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# ASSESSING ENERGY FLOWS AT THE ECOTARIUM

An Interactive Qualifying Project Report

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by

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# Abstract

Over the period of August 2002 through February 2003, a project was done concerning the replacement of a power source for the EcoTarium in Worcester, Massachusetts. The current system, a cogeneration unit, had come to the end of its useful life after thirty years of operation. Research included interviews, Internet sources, and documents relative to energy sources that would be efficient, economical, environmentally sound, and educational. Findings were presented in the form of a written paper, PowerPoint presentation, and CD.

## Acknowledgments

Many people have contributed to this final report; our group wants to thank Professors Robert Krueger and Scott Jiusto for their guidance and help during the execution of this project. We also would like to express thanks to Tom DiConza, Director of Finance and Operations of the EcoTarium, and David White, Manager Buildings & Grounds of the EcoTarium. Overall, a special thanks to all the organizations and people who made possible the culmination of this project.

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# 1 INTRODUCTION

The EcoTarium's power source is two cogeneration engines that have reached the end of their serviceable life. The need presents itself to replace the current system or change to a new one. Therefore, our group researched different energy sources, which must have environmental, educational, and economical characteristics that coincide with the EcoTarium's visions and mission as an environmental center. An interesting option for the EcoTarium could be the implementation of hybrid systems, which constitute a combination of solar and wind energy.

Our investigation will explore the different renewable energy sources that could be applied to this particular situation. The analysis will include cost, equipment, suppliers, size, and energy provided by each source. We will emphasize the utilization of a hybrid system with cogeneration. These ones will provide interesting educational opportunities at the EcoTarium. Both of them will be analyzed in this investigation.

The project guidelines that were created based the new power system project on what has been called the "four Es," economical, environmental, efficiency, and educational aspects of the power system. The new power system needs to reflect the appropriate budget that the EcoTarium has established. The new system cannot include generators based on cutting edge technology without financial assistance. The cost to install an entirely new power generation system is quite large. A financial decision of this size requires a lot of research. The students researched all of the cost considerations in the different technologies that can be used to generate the power. This information would be used in the future as a first step to narrow down the possibilities of which technology will be used. The financial aspect of the power generation is flexible. The costs of the new system can be adjusted to accommodate large benefits in other areas such as cleaner emissions, but only within reason. The student research would present this financial compromise in the research along with the other considerations.

The second "E" is for energy reliability and efficiency. A main consideration of the EcoTarium's new power supply is a reliable amount of power. A portion of the EcoTarium's power is for habit regulation of some animals. Without the supply of power these animals are at risk. The EcoTarium places great importance on the well being of the animals making the reliability of the system a priority. The efficiency of the power generator is another aspect that must be considered. The efficiency of the power generation ties directly into the economical and environment aspects of the project. The power generation needs to be efficient financially to produce a reasonable amount of power for the fuel purchased. The generator also must be efficient so that fewer emissions are produced. The student research was to see which technologies could provide the most reliable power while working with a good efficiency. The reliability information will be of great use to the EcoTarium staff that makes the decision on the technology that will be used.

The third "E" is the environmental aspect of the new power generation system. When the power demand is met, it is important to have the power generation process be as environmentally friendly as possible. The EcoTarium has a goal as being a role model in using greener energy. This greener energy is energy that is derived from renewable resources. A goal is to maximize the amount of green energy used in the power system. A new power system that is efficient and environmentally friendly will benefit the entire region. The student involvement was to look in to the renewable resources that could be used at the EcoTarium. This research includes emissions comparisons and fuel types as well as clean non-combustion generation. The research also included the possibility of creating a hybrid system combining different types of power generation.

The final E is the educational possibilities that can come from such a project. The first educational aspect is the student involvement in the project. The students researched how the new system itself can be integrated into an educational experience. The EcoTarium can make an exhibit to show the steps taken to make their own power system more efficient. The new power system will serve as a display to the public about how greener energy can be incorporated. The EcoTarium can create exhibits that allow them to teach about the connection between energy and the environment. This exhibit system will explain things like how renewable resource power generation takes place and even how energy efficiency can be achieved at home. It is important the EcoTarium educates the future generations about the consequences of our actions on the environment. This sort of educational system is the goal of the EcoTarium, and the main reason for its involvement of everyone in this project.

The research completed has served to make decisions to give the EcoTarium a new system for power generation. The new system's first priority is to provide reliable power, so the animals under the care of the EcoTarium are not placed at risk. The system is to also reasonably reflect the budget the EcoTarium has established for this project. Another important consideration is that the efficiency of the system is high enough so the fuel source is being used in an environmentally friendly way. All these considerations result in a well rounded primary power source that not only meets the needs of the EcoTarium, but also can serve as a model system. Making this system a model system will include incorporating renewable power sources to make it a hybrid system. This system can be made into an educational exhibit that will serve to educate people about practical solutions to energy efficiency and their large scale environmental benefits.

# 2 METHODOLOGY AND DATA ANALYSIS

## *2.1 Technologies considered*

After eliminating the unfeasible technologies, extensive research of the feasible energy possibilities began. The following is the methodology and brief overview of how research was conducted concerning energy technologies considered.

### 2.1.1 Wind and Solar

Research concerning wind and solar energy resulted in a variety of Internet sources through which one could learn about possibilities for implementation of use in the EcoTarium. The development of these technologies has been done throughout the last twenty years. First, the research began with the research of the basics that we have to learn about these two technologies and the history behind those ones. There were numerous examples of applications related to wind and solar energy issues; moreover, some of them showed the benefits, but also the constraints and problems that a person might find when installing these systems.

The Internet sources that we used in this case were all related to the investigation and experimentation of new technologies to produce energy. They also contained the development of these experiments by different countries around the world and their experiences. Other important sources of data were the stores that sell this equipment, which as we could observe, constitute an excellent business in many states in the United States. Massachusetts, which has the reputation of being the most advanced state in technological issues, has many different locations that advertise these types of installations. These stores provide information about the equipment, pricing, quality, and numerous tutorials related to solar and wind energy issues[1]. Moreover, they also supply special calculators through their websites that provide information related to weather issues and conditions related to the person's geographical location[2].

Therefore, most of them show the benefits of using Solar and Wind to obtain energy, but also they show the difficulties or problems that these two energy sources might cause, for example, landscape damage or noise.

Research of this topic was done through the Internet, and interviews with Solar Now Inc., which is located in Beverly, Massachusetts. The Internet provided with an excellent source of material, books were also used but they weren't updated. Consequently, the Internet was the main source of information. The main WebPages that were used in the project were related to potential suppliers and educational sources. For example, Alternative Energy Store, which not only supplies the necessary equipment to be installed, but also provides with a variety of educational sources related to wind and solar energy use. Other important source was RWE Schott Solar[3] which was known before as ASE Americas. They also provided us with valuable information related to this topic.

Documents related to Wind and Solar energies were provided by Solar Now Inc., texts were also used, but they were employed just as a reference since most of them were written five to ten years ago. Solar Now Inc. is located in Beverly, Massachusetts; they actually have a photovoltaic array which has been working during the last twenty-five

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[1] [36]
[2] Appendix A.1
Appendix A.2
[3] [37]

years, and a wind turbine. They had helped us with their expertise in Solar Cells; however, they also supplied us with important papers related to the different associations and organizations that collect information related to Solar Power.

The implementation of Wind and Solar equipments is not difficult; moreover, one might do it in a short period of time without any delays. The companies help with the installation, and usage of the equipment. Hybrid systems have been implemented in many countries around the world with excellent results[4].

### 2.1.2 Power Grid

The Internet provided links to documentation by the Department of Transportation and Energy. The documentation listed all costs information for large commercial institutions that was needed along with any other useful information that was obtained about the power grid. The link to the paper can be found in Appendix A.5 and A.11. Further information about installation of the grid and actual rates would have to be discussed between the EcoTarium and the power company.

One of the technologies that can be implemented into the EcoTarium's power system is the power grid. The power grid like all the other technologies has its strong and weak points. The power grid's first benefit is the offsite generation of power. The power company will transport the power to the EcoTarium, so that the generators will not have to be replaced. This eliminates all operation and maintenance costs currently associated with the current power generation. The lack of onsite power generation eliminates the worries of part replacement and generator repair. The area that the generators are in now could be used for another purpose.

The installation of the power grid is an issue. The cost[5] of installation has been estimated at $500,000. This figure is a ballpark estimate. The reason for this is that specific talks between the EcoTarium and Mass Electric have no taken place yet. Mass Electric would have to tap into a current power line, and run it to the EcoTarium. Previous talks with Mass Electric have made it know that there are no power lines close to the EcoTarium that could deliver the needed load. The current belief is that a separate line would have to be run to a close line, which would be upgraded to handle the demand. All details about the actual installation project and all related costs would have to be done in talks between the EcoTarium and Mass Electric.

The cost per kWh of the power grid is higher than other technologies by a few cents. This is offset by the lack of any operational and maintenance costs. The averaged cost per kWh is around 11 cents. The annual cost of the power grid with total kWh charges and capital reinvestment is $151,400. This cost is similar or cheaper than other primary power source technologies.

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[4] [7] [40][42]
[5] Appendix A.13

One of the concerns with the power grid is that the source from the bulk of the power is fossil fuels. One of the purposes of the project is to convert the power system into the cleanest possible generation of power. If the EcoTarium decided to use the power grid, they could contract to buy their power from a certain plant. This would allow them to purchase power from the plant that incorporates the largest amount of "green" power. Environment – made form coal, buying higher percentage green generated power still incorporate solar and wind

Another concern about using the power grid as the main source of power is the possibility of black outs. While the power grid is capable of transmitting any amount of power needed at anytime, it is possible for the power lines to go down. The power company cannot guarantee that power will always be available. This is a problem because of the power needed for the animal habitats. The EcoTarium would need a backup generator so the animals would not be in danger.

### 2.1.3 Cogeneration

Cogeneration is a widely used source of energy with many benefits. When searching the library for books written about cogeneration, much information was found concerning the basic way cogeneration works.[6] But when trying to understand how cogeneration is a good choice of the EcoTarium specifically, the Internet had to be used. With the help of search engines, it was easy to find other case studies that were similar to the needs of the EcoTarium. Also doing database studies allowed us to find information that was more difficult uncover. The database studies allowed us to find information about emissions and other efficiency levels that were unable to be uncovered using books and the Internet.

Using case studies turned out to be very beneficial when studying cogeneration. Because cogeneration is so widely used, there were many examples that we could study to help us better understand how cogeneration worked, and the benefits of using this type of energy. Also because cogeneration was the existing system at the EcoTarium, we were able to look at how it worked for them in the past, and weigh its pros and cons. Many studies were found on the Internet, but the majority of quality studies were found on databases that were posted in the library. These databases not only gave different examples of cogeneration systems, but also analyzed that pros and cons of such systems.

Contacting distributors of cogeneration engines turned out to be the most useful of all the research done. It tied up all the loose ends of the research. Companies like Caterpillar and Capstone were contacted and were able to assist us in better understanding how a new system could be implemented and the price range of these new systems. They were also able to elaborate on the positives that a new cogeneration system could bring to the table. When meeting with Caterpillar, engineers were also in attendance to allow us to better understand the process of implementing a new system and understanding the steps that need to be taken before implementation can begin.

[6] Appendix A.17

Cogeneration is the combining of heat and power to produce a more efficient energy flow within a system. Excess heat wasted from a conventional generator is collected and used to produce thermal energy. This thermal energy can then be used to provide heat or cool facilities in which this technology is used. Some cogeneration technologies include combustion turbines, boilers with steam turbines, microturbines,[7] and fuel cells. Since the "waste heat" is used, this greatly increases the usual efficiency of a conventional power source; the system would operate at a 50% - 70% rate. In comparison, standard fossil fuel generator at only about 33% efficient.

The cost of a new cogeneration system can vary dramatically. It depends on the size of the facility that you are working with, and the amount of energy it needs to run. In the case of the EcoTarium, it is currently running the site with two 300 kilowatts engines, with a back-up 150 kilowatts engine in case of emergency. Also when using cogeneration it is cost efficient because it does not waste as much by-product as other energy sources. This is because it uses the "waste heat" to help with the HVAC system and the heating system.

From an environmental perspective, cogeneration helps the environment because emissions from power sources are recycled, reducing the amount of pollution in the atmosphere. Also, energy from cogeneration decreases the need for energy to be produced from fossil fuels, helping to preserve the world's supply.

Some advantages of using a cogeneration system are that this is what is already being used at the site and it will take minimal retraining to learn had to use the system. Also it is very safe if you have a power outage or an engine failure you can keep the site running if you run the system with a back-up generator. Another advantage is that it is more environmentally safe then most energy systems, because it uses most of the energy it makes instead of letting it escape into the air. The final and most important reason it is a good choice is that it has a good reputation. The EcoTarium has used this technology for years, and has worked very well for them.

Some disadvantages are that it is hard to show cogeneration as an educational tool to younger kids, because of its complexity. It would also be more expensive in the short run then just hooking up to the power grid.

Overall, we feel that cogeneration may be one of the best ways that the EcoTarium can handle its energy problem. It is a time-tested method that has worked in the past and is environmentally safe and cost efficient.

### 2.1.4 Fuel Cell

Fuel cells are a relatively new technology for industrial power production. Because of this, they automatically gained some consideration to become a primary power source for the EcoTarium. Since they are a relatively new technology, it was necessary to conduct a significant amount of research to fully understand how they work,

[7] Appendix A.18

and how the EcoTarium could benefit from the use of one. Several books on alternative energy sources provided basic information on fuel cells, primarily on how fuel cells were a breakout, up-and-coming technology. However, since the books were published almost a decade ago, they did not provide adequate information concerning industrial, large-scale use of fuel cells. Thus, to obtain more useful information, extensive searches through the Internet via search engines were conducted. Several web sites were found that provided information concerning the history of fuel cells, different types of fuel cells, physical sizes, power output ranges, operating conditions, distributors, and costs, and emissions.

After comparing the data found from the Internet research, there were still some concerns with the findings, particularly when considering costs. Research then shifted to finding case studies of actual industrial fuel cell use. About eight case studies were found and provided very useful information on costs and funding received.

Research then shifted to seeking possibilities for implementing a fuel cell in the EcoTarium. Decisions were made as to the type of fuel cell that would be most logical for EcoTarium use and providing a fuel source for the fuel cell to operate. Fuel cells are differentiated by the type of electrolyte used. Electrolyte types include phosphoric acid, molten carbonate, proton exchange membrane and solid oxide[8]. After determining how the fuel cell would be powered, considerations of emissions levels came into play, and again, more operational costs had to be considered. Conversations with area fuel cell distributors were initiated to help gain better understanding of industrial implementation. Costs were added to the previous findings, and all information considering fuel cells (costs, power output, and emissions) were added to the energy source matrix, and initial PowerPoint presentation to the EcoTarium.

Since fuel cells are a new technology, and have only been used for industrial use in a few instances, it is important to understand how they work. Fuel cells work similarly to batteries, producing energy through chemical reactions. Powered by hydrogen gas, the hydrogen enters the fuel cell and passes through a negatively charged electrode, called the anode. The anode strips the hydrogen of its electron, which passes through wires, providing the electrical current. The hydrogen ion is then passed through the cell by a chemical compound called the electrolyte. The electrolyte ensures that no foreign substances enter the fuel cell and interfere with the reactions. The type of electrolyte differentiates each type of fuel cell. Proton exchange membrane and phosphoric acid are the most logical choices for electrolytes in the EcoTarium due to their energy output capabilities and operating conditions. At the other end of the fuel cell, oxygen enters, and combines with the hydrogen ion at another electrode, called the cathode. The two combine and form the sole emission, completely safe water. In the case of the EcoTarium though, there is not an available hydrogen line to the building, nor would there be the desire for one since hydrogen is extremely explosive. To produce the hydrogen, an additional device, a reformer, would have to be implemented. A reformer connects to a natural gas line and strips the hydrogen from the gas compounds for use in the fuel cell[9].

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[8] Refer to Appendix A.15
[9] Refer to Appendix A.14

Since such fuel cells would obviously be the most expensive technology to implement in the EcoTarium, the properties of fuel cells must be analyzed. One benefit of fuel cells is that they are extremely reliable and are highly unlikely to fail before a scheduled maintenance. The use of a fuel cell will give the EcoTarium a sense of security in that they will have constant power throughout the lifetime of the fuel cell. Another capability of fuel cells is maintaining a cogeneration system. When running, fuel cells give off enough waste heat that can be harnessed for cogeneration uses, increasing the overall efficiency of the unit. Lastly, since all energy is produced via chemical reactions and there are no moving parts, noise levels within the operating area is greatly reduced, making communication around the area very easy.

## *2.2 Implementing new technologies*

After speaking to the EcoTarium staff, and examining the facilities, the following conclusions were made concerning criteria for the technologies.

### 2.2.1 Physical size

The technology chosen will fit in the area where the current cogeneration system exists, or in a similarly sized area outside of the building. This is necessary due to the fact that the building itself cannot be remodeled to accommodate a large unit, nor can a significant amount of land be destroyed as well.

### 2.2.2 Company cooperation

The company providing the technology will be able to provide and install the technology in a timely matter. Since the current engine is nearing the end of its useful life, the supplier must be able to have the new system installed and operating as possible. It is also important that there be a smooth transition between systems (limited down time).

### 2.2.3 Costs

While considering different technologies, different models and distributors (if applicable) were researched, so that the best quality for the best price can be found. Research towards finding all possible models/distributors was essential

### 2.2.4 Environment

Emissions types and levels (if applicable) were crucial in making a suggestion to the EcoTarium. It was important to understand how emissions were created, how they are harmful, and in what quantities. After finding this information of emissions, research then shifted to the emissions types and level produced by each technology. Efforts were also shifted to any possibilities of reducing these levels.

## *2.3 Costs of Technologies*[10]

When looking at the price of a reciprocating cogeneration engines the size of the engine changes the price dramatically. For instance the standard 200 kW engine will have a capital cost of approximately $150,000 with additional fees coming from operation and maintenance cost and the cost of fuel to run the engine. These additional fees on average cost $44,000 for operation and maintenance for one year and $138,000 for fuel cost per year as well.

Industrial sized fuel cells are only available through one manufacturer, United Technologies Corporation (UTC) Fuel Cells. After speaking with Mr. John Trocciola[11], the Northeast Sales Manager for UTC Fuel Cells, he was able to provide an idea of what a fuel cell for the EcoTarium would cost. Generally, a fuel cell will cost $4,500 per kilowatt of energy, or about $900,000 for a 200 kilowatt unit for the EcoTarium. The annual cost for regular maintenance is approximately $30,000 per year, with fuel cell stack replacement occurring after the fifth year for $315,000. A reformer would cost in the order of $40,000 with replacement occurring after year 7 for $60,000. It is clear to see that fuel cells are an extremely costly product. However, case studies have shown that the Massachusetts Renewable Energy Trust, with the Department of Energy, has provided grants for projects concerning fuel cells. Up to 25% of the cost of the project can be relieved through these grants[12].

The prices of equipment for Solar and Wind Energy are related to the power that is provided by the equipment, and the location in which it will be located. Wind turbines price range might be from 400 to 20,000 dollars (or more expensive units); moreover, one has to add the cost of installation and other equipment needs. A Wind turbine that provides 1 KW will have a capital cost of $ 2,000, and operation and maintenance costs per year of $ 46 (if we consider 25 years as the turbine's lifetime). Solar Panels prices also depend on how much energy one wants to obtain from them; consequently, the price range might be from 200 to 10,000 dollars per panel or group of panels. However, one needs to include other installation costs that might be needed according to each particular situation. For example, solar panels that provide 3 KW will have a capital cost of $ 67,000, and operation and maintenance costs of $ 5,000 per year. All these costs will be effective if we consider 30 years as the panels' lifetime).

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[10] Refer to Appendix A.13
[11] [25]
[12] Refer to Appendix A.22

The price to hook up to the grid is to be determined by the power company. The installation price has been estimated at $500,000. This figure is related to the expected costs of installation that include running wires from the grid to the site. The power company's expenses are unknown, but the $500,000 is a high end estimate. The averaged cost per kWh is around 11 cents. The annual cost of the power grid with total kWh charges and capital reinvestment is $151,400. Using the power grid produces no onsite maintenance costs. This yearly cost is similar or cheaper than other primary power source technologies.

## *2.4 Current System*

### 2.4.1 Current EcoTarium energy system

The facilities manager David White took our group on a guided tour of the EcoTarium's facilities. He showed our group the current power system and explained to us how the system operated and what the current needs of the system were. After this we received a large packet containing floor plans, system specifications, and past system reports. Using this packet and the information given to us by the facilities manger, we were able to compile a current system description.[13]

The EcoTarium current energy system and HVAC system runs 24 hours a day and 7 days a week. A cogeneration plant is providing all the energy, cooling and heating needs for institute. This cogeneration plant is located right on the grounds. The cogeneration plant is made up of two 300 kW Caterpillar reciprocating engines, and has been taken care of very well over its 33 year life, but this continued use is starting to show signs of its age. These cogeneration units also generate heat in the form of hot exhaust gas and water-jacket heat. The heat that is provided is then passed through a waste heat boiler and generates steam. These waste heat boilers are produced by Cleaver Brooks and each engine has its own waste heat boiler. Any excess heat that is no used is then sent to a cooling tower outside the building and is released; each engine has its own cooling tower.

The buildings HVAC system is made up of 7 air handling units, and each unit is used in its specific area of the building. In the summer the cooling is provided by a 250 ton York, single stage absorption chiller, which is found in the cogeneration plant. [14]

The switchgear that is being used is 5 sets of four 500 MCM RHW conductors. This switchgear transfers power to the 2000 Amp bus. These are also very old and starting to show signs of age as well.[15]

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[13] Appendix A.21
[14] Appendix A.19
[15] Appendix A.20

## 2.4.2 System dynamics model[16]

To further understand the current system in the EcoTarium, a system dynamics model was created to simulate the power distribution in the building. The system dynamics model provides a visual interactive power system. The first thing that you can see from the model is the main flows of the system (see Appendix A.16). The gas flow split is 75% to the power grid and 25% to the boilers. An important thing that has been learned from the modeling is where the power the generator makes is going to. The major consumer of power is the exhibit building and the HVAC system. Each of these is responsible for about 40% of the daily increase in the load. The other power is for the mechanics shed.

| Time | load |
|---|---|
| 0 | 237.00 |
| 1 | 237.00 |
| 2 | 257.00 |
| 3 | 237.00 |
| 4 | 257.00 |
| 5 | 237.00 |
| 6 | 257.00 |
| 7 | 237.00 |
| 8 | 307.00 |
| 9 | 287.00 |
| 10 | 307.00 |
| 11 | 312.00 |
| 12 | 332.00 |
| 13 | 312.00 |
| 14 | 332.00 |
| 15 | 287.00 |
| 16 | 307.00 |
| 17 | 287.00 |
| 18 | 257.00 |
| 19 | 237.00 |
| 20 | 257.00 |
| 21 | 237.00 |
| 22 | 257.00 |
| 23 | 237.00 |
| 24 | 257.00 |

There is a seasonal difference in the power load. The exhibit building requires a certain amount of power as a standard demand of operation. This amount of power is constant throughout the year. The amount of power that is required to heat and cool the exhibit building varies. The cooling of the building requires much more power than to heat it. This is from the power used in the dx compressor, the new ac unit, and the chiller. This is the reason the summer peak is 40 kilowatts higher than the winter demand peak. The typical summer maximum demand is from 320 kWh to 340kWh. The table below shows the hourly demand during a summer day simulated by the model. Another season difference has been the amount of power required for the animal habitat maintenance. Some of the exterior habitats such as the polar bear pool need to be maintained only in the summer. Differences such as these result in the lower gas use and a smaller daily power demand in the winter.

The value of having a model such as this is that it makes it easy to see where changes in a system can be made. Some things that demand power are unchangeable such as the animal habitats. Other power users especially the ones that consume significant amount of power are opportunities for efficiency. The first of which is the exhibit building. The exhibit building always needs power so any changes such as more efficient light bulbs will lower the constant demand. The HVAC system is the other efficiency opportunity. The current system does not have variable speed blowers. A change such as this would reduce the power demand and save gas. The night time usage of power is another major area of possible efficiency change. The EcoTarium currently runs a rather constant nighttime demand of 180 kWh. This is from all the lighting on the grounds and the animal habitats. Steps could be taken to reduce this number by using less or different lights.

[16] Appendix A.10

The final detail learned from the model is about the gas going into the boiler. The amount of gas going into the boiler is known. Where the gas is being used after that isn't know to exact numbers in the model. This is of importance to know because any improvements in efficiency would help lower the total amount of gas used. The picture of the model and the information for it is listed in the appendix.

## 2.5 Emissions

A major factor that had to be understood when analyzing what energy option should be implemented at the EcoTarium was the emissions levels that were being produced by that energy option. Because the EcoTarium is a science center and is concerned about the environment, it made it even more important to have a system that is environmentally sound and will have little to no repercussions on the environment.

When looking at such energy options as wind, solar and hooking up to the power grid, the amount of emissions that are being produced are little or none. In the case of wind and solar, these energy options are considered to be renewable energies and do not produce any emissions, the problem with these options, is the amount of energy they produce will not be sufficient by themselves to supply energy to the whole EcoTarium, and will need some sort of hybrid system to assist in the energy output. In the case of hooking up to the power grid, there will be no emissions coming from this option at the site, but there will be emissions being produced at the source of the power. But this option will have enough energy output to supply the whole institute.

When looking at cogeneration and fuel cells, these two options do have slit emissions. This is caused by the fact that they are using a fossil fuel, most likely natural gas to provide energy for the EcoTarium. The by products of the natural gas is where the emissions are being produced. The major emissions that are being produced are Nitrogen Oxides (NO x), Sulfur Oxide (SO x), Carbon Monoxide (CO), Carbon Dioxide (CO2), particulate matter (PM), and Volatile Organic Compounds (VOC). To better understand some of these emissions you have to understand the compounds first. Carbon is an element that serves as a foundation for most organic molecules. When organic fossil fuels are burned, such as coal and oil, carbon is released and can combine with atmospheric oxygen and form carbon dioxide. Carbon Dioxide or CO2 is a gas that makes up .033% of the earth's atmosphere but has been slowly rising over the past century. The increased concentrations of carbon dioxide in the atmosphere create acid rain that can dissolve limestone, and also contributes to the green house effect. Carbon dioxide is produced from the burning of fossil fuel. Sulfur Dioxide or SO2 is a product of fossil fuel combustion. It is a colorless gas that is a major contributor to the creation of acid rain. And Nitrogen Dioxide or NO2 is a reddish brown gas that is toxic at high concentrations and is heavier than air. While in the atmosphere it contributes to the production ground level ozone and is a major component of smog. Nitrogen Dioxide is formed as a product of in air combustion such as in power generation.[17]

[17] Appendix A.20

Although fuel cells and cogeneration are the only two energy sources that produce emissions in the study that we took, both are fairly low, with fuel cells having very low emissions and when cogeneration is equipped with a heat recovery unit, it allows for better efficiency and even lower emissions.

**Criteria Pollutants**

| Pollutant | lb/hr | lb/yr | tpy | Emission Factor (lb/hp-hr) | Factor Quality Rating |
|---|---|---|---|---|---|
| PM | 2.1E-01 | 1.8E+03 | 9.2E-01 | | |
| PM-10 | 2.1E-01 | 1.8E+03 | 9.2E-01 | 7.00E-04 | B |
| PM-2.5 | 2.1E-01 | 1.8E+03 | 9.2E-01 | 7.00E-04 | B |
| $NO_x$, uncont. | 7.2E+00 | 6.3E+04 | 3.2E+01 | 7.00E-04 | B |
| $NO_x$, cont. | 3.9Edoin tons of +00 | 3.4E+04 | 1.7E+01 | 2.40E-02 | B |
| TOC (as $CH_4$) | 2.1E-01 | 1.9E+03 | 9.3E-01 | 1.30E-02 | B |
| NMTOC | 1.9E-01 | 1.7E+03 | 8.4E-01 | 7.05E-04 | C |
| CO | 1.7E+00 | 1.4E+04 | 7.2E+00 | 6.42E-04 | E |
| $SO_x$ | 1.2E+00 | 1.1E+04 | 5.3E+00 | 5.50E-03 | C |
| Total HAP | 6.9E-05 | 6.1E-01 | 3.0E-04 | 4.05E-03 | B |
| Largest HAP | 1.6E-03 | 1.4E+01 | 7.1E-03 | 2.32E-07 | |
| | | | | 5.43E-06 | |

**Toxic/Hazardous Air Pollutants**

| Pollutant | lb/hr | lb/day | lb/yr | | |
|---|---|---|---|---|---|
| Acetaldehyde | 5.3E-05 | NA | 4.6E-01 | | |
| Acrolein | 1.7E-05 | NA | 1.4E-01 | 1.76E-07 | E |
| Benzene | 1.6E-03 | NA | 1.4E+01 | 5.52E-08 | E |
| Benzo (a) pyrene | 5.4E-07 | NA | 4.7E-03 | 5.43E-06 | E |
| Formaldehyde | 1.7E-04 | NA | 1.5E+00 | 1.80E-09 | E, < |
| Napthalene | 2.7E-04 | NA | 2.4E+00 | 5.52E-07 | E |
| PAH | 4.5E-04 | NA | 3.9E+00 | 9.10E-07 | E |
| Toluene | 5.9E-04 | 1.4E-02 | 5.2E+00 | 1.48E-06 | E, < |
| Xylenes | 4.1E-04 | 9.7E-03 | 3.6E+00 | 1.97E-06 | E |

## *2.6 Proposals*[18]

The EcoTarium seeks proposals from qualified suppliers of different power generating systems to install, and interconnect a new system as part of the development of a new hybrid power generating plant, which will be capable of meeting EcoTarium energy needs and educational mission.

[18] Appendix A.12

These proposals will contain essentially all the important points that must be accomplished by each company that wants to participate in this project. An example of a proposal for Wind turbines can be read in Appendix A.12. An RFP, Request for Proposal, has all the technical specifications and business requirements that the client needs to achieve. For example, educational and environmental qualifications are essential for this project because it is related to the EcoTarium, which is an ecological and a learning center.

# 3 PRELIMINARY RECOMMENDATIONS

- Replace the current cogeneration engine with a new cogeneration engine.

- Caterpillar is extremely enthusiastic replacing the current unit, and is seemingly ready to install the new system at the desire of the EcoTarium.

- The maintenance staff of the EcoTarium already has experience using cogeneration engines. Two, 350 kilowatt Caterpillar engines will be installed. Thus, one engine can supply enough power to meet the electricity demand on higher demand days (approximately 330 kilowatts) for the EcoTarium. The second engine can serve as a backup to the first engine, or the two engines may be run simultaneously to reduce the workload on a single engine. The capital costs for these two units would be approximately $913,000. Installation costs are not added to this total.

- A hybrid energy system might be used, for example, cogeneration and fuel cell, cogeneration and wind turbines, cogeneration and solar cells, wind turbines and solar cells, etc.

- Fuel cell can be used simultaneously with a cogeneration engine. Since fuel cells do offer cogeneration options if waste heat is captured, then it is quite logical to do so. The fuel cell can run independently on low demand days. A low power fuel cell (1 – 5 kilowatts) can be purchased simply for display purposes. The unit can be connected to the overall power supply, or be used independently for use.

- A fuel cell exhibit would be the ideal use for a small-scale fuel cell. It would also be important to provide a full description of how fuel cells operate via chemical reactions, since there is little knowledge among the public of fuel cells. Since there is close relation between fuel cells and batteries, a possible idea would be to power a device with a fuel cell, and calculate approximately how many batteries would be necessary to have provided that amount of power for that duration (ex. a fuel cell powering a device for "x" hours would necessitate 'y' batteries), showing that fuel cells are definitely the technology of the future.

- Wind turbines and solar cells would have to be used purely as supplemental energy to the cogeneration system.

- Exhibits showing how wind turbines and solar cells generate electricity would be very easy to display.

- Solar cells can be displayed in a similar fashion. By connecting a solar cell to a low wattage device (light bulb, toy car, etc.), a light can be shined on the cell, powering the device. These are simple ways to show and educate EcoTarium visitors of the uses of wind turbines and solar cells.

- EcoTarium could offer tours of the current system; it was observed that the area of the current system had been designed in such a way that tours could enter the area and examine the system. While a new system is being installed, the area of the system can be designed in such a manner that it can once again become an up close exhibit.

While conducting this project, the group learned from a hands-on approach of how major decisions considering technology must be approached. Factors including finance, risk, and feasibility were addressed at all times. The knowledge gained from conducting such work will undoubtedly be beneficial in future uses. However, the greatest satisfaction from the project is seeing the product of the labor being implemented in a real-life situation for the benefit of an organization such as the EcoTarium.

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# 5 APPENDICES

## *Appendix A: Businesses that offer Wind, Solar and Biomass Energy in Massachusetts*


Alternative Energy Store

***Making Renewable Energy Affordable. The leading online renewable energy retailer for solar and wind systems and components. Friendly sales and support personnel will help you find the right system for your needs - whether it's for your home, off-grid, grid-intertie, selling energy back to the grid, industrial application, RV, boat/marine use or just a scientific project.***

**Business type:** retail sales, wholesale supplier, exporter
**Product types:** lead acid batteries, photovoltaic modules, solar water pumping system components, solar water pumping systems, wind energy system components (small), wind turbines (small), wind turbine towers, photovoltaic module mounts, inverters, charge controllers.
**Address:** 26 Evergreen St., Chelmsford, Massachusetts USA 01824
**Telephone:** (877) 878-4060
**FAX:** (877) 242-6718, +1(207)469-7026
**Web Site:** http://www.AltEnergyStore.com
**E-mail:** Send Email to Alternative Energy Store

Second Wind
**Business type:** manufacturer
**Product types:** wind energy measurement and data logging equipment.
**Address:** 366 Summer Street, Somerville, Massachusetts USA 02144
**Telephone:** (617) 776-8520
**FAX:** (671) 776-0391
**Web Site:** http://www.secondwind.com
**E-mail:** Send Email to Second Wind

American Independent Power
**Business type:** manufacturer, distributor, service
**Product types:** Wind power systems.
**Address:** 60 Firehouse Rd., Plymouth, Massachusetts USA 02360-3280
**Telephone:** 800DCSOLAR, 508-759-6706

Brower and Company
**Business type:** service

**Product types:** wind energy systems (large), wind energy systems (small), wind turbines (large), wind turbines (small).
**Address:** 154 Main Street, Andover, Massachusetts USA 01810
**Telephone:** 1-978-749-9591
**FAX:** 1-978-749-9713

Central Mass Machine Inc.
**Business type:** manufacturer
**Product types:** cogeneration system components, composting system components, fuel powered electric generators, wind energy system components (large), steam turbine electric generators, hydro energy system components (large), Medium to large machining of mechanical components for all sectors of industry.
**Service types:** research services, maintenance and repair services
**Address:** 529 South East Street, Holyoke, Massachusetts USA 01041
**Telephone:** 413-538-9880
**FAX:** 413-533-9602

Lanes End Design
**Business type:** retail sales
**Product types:** solar electric power systems, photovoltaic systems, photovoltaic modules, wind energy systems (small), wind turbines (small), renewable energy system batteries.
**Service types:** design, installation
**Address:** Off Spring Street, P.O. Box 437, Essex, Massachusetts USA 01929
**Telephone:** 978-768-6396

Reeves Wind Company
**Business type:** retail sales, wholesale supplier
**Product types:** uninterruptable power supplies UPS, biomass energy systems, wind energy systems (large), wind turbines (small), ocean energy systems.
**Service types:** consulting, project development services, research services
**Address:** 157 Nesmith St., Lowell, Massachusetts USA 01852
**Telephone:** 978-441-6223

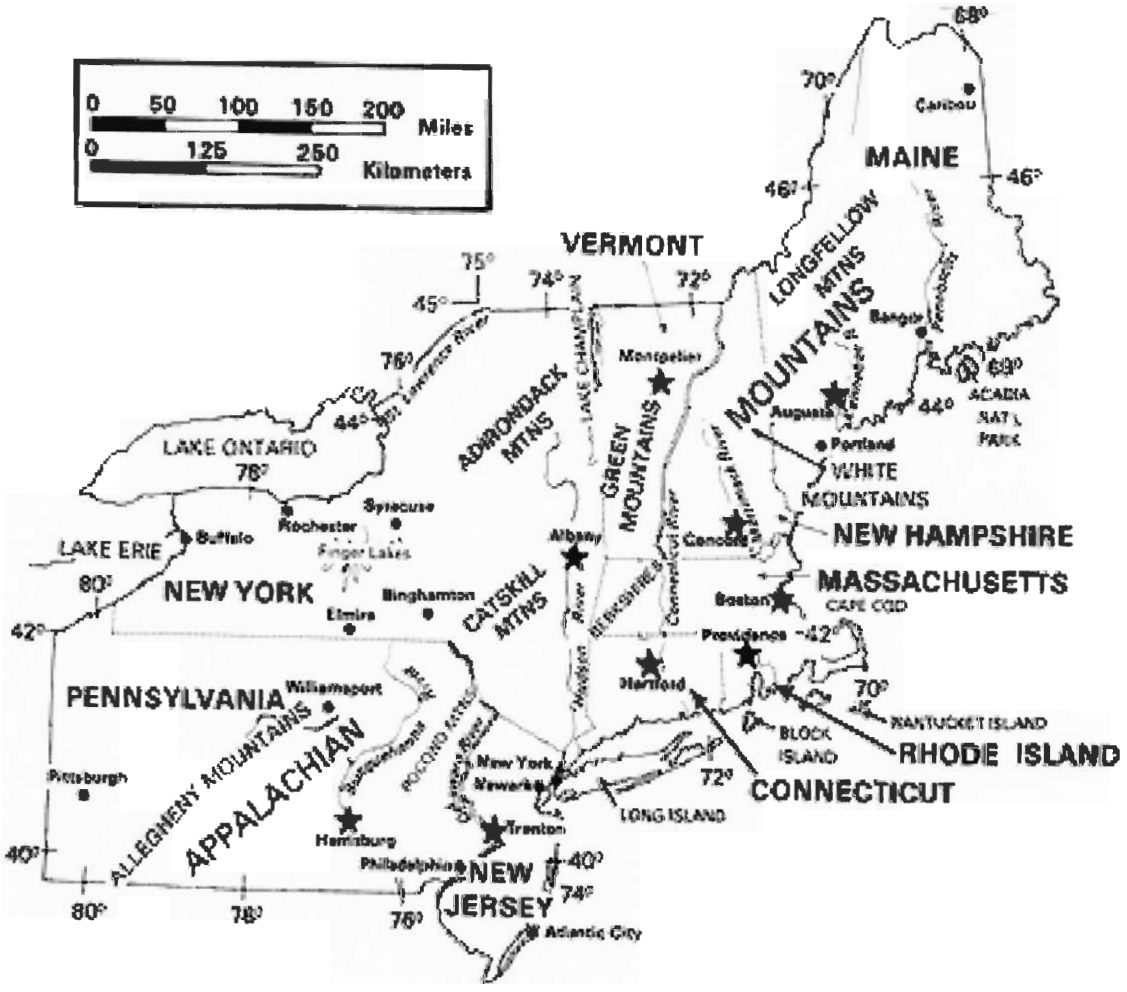
## *Appendix A.1: Probabilities for Wind Energy in Worcester*

Information obtained from:

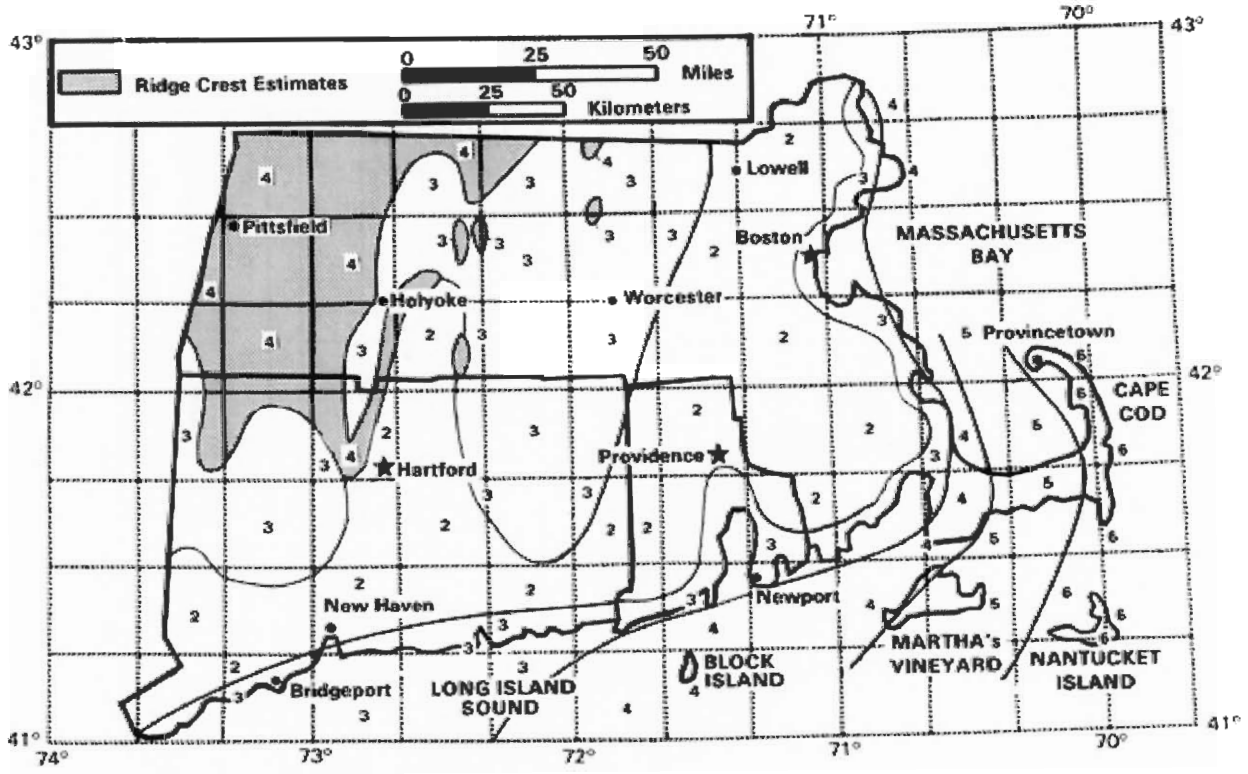
**Wind Energy Resource Atlas of the United States**

http://rredc.nrel.gov/wind/pubs/atlas/atlas_index.html

**Northeast Region**



## Connecticut, Massachusetts, and Rhode Island annual average wind power




Wind power classes:

| Level | Number |
|---|---|
| Lowest | 1 |
| Marginal | 2 |
| Suitable for most wind energy | 3-7 |
| Highest | 7 |

***Wind ranges of each category**:
http://rredc.nrel.gov/wind/pubs/atlas/maps/chap2/2-01m.html

## *Appendix A.2: U.S. Department of Energy candidate wind turbine sites*

## *Appendix A.3: Average Temperature in Worcester (30 years)*

| Month | Avg. High | Avg. Low | Mean | Avg. Precip. | Record High | Record Low |
|---|---|---|---|---|---|---|
| Jan | 30°F | 15°F | 23°F | 3.70 in. | 67°F (1950) | -13°F (1976) |
| Feb | 33°F | 16°F | 25°F | 3.50 in. | 67°F (1985) | -12°F (1967) |
| Mar | 42°F | 24°F | 34°F | 4.00 in. | 81°F (1990) | -6°F (1950) |
| Apr | 54°F | 34°F | 44°F | 3.90 in. | 91°F (1976) | 11°F (1982) |
| May | 65°F | 45°F | 56°F | 4.30 in. | 92°F (1962) | 28°F (1970) |
| Jun | 74°F | 53°F | 64°F | 3.90 in. | 98°F (1952) | 36°F (1986) |
| Jul | 79°F | 60°F | 70°F | 3.90 in. | 96°F (1988) | 43°F (1988) |
| Aug | 77°F | 58°F | 68°F | 3.80 in. | 98°F (1948) | 38°F (1965) |
| Sep | 69°F | 50°F | 60°F | 4.00 in. | 99°F (1953) | 30°F (1992) |
| Oct | 59°F | 40°F | 50°F | 4.30 in. | 85°F (1963) | 20°F (1969) |
| Nov | 47°F | 31°F | 39°F | 4.50 in. | 79°F (1950) | 6°F (1989) |
| Dec | 34°F | 20°F | 27°F | 4.10 in. | 70°F (1984) | -13°F (1962 |

****Table obtained from "The Weather Channel"**

## *Appendix A.4: Electricity Bill Savings for a Net-Metered PV System*

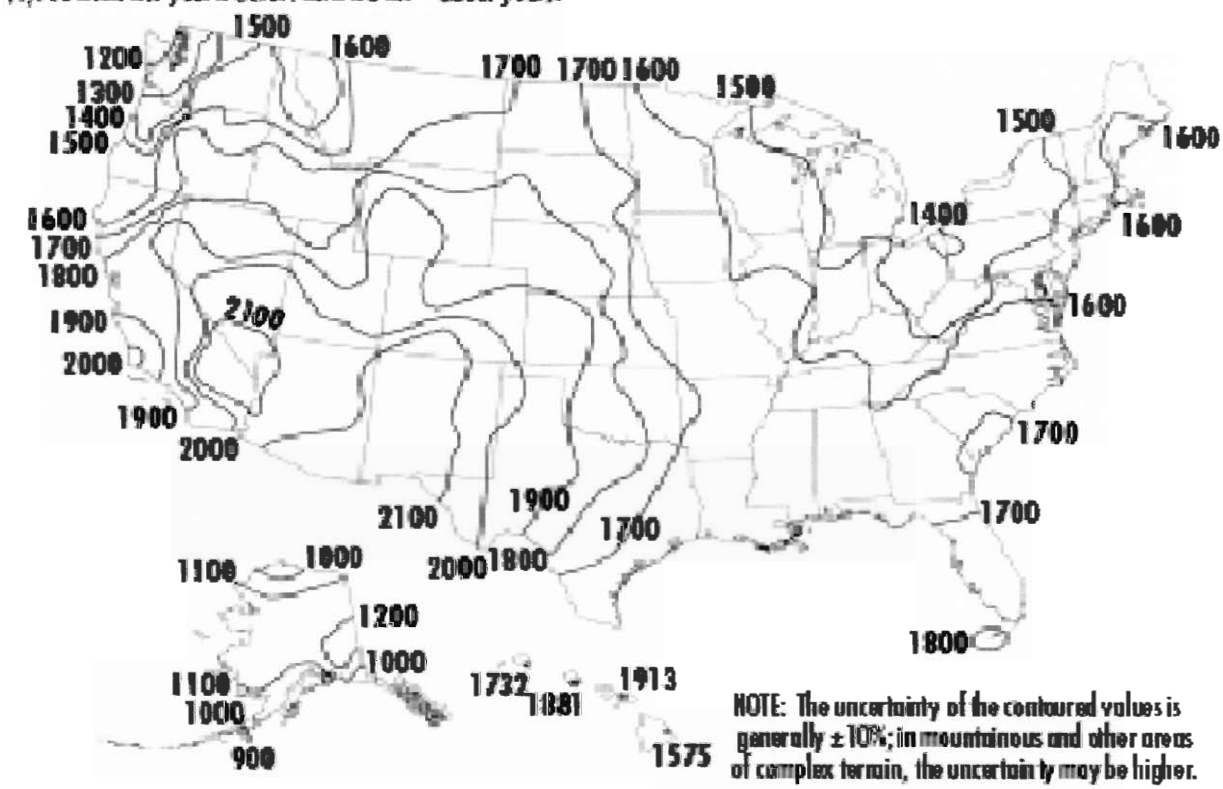
### Calculating Electricity Bill Savings for a Net-Metered PV System

- Determine the system's size in kilowatts (kW). A reasonable range is 1 to 5 kW. This value is the "kW of PV" input for the equations below.
- Based on your geographic location, select the energy production factor from the map below for the "kWh/kW-year" input for the equations.

**Energy from the PV system = (kW of PV) x (kWh/kW-year) = kWh/year**
Divide this number by twelve if you want to determine your monthly energy reduction.

**Energy bills savings = (kWh/year) x (Residential Rate)/100 = $/year saved**
(Residential Rate in this above equation should be in dollars per kWh; for example, a rate of 10 cents per kWh is input as $0.10/kWh.)

*For example, a 2-kW system in Denver, CO, at a residential energy rate of $0.07/kWh will save about $266 per year (1,900 kWh/kW-year x $0.07/kWh x 2 kW = $266/year).*

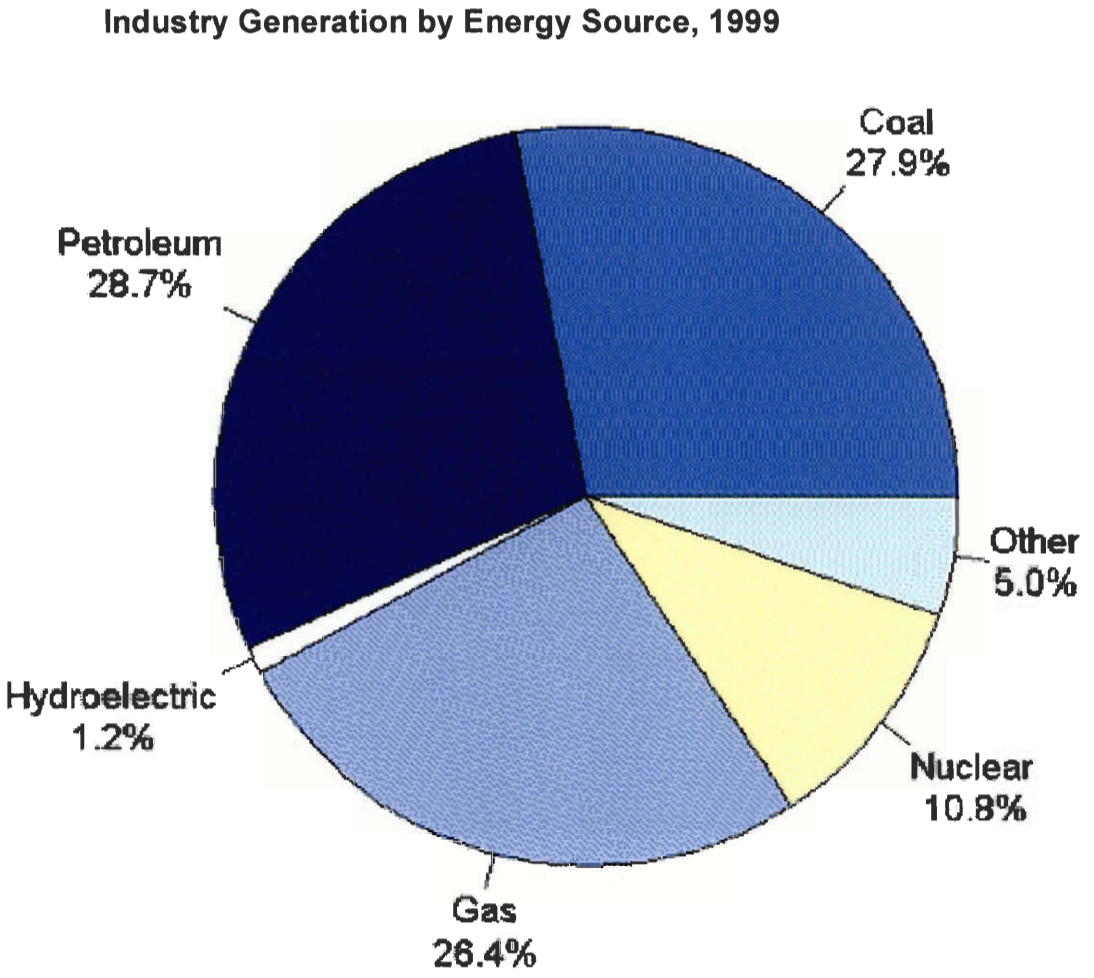



NOTE: The uncertainty of the contoured values is generally ±10%; in mountainous and other areas of complex terrain, the uncertainty may be higher.

*Graphic obtained from http://www.nrel.gov/ncpv/pdfs/26591.pdf

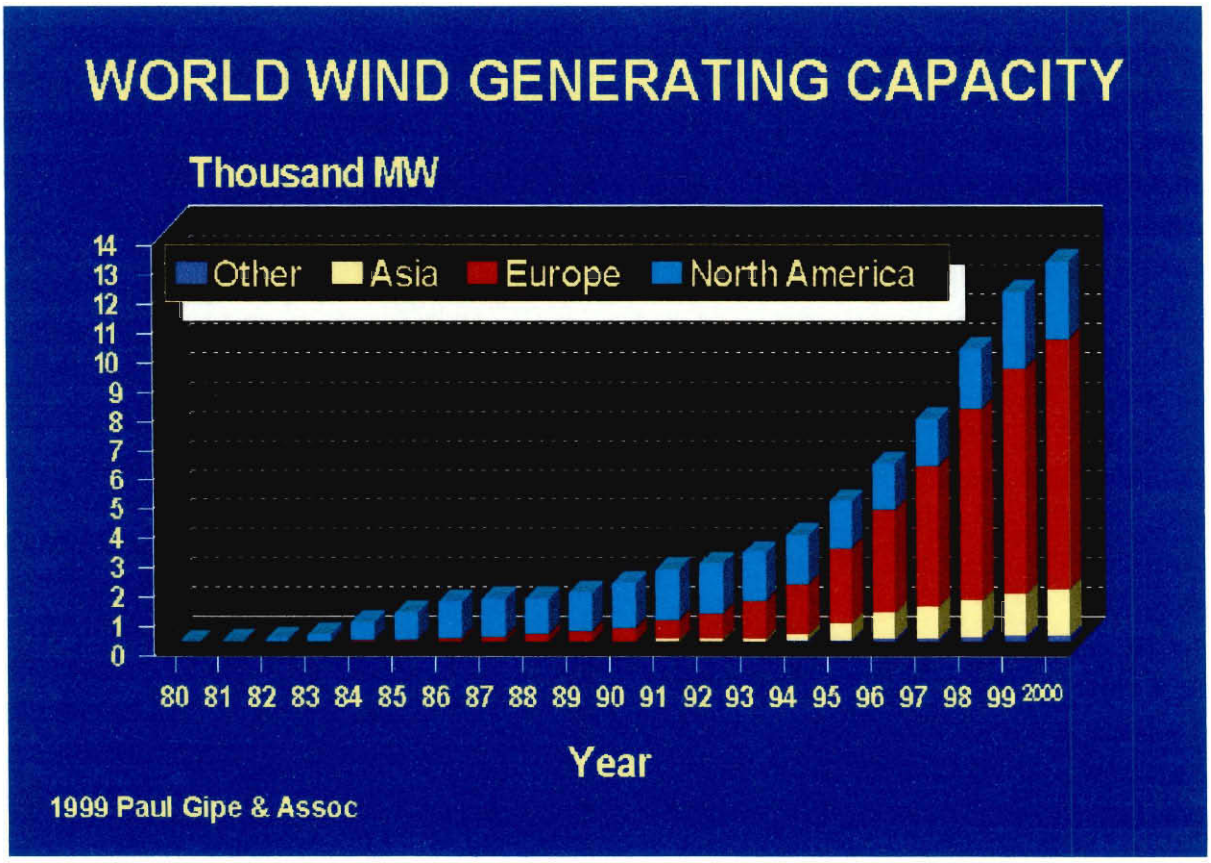
## *Appendix A.5: Power Grid Costs in Massachusetts*

**POWER GRID (OPTION): COSTS / MASSACHUSETTS[19]**



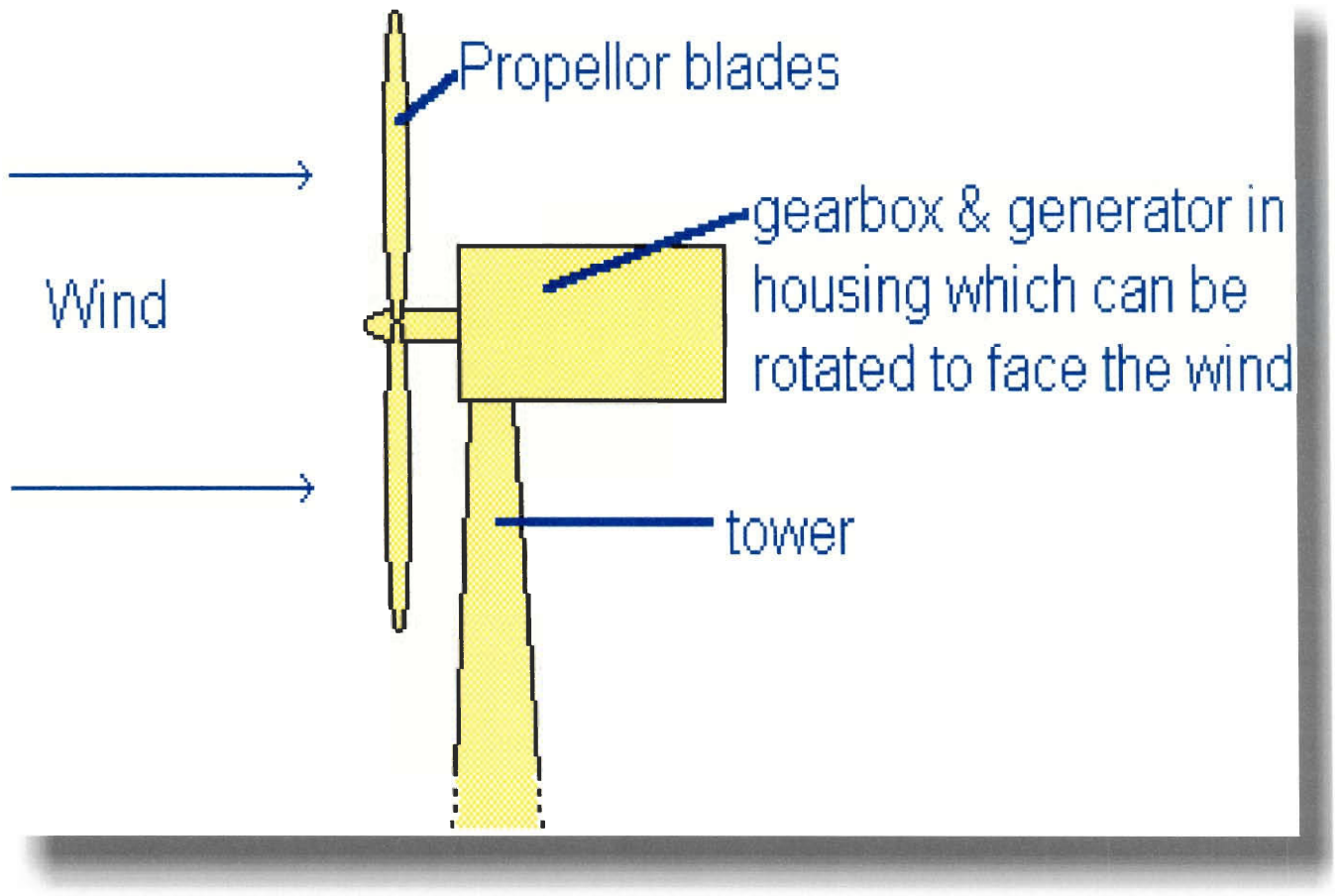

[19] **Information obtained from
http://www.eia.doe.gov/cneaf/electricity/st_profiles/massachusetts/ma.html#t1

## *Appendix A.6: World Wind Generating Capacity*




*Graphic obtained from:
Paul Gipe and Associates, "Overview of Worldwide Wind Generation",
http://environment.about.com/gi/dynamic/offsite.htm?site=http%3A%2F%2Frotor.fb12.tu-berlin.de%2Foverview.html
* 1 Megawatt (MW) = 1,000 KW

***Appendix A.7: Wind Turbine***




*Graphic obtained from: Andy Darvill, "Wind Power 'Energy from the air'", http://www.darvill.clara.net/altenerg/wind.htm

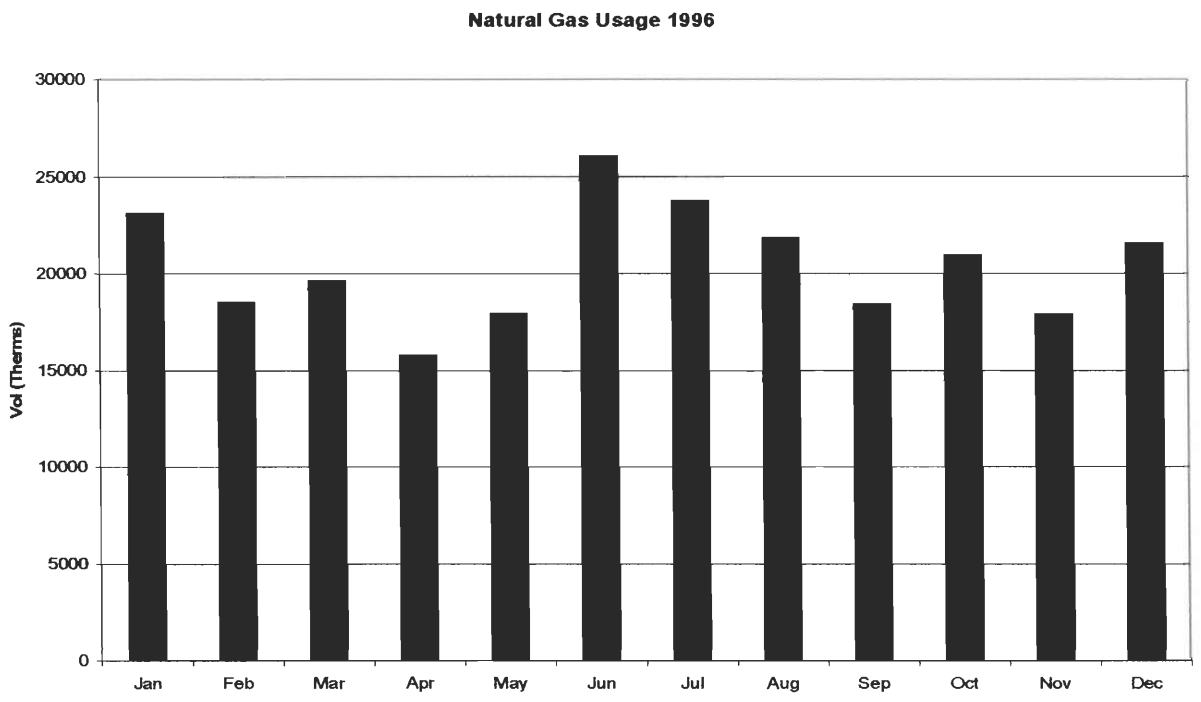
## *Appendix A.8: Gas Data*

The EcoTarium uses a little less than 250,000 therms a year. Each therm is an equivalent of 100,000 btus. The largest use of natural gas is during the months of Jun, July, and August, and then in the winter during December and January. The usage in these months exceeded 21,500 therms. The average amount of natural gas used in a month is about 20,500 therms.

Every month the Compressed Cubic foot meter is read to see how much gas was used. The c.c.f. reading is multiplied by a therm factor to convert it to the amount of terms used. The customer is billed about $0.43 per therm used. In addition to this the customer is billed around $0.11 per therm used in a demand charge. This is a peak time transportation charge. There is also a $100 customer charge. This is the fee to have the meter read and other related services. The final charge or credit is the Gas Adjustment Factor. This figure is an adjustment to the bill that compensates for the changing gas prices. Currently the EcoTarium has $3,500 budgeted for gas and Electric to run the physical plant. There also is a budget of $143,000 for Gas and Electric for the Total Facility.

The graph shows the natural gas usage for the year. The peak usage was in June with 26,081 therms. The total usage of the year was 245,631 therms. Gas Use 1996:

| | |
|---|---|
| Jan | 23140 |
| Feb | 18517 |
| Mar | 19660 |
| Apr | 15796 |
| May | 17938 |
| Jun | 26081 |
| Jul | 23786 |
| Aug | 21849 |
| Sep | 18434 |
| Oct | 20969 |
| Nov | 17902 |
| Dec | 21559 |




## *Appendix A.9: Gas Data 1999-2002*

The EcoTarium uses a little less than 250,000 therms a year. Each therm is an equivalent of 100,000 btus. The largest use of natural gas is during the months of Jun, July, and August, and then in the winter during December and January. The usage in these months exceeded 21,500 therms. The average amount of natural gas used in a month is about 20,500 therms.

Every month the Compressed Cubic foot meter is read to see how much gas was used. The c.c.f. reading is multiplied by a therm factor to convert it to the amount of terms used. The customer is billed about $0.43 per therm used. In addition to this the customer is billed around $0.11 per therm used in a demand charge. This is a peak time transportation charge. There is also a $100 customer charge. This is the fee to have the meter read and other related services. The final charge or credit is the Gas Adjustment Factor. This figure is an adjustment to the bill that compensates for the changing gas prices. Currently the EcoTarium has $3,500 budgeted for gas and Electric to run the physical plant. There also is a budget of $143,000 for Gas and Electric for the Total Facility.

The graph shows the natural gas usage for the year. The peak usage was in June with 26,081 therms. The total usage of the year was 245,631 therms.:

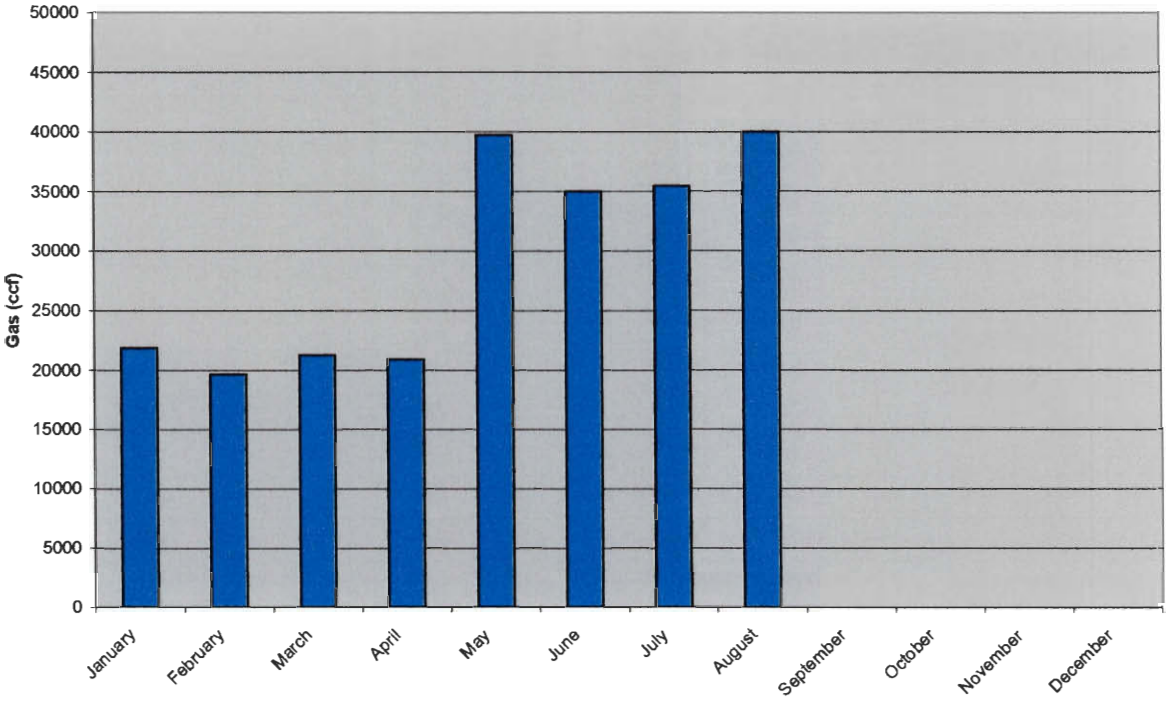
atural Gas Consumption

CCF USAGE

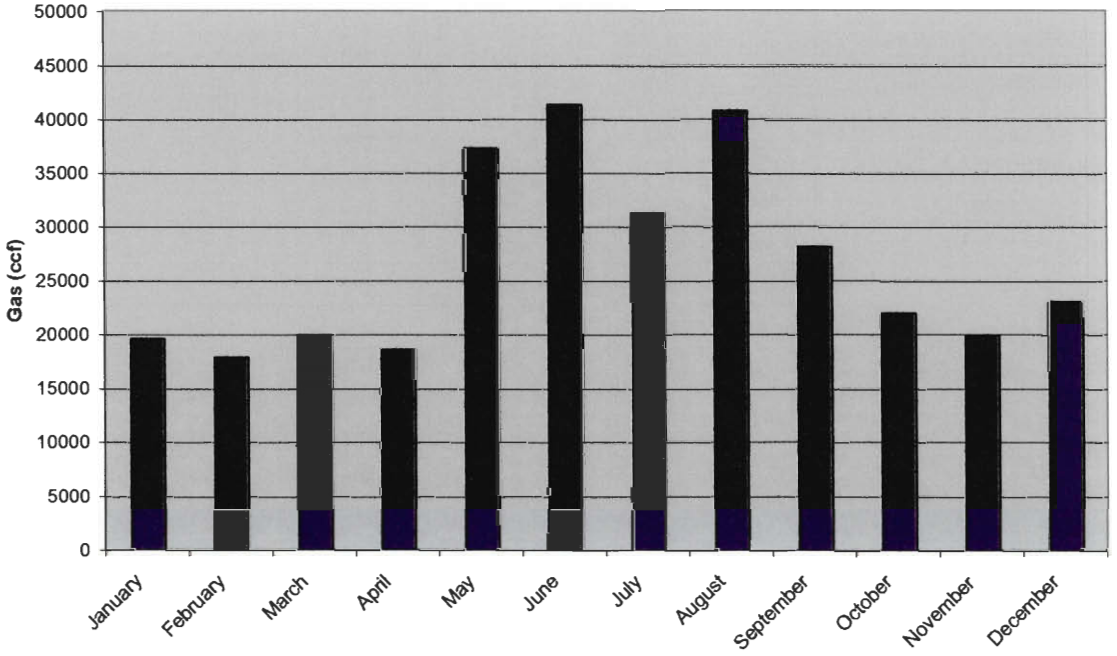
| | FY 1999 | AMOUNT | FY 2000 | AMOUNT | FY 2001 | AMOUNT | FY 2002 | AMOUNT |
|---|---|---|---|---|---|---|---|---|
| nuary | 21390 | $8,017.00 | 22370 | $9,230.49 | 19610 | $8,617.40 | 21910 | $9,064.95 |
| ebruary | 16800 | $8,915.95 | 19310 | $8,226.53 | 17940 | $8,200.09 | 19680 | $8,382.02 |
| arch | 17970 | $7,520.51 | 18990 | $8,193.91 | 19990 | $8,743.46 | 21280 | $8,883.64 |
| ril | 17240 | $7,848.79 | 22450 | $9,161.65 | 18620 | $8,318.66 | 20910 | $8,808.50 |
| ay | 20570 | $7,621.64 | 22970 | $8,459.36 | 37310 | $13,453.83 | 39730 | $13,971.83 |
| ne | 31840 | $8,600.50 | 31250 | $10,880.59 | 41350 | $14,633.07 | 34990 | $19,845.16 |
| ly | 14560 | $10,736.47 | 48410 | $16,251.38 | 31300 | $11,530.46 | 35440 | $19,462.87 |
| ugust | 29290 | $5,584.31 | 43980 | $15,063.29 | 40730 | $14,318.12 | 39990 | $20,082.70 |
| eptember | 26660 | $2,512.94 | 42040 | $14,435.13 | 28140 | $10,549.81 | | |
| ctober | 21083 | $3,652.62 | 27230 | $10,100.78 | 21940 | $10,539.61 | | |
| ovember | 20520 | $8,432.67 | 18550 | $8,596.87 | 19920 | $8,487.92 | | |
| ecember | 20280 | $8,635.13 | 19490 | $8,556.42 | 22990 | $9,463.14 | | |
| | 258203 | $88,078.53 | 337040 | $127,156.40 | 319840 | $126,855.57 | 233930 | $108,501.67 |

ote: FY 99 is a best guess, based on G/L information.

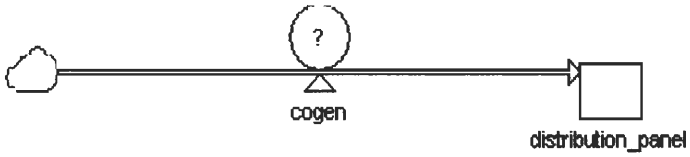
**Gas use 2002**



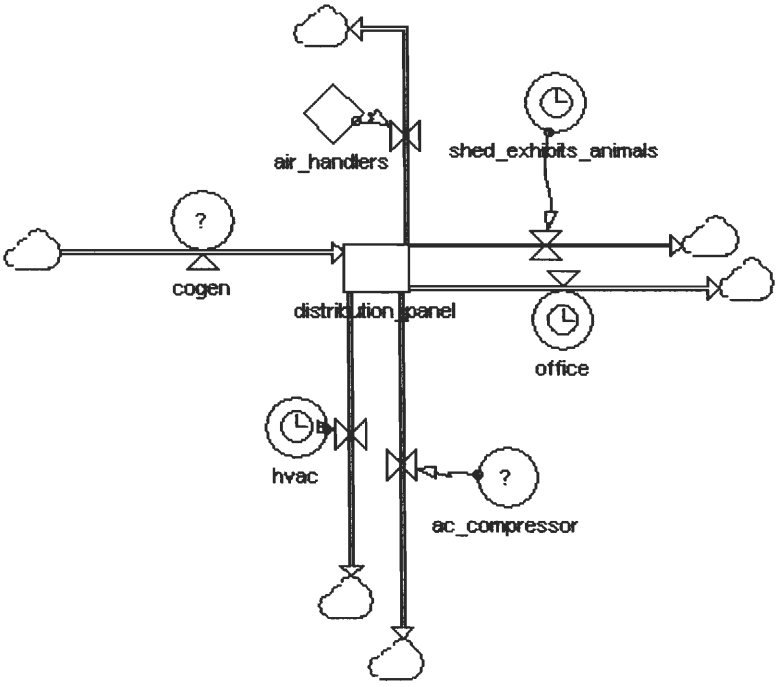

**Gas Use 2001**



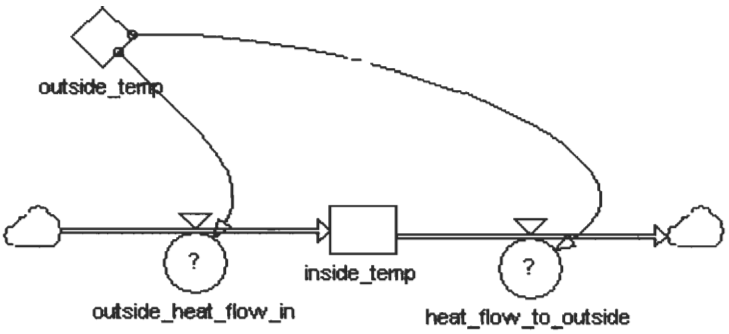
## *Appendix A.10: Demand Model*



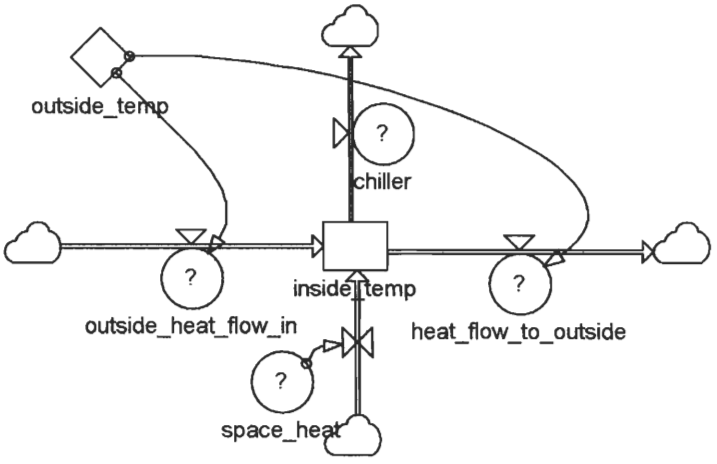

The flow here shows the gas going into the cogen engines. The gas is converted into electricity and flows into the distribution panel. The cloud on the left is the model representation of an external source. The cloud here is the external gas line. The model would also use this for something such as exhaust, which would be represented as a flow going into a cloud.



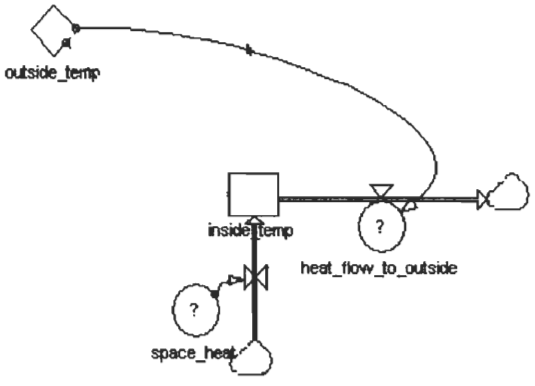

Off the distribution panel we add in the things that consume the power. All these power consumers make up the cogen's demand load. The next part of the model is for the inside temperature of the museum building. The left to right flow is the environment's effect on the inside temperature. The feedback arrows allow for the model to have heat either flowing into or out of the building depending on the outside temperature.



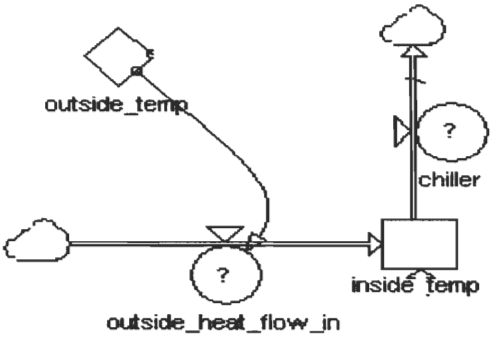

The chiller and space heat are added in to control the inside temperature



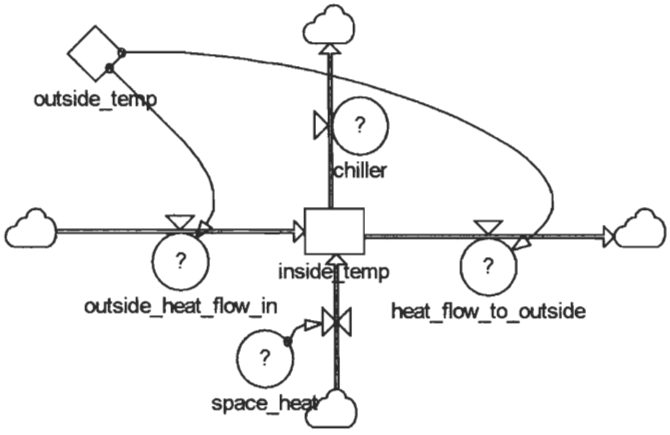

- Heat flow on a hot summer day



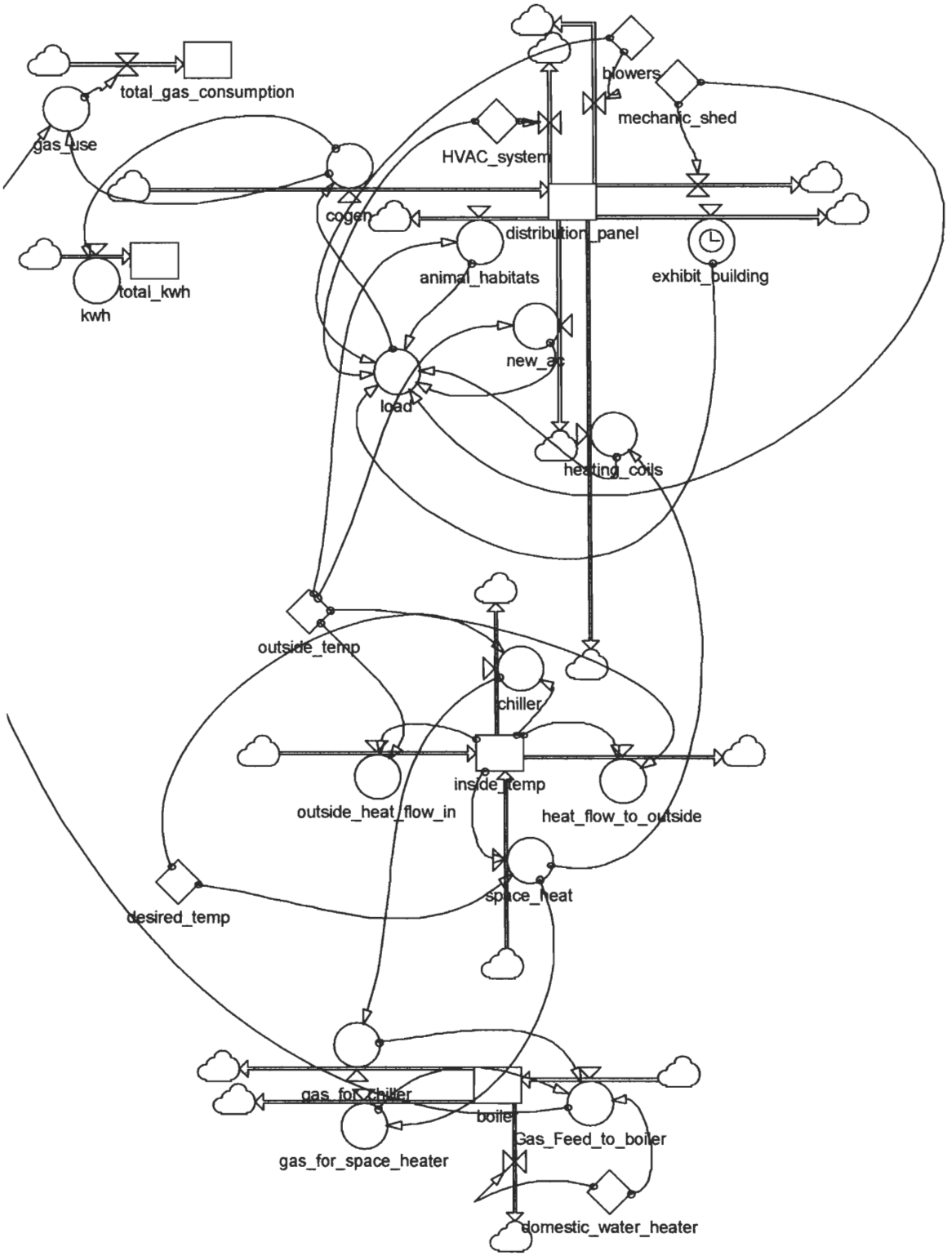

Heat flow on a cold winter day



The combined heat model:




Since the heating system needs power, the two need to be combined. This makes the model rather large:


total_gas_consumption
gas_use
blowers
mechanic_shed
HVAC_system
cogen
distribution_panel
animal_habitats
exhibit_building
total_kwh
kwh
new_air
load
heating_coils
outside_temp
chiller
inside_temp
outside_heat_flow_in
heat_flow_to_outside
space_heat
desired_temp
gas_for_chiller
boiler
Gas_Feed_to_boiler
gas_for_space_heater
domestic_water_heater

WINTER 30 degrees

| Time | load |
|---|---|
| 0 | 134.00 |
| 1 | 154.00 |
| 2 | 134.00 |
| 3 | 154.00 |
| 4 | 134.00 |
| 5 | 154.00 |
| 6 | 134.00 |
| 7 | 154.00 |
| 8 | 184.00 |
| 9 | 204.00 |
| 10 | 184.00 |
| 11 | 229.00 |
| 12 | 209.00 |
| 13 | 229.00 |
| 14 | 209.00 |
| 15 | 204.00 |
| 16 | 184.00 |
| 17 | 204.00 |
| 18 | 134.00 |
| 19 | 154.00 |
| 20 | 134.00 |
| 21 | 154.00 |
| 22 | 134.00 |
| 23 | 154.00 |
| 24 | 134.00 |

SUMMER 80 degrees

| Time | load |
|---|---|
| 0 | 134.00 |
| 1 | 154.00 |
| 2 | 134.00 |
| 3 | 154.00 |
| 4 | 134.00 |
| 5 | 154.00 |
| 6 | 134.00 |
| 7 | 154.00 |
| 8 | 184.00 |
| 9 | 204.00 |
| 10 | 184.00 |
| 11 | 229.00 |
| 12 | 209.00 |
| 13 | 229.00 |
| 14 | 209.00 |
| 15 | 204.00 |
| 16 | 184.00 |
| 17 | 204.00 |
| 18 | 134.00 |
| 19 | 154.00 |
| 20 | 134.00 |
| 21 | 154.00 |
| 22 | 134.00 |
| 23 | 154.00 |
| 24 | 134.00 |

## *Appendix A.11: Power Grid Facts*

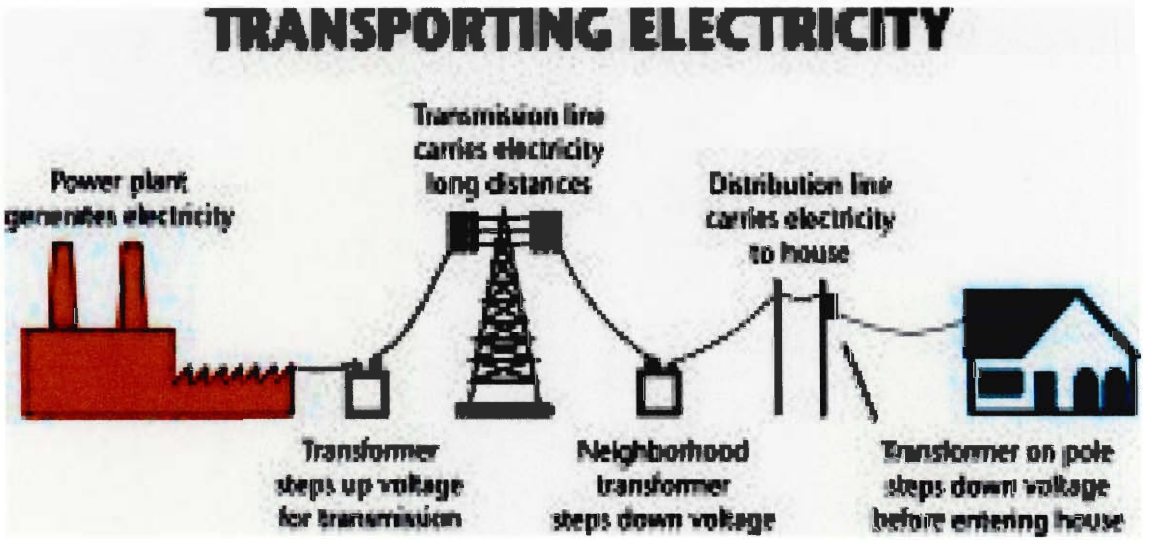
### Power Grid

### Introduction

Using electricity from the power grid allows for a facility to get all the power needed without having to generate it onsite. Once the installation is finished, the consumer has a simple role to just use power and pay for it. The issues of generator problems and demand size are taken care of by the power company. The use of the power grid makes the need for power a simple and easy process for the consumer.

### How It Works

The first task to using the power grid is to decide how much power from the grid is desired. After the amount of power needed is decided, the power company runs transmission lines to the facility. If the grid is to be used as a backup source of power only, then much less power will be needed and smaller transmission lines can be used. The transmission lines serve as the carrier for the power that is created at the power plant to the facility.




The transformer outside the plant needs to increase the voltage on the electricity coming out of the plant because of the resistance in the lines. The farther the electricity is carried the more power is lost. This makes transmission of power over long distances less efficient than producing the power onsite and using it without transmission. The electricity is then entered into the grid. When power is needed, the customer can draw it off the grid. When the electricity has reached its destination another transformer steps

the voltage down so that it is usable in standard form of 120 volts. Once the facility is hooked up to the power grid there is a constant supply of power ready to be used.

## Costs

### Installation

The amount of power needed affects the installation and its cost. The larger the amount of power needed the larger the lines will have to be. The cost of installation also depends on how far the power lines have to be run to the facility. If the power grid is to be the main source of power in a large facility, hooking up to the grid can be quite expensive. If the EcoTarium were to fully rely on the grid for power the cost of installation would be about $500,000.

### Operation costs and cost per Kilowatt hour

These are the rates for each kilowatt-hour used. In addition to the standard charges there are other fees and charges for transmission of the power. The fees are listed in the appendix. Currently Mass Electric offers a standard rate of 4.2 cents a kWh. This rate increases every year and the offer ends in 2005. There are six companies that can be contracted with that sell power. All six companies use Mass Electric as a distribution company. This means that if you buy power from a company, you still need to pay the distribution and service fees to Mass electric. The six companies and their contact information are listed in the appendix. A final cost comes from a "service benefit charge", a small fee (~3%) every electricity customer in Massachusetts pays on its power usage to pay for state programs to promote renewable energy resources, improved energy efficiency, and low-income energy assistance. The Massachusetts Renewable Energy Trust, a potential contributor to the EcoTarium project, is funded through this fee.

## Environmental Concerns

When using the power grid there are very few environment concerns at the site where the power is being used. There is some land that is needed to place poles for the transmission lines. The real environment concerns come from the power plant that the electricity is being purchased from. A larger portion of the nation's electricity is produced from fossil fuels. In order to be environmental conscious as possible, the power companies would need to be contacted to obtain the information of how much of their power is produced form renewable resources.

## Recommendations

### Advantages and Disadvantages

Using the power grid as a source of power is an easy method of power generation because someone else deals with creating the power. This eliminates the problems of generator break down and repair. While the power company cannot guarantee continuous power, it is a reliable source of energy. There also are no worries of a lifespan on the power grid as with a generation system. It is a finalized solution to the need for power.

The ease of the power source does have its disadvantages. Power from the grid on a large scale can be more expensive than generation of one's own power per kilowatt-hour. There are also concerns with times that the company may not be able to provide service such as after severe weather where transmission lines could be damaged. This could cause problems for such things as refrigeration that needs power.

## Recommendations

Hooking up to the power gird is a good option to consider satisfying energy needs. For a large facility that generates its own power, the power grid can serve as a good back up system for when the generators are offline.

| | Grid connection |
|---|---|
| Size range (kW) | 1-500 |
| Lifetime (years) | 25 |
| **Capital cost total** | $ 500,000 |
| **Capital annually ($/year)** | $ 20,000 |
| **O&M annually ($/year)** | |
| **Fuel annually ($/year)** | $ 131,400 |
| **Total annual cost** | **$ 151,400** |
| | |
| **Cost $/kWh** | $ 0.09 |
| Power output max (kWh/year) | 1,752,000 |

***Appendix A.12: Example of Request for Proposal***

Example of proposal (Wind Turbine)

# GREENER ENERGY
# GREENER NEW ENGLAND
# REQUEST FOR PROPOSALS

## INTRODUCTION

The EcoTarium is a center for environmental exploration and discovery located just two miles from downtown Worcester, Massachusetts, and it has been in existence since 1970. It has approximately 148,000 visitors each year. The EcoTarium needs to renovate its current energy supply; consequently, a hybrid system has been considered to accomplish this task. Greener Energy, Greener New England has been created for that purpose, which consists in the implementation and study of renewable energy sources, which will be used in different locations in Massachusetts. One of the objectives of this project at the EcoTarium is to provide information and education regarding Renewable energy, and how this type of energy helps the planet through a better and efficient administration of resources. Our project includes a partnership among the EcoTarium, WPI and Clark University. One objective will be to educate the general public, businesses and institutions, about the importance of wind energy, its applications and advantages. This will be done through the EcoTarium in collaboration with area universities, colleges and secondary schools.

The mission of the EcoTarium is "to promote appreciation, increase knowledge and foster stewardship of New England environments by stimulating learning about the world in which we live." This is accomplished through different educational and environmental programs managed by the EcoTarium. These programs reflect the importance of the education of the future generations in energy and environmental issues. Our planet is our home, and we must learn to preserve it; however, much work needs to be done. Institutions such as the EcoTarium have an important role in our societies.

## GENERAL TERMS

### Project Goals

The EcoTarium seeks proposals from qualified suppliers of wind electrical power generating systems to install and interconnect a small wind turbine system as part of the development of a new hybrid power generating plant capable of meeting EcoTarium energy needs and educational mission.

The proposal must complete these characteristics:

### Cost Effective

Proposals should specify expected power output and total installed cost/kWh, based on actual recent year, Worcester area wind data, modified as appropriate for site conditions at EcoTarium. Proposers should clearly specify all assumptions used in estimating power production and costs.

**Environmentally Sound**
The installation and operation of the equipment should not cause any disturbance at the exhibits of the EcoTarium. The proposal will require a noise-level and environmental impact study.

**Education and Promotion**
Proposals should include a scheme, which will explain the proposal's educational contribution (if applicable).

**Project Size**

The total power system design is approximately 300 kW. Given site limitations, we expect only a small fraction of total power will be generated by wind on-site, but proposers should specify what they believe is a cost-effective system for power production, environmental, and educational purposes.
The current generation system consists of two Caterpillar generators at 300 kW each. The maximum demand met by the generators is produced during the summer (360 kW) and the lowest demand is at night (180 kW).

***Existing conditions***
Important characteristics of the site:

- There is no connection to the grid
- The current system that provides energy to the buildings is a cogeneration plant.
- No renewable energy sources currently in use.
- Installation as soon as possible
- An existing tower on-site may be used if deemed suitable by proposer

***Proposal Requirements***

**Project Description**
All proposals should have a detailed description of all the facts (technical and specification requirements) that will be accomplished regarding energy efficiency, education purposes, cost effectiveness, and environmental issues.

The proposal should also provide how the company will provide energy in the future, support and maintenance issues, and future energy projections.

**Financial**

*Proposals should describe and price each of the following components*:
- Equipment
- Wind turbine
- Tower
- Interconnection equipment

- Batteries (if necessary)
- Installation
- Operation and maintenance: *Identify routine O&M activities and expected costs. Indicate whether and under what conditions proposer might provide ongoing service.*
- Annual energy production and assumed revenue
- Annual operating expenses including turbine and balance-of-plant operations

**Price Proposals**

***Proposal submissions*:**
Submit proposals by {date} to Thomas DiConza, Director of Finance and Operations. E-mail: tomd@ecotarium.org

## *Appendix A.13: Cost of Technologies*

*Assumptions: Inflation rate 3% per year*
*Compound interest formula used in the calculations*

| WIND | | 1 KW | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Capital Cost | $2,000 | | | | | | | | |
| O&M Cost | $800 | | | | | | | | |
| Fuel Cost | $0 | | | | | | | | |
| Lifetime(years) | 25 | | | | | | | | |
| | | | | | | | | | |
| Lifetime (years) | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | ...2 |
| Capital cost | 2,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| O&M cost per year | | 46 | 46 | 46 | 46 | 46 | 46 | 46 | 4 |
| Fuel cost per year | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| | | | | | | | | | |
| Total Cost | 2,000 | 46 | 46 | 46 | 46 | 46 | 46 | 46 | 4 |
| Approx. output Kwh | | 4,300 | 4,300 | 4,300 | 4,300 | 4,300 | 4,300 | 4,300 | 4,3 |
| Cost per Kwh | | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.0 |

| SOLAR | | 3KW | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Capital Cost | $66,200 | | | | | | | | |
| O&M Cost | $90,000 | | | | | | | | |
| Fuel Cost | $0 | | | | | | | | |
| Lifetime(years) | 30 | | | | | | | | |
| | | | | | | | | | |
| Lifetime (years) | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | ...1 |
| Capital cost | 66,200 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| O&M cost per year | | 4,592 | 4,592 | 4,592 | 4,592 | 4,592 | 4,592 | 4,592 | 4,59 |
| Fuel cost per year | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| | | | | | | | | | |
| Total Cost | 66,200 | 4,592 | 4,592 | 4,592 | 4,592 | 4,592 | 4,592 | 4,592 | 4,59 |
| Approx. output Kwh | | 19,400 | 19,400 | 19,400 | 19,400 | 19,400 | 19,400 | 19,400 | 19,40 |
| Cost per Kwh | | 0.24 | 0.24 | 0.24 | 0.24 | 0.24 | 0.24 | 0.24 | 0.2 |

**POWER GRID**

| | |
|---|---|
| Capital Cost | $500,000 |
| O&M Cost | $0 |
| Fuel Cost | $3,285,000 |
| Lifetime (years) | 25 |

| Lifetime (years) | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | ...2 |
|---|---|---|---|---|---|---|---|---|---|
| Capital cost | 500,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| O&M cost per year | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| Fuel cost per year | | 188,651 | 188,651 | 188,651 | 188,651 | 188,651 | 188,651 | 188,651 | 188,65 |
| | | | | | | | | | |
| Total Cost | 500,000 | 188,651 | 188,651 | 188,651 | 188,651 | 188,651 | 188,651 | 188,651 | 188,65 |
| Approx. output Kwh | | 1,752,000 | 1,752,000 | 1,752,000 | 1,752,000 | 1,752,000 | 1,752,000 | 1,752,000 | 1,752,00 |
| Cost per Kwh | | 0.11 | 0.11 | 0.11 | 0.11 | 0.11 | 0.11 | 0.11 | 0.1 |

**RECIPROCATING CO-GEN ENGINE** 200 KW

Cost*

| | |
|---|---|
| Capital Cost | $150,000 |
| O&M Cost | $766,500 |
| Fuel Cost | $2,391,125 |
| Lifetime (years) | 25 |

| Lifetime (years) | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | ...1 |
|---|---|---|---|---|---|---|---|---|---|
| Capital cost | 150,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| O&M cost per year | | 44,018 | 44,018 | 44,018 | 44,018 | 44,018 | 44,018 | 44,018 | 44,0 |
| Fuel cost per year | | 137,317 | 137,317 | 137,317 | 137,317 | 137,317 | 137,317 | 137,317 | 137,3 |
| | | | | | | | | | |
| Total Cost | 150,000 | 181,336 | 181,336 | 181,336 | 181,336 | 181,336 | 181,336 | 181,336 | 181,3 |
| Approx. output Kwh | | 1,752,000 | 1,752,000 | 1,752,000 | 1,752,000 | 1,752,000 | 1,752,000 | 1,752,000 | 1,752,0 |
| Cost per Kwh | | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | 0. |

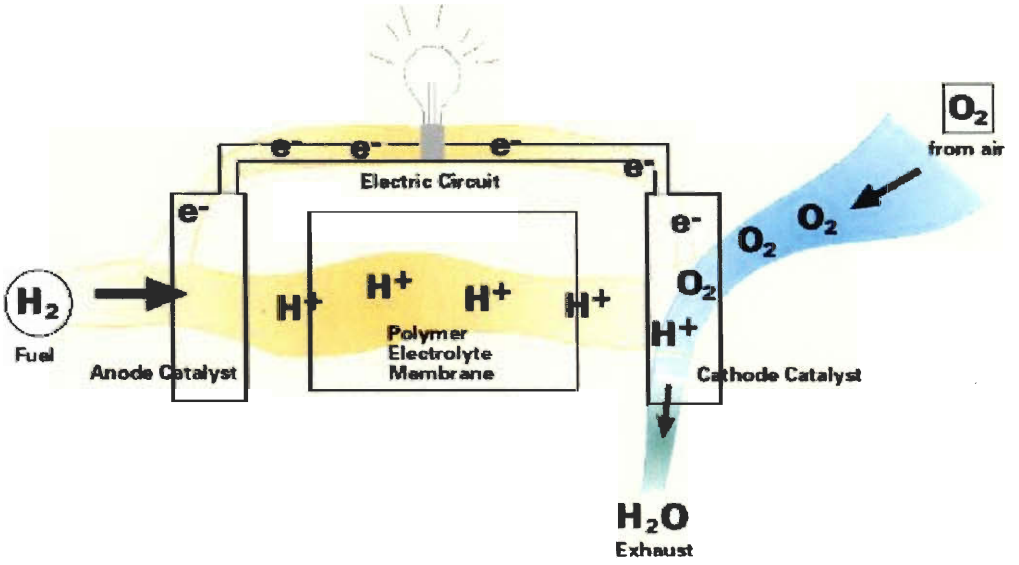
**FUEL CELL** 200 KW

| | |
|---|---|
| Capital Cost | $960,000 |
| O&M Cost | $1,200,000 |
| Fuel Cost | $1,551,000 |
| Lifetime (years) | 20 |

| Lifetime (years) | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | ...1 |
|---|---|---|---|---|---|---|---|---|---|
| Capital cost | 960,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| O&M cost per year | | 80,659 | 80,659 | 80,659 | 80,659 | 80,659 | 80,659 | 80,659 | 80,6 |
| Fuel cost per year | | 104,252 | 104,252 | 104,252 | 104,252 | 104,252 | 104,252 | 104,252 | 104,2 |
| Replacement Stack/ Convertor | | | | | | 315,000 | | 60,000 | |
| Total Cost | 960,000 | 184,910 | 184,910 | 184,910 | 184,910 | 499,910 | 184,910 | 244,910 | 184,9 |
| Approx. output Kwh | | 1,752,000 | 1,752,000 | 1,752,000 | 1,752,000 | 1,752,000 | 1,752,000 | 1,752,000 | 1,752,0 |
| Cost per Kwh | | 0.11 | 0.11 | 0.11 | 0.11 | 0.29 | 0.11 | 0.14 | 0.1 |

# How Fuel Cells Work

Currents created within a fuel cell are created through a series of chemical reactions within the cell itself. Hydrogen is pumped into the cell, through a negative electrode, called the anode. Once the hydrogen atoms pass the anode, they become "ionized," being stripped of their electrons. These free electrons are then run through wires, in turn generating DC electricity. The positively charged hydrogen ions are carried through the body of fuel cell by means of a chemical substance called an electrolyte. The electrolyte ensures that only hydrogen ions pass through so as not to disturb any reactions. At the other end of the fuel cell, oxygen enters through the cathode, a positively charged electrode. This oxygen meets the hydrogen ions carried to it by the electrolyte, and the electrons previously stripped. At the cathode, the three particles combine, forming the harmless waste water which is drained from the cell.




The process of generating power in a fuel cell

## Alternatively Fueled Fuel Cells

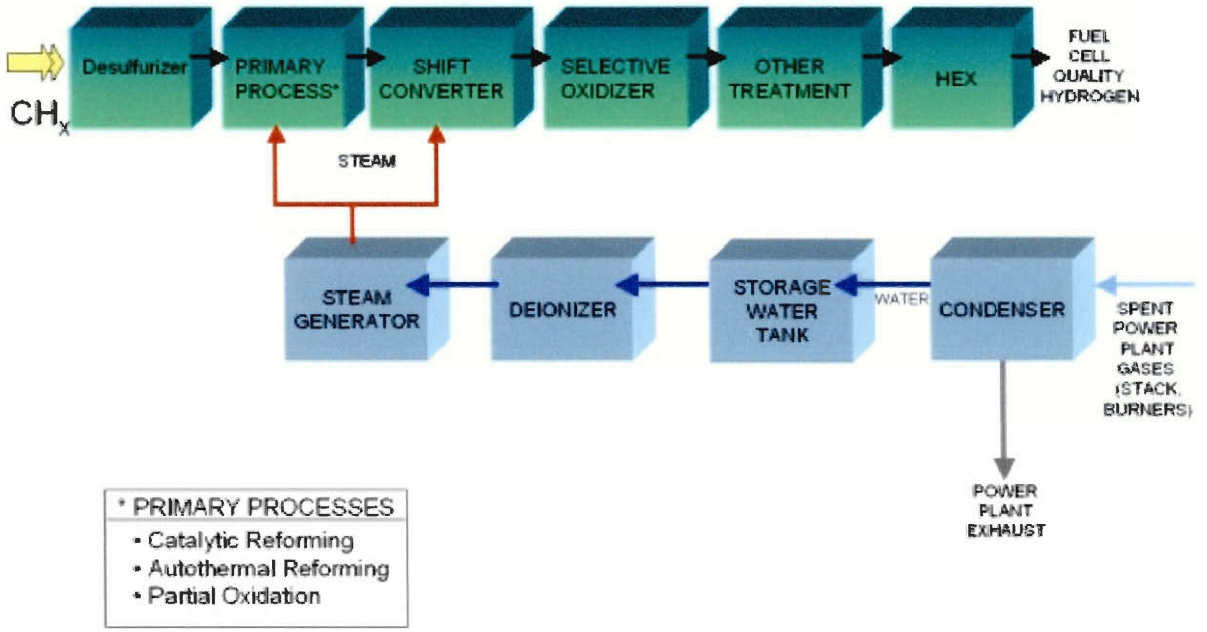
Due to the limited availability and difficulty to store pure hydrogen to power a fuel cell, it is common to retrieve the necessary hydrogen by other means. Alternative fuels may be processed through a device called a reformer, which can then supply the fuel cell with hydrogen. Typical alternative fuels are natural gas, propane, gasoline, methanol, and ethanol. These are all rich in hydrogen, easier to supply, transport, and store.

## Reforming Alternative Fuels

The process of reforming alternative fuels may be achieved in a few different ways, steam reforming, partial oxidation reforming, and autothermal reforming. All three work

on a similar process, but yield slightly different products. The first step in the reforming process is to remove sulfur from the fuel. Removing sulfur helps to ensure a purer product. After sulfur is removed, the source fuel then enters the primary conversion step where the fuel is then separated to products of hydrogen, and typically carbon monoxide and carbon dioxide. Those reformed by steam produce more hydrogen, whereas those reformed by partial oxidation produces less, but without the need for steam. Autothermal and partial oxidation achieve this conversion by burning some of the fuel with air, but yield hydrogen products with slightly different compositions due to the nitrogen introduced in the process.

The hydrogen products then undergo shift conversion, where carbon monoxide levels are decreased. Steam is added to the chemical mix, reacting with the carbon monoxide, and in turn increases the hydrogen concentration. The last steps in the process is purification and conditioning, where final impurities are removed and the temperature of the hydrogen is adjusted to a suitable level for use in the fuel cell.




*The process of reforming alternative fuels*

## *Appendix A.15: Types of Fuel Cells*

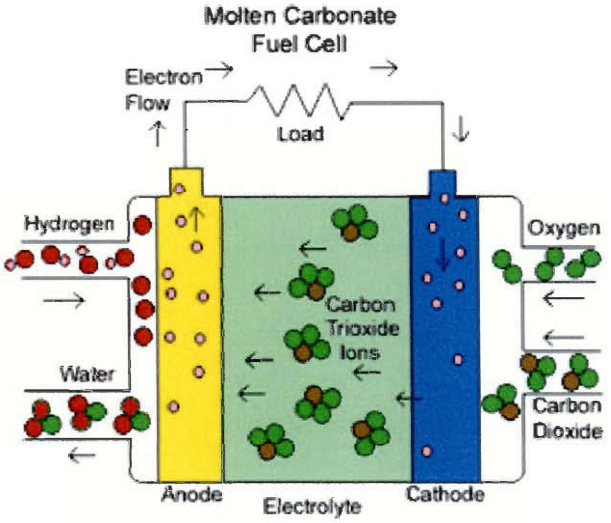
### Types of fuel cells

Many types of fuel cells exist, differentiated simply by the type of electrolyte contained inside the cell.

### Infeasible Fuel Cell Types

### Molten Carbonate Fuel Cell

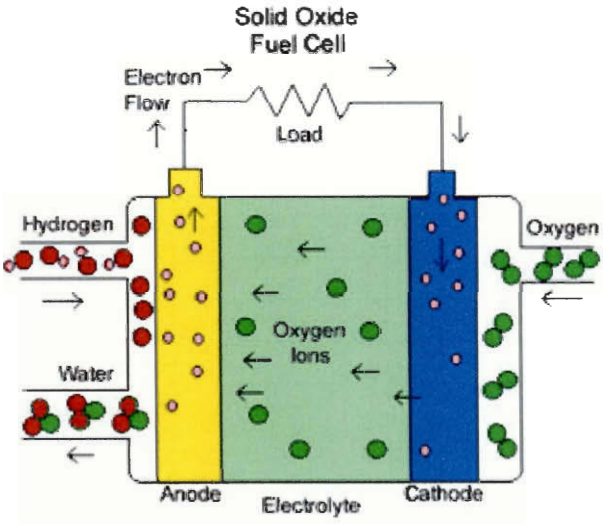
As its name would suggest, molten carbonate fuel cells operate at astoundingly hot temperatures, reaching upwards of 1,200 degrees F. The use of salt carbonates as the electrolyte requires an incredibly hot temperature to be maintained in the cell. Such exceedingly hot temperatures would make maintenance very difficult and would be very hazardous to those in the vicinity of the cell.




Molten Carbonate fuel cells can produce upwards of 2 MW of energy, but their heat makes them incredibly difficult to operate near.

### Solid Oxide Fuel Cells

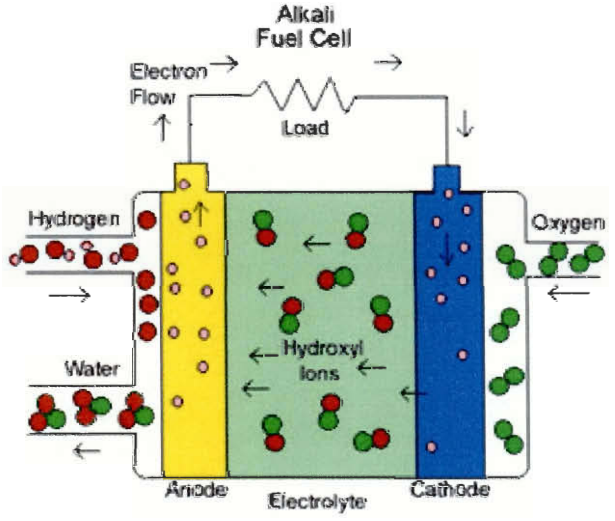
For the same reason as molten carbonate fuel cells, solid oxide fuel cells run at even higher temperatures, reaching 1,800 degrees F, to support their metal oxide electrolyte. Also, they tend to be very massive, which would pose problems for facilities with physical limitations.




Only producing upwards of 100kW, solid oxide fuel cells are not worth the extreme heat produced.

## Alkali Fuel Cells

Alkali fuel cells use the chemical potassium chloride (KOH) as an electrolyte. Though their operating temperature is more tolerable at about 300-400 degrees F, they do not produce great power output ranging from 300W to 5kW. Anti-corrosive parts add to the cost of these cells, and if damaged, may leak their harmful electrolyte.




Alkali fuel cells do not produce enough energy for large institutional use, and could leak their dangerous contents to the environment.

## Feasible Fuel Cells

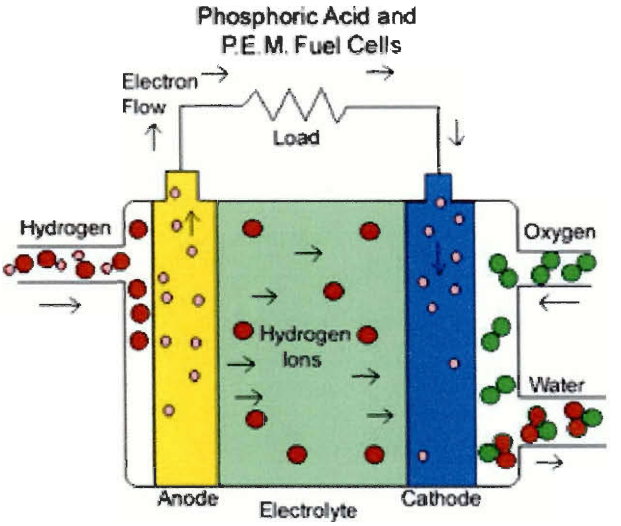
The following fuel cells may be practical for use in a commercial situation.

## Phosphoric Acid Fuel Cells

Phosphoric acid fuel cells contain phosphoric acid as an electrolyte. Operating temperatures are a manageable 300-400 degrees F, and produce energy at levels of 200kW to 11MW.

## Proton Exchange Membrane Fuel Cells

Proton exchange membrane fuel cells differ from their counterparts in that they use a thin polymer sheet as an electrolyte, rather than a liquid chemical. Operation temperatures are a very reasonable 175 degrees F, and can produce energy in the range of 50kW to 250kW.




The power outputs and reasonable temperatures make phosphoric acid and proton exchange membrane fuel cells practical for an institution such as the EcoTarium.

## *Appendix A.16: Cogeneration Manufacturers*

ADVANCED ENERGY SYSTEMS INC.

Advanced Energy Systems

***Established in 1970, Advanced Energy Systems, Inc. is an Energy Services Company that has the experience to fully understand the importance of reliable, affordable energy resources for us all. Time tested know how combined with innovative solutions have been the hallmark of Advanced Energy Systems for the last thirty-one years. Our real-world perspective of today's energy markets and their effect on energy consumers of all sizes enable us to provide complete systems and solutions that will optimize our clients energy position both now and in the future. Whether it is combined heat and power, lighting systems, energy management, energy consultation or design/build projects, AES will make sure you have the power to profit.***

**Business type:** Energy Analysis, combination heat and power systems , consulting, construction. Full turn-key systems.

**Product types:** Combination Heat and Power Systems, cogeneration systems, backup power systems.
**Service types:** turn key cogeneration systems, design, installation, and service
**Address:** 1350 F Street, Fresno, California USA 93706
**Telephone:** (559) 237-1044
**FAX:** (559) 237-2867
**Web Site:** http://www.aesprovensolutions.com
**E-mail:** Send Email to Advanced Energy Systems

AKASYA BPV Akasya BPV, Inc.

***We are Mechanical Engineers and Metal Fabricators. We are ASME U,S, and PP Stamp holders as well Industrial Valve makers. We make components for the Energy Industry including but not limited to Geothermal Systems, Wind Systems, Cogeneration. We also do project development and turnkey for mini energy systems such as mini hydro, cogenearation and distributed processing.***
**Business type:** manufacturer
**Product types:** heat exchangers, biomass energy boilers, cogeneration systems, geothermal energy system components, hydro energy systems (large), wind energy system components (large).
**Address:** Building 15 Gridley Road,, SRG, Subic Bay Freeport Philippines 2222
**Telephone:** +63 2 633 3013
**Web Site:** http://www.akasyabpv.com
**E-mail:** Send Email to Akasya BPV, Inc.

Capstone Turbine Corp.

***FT Energy award-winner Capstone has shipped 2,000 30- and 60-kW commercial microturbine power systems for applications ranging from hybrid electric vehicles to converting landfill gas and other waste gases into electricity. The systems are CSA, CE and UL-Listed (2200 and 1741), have just one moving part, use no oil, no lubricants, no coolants and are designed to operate at continuous full load or load-follwing (down to 0 kW idle) 24/7/365, on or off grid. NOx emissions are significantly below any US and foreign standards. These lightweight, compact microturbines can be multipacked into n+x arrays of up to 100 units with no paralleling switchgear, all with single-point-access dispatching/diagnostics. Conforms to IEEE and ANSI specs; UL 1741/CA Rule 21 compliant grid interconnect functionality (including protective relays) is built in. 8,000-hour annual maintenance comprises air and fuel filter inspection/replacement; temp sensor and ignitor every two years. En!! gine overhaul suggested at 40,000 hours. Fuels: natural gas, propane, high and low Btu waste gases (as low as 350 Btu) with up to 7% hydrogen sulfide content, diesel and kerosene.***
**Stock Symbol:** Nasdaq : CPST
**Business type:** manufacturer

**Product types:** micro-cogeneration systems, gas microturbine electric generators, hybrid electric vehicle power systems.
**Address:** 21211 Nordhoff Street, Chatsworth, California USA 91311
**Telephone:** 818-734-5300
**FAX:** 818-734-5320
**Web Site:** http://www.microturbine.com
**E-mail:** Send Email to Capstone Turbine Corp.

ELETTRONICA SANTERNO Elettronica Santerno S.p.a.

***Thanks to a skilled technical team and to the use of a wide range of advanced technologies, Elettronica Santerno can offer a comprehensive range of innovative, high quality, EEC standard compliant products.***
**Business type:** manufacturer, research institution
**Product types:** cogeneration systems, DC to AC power inverters, DC to DC power converters, photovoltaic systems, solar water pumping systems.
**Service types:** project development services, research services
**Address:** Via G.Di Vittorio 3, Casalfiumanese, Bologna Italy 40020
**Telephone:** 0039 0542 687711
**FAX:** 0039 0542 687722
**Web Site:** http://www.elettronicasanterno.it
**E-mail:** Send Email to Elettronica Santerno S.p.a.

PES. Pacific Power Solutions, Inc

***We are a developer, integrator and funder of energy generation, conservation and wastewater systems. We offer turnkey design build projects from cogeneration and thermal storage to photovoltaic and wind based systems and hybrids. PPS is focused to developing environmentally friendly highly reliable certified power generation and energy conservation systems to the market.***
**Business type:** Distribution, development, engineering, integration, 100% funding, turnkey construction
**Product types:** cogeneration systems, gas and steam turbine driven electric generators, reciprocating engine generators, fuel cells, thermal storge systems, investment and financial services, industrial wastewater treatment systems.
**Service types:** Pratt & Whitney, Kawasaki, Vericor gas turbine generators, UT fuel cells, Blue Point ultra low NOx recip cogeneration, C.E.Rogers dairy and wastewater systems, Cistropia Thermal Storage, Thermax Absorbtion and Nishiyodo Adsorbtion Chillers
**Address:** 500 Oxford Court, Carson City, Nevada USA 89703
**Telephone:** 775-841-6194

**FAX:** 775-841-6206
**Web Site:** http://www.pacificpowersolutions.com
**E-mail:** Send Email to Pacific Power Solutions, Inc


VECTOR CoGen LLC

***Generate your own power. VECTOR CoGen LLC, 4800 Arrowhead Dr. Carson City, Nevada announces cogenerator systems that produce 3, 5, 10, and 20 KW for less than .05 /KWH! Also producing up to more than 90,000 BTU's of heat. These systems are powered by KAWASAKI ultra long life engines. only need service once a year, 3 year limited warrantee, 3KW and 5KW units are only 20 inches tall, 30 inches wide and 40 inches deep. Natural gas, Propane, Butane or Gasoline powered. DEALERS WANTED, secure your territory NOW.***
**Business type:** manufacturer
**Product types:** cogeneration systems.
**Address:** 4800 Arrowhead Dr., Carson City, Nevada USA 89706
**Telephone:** 775-883-4470
**Web Site:** http://www.vectorcogen.com
**E-mail:** Send Email to VECTOR CoGen LLC

Appropriate Building Solutions
**Product types:** alternative home and building construction materials, alternative homes and buildings, solar electric power systems, solar water heating systems.
**Service types:** contractor services
**Address:** 195 Rippling Water Lane, Blowing Rock, North Carolina USA 28605
**Telephone:** 828-268-0032
**Web Site:** http://www.buildsustainable.com
**E-mail:** Send Email to Appropriate Building Solutions

CIDETE INGENIEROS SL
***Engineering and Thermoelectric Manufacture, Seebeck effect modules for Power Generation, Cathodic Protection systems. Cooling devices, Automobil TE Technology applications. Prototype developments. Consulting. Peltier devices. FREE THERMOELECTRIC PROJECT CONSULTING ADVISORS If you have a doubt about Thermoelectrics..... we are here! Office in Beijing (China), Barcelona (Spain), Miami (USA)***
**Business type:** manufacturer, exporter
**Product types:** cathodic protection systems, heat pumps, water cooling systems, air cooling systems, cogeneration systems, solar air heating system components, Thermoelectric Cooling Devices.

**Address:** c/ Anselmo Clave, 98, Vilanova i la Geltru, Barcelona Spain 08800
**Telephone:** 34 938157003 - 34 676863424 mobil
**Web Site:** http://www.arrakis.es/~cidete
**E-mail:** Send Email to CIDETE INGENIEROS SL

GIACOMO & CIDETE TECHNOLOGIES SL
***Engineering Consulting Advisors. Calorimeter manufactures, Thermoelectric Cooling Technlogy. Apace Applications. Military Application Technology. Cryogenic Systems. Vest cooling and Liquid cooling technology. Air to Air Cooling. Cogeneration, European Researchers.Skutterudite materials http://www.nanothermel.org***
**Business type:** manufacturer, exporter
**Product types:** telecommunications power systems, hybrid power systems, solar water heating systems, energy efficient appliances, remote home power systems, cogeneration systems, Building Heat Flux meassure equipment - Calorimeters Peltier Effect Devices.
**Address:** c/ Anselmo Clave, 98, Vilanova i la Geltru, Barcelona Spain 08800
**Telephone:** 34 938157003 - 34 676863424 mobil
**Web Site:** http://www.arrakis.es/~cidete/ingles.htm
**E-mail:** Send Email to GIACOMO & CIDETE TECHNOLOGIES SL
Hess Microgen

***Hess Microgen is the world's leading provider of packaged cogeneration. A wholly owned subsidiary of Amerada Hess, a Fortune™ 200 company, Hess Microgen provides the most reliable, economical, and environmentally-friendly combined heat and power systems available.***
**Business type:** manufacturer, retail sales, wholesale supplier
**Product types:** cogeneration systems.
**Address:** 12 Industrial Parkway, Carson City, Nevada USA 89706
**Telephone:** 775-884-1000
**FAX:** 775-884-3417
**Web Site:** http://www.hessmicrogen.com
**E-mail:** Send Email to Hess Microgen

M&I Power Technology
**Business type:** manufacturer
**Product types:** air filtering and purification systems, air cooling systems, cogeneration systems, steam turbine electric generators, Air filters, Evaporative cooling and fogging systems.
**Service types:** design, manufacturing, installation
**Address:** 3614 Mossville Ct., Houston, Texas USA 77068
**Telephone:** 281-610-0738
**FAX:** 281-580-3467
**Web Site:** http://www.mipowertechnology.com
**E-mail:** Send Email to M&I Power Technology

Nanothermel Group
***Engineering Research Group - EC Project Nanothermel Skutterudite Technology Expertise group.***
**Business type:** research institution
**Product types:** cathodic protection systems, hybrid power systems, photovoltaic cell materials, energy efficient appliances, electric vehicle components, cogeneration systems, New Thermoelectric Materials Skutterudites technology Z>3.
**Address:** c/ Anselmo Clave, 98, Vilanova i la Geltru, Barcelona Spain 08800
**Telephone:** 34 938157003 - 34 676863424 mobil
**Web Site:** http://www.nanothermel.org
**E-mail:** Send Email to Nanothermel Group

OmniTrans
**Business type:** manufacturer
**Product types:** cogeneration systems, alternative fuel vehicles, fuel powered electric generators, backup power systems.
**Address:** 9601 North Broadway Extension, Oklahoma City, Oklahoma USA 73114
**Telephone:** 405-840-2622
**FAX:** 405-840-3969
**Web Site:** http://www.cngvehicle.com
**E-mail:** Send Email to OmniTrans

SCHMITT ENERTEC GmbH
***SCHMITT ENERTEC is manufacturer of Cogeneration units from 20 - 300 kWe with internal combustion engines. SCHMITT ENERTEC CHP units are availible for Natural gas, biogas, propane, or diesel fuel. The benefits are compact design, efficient and reliable engine technology and longevity availible for a god price/performance ratio. SCHMITT ENERTEC is also dealing with gasification systems for woody biomass.***
**Business type:** manufacturer
**Product types:** cogeneration systems, biomass energy systems.
**Address:** Kottenheimer Weg 37, 56727 Mayen, Germany
**Telephone:** 0049 2651 409310
**Web Site:** http://www.schmitt-enertec.com
**E-mail:** Send Email to SCHMITT ENERTEC GmbH

Schonauer Energie-Initiativen
**Business type:** manufacturer
**Product types:** cogeneration systems.

**Address:** Ledergasse 5, Schoenau, Germany D - 79675
**Telephone:** +49-7673-931578
**Web Site:** http://www.oneworldweb.de/schoenau/
**E-mail:** Send Email to Schonauer Energie-Initiativen

Spillingwerk GmbH
**Business type:** manufacturer
**Product types:** Steam Engines 60 - 1500 kW, Steam Engine Generating Sets, Cogeneration Power Plants, Biomass Power, Waste to Energy, Natural Gas Expansion Power Generation, Steam Compressors.
**Address:** Werftstrasse 5, Hamburg, Germany 20457
**Telephone:** ++49 - (0)40 - 789 1750
**FAX:** ++49-(0)40-7892836
**Web Site:** http://www.spilling.de
**E-mail:** Send Email to Spillingwerk GmbH

American Photovoltaics & Homes, Ltd.
**Business type:** manufacturer, wholesale supplier, retail sales
**Product types:** Environmentally Friendly & Renewable Energy Homes, energy efficient buildings, alternative construction..
**Address:** 5951 Riverdale Avenue-Box 1199, Riverdale, New York USA 10471
**Telephone:** (718) 548-0428

Bowman Power Systems Ltd
**Business type:** manufacturer, supplier
**Product types:** microturbines, cogeneration systems, high speed alternators, power electronics supplier.
**Address:** Ocean Quay Marina, Belvidere Road, Southampton, United Kingdom SO14 5QY
**Telephone:** +44 23 80 236700
**FAX:** +44 23 80 212110

CITIC Heavy Machinery Company Ltd.
**Business type:** manufacturer, wholesale supplier, service, exporter, engineering, financial services
**Product types:** power plant equipment, steam turbine electric generators, gas turbine electric generators, cogeneration systems, hybrid power systems.
**Address:** 206 Jianshe Road, Luoyang City, Henan China 471039
**Telephone:** +86-379-4218067 +86-379-4218711-5455
**FAX:** +86-379-4218509 +86-379-4218067

Cethar Vessels Limited
***We supply FBC boilers. We have been actively involved in the development and popularising of fbc technology in the country from a early and today in the field of fbc boilers we have emerged at the top in the country with more than 700 boilers to our credit.Out of this, about 100 boilers are in the capacity range of 20-125 tph, and some more in execution. Also we do the retrofit of existing inefficient boilers into high efficient cethar fluidix fbc system. We can also supply power plants(capative&co-generation) on turnkey basis upto 20mwe capacity. Now we look forward to the pleasure of having association with you for your proposed boilers,captive and co-generation power plant. So we reqest you to please float your most valued enquiry on us to enable us to serve you.***
**Business type:** manufacturer, exporter
**Product types:** biomass energy boilers, biomass energy boilers, biomass energy systems, biomass energy furnaces, cogeneration systems, cogeneration system components.
**Address:** 2006, Emerold House, S.D.Road, Secunderabad, Secunderabad, A.P. India 500003
**Telephone:** 7818946, 7815920
**FAX:** 7815920
**E-mail:** Send Email to Cethar Vessels Limited

CoPower
**Business type:** manufacturer, retail sales, wholesale supplier, financial services, Corporate Finance, Sales and Marleting Consultants
**Product types:** portable power systems, alternative fuel vehicles, hydro energy system components (small), energy efficient homes and buildings, backup power systems, cogeneration systems, Hydrogen Fuel Cells & Hydrogen Sensors.
**Address:** 23350 Water Circle, Boca Raton, Florida USA 33486
**Telephone:** 561-338-3390
**FAX:** 561-394-9695

Coast Intelligen, Inc.
**Business type:** manufacturer
**Product types:** cogeneration systems.
**Address:** 2460 Ash Street, Vista, California USA 92083
**Telephone:** Sales inquiries 877-34 COAST
**FAX:** (760) 597-2999

Cogeneration Consultants
**Business type:** manufacturer

**Product types:** Turn-key cogeneration and trigeneration systems, gas and steam turbine gensets, energy enginering, thermal engineering, economic/life-cycle studies, cogeneration and trigeneration feasibility stidies.
**Service types:** consulting, engineering
**Address:** 68307 East Palm Canyon Drive, Cathedral City, California USA 92234
**Telephone:** 760-202-2823
**FAX:** 760-202-2842

Cooper Electric Supply Company
**Business type:** manufacturer, retail sales, service, exporter, contractor, construction, engineering
**Product types:** fuel powered electric generators, cogeneration systems, cogeneration system components, packaged power systems, alternative home and building construction materials, emergency backup batteries, Y2K and emergency preparedness supplies.
**Address:** 1924 Heck Avenue, Neptune, New Jersey USA 07753
**Telephone:** 732-774-1058 or toll free 800-216-7851
**FAX:** 732-774-8334

ENER-G Combined Power Limited
**Business type:** manufacture, service and operation
**Product types:** Cogeneration Systems/ Combined Heat and Power Total Energy Management.
**Service types:** design, installation, construction, engineering, site survey and assessment, maintenance, repair services
**Address:** ENER-G House, Daniel Adamson Road, Manchester, United Kingdom M50 1DT
**Telephone:** +44 0161 745 7450
**FAX:** +44 0161 745 7457

Energie fei inc
**Business type:** manufacturer
**Product types:** biomass energy systems, steam turbine electric generators, cogeneration systems, Dry kiln.
**Service types:** consulting, engineering, project development services
**Address:** 2155 Bombardier, Ste-Julie, Quebec Canada J3E2J9
**Telephone:** 450-922-3117
**FAX:** 450-922-4885

Energy Products of Idaho (EPI)

**Business type:** manufacturing, engineering, technology developer, pilot plant studies, fuel handling, and emissions control
**Product types:** fluidized bed biomass combustors, fluid bed biomass boilers, and fluid bed biomass gasifiers.
**Address:** 4006 Industrial Avenue, Coeur d'Alene, Idaho USA 83815
**Telephone:** (208) 765-1611
**FAX:** (208) 765-0503

Entropic Energy Corp.
**Product types:** biomass energy systems, cogeneration systems.
**Service types:** engineering
**Address:** 106 - 1656 Martin Drive, Suite 189, White Rock, BC Canada V4A 6E7
**Telephone:** 1-604-538-3033
**FAX:** 1-604-538-3553

Genergy Power Solutions
**Business type:** manufacturer, exporter
**Product types:** fuel powered electric generators, cogeneration systems, packaged power systems, telecommunications power systems, backup power systems, biomass energy systems, power generation switchgear, monitoring and control equipment, communications equipment.
**Service types:** installation, project development services, research services
**Address:** P.O. Box 3377, Roswell, New Mexico USA 88202-3377
**Telephone:** 505-623-3700
**FAX:** 505-623-9003

Hurst Boiler and Welding Co., Inc.
**Business type:** manufacturer, wholesale supplier, service, exporter, contractor, construction, engineering
**Product types:** biomass energy boilers, biomass energy furnaces, biomass energy system components, biomass energy systems, cogeneration systems, wood burning stoves and furnaces.
**Address:** 21971 US Hwy 319 South, Coolidge, Georgia USA 31738
**Telephone:** (229)346-3545 x 139
**FAX:** (229)346-3874 Attn. Gene Z.

Ingersoll Rand Energy Systems
**Business type:** manufacturer
**Product types:** gas turbine electric generators, cogeneration systems, biomass energy systems.
**Address:** 800-D Beaty Street, Davidson, North Carolina USA 28036
**Telephone:** 704-896-5373

**E-mail:** Send Email to Ingersoll Rand Energy Systems

Innovative Energy Solutions Pvt. Ltd.
**Business type:** manufacturer, wholesale supplier, exporter
**Product types:** solar water heating systems, solar cooking systems, solar pool heating systems, cogeneration systems, tankless water heating systems, water cooling systems, waste heat recovery systems .
**Service types:** consulting, design, installation, project development services, education and training services, research services, site survey and assessment services, contractor services, maintenance and repair services, recycling services
**Address:** Bg-7/69, Paschim - Vihar, New Delhi-110063, India 110063
**Telephone:** 5275390
**FAX:** 5275390

JX Crystals, Inc.
**Business type:** manufacturer
**Product types:** cogeneration systems, cogeneration system components, photovoltaic cells, thermophotovoltaic cells and systems, gallium antimonide photovoltaic cells.
**Address:** 1105 12th Avenue NW Suite A2, Issaquah, Washington USA 98027
**Telephone:** 425-392-5237
**FAX:** 425-392-7303

Next Step Energy Systems
**Business type:** manufacturer, retail sales, wholesale supplier, exporter
**Product types:** energy efficient appliances, backup power systems, lead acid batteries, renewable energy system batteries, cogeneration systems, DC to AC power inverters, infloor radiant heating.
**Service types:** consulting, design, installation, construction, project development services, site survey and assessment services, contractor services, maintenance and repair services
**Address:** 30497 Chippewa Trl, New Auburn, Wisconsin USA 54757
**Telephone:** 888-926-1603
**FAX:** 715-967-2730

Pressels Private Limited
**Business type:** manufacturer
**Product types:** cogeneration systems, biomass energy boilers, cogeneration system components.
**Address:** Madhupatna, Cuttack, Orissa India 753010
**Telephone:** 00-91-0671-344746
**E-mail:** Send Email to Pressels Private Limited

Quasiturbine Agence Inc.
***New efficient and environment friendly rotary engine. Internal combustion, steam, air, pneumatic, Stirling, all fuels compatible including hydrogen. Ideal for combined power and heat cycle.***
**Business type:** manufacturer
**Product types:** hybrid power systems, gas turbine electric generators, solar electric power systems, alternative fuel vehicles, biomass energy systems, cogeneration systems, Pneumatic Air Steam gasoline or diesel rotary engine.
**Address:** Casier 2804 - 3535 Papineau, Montreal, Quebec Canada H2K4J9
**Telephone:** 514-527-8484
**FAX:** 514-527-9530

S.T.E. srl
***S.T.E. designs, builds as "General Contractor" and can subsequently undertake the routine management of Energy production plants as hydroelectric powerplant, biomass and cogeneration plants. S.T.E. offers its customers a Global Service with Turnkey solutions. It has long been operating as a General Contractor and can therefore construct the most diverse projects on schedule and according to plan, offering every possible guarantee regarding required performance. • Preliminary and final projects. • Construction of foundations, river bed constructions and civil engineering work. • Penstocks. • Electro mechanical construction (Turbines, Generators, Electrical Equipment, Mechanical Equipment). • Plant Assembly. • Start up and commissioning. • Financing solutions.***
**Business type:** manufacturer
**Product types:** Hydroelectric Powerplants: "Turnkey" solution, Water to wire, Turbines, Generators, Electrical Equipment, MV & LV Switchgears, Automation Systems, SCADA.....
**Service types:** Turnkey Supplier
**Address:** via Sorio 120, Padova, Italy Italy 35141
**Telephone:** +39 049 2963900
**FAX:** +39 049 2963901

Shimshon Renewables
**Business type:** manufacturer
**Product types:** cogeneration systems, geothermal energy systems, solar electric power systems, hydro energy systems (large), solar air heating systems.
**Service types:** consulting, design, installation, engineering, project development services, financial services, maintenance and repair services, recycling services
**Address:** M-10/1697, M.H.B., Yerwada, Pune, Maharashtra India 411006
**Telephone:** 0091-20-6685351
**FAX:** 0091-20-6685351

Solar Turbines Incorporated

**Business type:** manufacturer
**Product types:** gas turbine electric generators, cogeneration systems.
**Address:** Harbor Drive Facility, 2200 Pacific Highway, San Diego, California USA 92101
**Telephone:** 619-544-5000
**FAX:** 619-544-2849

Sonat Power Systems
**Business type:** manufacturer
**Product types:** fuel powered backup generators, cogeneration systems, gas microturbine electric generators.
**Address:** 1900 5th Ave North, Birmingham, Alabama USA 35203
**Telephone:** 205-326-2085 or toll free 888-KWTURBO
**FAX:** 205-325-3812

TECNOLOG s.a.
**Business type:** manufacturer, exporter
**Product types:** Watertube APIN Boilers , cogeneration systems, biomass energy systems, biomass energy boilers, heat exchangers, steam turbine electric generators, water heating systems.
**Address:** Av. Venezuela 2005, Lima, Lima Peru 001
**Telephone:** (511) 946-6008
**FAX:** (511) 337-7247

Transparent Energy Systems Pvt. Ltd.
**Business type:** manufacturer, exporter
**Product types:** cogeneration systems, heat exchangers, air cooling systems, air heating systems, waste treatment systems, water heating systems, Ammonia Absorption Refrigeration Plant.
**Service types:** consulting, design, installation, engineering, project development services, recycling services
**Address:** 1st floor, Pushpa Heights, Bibwewadi Corner, Pune-Satara Road, Pune, Maharashtra India 411 037
**Telephone:** 91-20-4215665/4211347
**FAX:** 91-20-4212533

Turbosteam
**Business type:** manufacturer, service, exporter, engineering, packager of cogeneration systems
**Product types:** cogeneration systems, packaged power systems, steam turbine electric generators.
**Address:** 161 Industrial Blvd., Turners Falls, Massachusetts USA 01376
**Telephone:** 413-863-3500
**FAX:** 413-863-3157

WADE -World Alliance for Decentralized Energy
**Business type:** trade association
**Product types:** cogeneration systems, cogeneration system components, gas turbine electric generators, fuel powered electric generators, biomass energy systems, air cooling systems.
**Address:** 15 Great Stuart Street, Edinbugh, Lothian Scotland EH3 7TP
**Telephone:** +44 131 625 3333
**FAX:** +44 131 625 3334

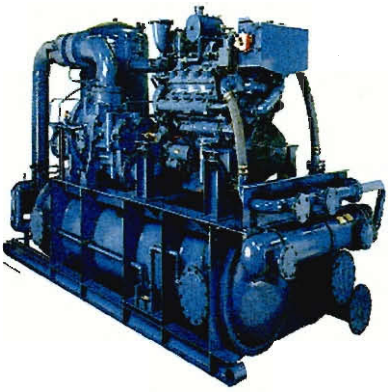
Wilmott Brothers Power Systems Ltd
**Business type:** manufacturer
**Product types:** alternative fuel vehicles, biomass energy systems, cogeneration systems, heat exchangers, packaged power systems, uninterruptable power supplies ups, gas fuelled locomotives, gas fuelled generators, air /fuel ratio controls,detonation control,generator control panels..
**Service types:** design, installation, engineering, project development services, research services, site survey and assessment services, maintenance and repair services
**Address:** Manners Ind Est , Manners Avenue, Ilkeston, Derbyshire United Kingdom DE7 8EF
**Telephone:** 0044 (0)115 932 2651
**FAX:** 0044(0)115 944 0603

Ztek Corporation
**Business type:** manufacturer
**Product types:** fuel cell systems, cogeneration systems.
**Address:** 300 W. Cummings Park, Woburn, Massachusetts USA 01801
**Telephone:** (781) 890-5665
**FAX:** (781) 890-3731

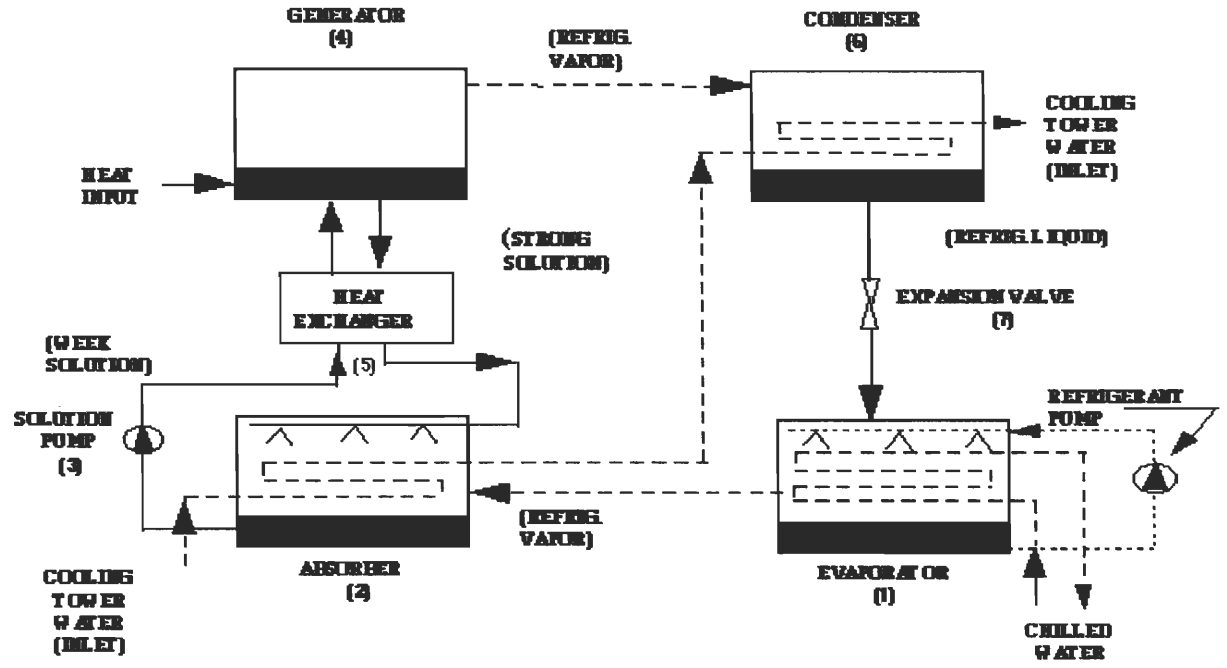
## *Appendix A.17: How natural gas works in cooling*

- Natural gas cooling technologies have existed for many years. However, due to high initial costs of equipment, cooling with natural gas has not been widely accepted.
- Today, with deregulation, and the drop in the cost of natural gas for commercial and industrial consumers, natural gas cooling is becoming widely accepted as an economically-viable alternative to the conventional electrically driven cooling systems.
- There are three primary types of natural gas cooling technology.
    1. *GAS ENGINE DRIVEN COOLING*
    2. *ABSORPTION COOLING SYSTEMS*
    3. *DESICCANT DEHUMIDIFICATION*

- ***Gas Engine Driven Chillers*** have been marketed in the United States since 1960. Gas Engine Driven Cooling Systems use natural gas-fueled internal combustion engines which drive the compressors in conventional vapor compression refrigeration systems. Natural gas fueled engines can be used to drive chillers and direct expansion systems. An engine driven chiller is similar to an electric motor except the motor that drives an electric chiller is replaced by a gas engine. An open drive configuration is required since the engine must be housed outside the compressor casing. Waste heat from the engine can be used for service water heating. Furthermore, it can be used as a steam provider for an absorption chiller unit. Gas Engine Driven Cooling units range in capacity from 2100 ton water cooled centrifugal chillers to 3 ton residential heat pumps which operate in the same maner as the conventional vapor compression cycle. Performance of engine-driven chillers is the function of the gas-engine efficiency and the compressor Coefficients of Performance (COP). Generally, the COPs for engine-driven chillers are slightly higher than those for absorption chillers.

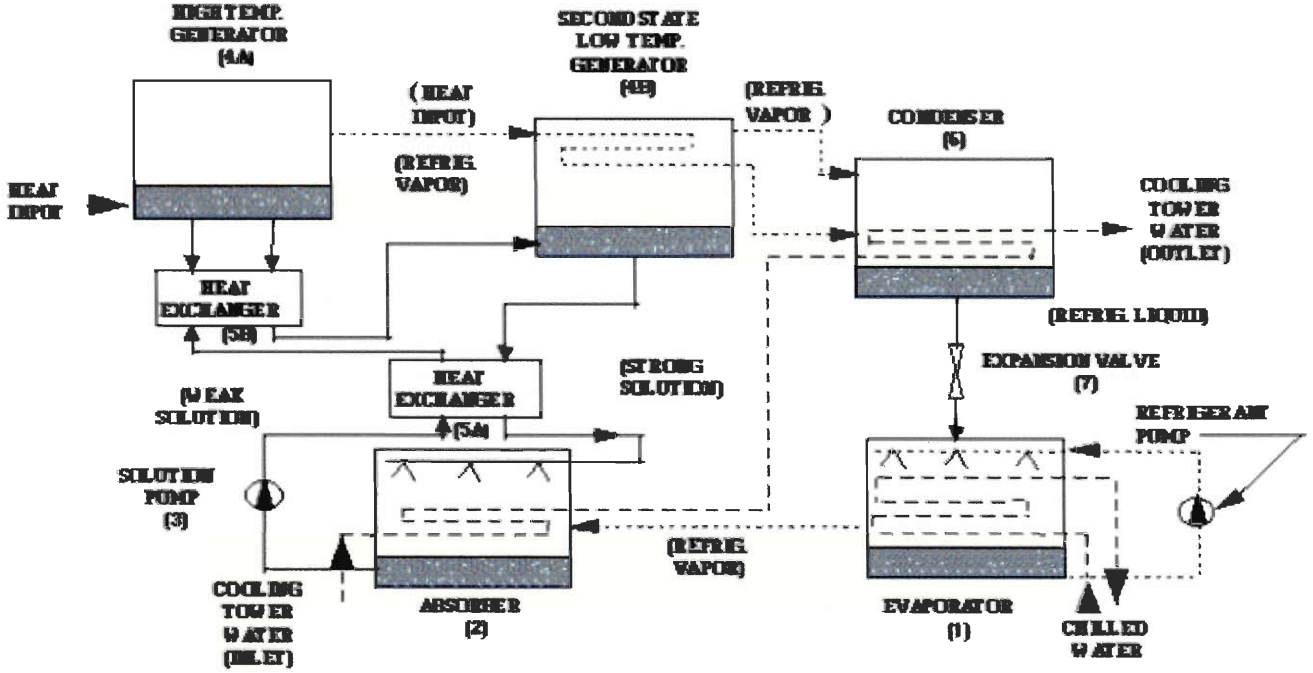


- ***Absorption Cooling Systems*** have been on the market for over a 100 years. In the late 1800's, absorption chillers were used for large refrigeration plants. During the 1950's, technological advances occured, and the systems were fine-tuned for commercial use. Popularity declined in the late 1970's due to the inexpensive cost and abundance of electricity.
- Similar to the vapor compression-cycle, absorption chillers rely on a cycle of condensation and evaporation to produce cooling. Both systems have an evaporator and condenser coil which expands the refrigerant from high to low pressure between the condenser and evaporator. The mechanical compressor of the vapor-compression cycle of condensation and evaporation is replaced by a heat source in the absorption chiller. This heat source is either direct fired using a burner or indirect fired using steam, hot water, or waste heat from other processes. Most absorption systems use a water and lithium bromide combination as the working fluid.
- Absorption chillers are available in two types. The first, a single-effect, operates with low-grade waste heat. The second, double-effect, requires direct firing or high grade steam as the heat source.
- In addition, natural gas absorption chillers have low COPs as compared to the electric chiller. Often, the absorption chiller is cost effective and is environmentally correct.

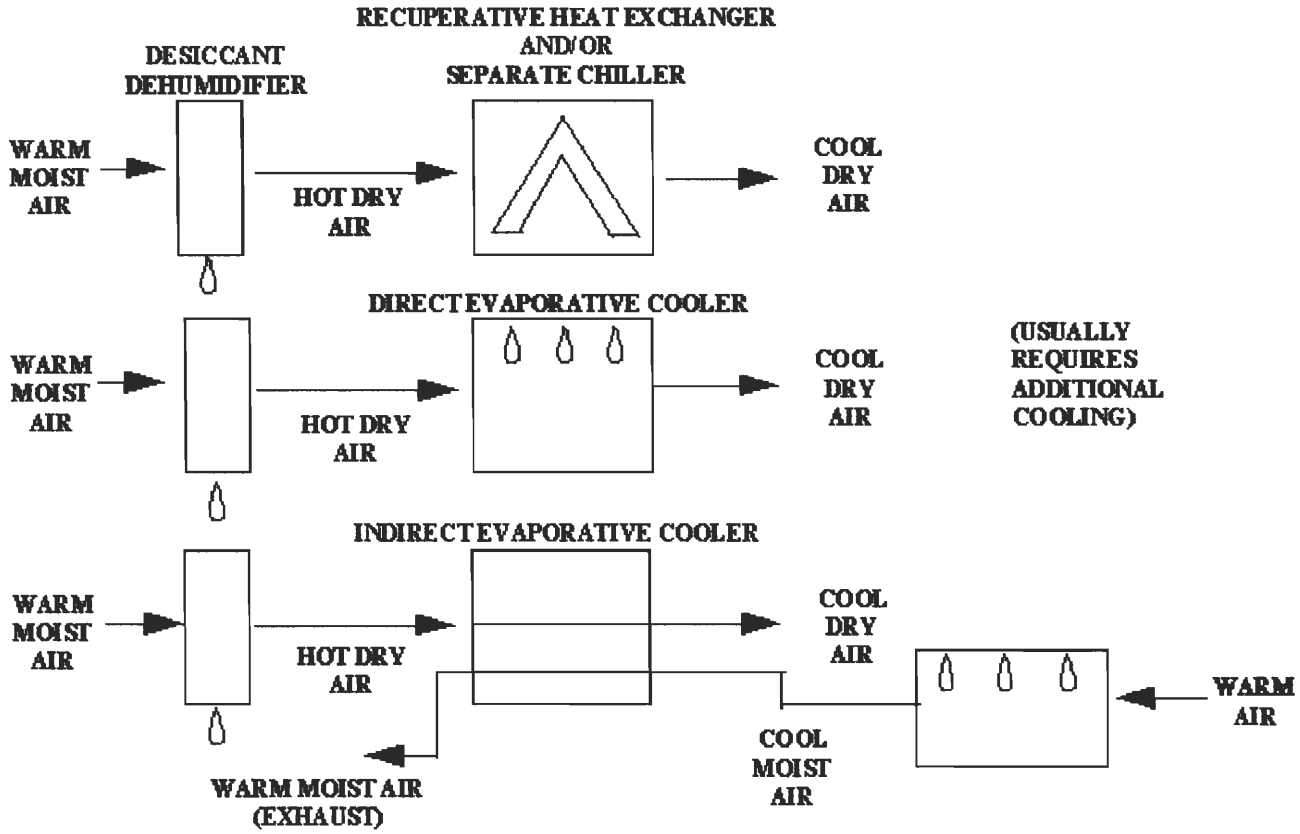



Single-effect absorption system

Double-Effect Absorption system



- ***Desiccant Dehumidification Systems*** use solid or liquid desiccant materials to remove moisture from the air. Common desiccants are lithium chloride, silica gel, and molecular sieve. As the air passes through the desiccant, the latent heat load is converted to warm, dry air. This air is then cooled to the desired air temperature. Desiccant dehumidification cooling reduces humidity by removing moisture from the air. Desiccant systems are heat actuated devices that remove moisture from the air. However, when combined with other components, it becomes a sensible cooling device.
- Dessiccant dehumidification systems normally operate in conjunction with a natural gas or an electric chiller.

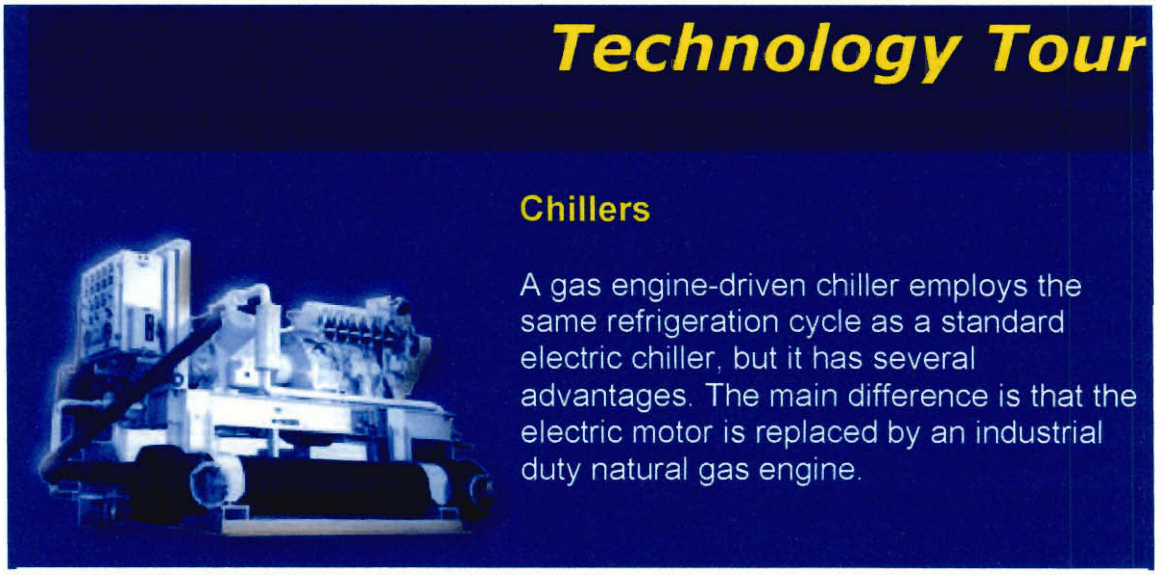



- Since Desiccant Systems remove moisture from the air, they reduce mold, mildew, and bacteria growth. Through this process, condensation is eliminated and the humidity is reduced. Operating costs are reduced because comfort cooling levels are achieved in low humid conditions and a higher chiller temperature set-point which results in significant energy cost savings. Furthermore, the higher chiller temperature set-points permits the use of desiccant cooling system chillers that are downsized. Reducing chiller sizes could yield significant cost savings. By adding a desiccant system, the chiller's capacity to meet the cooling load can be extended.
- Desiccant systems have been used extensively in industrial applications for many years. Recent focus on environmental issues of CO2 global warming, chlorine

depletion of the ozone layer, and improved air quality have sparked an interest in desiccant dehimidification and cooling.

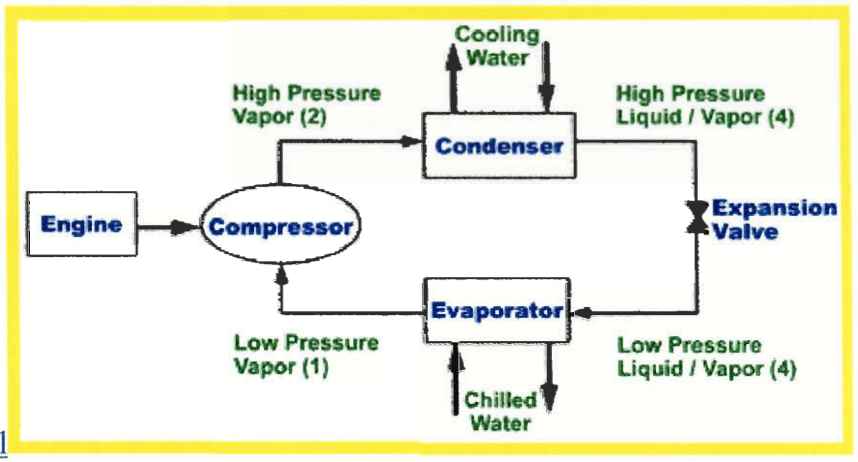
- Additionally, desiccant systems that utilize natural gas as the energy source is less costly to operate than electric driven machines. Desiccant systems provide great benefit to facilities such as commissaries, bachelor officer/enlisted quarters, and health care facilities.

http://www.equitablegas.com/tech/ngcool.htm#whatis



**The four main steps in this cycle are** (see diagram below):

| | |
|---|---|
| **1** | The compressor raises the pressure of low pressure refrigerant to a high pressure. This process is shown from (1) to (2). The higher pressure refrigerant now has a higher saturation temperature. |
| **2** | The condenser removes heat from the high-pressure vapor, allowing it to condense to liquid at the higher temperature. Heat is rejected to the cooling water. The process is shown (2) to (3). |
| **3** | The expansion valve reduces the pressure of the liquid refrigerant. Because the pressure is reduced, the saturation temperature is reduced. Some liquid flashes to vapor in the process. This process is shown from (3) to (4). |
| **4** | The evaporator supplies heat to the refrigerant from the chilled water. This boils the refrigerant at the lower temperature and pressure. By removing heat from the chilled water steam, the chilled water is cooled. This process is shown from (4) to (1). |




**http://www.energysolutionscenter.org/techtour/TechTour.htm

## *Appendix A.18: Possible Microturbines*

1) Capstone
2) Honeywell Power Systems (these two make up 90% of the market)
3) Elliott Energy systems
4) Ingersoll-Rand Energy Services (formerly Northern Research Engineering Corporation)
5) Turbec (joint venture of ABB and Volvo)

Most of these microturbines range from 50-300 kW per unit and come with a price tag of $750 -$900 per kW. They also have a significant lower amount of emissions then the normal cogeneration engine.

## *Appendix A.19: Current System Breakdown*

Appendix not included
in original submission

# IQP/MQP SCANNING PROJECT

## *Appendix A.20: Emissions break down*

Appendix not included
in original submission

# IQP/MQP SCANNING PROJECT

## *Appendix A.21: Floor Plan of EcoTarium*

Appendix not included
in original submission

# IQP/MQP SCANNING PROJECT

*Appendix A.22: Funding Granted For Previous Fuel Cell Use*

# Funding Granted For Previous Fuel Cell Use

| Location | Fuel Cell Type | Power Output | Use | Funding Receive |
|---|---|---|---|---|
| Woburn, MA | Proton Exchange Membrane | 5 kW | 500 hr reliability demonstration for Verizon | $400,0 |
| Braintree, MA | Phosphoric Acid | 200 kW | produce electricity using landfill gas | $300,0 |
| West Barnstable, MA | Phosphoric Acid | 200 kW | provides power to Cape Cod Community College | $200,0 |