
21	Cummins	QSK 60 G6	5995x2316x2875mm	2000000-182500(	2,000,000	$335,595.00	$0.167798	at load	0.5	67.107	0.06711	$0.192
								at load	0.75	95.1123	0.06341	$0.181
								at load	1	124.439	0.06222	$0.178
22	MTU	20V4000G43	7300x3003x2280mm	2550000-231200(	2,550,000	$640,300.00	$0.251098	at load	0.5	86.6578	0.06797	$0.194
								at load	0.75	124.4386	0.06507	$0.186
								at load	1	160.634	0.06299	$0.180
23	MTU	20V4000G83	7300x3003x2280mm	2820000-256000(	2,820,000	$735,400.00	$0.260780	at load	0.5	94.5839	0.06708	$0.191
								at load	0.75	136.3276	0.06446	$0.184
								at load	1	178.3355	0.06324	$0.180
24	Cummins	QSK78-G8	3062x1570x2031mm	2750000-250000(	2,750,000	$750,000.00	$0.272727	at load	0.5	93	0.06764	$0.193
								at load	0.75	132.1	0.06405	$0.183
								at load	1	167.6	0.06095	$0.174
25	MTU	20V4000G83L	7300x3003x2280mm	3110000-282400(	3,110,000	$824,900.00	$0.265241	at load	0.5	101.9815	0.06558	$0.187
								at load	0.75	146.8956	0.06298	$0.180
								at load	1	197.886	0.06363	$0.182

Table 1: Technical and Cost Characteristics for 25 Name Brand Diesel Generators

Table 1 has been sorted with color conditional formatting to easily indicate which variable costs more in a particular area. Darker colors equate to more cost associated with that option. The ideal generator will have lighter options for both cost and diesel consumption rate, indicating a cheap option that also does not consume a lot of fuel. Options number 12 and 18 are highlighted in yellow to indicate that they are the best options for their diesel class capacity.

Based on Table 1, there are linear relationships between generator load and diesel consumption rate. Each diesel generator consumption rate is dependent on the load that is given. In general, diesel engines run more efficiently and consume less diesel per kW at full load. A similar relationship could also be found on the utility of each diesel generator in the 1 kW and above capacity. In general, the larger the capacity of a diesel generator the higher the capital cost.

With the bases of these calculation we have come up with three different options to meet our objective function. Below are the options that we have picked exclusively to provide an advantage for 2500 kW of capacity:

Option 1: (1x1500 kW) + (1x 1000 kW)
This option consist of purchasing two new diesel generators: one 1000 kW and one 1500 kW. This system primarily focuses on meeting the energy demand whenever there is a power outage. This particular option will provide the reliability of a new system as well as the efficiency of a new diesel generator system.

Option 2: (2x1500 kW)
This option consists of purchasing two new diesel generators at a rated power of 1500 kW each, totaling 3000 kW. This system has two primary goals. The first one is to meet and exceed the current energy usage. Secondly, this system will be slightly future-proofed in order to meet potential increase in energy usage. With a life expectancy of 25 years, this option could provide for future predicted energy demand. In addition, many healthcare facilities have plans to potentially expand its medical campus facility dramatically. Again, oversizing the diesel generators now will allow the hospital to have sufficient emergency power even if the demand dramatically increases in the near future. This method may save time and capital cost in the long term.

Option 3: (2x500 kW) + (1x1500 kW)
This option consists of combining smaller and larger generators to achieve a total energy output of 2500 kW.

Our calculations breakdown is shown in Table 2.

	Configuration	Power Output	Equipment	Operating Cost

		(kW)	Purchase Price ($)	($/hr)
Option 1: (2500-kW)	(1x1500-kW) + (1x1000-kW)	2500	374,000	435
Option 2: (3000-kW)	(1x1500-kW) + (1x1500-kW)	3000	446,000	417
Option 3: (2500-kW)	(2x500-kW) + (1x1500-kW)	2500	223,000	478

Table 2: Potential System Configuration Cost Calculation

Table 2 above shows summarizes the calculations for each option. All calculations did not take into consideration any salvage value the current system could hold due to uncertainty in the current equipment condition and widely variable market value. Our calculation also did not take into consideration discounted pricing including in the new equipment purchase price.

Steam to Hot Water Conversion

Our research revealed that hospitals consume large amounts of energy because of the large systems that they support and many high energy devices that run in the facility on a daily basis. The team analyzed both the economic and environmental benefits of performing a steam to hot water conversion. Steam to hot water conversion reduces energy demand by controlling inefficiencies associated with the transmission of heating energy. Hot water heating minimizes energy losses during transmission and promises significant energy cost savings in the long term.

According to the research conducted by the University of British Columbia on “Steam to Hot Water Conversion,” and the data that we’ve obtained from Cornell University, we estimate that converting from steam to hot water distribution for heating will significantly reduce the current energy demand for heating for facilities that use steam for heating.

Steam Distribution Loss	Hot Water Distribution Loss
22%	3-5%

Table 3: Cornell University Distribution Losses for Steam and Hot Water

Steam Distribution Loss	Hot Water Distribution Loss
20%	3%

Table 4: University of British Columbia Distribution Losses for Steam and Hot Water

Savings in specific locations depend on the losses in the system that distributes steam from the central plant to the main building are, and the magnitude of the losses. Similar initiatives performed from the University of British Columbia and proposed for Cornell University to compare steam and hot water system efficiencies are representative. Then, the system efficiency of each mode can be calculated as shown below.

$$System\ Efficiency\ =\ Power\ Generation \times Distribution \times End\ Use$$

Mode	Power Generation	Distribution	End use	System Efficiency
Steam	0.80	0.78	0.90	0.56
Hot Water	0.88	0.95	1	0.84
% Inc. in Efficiency				0.49
Energy savings (Therms)				Depends on System size

Table 5: Steam to Hot Water Conversion Estimates

Steam is a cost-effective heating medium when it is available as a process waste or where it can be used for other applications, but hot water offers greater efficiency, safety and convenience. The team considered two approaches for converting from steam to hot water distribution. The first option is to retrofit the current heating system. Adapting the existing installation to use hot water is the most cost-effective option when the building will not undergo major renovations in the short term. However, part of the efficiency of a hot water installation is lost when using equipment originally sized and specified for steam. Also, managing the change process of retrofitting the existing system might become a major challenge for the implementation partly due to unforeseen conditions that might exist in the current system and because the process needs specialized personnel. It is necessary to upgrade the piping, since the hot water system will be operated with higher pressures. Although the existing pipelines are generally adequate for the higher pressures, network installations such as fittings and expansion joints must be modified at an additional expense.

The conversion of the steam system will be profitable in the long term, since the additional costs resulting from refitting the hot water main pipe, the network upgrading and modifications to the generator pumps will be more than offset by the savings from the lower operating cost and the reduced heating losses.

Requirements:

Pumping system:

The retrofitted system will be subject to a very different set of operating conditions once the installation is upgraded to hot water. Steam rises by itself, while hot water is pumped**.** The piping must be able to tolerate the water pressure at the pump outlet, as well as the static pressure from the water in the system.

Retrofitting Piping system

Both the supply and return lines will carry water**.** Although the return line is designed for this, the supply line is larger because it was sized to carry steam, and valves are typically required to balance the flow. Piping can be sized specifically for hot water, eliminating the need to use valves on oversized lines that were originally calculated for steam. Balancing the supply and return of water is much simpler if piping is adequately sized.

Heat exchanger:

Radiators can be replaced with more efficient alternatives, such as hydronic floor heating systems or water-source heat pumps. Automation can be deployed for the entire hot water system, achieving the lowest possible operating costs.

The second steam to hot water conversion approach is to improve distribution efficiency is to replace the heating system completely. Although this may seem expensive at first, it is cost-effective in the long term and is a more efficient solution than retrofitting a steam system. Thus, this plan is the better option if the building is to go through a major renovation. To implement this plan, replacing the facilities' current system with new piping and distribution, new boiler, new heat exchange system, and pumping system are required. The table below summarizes the pros and cons of the two possible hot water distribution approaches for a hypothetical medium-sized healthcare facility:

Mode	Retrofitting	New system
Changes	Retrofit current piping, add pumps, remove valves, redesign heat transfer station, pumping energy	New piping and distribution, new boiler, new heat exchange system, pumping system

Benefits	$92,000	$130,000
Downside	Part of the efficiency is lost, short term fix	Expensive, major renovation required
Initial costs	$0.8M	$1.1 M

Table 6: Comparison Between Retrofitted vs. New Hot Water System

We conducted a cost benefit analysis to examine the costs of implementing the steam to hot water conversion and compared the benefits over a 25-year investment horizon for a hypothetical medium-sized healthcare facility. Our initial costs for the new system were obtained from an estimate of the cost of installation for a comparable hospital adjusted with the Engineers New Record Index for December 2017. We obtained the initial costs for retrofitting the existing system by calculating the total cost of installing new piping, adding pumps, installing new heat exchangers and refitting boilers. Consequently, we calculated the annualized cost for the two scenarios, retrofitting the current system and installing an entire new system, for comparison. The initial costs for retrofitting the current steam system is 0.8M, the annualized cost for this assuming a 25-year period and 5% interest is about $92,000 whereas initial costs for installing an entirely new system is $1.1M with an annualized cost of about $130,000 to install new piping, pump station, redesigning heat exchangers with the associated labor.

Peak Energy Efficiency

Typically, healthcare facility energy usage fluctuates throughout the year. As a result, there are periods of high demand, during which rates per kWh are often higher than at other points in the year, but there are also periods of low demand. To assist with periods of high demand, battery storage of large amounts of energy will be considered. To better use existing energy sources during periods of low demand, the use of variable frequency drives (VFDs) on some equipment and the addition of absorption chillers will be considered. These measures would be in addition to the continuous or total energy use reduction measures detailed previously.

Large-scale batteries have emerged as effective methods of energy storage over the past few years, providing organizations with greater control over their energy usage. Two major uses for these batteries are “peak shaving” and “load-shifting.” For peak shaving, energy is purchased to charge batteries overnight or during times of low demand, and later discharged during periods of peak demand throughout the day. An example of this is shown in Figure 18. In this hypothetical case, power output does not exceed 600 kW, and therefore peak demand charges would be based upon 600 kW, as opposed to the original 700+ kW. This helps reduce the maximum power output during the billing period, which is the metric upon which peak demand charges are based. Therefore, if an organization can effectively peak shave, they are able to reduce their peak demand charge, since it is dependent only on maximum demand seen during the period, not total energy usage.

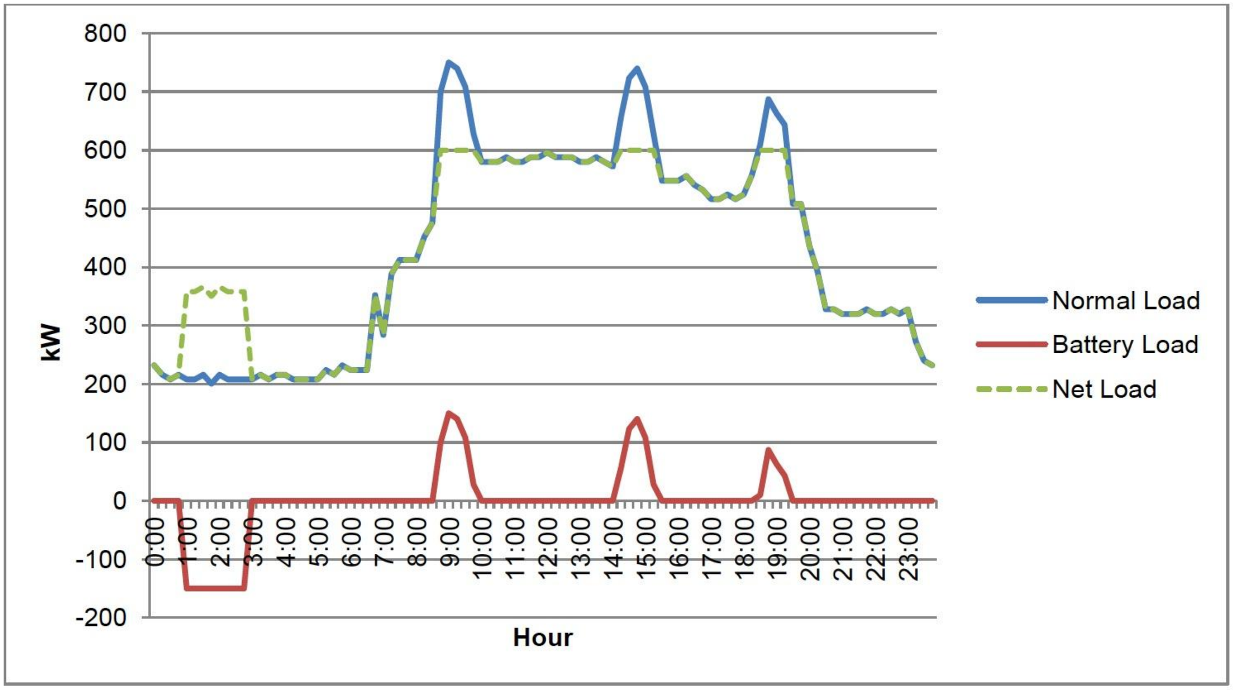


Figure 18: Example Using Peak Shaving to Reduce Maximum Demand

The second scenario in which batteries can be leveraged to better manage energy use and reduce costs is "load-shifting." In this case, energy is again purchased and stored during a period of low demand. However, here, energy is strategically purchased when rates are low, which happens to coincide with periods of lower demand. The battery is then completely discharged during the time at which rates are highest during the day. In contrast to the peak shaving scenario, the battery is not triggered by a threshold power output, but instead by a certain rate. Upon reaching this rate, the battery will begin to discharge and then fully discharge, instead of stopping the discharge and restarting only later when a certain demand is reached. An example is shown in Figure 19. In this hypothetical situation, it is more economical to purchase energy during the early morning than during the early afternoon, so stored energy is used to satisfy some part of the demand during that time. By operating in this manner, organizations save money by avoiding higher rates during periods of higher energy demand.

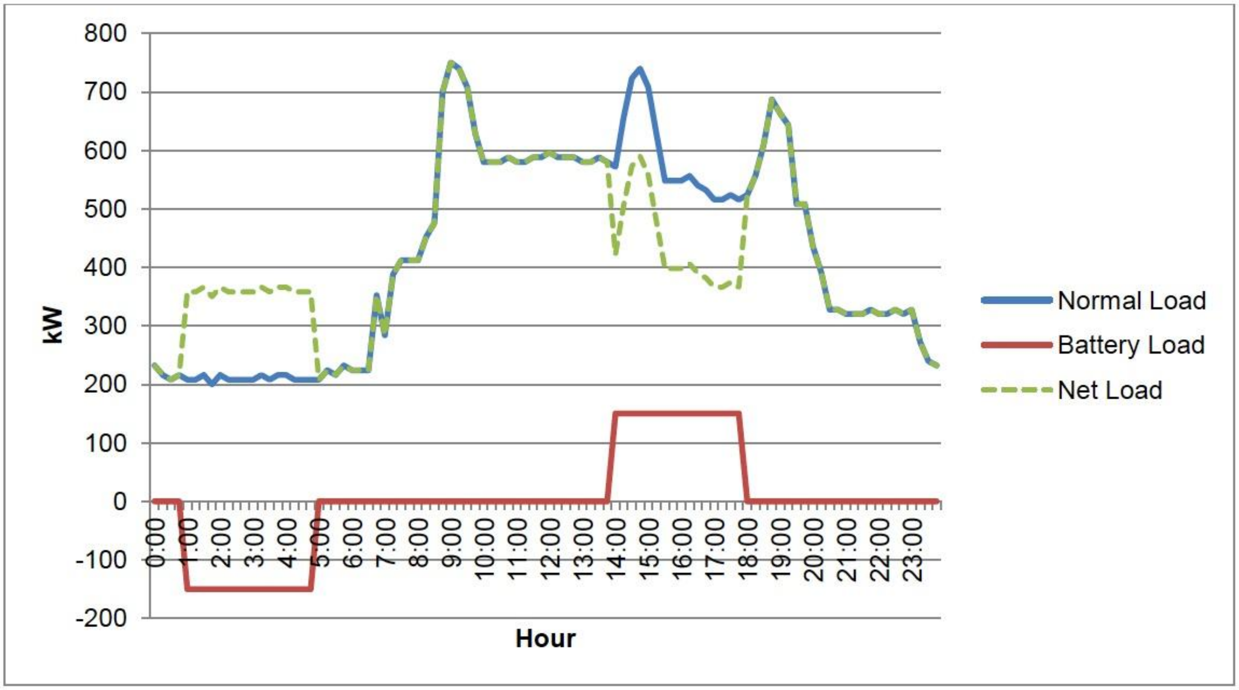


Figure 19: Example Using Load Shifting to Reduce Demand During High Cost Periods

Both of these scenarios have the ultimate goal of saving money for the organization that is implementing these battery storage technologies. They also have the added benefit of assisting the utility grids by offsetting some energy demand during periods of peak demand. Some states have created incentive schemes to encourage the use of energy storage to alleviate stresses on their utility grids. Most notably, California has begun a strong push for energy storage. Several laws have mandated target levels of energy storage for some regions within the state. One such target is 50 MW of energy storage in the Los Angeles Basin by 2020, as determined by the California Public Utilities Commission. Additionally, some funding from the state of California's Self-Generation Incentive Program, which previously had been used to facilitate combined heat and power system installations, has been made available to incentivize battery storage. Other states have followed with similar initiatives encouraging energy storage.

In 2010, New York established its own organization, named NY Battery and Energy Storage Technology Consortium (NY-BEST), which participates in everything from research and development of battery technologies to the promotion of new policies and standards for battery usage. Additionally, in 2013, the New York State Energy Research and Development Authority (NYSERDA) commissioned a very thorough report entitled "Behind-the-Meter Battery Storage: Technical and Market Assessment." This report gives an in-depth overview of the technology behind batteries, including those on the market and those still in development, in addition to analyses of several uses of batteries. It includes market-specific details such as comments on the effectiveness of these strategies in hospitals. The report also investigates differences between upstate and downstate costs and uses, which render it especially useful as a potential resource and source of information for energy storage.

Organizations that see large peaks in demand or large fluctuations in hourly energy rates throughout the day are great candidates for energy storage because the savings captured by lowering peak demand charges and/or reducing the purchase costs of energy can work to offset the capital cost of the battery, as well as associated maintenance and installation costs. If the healthcare facility experiences distinct peaks throughout the day, these can be alleviated with energy storage, and load-shifting can offset initial capital costs. Analysis and sample calculations for energy storage are therefore included in this report to increase awareness of the technology and potential future benefits. Also, if energy storage costs continue to decrease, this option will become even more attractive.

Many different types of batteries are currently on the market, and four in particular are prominent and established enough to be used for energy storage. Of these, lead-acid and lithium-ion are the most prevalent. Lithium-ion batteries are found most often in cell phones and other small devices since they are very compact and allow for almost a complete discharge without any harm to the battery. Additionally, these batteries have a comparatively long life cycle, and correspondingly high replacement costs. Lead-acid, the current market leader, has a much lower cost per kilowatt, but a shorter life cycle, and thus requires more frequent replacements. For the purposes of typical healthcare facilities, a lithium-ion battery would be the most appropriate choice, despite its higher capital cost, because it requires fewer replacements and less physical area for installation. Typically, these large batteries are delivered and installed in housings that resemble trailers, and could thus be placed in the parking lot or another discreet location. It is sometimes possible to place these units on the roof of the facility, but this is dependent upon the strength of the roof. Safety concerns were considered, but both battery types pose approximately similar hazards that are well known and understood. An additional bonus of lithium-ion technology is its continuously decreasing cost per kilowatt-hour. Of all battery types, lithium ion costs have been decreasing most rapidly over recent years as seen in Figure 20. The same cannot be said for installation costs, which have remained somewhat constant, though these costs would exist for all battery types.

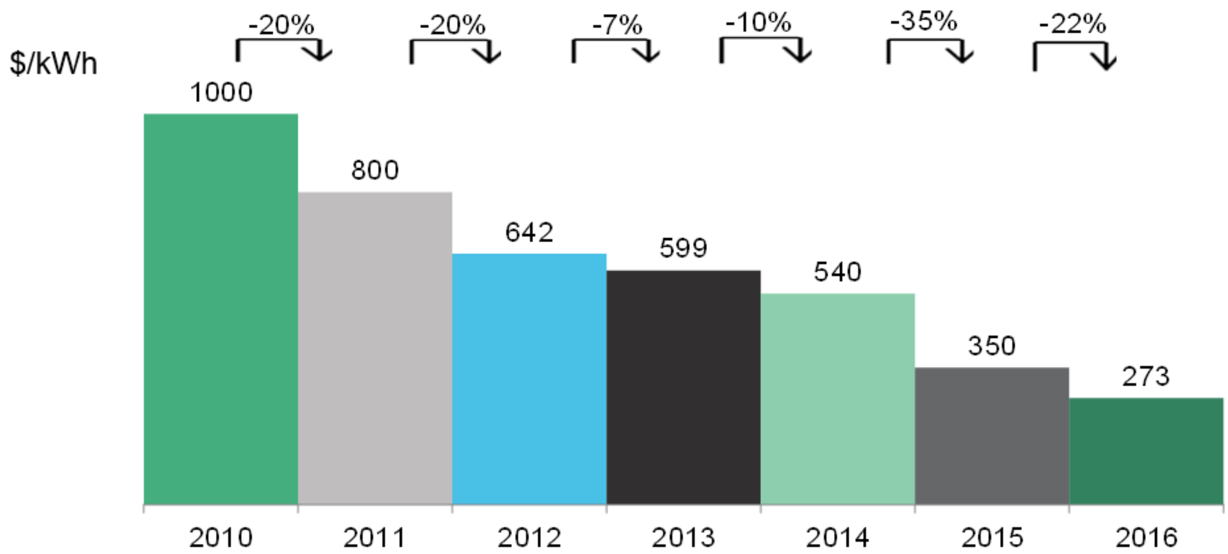


Figure 20: Price Drops in Lithium-ion Batteries From 2010 to 2016

To perform a cost-benefit analysis of the use of batteries for a healthcare organization, the capital cost of the new battery system must first be determined. The capital cost will include the cost of the battery itself, as well as installation, control units, and housing for the system. To be conservative, it is fair to assume a price of $1000 per kilowatt, as used by NYSERDA in its Behind-the-Meter report. Though the report was written in 2014 and the price of lithium ion batteries has decreased, installation and other costs did not decrease as substantially, so a higher per-kilowatt price is used. Looking at a 25-year lifetime, the lithium-ion battery itself will likely have to be replaced at least once, or maybe twice, since it has a lifetime of 10-15 years. Assuming a 12-year lifetime, the healthcare facility would need to replace the battery exactly twice, at a cost of $400 per kilowatt each time, from a NSYERDA assumption that lithium-ion battery replacement costs are 40% of the upfront cost. In all years in which equipment is not purchased, the healthcare facility will also have to pay maintenance costs to ensure that the battery remains functional and in working order. This annual maintenance cost is estimated to be 2% of the total upfront cost of the system, or around $20 per kilowatt installed.

The benefits of this system differ for peak shaving and load-shifting. Both cases, however, could benefit from additional governmental incentives for the installation and use of energy storage. For peak shaving, benefits consist of the decrease in peak demand charges over time, which are based off of the maximum energy output in a given time frame, ranging from one month to eighteen months, depending on billing structure. With energy storage, an organization could decide on a new maximum above which stored energy would be used to meet demand. The difference between the former peak and this new peak, Δpeak, can then be used to calculate peak demand charge reduction as follows:

$$Peak\ Demand\ Savings = \Delta Peak \cdot Peak\ Demand\ Rate \cdot Efficiency$$

An efficiency factor is included in this calculation to account for possible losses or inefficiencies in the use of the energy storage system. This number can be varied in models to determine the effects that battery reliability have on overall savings. For load-shifting, we are looking at billable kilowatt-hours instead of a fixed number of kilowatts. In this case, the organization is looking to maximize Δprice, the difference between the price at the most expensive point in the day and the price at the lowest, over the energy output of the battery. For a 500 kW system, this could be 2000 kWh over a four-hour discharge period. The annual savings can then be determined as follows:

$$Load\ Shifting\ Savings = \Delta Price \cdot Energy\ Output \cdot Efficiency \cdot 365$$

An efficiency factor is again included. Note that both of these benefits are calculated over an annual basis so that costs and benefits can be compared easily. Incentives based upon energy storage should also be included in total annual benefits, depending on the years in which they are earned.

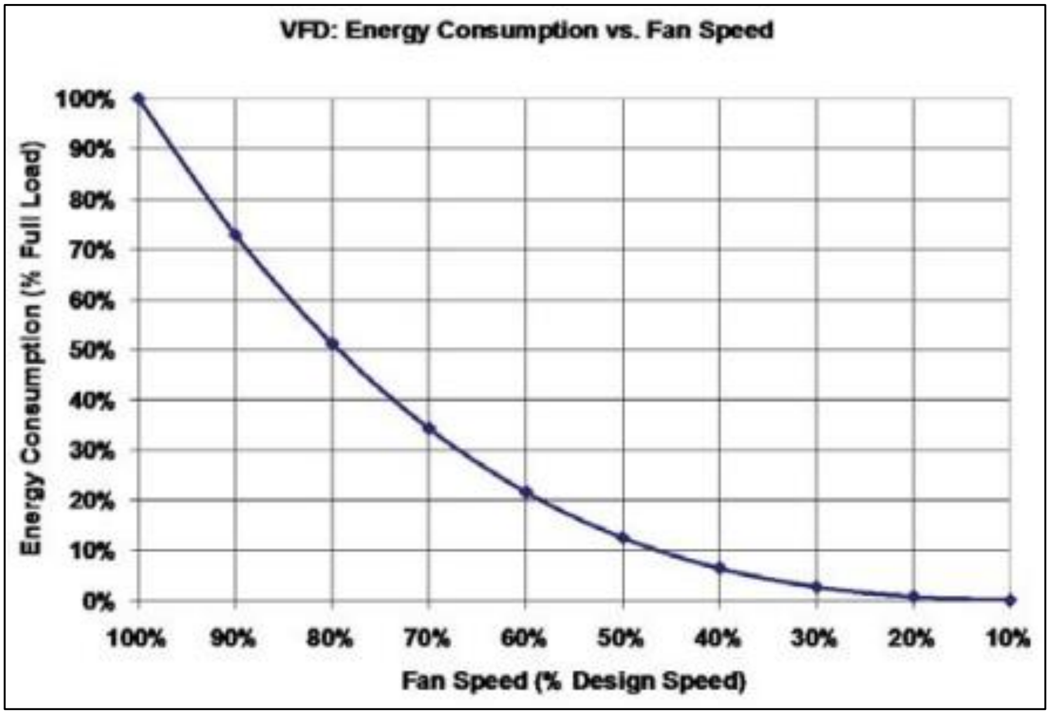
To perform the cost-benefit analysis, total annual benefits should be added to total annual costs, whether those are capital costs for new equipment or annual maintenance costs, to determine the annual net benefit of energy storage over the 25-year lifetime. Note that this could be negative, especially in years with high investment in technology. The net present value can then be determined by discounting these cash flows at a 5% rate, as assumed over the entirety of this report. If the net present value is positive, the installation and use of energy storage would be economically beneficial to the organization. If it is negative, it may not be. However, it could be a viable candidate for the organization for alternative reasons, such as a desire for greater energy autonomy or energy usage management.

To conclude regarding battery storage, a healthcare facility can consider purchasing and installing a 500-kW or 1000-kW lithium-ion battery system, capable of producing 2000 kWh or 4000 kWh, respectively, to better manage the costs of their energy usage. This battery, in its housing, could be placed in a non-central location such as a parking lot where it would be out of the way of the main building operations.

In addition to steam-to-hot water, further equipment updates were analyzed to aid in the reduction of energy consumption at healthcare facilities, specifically the movement away from electric chillers to absorption chillers and the retrofitting of equipment to include variable frequency drives (VFDs). To address the needs of typical healthcare facilities, the team decided to focus on measures that can be generalized to determine cost and energy savings for standard units. As such, an analysis of the addition of VFDs, flow modulators, and controls to be installed onto fixed-flow fans, pumps, and other HVAC equipment was completed. The implementation of this measure has the potential to reduce both energy demand as well as emissions through a decreased need for energy input. Additionally, the team considered the potential for replacing the current electric chillers with absorption chillers, which have potentially increased cost savings per unit energy and emissions reductions through higher energy efficiency and lower fuel source costs. A cost-benefit analysis and payback period on the new equipment are detailed in the following paragraphs. For these measures, specifications on the current equipment as well as proposed units will be utilized to create a hypothetical scenario to reflect what could occur at a representative healthcare facility.

VFDs are a type of system controller that monitor and vary motor speed, frequency, and voltage to meet system demands while minimizing excess flow and energy usage. They can be installed on a wide range of equipment, including chilled water pumps and condenser water pumps on chillers, boiler feed pumps, hot water pumps, air compressors, fans, and air handler units. VFDs work by flowing current through a converter with a number of valves that open and close to allow more or less flow through depending on what the system needs at that time. Often HVAC equipment operates at constant speed fixed by the specifications of the system, whether that be load capacity, power input and output, or current or voltage. However, this equipment often does not need to be running at these speeds as equipment must be designed for maximum demand but on average run below this peak. For example, many healthcare facilities might have an average demand that is approximately 60-80% of the peak, which suggests that some equipment does not run, or does not need to run, at full speed; therefore, there is opportunity for VFDs to be installed on equipment to further reduce this average. These controls would be purchased and placed on equipment motors to meet varying load requirements based on input signals and feedback from temperature sensors on outside air temperature.

VFDs are typically a great investment for facilities with varying demands and loads as they can reduce energy consumption by 20-70% by modulating motor speed. The relationship between fan speed and subsequent energy consumption is detailed in Figure 21.



Source: Cohen, Benjamin. "Variable Frequency Drives: Operation and Application with Evaporative Cooling Equipment."

Figure 21: Relationship Between Fan Speed and Energy Consumption

Source: Cohen, Benjamin. "Variable Frequency Drives: Operation and Application with Evaporative Cooling Equipment."

Figure 21 suggests that with a 10% reduction of fan speed, there is almost a 30% reduction in energy consumption. This exponential relationship is a major proponent for why VFDs work and have become popular for increasing energy efficiency. This equipment addition is typically a good option for improving energy efficiency for companies as VFDs have a fast payback period between six months and two years and are easily retrofitted into existing systems. MYSTERY devised a generic relationship between electric energy consumption and percentage of energy usage savings based on the assumption that VFDs are to be placed on 50% of electric equipment. The percentage of savings was assumed to be independent to simply reflect the range of savings that could occur through this implementation. Energy savings are typically between 20-70%, depending on the specifications of the equipment and the facility itself. The general relationship is detailed below. The equation used to derive the linear relationship in Figure 22 for estimated electric usage after the addition of VFDs, is as follows:

$$Estimated\ Electric\ Usage\ \left(\frac{kWh}{yr}\right) = Total\ Electric\ Usage\ \left(\frac{kWh}{yr}\right)(1 - 50\%\ of\ equipment \times \%\ of\ Energy\ Savings)$$

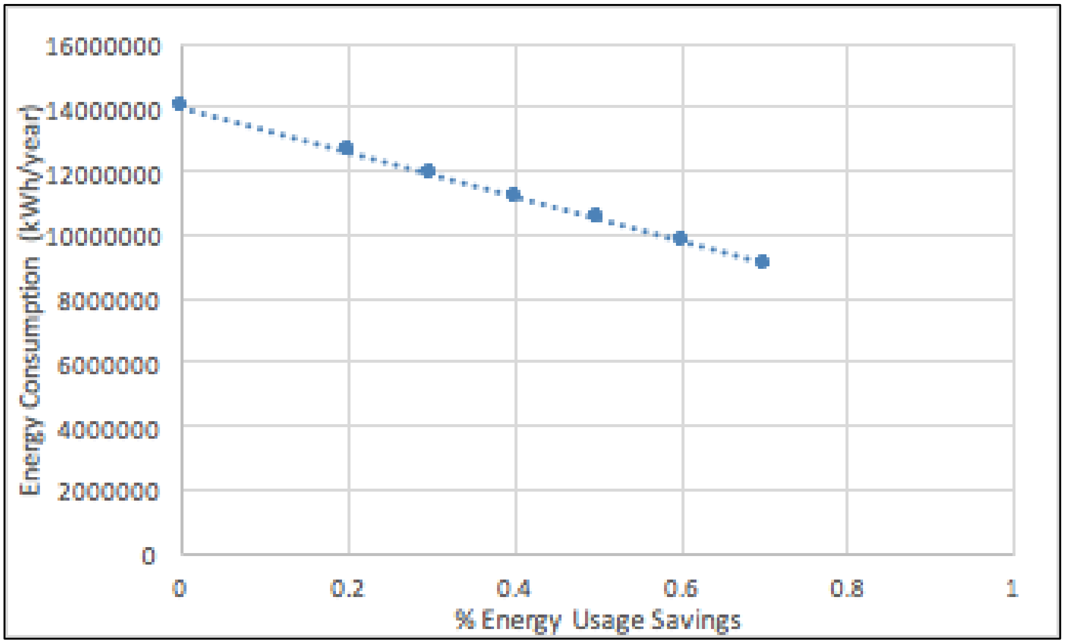
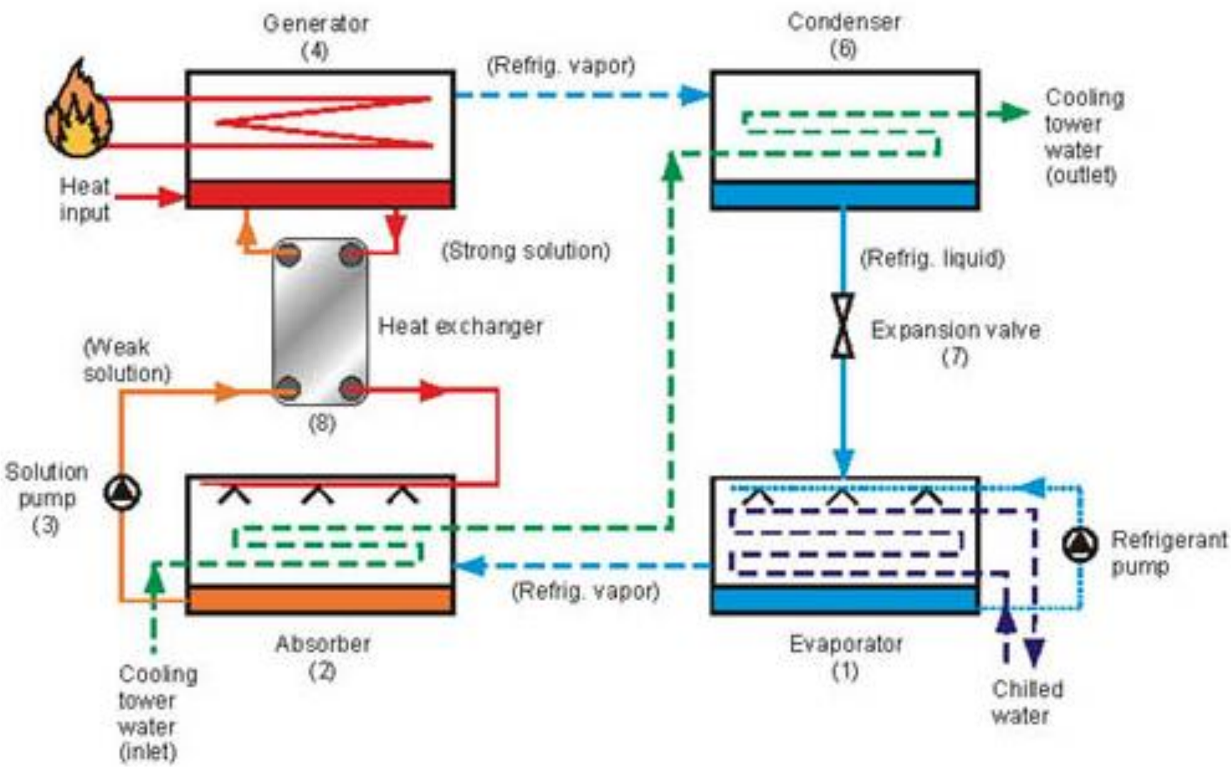


Figure 22: Derived Relationship Between Percentage of Energy Savings and Electric Energy Consumption

As hospitals have substantial and constant cooling loads to meet low temperature requirements for operating rooms, patient rooms, and medical equipment, absorption chillers are often a good option to meet these demands as their energy source is often less expensive than that of electric chillers, which helps to save money on these large load requirements. Absorption chillers use a condensation and evaporation cycle of refrigerant to create a cooling effect on water to be circulated throughout the facility. They are driven by a thermal heat source, such as natural gas, as opposed to mechanically operated with electric power, and this heat source drives refrigeration as heat naturally travels from warm spaces to cooler spaces. Two key components of absorption chillers are the chosen refrigerant and absorbent liquids; the refrigerant vapor dissolves in the absorbent and the cooling tower water helps to drive this step in the process and drives solution to higher pressure area to recycle throughout the process. The typical refrigerant used is water and a typical absorbent is lithium bromide, which have a high affinity to each other. The process is depicted in Figure 23.



Source: SWEP. "Absorption Chillers."

Figure 23: Absorption Chiller Process

The heat source vaporizes the refrigerant, which is then condensed in the condenser to liquid. Heat is extracted through heat exchanger using the warmed exit water stream to the cooling tower. The cooled liquid refrigerant flows to the cold evaporator, where water is chilled with a small refrigerant pump and the refrigerant is vaporized as a result. This chilled water is then used to cool the facility.

MYSTERY group proposes estimating the annual energy consumption and cost of the electric chillers for a healthcare facility using total annual energy consumption, total square-footage of the hospital, and typical hospital chiller plant Energy Use Intensities (EUIs):

$$Square\ Footage \cdot Hospital\ Chiller\ Plant\ EUI = Annual\ Chiller\ Plant\ Usage$$
$$Electricity\ Costs \cdot Annual\ Chiller\ Plant\ Usage = Annual\ Operating\ Costs$$

These calculations are made assuming that the chiller energy usage is similar across hospitals as the typical hospital chiller plant EUIs are used for the estimate. Another assumption is that the cost of electricity is to remain constant per kWh.

To help reduce significant energy costs for chillers, MYSTERY Consulting Group chose two different types of absorption chillers to analyze in combination with other energy independence measure recommendations. The following is a worked example based on representative figures.

The first option is the two-stage exhaust-fired chillers. This type of chiller uses exhaust from CHP systems as the energy source to cool water to be circulated throughout the hospital; therefore, it should only be considered in combination with the CHP system that will be discussed elsewhere in the report. The two greatest benefits of this type of system are the low operating and maintenance costs, as the energy source is a waste product from another system, and the lack of incremental CO_2 emissions from the system, for the same reason. The specifications of this system cause it to cost around $4 million total for capital and installation for a 1000-ton chiller, making it the more expensive of the two systems being considered. The total operating and maintenance costs were estimated using the proposed system specifications, the cooling capacity of the system, and the annual hours of operation.

$$Annual\ Chiller\ Operating\ Hours \cdot Cooling\ Capacity \cdot O\&M\ Costs = Annual\ O\&M\ Costs$$

For these calculations, it was assumed that the chillers run continuously, so the total annual hours of operation were assumed to be 8,760 hours per year. Total operating and maintenance costs for this system are approximately $18,000 per year. It was also assumed that this system could be supplied completely by exhaust from CHP to meet the 14,300 dekatherm per year demand of the system. Finally, the net present value over the 25-year life of the system was determined to be -$4.1 million. As previously mentioned, there are no incremental emissions, or additional emissions for the chillers besides that from CHP, produced from this system.

The second option is a system of two 800-ton direct-fired natural gas absorption chillers. This system operates similarly to option 1, but instead uses natural gas as the fuel source. Its simpler technology allows for a much lower capital cost of approximately $1 million, but the annual operating and maintenance costs are higher because the cost of the fuel source must be considered. Calculations to estimate this cost were completed assuming $5.453 per dekatherm.

$$Annual\ Chiller\ Plant\ Usage \cdot Cost\ of\ Natural\ Gas\ = Annual\ Operating\ Cost$$

$$Annual\ Chiller\ Operating\ Hours \cdot Cooling\ Capacity \cdot Maintenance\ Costs$$
$$= Annual\ Maintenance\ Cost$$

The total operating and maintenance costs were found to be $92,000 annually, including the cost of natural gas. The net present value was then estimated to be -$3.2 million, with annual CO_2 emissions of 1.6 million lbs. CO_2 per year. A summary of the two options for chiller upgrades is shown in Table 7.

	Representative Option 1	**Representative Option 2**

Description	Replace existing with 2x1000-ton two-stage exhaust-fired chillers	Replace existing with 2x800-ton direct-fired natural gas absorption chillers
Capital Cost	$4M	$1M
Est. Consumption	14,300 dekatherms/year	14,300 dekatherms/year
Annual O&M Costs	$18,000	$92,000
NPV (25 years)	-$4.1M	-$3.2M
Annual Emissions	~0 lbs CO2/year (incremental)	1.6M lbs CO2/year

Table 7: Summary of Representative Absorption Chiller Options

MYSTERY Consulting Group also examined other possible avenues for better optimizing energy use. In particular, the use of Smart Grid technology, which could provide a healthcare facility with the reliable energy it needs to operate in case of emergency, was assessed. The use of LED lighting or occupancy sensors that would better regulate lighting use would help reduce some costs. Rescheduling energy-intensive procedures, such as some cancer therapies, could help smooth out energy demand throughout the day. However, this would not be a practical adjustment since it is difficult to tailor procedures to energy needs, and there is not much variation in energy use throughout the day. Installing more advanced windows or re-evaluating air conditioning could also be considered.

As a supplementary recommendation, MYSTERY Consulting Group recommends that at the beginning of this process the healthcare facility hires a team of consultants or energy auditors to conduct an energy audit, which would include an analysis of their current energy consumption and equipment performance as well as recommendations to become more energy efficient. This process typically involves a site visit where data loggers are installed on equipment to collect energy usage data to be used to analyze performance and an interview with a facility manager to gain a better understanding of facility operations. A final report will be created that summarizes the current energy consumption and facility performance, gives equipment upgrade and alterations recommendations to reduce energy consumption, and details the estimated cost savings and payback period for the project. Energy audits range in price, but in the case of large facilities with high energy bills and large potential for energy savings, they typically are a good investment. Energy audits help facilities better gauge which of their machines and equipment are contributing most to their total energy usage and environmental footprint. With this information, the hospital can focus more narrowly on optimizing the use of certain machinery instead of their whole system, thus raising their energy star rating.

Supplemental Energy Sources

This section first focuses on methods for powering the healthcare facility (ie., electricity supply) as well as providing heat.

Solar Photovoltaic Energy Source

As the industry of solar energy continues to grow and the technology reaches new limits, it is important to consider the benefits of solar energy on facilities. The benefits of photovoltaic solar technology include the fact that it would be able to provide energy at very low cost after its initial investment. It takes a relatively short amount of time to install the system, and there is no need for a large infrastructure investment, since the panels could be setup on existing buildings, and available area. There are no moving components to be considered, no re-charging, and panels have a relatively long life-time with only a 1% decrease in efficiency per year. Lastly, it is worth noting that this technology is predictable and reliable, which is an asset in the medical industry.

As expected there are some drawbacks to using solar, especially when it comes to a healthcare facility due to large demand size. The photovoltaic solar technology will typically not be able to provide enough energy to supply the demand for a medical facility on the order of hundreds of thousands of square feet, nor reach the peak electric load on the order of megawatts. Lastly, there is a significant initial investment, as solar technology is still quite expensive.

Despite the inherent limitations of solar energy, there are interesting opportunities that solar energy could provide for this facility. Imbedded in the analysis made the team, there are several hidden opportunities that could maximize the use of this technology to produce energy, and provide a substantial contribution to the demand of the hospital. One of these opportunities came from the limitation of available land to incorporate a PV solar system. The team explored the idea of using metal structures otherwise known as "carports" which could provide the needed area, by using the area above existing parking lots for solar panels. It could be anticipated that in addition to providing extra area for the PV solar system, the carport could provide additional service to facility visitors and employees by providing some shelter for them and their vehicles during the hot summers, and the snowy winters. As an example, the cost of a carport structure that would extend over a 4,000 space parking lot area (= 13,000 square feet) would be of around $1.3 million. This estimate is based on similar projects and adjusted given the location of Ithaca.

Basic Data, PV panel	
Rated efficiency:	0.181
Rating temperature(C):	25
Temperature coefficient(/K):	0.0038
U sub L(kW/m2K):	0.02
tau*alpha (.85 in combinaiton)	0.85
Gamma(solar intensity coeff for cell eff):	0
Ta-TsubM (k)	3
roof rise (in)	5
roof run (in)	12
Watts/panel	250
area per panel (m^2)	1.244
number of panels	11000

Table 8: Solar Panel Basic Specifications

Given the intention to use all of the 13,000 square feet of newly available area, a system of 11,000 solar panels could be implemented. For the analysis performed, data values were assumed based on average constant rated efficiencies for 250 W panels, and other common panel characteristics.

Additionally, a thorough analysis of weather characteristics of the area of Ithaca, NY was performed in order to try and determined the conditions to which the panels would be exposed. This also included the analysis of deterring factors that ought to be included to provide an accurate estimate of the true output of energy provided by the panels. The following tables are some of the data collected as well as some snapshots of the performed analysis.

Derating Factors	
PV moldule nameplate DC	0.950
Inverter and transformer	0.920
Mismatch	0.980
Diodes and connections	0.995
DC wiring	0.980
AC wiring	0.990
Soiling	0.925
System availability	0.980
Shading	0.950
Sun-tracking	1.000
Age	1.000
Estimated total system derating	0.712

Table 9: Deterring Factors

Basic Data, location	Ithaca, NY
Latitude, degrees	42.4
Latitude, radians	0.740
Fixed tilt offset, deg(from lat.)	-19.8
Fixed tilt angle, degrees	22.6
Fixed tilt angle, radians	0.395
kW of system	2750

Table 10: Basic Location Data and Panel Setup

Adjustable Tilt										
Month	K sub T	T sub M	Tilt, radian	Solar, kWh/m2	UL * etc	Tc-Ta	Efficiency	kWh/day	days/mo	kWh/mo
January	0.470	-5.00	1.246	2.91	0.6100	25.93	0.182	0.53	31	16.40
February	0.470	-3.61	1.054	3.93	0.6100	25.93	0.181	0.71	28	19.91
March	0.490	0.28	0.792	4.32	0.6267	26.63	0.178	0.77	31	23.77
April	0.500	7.22	0.565	4.40	0.6350	26.99	0.173	0.76	30	22.81
May	0.530	13.06	0.356	5.54	0.6600	28.05	0.168	0.93	31	28.84
June	0.520	18.06	0.304	6.17	0.6516	27.69	0.165	1.02	30	30.47
July	0.550	20.56	0.321	6.24	0.6766	28.76	0.162	1.01	31	31.36
August	0.530	19.72	0.565	5.48	0.6600	28.05	0.163	0.90	31	27.76
September	0.520	15.56	0.705	4.85	0.6516	27.69	0.166	0.81	30	24.21
October	0.480	9.17	0.915	4.19	0.6184	26.28	0.172	0.72	31	22.29
November	0.390	4.44	1.141	2.55	0.5435	23.10	0.177	0.45	30	13.56
December	0.430	-1.67	1.264	2.95	0.5768	24.51	0.180	0.53	31	16.47
Sum/Average	0.490	*8.15*		53.53	*0.6267*	*26.63*	*0.172*	9.13		277.9

Table 11: Adjustable Tile Electricity Output

Monthly Insolation Analysis (Btu/ft2-day)												
Month	T ave, F	K sub T	H ave, Btu/ft2	reflectivity	Hd/H	day no	delta	h sub s	h' sub s	R sub b	R	H sub T, Btu/ft2
January	23.0	0.470	434.3	0.5	0.3946	15	-0.371	69.18	69.17882549	2.8003	2.1258	923
February	25.5	0.470	755.0	0.5	0.3946	46	-0.232	77.55	77.545089	2.0324	1.6517	1247
March	32.5	0.490	1075.0	0.3	0.3772	74	-0.049	87.42	87.42306257	1.4578	1.2736	1369
April	45.0	0.500	1323.0	0.2	0.3688	105	0.164	98.71	98.70869418	1.1089	1.0556	1397
May	55.5	0.530	1779.0	0.2	0.3445	135	0.328	108.10	108.1019957	0.9885	0.9879	1758
June	64.5	0.520	2026.0	0.2	0.3524	166	0.407	113.17	113.1740908	0.9522	0.9655	1956
July	69.0	0.550	2031.0	0.2	0.3289	196	0.376	111.10	111.1007417	0.9658	0.9737	1978
August	67.5	0.530	1737.0	0.2	0.3445	227	0.241	102.94	102.944517	1.0191	1.0013	1739
September	60.0	0.520	1320.0	0.2	0.3524	258	0.039	92.03	92.02572859	1.2834	1.1653	1538
October	48.5	0.480	918.0	0.2	0.3858	288	-0.168	81.12	81.11604386	1.7858	1.4464	1328
November	40.0	0.390	466.0	0.2	0.4749	319	-0.334	71.52	71.51527995	2.5540	1.7357	809
December	29.0	0.430	430.0	0.4	0.4323	349	-0.407	66.80	66.80139452	3.0845	2.1720	934

Table 12: Monthly Insolation Analysis for Ithaca

Fixed Tilt													
Month	K sub T	T sub M	Opt. tilt, deg	Tilt factor	Solar, kWh/m2	UL * etc	Tc-Ta	Efficiency	kWh/day	days/mo	kWh/m2-mo	derated kWh/m2	monthly kWh
January	0.470	-5.00	71.4	0.7216	2.15	0.4402	18.71	0.187	0.40	31	12.42	8.85	121040
February	0.470	-3.61	60.4	0.8330	3.28	0.5082	21.60	0.184	0.60	28	16.86	12.00	164256
March	0.490	0.28	45.4	0.9393	4.07	0.5886	25.02	0.179	0.73	31	22.53	16.04	219535
April	0.500	7.22	32.4	0.9888	4.45	0.6279	26.69	0.173	0.77	30	23.09	16.44	224998
May	0.530	13.06	20.4	0.9994	5.56	0.6596	28.03	0.168	0.93	31	28.93	20.60	281929
June	0.520	18.06	17.4	0.9968	6.12	0.6496	27.61	0.165	1.01	30	30.22	21.52	294477
July	0.550	20.56	18.4	0.9979	6.21	0.6752	28.70	0.162	1.01	31	31.26	22.26	304588
August	0.530	19.72	32.4	0.9888	5.65	0.6526	27.73	0.163	0.92	31	28.65	20.40	279151
September	0.520	15.56	40.4	0.9630	4.77	0.6275	26.67	0.167	0.80	30	23.89	17.01	232806
October	0.480	9.17	52.4	0.8962	3.75	0.5542	23.55	0.174	0.65	31	20.20	14.38	196791
November	0.390	4.44	65.4	0.7859	2.09	0.4271	18.15	0.181	0.38	30	11.34	8.07	110457
December	0.430	-1.67	72.4	0.7101	2.15	0.4095	17.41	0.185	0.40	31	12.37	8.81	120570
Sum/Average	*0.490*	8.15			50.25	0.5683	*24.15*	*0.174*	*0.72*		261.8	186.4	2550599
											Average	15.53	

Table 13: Fixed Tilt Electricity Output Analysis

ideal tilt, deg	ideal tilt, rad	derated kWh/m2
29	0.506	11.68
18	0.314	14.17
3	0.052	16.93
-10	-0.175	16.24
-22	-0.384	20.54
-25	-0.436	21.70
-24	-0.419	22.33
-10	-0.175	19.77
-2	-0.035	17.24
10	0.175	15.88
23	0.401	9.65
30	0.524	11.73
	Sum	197.9
	average	16.49

Table 14: Ideal Tilt Electricity Output Analysis

It is expected that in the example the 11,000 panels will be able to generate ~2.5 million kWh per year with fixed tilt position and somewhat higher generation with adjustable tilt. This is a significant amount of energy, though it will not come close to covering the full energy demand of a medium to large healthcare facility. Additionally, it is a green energy that will help the facility achieve a higher Energy Star rating. The cost of the 11,000-panel solar system including installation costs has been estimated to be around $9.8 million (this comes from an assumed price of $3.57 per watt, which is considered to be an average cost for solar panels). However, there are many federal and state incentives including the Federal Investment Tax Credit which reduced the net cost of the solar system by 30%, the New York Solar Tax Credit which provides $5,000, and New York's Megawatt Block Solar Incentives which could provide around $0.30/W incentives. This brings down the total cost of the system to around $6 million. There may be even more incentives that were not included in this report that could further drive down solar costs. Below there are two scenarios for a cash flow analysis determining the IRR and payback periods. Scenario one assumes the facility owner would provide the capital for all of the solar and carport systems (with an inflation rate of 5% that accounts for future uncertainty), and scenario two assumes the facility owner would borrow the money with an annual interest rate of 5%, and an amortization period of 20 years. Both Scenarios are performed over a 25-year period.

Capital Recovery Factor	
Amount Borrowed	$ (7,477,070)
Annual Interest Rate	5.00%
number of years	20
A/P factor	0.080242587
Annual Payment	$ (599,979.47)
Elec. Inflation Factor	5.0%
Current year's $/kWh	$ 0.065
Net installed Cost	$ (7,477,070)
NPV Rate of return	5.00%

Table 15: Capital Recovery Factor and Economic Inputs for Cash Flow Analysis

Scenario 1	
Net Present Value of benefits	$4,144,723
Less Cost of Initial Investment	$ (7,477,070)
Total Net Present Value	($3,332,347)
IRR	0.69%

Table 16: Scenario 1 Analysis Report Outputs

Scenario 2	
Net Present Value of benefits	$4,144,723.20
Less Cost of borrowed capital with interest	$ (11,999,589)
Total Net Present Value	($7,854,866.16)
IRR	-6.61%

Table 17: Scenario 2 Analysis Report Outputs

It can be concluded from the financial analysis performed that the high costs of implementing solar energy are in fact a limitation. Nonetheless, if there are more incentives, or the consideration to become for sustainable is deemed to be worth the cost, then solar could be an option. Facility owners may look into other business ventures like the Saint Francis Hospital and medical center in Hartford, CT, which allowed renewable energy provider Soltage LLC. to use their infrastructure to place 1,485 photovoltaic solar panels with a total capacity of 455 kW. In exchange, Soltage sold some of the electricity at a discounted rate back to the hospital.

Combined Heat and Power Plants

New systems may be implemented to generate energy in ways that may be more cost effective, lower in emissions, or both. A CHP plant is a potential energy source that operates by burning natural gas. CHP plants generate electricity at electrical efficiencies below 50% but also utilize waste heat, reducing the need for conventional methods of heat generation. Smaller CHP systems may be installed to serve as emergency backups, to lighten the burden of energy generation for other systems, or to reduce energy purchased from the grid during peak hours. Larger CHP systems can act as standalone systems and can often generate most or all of a facility's demand.

For our representative analysis, we focused on a variety of systems that could be constructed in order to supply both the heat and power for the hospital. For our analysis, in order to determine the effectiveness of the facility, a study by the Department of Energy was found that gives the expected efficiencies and outputs of multiple generators (DOE/EE, 2016). These efficiencies were entered into a spreadsheet, shown in Table 18, to determine the yearly costs of each system. The thermal and electrical efficiencies tend to increase with larger systems, with the peak reach with a 323-kW generator.

System	1	2	3	4	5
Net Power Rating (kW)	61	190	242	323	950
Fuel input (MMBtu/hr)	0.84	2.29	3.16	3.85	11.43
Useful Thermal (MMBtu/hr)	0.39	0.87	1.2	1.6	4.18
Electric Efficiency	0.247	0.284	0.261	0.287	0.283
Thermal Efficiency	0.469	0.38	0.38	0.416	0.366
Overall Efficiency	0.716	0.663	0.64	0.702	0.649
Installed Cost ($/kW)	$3,220	$3,150	$2,700	$2,560	$2,500
O&M ($/kWh)	$0.01	$0.02	$0.01	$0.01	$0.01
CO2 Emissions - Electricity Or	1613	1406	1529	1392	1407
C02 Emissions - w/ thermal c	667	739	804	668	764

Table 18: CHP System Information by Size

Note: Bottom row shows CO2 emissions with thermal credit.

The spreadsheet calculations were completed based on a representative year used to represent heat and electricity use for purposes of creating an example. Secondary sources of heat and electricity, boilers and the electrical grid, can be used to supplement the deficiencies from the CHP system under either higher than average usage or if the CHP system built does not meet the average usage.

For the analysis, electricity and heat would be generated until the average monthly heating demand was met. This was done because, if more natural gas is burned than is required to heat the facility, the waste heat must be vented. This represents an inefficiency in terms of both cost and environmental impact.

With these constraints in mind, the team created a model that uses only a CHP plant to power and heat the facility with any excess needed power and heat coming from the current boiler and electrical grid. The first scenario did not include any CHP to ensure that the model was applicable for the study. Once the model was validated, the amount of CHP generation was increased. This was done for multiple sized reactors, each with different efficiencies. Each of the reactors had different efficiencies for both heat and electrical generation, but the general trend is with a larger single unit, the more efficient the generator is in both generating heat and electricity. The results of different numbers of generators are displayed in Figure 24. Each colored line represents a generator of a different size. Each point within the lines represents adding more generators of that size to the system.

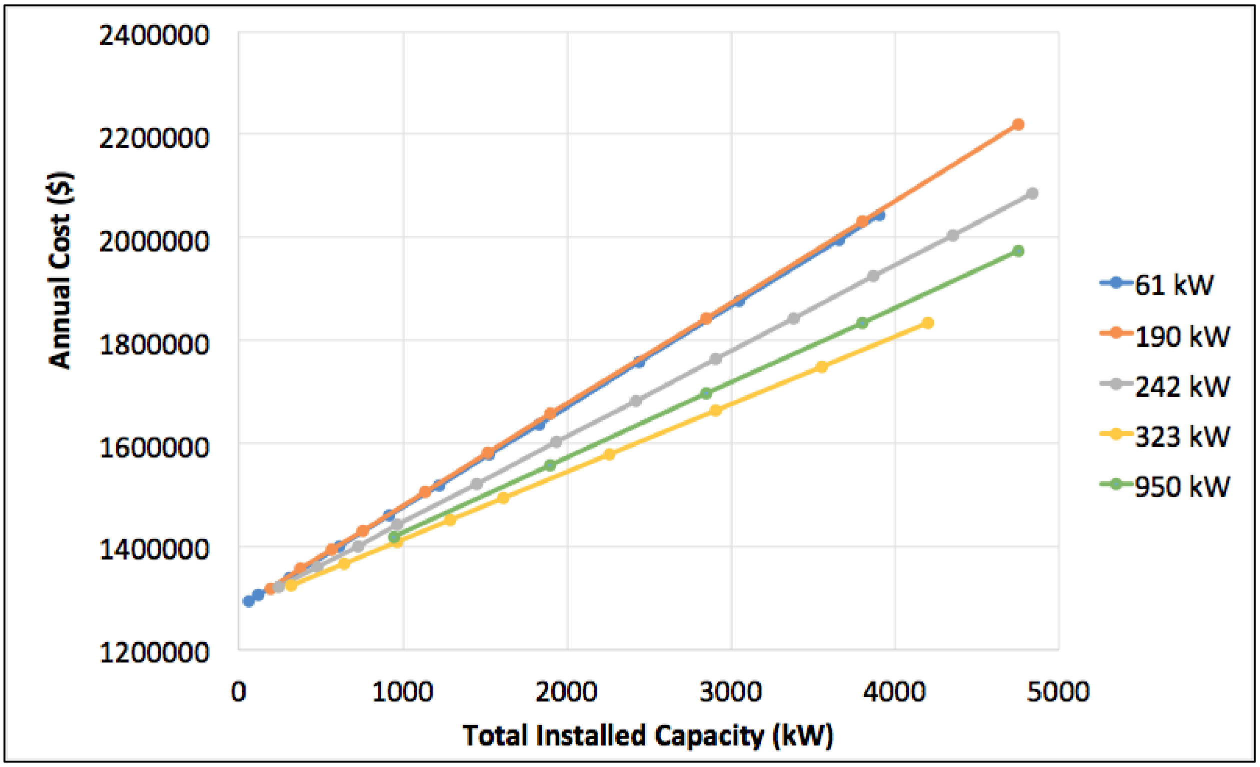


Figure 24: Total Annual Cost Including Excess Gas and Electric for Differently Sized CHP Systems

There is a linear increase to the annual cost of the system as more capacity is installed. This is due to the facility in this example having such a low cost of electricity that even cogenerated heat and power cannot offset the cost of the grid. Even though on-site generation does offer both heat and power, the grid is still less expensive in this case. CHP can still be an option for the facility if there is a large desire for reliability or continuous power, two aspects that are important to hospitals. Also, changes in the cost structure in the future might make CHP preferable.

Another important portion of this analysis is to determine how certain we are about the decision, and how the future prices of electricity and natural gas will affect the values of a CHP system. For example, if the price of natural gas decreases and the price of electricity increases, a CHP system may become a cheaper option. A sensitivity analysis was performed to determine the resilience of the team's calculations to changing natural gas and electricity prices. By slightly changing the rate of change of cost for both electricity and natural gas, we can determine how certain we can be in the results.

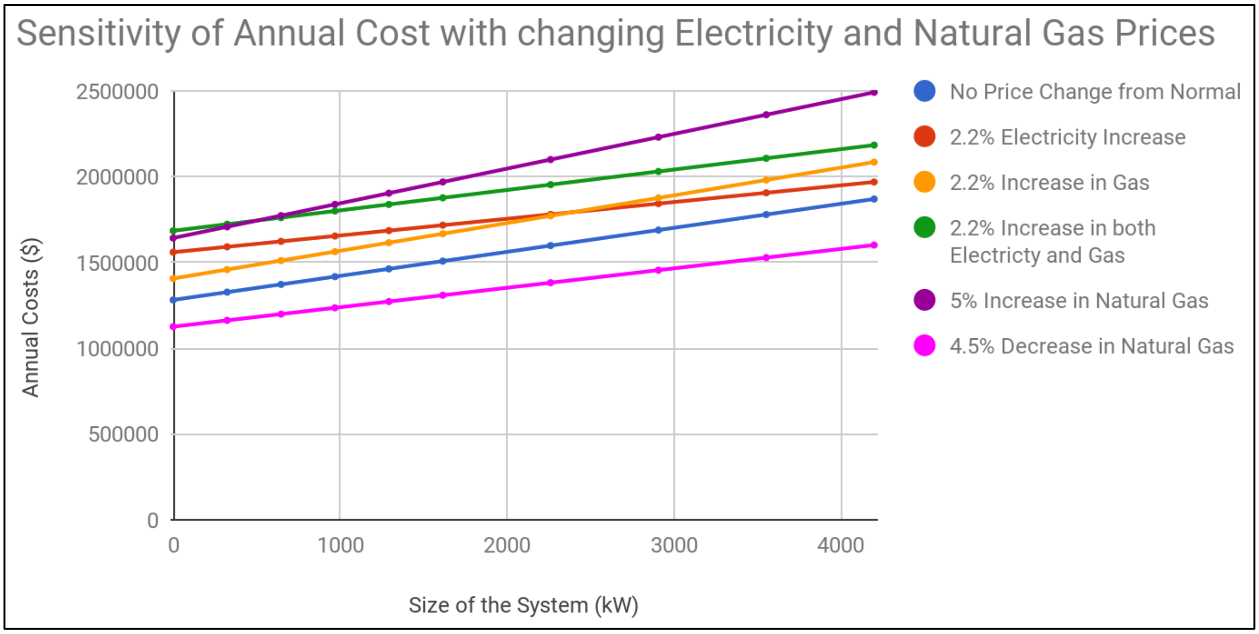


Figure 25: Sensitivity of Costs for a 323 kW Generator to Changes in Gas and Electricity Cost Changes

With the sensitivity analysis completed as show in Figure 25, we need to understand the results. Increasing the cost of natural gas increases the rate at which the systems increase in cost. As the cost of natural gas increases, the system becomes less economically feasible. It is therefore critical to ensure the cost of natural gas does not increase, which is discussed later in the paper. As electricity becomes more expensive, the CHP system becomes more economically feasible due to the price of electricity generated at CHP approaching the cost from buying electricity from the grid.

When the environmental impact of CHP and electrical transmission are explored, the CHP system is much better than the electrical transmission on a strict carbon dioxide emission basis. The line losses and the use of coal for generation cause the electricity produced for electrical transmission to produce more CO_2 per kWh produced than a CHP system. This can be seen in Figure 26.

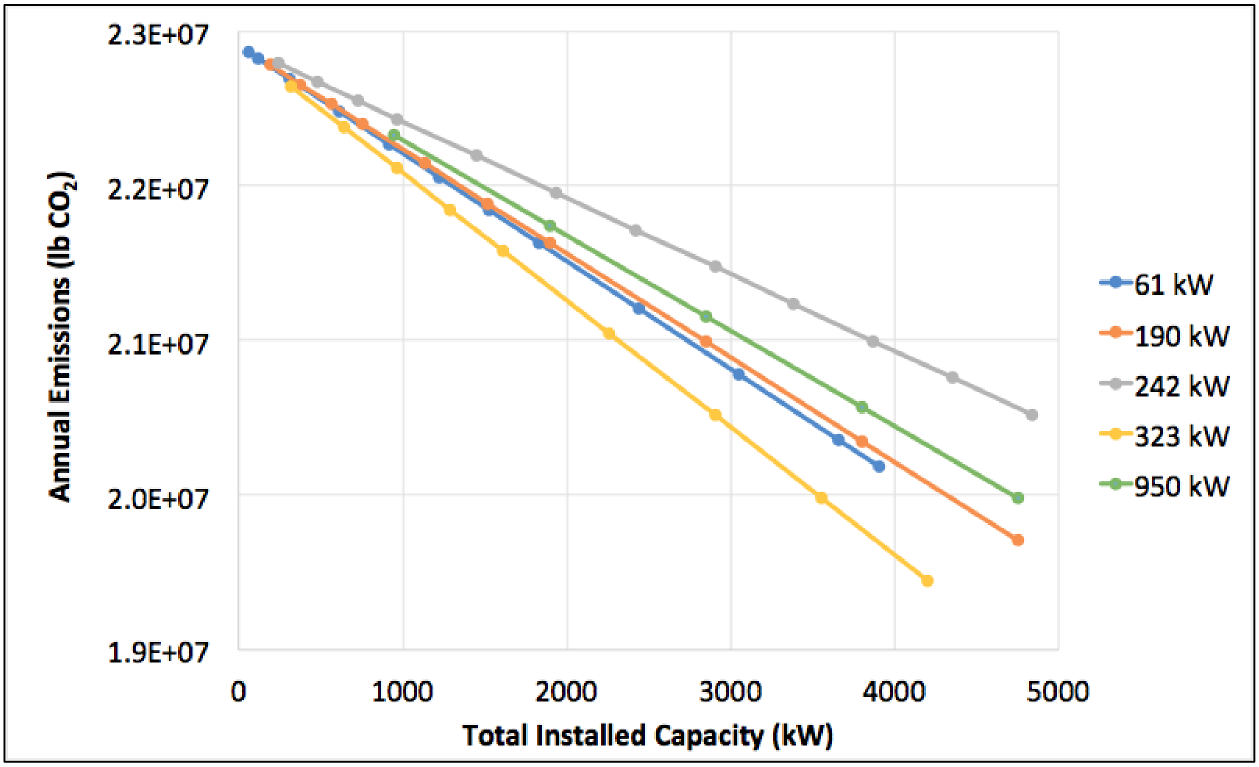


Figure 26: Annual CO_2 Emissions For CHP Systems

To understand the full environmental impact of using natural gas in terms of climate change, the possible leakage of natural gas is considered. Natural gas, or methane, is a potent greenhouse gas that is 25 times worse than carbon dioxide. What this means is that if 1 gram of methane is emitted, it is the equivalent of 25 grams of carbon dioxide to be emitted. In a scenario where the least amount of carbon dioxide is emitted, if there is a 4.5% loss of methane, the saving of emitted carbon dioxide is completely negated. While this environmental impact is great, there are some positives when compared to coal. Over a 100-year lifespan, burning natural gas emits an equal amount of carbon dioxide equivalents to burning coal (Howarth, 2015). While this focuses on shale natural gas, most natural gas is being extracted from shale rock. A lifetime analysis is important to fully understand the impact of natural gas burning.

The addition of a CHP plant to a healthcare facility has the potential to increase their Energy Star rating, as they are reducing their demand for electricity from the grid and replacing it with natural gas demand, which is favored by Energy Star. The change in the Energy Star rating was computed as part of the CHP analysis, with new ratings calculated for several system options. The extreme case, consisting of 13 323-kW microturbines, results in an estimated Energy Star rating of 42. This is a substantial increase over the base rating without CHP, and smaller CHP systems still result in sizable improvements.

Lake Source Cooling

For facilities close to a large body of water, lake source cooling or LSC may be an option. There are many prohibitive factors that might prevent exploration of an LSC system such as the potential high costs of construction, as well as the logistics surrounding the installation of the required piping under residential property, and the required environmental monitoring. Due to the complexity, an in depth study of the costs and sizing for a LSC system was not conducted. However, a brief study was performed for the sake of this report. A hypothetical demand for chillers of 1,600 tons was adopted as a basis for comparison, which is equivalent to 19,200,000 Btu/hr. In order to fully replace cooling demand, an LSC system would need to meet that number.

Data on the performance of lake source cooling systems is limited due to the relative immaturity of the technology and lack of existing systems. The Cornell University Lake Source Cooling Plant is the most established and well documented system, is located on Cayuga Lake, and will provide a model for calculation purposes. The heat exchangers for the Cornell system are designed to handle a maximum cooling load equivalent to 3,000 tons, or approximately 36,000,000 Btu/hr at 4,600 gpm (Energyandsustainability.fs.cornell.edu, 2005). The Cornell system consists of 7 heat exchangers, for a total effective surface area of about 102,000 ft^2. Assuming the capacity of the system scales linearly with the effective surface area of the heat exchangers, a cooling load of 1600 tons would require 54,400 ft^2 of heat exchanger surface area operating under the same conditions as the Cornell system.

The cost of installing a lake source cooling system is likely not linear with respect to cooling demand. Economies of scale and learning factors should make larger systems cheaper per ton of capacity. Therefore, approximating cost as linear with respect to cooling demand will give a lower bound for the potential cost of a lake source cooling plant. Using the cost of Cornell’s system when adjusted for inflation as a baseline, a lake source cooling plant for 1600 tons would cost approximately $44 million to install, as a low estimate. A conventional cooling system using 4,200,000 kWh/yr would only use 590,000 kWh/yr, assuming the same reduction in energy consumption as the Cornell system. This would bring the annual cooling costs down from $275,000 to $38,000. Even considering the fact that the lifetime for a lake source cooling system is around twice as long as typical commercial chillers (Energyandsustainability.fs.cornell.edu, 2005), the annual savings are not nearly enough to justify the costs of installation for such a system. Additionally, there will be recurring annual costs related to the required environmental testing in Cayuga Lake for such a system, as well as upfront costs related to running piping below residences on the waterfront.

Deep Geothermal Heating

While outside the scope of current technologies for hospitals and business, forward planning and estimations of system sizes can be used for planning a deep geothermal system. A deep geothermal heating system can be useful if the cost of natural gas increases to such a level that this form of heating becomes economical.

To best estimate the amount flow needed for a deep geothermal system, a test bore would be completed to determine the heat available at the digging depth. This would be done by boring to the planned depth and extracting water to find the temperature. Due to unavailable data, an estimation of the temperature must be used. This can be assumed to be approximately 100° C if we can dig deep enough.

An individual healthcare facility alone would be too small of a location to have its own system, so we will assume that the heat will be from a community sourced deep geothermal project. What needs to be estimated then is the amount of flow needed for the facility and what that will cost. The cost estimation can be done by multiplying the current heating demand by the estimated price of heat. Using the cost calculation from Tester et. al., the total cost per year is $864,000 when the technology is fully developed. With this fully developed deep geothermal system, the flow rate of the entire system is 80 kg/s. As an example, the flow from a system could be divided between the facility and the surrounding residences. Under the assumption that the heating demand of the hospital is the equivalent to 1,300 houses, and the surrounding area has approximately 17,000 home equivalents, the calculation leads to an estimate of the flow to be 6.1 kg/s to the facility.

If instead we consider geothermal at a smaller scale, the flowrate will change due to different estimation techniques. Using the current natural gas data and thermal conductivity, we should get a more accurate estimation. If we convert the month with the largest demand for natural gas into the amount of natural gas needed per second of that month, we have a demand of 3050 btu/sec. If we assume that the change in injection water temperature is 65°C, and use the specific heat of water, we can calculate a more accurate demand. Using a perfect heat exchanger, the amount of flow needed to meet the heating demand is 12 kg/s. With losses from pipe to air contact and imperfect heat transfer, the required flow rate will increase (See Appendix B).

Business & Environmental Case

MYSTERY Consulting Group is no longer looking at revenues from selling energy back to the grid, as these payoffs would be marginal and likely would not offset investment costs. Though there likely won't be much excess energy, it would be more reasonable to store any excess in batteries for in preparation for high-demand periods.

There are several asset classes within market risk to which a healthcare facility is susceptible. The most pivotal two include interest rate risk and commodities risk. Though credit risk could be arguably a significant component as well, MYSTERY Consulting Group assumed for the purpose of the analysis that any debt or outstanding bonds on the facility's balance sheet are marginal. Interest rate risk was considered, as the Fed is currently entering in a strictly tightening monetary policy via unwinding large positions taken after the '08 crisis; however, though the facility could consider entering in a variety of interest rate hedge positions including forward rate agreements, swaps, or even swaptions, the main risk is commodities risk, specifically natural gas, which became the target focus.

Currently, facilities typically use a commodities pricing model which allow it to lock-in prices for a predetermined amount of natural gas, after which they must pay a variable rate. MYSTERY Consulting Group is interested in examining some alternative pricing options that may economically benefit the hospital. To begin this analysis, additional information about the natural gas commodity was investigated. The futures curve for natural gas displays strong seasonality due to demand and storage costs, as shown below from Bloomberg.

Figure 27: Seasonal Fluctuations in Natural Gas Futures Prices

In general, the commodity futures curve as a function of its term structure over time has displayed decreased seasonality and lower price levels likely due to improved storage technology and oversupply. Futures are priced due to synthetic replication or a simple cash-and-carry trade, not market speculation. Thus, what investors believe will happen does not influence the pricing of the contracts. Simplifying storage costs and convenience yields to a continuous-time factor, the upper bound of a commodity future becomes:

$$F_{t,T} = S_t e^{(r_f + u - y)(T-t)}$$

From the equation it can be seen that with upcoming rising interest rates, the price of the contract increases. Intuitively, this makes sense, as the value of delaying paying the purchase price becomes higher. Though it may seem that it is less beneficial to enter in the more expensive futures, MYSTERY analyzed the projected spot of natural gas in the long-run via the contango of the natural gas futures curve, and found that it may be a worthwhile investment strategy to hedge the likely increase in gas prices with a variety of derivative combinations. It is also worthwhile to note that the facility could cut costs by accounting for the liquidity of the contract via volume or open interest, assuming that the contracts are traded on exchange, and are not merely bi-party forward agreements. Because the most liquid month to enter in might not be the month needed in demand, a strategy can also be formed around rolling or lifting the hedge. In this case, the number of contracts can be decided to exactly match and cancel out the random variable in gas prices.

To analyze a time series without danger of spurious results, MYSTERY consulting group first checked for stationarity using Dickey-Fuller test. As you can see from the below autocorrelation plots, as well as a simple plot of both the spot time series and futures time series, it was easy to intuitively deduce there was no issue. This intuition was further confirmed with P-value<0.01, which strongly rejected our null hypothesis that a unit root was present.

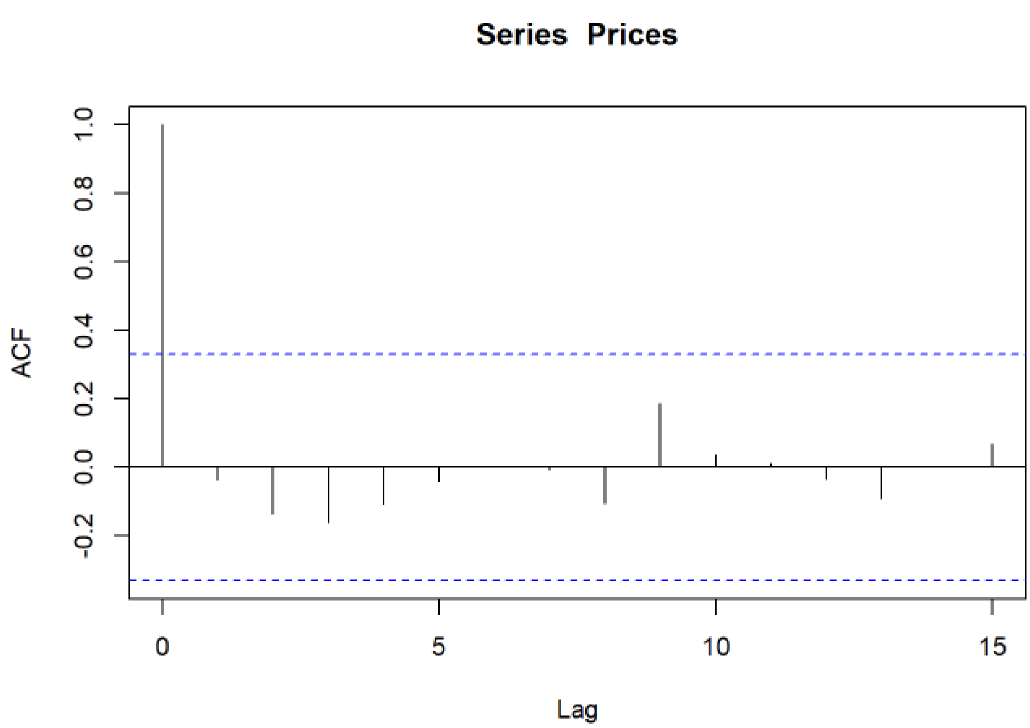


Figure 28: Natural Gas Price Residuals

```
## [[1]]
## Statistic.Dickey-Fuller                    P-value
##                -10.59222                  0.01000
```

Figure 29: Results of Dickey-Fuller Test

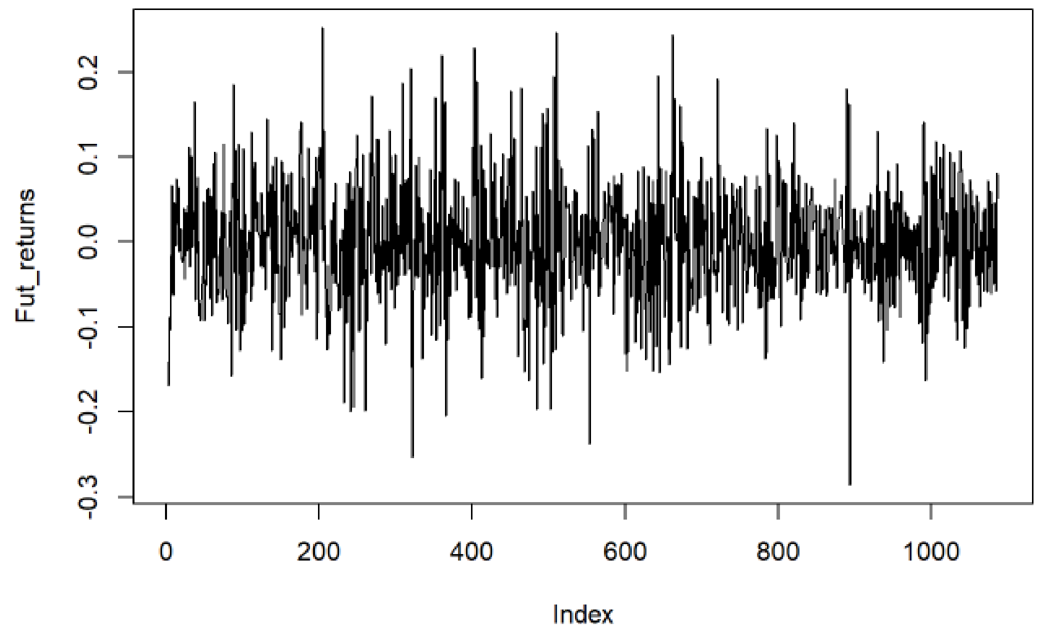


Figure 30: Futures Time Series

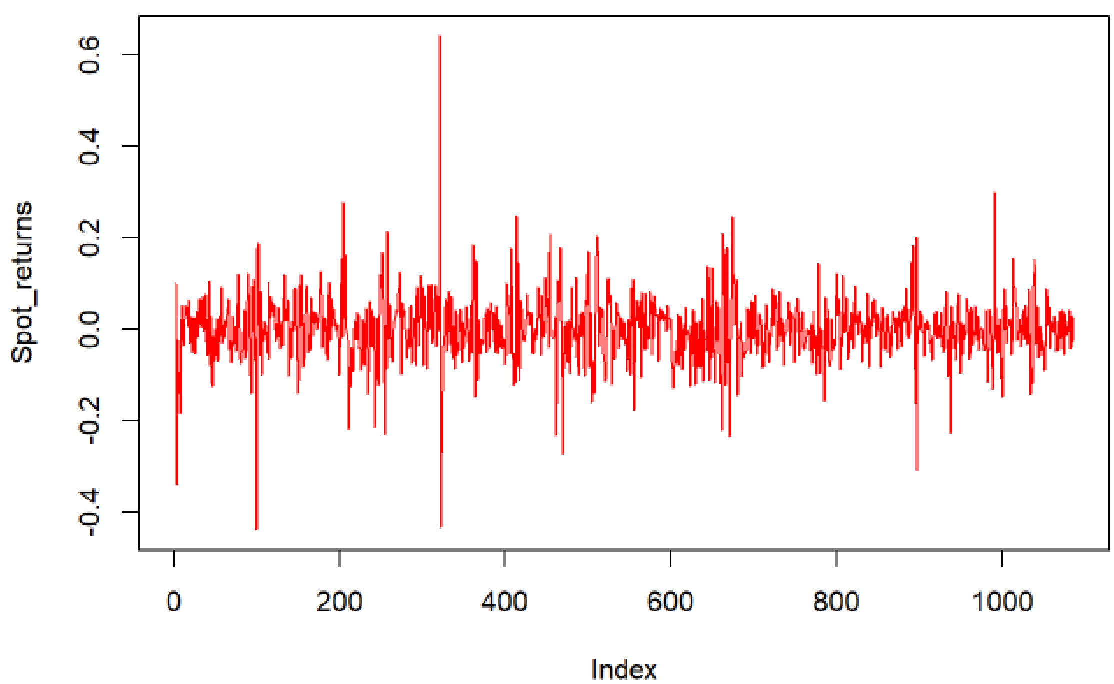


Figure 31: Spot Time Series

Using a minimizing variance portfolio, the team found the optimal number of contracts to enter was 150. This method uses the estimated amount of natural gas the facility needs as well as the spot natural gas price currently, calculates the variance of the portfolio, and iterates through number of contracts to buy, searching for the minimum.

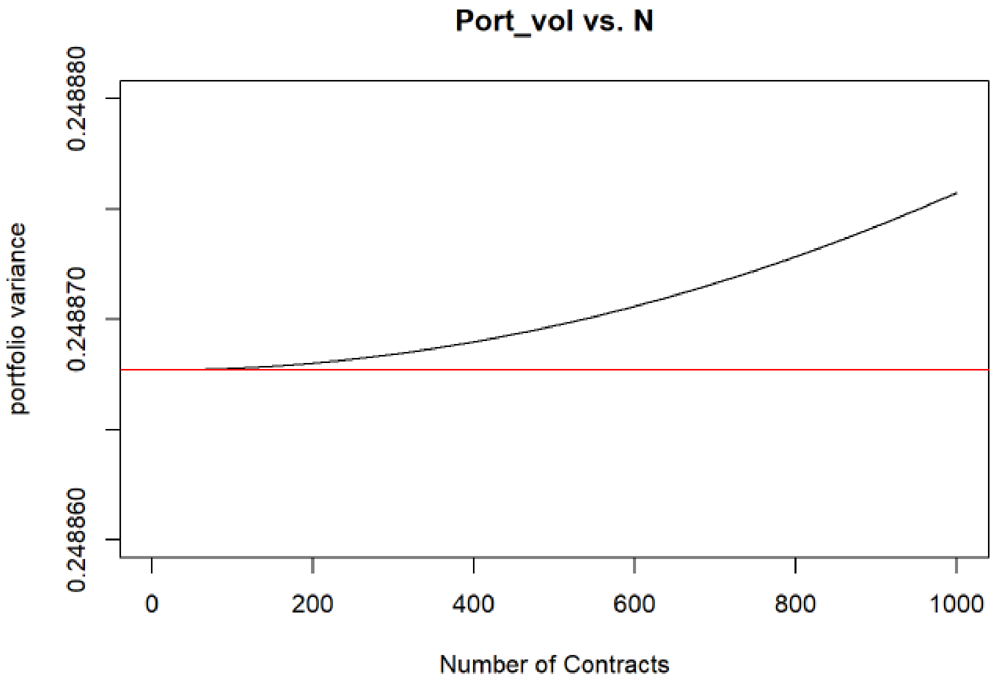


Figure 32: Number of Contracts vs. Variance

Finally, depending on the facility's risk appetite, strategies in the combinations of multiple options can also be considered, potentially forming a payoff function that hedges both price directions, bets on the volatility, or even extends to a single point mass that guarantees non-zero payoff, becoming increasingly more expensive as more instruments are added. For example, a long position gives you positive payoff if prices go up i, however if it does not, they are exposed to a linear downside as well. This is depicted in the payoff function shown in Figure 33.

Figure 33: Price vs. Payoff

In order to cap the downside while still keeping positive exposure to the upside gains, the facility can consider long call options, which gives the right to walk away at a certain strike price, as shown in the graph below, as well as a long straddle position, which makes profit as long as the underlying moves in either direction.

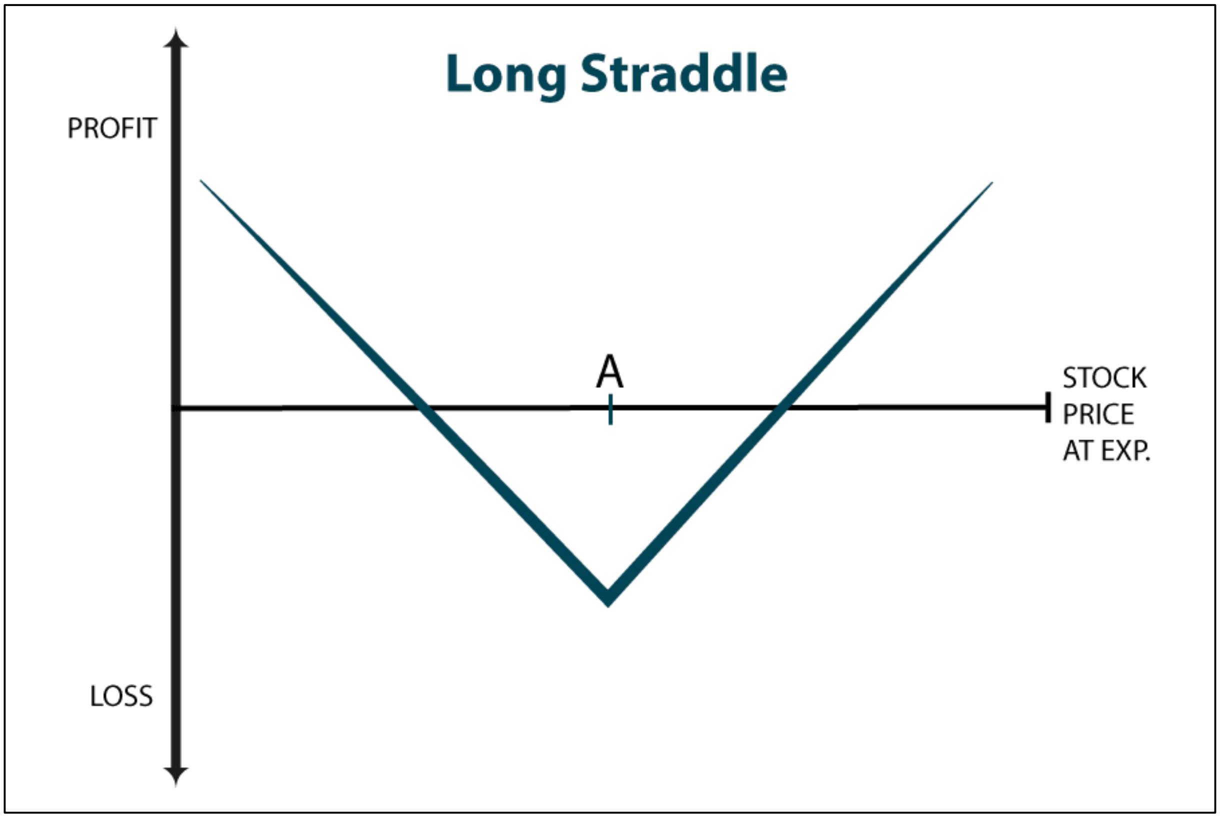


Figure 34: Long Straddle Position

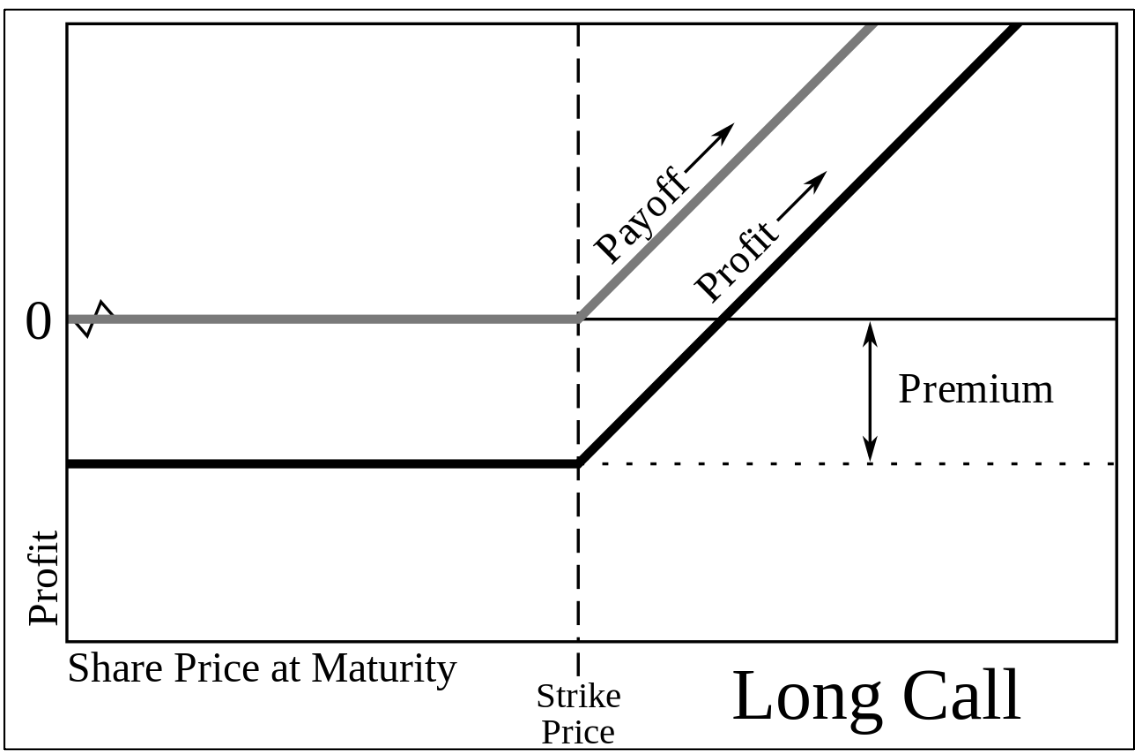


Figure 35: Long Call Option

It is important to note that more complex combinations of options will substantially increase costs, especially as the straddle requires 2 complex options wrapped together, paying a premium and crossing spreads on both.

Team Structure and Staffing

To efficiently organize project work, MYSTERY Consulting Group developed three major subteams: Energy Efficiency, Supplemental Energy Sources, and Business. Due to the number of possible solutions encompassed by Energy Efficiency, this subteam was further broken into two subteams focusing on Continuous Energy Efficiency and Peak Shaving.

Team 1: Energy efficiency

1A: Continuous: Titus Maritim, Rosa Won, Prajnavaro Selamet

1B: Peak shaving: Emma Burke, Makayla Mellas

Team 2: Supplemental energy source: Edward Crocker, Peter Ferenz, Mario Saldana, Vincent Sheppard

Team 3: Business: Jessica Yuan

Assumptions

In order to complete calculations regarding various energy systems in the context of healthcare facilities analysis, several fundamental assumptions had to be made. These assumptions cover situations that cannot be predicted by the team, or that would make the team's models too complication to resolve. In addition, the team used a uniform set of established values in our calculations, to ensure that all systems were compared on equal grounds. These values are reported in Table 19.

1. **The systems design is built out of existing, off-the-shelf component designs**, or representative systems that approximate the performance of modern off-the-shelf components. Development of specific hardware designs is outside the scope of the project. The type of project is a systems-level feasibility study, so it is not the intent to design changes to the technology to address some problem or other.
2. **All stakeholders studied by the team are assumed to acting in good faith and to be truthfully stating cost or performance characteristics** of any system in which they have an interest, and so on. This is a reasonable assumption given that the stakeholders have no motivation to be intentionally dishonest, and are trusted to not mistakenly report incorrect data.
3. **It is not the responsibility of the team to overcome limitations such as political or social barriers** which may bring into question the overall feasibility of a proposed technology or system, as the primary focus of the study is technical and economic. The team will, however, acknowledge such barriers as they arise as areas for future study.
4. **Exploration of energy consumption and greenhouse gas (GHG) emissions will be limited to the end use stage of the life cycle.** Thus other life cycle stages (manufacturing, installation, dismantling and resource recovery) are outside of the scope. For example, a new piece of energy technology such as a combined heat and power generator contains embodied energy from manufacturing and delivery, but it will be ignored. Inclusion of methane lost during extraction and delivery of natural gas, and its CO_2 equivalent, is within the scope of the project. These emissions do not affect the day-to-day operations, but do affect the overall sustainability of any solutions implemented.
5. **Equipment performance will meet manufacturer's specifications.** This assumption is largely

an extension of Assumption 2, stating that manufacturers are accurately stating the performance metrics of their supplied systems. This is a safe assumption given that a manufacturer's reputation is founded on the quality of their systems, and disreputable companies may face legal issues.

6. **Utilities will not introduce additional fees in response to on-site generation.** The response of energy companies around the country to the increase in on-site generation has been varied. While some embrace it, others have increased tariffs to consumers that generate their own electricity. Since it is uncertain how the utility will react, the results are treated as if there is no change in how they are billed.
7. **Installation and labor will double the cost of equipment alone.** This is a rule of thumb based on team members' previous experience, and is a weak assumption. This assumption is being used to account in some way for labor costs, but further analysis on labor costs for contractors in the region surrounding Ithaca would need to be completed for a more complete picture of the total cost of proposed systems.
8. **The facility will have space to fit all proposed equipment.** This is an assumption made by the team so that the project did not focus on architectural changes that would need to be made to the hospital in order to accommodate new equipment. The team instead leaves the onus of finding an installation location on the facility, so that it may be incorporated into any plans for expansion.
9. **Maintenance on proposed systems will not significantly affect facilities staffing requirements.** The team assumes that any additional maintenance on proposed systems will not drastically increase the workload of staff to the point of requiring additional hires, which affects the operating cost. Healthcare facilities desire low maintenance systems, so the team has specifically suggested lower maintenance systems.
10. **Unless otherwise noted, savings are calculated assuming consistent prices for electricity and natural gas.** This assumption allows the team to have a consist base by which to measure future operating costs for various systems. The variations in prices over time are explored in some cases in order to highlight the effects it would have on the overall costs of systems.

Asset Lifetimes	25 years
Discount Rate	5%
Price for Natural Gas	$5.453/dekatherm
Price for Electricity	$0.065/kWh
Price for Diesel	$2.854/gallon
Emissions from Grid Electricity	325 g/kWh

Table 19: Assumed Values for All Calculations

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Appendix A: Comparison of modeled and observed solar PV output

As an indication of the validity of National Renewable Energy Lab's modeling programs for estimating energy output from solar PV arrays, historical output from an existing array for the years 2011-2016 is compared to modeled output from the same array entered into NREL's "PV-Watts" model.

The array has 16 140-watt panels for a total nameplate capacity of 2.24 kW. It is raised 25 degrees toward the south and is oriented 15 degrees west of due south (195 degree azimuth angle). It is assumed to have a derate factor of 25% due to wiring and inverter losses, shading at certain times of day, intermittent dust on the panels, and other factors. PV Watts does not have access to meteorological data for Ithaca, NY, so the weather station for the city of Binghamton, NY, about 40 linear miles away from Ithaca, is used instead, and this is thought to be a reasonable approximation.

Entering the values into PV Watts using the above assumptions and asking the software to calculate monthly output values gives the following table:

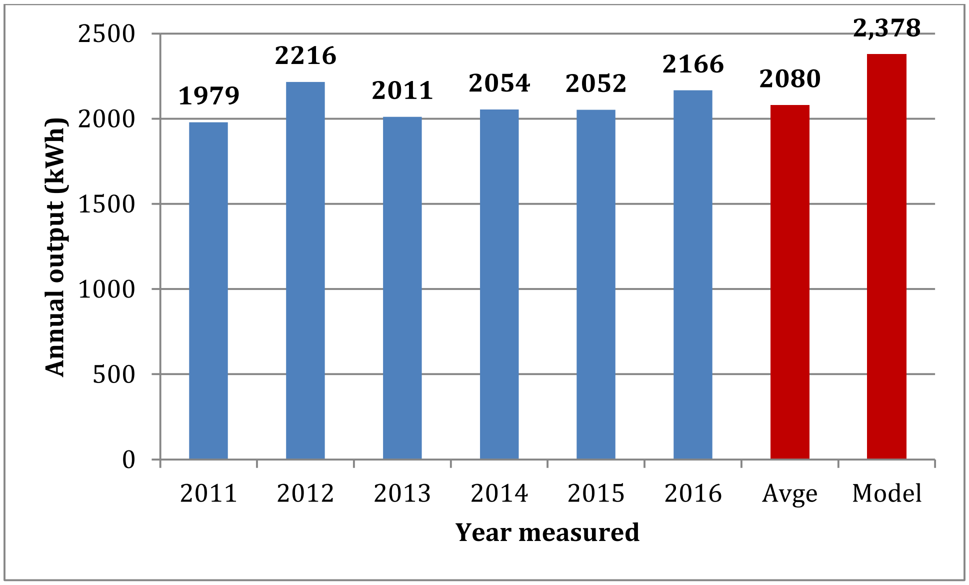
Month	kWh/m2	kWh/mo	Energy $
January	2.47	133	12
February	3.42	166	15
March	4.17	217	20
April	4.88	238	22
May	5.29	258	24
June	5.59	257	24
July	5.66	263	24
August	5.38	253	23
September	4.3	200	18
October	3.62	179	17
November	2.29	116	11
December	1.82	98	9
Annual	4.07	2,378	$219

Note that the first column gives average kWh of insolation per square meter per day, including the average for the entire year. The second gives kWh of AC electricity output, and the third column the value per month assuming $0.09/kWh cost.

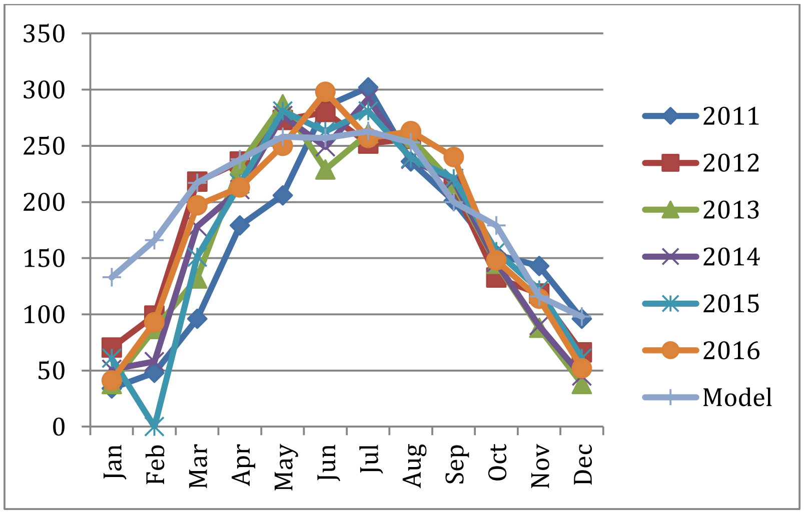
Thus NREL is predicting 2,378 kWh/year of output. This figure can be compared with the observed values for 2011-2016, which averaged 2080 kWh/year, as shown in the figure below (standard deviation of 92 kWh/y, coefficient of variation of 4.4%).

The NREL prediction exceeds the 6-year average by about 14%. On one level, this result shows that the model is reliable for at least an approximate output that might be expected from an array installed in

Ithaca. On the other hand, an attempt should be made to explain the discrepancy. One possible explanation is that the actual derating factor is larger than the chosen value of 25%. Increasing the derating factor reduces the predicted output and brings it closer to the observed value.



Another possible explanation is that the model is subject to greater error at certain times of the year, namely in the winter month when the angle of incidence to the panels is the most oblique due to low position of sun in the sky. This can be observed by visually comparing the observed monthly output for the period 2011-2016 to the modeled output from the table above, as shown in the figure below. It appears that for the period March to November inclusive, the model is in reasonable agreement with the range of values shown for the observed years. For December to February, however, and especially for the months of January and February, the difference is more visible. Snow cover may come into play: The model does not consider the possibility that snow coverage would reduce output, but it would have affected the observed values in some months and some years, and in fact in February 2015 the observed output falls to 0 kWh because the array was buried in snow for the entire month.



Appendix B Calculations for preliminary design of deep geothermal system

The goal of this analysis is to provide a preliminary analysis of the size of deep geothermal system that would be required to meet the baseline heating load for a representative healthcare complex in winter. For simplicity it ignores thermal losses in the system and seeks instead to show that the difference between energy supply and demand is sufficient to cover any losses. The focus is on the physical dimension, and questions of cost and revenue are left out.

As a starting point, data on deep geothermal for a small Pennsylvania town (Clarion, PA) from a paper by Reber et al (2014) is used. Clarion has a population of 5,276 and a maximum load of 22 MW, so the facility is somewhat smaller, although it might grow to this magnitude in the future if the complex expands. The supply pipe from the geothermal resource to the load might provide maximum 30 kg/s flow, and the typical heat transfer from the geothermal supply to the heating distribution system might be on the order of $\Delta T = 65$ deg K, based on the paper. Also used in this analysis is an approximate energy density value of 1 kg per L for water, and a heat transfer coefficient of 4.19 kJ to heat 1 kg of water by 1 degree K. The system discussed in this appendix is larger than the 12 kg/s system that appears in the main paper, to allow a future system to expand beyond the current load.

For reference, we assume a natural gas consumption value of 7900 dekatherms (7.9 billion Btu) for a cold winter month. We use this rate of energy consumption as a baseline power requirement for heating the facility. Converting from Btu per month to kW using 2.68 million seconds per 31-day month and 1.055 kJ/sec per 1 btu/second gives a power requirement of 3.11 MW:

$$(7.9 bil.btu)\left(\frac{1mo}{2.68 mil.\sec}\right) = 2950 btu/s$$

$$(2950 btu/s)(1.055 kJ/btu)(1MW/1000 J/s) = 3.11 MW$$

The energy provided by cooling the water from the production well by 65 deg K is the following:

(4.19 kJ/kg)(65 degK) = 272.4 kJ/kg

If the flow is 30 kg/s, the rate of energy transfer is:

$$(272.4 kJ/kg)(30 kg/s) = 8170 kW = 8.17 MW$$

Thus comparing production rate of 8.17 MW to demand of 3.11 MW the well should be able to meet the baseline heating need for the facility, even after taking into account losses, or even accommodate growth in demand in future years or possibly expansion into a district heating system that might support the facility plus surrounding energy loads.

The sizing of the production pipe can be estimated from an equation given in Reber et al. Since the flow is 30 kg/s, the equation for diameter *D* in inches gives:

$$D = 1.5197(m)^{0.427} = 1.5197(30kg/s)^{0.427} =\sim 6.5 inches$$

The pipe diameter of 6.5 inches is equivalent to a cross-sectional area of 33.12 square inches. The speed of flow of the extracted fluid is calculated based on a mass of 1 kg per 1000 cubic centimeters of water. One cubic cm is equal to ~ 0.061 cubic inch, so the number of cubic inches per second and hence meters per second of flow is:

$$(30kg)(1000cc/kg)(0.061in^3/cc) = 1830in^3/s$$
$$(1830in^3/s)/(33.12in^2)/(39.37in/m) = 1.4m/s$$

Source:
Reber, T, K Beckers, and J Tester. (2014) “The transformative potential of geothermal heating in the U.S. energy market: A regional study of New York and Pennsylvania.” *Energy Policy*, 70: 30-44.