Project Number: IQP NAB PC01

CONNECTING THE WORCESTER ECOTARIUM TO THE PUBLIC POWER GRID

An Interactive Qualifying Project Report

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by

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Abstract

The Worcester EcoTarium has been producing its own power since 1971. Due to safety and financial reasons, the need to connect to the public grid has arisen. By calculating current and future costs for both above and below ground transmission wires, we were able to recommend an underground connection. Connecting underground best fits the needs of the EcoTarium because having the backup is necessary, and the rebate potential will help alleviate any capital costs.

Acknowledgements:

We would like to extend our appreciation towards the many people involved with the success of our project. We thank our professors at WPI, Rob Krueger for finding us the project, and Nancy Burnham for being our advisor and helping us through the project. This project would also not be possible without the help of the EcoTarium. President Stephen Pitcher was an integral part of helping answer any questions. The Board of Advisors for the Buildings and Ground of the EcoTarium let us sit in on a meeting and allowed us to give a presentation detailing the goals of our research. Team Leader of Maintenance Mike Mitzcavitch and Technician Tom Thompson were experts on all functions of the cogeneration machines and the technical workings of the whole plant.

Executive Summary

The EcoTarium, a natural science museum in Worcester, Massachusetts, has been off the power grid since the construction of its current facility in 1971. The EcoTarium started an expansion project in 1998, and this expansion has increased power demand for the museum. The generators are struggling to keep up with this increase in power demand. The EcoTarium wants to have a safe building with constant power supply, while maintaining its current look and feel. In order to do this the EcoTarium is considering connecting to the power grid through underground transmission lines.

Over the past term our Interactive Qualifying Project (IQP) team has been working with the EcoTarium staff, National Grid, the City of Worcester, and other contacts acquired through Mr. Stephen Pitcher, President of the EcoTarium. The purpose of working with these people was to gain more knowledge about the power usage of the EcoTarium, and to find an estimate of the construction costs that come with connecting a building to the power grid. This research paper documents our findings, analysis, and recommendations for the EcoTarium's connection to the grid.

The way that we went about finding the cost of connecting and being connected to the power grid was to first find the total amount of energy that the EcoTarium used. We use this value to estimate the cost of electricity from National Grid. Then we used an estimate of construction costs from John Shepherd, a member of the EcoTarium buildings and grounds committee, in order to give our estimate for the construction. We researched the average the lifetime costs of maintaining the system that we are recommending the EcoTarium should install.

The estimates of the construction cost of connecting to the grid are calculated in different ways, but they both have very similar subtotals. Neither of the two quotes are complete, but are a

good starting point for knowing what the magnitude of the amount of money the EcoTarium has to raise. A member of the board gave an estimate based on price of the materials required to build the infrastructure involved in connecting to the power grid. The second cost estimate comes from an industry standard of the average cost of connecting to the grid.

The report will also have a few recommendations EcoTarium to take advantage of in the future. Our most important recommendation will be that it is in fact a good idea to connect to the grid. Other recommendations include running the generators in a way to optimize the load factor, sell power back to the grid when demand is high, and take advantage of rebates from national grid. The most important part is that for most of our recommendations to be applicable the EcoTarium must be connected to the power grid.

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Chapter 1: INTRODUCTION

The EcoTarium project team's objective for this IQP is to find the cost benefit analysis of connecting the EcoTarium to the Worcester power grid. The challenges our team needs to overcome are finding the current cost of electricity to the EcoTarium, estimating the cost of construction for the connecting to the power grid, and deciding if the most aesthetically appealing method of connecting to the grid is cost effective. The introduction includes information about the EcoTarium's history and a more detailed look at the current situation and problems they are having. The background chapter explains cogeneration and connecting a facility to the power grid, along with the positives and negatives of both. The methods chapter outlines how the EcoTarium team plans to tackle the problems they are facing with this project.

In 1825, the Worcester Lyceum of Natural History was founded by a small group of men. Over the next 150 years, the group grew in size by combining its membership with other groups. It received several donations of land as part of the Worcester Natural History Society, and put them to use for natural history education programs. The society changed its name to the Worcester Science Museum to reflect its change in purpose. When the museum moved to its current location in 1971, it built new facilities that included a cogeneration plant. The new location required that it produce its own electricity, heat, and cooling due to its lack of proximity to the public power network. Most recently in 1998, the museum changed its name to the EcoTarium and built a large addition (EcoTarium, 2010). Figures 1 and 2 show satellite pictures of the EcoTarium and the nearby North High School.

Figure 1 : EcoTarium

(Map of Worcester, MA, retrieved Jan 26, 2011 from http://maps.google.com)

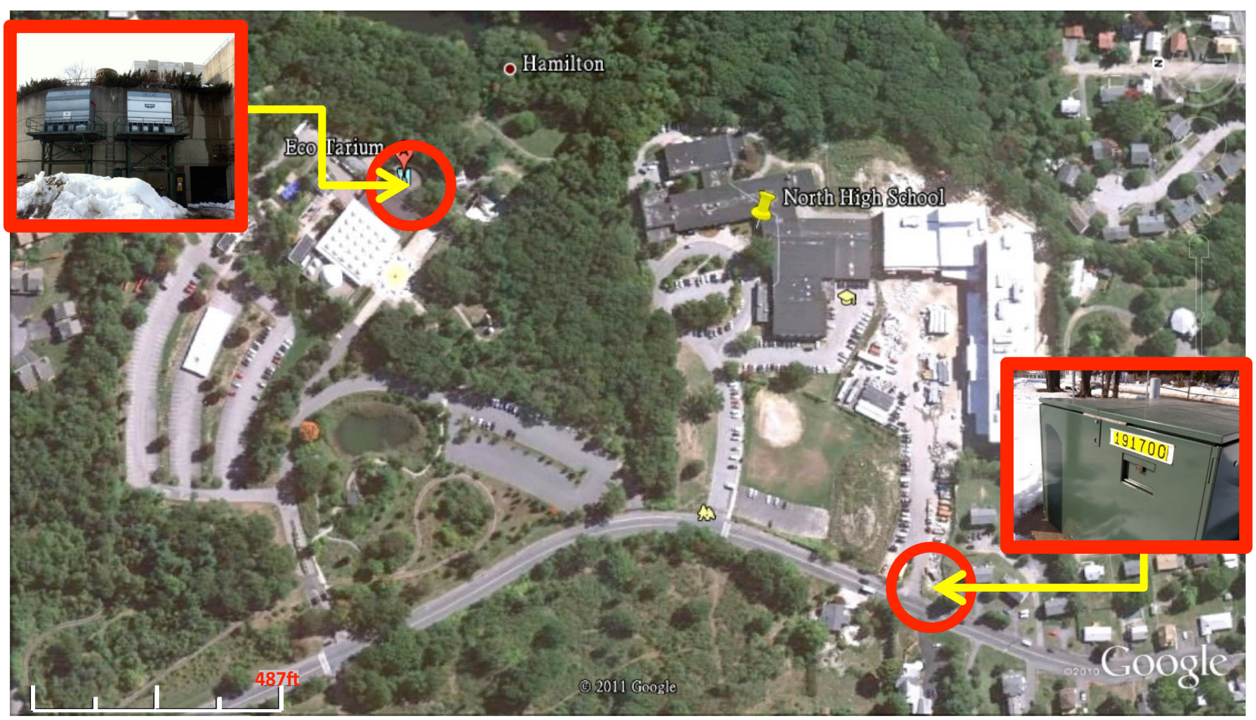

Figure 2 : EcoTarium, North High School, and Proposed Connection Points

(Map of Worcester, MA, retrieved Jan 26, 2011 from http://maps.google.com, annotated by Yow Chyuan-Yeh)

The problem they are currently facing is that the cogeneration plant is not keeping up with the energy needs of their expansion, and the plant itself is getting old. The plan for the facility is to connect to the Worcester County power grid, but then also update the cogeneration plant so that it is energy efficient and large enough to power the EcoTarium. By finding a cost benefit analysis of a cogeneration plant and being connected to the grid, this will help to find the best way to have both.

The deteriorating reliability of the EcoTarium's power facilities has had an observable effect on the community. If the generators for the building fail, the museum has to shut down for the day and the employees cannot do their job without the electricity. The animal caretakers can continue to do their job for the most part, but the machines that keep the animals alive will not work. A problem that arises with the fish that live at the EcoTarium is that the water aerators fail and there isn't enough oxygen in the water to sustain the fish. (Pitcher, 2010) This cost extra money to the EcoTarium, and they have to shut down the exhibits if the animals die. It would be in the best interest of the EcoTarium to connect to the grid in order to have a backup system to support them in the case of the generator failing. If they connect to the grid they could also potentially sell the power they make with it back to the electricity company to make back the money of connecting to the grid in the first place.

Another societal issue that is being dealt with when looking at the Worcester EcoTarium is the difficulty of saving money and protecting the environment. They are looking for a way to heat, cool, and power their campus. The EcoTarium's mission is, "To contribute to a better world by inspiring a passion for science and nature through discovery." (EcoTarium, 2010) Our group concluded from the mission statement that our sponsor wants continue running the cogeneration plant because it is more environmentally friendly. This has affected the community because it seems natural that a group devoted to teaching the youth about nature would want to help the environment. If the EcoTarium were to show its visitors the cogeneration plant and have information available on the advantages of using cogeneration, people would be more knowledgeable and supportive.

The main task that is presented is connecting the EcoTarium to the grid. The appearance of the facility is very important to the president therefore our project group will recommend ways to connect them to the grid, but also to maintain the earthy appearance juxtaposed with a new age building. The above ground power lines will potentially mar the appearance, so it has been suggested to find the cost difference between above ground lines and underground lines.

Figure 3 : Tax Map of North High and EcoTarium

(Retrieved 2/14/2011, http://www.worcesterma.gov/e-services/online-maps)

The cogeneration part of the project will need a lot of different research. Looking into the cost of maintaining a cogeneration plant will help to approximate the cost of installing a new generator in the EcoTarium. The EcoTarium will also need to know the estimated revenue from selling the excess power back to the grid. If the EcoTarium is planning on upgrading the systems, an overall cost and payback time estimate should also be researched, as this would affect current costs. After reviewing the cost of fuel to generator and comparing it to the cost of getting power from the grid, our group will be able to give an informed recommendation to the President of the EcoTarium, Steven Pitcher.

Chapter 2: BACKGROUND

2.1 Introduction

In order to better understand the challenges and proposed solutions associated with this project, it is important to understand the history of cogeneration, some current uses of cogeneration in the area, and some information about the local power grid. The topics are broad in order to ensure a full understanding. These topics have been specifically picked in order to inform the reader on the issues surrounding the project before they have read deeper into the methods, analysis, and conclusion.

Ideally, the EcoTarium would be able to provide power and heat for its facilities. The renovations the EcoTarium plans to do will require more power and will have to heat more space. The current combined heat and power generator has enough capacity to provide for its needs, but will be insufficient for its future plans. In 1989, The Worcester Science Center (The EcoTarium) was recorded as having 0.68 MW of power generation capacity (McKernan, 1989). The EcoTarium has two 350kW generators that provide power and heat for its facilities. It is estimated that the generators achieve about 80% efficiency. The EcoTarium purchases the fuel for the generators on the open market and pays market value for their fuel which fluctuates over time (Gabrielson, Hanly, & Montville, 2009). Despite the generators achieving high efficiency, the generators are run to only produce the power required to operate the facility. The threshold for safe power generation is 260 kW per generator. This reduces wear on the machines, and allows only the amount of power needed to be produced.

2.1.1 What is Cogeneration?

Cogeneration, sometimes called combined heat and power (CHP) is a system that can produce heat and power for a complex of buildings or a small urban area. These systems recycle the heat that is normally wasted in centralized power generators. This makes these power plants significantly more efficient because energy is not lost by heating the buildings that it is connected to ("What Is Decentralised Energy?", 2010). This system of power and heat can be renovated more easily than a non-local system could be, since all upgrades would be added on-site. So as technology gets better, the cogeneration plant can be upgraded at the same pace as the technological advances.

Most cogeneration systems use natural gas to produce power and heat in the form of hot water or steam. Other fuels used in cogeneration include oil, diesel fuel, propane, coal, wood, wood-waste and bio-mass. The electricity made from cogeneration is three to four times less expensive than the electricity made at the centralized power plant (Cogeneration Explained, 2010). This source also explains how people can relate to cogeneration used on a daily basis. One such example of cogeneration is the car. The combustion engine in the car supplies power to the drive-train, electricity, and heat to the interior.

2.1.2 History of Cogeneration

Many people are unaware that cogeneration is one of the oldest forms of power generation, but they also use it every day. Cogeneration's origins take place long ago in what is currently Tibet during the Middle Ages as a way to turn prayer wheels (Pierce, 2001). The concept made its way to Europe, where it developed into the smoke-jack. The smoke-jack is a simple turbine which is placed inside a chimney and creates mechanical work which can be applied in many ways. In the 19th century, the concept was applied to pump water for heating or cooling. During the period when steam power was gaining popularity, cogeneration allowed for the waste steam to be reused as mechanical work or as space heating. Since it is so simplistic, it has become well accepted worldwide.

2.1.3 Cogeneration Today

Cogeneration is becoming a trend worldwide, especially in Europe. Switzerland and Denmark have a total of 77 and 40 percent of its electricity plants operated by cogeneration, respectively. Compared to the public power grid cogeneration plants save more energy by reusing the otherwise wasted heat to heat a building. Cogeneration is popular in Europe because it has many small, compact communities which benefit from the high efficiency (Puncochar, 2009).

One of the reasons that cogeneration is so popular is its high energy efficiency. Using the public grid is convenient to consumers, but it is very inefficient and wastes almost 75 percent of the energy during generation and transmission. Cogeneration can use 50% of the energy to heat buildings, and another 38% – 40% to produce electrical loads (Puncochar, 2009).

Another reason that makes cogeneration popular is that its high efficiency makes it popular with those promoting 'green' energy. Cogeneration will decrease the level of carbon dioxide in the atmosphere, which is harmful to the environment. As an example, a commercial facility in Southern California easily reduced by more than 6.14 tons of nitrogen oxide, 14.60 tons of sulfur dioxide, and 3,056 tons of carbon dioxide each year. Economically, countries can save up to hundreds of millions of dollars by trying to lower the level of carbon dioxide in the atmosphere (Punochar, 2009).

However, there are some challenges and negative impacts with cogeneration. Although cogeneration can reduce the amount of fuel burned, it still has to burn fossil fuels to produce energy. The gas that is used for cogeneration plants is really expensive compared to the fuel from traditional coal plants or nuclear power plants. High cost for both installation and fuel frequently prevents more people from adopting cogeneration. Also, district heating produced by cogeneration is only efficient within a short distance. The heat produced will cool down if the customer is too far from the cogeneration plant. However, the low cost of providing heat to a small area is attractive to investors, despite the costs of construction and maintenance (CODE, 2010). Lastly, even though the grid loses more energy than a cogeneration plant would, it still has a larger amount of energy and power to supply the places that need power instantly.

Much of power generated in the mid-20th century in the U.S. was produced by large, utility power plants. The cost was distributed among many customers and sometimes made it more economical than cogeneration. Similarly, steam generated for industrial applications was produced in such a manner that cogeneration was not efficient (Butler, 1984). It was at this time that facilities unable to utilize the economic savings of public power, usually due to geographic reasons, used cogeneration for power, heating, and cooling (Pierce, 2001). In 1978, the Public Utility Regulatory Policy Act (PURPA) was passed, and required that power companies pay cogenerators for power delivered to the public power network. The act exempted small generators from some regulations and spurred significant growth in small and medium cogeneration power production (Pierce, 2001; Butler, 1984). Part of this growth in cogeneration was compounded by the general increase in fuel and electricity costs (Wilkinson & Barnes, 1980).

2.1.4 Worcester Power Agenda

The city of Worcester has been pushing towards becoming more "green" and has been proposing various changes that would better benefit the community. The Energy Task force is a group of fifteen individuals appointed to develop and propose ideas that would help Worcester carry out green renovations. One of the biggest contributions the Energy Task Force has prepared was the release of a Climate Action Plan that details in depth various projects throughout the city to improve the green footprint. The Climate Action Plan pushes Worcester to reduce energy use and pollution from greenhouse gases. The focus is on using methods that are not just less expensive than traditional plans, but to propose projects that are cost neutral, or plans that allow some of the costs to be recoverable. Their proposed changes involve working with public services to reduce emissions from fleet vehicles, replacing light bulbs in public buildings and people's homes to those with higher efficiencies, and working with schools to promote education about sustainability and green challenges to reduce energy (Energy Task Force,).

With increasing publicity, the Energy Task Force developed a Climate Action Plan to promote green development on a statewide and nationwide level. Their agenda is related to many national programs that have very similar motives, such as the Cities for Climate Protection Campaign. The Cities for Climate Protection Campaign is a national program to reduce carbon emission and energy waste. Worcester seeks to not only meet the minimum standards, but also to exceed them in various areas.

2.1.5 EcoTarium Projects

The EcoTarium, a promoter for the green energy movement, has become a partner in a few major projects. One of the external projects for the EcoTarium would be the proposed construction of a wind turbine on the land directly in back of their building complex to help provide power to the new high school. This could potentially provide the EcoTarium, as well as the existing grid, with a subsidized power supply. This construction is estimated to reduce an average of 1,584 lbs/year of the common air pollutants associated with traditional power generation (Energy Task Force, 2010). By also developing a partnership between the EcoTarium and North High School, educational opportunities become available to teach the public about how green energy and renewable power sources are important.

When the EcoTarium complex was originally built, the option to connect to the grid was nonexistent. There were no available power sources near the land, and the costs of extending the power lines greatly outweighed the benefits. The recent construction of the North High School next to the EcoTarium has opened up opportunities for connection to the power grid. The Worcester Public School system paid for the construction of the power lines to bring enough power to the new buildings (Pitcher, 2010). This also would give the EcoTarium a location where they can connect their system to the public. The main reasons for considering the connection are for safety and economy.

One of the main issues with safety is that since the EcoTarium is a museum, it has many wildlife exhibits. If for some reason, the generators were to fail for a few hours, animals would be put at risk. Some exhibits are dependent on the electricity, such as the fish relying on oxygen and water supplies and reptiles needing the heat lamps. Also an important safety factor for guests would be if the power happened to give out during visiting hours and the lights were not functioning. This could pose a potential danger for people.

Economically speaking, in the case of a failed generator, having the backup of a grid connection would allow the museum to function even when it cannot provide its own power. Otherwise, guests would have to be turned away while the plant was inoperable, thus losing admission money. Also staff productivity would suffer due to the lack of power and possible lighting. At times in the past when the power has gone out, generally only the engineers and mechanics could work on fixing the failed machine while the receptionists and office workers would no longer have work to do. This has been a waste of the EcoTarium's money because they have been paying for work that was not happening.

The main benefit for hooking up to the power grid would be so that any excess power generated by the EcoTarium could be metered back to the grid to generate income. This is their main focus right now, and much research is needed to accurately estimate costs and feasibility. Since the EcoTarium wants to connect, the possible methods of connection must be considered. One proposed option is to connect above ground to the high school location. This is likely to be least expensive of the options due to minimal construction, but it is aesthetically unappealing to the EcoTarium. They desire a cleaner and more modern look, so unsightly power lines running across their campus would clash with their style. The other option is to dig underground and bury the lines so that they are out of the way. The EcoTarium prefers this method, but may not be practical due to higher construction costs. The costs would include digging a large trench from the EcoTarium powerhouse to the North High School connection to bury the power cables in. Additionally, the installation of the underground connection would also take more time to complete.

The EcoTarium has asked our project group to generate a cost benefit analysis for the two proposed options and make a final proposal as to which method is better for them. In order to make the estimate as accurate as possible, our group must first research to find relevant cost data. An important topic that must be looked at is getting a general quote for construction of the two methods as a capital cost. This will determine how much the EcoTarium will have to spend initially in order to finance this project. Our project group must also determine how much excess power the EcoTarium will generate and the rate at which the public power company will purchase the excess power. While the EcoTarium is open for business, the power plant might not generate excess power due to the usage of lights, office machines, and the exhibits. However, when the EcoTarium is closed to the public, excess power production could generate income for the museum. If the resale value of power is low, or the excess power generated during the rest of the week is minuscule, then the more expensive connection might not pay for itself in a reasonable amount of time. Estimation of power demand by the power company will determine the rate of buyback. If the EcoTarium is generating excess power, then the power company will purchase the generated power at a much lower rate than if the EcoTarium's energy was in high demand. This would also affect whether or not the EcoTarium is looking to upgrade their current cogeneration systems, because that could affect the estimation. Our project group will need to research all possible ideas (Pitcher, 2010).

Another concern is the maintenance of the power lines. If an above ground connection were to be installed, its maintenance would be less complicated and less expensive. If an underground power connection were to be installed, maintenance would be more expensive due to excavation costs. All of these factors influence our proposal.

Chapter 3: METHODOLOGY

3.1: Guiding Questions

What are the differences between above and underground transmission lines for commercial buildings?

(In depth analysis of the two different types will detail construction and material requirements)

How will the fluctuations of fuel price affect the cost of the comparison?

(Rising natural gas prices could render cogeneration inefficient compared to public power generation, reducing demand for selling back)

How does the path and distance to the grid connection affect the cost of the project?

(Due to the existing landscape, there could be a difference in overall transmission distance. This affects construction costs and material costs.)

What is the range of estimates in the construction?

(Different companies could give different price quotes, and our project group needs to find one that fits the budget)

What kind of information do we need from respective manufacturers about the system?

(The costs of the different construction materials could affect overall cost)

How much power can be sold back to the public grid by using the cogeneration?

(This will decide how much revenue the EcoTarium can make from the project)

How many years of data do we need to find and base our proposal on?

(This will give us a timeframe with which our data samples are accurate)

What are the proposed maintenance costs?

(Each of the different methods will have different annual maintenance costs associated with them. This will greatly help to determine the best method)

3.2 Overall Approach and Rationale

The EcoTarium is facing big improvement options to its infrastructure and the most cost effective method is required so that the future of the EcoTarium can benefit from these changes. Our project group plans on making quantitative studies and calculations so that the exact method can best reflect both our sponsor's needs and the financial needs of the EcoTarium. In order to make these quantitative decisions though, qualitative preliminary research must occur to better familiarize ourselves and the EcoTarium staff with all associated costs and requirements. We will look at closely related projects around the Worcester Area, along with the construction of the new North High School and their connection to the power grid, and compare relative costs and ease of construction. The requests of the EcoTarium are straightforward; with comparison to similar construction projects and slight interpolation to fit this particular case, it will be possible come up with an estimated proposal for our sponsor.

3.2.1 Grounded Theory

This project, due to the nature of the problem, fits neatly into a grounded theory protocol. Grounded theory allows the researchers to simplify their research and minimize the amount of time spent in the field. The protocol removes the necessity of proposing and proving a hypothesis during the project. Grounded theory allows the methodology and the theory to 'emerge' simultaneously (Dick, 2005). There are generally two criteria for using grounded theory: that it works, and that it helps to make the situation better.

3.2.2 Case Study

The Alameda County Jail in Dublin, CA generates power and heat through a variety of methods. Initially, the correctional facility supplemented its power demand through the installation of solar panels. More recently, a fuel cell was installed and was incorporated into a combined heat and power system. It generates about two thirds of its estimated electrical power demand and a fifth of its hot water annually (Skok, 2007). The Santa Rita jail buys the remainder of its power and generates the remainder of its heat through its connection to the public power grid.

The Alameda County Jail is similar to the EcoTarium, since they are both multi-building facilities that generate their own power and heat. The correctional facility has begun to generate its own power due to costs and the unreliability of the power grid, whereas the unreliability of the generator is the main motivation for the EcoTarium to connect to the power grid. Additionally, the jail is significantly larger and requires significantly more power than the EcoTarium (Skok, 2007). Santa Rita's fuel cell adds reliability to the jail complex. This is important because the facility requires a reliable system for support.

3.3 Research Methods

In order to keep our methodology organized and scheduled correctly, Appendix 1 shows our proposed milestones and estimated time frame for our collection methods.

3.3.1 Archival Research

The primary method that our project group will use to develop a comparison is archival research. We will search databases for historical costs for fuel and electricity on a common basis. Additionally, it is hoped to find similar construction projects in public databases for comparison on that data. An example of this could be the nearby North High School construction project that includes the installation of power lines. Other data that could be found from archival research includes the installation costs of a new generator unit.

3.3.2 Interviews

The secondary method that will be used to gather data will be semi-structured interviews. We will consult various organizations to acquire data that we did not find during archival research. Interviewing several people at the EcoTarium will help to gather historical fuel, installation, and repair costs for the current cogeneration unit. Additionally, contacting one or more engineering firms will give an accurate and professional estimation of the construction costs. A professional estimation by an engineering firm might, in itself, have a cost. If it does, our group would need to consult the director of the EcoTarium, get approval for funding, or both. Additionally, an interview with a power company could provide accurate insight about the costs of power and the costs of installing power lines.

3.4 Protocols

3.4.1 Setting:

EcoTarium participants work and live in the Worcester area. Meetings and interviews will take place at either the EcoTarium or the Worcester Project Center.

3.4.2 Subject Selection Criteria:

The participants will be electrical contractors or engineering firms educated in the cost of connecting buildings to the power grid. The subjects must have experience installing systems in buildings the size of the EcoTarium. The subjects should have backgrounds in both above and below ground electrical systems. The goal is to get enough information from the different contractors to get an idea of the cost difference between both ways of connecting the EcoTarium to the grid. The contractor's experience will be taken into consideration during the cost analysis.

3.4.3 Comparison:

This method to ensuring validity will be the most effective process for the EcoTarium. Schram comments on the method of constant comparison being used for data analysis and says, "This method reflects the characteristic stance of refusal to accept a report at face value (Schram, 2006)." This concept of critical thinking will be helpful in finding the best approach to connecting the EcoTarium to the grid. Basing a recommendation on only one cost estimate would be insufficient to decide the feasibility of the project. However, comparing several estimates would provide a more accurate prediction of the actual cost. The more accurate our research, the more weight it will hold for our sponsor when giving him our recommendation. Therefore, acquiring as many opinions as possible from the contractors would benefit the validity of the research. Comparing several options will help to evaluate the data regarding cogeneration.

The local data obtained on this matter will be compared with the global data. Doing this will validate the information locally. If the local data agree with the global data it will be compared to the cost of connecting to the grid. This comparison will include the capital cost of installing both structures and the cost of maintaining both systems over time.

Defining the attributes that will have the greatest effect on the cost will make sure that the assessment of the cost is the most correct. The application of comparison is effective for the EcoTarium research because it closes the error gap on all of data.

3.5 Data Analysis

Data will be collected from many different types of sources, including written text and verbal quotes from interviews. We plan to cross-reference the data. When it comes to the quantitative data, we will keep a detailed Microsoft Excel Spreadsheet explaining different quotes, prices, and maintenance costs for the proposed methods. We will define which variables are known to us initially, and which are calculated either by us or by the contracting firms.

Table 1 : Proposed Data Collection Methods

Data Collection Tool	Amount	Additional Info
Interviews	Engineering Firms (One or more), Mr. Pitcher, EcoTarium Accountants, and Public Power Company Representatives	Latent: Recorded either vocally or written.
Related Construction Projects	All related for Worcester	Manifest: Quotes or Price Ranges
Archival Research	All DOE archives, Worcester Public Records (Past 30 years)	Manifest: Power Usage and Demand
EcoTarium Logs	Past 30 years, general	Manifest: Fuel Costs, Power Generation

Chapter 4: FINDINGS

4.1 Introduction

The findings chapter introduces and explains the data that have been collected over the past few weeks. The first data that are introduced explains how cogeneration is used at the EcoTarium. This is followed by the findings that explain Bob McLaren's data on the cost of electricity from National Grid. This chapter also covers the current energy usage of the EcoTarium along with a breakdown of the power that is used during the day. The findings also include the analysis of the construction plan for connecting the EcoTarium to the grid.

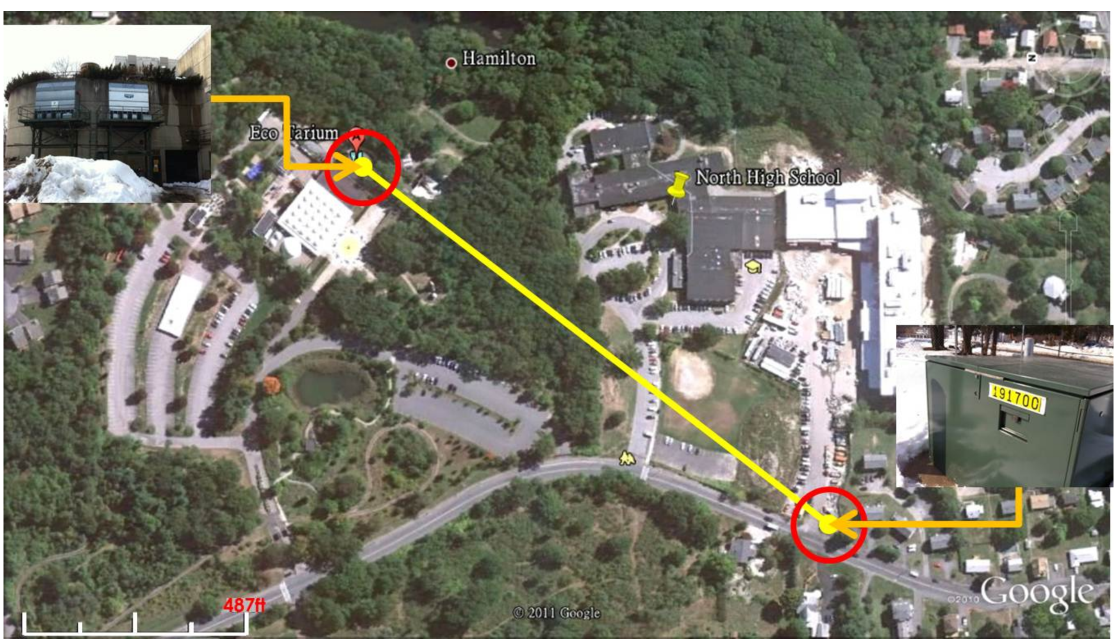

Figure 4 : EcoTarium, North High School, and Relative Distance of Travel

(Map of Worcester, MA, retrieved Jan 26, 2011 from http://maps.google.com, annotated by Yow Chyuan-Yeh)

The main reason that the EcoTarium wants to connect to the public grid is because of past problems of inconsistent power. This stems from a number of issues, such as unsteady flow of natural gas from the public supply lines, generators kicking on too early or too late, too high demand for the generators, or any mechanical failures associated with the machines. This creates an issue with the live exhibits at the EcoTarium and the safety of the guests and employees. By researching the possible causes for the inconsistencies, our project group can work with the EcoTarium engineers to create a safer, more reliable power plant. The North High School junction box location provides an ideal connection point, due to close proximity and the already existing capabilities to handle the electrical load of both North High and the EcoTarium

4.2 The Cogeneration System

Cogeneration systems consist of many different parts, such as the generators, boilers, switch gears, adsorption air conditioners, and the hot water distributors. There are two generators that run a lag-lead system. It works by only having one generator running if possible, and setting a threshold for the other generator to turn on if power demand is too high. The threshold for these specific generators is 260 kW. This allows the most efficient possible way to keep the generators running. It is also much better for the machines, because they are never allowed to run past their maximum limit. The threshold is usually set well below the maximum to further prevent any risks. On a rare occasion, this threshold is reached under specific circumstances such as when the air conditioning is running in the summer, as well as the planetarium and elevators being used. Each generator has its own boiler which is used only when the steam pressure from the generators is not enough to run the air conditioning. Otherwise the generators produce enough heat and electricity to keep the building complex working and comfortable. The below diagram demonstrates how the cogeneration system at the EcoTarium works.

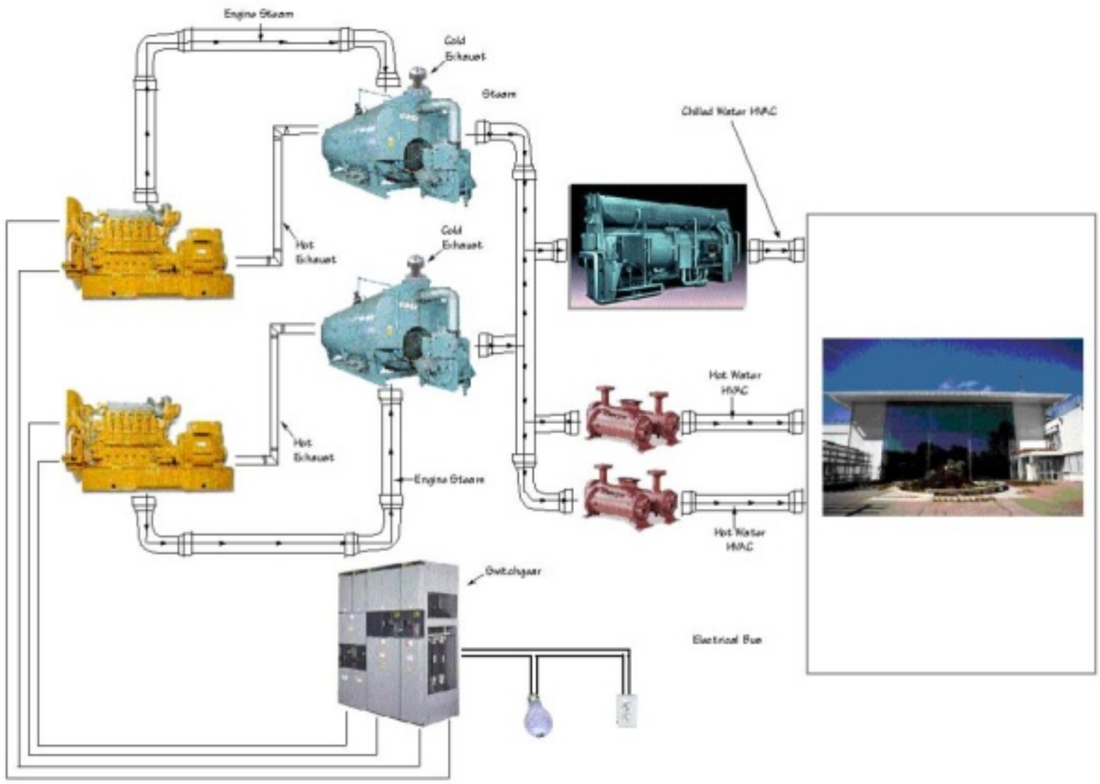

Figure 5 : Energy System Diagram

The Heat Recovery Steam Generator (HRSG) is a type of steam boiler that uses the heat produced in cogeneration systems to heat up water to generate steam. The steam will go through the turbine and then to individual heating elements. The boiler is needed because the velocity of the exhaust gas from the engine is not high enough, which prevents the steam from heating a larger volume. For the EcoTarium, each generator has its own specific boiler to help produce steam. The heat from the generators generally produces enough steam to heat the whole building, and the remainder goes to the absorption chiller. However, the left over heat is not enough for the absorption chiller to drive the cooling process. The boilers are not constantly running, so this also needs to be taken into consideration when calculating energy costs.

Figure 6 : Generator,

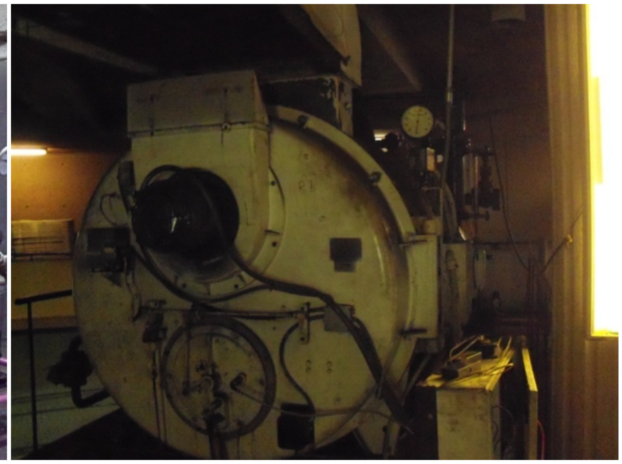

Figure 7 : Boiler

The cogeneration plant maintains different usage depending on the time of day, as well as the season, so this must be taken into account for calculating the yearly usage. Taking data from the logs showed the estimated energy usage in kW at a specific time of day. This is important to take into consideration because at different times of the day, different units are using energy. At night when the EcoTarium is closed, for example, the lights are not needed so the power draw is less than during the day. During the day when the lights are running, the power consumption is about 40 kW more just for the lights. Depending on what time of the year it is, the power consumption can vary anywhere from an additional 20 kW for the heat fans, to an additional 120 kW for the air conditioning. This sets an average range for possible energy consumption from about 100 kW to about 260 kW (Mitzcavitch, 2011).

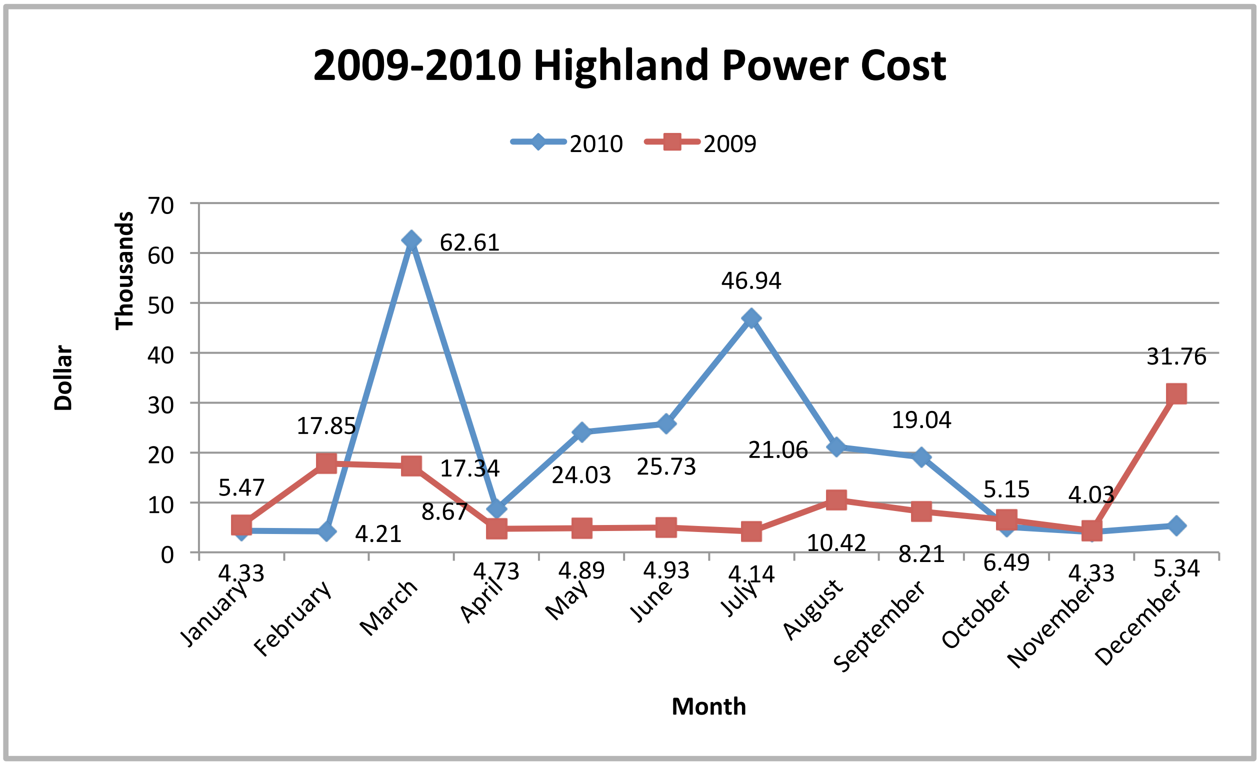

Figure 8 : Repair Costs

To make our cost analysis for comparing energy prices, we gathered data on repairs and maintenance for the boilers for the past two years from the accounting offices at the EcoTarium. The maintenance company, Highland Power, does most of the general repairs for the generators. These accounting logs were able to provide us with an estimate of maintaining generators, as well as any major repair costs. The average repair costs for 2009 and 2010 were $120,575 and $231,151 respectively. These repair costs help to support an accurate current cost for energy.

One repair that is needed is replacing all of pipes inside of the boilers at one time in order to save money in the long run. Replacing one of the pipes costs $5,000, but replacing 110 of them only costs $15,000. Budgeting for this repair knowing that there is wear on these pipes regularly will be the best plan. Another repair that should be made is replacing the gaskets throughout the system because they are the most common failure point in the cogeneration system. Regular maintenance has also been a problem that has kept the plant from running to its full capacity. Yearly water treatments will prevent unneeded damage to a majority of the system. Regular inspection of the entire plant especially all of the gaskets will help to prevent downtime for the plant. Taking action on these repairs and maintenance will likely cut down on future costs, and allow the generator sets to run longer before replacement. The information about these repairs and maintenance was obtained through Mike Mitzcavitch and his maintenance staff.

4.3 Energy Data

We collected power usage based on time of day as well as season to see when the nominal power usage was. The below diagram was developed from these estimates that we received from a maintenance worker. The lowest power demand is overnight, when no lights are on. During the day, more power is needed to run the lights and electronic equipment in the museum. During the winter and summer seasons, power demand increases due to the additional use of heating and air conditioning. The graph also shows the average power demand for 2009 and 2010, the data for which were developed from Figure 10. From this graph, we can determine that the power demand ranges from 100kW to 260kW during the year.

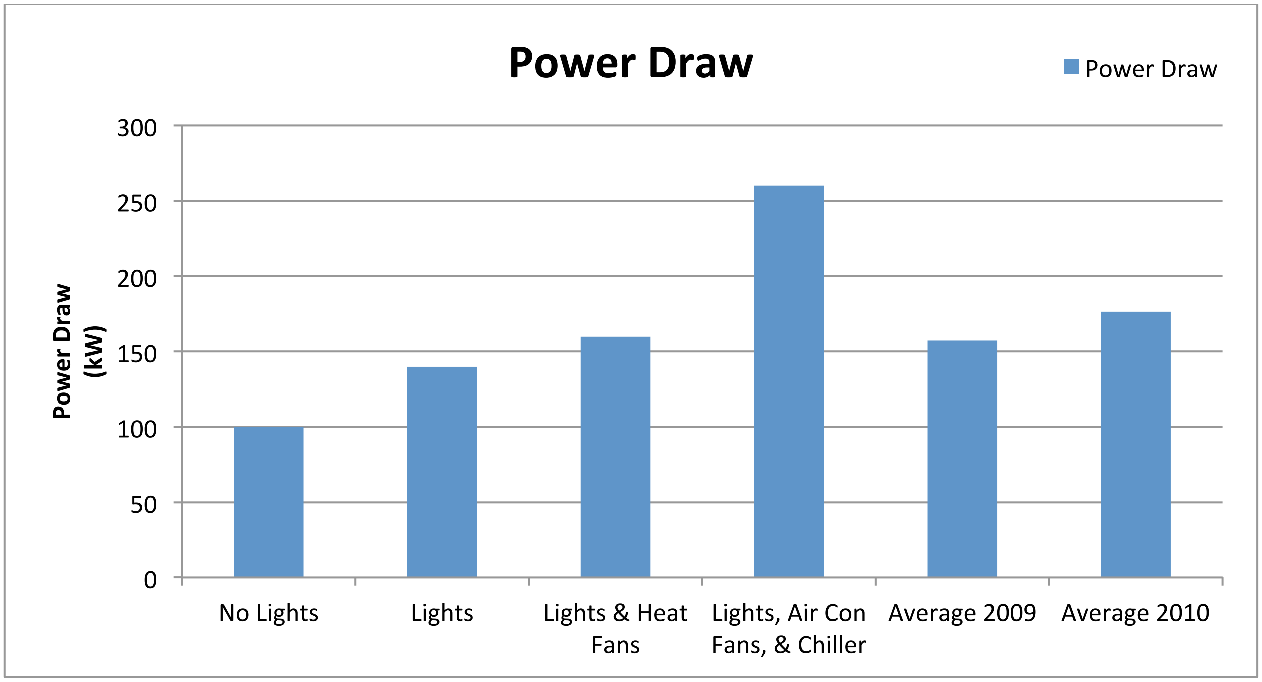

Figure 9 : Power Usage per Time of Day

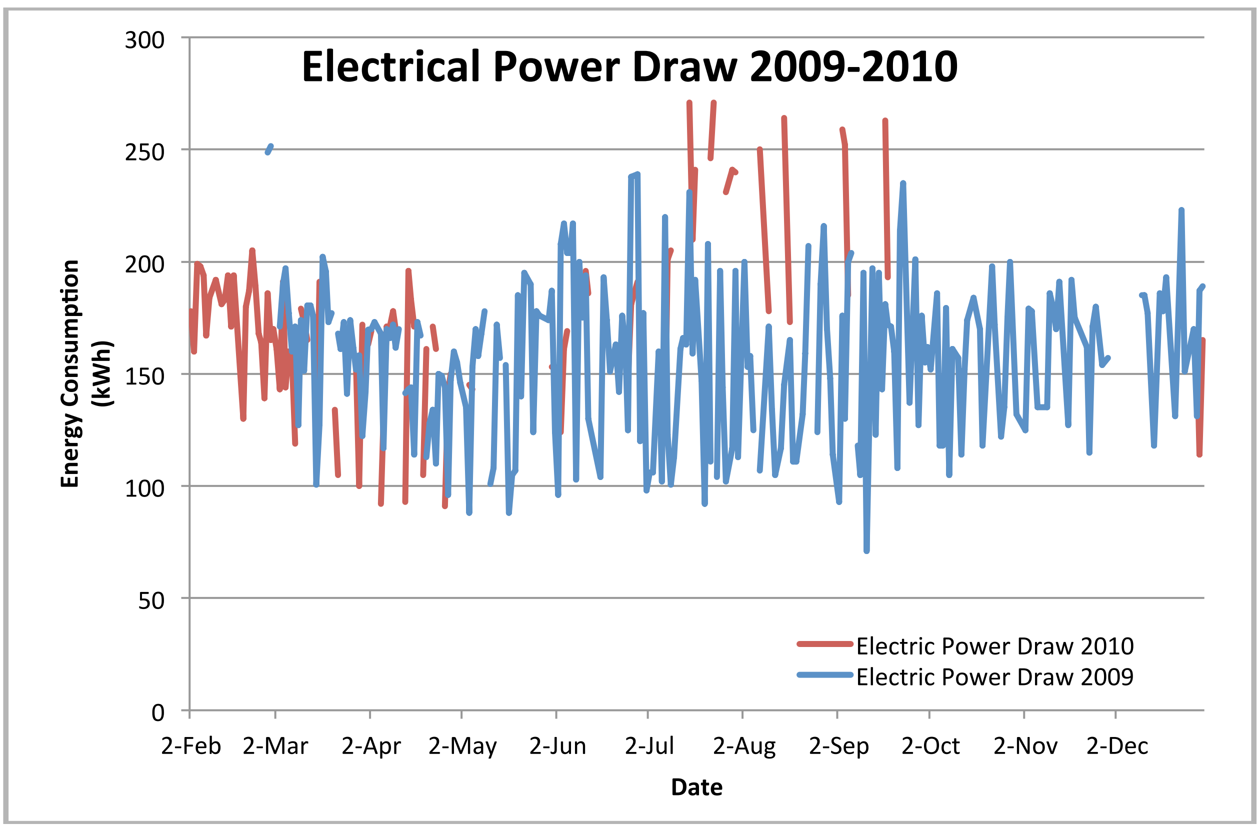

Figure 10 : Instantaneous Power Usage 2009-2010

Figure 10 shows how much electricity the EcoTarium consumed over the last two years. The data was gathered from maintenance reports, where an employee recorded data about the generators, including engine hours, oil pressure, and which generators were running. Also on these reports were recordings of the instantaneous power and voltage draw of the museum. There is currently no monitoring system to track energy usage by the switchbox, so this data may be incomplete. The reports were not taken every day or at the same time every day. However, the graph shows what kind of power demand the EcoTarium more accurately than the estimated power draw diagram found in Figure 9. This data can be directly compared to the museum's consumption of natural gas.

The primary form of data collection kept by the EcoTarium was in the form of therms of natural gas purchased per month, going back about ten years. In order to make this more accessible and easy to use, the therms were converted to kWh (1 therm per 29.3 kWh). This data was then organized graphically to better show the usage per month compared to other times of the year. The cogeneration plant runs countercyclical to traditional power generation, meaning that when power demand is high on the public grid, power demand is lower for the EcoTarium. This is because the plant produces its own heat and cooling, so there are no electrical needs for those units. This is shown by having dips in usage from June until August, and from October until April. Therefore the months with the most fuel purchased are September and May. The fuel purchase data is significant, since it contains a value that can be used as a standard for analysis of the cost of electricity. This data can be used as a base to compare to, and is calculated into the cost of running the plant.

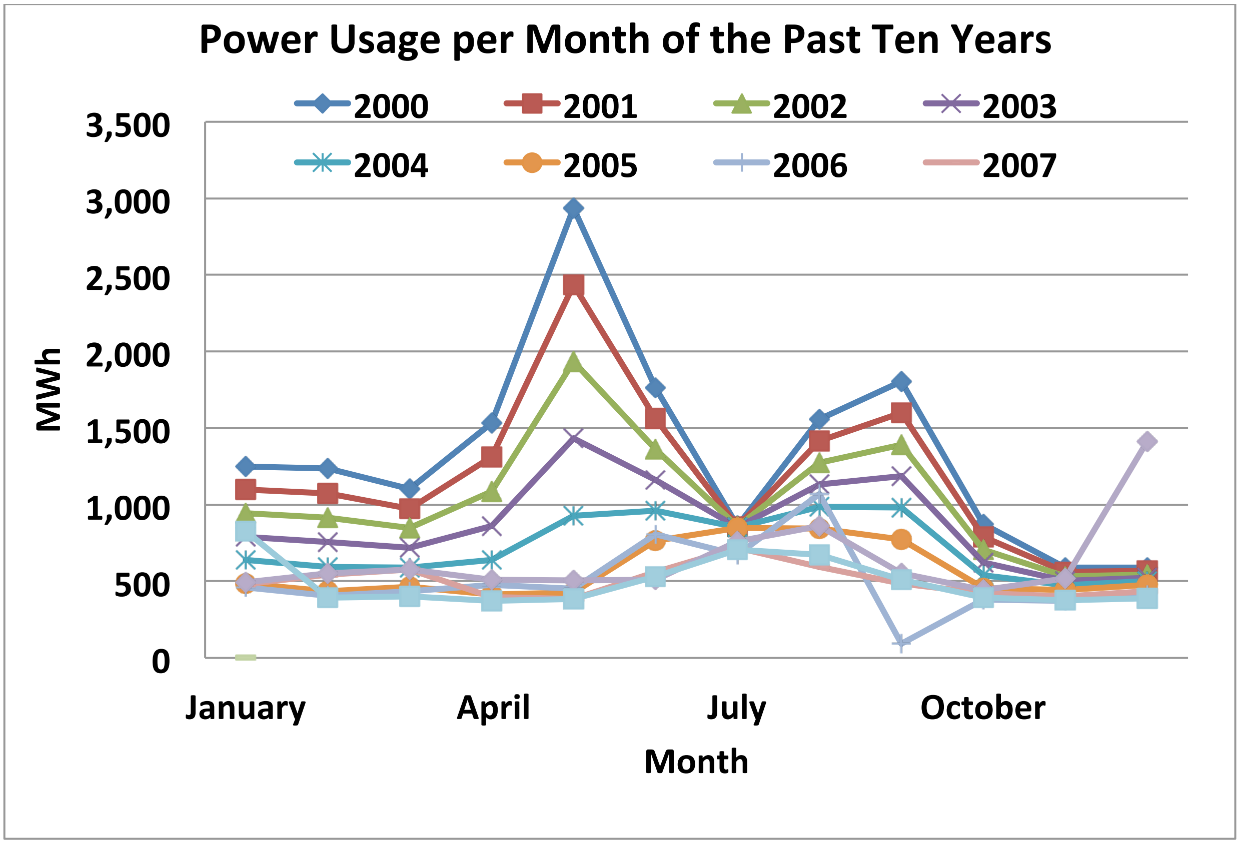

Figure 11 : Natural Gas Consumption per Month over the Past Ten Years

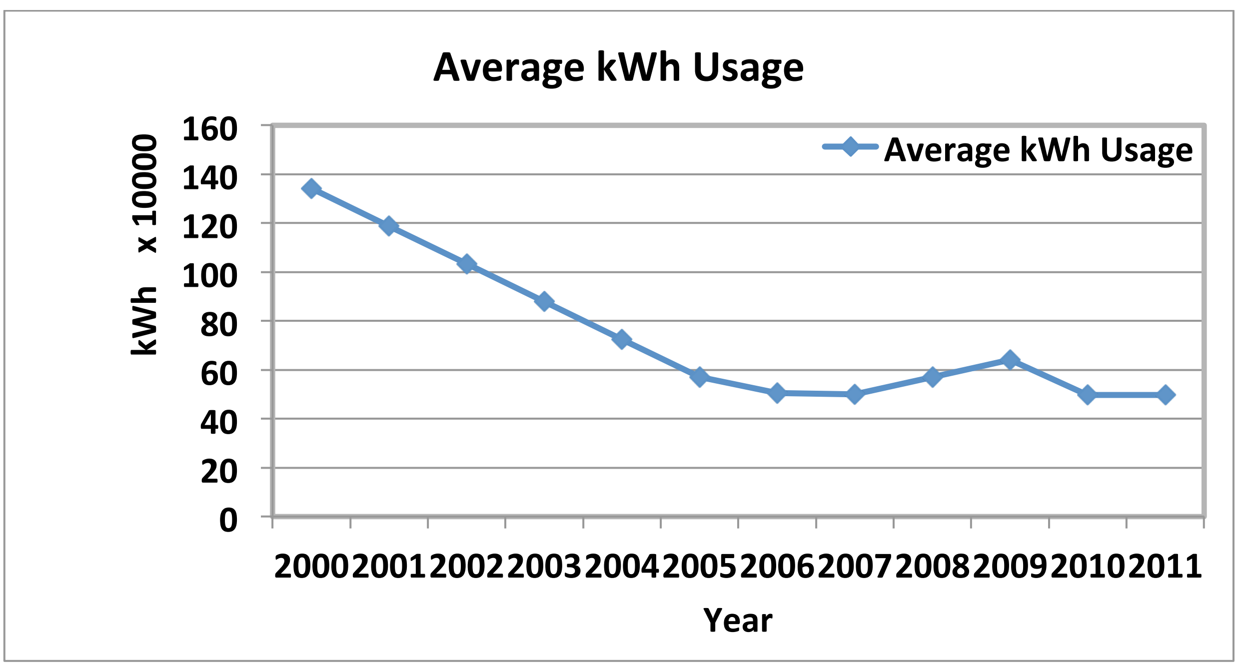

Figure 12 : Average kWh from 2000-2011

By comparing the average fuel usage per year, and calculating it in kilowatt hours, we have noticed a trend of decreasing energy usage and fuel purchase for the past ten years. This is due to changes in ways the plants are run, as well as how often the boilers are turned on. The boilers are the biggest uses of natural gas, which shows when the adsorption chiller is running in the summer. The chiller requires more steam pressure, so more natural gas is burned to run these boilers.

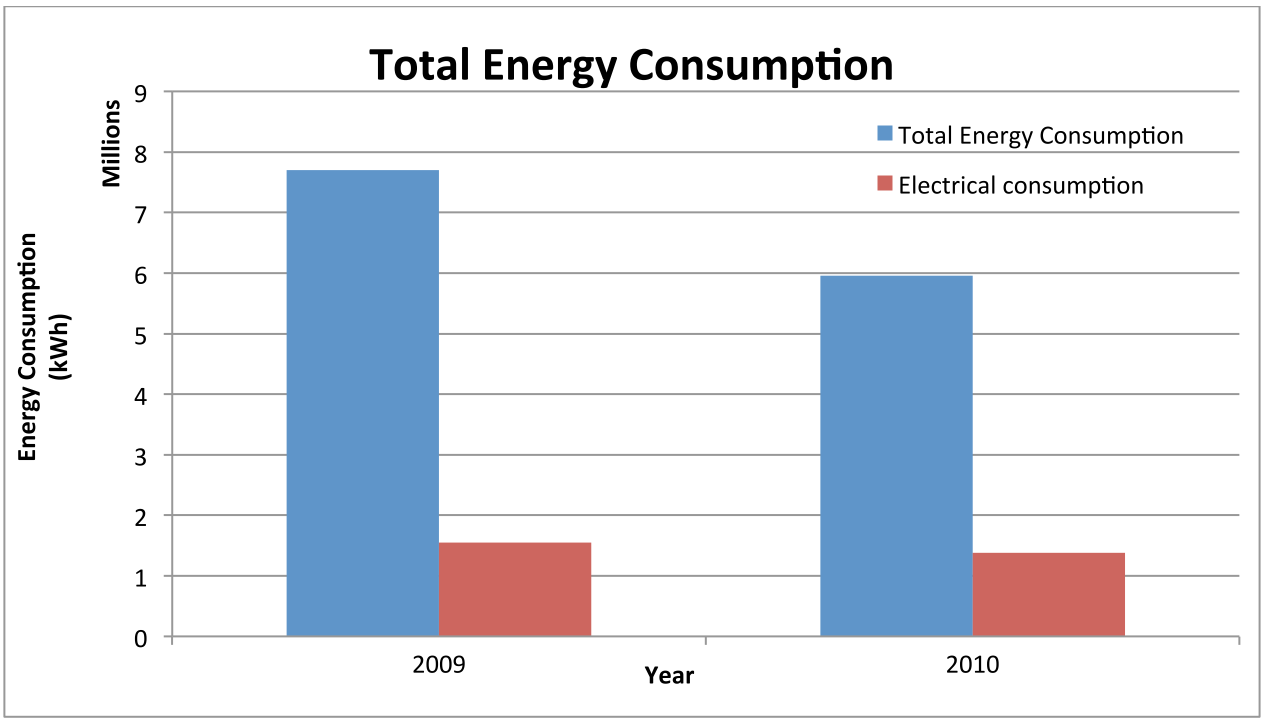

Figure 13 : Total Energy Consumption 2009-2010

Figure 13 outlines the energy consumption of the EcoTarium during 2009 and 2010. This chart includes the data from Figure 12, along with some of the data from Figure 11. The purpose of this diagram is to directly compare the electric demand with the amount of natural gas on the same basis. Using this diagram, it can be determined that most of the energy produced by natural gas is not translated into electricity. The lost energy can be attributed to several factors, which include the efficiency of the generators, the heat recovered by the heat exchangers, and the heat lost despite the cogeneration system.

The reason why our group had to manually calculate all the data for the energy consumption of the EcoTarium is because there is currently no electricity meter installed in the building. The EcoTarium has no way of tracking their electrical draw, so this makes it difficult for National Grid to estimate how much power they will need to supply the system. (Mitzcavitch, 2011)

4.4 Benefits and Drawbacks

Table 2 : Benefits and Drawbacks of Underground Connection

Benefits	Effect on museum
Aesthetics	Keeps natural environment for museum grounds
Reliability	Power lines are unaffected by snow & ice
Elimination of risks	Prevents vehicular and personnel hazards
Drawbacks	
Higher Cost	Installation cost for underground connection can be twice to four times as expensive
Shorter lifetime	Transformers tend to rust more quickly
Maintenance difficult	Maintenance of lines includes excavation; inspection impossible

During our research, our team found a source outlining the positive and negative qualities associated with installing underground power lines. Among the positive qualities, we found that the underground power connection is more visually appealing, avoids weather-related damage, and prevents vehicular accidents. Some facilities, like the EcoTarium, place a higher value on the aesthetics of their environment. In contrast, the negative qualities include the high cost of installation, diminished lifetime of some parts, and the difficulties associated with maintenance and inspection. Transformers, when placed underground, tend to rust twice as fast, because of air circulation. Additionally, any potential maintenance would require excavation in order to complete repairs. (EEI, 2009)

4.5 Energy Cost Comparison

In order to give the EcoTarium an accurate estimate for current and future energy costs, we compiled all the repair costs, fuel usage and costs, and power draw. Taking into account as many variables as we can will increase how precise our costs will be.

Table 3 : Estimated Current Cost of Electricity

Calculated Values	2009	2010
Average Power Draw (kWh)	157.35	176.40
Natural Gas Consumption (kWh)	7,728,871	5,959,982
Cost of Natural Gas	$166,209.00	$134,816.00
Price per kWh	$0.003867	$0.005869
Cost of Repairs	$120,575	$231,151
Adjusted Price per kWh	$0.006672	$0.015931

Taking all costs into consideration, we were able to come to the conclusion that the EcoTarium pays about $.007 to $.016 per kWh for energy. Since the total fuel cost currently was calculated into kWh, the next step was to compare these values and estimate a monetary value for the energy purchased from the grid. Bob McLaren of National Grid sent us an example table to estimate the current price that energy is purchased for.

Table 4 : Example Energy Costs from National Grid

National Grid Energy Costs						
Time of Use (G-3) Rates						
				Sample Bill Calculation		
		Peak Demand	700	kW	700	kW
		Load Factor	30%		45%	
		Monthly Energy	153,300	kWh	229,950	kWh
Cost Component			Peak Per kWh	Off-Peak Per kWh	Peak Per kWh	Off-Peak Per kWh
Customer Charge	$ 200.00	/month	$ 0.001305	$ 0.001305	$ 0.000870	$ 0.000870
Distribution Demand Charge	$ 3.92	/kW	$ 0.017900	$ 0.017900	$ 0.011933	$ 0.011933
Distribution Charge						
Peak Hours*	$ 0.01377	/kWh	$ 0.013770		$ 0.013770	
Off-Peak Hours*	$ 0.00624	/kWh		$ 0.006240		$ 0.00624
Transmission Charge	$ 0.01328	/kWh	$ 0.013280	$ 0.013280	$ 0.013280	$ 0.013280
Transition Energy Charge	$ 0.00030	/kWh	$ 0.000300	$ 0.000300	$ 0.000300	$ 0.000300
Energy Efficiency Charge	$ 0.00433	/kWh	$ 0.004330	$ 0.004330	$ 0.004330	$ 0.004330
Renewables Charge	$ 0.00050	/kWh	$ 0.000500	$ 0.000500	$ 0.000500	$ 0.000500
Basic Service (2/11)	$ 0.07539	/kWh	$ 0.075390	$ 0.075390	$ 0.075390	$ 0.075390
		Total Energy Cost	$ 0.126774	$ 0.119244	$ 0.120373	$ 0.112843

The table explains both peak and off peak values, and gives different prices depending on the load factors. An important part of deciding the cost is the relative load factor. The load factor is the peak demand in kW divided by the average energy usage in kWh. The higher the load factor, in percentage, leads to a lower cost. When purchasing public power, it saves money to keep the average energy usage constant. This is important because we are comparing the differences in generating power using the cogeneration method, or by simply buying it from the grid. To get an accurate representation of the costs of energy directly from the grid, we need to take into account that heating and cooling is not included in the cost. Based on the chart given by National Grid, we estimate the purchasing costs for electricity to be between $0.12 and $0.13 per kWh. Heating and cooling using traditional methods can be expensive, hence the benefits of the cogeneration.

Once connected to National Grid the EcoTarium could potentially sell power back to the grid. One way recommended to us of selling power back is net-metering. Net-metering is when a power producer redistributes any excess power back to the public, and the electricity meter is rolled back as power is sold.

4.6 Construction Estimates

After researching pricing options, it is shown that the cost for construction will be much higher to build underground lines. This accounts for both capital cost to build it and the proposed future maintenance costs. The costs rely on the geography of the surrounding land, from the North High School to the EcoTarium. The distance between the two is shown in the map below. The goal for our project is to develop an estimate of cost for both methods of connection. By researching all variables associated with the issue, and collaborating with Shepherd Engineering, our group will be able to make an educated estimate of the total costs.

OnTarget Utility Locating Services (http://www.ontargetservices.com) work with both National Grid and Charter Internet Providers to locate and provide safe estimates before running underground lines. Working with OnTarget, we can better estimate a feasible construction path. DigSafe (http://www.digsafe.com) is also a helpful surveying company that will work with local utilities to show any other utility lines, such as sewer, water, and natural gas. While sharing trenching with these utilities is impossible, knowing the layout will assist in finding the correct path.

4.6.1: Shepherd Engineering Proposed Costs

A brief proposal for construction was organized by Shepherd Engineering as a preliminary analysis for the EcoTarium. While the estimates may not be complete, we were able to assume similar variables and base our proposed costs on this report. Shepherd Engineering's estimate also included a profit factor, which our cost did not. Appendix 2 has tables which further break down the list of material costs and labor costs.

Table 5 : Shepherd Engineering Proposed Construction Costs

Proposed Construction Costs	Cost ($)
Total Material	76,922.66
Labor	91,351.98
Direct Job Expenses	28,750.00
Job Subtotal (Prime Cost)	197,024.63
Overhead (10%)	19,702.46
Profit (12.3%)	26,697.07
Job Total	243,424.17

4.6.2 Industry Standard Costs

Our proposed construction costs are similar to Shepherd Engineering's estimate. Our costs, however, were based on cost-per-foot standards. Many of the capital costs, such as entrance/exit points and landscaping were taken into account as well, which helped to show accuracy. We were unable to come up with labor costs to include in our estimate, as well as a cost for the actual copper wiring itself. With proprietary utility information, we would be able to add these estimates to our proposal, but we were unable to access this.

Table 6 : Proposed Construction Costs

Proposed Construction Costs – IQP Estimate	Cost ($)
Necessary Construction	17,500.00
Under Terrain - Bore	1,080.00
Under Asphalt	20,000.00
Asphalt Repair	10,500.00
Normal Ground	45,150.00
National Grid Back Charge	100,000.00
Job Total	194,230.00

Chapter 5: RECOMMENDATIONS

5.1 Construction

After researching the benefits and drawbacks of both above ground and below ground transmission lines, we propose that the best method is the underground construction. While it tends to be costlier, the convenience of having the North High School in close proximity and the added benefits of having a secure connection to the grid lead to it being the best fit for the EcoTarium. This will provide a safety net for the wildlife that also relies on the power supply. Having the backup will provide safety to all the guests and employees in case of any emergencies. To save money on running the cogeneration plant, as well as making it more efficient, the EcoTarium will have to spend money up front. The costs will come from regular repairs and regular maintenance.

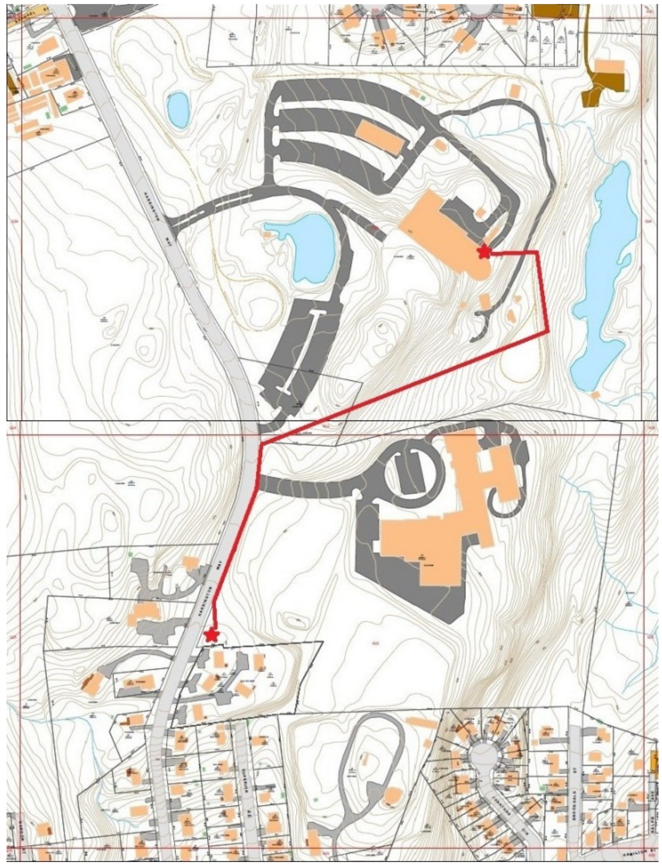

Figure 14 : Tax Map With Proposed Route

Our proposed area of construction, in Figure 14, is the best recommended path to take. Due to the existing structures and utilities, a direct path is not feasible. The lower star on the map is the transformer and vault, and the upper star is the cogeneration site. The path, following Harrington Way, will be expected to avoid any utility lines and current obstacles. The only issue we have noticed for the construction however is the amount of bedrock located under the surface. To avoid this issue, we propose that running the electric lines through the already existing conduit of communication lines, such as cable or internet, be considered.

5.2 After Connection

There are a few recommendations our IQP group has for the EcoTarium after they are connected to the power grid. The EcoTarium should run their generators in a way that will reduce their load factor do when they are connected to the grid. The load factor is the largest factor in the price of electricity per kWh, and reducing this will be a great way for the EcoTarium to save money. Over the past ten years, as shown by Figure 12, power usage in terms of kilowatt hours (kWh) has steadily been decreasing at the EcoTarium. If this trend is continued, the costs of running the power plant and buying the power from National Grid will be reduced. The only disadvantage is that the electricity purchased from the public will be more expensive. This difference can be anywhere from $0.06 to make their power or up to $0.12 to purchase it. We recommend working with Yankee Technologies (http://www.yankeetech.com) to add in monitoring software into the cogeneration system. This will help to give a better picture of exact usage, and can assist in optimizing the plant.

If National Grid can make a deal with the EcoTarium, the capital costs can be paid off with the added revenue. They could also be able to lower their purchase costs for the electricity. National Grid gives out rebates to power producing customers that work to help improve and maintain the plants. By connecting to National Grid, the EcoTarium faces the possibility of a subsidized upgrade to their cogeneration system. This is beneficial to the EcoTarium because their cogeneration engines are getting older, and maintenance is becoming more expensive as well. It will also be profitable for the EcoTarium to help National Grid supply local customers when there is high demand. This idea of load shedding has been around for a while, and will give the EcoTarium the best rate for selling back the power it makes. Since the EcoTarium runs countercyclical, demand for the EcoTarium and the public grid are inversely proportional.

To present our recommendations and the facts we based them on, our group held different presentations for the EcoTarium. We presented our facts to the board of advisors, the entire EcoTarium staff, and a final capstone presentation to outline our overall project. Appendix 5 is the slide show presented to the entire project center, our advisors and our sponsors.

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APPENDIX 1: Milestones

Table 7 : Milestones

EcoTarium Project Milestones	Mike Jenkins, Casey Rivera, Greg Anderson, Roy Yeh	23-Jan	30-Jan	6-Feb	13-Feb	20-Feb	27-Feb
		M T W T F	M T W T F	M T W T F	M T W T F	M T W T F	M T W T F
Task Name	**Description**						
Meetings/ Interviews	Any meetings or contact with consultants						
First contact with consultants	Calling: Mitzcavitch, Shepherd, McLaren, Gorman, National Grid, Yankee Technologies						
Second Contact with consulatants							
Interviews with consultants	When we plan on talking to the consultants we contacted						
9 am edits	Advice on editting what we submitted Sunday						
2 pm formal meetings	Meeting with sponsor and advisor						
1:30 pm meetings	Friday meetings (sometimes a presentation)						
Data collection and analysis	Any data we collect						
Natural Gas data	Changing the units and compare it togenerator run time						
Generator run time data	Acquire from EcoTarium maintanence						
Average cost of running the generators	From the two sources above						
Construction cost of connecting to grid	From the consultants						
Final Analysis	Anylisis of the effectiveness of plant						
Writing	All writing						
Chapters 1-3	re-write proposal						
Executive summary and outline findings chapter							
Draft of findings and discussion chapter							
Complete draft							
Revised complete draft							
Final report							

APPENDIX 2: Tables

Table 8 : Estimated Cost for Shepherd Engineering

Item#	Description	Qty
1059	4" GRC	20.00
1196	4" PVC Conduit	4200.00
1595	4" Locknut	36.00
1651	4" Grounding Bushing	2.00
2069	4" PVC Male Adapter	36.00
2123	4" PVC Coupling	28.00
2135	4" PVC Elbow	4.00
2146	4" PVC Elbow (36" Radius)	20.00
2169	4" GRC Elbow	4.00
2297	4" 2-Hole Strap	4.00
2368	4" x3" Base Spacer	525.00
2372	4" x3" Intermediate Spacer	525.00
2824	#3/0 XHHW CU Stranded Wire	560.00
2830	#500MCM XHHW CU Stranded Wire	2240.00
2884	#2 15KV Grd EP/PVC wire	3000.00
3125	#1/0 Stranded Bare Copper/Alum Lug	65.00
3127	#3/0 Stranded Bare Copper Wire	20.00
6673	3/4" x 10' Copper Ground Rod	5.00
6676	3/4" Ground Rod Clamp	3.00
6852	#350 Split Blot Connector	2.00
6860	#250 1-Hole Copper/ Alum Lug	8.00
6863	#500 1-Hole Copper/ Alum Lug	32.00
6928	HIGH VOLTAGE TERMINATIONS	3.00
6929	CUT AND CORE CONCRETE FLOOR	1.00
6930	WORK IN EXISTING SWITCHBOARD	1.00
7077	24"W x30"D Trench-Back Hoe	900.00
7089	36" W x48"D Trench- Back Hoe	60.00
7104	6'x 6' x6' Manhole Excavate/Backfill/C	2.00
7135	3000# Concrete (Cu. Yards)	133.33
7138	6'x 6' Concrete Transformer Pad	1.00
7152	6'x 6' Prefab Concrete Manhole	2.00

Table 9 : Shepherd Cost Summary

	Summary	$
Material		
	Non-Quoted	72,227.85
	Quoted	0.00
Sales Tax (6.5%)		4,694.81
Total Material		76,922.66
Labor		
	Direct (1,588.73 hours @ $57.50)	91,351.98
	Non-Productive	0.00
Direct Job Expenses		28,750.00
Subcontracts		0.00
Job Subtotal (Prime Cost)		197,024.63
Overhead (10%)		19,702.46
Profit (12.3%)		26,697.07
Job Total		243,424.17
Material to labor ratio: 0.46		
Cost per square foot		0.00
Selling price per square food		0.00

APPENDIX 3: Collected Costs

Table 10 : Estimates of Construction Costs

Construction Costs: "Industry Professional Quote"	
Capital Costs (not for conduit)	
Entrance Point	1,000$
Ladder for entrance for material (in the EcoTarium)	500$
Grounding	1,000$
Land renovations after construction	10,000$
Manhole/handhole	5,000$
Cable Conduit costs:	
Per foot average	30$
Going under concrete, road /ft	40$
Repair of asphalt /ft	21$
Cable pulling costs /ft	4$
Going under the train track/ft	180$
Additional Costs:	
Labor	
Additional Equipment	
Variances/Permit Costs	
National Grid BackCharges	
Total Capital Costs (Both Proposals)	17,500$ (+Tax)
Back Charge, National Grid	100,000$

Table 11 : Cost Estimates For Construction Paths

1316.26 ft straight line	
Under Train Distance: 10 ft estimated	1,080$
Under Concrete Distance: 305ft	12,200$
Repair Asphalt	6,405$
Normal Ground Distance: 1001.26	30,037.8$
Total	167,222.8$ + (420$ Tax)
2015ft total proposed. (Avoiding Obstacles)	
Under Train Distance: 10 ft estimated	1,080$
Under Concrete Distance: 500ft	20,000$
Repair Asphalt	10,500$
Normal Ground Distance:1505	45,150$
Total	194,230$ + (590$ Tax)

APPENDIX 4: Energy Usage Tables

Table 12 : Energy Consumption 2009-2010

Date 2009	Time (24 hr)	Power Draw (kW)	**Date 2010**	Time (24 hr)	Power Draw (kW)
30-Dec	1030	189	**30-Dec**		
29-Dec	1030	187	**29-Dec**		
28-Dec	1145	131	**28-Dec**		
27-Dec	1100	170	**27-Dec**		
24-Dec	1130	151	**24-Dec**		
23-Dec	930	223	**23-Dec**		
21-Dec	1030	131	**21-Dec**		
18-Dec	1230	193	**18-Dec**		
17-Dec	930	178	**17-Dec**		
16-Dec	1000	186	**16-Dec**		
14-Dec	900	118	**14-Dec**		
12-Dec	1400	177	**12-Dec**		
11-Dec	830	185	**11-Dec**		
10-Dec	1300	185	**10-Dec**		
8-Dec			**8-Dec**	930	165
4-Dec			**4-Dec**	2200	114
2-Dec			**2-Dec**	1100	161
29-Nov	1530	157	**29-Nov**		
27-Nov	900	154	**27-Nov**		
25-Nov	930	180	**25-Nov**		
24-Nov	930	171	**24-Nov**	1000	164
23-Nov	1030	115	**23-Nov**		
22-Nov	1600	162	**22-Nov**	2200	126
18-Nov	900	175	**18-Nov**		
17-Nov	900	192	**17-Nov**		
16-Nov	930	127	**16-Nov**	1215	156
13-Nov	930	191	**13-Nov**		
12-Nov	1700	170	**12-Nov**		
11-Nov	930	180	**11-Nov**		
10-Nov	1000	186	**10-Nov**		
9-Nov	900	135	**9-Nov**		
6-Nov	830	135	**6-Nov**		
4-Nov	930	178	**4-Nov**		
3-Nov	900	179	**3-Nov**		
2-Nov	900	125	**2-Nov**	900	164
30-Oct	830	132	**30-Oct**		
28-Oct	1400	200	**28-Oct**		
27-Oct	900	175	**27-Oct**		

26-Oct	900	135	**26-Oct**		
25-Oct	1745	122	**25-Oct**		
23-Oct	830	172	**23-Oct**		
22-Oct	900	198	**22-Oct**		
19-Oct	900	118	**19-Oct**		
18-Oct	1100	170	**18-Oct**		
16-Oct	900	184	**16-Oct**		
14-Oct	930	174	**14-Oct**		
13-Oct	900	152	**13-Oct**		
12-Oct	1100	114	**12-Oct**		
11-Oct	1530	157	**11-Oct**		
9-Oct	930	161	**9-Oct**		
8-Oct	1730	105	**8-Oct**		
7-Oct	900	179.3	**7-Oct**		
6-Oct	830	118	**6-Oct**		
5-Oct	730	118	**5-Oct**		
4-Oct	1330	186	**4-Oct**		
2-Oct	830	152	**2-Oct**		
1-Oct	900	162	**1-Oct**		
30-Sep	900	155	**30-Sep**		
29-Sep	930	176	**29-Sep**	1100	230
28-Sep	900	127	**28-Sep**		
27-Sep	1530	201	**27-Sep**	930	130
25-Sep	830	137	**25-Sep**		
23-Sep	1030	235	**23-Sep**		
22-Sep	1000	214	**22-Sep**	1030	191
21-Sep	830	108	**21-Sep**		
20-Sep	1000	160	**20-Sep**	900	135
19-Sep	1000	171	**19-Sep**		
18-Sep	900	172	**18-Sep**		
17-Sep	900	181	**17-Sep**		
16-Sep	900	143	**16-Sep**		
15-Sep	1730	195	**15-Sep**		
14-Sep	1030	123	**14-Sep**		
13-Sep	1200	197	**13-Sep**	1000	190
11-Sep	800	71	**11-Sep**		
10-Sep	1100	195	**10-Sep**	830	149
9-Sep	700	105	**9-Sep**		
8-Sep	1000	118	**8-Sep**		
7-Sep			**7-Sep**	900	164
6-Sep	1700	204	**6-Sep**		
5-Sep	945	200	**5-Sep**		
4-Sep	900	130	**4-Sep**		
3-Sep	900	176	**3-Sep**	900	193
2-Sep	830	92.8	**2-Sep**	1000	263

31-Aug	830	114	**31-Aug**		
30-Aug	1800	148	**30-Aug**		
29-Aug	1000	170	**29-Aug**		
28-Aug	1130	216	**28-Aug**		
27-Aug	930	190	**27-Aug**		
26-Aug	1230	124	**26-Aug**		
24-Aug			**24-Aug**	900	199
23-Aug	1700	207	**23-Aug**		
22-Aug	1800	159	**22-Aug**		
21-Aug	1000	132	**21-Aug**		
19-Aug	900	111	**19-Aug**	830	185
18-Aug	900	111	**18-Aug**	1030	252
17-Aug	830	165	**17-Aug**	930	259
15-Aug	830	145	**15-Aug**		
14-Aug	1000	117	**14-Aug**		
12-Aug	900	105	**12-Aug**		
11-Aug	1000	134	**11-Aug**		
10-Aug	900	171	**10-Aug**		
7-Aug	900	107	**7-Aug**		
6-Aug			**6-Aug**	930	264
5-Aug	900	125	**5-Aug**		
4-Aug	1745	158	**4-Aug**	830	197
3-Aug	900	153	**3-Aug**		
2-Aug	900	200	**2-Aug**		
31-Jul	900	113	**31-Jul**		
30-Jul	1730	196	**30-Jul**		
29-Jul	1000	117	**29-Jul**	700	173
27-Jul	1000	102	**27-Jul**	1045	264
26-Jul	1800	144	**26-Jul**		
25-Jul	945	196	**25-Jul**		
24-Jul	930	104	**24-Jul**		
23-Jul			**23-Jul**	830	178
22-Jul	900	111	**22-Jul**	1100	250
21-Jul	930	208	**21-Jul**		
20-Jul	900	92	**20-Jul**		
19-Jul	1730	147	**19-Jul**	930	191
17-Jul	900	192	**17-Jul**		
16-Jul	1800	159	**16-Jul**	900	261
15-Jul	930	231	**15-Jul**		
14-Jul	1800	163	**14-Jul**	900	240
13-Jul	1100	166	**13-Jul**	1100	241
12-Jul	830	161	**12-Jul**	900	231
10-Jul	900	113	**10-Jul**		
9-Jul	900	100.7	**9-Jul**	930	220
8-Jul	1000	123	**8-Jul**		

7-Jul	900	220	**7-Jul**	1100	271
6-Jul	900	102	**6-Jul**	1100	246
5-Jul	1030	160	**5-Jul**		
3-Jul	1800	106	**3-Jul**		
2-Jul	900	106	**2-Jul**		
1-Jul	900	98	**1-Jul**	1130	241
30-Jun	815	177	**30-Jun**	930	210
29-Jun	900	120	**29-Jun**	1030	271
28-Jun	1630	239	**28-Jun**		
26-Jun	900	238	**26-Jun**		
25-Jun	1900	125	**25-Jun**		
24-Jun	900	162	**24-Jun**		
23-Jun	1530	176	**23-Jun**	1030	205
22-Jun	900	142	**22-Jun**	930	201
21-Jun	1045	163	**21-Jun**	900	126
19-Jun	900	151	**19-Jun**		
18-Jun	930	174	**18-Jun**	1100	201
17-Jun	1000	193	**17-Jun**		
16-Jun	900	104	**16-Jun**	930	244
12-Jun	900	130	**12-Jun**		
11-Jun	1500	194	**11-Jun**		
10-Jun	930	175	**10-Jun**		
9-Jun	900	200	**9-Jun**	1030	191
8-Jun	930	103	**8-Jun**	1000	181
7-Jun	1430	217	**7-Jun**	1030	147
6-Jun	1000	204	**6-Jun**		
5-Jun	1000	204	**5-Jun**		
4-Jun	1000	217	**4-Jun**		
3-Jun	900	208	**3-Jun**		
2-Jun	1800	96	**2-Jun**	730	196
1-Jun	930	124.1	**1-Jun**		
31-May	1545	187	**31-May**		
30-May	930	174	**30-May**		
27-May	930	176	**27-May**	1100	186
26-May	1130	178	**26-May**	1100	196
25-May	1100	124	**25-May**		
24-May	1330	190	**24-May**	1030	190
22-May	900	195	**22-May**		
21-May	1800	140	**21-May**	945	196
20-May	930	185	**20-May**		
19-May	1730	107	**19-May**	1100	169
18-May	900	105	**18-May**	1100	161
17-May	1800	88	**17-May**	2300	124
16-May	900	154	**16-May**		
15-May			**15-May**	945	153

14-May	930	157	**14-May**	900	153
13-May	945	172	**13-May**		
12-May	1830	108	**12-May**	1030	161
11-May	930	101	**11-May**		
10-May			**10-May**	1000	188
9-May	1400	178	**9-May**		
8-May	930	168	**8-May**		
7-May	1730	158	**7-May**	2300	174
6-May	930	170	**6-May**		
5-May	1600	153	**5-May**	1130	195
4-May	900	88	**4-May**		
3-May	1100	135	**3-May**	1030	182
1-May	830	146	**1-May**		
30-Apr	1630	155	**30-Apr**	1030	149
29-Apr	930	160	**29-Apr**		
28-Apr	1800	147	**28-Apr**	1030	154
27-Apr	900	96	**27-Apr**		
26-Apr	1715	144	**26-Apr**	1000	106
25-Apr	1730	149	**25-Apr**		
24-Apr	900	150	**24-Apr**		
23-Apr	1800	110	**23-Apr**	900	163
22-Apr	830	134	**22-Apr**		
21-Apr	1800	128	**21-Apr**		
20-Apr	900	113	**20-Apr**	900	143
19-Apr			**19-Apr**	1100	145
18-Apr	1530	167	**18-Apr**		
17-Apr	930	173	**17-Apr**		
16-Apr	1900	114	**16-Apr**	900	156
15-Apr	830	143.9	**15-Apr**		
14-Apr	1700	143	**14-Apr**	1000	150
13-Apr	930	141.4	**13-Apr**	1100	142
12-Apr			**12-Apr**	900	91
11-Apr	1500	169.9	**11-Apr**		
10-Apr	930	161.7	**10-Apr**		
9-Apr	1200	172	**9-Apr**	1130	161
8-Apr	930	165.9	**8-Apr**	2300	171
7-Apr	1215	170	**7-Apr**		
6-Apr	900	117	**6-Apr**	1000	161
5-Apr	1600	168	**5-Apr**	1000	105
3-Apr	930	173	**3-Apr**		
2-Apr	1630	170	**2-Apr**	1100	171
1-Apr	930	169.7	**1-Apr**	1000	171
31-Mar	1700	142	**31-Mar**	1100	183
30-Mar	830	122.3	**30-Mar**	1100	196
29-Mar	1130	158.3	**29-Mar**	930	93

5	1630	152	**28-Mar**		
27-Mar	930	161.4	**27-Mar**		
26-Mar	1400	174	**26-Mar**	930	170
25-Mar	930	141.1	**25-Mar**	1130	178
24-Mar	1530	173	**24-Mar**	1230	171
23-Mar	930	161.2	**23-Mar**	1130	171
22-Mar	1200	168	**22-Mar**	1430	130
21-Mar			**21-Mar**	1800	92
20-Mar	900	177.1	**20-Mar**		
19-Mar	1515	173	**19-Mar**	1400	169
18-Mar	1045	195.5	**18-Mar**	1100	163
17-Mar	1215	202.1	**17-Mar**		
16-Mar	900	127.4	**16-Mar**	1200	172
15-Mar	1700	100.6	**15-Mar**	1230	100
14-Mar	1100	176	**14-Mar**	1100	155
13-Mar	900	180.6	**13-Mar**		
12-Mar	1145	180.5	**12-Mar**	930	178
11-Mar	930	151.3	**11-Mar**		
10-Mar	1430	174	**10-Mar**	1030	163
9-Mar	930	127.2	**9-Mar**		
8-Mar	1100	171	**8-Mar**	1100	105
7-Mar	1600	160	**7-Mar**	1700	134
6-Mar	900	177	**6-Mar**		
5-Mar	1000	197	**5-Mar**		
4-Mar	930	190.3	**4-Mar**		
3-Mar	1600	171	**3-Mar**		
2-Mar			**2-Mar**	1130	191
1-Mar			**1-Mar**	1100	115
28-Feb	1300	251.5	**28-Feb**		
27-Feb	900	248.8	**27-Feb**		
26-Feb			**26-Feb**	900	165
25-Feb	900	223.1	**25-Feb**	900	173
24-Feb			**24-Feb**	930	179
23-Feb	930	226.9	**23-Feb**		
22-Feb			**22-Feb**	900	119
21-Feb			**21-Feb**	1030	157
20-Feb			**20-Feb**	900	160
19-Feb			**19-Feb**	830	144
16-Feb			**16-Feb**	1030	191
15-Feb			**15-Feb**	830	143
14-Feb			**14-Feb**	1100	161
13-Feb			**13-Feb**	1330	170
12-Feb			**12-Feb**	830	165
10-Feb			**10-Feb**	1000	186
8-Feb			**8-Feb**	900	139

7-Feb			**7-Feb**	930	164
6-Feb			**6-Feb**	900	168
5-Feb			**5-Feb**	1100	189
4-Feb			**4-Feb**	1045	205
3-Feb			**3-Feb**	900	187
2-Feb	930	129.5	**2-Feb**	1500	180
1-Feb			**1-Feb**	2200	130
29-Jan			**29-Jan**	930	194
28-Jan			**28-Jan**	1700	171
27-Jan			**27-Jan**	2300	194
24-Jan			**24-Jan**	1415	183
23-Jan			**23-Jan**	930	181
21-Jan			**21-Jan**	1100	192
19-Jan			**19-Jan**	900	184
17-Jan			**17-Jan**	1445	167
15-Jan			**15-Jan**	1000	194
13-Jan			**13-Jan**	1100	198
12-Jan			**12-Jan**	1645	199
11-Jan			**11-Jan**	1000	160
10-Jan			**10-Jan**	1530	178
8-Jan			**8-Jan**	1030	201
7-Jan			**7-Jan**	930	207
6-Jan			**6-Jan**	1100	196
5-Jan			**5-Jan**	1630	183
4-Jan			**4-Jan**	1130	126
2-Jan			**2-Jan**	1100	180

Table 13 : Gas Usage 2005 - 2010

		2005	2006	2007	2008	2009	2010
January	Therms	16,576	15,759	16,474	25,514	16,861	28,199
	kWh	485,795	461,851	482,805	747,742	494,147	826,431
February	Therms	14,803	13,876	18,520	19,441	18,791	13,434
	kWh	433,833	406,665	542,768	569,760	550,710	393,712
March	Therms	15,810	14,895	19,728	14,491	19,684	13,718
	kWh	463,345	436,529	578,171	424,689	576,881	402,035
April	Therms	14,132	16,262	13,573	13,195	17,402	12,661
	kWh	414,168	476,592	397,785	386,707	510,002	371,057
May	Therms	14,623	15,484	13,091	14,553	17,243	13,176
	kWh	428,558	453,791	383,659	426,506	505,343	386,150
June	Therms	26,062	27,489	19,094	24,158	17,453	18,161
	kWh	763,802	805,623	559,590	708,001	511,497	532,246
July	Therms	29,012	23,030	24,531	31,189	25,995	24,110
	kWh	850,258	674,943	718,933	914,059	761,838	706,594
August	Therms	28,862	36,565	20,198	27,736	29,358	22,952
	kWh	845,862	1,071,615	591,945	812,862	860,398	672,657
September	Therms	26,416	3,158	16,565	16,478	18,873	17,388
	kWh	774,177	92,552	485,472	482,923	553,113	509,592
October	Therms	15,543	13,039	14,430	15,143	15,118	13,383
	kWh	455,520	382,135	422,902	443,798	443,065	392,217
November	Therms	15,194	12,783	13,667	14,223	17,733	12,895
	kWh	445,292	374,633	400,540	416,835	519,703	377,915
December	Therms	16,308	14,036	14,910	17,050	48,209	13,286
	kWh	477,940	411,355	436,969	499,686	1,412,867	389,374

Table 14 : Nominal Power Usage

Usual power draws	Duration	Hours	Power draw	days / year	Hours/ year	Power/year
No Lights	Overnight	7pm-6am	100 kW	214	2568	256.80MWh
Lights	During the day	7am-6pm	140 kW	92	1104	154.56MWh
Lights & Heat fans	During the day (winter)	All Day (Nov – March)	160 kW	151	3624	579.84MWh
Lights, Air Con fans, & Chiller	During the day (summer)	Day hours (June – Sept)	260 kW	122	1464	380.64MWh
					Total	1371.84MWh

APPENDIX 5: Final Presentation Slide Show

Connecting the Worcester EcoTarium to the Public Power Grid

Casey Rivera
Greg Anderson
Mike Jenkins
Yow-Chyuan Yeh

Professor N. Burnham
President S. Pitcher

Driving Question

- Is it reasonable for the EcoTarium to connect to the power grid based on:
  - Estimated current and projected power consumption ?
  - Construction costs above and below ground ?
  - Estimated change in revenue ?

Powering the EcoTarium

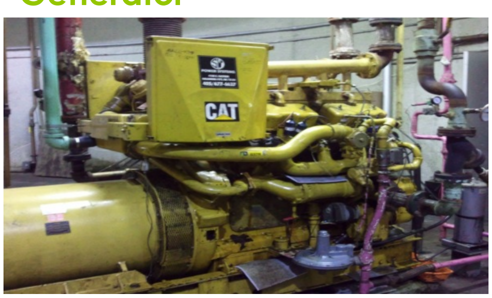
- Generating own power through cogeneration since 1971
- Began an expansion project in 1998

What is Cogeneration?

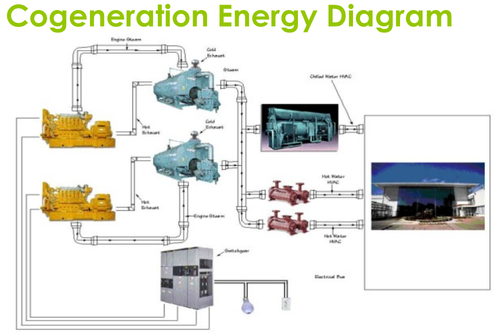
- An engine generates both electricity and heat
- Far more efficient over short distances than power from the grid

Internal Combustion Engine

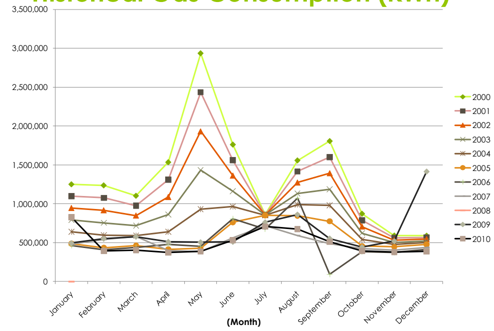
Generator



Cogeneration Energy Diagram



Historical Gas Consumption (kWh)



Current Energy Issues

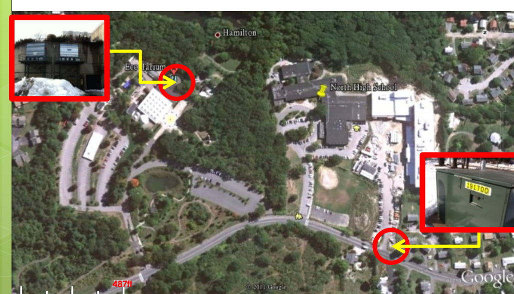
- Generators are not 100% reliable
- Renovations will require additional electricity
- Calculating current energy costs
- Determining all connection costs

Grid Connection

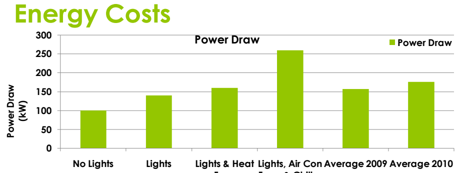
- Connecting to the grid below ground is preferred
- New transformer at North High makes this possible

Connection Points

1316.26 ft



Sample Calculations for Future Energy Costs



Sample Bill Calculation

Peak Demand	700kW		700kW	
Load Factor	30%		45%	
Monthly Energy	153,300 kWh		229,950 kWh	
	Peak	Off Peak	Peak	Off Peak
Total Energy Cost	$0.126774	$0.119244	$0.120373	$0.112843

Current Cost of Electricity

Calculated Values	2009	2010
Average Power Draw (kWh)	157.35	176.40
Natural Gas Consumption (kWh)	7,728,871	5,959,982
Cost of Natural Gas	$166,209.00	$134,816.00
Price per kWh	$0.003867	$0.005869
Cost of Repairs	$120,575	$231,151
Adjusted Price per kWh	$0.006672	$0.015931

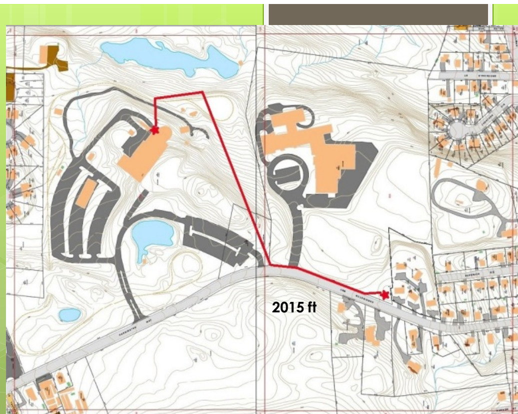
Benefits for EcoTarium

- A back up for generator failures
- An option to sell electricity back to power company
- The EcoTarium will be eligible for rebates once connected

Benefits and Drawbacks of An Underground Power Connection

- Underground's benefits include:
  - Aesthetics
  - Reliability
  - Elimination of risks
- Underground's drawbacks include:
  - Higher cost
  - Shorter lifetime
  - Maintenance far more difficult

Source: http://www.eei.org/ourissues/electricitydistribution/Documents/UnderVSOver.pdf



Proposed Construction Costs

Shepherd Engineering

Proposed Construction Costs	Cost ($)
Total Material	76,922.66
Labor	91,351.98
Direct Job Expenses	28,750.00
Job Subtotal (Prime Cost)	197,024.63
Overhead (10%)	19,702.46
Profit (12.3%)	26,697.07
Job Total	243,424.17

IQP Estimate

Proposed Construction Costs	Cost ($)
Necessary Construction	17,500.00
Under Terrain - Bore	1,080.00
Under Asphalt	20,000.00
Asphalt Repair	10,500.00
Normal Ground	45,150.00
National Grid Back Charge	100,000.00
Job Subtotal	194,230.00

Answers

- Is it reasonable for the EcoTarium to connect to the power grid based on:
  - Estimated current and projected power consumption ? ✓
  - Construction costs above and below ground ? ✓
  - Estimated change in revenue ? ✓

Recommendations

- Connect to the grid underground
- Install monitoring system for switchgear
- Optimize generators to lower load factor
- Regular maintenance for the cogeneration system


Summary
Collected data
Combined & analyzed
Suggested best solution