Auburn, Massachusetts Wind Feasibility Study

An Interactive Qualifying Project Report:
Submitted to the Faculty
Of the

WORCESTER POLYTECHNIC INSTITUTE

In partial fulfillment of the requirements for the
Degree of Bachelor of Science
By

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Chapter 1: Introduction

As corporations and governments move towards sustainable practices, more emphasis is being placed on sustainable sources of energy. Ideally these sources will produce electricity by utilizing resources that are ever present in nature and will not harm the planet, while limiting our reliance on natural resources that cannot be replenished. For companies and towns, and more importantly the nation's population, electricity has become a necessity of modern living that can be very expensive depending on one's location and reliance on it. New sustainable technologies that create electricity and that can potentially be paid for through grants from the state and federal governments are the perfect solution to the energy needs for our cities and towns. One of the modern sustainable technologies that have come to the forefront is wind generation of power the history of which goes back a number of centuries. Wind is a natural resource that, unlike oil, will be forever present and will not have to be replenished. The town of Auburn, Massachusetts, is proposing to harness wind energy to create electricity by installing one or more wind turbines on town property. To start the process, the Town of Auburn's Alternative Energy Committee hired the Renewable Energy Research Laboratory in the spring of 2008 to conduct a site selection survey, funded by the Massachusetts Technology Collaborative (MTC). Subsequently, in the fall of 2009 the Alternative Energy Committee sent out a Request for Qualifications for companies to conduct a wind turbine feasibility study. This request was accepted and funded in February 2010 by the Massachusetts Renewable Energy Trust (MTC-RET).

1.1 Interdisciplinary Qualifying Project (IQP) Mission Statement

The purpose of this IQP was to produce a "second look" and assessment of the wind energy potential at a specific site in Auburn, to establish constraints and criteria, and to complete a cost-benefit analysis. Characterizing the site's wind energy potential required; researching Auburn's energy needs, interacting with the town chair, background research of the issue, and performing a trade study of wind turbines. To establish constraints and criteria, we examined social constraints such as; potential problems with neighbors, access road and entrance locations and anemometer placement. For our cost-benefit analysis, we studied different project implementations in terms of the turbine height, blade length, generator size, installation complexities and planning, and wind speeds. Through all the steps of this process we coordinated our work with the Auburn Wind Turbine & Alternative Energy Committee as well as the WPI Auburn Wind MQP Team.

1.2 Chapter Summary

This chapter has presented an overview of our project as well as our goals and objectives. In Chapter 2 we present pertinent background material and information needed to understand this project. Chapter 3 provides a methodology which outlines the steps that were taken in order to reach our results. The results and findings which provide the backbone for the final recommendation are found in Chapter 4. In Chapter 5 a final recommendation for total number of turbines, placement, generator size, and energy utilization is provided for the Auburn Wind Committee.

Chapter 2: Background & Literature Review

This section of the Interdisciplinary Qualifying Project provides significant background information that was necessary to understand how wind energy works. The following background helped identify the research areas that would ultimately aid in the final turbine recommendation to the Auburn Wind Committee.

2.1 History of Wind Power

The history of wind power shows a general evolution from the use of simple, "light devices driven by aerodynamic drag forces; to heavy, material-intensive drag devices; to the increased use of light, material-efficient aerodynamic lift devices in the modern era"(Dodge, 1996-2001). But it shouldn't be imagined that aerodynamic lift which is the force that makes airplanes fly, is a modern concept that was unknown to people during the ancient time period. The earliest known use of wind power, of course, is the sail boat, and this technology had an important impact on the later development of sail type windmills. Ancient sailors understood lift and used it every day, even though they didn't have the physics to explain how or why it worked.

The first sign of documented wind mill applications were grain grinding machines. The grinding stone was attached to the same vertical shaft. Vertical-axis windmills are claimed to have been created in China close to 2000 years ago. The earliest documentation of a Chinese windmill was in 1219 A.D. being used in grain grinding and water pumping.

The first wind mills had four paddle-like wooden blades. They were followed by mills with thin wooden slats nailed to wooden rims. Most of these mills had, "…tails that made them face the wind. Speed control of some models was provided by hinging sections of blades, so that they would fold back like an umbrella in high winds. The most important improvement of the American fan-type windmill was the development of steel blades in 1870"(Dodge, 1996-2001). Steel blades could be made lighter and modeled into more efficient shapes. They worked so well, in fact, that their high speed required a gear system to turn the standard reciprocal pumps at the required speed.

You have probably seen old, wooden windmills on a trip through rural or farmland areas. Some were used strictly for pumping water out of the ground, while "other systems provided a farm or ranch their electricity source where conventional power lines were not available in an area. The older versions were often made from wood and some metal parts, while newer versions were metal constructions. (Either way, they performed the same basic tasks)" (Dodge, 1996-2001).

Between 1850 and 1970, over six million mostly small (1 horsepower or less) mechanical output wind machines were installed in the U.S. The main use for the small output wind machines was for water-pumping and the primary applications were for livestock watering and farm house water needs. Very large windmills, with rotors up to 18 meters in diameter, were used to pump water for steam railroad trains that provided the primary source of commercial transportation in areas where there were no crossable rivers. In the late 19th century, the successful "American" multi-blade windmill design was used in the first large windmill to generate electricity.

The first use of a large windmill to generate electricity was a system built in Cleveland, Ohio, in 1888 by Charles F. Brush as seen in figure 1. The Brush machine was a post mill "(The defining feature of a post mill is that the whole body of the mill that houses the machinery is mounted on a single vertical post, around which it can be turned to bring the sails into the wind)" with a multi-blade picket fence rotor 17 meters in diameter, featuring a large tail hinged to turn the rotor out of the wind(Association, 2003). It was the first windmill to incorporate a step-up gearbox (with a ratio of 50:1) in order to turn a direct current generator at its required operational speed (in this case, 500 RPM). Despite its relative success in operating for 20 years, the Brush windmill demonstrated the limitations of the low-speed, high-solidity rotor for electricity production applications.

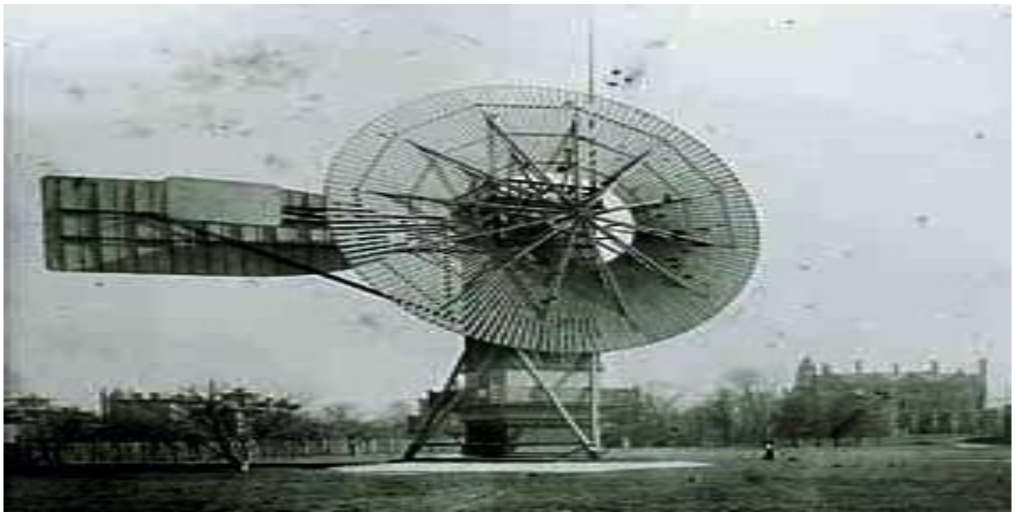

Figure 1: The Giant Brush Windmill in Cleveland, Ohio

(Association, 2003)

In 1891, Poul La Cour developed the first electrical output wind machine to incorporate aerodynamic design principles, “It featured low-solidity, four-bladed rotors incorporating primitive airfoil shapes”(Dodge, 1996-2001). The higher speed of the La Cour rotor made these mills quite practical for electricity generation. By the close of World War I, the use of 25 kilowatt electrical output machines had spread throughout Denmark, but cheaper and larger fossil fuel steam plants soon put the operators of these mills out of business.

By 1920, the two dominant rotor configurations which were fan-type and sail, had both been used and people realized that they were not viable for efficiently generating large amounts of electricity. The further development of wind generator electrical systems in the United States was inspired by the design of airplane propellers.

The development of bulk power, utility-scale wind energy conversion systems was first designed in Russia in 1931 with the 100kW Balaclava wind generator. This machine operated for about two years on the shore of the Caspian Sea, generating 200,000 kWh of electricity. “Subsequent experimental wind plants in the United States, Denmark, France, Germany, and Great Britain during the period 1935-1970 showed that large scale wind turbines would work, but failed to result in a practical large electrical wind turbine”(Dodge, 1996-2001).

European developments continued after World War II, when temporary shortages of fossil fuels led to higher energy costs. As in the United States, the primary application for these systems was interconnection to the electric power grid.

In Germany there was a development of a series of advanced, horizontal axis designs of intermediate size that made use of modern, airfoil-type fiberglass and plastic blades to emphasize light weight and high efficiencies. This design approach was to reduce air and structural failures by shedding aerodynamic loads, as opposed to withstanding them. “One of the most original load shedding design features was the use of a bearing at the rotor hub that allowed the rotor to teeter in response to wind gusts and vertical wind shear”(Association, 2003).

In the United States, the federal government's involvement in wind energy research and development began about two years after the so-called “Arab Oil Crisis” of 1973. The research from the Federal Government’s development activities resulted in; the design, fabrication, and testing of 13 different small wind turbine designs.

After 1980, the market in the United States was dominated by the emergence of the wind farm. This market was almost totally unexpected. Power produced by wind turbines in California was extremely attractive to utilities serving coastal cities because periods of high winds over the coastal hills are linked with high commercial and residential air conditioning loads in the summer. Among the key economic factors were the “federal energy credit of 15%, a 10% federal investment credit, and a 50% California state energy credit”(Dodge, 1996-2001). These, along with attractive rates offered by utilities for power produced by alternative sources, were packaged into an investment product by private financial firms and investment houses.

This boom was not expected to happen the way it did. The beneficiaries of the tax credits were supposed to be the “large U.S. aerospace and construction firms who were developing the MOD-2, MOD-5 and MOD-6 which were intermediate-scale wind turbines. These firms had primarily been responsible for obtaining federal wind energy funding in the first place; although a mid-course correction had been managed by the smaller, "counter-culture" wind energy entrepreneurs and communes who organized the American Wind Energy Association in the mid-70's”(Association, 2003).

The American Wind Energy Association is a Washington, D.C. based national trade association that represents wind power project developers, equipment suppliers, service providers, parts manufacturers, utilities, researchers, and others involved in the wind industry. With over 2,300 business members, American Wind Energy Association promotes wind energy as a clean source of electricity for consumers in the U.S. and around the world.

Between 1980 and 1981, several things happened that caused the new wind energy tax legislation to rise from Congress and it looked different than even people in the wind industry had expected:

1) "The large multi-megawatt turbines ran into predictable design problems because the development cycle was compressed by political impatience to an absurd 2-4 years instead of a more prudent 6-8 years;

2) An increase in federal military expenditures reduced the interest of aerospace firms in risky new business challenges like wind turbines,

3) the new *laissez faire*, de-regulating attitude of the in-coming Reagan administration toward the investment and banking community made it possible to invest large sums in suspect items like untested wind turbines, resulting in the erection of questionable systems like the Transpower "clothesline" machine (at left.)

4) Several firms appeared with apparently serviceable wind turbines which looked--to the mood of the times--like giant killers, including a "half-baked" 50kW design marketed by U.S. Wind power.

5) Federal managers, correctly reading the new anti-regulatory winds, and fearful of losing funding and support in Congress (and from the new Reagan Administration), resisted calls from several quarters to establish a quality control program to screen wind turbines for eligibility in the federal tax program,

6) Not understanding the important distinctions between rated power capacity and energy output, and not wanting to establish an "expensive and bureaucratic" data reporting requirement, Congressional staffers ignored recommendations of the American Wind Energy Association and others and acceded to independent industry lobbyist's requests for tax credits based on installed generator capacity rather than energy output.

7) The obsession of the incoming Reagan Administration with "free and open" markets, driven by the need to find foreign investors to fund the national debt and reinforced by Reagan's own grandiose sentimentality, dictated that any tax credit legislation would provide absolutely no protection for U.S. businesses, allowing subsidized foreign companies to under price U.S. firms, setting the stage for a flow of over a billion U.S. tax dollars to Europe.

8) Industry mistrust of federally-supported researchers (developed because they) 'dared' to question and discuss the unreliability of U.S. wind turbines… These mutual reactions effectively drove a wedge between the U.S. industry and the federal wind program, which was the only source of objective knowledge and discipline that could help most U.S. companies achieve technical viability"(Dodge, 1996-2001).

2.2 Alternative Energy Sources

Renewable energy sources are alternatives to fossil fuel that are 100% renewable and account for 7% of all energy consumed in the United States (Energy Information Administration, EIA). Biomasses, hydroelectric, geothermal and solar are all forms of renewable energy. Figure 2 shows that the most popular renewable energy resource in 2008 was biomass. Biomass includes wood, waste and bio fuels such as biodiesel and ethanol. Biodiesel is not renewable, but does contain renewable energy sources such as vegetable oil and are included in renewable energy resources. Wood and waste bio fuels are burned to create electricity, whereas bio fuels are used almost exclusively in cars as fuel.

The next most popular alternative energy source is hydroelectric, representing 34 percent of renewable energy in the United States. Hydroelectric power is the conversion of water flow into electricity via a generator. Water is currently the leading renewable energy source used to generate electricity. There are some advantages and disadvantages to this type of renewable energy. Water power causes little to no emissions or pollution. Another advantage is that it is inexpensive. The disadvantages are that it has adverse affects on the wildlife and environment near the river where the hydroelectric dam is situated. Dams can also create lakes hundreds or even thousands of acres in size where a river used to be. Another major disadvantage is that dams have been around for many years, thus making most of the best and suitable rivers taken. This leads to less growth over the years.

In 1973 the United States produced 2.861 quadrillion BTU's of hydroelectric power, and in 2006, the United States produced 2.869 quadrillion BTU's of hydroelectric power(Renewable and Alternative Fuels). The United States, for the past 30 years, has produced the same amount of hydroelectric power. In other words, hydroelectric power has essentially reached its potential in the United States.

Five percent of America's renewable energy comes from geothermal sites. The way this energy is generated is by underground steam reservoirs. This steam is used to power a generator to create electricity or used directly to heat or cool a house or building. All of these types of renewable energy are not feasible for the Town of Auburn because they do not want to build a bio fuel power plant, there is no suitable river in Auburn and there are not any underground steam reservoirs to generate power from. The only other feasible alternative to wind power for the Town of Auburn is solar power.

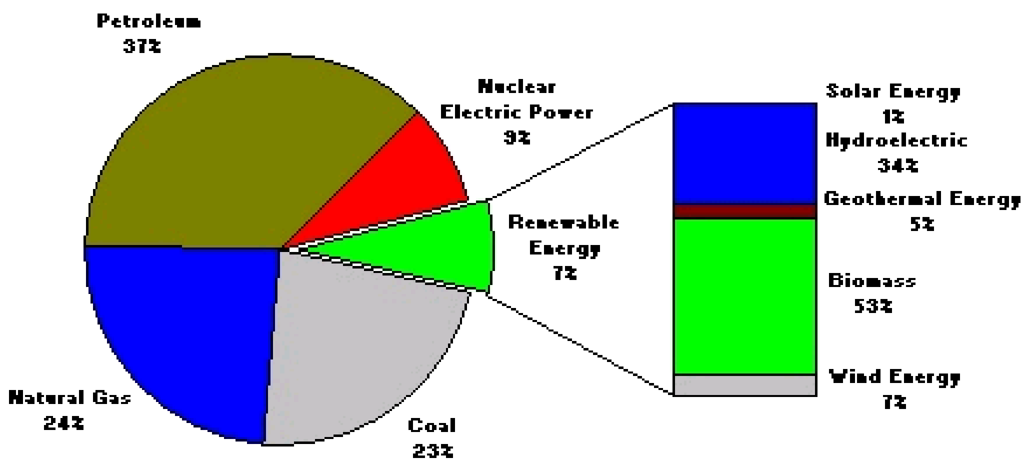

Figure 2: ***Breakdown of Energy Consumption in the United States***

(*Renewable and Alternative Fuels*)

There are two uses of solar power. Thermal solar power uses the heat of the sun to heat a house or a building. It can also be used to heat a liquid to create steam used by a steam generator to create electricity. The other type of solar power is photovoltaic devices or PV's for short. This type of power uses semi conductive material to turn sunlight directly into electricity. The way this works is when light strikes the semiconducting material it will absorb some of the energy. This energy releases electrons in the semiconducting material, and when metal contacts are placed on the top and bottom of the photovoltaic it forces the free flowing electrons in a direction, thus creating electricity.

Figure 3 shows the potential in the United States for Solar power, specifically the photovoltaic type. This map shows that the best areas of the United States are the southwest region, as would be expected. The largest solar power farm in the United States is located in California's Mojave Desert. This plant produces 354 megawatts of power which is enough electricity for about 500,000 people(Solar

Trough Systems, 1988).There are even larger solar power plants planned for the future. The reasons that some areas are better suited for solar power than others are that the amount of energy coming from sunlight has many variables that determine how much energy it can produce. These variables include cloud cover, the angle the sun is to the solar panel (ninety degrees being optimal) and time of day.

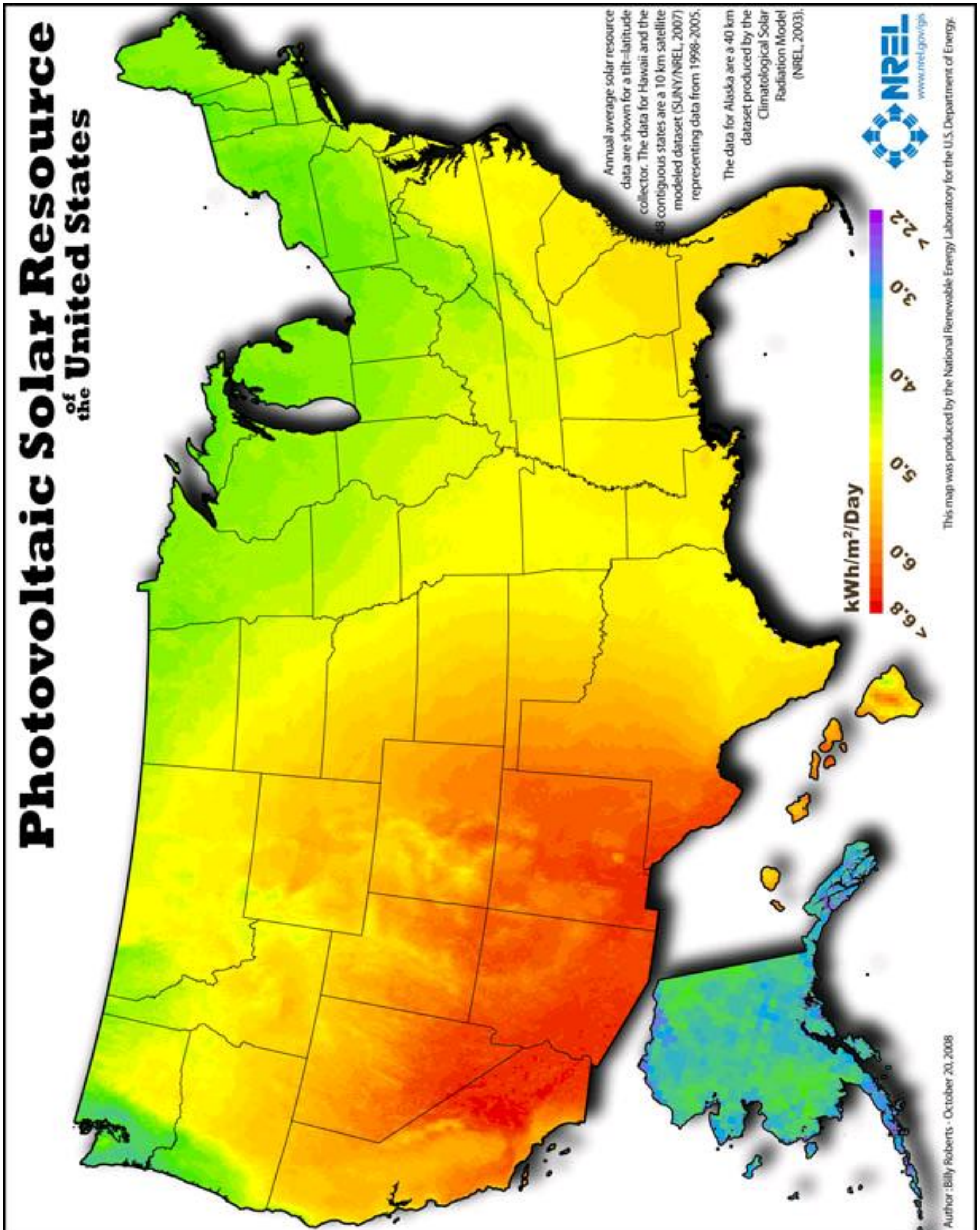

Figure 3: ***National Solar Photovoltaic (PV) Resource Potential***

(Solar Maps)

Solar power has not grown in use in the same way that wind power has in the United States. Figure 4 shows that both energy sources produced measureable amounts of energy in 1985, but since then wind power has grown over nine times that amount, whereas solar has not even come close. One major disadvantage that solar power has compared to wind power is the site chosen. It is not as feasible for solar power as it is for wind. That is why the better choice would be a wind turbine.

Primary Energy Production by Source
(Quadrillion Btu)

	Solar/ PV	Wind
1973 Total	NA	NA
1975 Total	NA	NA
1980 Total	NA	NA
1985 Total	(s)	(s)
1990 Total	.060	.029
1995 Total	.070	.033
1996 Total	.071	.033
1997 Total	.070	.034
1998 Total	.070	.031
1999 Total	.069	.046
2000 Total	.066	.057
2001 Total	.065	.070
2002 Total	.064	.105
2003 Total	.064	.115
2004 Total	.065	.142
2005 Total	.066	.178
2006 Total	.072	.264

Figure 4: ***Primary Energy Production by Source***

(Renewable and Alternative Fuels)

2.3 Federal Regulations

There are several United States programs that provide regulations for wind turbine installations. However, on a national scale, the Department of the Interior and not the Department of Energy provides most of the regulations for siting and development. The Department of the Interior's Bureau of Land Management (BLM) Handbook initiated a Wind Programmatic Environmental Impact Statement to address the impacts of possible future developments of wind turbines on public lands in October of 2003. The Bureau of Land Management's Land Use Planning Handbook requires that land use planning efforts address wind resource potential, public concerns and opportunities for wind in the areas of wind energy development with the land use planning area. Furthermore, the BLM's Land Use Handbook also requires that Visual Resource Management classes be identified in all land use plans based on available visual resources as well as any possible management considerations for other land uses such as wind or solar development. The BLM's land use plans also identify right-of-way avoidance areas or exclusions that are in accordance with the Land Use Planning Handbook. There are also criteria and recommendations issued by the Fish and Wildlife Service as well as guidelines for areas of critical environmental concern. These guidelines are currently voluntary procedures to help avoid the negative impacts of turbines (Bureau of Land Management, 2008). The Federal Aviation Administration also requires that for any new construction above 200 feet or within 20,000 feet from a public or military airport requires the Notice of Proposed Construction of Alteration to be filed, before construction can take place(Obstruction Evaluation, 2004).

2.4 Massachusetts Regulations and Wind Programs

The State of Massachusetts has multiple laws, regulations, and incentives that effect new wind farms. State laws include; the Agriculture and Conservation Act, the Community Preservation Act, the Massachusetts River Protection Act, the Massachusetts Noise Control Regulations, the Water Management Act, the Wetlands Protection Act, and the Massachusetts Clean Air Act. These are all state laws that can have an effect on wind farms siting and installations(Castaneda, 2009).

Two state agencies that are responsible for developing and promoting economic and environmental benefits through renewable energy technologies are the Massachusetts Technology Collaborative (MTC) and the Massachusetts Renewable Energy Trust (MRET). The MTC administers the MRET which was developed by Legislature in 1997. The MTC is defined as "The state's development agency for renewable energy and the innovation economy"(Key Policy Bodies and Organization, 2009). While the MRET's goal is to "Generate economic and environmental benefits for the Commonwealth citizen's by pioneering and promoting the successful commercialization by fostering the emergence of sustainable markets for power generated from renewable energy sources"(Key Policy Bodies and Organization, 2009). The Renewable Energy Trust also contains a Policy Unit, whose goal is to increase the availability, affordability and use of renewable energy by assessing market and regulatory challenges, assembling objectives and assisting the MTC in developing policy recommendations (Key Policy Bodies and Organization, 2009).

A new state incentive program advocating the use of wind power is the Commonwealth Wind program. The section of this program that more directly relates to our project is the Community-Scale Wind initiative. This program is administered by the MRET and awards grants to qualifying wind projects of 100kW or more. There are several application steps for this grant including: Site Assessment Application, Feasibility and Design &Construction Application, Insurance Requirements, and Minimum Technical Requirements, among others.(Community-Scale Wind , 2009)

2.5 Electric Infrastructure in Massachusetts

Electricity in Massachusetts is generated almost entirely by large electric facilities in Massachusetts or in the surrounding states. This electricity is then is sent through the electrical grid, which is best described as a complex web of power lines, to individual consumers.

How electricity goes from power plant to individual consumers is complicated. First there is the Independent System Operator of New England (ISO New England or ISO-NE). The purpose of this organization is to oversee the production of power in order to provide stability to the system. It also regulates how much generators can charge for the energy they produce. Generators are the next step in the process. Generators are power plants that are independently owned, but are still overseen by ISO-NE. The generators sell the electricity to suppliers who sell it to consumers. Lastly there are transmission and distribution companies. These companies own the wires that make up the electricity grid. They are responsible for transporting the electricity to consumers as well as maintaining the power lines, high-voltage lines, transformers and substations. They also do the meter reading, customer service and recovery after power outages. In some areas there are municipally-owned utilities which own everything involved in the generation, transmission and distribution of electricity and makes the local utility responsible for everything the individual companies mentioned previously are responsible for. Auburn, however, is not one of these towns. Auburn uses the transmission company National Grid and Massachusetts Electric distributes the electricity ("MTC: Sources of Electricity," 2008).

The electricity produced in Massachusetts is generated using oil, natural gas, coal, renewable and nuclear energy sources. The majority of the energy is non-renewable and is used primarily for three general purposes: industrial, residential and commercial. Figure 5 shows the percentages of electricity these three uses.

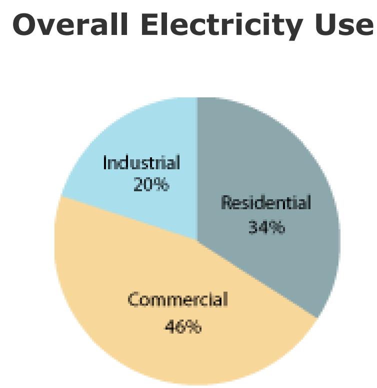

Figure 5: ***Electricity use by zoning in Massachusetts***

(*Massachusetts Technology Collaborative*, 2009)

2.6 Wind Power in Massachusetts

Massachusetts may not be known for its alternative energies but has significant potential in harnessing the natural power in wind to help with energy needs. Massachusetts' energy use is divided up in near quarters between commercial, industrial, residential and transportation use (Fig. 7) ("MTC: Sources of Electricity," 2008). This shows that the energy is not being consumed by one specific sector and all consumers need to take responsibility in utilizing the use of clean and renewable energy. Energy sources are dominated by fossil fuels, 89%, leaving only 6% renewable energies and 5% nuclear (Fig.6) ("MTC: Sources of Electricity," 2008). This fact is one to be aware of because of the lack of fossil fuel accessibility and the environmental affects that they cause such as green house gas emissions. These graphs clearly illustrate why Massachusetts is pushing toward a future fueled by renewable energy.

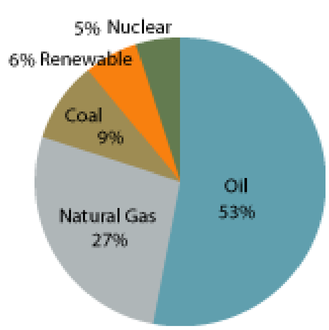

Figure 6: MA Energy Sources

(ibid)

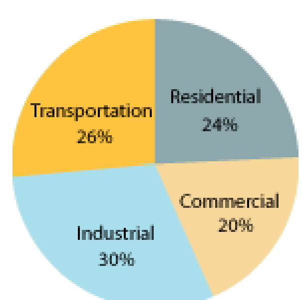

Figure 7: Overall MA Energy Use

(MTC, 2009)

2.6.1 Massachusetts Wind Potential

Massachusetts holds good potential for renewable energy, especially for offshore wind power as shown in figure 7. In Massachusetts 3.5% of the land area is judged to have sufficient average wind speed to generate power through turbines. If the 3.5% of the land in Massachusetts were used to support wind turbines, only 0.35% of that 3.5%, or 900 acres, would be needed ("MTC: Renewable energy Potential," 2008). Specific areas with excellent wind in this state include Cape Cod, Martha's Vineyard, Nantucket, the Berkshires and parts of western Massachusetts ("Massachusetts Government," 2009).

Massachusetts has wind potential from the coast to the western border and although wind power is only starting to become main stream in the United States, it has existed in the state for awhile. For example Princeton is home to the oldest commercial wind power plant in the state. In 1984 eight 40 kW turbines were put up and recently replaced these with two new 1.5MW turbines ("Massachusetts Government: Energy and Environmental Affairs," 2009). The two new turbines, pictured in figure 8 would be able to supply the town with 40% of their power needs.

Figure 8:Princetons 2 1.5 MW turbines

(Power Engineers, LLC)

The town of Hull is also known for their advances in harnessing wind by erecting their first 40 kW tower in 1984 which became damaged and unusable in 1997 ("Hull wind," 2006). Four years later, a 660 kW turbine named Hull 1 was built ("Hull wind," 2006). The most recent turbine, Hull 2 (1.8 MW), was built in 2003. Both turbines supply the town with over 10% of the energy they consume ("Hull wind," 2006). Mount Tom in Holyoke is home to the second largest wind turbine in Massachusetts. Built in 1994 this 250 kW is owned by UMass and was initially built for research purposes. The town of Beverly contains a 10 kW tower which was built in 1997 for the High Schools use. With the constant use it was replaced in 1999 and still operates to supply the school. One last place where wind power is taken advantage of is Great Island in Westport. This turbine is a 1.5 kW tower and is built on a private island ("Massachusetts Government: Energy and Environmental Affairs," 2009). The wind potential in Massachusetts allows for construction of turbines to be feasible, creating a market for alternative energy and pushing toward a more sustainable future ("Google Maps: Massachusetts," 2008).

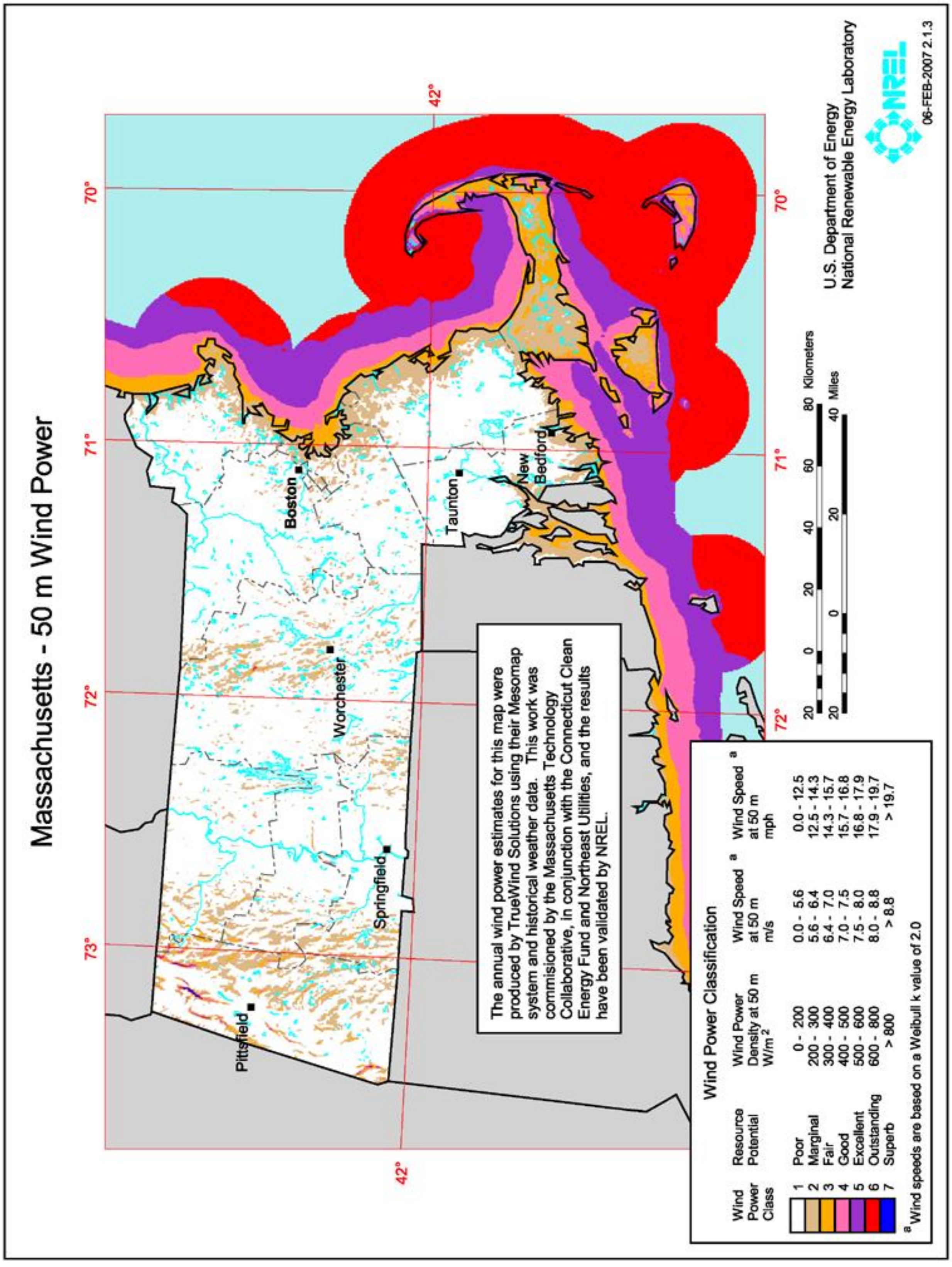

Figure 9:Massachusetts Wind Resource Map at 50 meters above the ground

(*Energy Efficiency & Renewable Energy: Wind Powering America*, 2009)

2.6.2 Renewable Energy Initiative Programs

To address the potential of renewable energy in Massachusetts, the state has created several programs to aid in the renewable energy initiative. One of these programs is Massachusetts Technology Collaborative, the state's development agency for renewable energy as well as the economy ("MTC: What We Do," 2008). MTC takes credit for 25% of jobs in Massachusetts and has been in service to the state for 23 years.

MTC's function is to collaborate with companies, academia, and the government to build innovative economic opportunities as well as work toward a cleaner environment ("MTC: What We Do," 2008). MTC administers the John Adams Innovation Institute which helps in research for their programs, as well as the Massachusetts Renewable Energy Trust (MRET) ("MTC: What We Do," 2008). MRET, "seeks to maximize environmental and economic benefits for the commonwealths citizens by pioneering and promoting clean energy technologies and fostering the emergence of sustainable markets for electricity generated from renewable sources ("MTC: Renewable Energy Trust," 2008)." The trust uses several programs to push for their goal of cleaner technologies.

When considering wind technology in Massachusetts the largest program for wind turbine development is the Commonwealth Wind Incentive Program. This program awards grants to communities and individuals planning on building a turbine with 100kW energy potential or larger as long as the electrical needs are linked to the renewable energy trust by the state or town ("MTC: Commonwealth Wind Incentive Program," 2008). The grants help to pay for site assessments, feasibility studies and design and construction of the sites and turbines.

Figure 10: S*ites of existing and potential future wind turbine locations in Massachusetts*

(*Google Maps: Massachusetts Wind Data*, 2008)

2.7 Auburn Regulations and Zoning

A review of the Town of Auburn's General Provisions and Zoning revealed that the town does not have detailed bylaws and zoning focused on wind turbines. However, under section *3.9.4 Accessory Uses Permitted in any Zoning District* there was an amendment concerning 'wind machines.' The amendment reads, **"**Wind machines designed to serve a principal use on a lot may be authorized by special permit from the Board of Appeals provided the Board of Appeals finds that the wind machine is set back from all plot lines at least the distance equal to the height of the tower from its base on the ground to the highest extension of any part of the wind machine." If granted the special permit, we would have to work to identify the maximum height of the turbine based on site limitations in terms of the nearest private lot, as well as the ideal height in regards to maximizing the turbines effectiveness.

The amendment itself stated that the Turbine may be allowed to exceed the maximum height limitations if the set-back requirements are still met.

While trying to identify the maximum height restrictions for wind turbines, the Towns Zoning Bylaws provided several regulations for different types of buildings and objects, however failed to identify wind turbines specifically. The maximum height for mixed-use developments cannot exceed 70 feet in height. Homes in residential areas cannot surpass 25 feet in height, and commercial developments cannot exceed 35 feet. Finally, a monopole, which is a self supporting tower which is used to hold the turbine blades of a wind turbine, cannot exceed 100 feet from the base of the facility. Since it is unclear what the specific height restriction is, we could simply use the zoning by-law that requires a setback of the machines total height from its base to the tip of the blade. (Auburn By-Laws, 2009)

2.8 Renewable Energy Research Laboratories Auburn Study

In this section we provide a summary of the Renewable Energy Research Laboratories Study for the town of Auburn (Renewable Energy Research Laboratory, 2008).

> **I. Introduction:** The Town of Auburn is looking into the idea of wind power. The UMass Renewable Energy Research Laboratory (RERL) compiled a report to help the town come to a conclusion on a location.
>
> **II. Initial Sites Considered**
>
> 1. Site 1: Prospect Hill #: Granger Cliffs Site.
> 2. Site 2: Prospect Hill #2, parcel not large enough to provide proper distance of turbine from residences. This site was not visited.
> 3. Site 3: Upland Street: This site is located too close to residences. This site was not visited.
> 4. Site 4: Pakachoag Meadows
> 5. Site 5: Crowl Hill Site, former landfill with wind speed lower than other sites. This site was not visited.
>
> **II. Wind Turbine Site Considerations**

A. Predicted Wind Resource

Site 1	**5.83 m/s**
Site 2	5.63 m/s
Site 3	5.77 m/s
Site 4	5.34 m/s

Medium Scale Turbines: 50 meters

B. Noise

1.) Regulatory Compliance

2.) Human Annoyance

C. Proximity to Nearby Airports

The form "7460-1 - Notice Of Proposed Construction or Alteration" must be filed with the Federal Aviation Administration (FAA) before construction of any structure over 200 feet (i.e. all utility-scale wind turbines). The corresponding form for the Massachusetts Aeronautics Commission (MAC form E10, Request for Airspace Review) must also be filed.

D. Environmental Issues and Permitting

Take into consideration

- State designations of Natural Heritage & Endangered Species Program (NHESP), Open Space, Wetlands and other land-use restrictions
- Massachusetts Audubon Society Important Bird Area (IBA)
- Current or former landfill

E. Wind Turbine Component Transportation & Access

F. Distance to Distribution/Transmission Lines for Power Distribution

- No sites contained distribution lines.
- Granger Cliffs (Site 1) is at least 700-800 meters from the nearest lines.

G. Potential Electrical Loads Offset

- Energy used on-site is more valuable than energy sold onto the wholesale market
- The town of Auburn has a total annual average electrical usage of approximately 4,500,000 kWh/yr.

Estimated Annual Energy Production of Selected Turbines

Wind Turbine (rated power) – hub height	Annual estimated wind speed at 70 m (hub height) (m/s)	Annual Energy Production (kWh/year)
Fuhrländer FL 100 (100 kW) – 50 m	6.5	261,776
Fuhrländer FL 250 (250 kW) – 50 m	6.5	472,924
Vestas V47 (660 kW) – 70 m	6.5	1,550,000
GE 1.5 s (1.5 MW)	6.5	3,553,000

H. Turbine Spacing

The 320 meter diameter is based on a four-rotor-diameter spacing for an 80 meter rotor diameter turbine.

IV. Conclusions

Site 1: Granger Cliffs has the more favorable wind speed. This town owned site is a suitable distance from neighboring houses for the siting of a utility-scale wind turbine. Removal of trees would improve the quality of the wind resource at the Granger Cliffs site. The former pig farm (Auburn Assessor's Map 73, Parcel 2) that occupies the parcel next to the Granger Cliffs site may be a potential location for multiple turbines (see Map 13 of this report for owners of parcels near Site 1 at Granger Cliffs); however, the town would have to establish control of the land for the project. The lack of an electric load at this site and its longer distance for electrical interconnection and an access road are serious drawbacks.

2.9 Wind Technology

There are three different turbine sizes that determine electrical energy output; Utility Scale, Industrial Scale, and Residential Scale. Utility scale "corresponds to large turbines (900 kW to 2 MW per turbine) intended to generate bulk energy for sale in power markets. They are typically installed in large arrays or 'wind energy projects,' but can also be installed in single towers on distribution line towers, otherwise known as distributed generation. Industrial-Scale corresponds to medium sized turbines (50 kW to 250 kW) intended for remote grid production, often in conjunction with diesel generation or load-side generation (on the customer's side of the meter) to reduce consumption of higher cost grid power and possibly to even reduce peak loads. Lastly Residential-Scale corresponds to micro and small-scale turbines (400 watts to 50 kW) intended for remote power, battery charging, or net metering type generation. The small turbines can be used in conjunction with solar photovoltaic's, batteries, and inverters to provide constant power at remote locations where installation of a distribution line is not possible or is more expensive" (NYSERDA).

As seen in figure 11, the greater the wind speed (variable X) the greater the Power (variable Y). Assessment of power need is necessary because high power production does not mean larger money savings. If a town or household needs a fixed power production and too much power is produced, then not all the electricity produced is used locally and is either wasted which means lost revenue, or perhaps fed back into the power grid at a wholesale rate (no net metering).

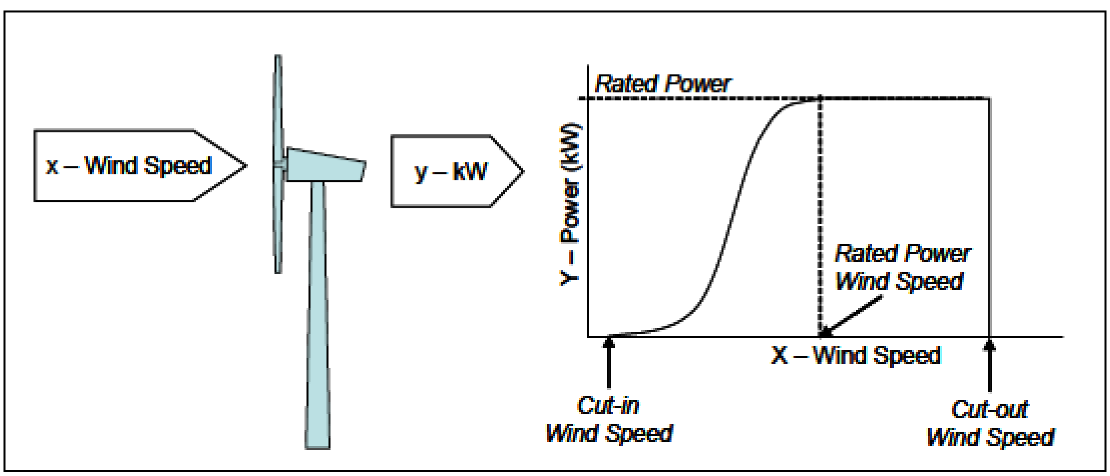

Figure 11: Wind Speed and Power Production Relationship

(Paterson, 2004)

As seen in Figure 12, most of today's wind turbines are configured on a horizontal axis which consist of three-blades connected to a hub that rotates about its axis. Electricity is generated by wind hitting the blades, which causes the blades to rotate. The blades on the hub are connected to a shaft which is also connected to a gear box and generator. The rotation from the blades spins the gear box and generator to make electricity. To compensate for low wind speeds or no wind speeds on some days, some turbines are equipped with another fuel generator to produce electricity allowing a building or household to still run electric components such as lighting or heating.

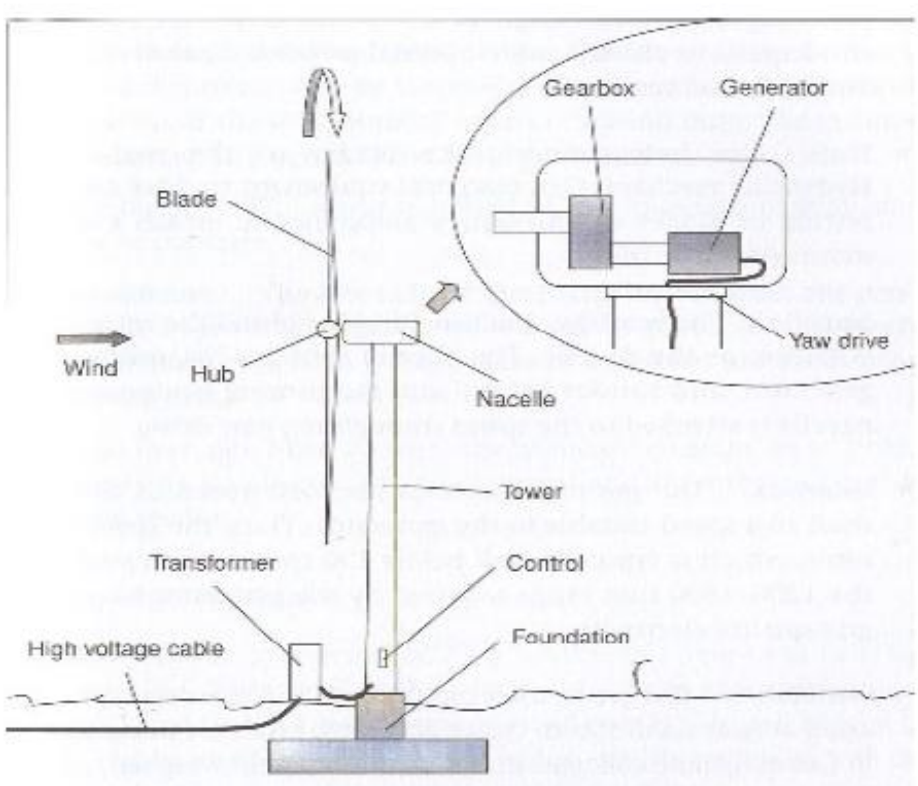

Figure 12: Wind Turbine Components

(Paterson, 2004)

While horizontal wind turbines are the most popular, there are other styles available such as vertical axis wind turbines (Fig. 13). Vertical axis wind turbines have two blades shaped like an egg-beater. These turbines however are primarily used for individual household use.

Figure 13: Vertical Axis Wind Turbine

(Setting a Good Example)

2.10 Wind Energy Potential

There are many obstacles and parameters that need to be addressed in order for wind generator technology to be cost effective. For example when a cost analysis is performed, a key issue is how long the pay-back period will be. The pay-back period is the length of time it takes for the savings made from producing electricity to offset the cost of installing and maintaining the wind turbine.

Another important factor to evaluate is variations in wind speed and direction. Wind speed varies day by day, some days it doesn't blow enough to spin the blades on the turbine and sometimes the wind doesn't blow at all. To compensate a backup plan needs to be implemented to provide electricity, such as backup electricity storage or more commonly a grid tie-in. In some countries reserve margins from power plants are accounted for since the wind technology won't operate all the time.

2.11 Net Metering

Net metering was originally authorized for “renewable energy systems and combined-heat-and-power (CHP) facilities with a generating capacity up to 30 kilowatts (kW) by the Massachusetts Department of Public Utilities in 1982. In 1997, the maximum individual system capacity was raised to 60 kW and customers were permitted to carry any net excess generation (NEG) -- credited at the "average monthly market price of generation" -- to the next bill.” (Drupal, 2009)

In July 2008, net metering was significantly expanded by S.B. 2768, which established three separate categories of net-metering facilities. “Class I” facilities are generally defined as systems up to 60 kW in capacity.”(Drupal, 2009) “Class II” facilities are generally defined as systems “greater than 60 kW and up to one megawatt (MW) in capacity that generate electricity from agricultural products, solar energy or wind energy.”(Drupal, 2009) “Class III” facilities are generally defined as systems greater than 1 MW and up to 2 MW in capacity that generates electricity from agricultural products, solar energy or wind energy.

Massachusetts also allows “neighborhood net metering” for neighborhood-based “Class I, II or III facilities that are owned by (or serve the energy needs of) a group of 10 or more residential customers in a single neighborhood and served by a single utility.”(Drupal, 2009)

220 Code of Massachusetts Regulation, Section 11

RULES GOVERNING THE RESTRUCTURING OF THE ELECTRIC INDUSTRY

....
11.04: Distribution Company Requirements.
....
(7) Renewable Resources.
....
(c) Net Metering.
“A Customer of a Distribution Company with an on-site Generation Facility of 60 kilowatts or less in size has the option to run the meter backward and may choose to receive a credit from the Distribution Company equal to the average monthly market price of generation per kilowatt hour, as determined by the Department, in any month during which there was a positive net difference between kilowatt hours generated and consumed. Such credit shall appear on the following month's bill. Distribution Companies shall be prohibited from imposing special fees on net metering Customers, such as backup charges and demand charges, or additional controls, or liability insurance, as long as the Generation Facility meets the Interconnection Standards and all relevant safety and power quality standards. Net metering customers must still pay the minimum charge for Distribution Service (as shown in an appropriate rate schedule on file with the Department) and all other charges for each net kilowatt hour delivered by the Distribution Company in each billing period.”(Regulations, 2005)

2.12 Operation & Maintenance

An important factor in balancing the budget for turbine installation and maintaining a reliable wind farm is operation and maintenance. Designing an effective operation and maintenance plan includes examining two major parameters; preventative and un-preventative maintenance. Preventative maintenance involves equipment inspection to ensure the turbine runs properly, whereas un-preventative maintenance involves repairing the turbine if something fails.

Operation and maintenance affects every parameter of a wind project both directly and indirectly(Walford, 2006). Nearly 10-20% of the total project costs can go into operation and maintenance. It is estimated that operation and maintenance for turbines on the scale of 600kW can cost around $20/kW which in turn can affect the cost of energy and if done poorly can diminish the life span of the turbine.

An important preliminary step in planning proper operation and maintenance is examining the turbine's internal component. The technology of today's wind turbines has changed over the past ten years. New materials are now being used to design turbines that are lighter in weight and harness the wind to transfer into electricity more efficiently. However, because the technology has upgraded so recently, there is concern with reliability. One upgrade that has been implemented in new MW scale turbines is a generator that runs at a lower speed opposed to a gear box because of premature gearbox failures. However it has been shown that in a study by the Dutch Offshore Wind Energy Concepts (DOWEC) that this new technology has had problems when the turbines get to the scale of about 5 MW. "The German Insurance Industry estimated that addition operation and maintenance cost for a MW size turbine may be $125,000 every five years based on a 30% capacity factor (Wind Turbine Reliability)." Another important cost factor due to upgraded technology is availability. If a problem occurs and a part needs to be replaced from a newly designed generator, it may not be readily available due to a limited number of companies carrying the part. This can lead to issues concerning downtime of the turbine, concerns of the cost of shipping and installation. Overall it is important to plan preventative and failure based measures to make sure the turbine will run efficiently.

2.13 Holy Name High School Case Study

Holy Name is a private Junior/Senior High School located in Worcester, Massachusetts that enrolls 800 students. Most of electricity used at Holy Name is for winter heating which is roughly 60-75%

of their total electricity needs. To accommodate the school's budget and needs for electricity, the school decided it was necessary to install a wind turbine to generate its electricity. Before selecting their turbine, many different analyses had to be conducted. The first analysis conducted was gathering of wind data. The first step in this process was selecting a location for an anemometer. To do this, the Holy Name project team drew a matrix of possible locations and analyzedthe available data to determine the best wind generation location (Fig. 14).

Factors											
Possible Locations	Existing Elevation	Height Potential	Cost	Fabrication	Power Availability	Vandalism	Time to Completion	Ease of Monitoring	Wind Shear/Data Accuracy	Total	Rank
Scoreboard at Football Field	8	5	5	8	6	7	7	6	7	59	2
Roof of School	7	3	9	7	9	10	8	9	4	66	1
Fence at Football Field	10	7	4	5	3	5	6	6	7	53	4
Freestanding in Field	6	8	1	2	2	3	2	5	9	38	5
Roof of Announcers Box	7	5	4	6	5	7	5	6	6	54	3

Figure 14: ***Decision Matrix for Holy Name Anemometer Location***

(Jensen, 2006)

The next step once a location was found was installing an anemometer and collecting wind data from the site. The collected data was then processed to make graphs and tables of velocity and time. From there the team researched different brands of turbines. The different models of turbines that were considered were Fuhrlander, Suzlon, and Vestas. In order to determine what each turbine would generate, an online calculator was used (http://www.windpower.org/en/tour/wres/pow/index.htm) where the Holy Name project team could input the average wind speed and other wind distribution data. The next step was drawing power curves to analyze efficiency. Once the curves were made and the parameters of funding, size and zoning were observed, a turbine was selected. The selected turbine was a Fuhrlander FL600. Lastly once the turbine was selected, grid interconnection was examined. It was decided that the interconnection would be in the basement to help reduce costs of installation.

2.14 Auburn Topographical Map: Granger Cliffs

Granger Cliffs, located on Prospect Hill in Auburn seen in figure 15, is the potential location for Auburn's turbine(s). The contour lines show that the highest possible elevation for the turbine at this location would be 265 meters.

Figure 15: ***Topographical Map of Granger Cliffs***

(Worcester South Topographical Map, 1983)

2.15 Summary

This chapter provided an overview of the materials necessary to conduct the methods of the project. Background literature along with federal and state regulations and the mechanics of wind technology were all researched and covered in this chapter to better understand what was necessary to come in the project. Every component covered in this chapter helped the process of the methodology which is discussed in Chapter 3.

Chapter 3: Methodology

This section describes the methods used to find the results that lead to a turbine recommendation for the Town of Auburn. It includes; site constraints, public concerns, turbine location analysis, site visits, wind study, cost analysis and turbine recommendation.

3.1 Site Constraints & Public Concerns

Site constraints and public concerns come in three distinct levels: local, state and federal. Concerns that affect the local level include; noise level, visual appeal and ice throw. The team researched other wind turbines in order to determine if any of these concerns will affect the neighboring area of the turbine site.

State and federal constraints and concerns include; wildlife, avian, endangered species, archaeological/historical, transportation and safety. The constraints and concerns need to be considered in great detail due to the high level authority monitoring each one. The wildlife, avian and endangered species need to be researched in the area in order to determine if the site is buildable. The location of wetlands also needed to be taken into consideration to determine the location of the access road and turbine erection site. Permits to allow wetland altercation also could not be overlooked. Transportation and safety concerns are also overseen by state and federal regulations. Potential routes and safety concerns were researched by the team.

3.2 Turbine Location Analysis

In order to choose a site which would be best for Auburn's turbine(s), it was crucial to complete a full site analysis. The analysis would include analyzing; wind speed profiles, access, proximity to residences, and land characteristics. Many of the crucial components of a site analysis could be broken down from the data which was collected by the Renewable Energy Research Laboratory (RERL), in their report; *Wind Power in Auburn: Siting Considerations for a Wind Turbine*, or Massachusetts Geographic Information Systems (GIS) data.

3.2.1 Potential Turbine Locations.

The RERL study provided the town with five potential sites, visible in figure 16. The sites were narrowed down to two possible locations; Prospect Hill #1 at Granger Cliffs and Pakachoag Meadows. This was due to the reasoning provided in the information column in table 1, with detailed background provided in the RERL study.

Table 1: Sites Considered

Site #	Location	Information
Site 1	Prospect Hill #1	Granger Cliffs Site.
Site 2	Prospect Hill #2	Parcel not large enough to provide proper distance of turbine from residences. This site was not visited.
Site 3	Upland Street	This site is located too close to residences. This site was not visited.
Site 4	Pakachoag Meadows	
Site 5	Crowl Hill Site	Former landfill with wind speed lower than other sites. This site was not visited.

(Renewable Energy Research Laboratory, 2008)

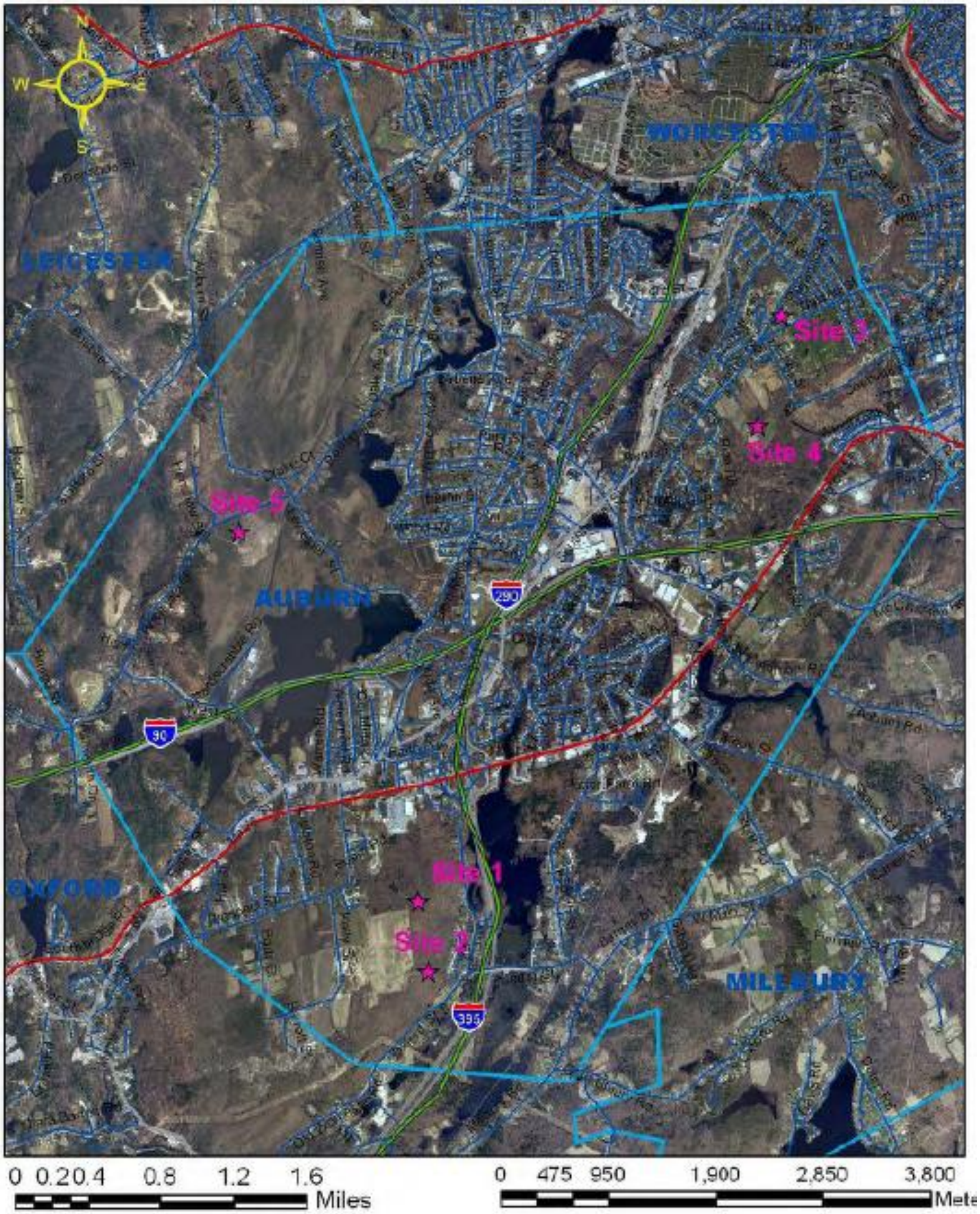

Figure 16: Orthographic (Aerial) Photo of Sites Considered

(Renewable Energy Research Laboratory, 2008)

3.2.2 Site Visit.

In order to be able to visual and apply the data which we had researched, a site visit was crucial. To make the visits as productive and thorough as possible, a list, comprised by both the MQP and IQP teams as well as the advisors, of key elements to identify and look for was marked out as follows:

Site Visit Data Collection

- Size and layout of site (sketch out the site and some basic features – existing access road or path, large boulders, clearing/meadow, stand of pine trees, old shack, etc…)
- Sense of direction while you are on site (NSEW)
- UTM coordinates of particular importance (perhaps even height above - the UTM coordinates can be traced back to a top map of the area)
- Grade of site (topography & slopes)
- Approximate distances between features (Pacing)
- Proximity to neighbors & structures (3 phase power lines)
- Land
    - roadways and traffic characteristics
    - current uses of land
    - observations regarding wildlife/ecology
    - vegetation
    - soil conditions
    - presence of bedrock
    - tree canopy
    - wetlands
    - drainage patterns

Visiting the sites and completing the data collection sheet allowed the group to compare and contrast the sites in many different aspects. The locations of several of these sites were difficult to access due to heavy plant growth, regardless an Assisted Global Positioning System (A-GPS) allowed for tracking of position which was then transferred to a topographic map. This allowed for position relative to the ideal site to be determined. Another piece of equipment which was crucial was a camera. This helped to create a visual for members who had not visited the site and for the final decision on what site to choose.

Figure 17: Auburn town engineer, planner and electrician on a site visit

(Photo by: Bryan Watkins)

3.2.3 Massachusetts Geographic Information Systems (Mass GIS).

Mass GIS made it possible to create site specific maps using layers such as; roads, contours, wetlands, soils, parcels, and wind speeds. These layers were turned on and off to create an array of different maps which helped in the final site decision as well as the final site design as seen in figure 18.

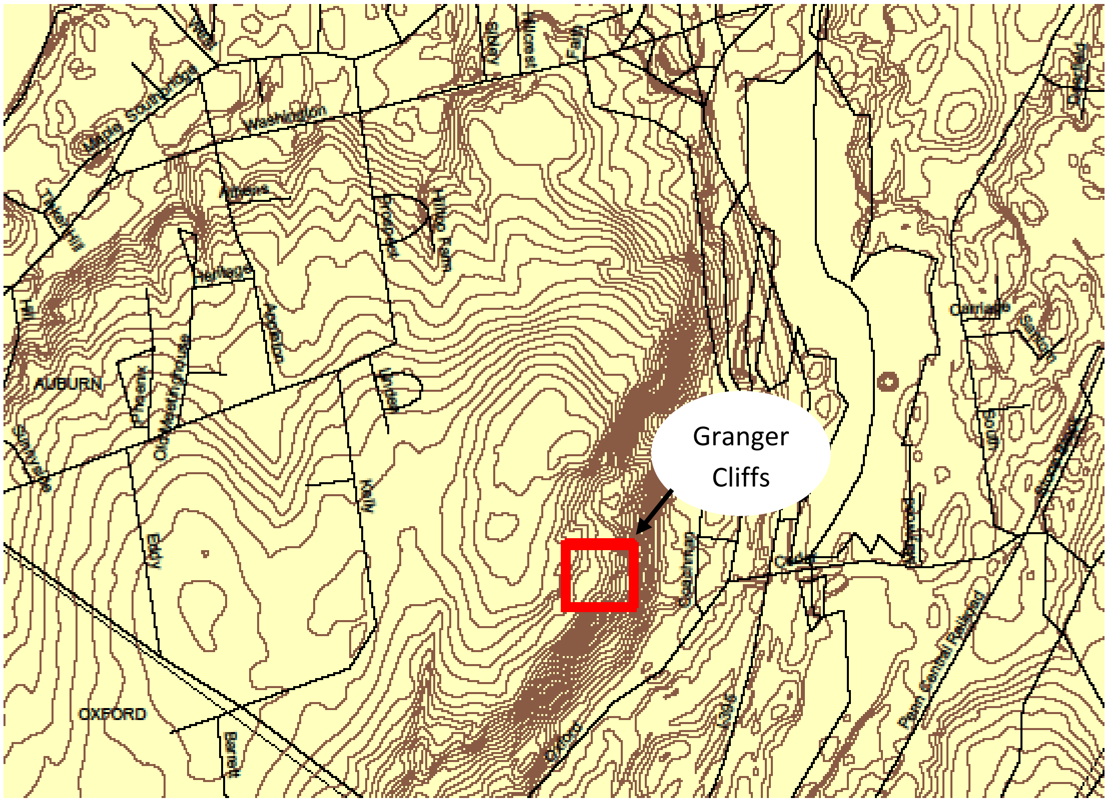

Figure 18: Mass GIS Map of Site 1, Prospect Hill #2 at Granger Cliffs

(Mass GIS, 2009)

3.3 Wind Study

In order to provide the town of Auburn with the most accurate wind power recommendation, wind analysis is crucial. In order to measure the wind at a specific height, a device called an anemometer is used. The wind speed is measured by using a cup anemometer which is an instrument with either three or four small hollow metal hemispheres set which allows it to catch the wind and revolve around a vertical rod. While this is going on, an electrical device records the revolutions of the cups going around the metal rod, and then calculates the wind velocity.

There are two different types or classes of anemometers. One type measures the velocity or speed of the wind and the other measures the pressure or force of the wind. Since there is a known relation between both wind velocity and force, either type of anemometer to measure wind speed.

Learning how to assemble and monitor the anemometer, provided by WPI, was the first step to getting wind data in Auburn. After a team site visit, the location of Granger Cliffs did not allow for easy access to anemometer placement due to the height and amount of trees in that area. A nearby farm or possibly the BJ's and Home Depot were the next possible locations for anemometer set up because of no wind obstructions. The local farm had been in support of the project yet it was decided by the Auburn Wind Committee that it would be best not to approach the residence. Due to insurance reasons, the BJ's and Home Depot did not allow access to their property.

Without the ability to record live wind data, the next best data came from personal wind systems, a previously completed local wind study, and computer data collection systems. Although the data was not collected on site by the team, the alternatives helped collect accurate data, determine the variable wind speeds over twelve months, opposed to one, and find the primary wind direction. The data found was then analyzed and matched up with a variety of turbine power curves in order to best size the turbine for Auburns wind capabilities.

3.4 Cost Analysis

The cost analysis of a wind turbine is calculated in three parts: the amount of electricity the turbine will produce, the value of the electricity and the cost of the turbine. All of these parts have factors which determine the payback period of a wind turbine.

The first step the team did was determined the size of the turbine as well as whether or not there will be one or two turbines. The next step in the process was to determine the capacity factor, the percentage of the maximum amount of electricity the turbine could produce, as well as the availability of a wind turbine. Researching other turbine projects in the area as well as studies helped the team determine a practical capacity factor. The availability of the turbine was also determined from other projects in the area such as Holy Name and Princeton. The team then determined the annual energy production with this information.

The next step the team proceeded with was to determine what the produced electricity is worth. We looked at consumer bills for people in Auburn and determined the worth of each kilowatt-hour produced by the wind turbine would be. We also researched how much the credits, renewable energy and federal tax, are worth per kilowatt-hour. Each of these revenues were then added and multiplied to estimate the yearly revenue of the turbine.

After the revenues are estimated an estimate of the installation cost of the turbine or turbines. With research and observations from other projects the team was able to determine operation and maintenance costs per kilowatt-hour as well as the installation cost per kilowatt-hour. The latter was calculated by averaging a few wind turbines in Massachusetts. The next costs were determined were the cost of transmission lines, access roads, site clearing and the planning and design. This was all determined by the final MQP team's design. Once these values were finalized they were added up to estimate the installation cost of the turbine.

The payback period is the most important part of the cost analysis. The team determined a payback period by taking the estimated installation cost and dividing that by the estimated turbine revenue. This value is an estimation of how long it will take for the turbine to produce enough electricity to cover the cost of the installation and maintenance.

3.5 Turbine Recommendations

The criteria involved and the methods mentioned earlier in this chapter were used in order to choose a turbine size for Auburn. Wind speed, capacity factor and location among other things were analyzed while considering each turbine. The team researched turbine companies and the specs of their turbines to see if their cut-in wind speeds as well as average wind speed was good enough for the chosen location. Also, the amount of area needed for the turbine was researched. The cost of each configuration, size as well as number, of wind turbines was analyzed. By doing a cost analysis of each configuration of the turbines we decided were best suited, the team then could compare and recommend the best option.

3.6 Summary

Starting off this seems like a large, time consuming project, but if all of these steps and methods are done in the right order the teams can make the best decision regarding a wind turbine for Auburn. First, by visiting the site, using MassGIS, and analyzing wind data the team can determine the best available site for a wind turbine. Next the team must complete multiple cost analysis sheets for different sizes and number of turbines. Then we can make the recommendation to Auburn for the turbine that best suits their needs.

Chapter 4: Results

This section includes the results which were found by following the methods described in Chapter 3. The following section includes; turbine location, required permits, wind data, electrical use, cost analysis, and a wind energy recommendation.

4.1 Turbine Location

Members of the Auburn Wind Committee, including the town planner and town engineer, visited the site of Granger Cliffs with the group. It was found that the following statement made by the RERL study about site #2 on Prospect Hill, “Parcel not large enough to provide proper distance of turbine from residences”(Renewable Energy Research Laboratory, 2008), was false. Rather, site #1 was located too close to the parcels owned by BJ’s and The Home Depot, creating an undesirable location for a turbine. The area between the RERL studies marked site #1 and site #2 was adopted as Granger Cliffs by the group, due to the steep ledge.

It was decided by the members of the Auburn Wind Committee at the Auburn Town Hall on December 15, 2009, that Granger Cliffs would be the future site of Auburns Wind Turbine(s). The information that was collected from the site analysis pointed toward this decision due to elevation, wind speeds, proximity to residence, and access.

Table 4 provides a detailed profile of the Granger Cliffs site that was chosen to be the future location for Auburn’s Wind Turbine(s).

The correct turbine location needed to meet several different forms of criteria. The first main criterion was elevation. The site needed to be high enough for the wind turbine to work efficiently. The higher the site, the stronger the wind speeds, equating more electricity being produced. The elevation for Granger Cliffs is 828 ft (252.4 m). The second major criterion was wind speeds. According to the specifications of the chosen turbine, the cut in speed for the turbine is 3 m/s. The site has an average wind speed ranging from 6.25-6.74 m/s, surpassing the required cut in speed based on a hub height of 70 m or 100 m. The next key factor for the turbine location was economics. Ideally a turbine site must be easy to access. The easier the accessibility to set up the turbine, the less money it costs. It was determined that the access road to be built for Granger Cliffs had the easiest accessibility for transporting the different parts of the turbine to the site due to the fact that the BJ’s/Home Depot parking in the surrounding area allow easy accessibility for delivery vehicles. In addition to economics, the site is large enough for more than one turbine. If more turbines were installed on the site, then the payback period for installing the turbines would decrease due to the turbines producing more electricity. The last key factor in the turbine location was environmental aspects. Some environmental considerations that were examined were if the area was considered to be wetlands, if endangered species inhibited the area, and if the site was originally a landfill. Fortunately Granger Cliffs did not match any of these concerns.

Table 2: Granger Cliffs Site Profile

Site Overview	
Description, current land use	Prospect Hill Map 67, Lot 1
Address	Oxford St. South
Owner	Town of Auburn

Location	
NAD 83, lat & long	42.1739° -71.8517°
Degree, minute, second	42° 10' 26.00" N 71° 51' 6.00" W
Approximate Elevation (ft)	828

Wind Speeds	
Estimated Mean Speeds (m/s)	
At Height of 100m	6.74
At Height of 70m	6.25
At Height of 50m	5.83
At Height of 30m	5.22
Wind Speed Summary (for utility scale)	Fair
Existing Wind Data	Anemometers mounted on an existing tower in Paxton 9.25 miles away

Wind Turbine Considerations	
Economic	
On-site Electric Loads	None
Electric Loads, kWh/year	Possible Future School site
Distance to Distribution/ Transmission Lines	800 meters to residential area

Access for blade transportation	Access road part way to site: clearing, road upgrade, extension and construction are needed
Obstructions to wind	
Terrain	Wooded lot adjacent to large open field
Obstacles to wind	Mature Trees
Noise	
Nearby residential areas	yes
radius to residences (m): (ideally > ~300m for utility scale	360 meters

Environmental Permitting	
Designated by the Natural Heritage & Endangered Species Program as a Core Habitat or a Supporting Natural Landscape?	None
Designated by the DEP as Wetlands?	None
Designated by the Massachusetts Audubon Society as an Important Bird Area (IBA)?	None
Is the site a current or former land-fill? (RERL does not install met towers on landfills)	None
Other land-use restrictions	It is not known if this site carries Article 97 restrictions

Other Permitting	
Distance to airport(s)	6.52 miles to Worcester Municipal Airport

Wind Turbine: Conclusion	
Primary constraint(s): If this site is of interest for a utility-scale turbine, what factors will most affect feasibility and/or micro siting?	No electric load
Next step/To be determined: To pursue wind power at this site, these items should be explored first (along with wind monitoring and public outreach)	File FAA form 7460-1 Discuss land control proposal with stakeholders Access wind resources
Recommendations: Should the town consider this site for a utility-scale wind turbine?	Yes
Multiple Turbines: If the town is interested in installing more than one turbine, how many could fit at this site?	Two or three turbines if the pig farm land becomes available for a wind project site

(Renewable Energy Research Laboratory, 2008)

4.2 Wind Data

An anemometer could not be placed on site with the equipment available because there were no clearings, therefore alternative options were used in order to correctly analyze the wind potential at Granger Cliffs. The desired wind speeds for Granger Cliffs ranged from 6-7 meters/second (m/s) (~13-16 miles per hour (mi/hr)) for a commercial turbine to work efficiently.

4.2.1 Personal Weather Station at Pakachoag Meadows Golf Course

The first solution to collecting wind data for Auburn was using a personal weather station (PWS) that was located at Pakachoag Golf Course in Auburn. A PWS is a private weather station. This specific PWS made it easy to access its data by logging it on the website, Weather Underground. The website included wind speed data for the first eleven months of 2009 at a height of 1 meter above the ground. The PWS located at Pakachoag Meadows Golf course is 1 meter above the ground and potentially blocked by obstacles such as trees, and buildings. These obstacles made the raw wind data that was collected from the PWS useless therefore a wind shear equation found in Table 2 was applied. The wind shear equation allowed for wind speed at different heights to be calculated by taking into consideration; the height and speed of the initial data, the wind shear exponent and the desired height for the newly calculated wind speed. The wind shear exponent is based on land characteristics of the golf course where the PWS is located; taking the obstructions that may alter the wind readings into consideration. The desired heights used to calculate the new wind speeds were 30m, 50m, 70m, and 100m. The initial wind speed data as well as the calculated wind speed data, at the desired heights, are located in Table 6 in the appendix. The highest wind speed calculated for Pakachoag Meadows Golf Course was 4.7 m/s at 100 meters. The calculated wind speeds were lower than expected at Pakachoag Meadows, forcing the team to research more sources for wind data at Granger Cliffs.

Table 3: Wind Shear Equation

Wind Shear Equation: v / vo = (h / ho)^α
v = [(h / ho)^α] vo
v = velocity at height h
h = velocity height
vo = initial velocity
ho = initial velocity height
α = wind shear exponent

Terrain	Wind Shear Exponent
Open water	0.1
Smooth, level, grass-covered	0.15
Row crops	0.2
Low bushes with a few trees	0.2
Heavy trees	0.25
Several buildings	0.25
Hilly, mountainous terrain	0.25

(Wind Shear, 2005)

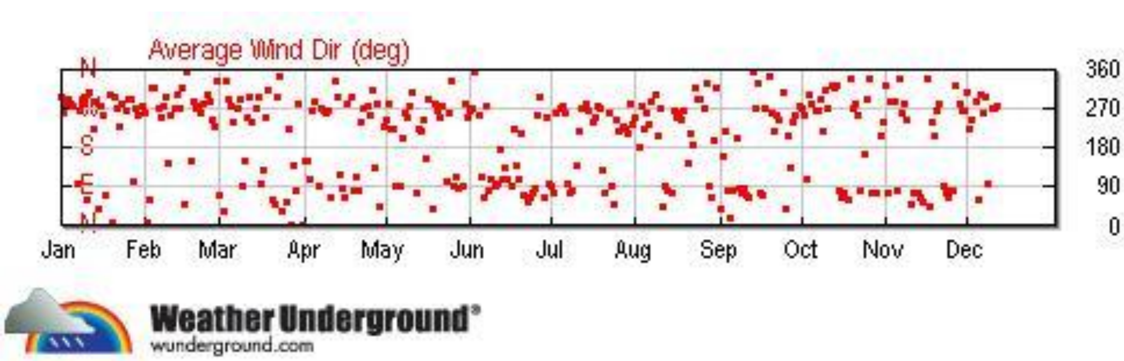

Figure 19: Weather Underground Wind Direction for the Personal Weather Station at Pakachoag Meadows

The PWS proved to be an inadequate source for wind data in Auburn, yet the Weather Underground website provided a wind direction graph found in figure 19, which helped describe wind patterns for the year. The conclusion from this figure was that the winds predominantly blow from the northwest. This information is crucial in the placement of the turbines on Granger Cliffs.

4.2.2 Renewable Energy Research Laboratory Anemometer in Paxton, MA

The second source used to access wind data was the Renewable Energy Research Laboratories anemometer located in Paxton, Ma. Due to the proximity of the town of Paxton to Auburn, the wind data from this source could be used. The installation and maintenance of the anemometer was provided by the Center for Energy Efficiency and Renewable Energy at the University of Massachusetts Amherst. The data collected from the anemometer at a height of 78 meters, as well as calculated speeds at 30, 50, 70, and 100 meters using the wind shear equation, are found in Table 7 of the appendix. At a height of 100 meters, the average wind speed in Paxton, MA was calculated to be 8.2 m/s, ideal for a turbine.

4.2.3 Associated Weather Services Wind Navigator Map System

The Associated Weather Services Wind Navigator map system allowed for computer technology to describe wind speeds at Granger Cliffs. The *MesoMap* wind data program, found on the Associated Weather Services website is, "… powered by an integrated suite of atmospheric data and models running on a large distributed computer network at AWS Truewind's Albany headquarters (Wind Navigator Map System)." The average wind speed at any location in the United States for heights of 60, 80 and 100 meters can be found by either typing in the coordinates or eyeballing a location. The exact coordinates of Granger Cliffs were typed into the Wind Navigator System (42° 10' 26.00" N, 71° 51' 6.00" W) finding the average wind speed at 100 meters to be 6.02 m/s (Wind Navigator Map System). The average wind speeds for Granger Cliffs at heights of 60, 80, and 100 meters can be found in Figure 20.

Figure 20: Granger Cliffs Wind Speeds @ 60,80 & 100 Meters

4.2.4 Massachusetts Geographic Information System

Massachusetts Geographic Information System allowed the team to create maps of Granger Cliffs with topographic lines, parcels, roads and wind speeds at heights of 30, 50, 70 and 100 meters. Figure 21 is an example of a map that was created in order to determine the average wind speed at 100 meters for Granger Cliffs. The average wind speed at this location was determined to be around 9.0 m/s at 100 meters, sufficient for a turbine.

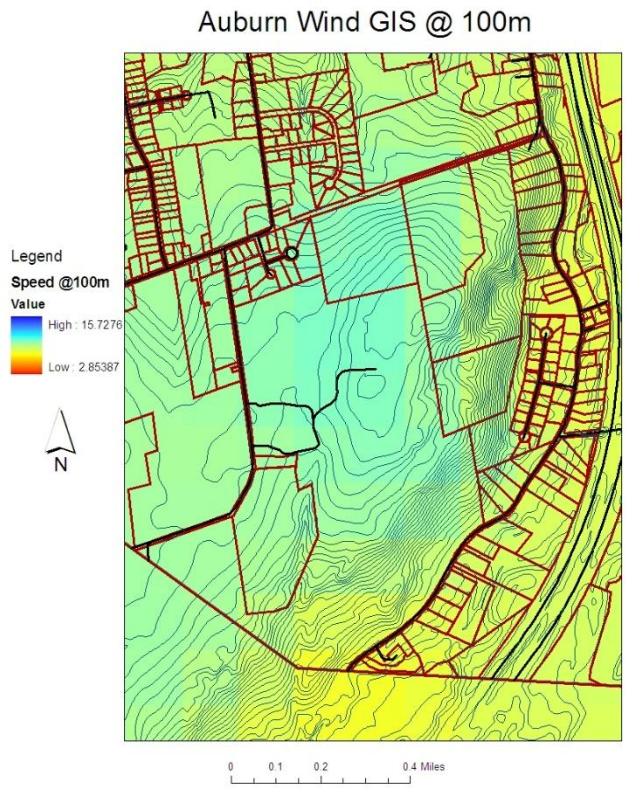

Figure 21: Mass GIS Wind Map of Granger Cliffs @ 100 Meters

4.2.5 Sonic Wind Profiler

Setting up an anemometer just was not feasible for the team to set up at the turbine location, so Second Wind's relatively new technology for wind profiling was researched as an option. The company has been in the business of providing wind information to companies for the past three decades. Recently the company has been using the Triton Sonic Wind Profiler to provide the wind energy industry with important wind data.

The reason an anemometer is not feasible is due to the geography of the area surrounding the wind turbine location. There is neither an area clear enough or at the required height to get good enough data from an anemometer. This Triton Sonic Wind Profiler is feasible because of its size. It is basically a six by four meter box with a height of two meters. It is also operational remotely and within two hours of getting it on site. This technology does not require as much clear area an anemometer would require.

Figure 22: Triton Sonic Wind Profiler

(Second Wind)

This technology is also cost effective. A full ninety day wind study done by Second Wind is only 22,500 dollars and a one hundred and eighty day wind study is 32,000 dollars. This cost is less than a meteorological tower at a height much less than the capabilities of the Triton Sonic Wind Profiler, not to mention the tree clearing that is required if an anemometer was used. Second Wind is also located locally which also reduces some cost.

The Triton Sonic Wind Profiler uses an advanced sodar, "which measures the scattering of sound waves by atmospheric turbulence" that can measure wind data up to two hundred meters above the ground. The data collected is also very accurate even at heights of one hundred and forty meters. The information that this machine determines includes wind speed, wind shear characteristics, inflow distribution and coupled with a nearby data source it can determine the seasonality. With all of this information at hand we can determine how viable a wind turbine would be, estimations on the energy production and the capacity factor of a wind turbine at the location. After these factors are determined the best turbine size, placement and operation can be determined.

4.2.6 Wind Data Conclusion

Table 4 provides the average wind speed at 100 meters for Granger Cliffs using three different wind data sources. The average wind speed at 100 meters for Granger Cliffs was determined by calculating the speeds at 100 meters using the wind shear equation, averaging the total yearly wind speeds and finally averaging all three of the sources averages to receive a final combined average wind speed of 7.7 m/s. This average wind speed surpasses the range of 6-7 m/s necessary for a productive turbine, proving Granger Cliffs to be a positive choice for harnessing wind.

Table 4: Wind Data Averages at 100 Meters

Wind Data	Average Wind Speed @ 100m (m/s)
AWS Wind Navigator Map System	6.0
Mass GIS	9.0
Paxton, MA Anemometer (RERL)	8.2
Granger Cliffs Combined Average Wind Speed:	7.7

4.3 Electrical Use

The Town of Auburn does not have many options for the electricity that the wind turbine will produce. National Grid does provide net metering and selling the electricity to them is one option, but this option would require a contract and negotiations between Auburn and National Grid. The other options would be to use the electricity at a location such as a high school or the nearby BJ's or Home Depot.

4.3.1 Selling Electricity to National Grid

Massachusetts state law requires electricity providers to offer net metering for excess electricity that the wind turbine will produce. The charges that are net metered for either turbine include the basic service kWh, the transmission KWh and the transition kWh charges. One problem with this is that the law only requires the electricity provider to return credits for the excess electricity produced. This means that Auburn will not be able to use the electricity to its fullest potential as if it provided electricity and used it on-site such as a high school or Home Depot. It would lower the town's electricity bill, but not as much as it potentially could. If the town decides to go forward with this option it will require negotiations and a contract for things such as the amount each charge credited is worth, but it is still the best option for the town.

4.3.2 Other Electricity Options

The other option for the electricity produced by Auburn's wind turbine is to use it on-site and receive full value for the electricity. The best option is a town owned property where the electricity is worth the full value. Unfortunately there are no town owned properties close enough to warrant the cost of the transmission lines to get the electricity from the turbine to the location. The next option would require about a half mile of transmission lines to either the Home Depot or BJ's. This is not as good of an option as a town owned property due to the town having to sell the electricity at a lower than full value price but higher than the net metered credit value. The value would be determined by a contract between the company and the town as well as a contract with national grid for any excess electricity produced. This option is much more work and will cost more, and is therefore not the best option.

4.4 Cost Analysis

The cost analysis consists of four main components or calculations that are derived from other calculations and factors. The four main components are: annual energy production, estimated turbine revenue, estimated installed cost and pay-back period. There are several factors that are used to calculate these numbers and will be discussed in this chapter.

4.4.1 Annual Energy Production

Annual Energy Production is calculated via four major components. The most important of which is capacity factor. Capacity factor is how much energy the turbine produced over time divided by how much energy the turbine would produce if it rand at 100% power. After researching other turbine projects in the area the team concluded, conservatively, that this area has a capacity factor of 20%. The next component is what power the turbine is rated at. This is pretty straight forward. A 600 kilowatt turbine is rated at 600 kilowatts and a 1.5 megawatt turbine is rated at 1500 kilowatts, and so on and so forth. The third component is the availability of the wind turbine. Due to maintenance and other fixes to the machine it will be down and unable to produce electricity from time to time. Over the course of a year a turbine will be operational 95% of the time. Lastly the 8,760 hours in a year has to be factored into the equation. Multiplying each of these factors together will yield the annual energy production in kilowatt hours.

4.4.2 Estimated Turbine Revenue

Estimated turbine revenue is calculated using the annual energy production and multiplying it by three factors. The first of which is the value of electricity. After looking at a National Grid's consumer's bill, the price they charge for electricity is about ten cents per kilowatt hour. The next revenue is REC's by MA RPS Standards. These are renewable energy credits that will be given to Auburn for using a source of renewable energy. These are five and a half cents per kilowatt hour. The last source of revenue is a federal tax credit which is 1.9 cents per kilowatt hour. All three of these revenues were multiplied by the annual energy production. Then these three numbers are added together to come up with a revenue in dollars and cents.

4.4.3 Estimated Installed Cost

The cost of installing a turbine in Auburn was estimated with several factors. Some costs are over time and others are onetime costs. The first cost is operation and maintenance, the US Department of Energy data has an average operation and maintenance cost at three cents per kilowatt hour. This is then multiplied by the annual energy production to get a cost in dollars and cents. This is an important cost and has many factors that change the outcome of this. Thus it is discussed in more depth later in the section.

The next cost is the estimated installed cost of just the turbine. This cost depends on the size of the turbine being installed and is thus a cost in terms of dollars per kilowatt. After researching other turbine products in the area including the projects in Hull and Princeton the team averaged those costs per kilowatt and came up with 2316.14 dollars per kilowatt. This number was then multiplied by the turbine's power rating to come up with a figure for the cost of turbine installation.

The rest of the costs are just flat costs such as transportation, cost of the access road, land clearing, planning, design, etc. All of these costs, including operation and maintenance cost as well as the turbine installation cost, are added together and become the estimated installed cost for Auburn's wind turbine project.

4.4.3.1 Operation and Maintenance

The two key parameters to consider for operation and maintenance are scheduled and unscheduled operation and maintenance. The important components that need to be examined for operations include scheduled site visits and monitoring the turbine's activity. In addition there are off-site activities of operations including "inventory management, coordinating with sub-suppliers for site and maintenance services, administering power purchase agreements, and submitting and tracking warranty claims (Wind Turbine Reliability)."

Scheduled maintenance includes equipment inspection, calibration for any sensors or actuators, regular cleaning and any replacements for any parts. Unscheduled maintenance has two categories of costs, both direct and indirect. Direct unscheduled costs refer to payment of labor and equipment whereas indirect unscheduled costs refer to lost revenue from the turbine being offline. To ensure safety, climbing equipment will need to be purchased such as harnesses and helmets. It is typical to have a two person crew operating on the turbine for safety issues.

Over time as the turbine gets older, it will cost more money to maintain and operate it. It has been reported that the cost for replacing a gearbox from a 660 kW turbine is about $120,000. This price was based on a wind farm that had service equipment such as a crane onsite. It will be necessary for the town of Auburn to devise a plan to eventually reduce extended future maintenance costs. Some basic tasks the town will have to perform in the future include determining what the main problems are of the turbine and invest in ongoing diagnostics to optimize performance. For example if the turbine's sensors are found to be a weak point, then the town should focus on keeping that particular portion of the turbine well maintained. In addition, it is recommended that the town of Auburn have onsite training for staff to improve maintainability and monitoring. This will be determined by the town's available budget.

4.4.4 Summary

The whole purpose of a cost analysis is to determine the payback period of the different sizes and configurations of turbines. The team calculated several payback periods of different size turbines as well as just one or two turbines. The payback period is determined by taking the estimated installed cost and dividing it by the estimated turbine revenue giving you a number in years when the turbine energy production has nullified the cost of installing the turbine. The payback periods for all of the configurations were about eight years, but some were better than others with a lower payback period as seen in cost analyses in appendix B.

4.5 Turbine Recommendation

Critical research needed to be conducted to choose the correct turbine. The decision of the turbine was based on several major criteria. The first criterion to be met was cost. Cost is based on payback period and cost of delivery. The second criterion is energy efficiency. Energy efficiency is based on operation & maintenance and mechanical specifications. Cost and energy are usually related because the more efficient the turbine, the shorter the payback period and vice versa. The third criterion was size. The size of the turbine was based on the town's energy needs. Size is a critical parameter because if the chosen turbine is too small then the town's energy requirements will not be met. In addition it is possible to have a turbine that is too big because although the turbine may meet the town's energy requirements, the wind speeds may not be strong enough to keep the turbine running efficiently.

The team researched several different turbine companies and narrowed the search down to four different models, seen in table 5.

Table 5: Potential Turbine Sizing Options

Model	Hub Height (m)	Rotor Diameter (m)	Output (kW)	Cut In Speed (m/s)	Rated (m/s)	Cut Out Speed (m/s)
Fuhrlander FL 600	50/75	43-50	600	3	10.8	25
Fuhrlander FL 1500	65/80/100	70/77	1500	3	11/12	20/25
General Electric GE 1.5	65/80	77/82.5	1500	3.5	14/11.5	25/20
General Electric GE 2.5	75/85/100	100	2500	3	12.5	25

The hub height refers to the distance from the ground to the hub of the turbine which is the piece of the turbine that holds all of the blades together. Output is the energy output that the turbine is rated to produce. The cut in speed is the minimum speed needed to rotate the blades of the turbine and produce energy. The cut out speed is the stopping speed of the turbine and rated speed is the speed to produce name plate power rating. It is the speed in which the maximum output is achieved and the output remains constant when looking at a power curve.

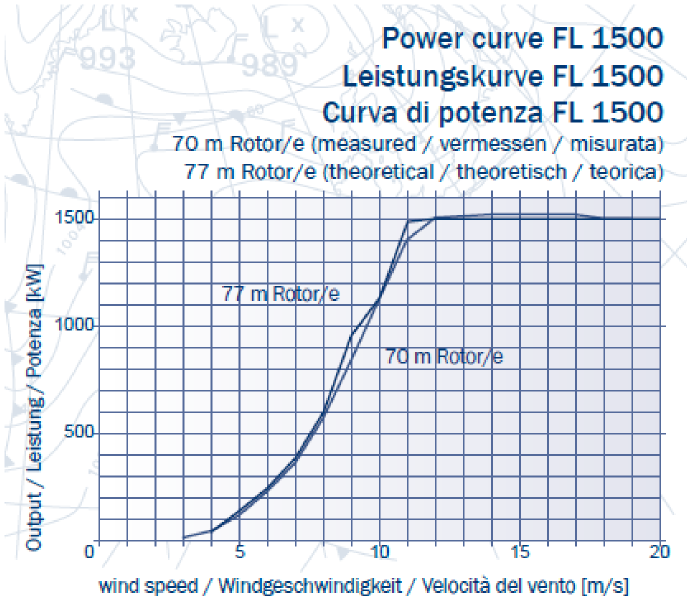

Figure 23: Fuhrlander FL 1500 Power Curve

(Fuhrlander Wind Turbines, 2009)

Chapter 5: Conclusion

This section summarizes the methods and results of the report with a final turbine location and selection. It concludes the report with future recommendations for the town of Auburn along with an observation of Auburn's future with wind energy.

5.1 Auburn's Future with Wind Energy

After critical research the team decided the best choice for the town of Auburn would be two Fuhrlander FL 1500 turbines. The turbine met both short term and long term cost projections. For the short term cost projection, it was found to be beneficial to use two turbines based on the access road. The access road that is designed to help deliver the turbine to the site can be used to deliver more than one turbine which is very beneficial for immediate cost. In addition to short term costs, it the shipping of the turbine to the United States would cost less and be easier to deliver to the site. The long term costs are primarily based on payback period. It was found that the payback periods for installing one or two 1.5 MW turbines differed slightly. Since the payback periods varied slightly, installing two turbines would be more cost beneficial. The energy output of the turbine, 1.5 MW, was found to adequately meet Auburn's energy requirements. In addition based on the wind data, the Fuhrlander FL 1500 would run the most efficient. The cut in speed of the turbine is 3 m/s and the rated speed is 11-12 m/s. These wind speeds matched the data collected from different wind stations around the area. Overall two Fuhrlander FL 1500 turbines would be both cost and energy efficient for the town of Auburn's wind site.

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Appendix A: Monthly Wind Speeds

Table 6: Personal Weather Station Wind Data from Pakachoag Meadows Golf Course (2009)

Average Monthly Wind Speed @ 1 m (3.3 ft)		
Time (month)	Wind Speed (m/s)	Wind Speed (mi/hr)
January	1.1	2.5
February	1.7	3.8
March	1.4	3.2
April	1.8	4
May	1.1	2.5
June	0.9	2.1
July	0.8	1.9
August	0.6	1.4
September	1.0	2.2
October	1.2	2.6
November	1.9	2.1
December	-	-

(Weather Underground, 2010)

Estimated Average Monthly Wind Speed @ 30 m (98.4 ft)		
Time (month)	Wind Speed (m/s)	Wind Speed (mi/hr)
January	2.2	4.9
February	3.4	7.5
March	2.8	6.3
April	3.5	7.9
May	2.2	4.9
June	1.9	4.1
July	1.7	3.8
August	1.2	2.8
September	1.9	4.3
October	2.3	5.1
November	3.7	8.3
December	-	-

Estimated Average Monthly Wind Speed @ 50 m (164.0 ft)		
Time (month)	Wind Speed (m/s)	Wind Speed (mi/hr)
January	2.4	5.5
February	3.7	8.3
March	3.1	7.0
April	3.9	7
May	2.4	5.5
June	2.1	4.6
July	1.9	4.2
August	1.4	3.1
September	2.2	4.8
October	2.5	5.7
November	4.1	9.2
December	-	-

Estimated Average Monthly Wind Speed @ 70 m (229.7 ft)		
Time (month)	Wind Speed (m/s)	Wind Speed (mi/hr)
January	2.6	5.8
February	4.0	8.9
March	3.3	7.5
April	4.2	9.4
May	2.6	5.8
June	2.2	4.9
July	2.0	4.4
August	1.5	3.3
September	2.3	5.1
October	2.7	6.1
November	4.4	9.8
December	-	-

Estimated Average Monthly Wind Speed @ 100 m (328.1 ft)		
Time (month)	Wind Speed (m/s)	Wind Speed (mi/hr)
January	2.8	6.3
February	4.3	9.5
March	3.6	8.0
April	4.5	10.0

May	2.8	6.3
June	2.4	5.3
July	2.1	4.8
August	1.6	3.5
September	2.5	5.5
October	2.9	6.5
November	4.7	10.5
December	-	-

Table 7: Paxton Renewable Energy Research Laboratory Wind Data (2006)

Average Monthly Wind Speed @ 78 m (255.9 ft)		
Time (month)	Wind Speed (m/s)	Wind Speed (mi/hr)
January	8.4	18.7
February	8.6	19.2
March	8.3	18.5
April	7.8	17.4
May	7.7	17.3
June	7.0	15.5
July	6.8	15.1
August	6.8	15.1
September	7.1	15.9
October	8.2	18.4
November	7.7	17.3
December	9.1	20.4

(University of Massachusetts Amherst, 2007)

Estimated Average Monthly Wind Speed @ 30 m (98.4 ft)		
Time (month)	Wind Speed (m/s)	Wind Speed (mi/hr)
January	6.9	15.4
February	7.1	15.9
March	6.8	15.2
April	6.4	14.4
May	6.4	14.3
June	5.7	12.8
July	5.6	12.5
August	5.6	12.5
September	5.9	13.2

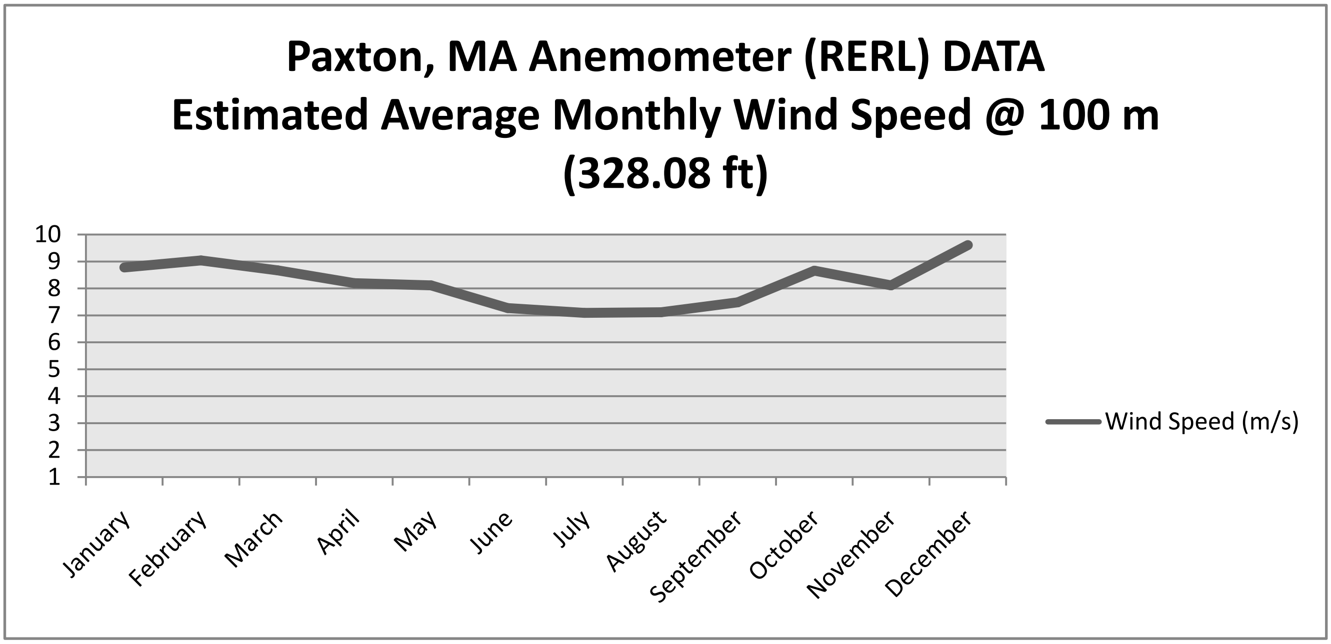
October	6.8	15.2
November	6.4	14.3
December	7.6	16.9

Estimated Average Monthly Wind Speed @ 50 m (164.0 ft)		
Time (month)	Wind Speed (m/s)	Wind Speed (mi/hr)
January	7.6	17.1
February	7.9	17.6
March	7.5	16.9
April	7.1	16.0
May	7.1	15.8
June	6.3	14.2
July	6.2	13.8
August	6.2	13.9
September	6.5	14.6
October	7.5	16.9
November	7.1	15.8
December	8.4	18.7

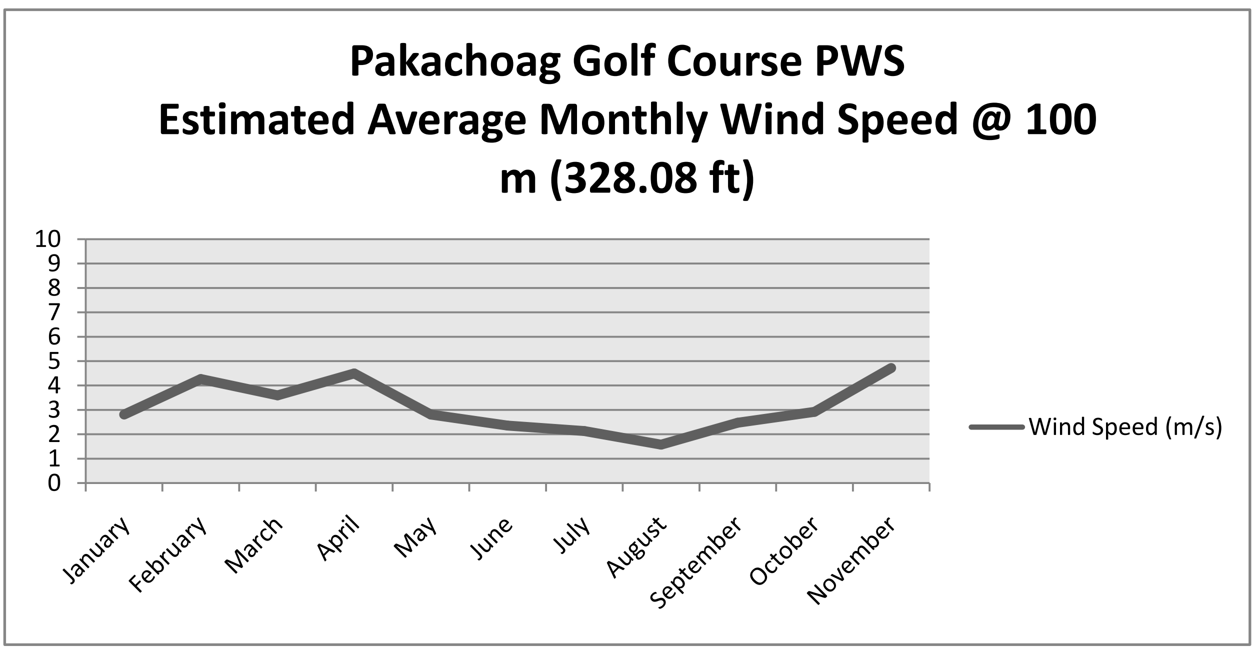
Estimated Average Monthly Wind Speed @ 70 m (229.7 ft)		
Time (month)	Wind Speed (m/s)	Wind Speed (mi/hr)
January	8.2	18.3
February	8.4	18.8
March	8.1	18.1
April	7.6	17.1
May	7.6	16.9
June	6.8	15.1
July	6.6	14.8
August	6.6	14.8
September	7.0	15.6
October	8.1	18.0
November	7.6	16.9
December	8.9	20.0

Estimated Average Monthly Wind Speed @ 100 m (328.1 ft)		
Time (month)	Wind Speed (m/s)	Wind Speed (mi/hr)
January	8.8	19.6
February	9.0	20.2

March	8.7	19.4
April	8.2	18.3
May	8.1	18.1
June	7.3	16.3
July	7.1	15.9
August	7.1	15.9
September	7.5	16.7
October	8.7	19.4
November	8.1	18.1
December	9.6	21.5



Paxton, MA Anemometer (RERL) DATA
Estimated Average Monthly Wind Speed @ 100 m
(328.08 ft)
10
9
8
7
6
5
4
3
2
1
January
February
March
April
May
June
July
August
September
October
November
December
Wind Speed (m/s)



Pakachoag Golf Course PWS
Estimated Average Monthly Wind Speed @ 100
m (328.08 ft)
10
9
8
7
6
5
4
3
2
1
0
January
February
March
April
May
June
July
August
September
October
November
Wind Speed (m/s)

Appendix B: Cost Analyses

WPI Auburn Wind Draft Cost Analysis (600 kW)

Production	Values	Units
Capacity Factor *= Actual Amount of Power Produced over time / Power that would have been produced if turbine operated at maximum output 100% of the time	0.2	
Rated Power Per Turbine *	600	kW
Availability *	0.95	
Conversion Factor	8,760	hrs/yr
Annual Energy Production = Capacity Factor * rated Power per turbine * Availability * 8,760 hrs/yr	998640	kWh/yr
Revenue		
Auburn Consumer Electricity Price	0.15	$/kWh
National Grid Wholesale Price *	0.097	$/kWh
REC's by MA RPS Standards*	0.055	$/kWh
Federal Tax Credit*	0.019	$/kWh
Estimated Turbine Revenue	170767.4	$/yr
Turbine Cost		
Operations & Maintainence Costs*	0.03	$/kWh
Transmission Lines*	100,000	$
Access Road*	118,800	$
Site Clearing*		$
Planning & Design*		$
Estimated Installed Cost/kW *	2136.14	$/kWh
Estimated Installed Cost in Auburn	1500502	$
Pay Back Period	8.8	years

WPI Auburn Wind Draft Cost Analysis (1.5 MW)

Production	Values	Units
Capacity Factor *	0.2	
Rated Power Per Turbine *	1500	kW
Availability *	0.95	
Conversion Factor	8,760	hrs/yr
Annual Energy Production	2496600	kWh/yr
<u>Revenue</u>		
Auburn Consumer Electricity Price	0.15	$/kWh
National Grid Wholesale Price *	0.097	$/kWh
REC's by MA RPS Standards*	0.055	$/kWh
Federal Tax Credit*	0.019	$/kWh
Estimated Turbine Revenue	426918.6	$/yr
<u>Turbine Cost</u>		
Operations & Maintainence Costs*	0.03	$/kWh
Transmission Lines*	100,000	$
Access Road*	118,800	$
Site Clearing*		$
Planning & Design*		$
Estimated Installed Cost/kW *	2136.14	$/kWh
Estimated Installed Cost in Auburn	3423055	$
Pay Back Period	8	years

WPI Auburn Wind Cost Analysis (Two 1.5 MW)

Production	Values	Units
Capacity Factor *	0.2	
Rated Power Per Turbine *	3000	kW
Availability *	0.95	
Conversion Factor	8,760	hrs/yr
Annual Energy Production	4993200	kWh/yr
Revenue		
Auburn Consumer Electricity Price	0.15	$/kWh
National Grid Wholesale Price *	0.097	$/kWh
REC's by MA RPS Standards*	0.055	$/kWh
Federal Tax Credit*	0.019	$/kWh
Estimated Turbine Revenue	853837.2	$/yr
Turbine Cost		
Operations & Maintainence Costs*	0.03	$/kWh
Transmission Lines*	100,000	$
Access Road*	118,800	$
Site Clearing*		$
Planning & Design*		$
Estimated Installed Cost/kW *	2136.14	$/kWh
Transportation Cost	150,000	$
Estimated Installed Cost in Auburn	6777310	$
Pay Back Period	7.9375	years

ASSUMPTIONS (*) For All Cost Analyses

4.) Capacity Factor: global average of 20% =
Actual Amount of Power Produced over time
/
Power that would have been produced if
turbine operated at maximum output 100% of
the time

6.) Availability: RERL Wind Economics Study

8.) Annual Energy Production: Capacity Factor * rated Power per turbine * Availability * 8,760 hrs/yr

12.) Auburn Consumer Electricity Price: Auburn Residence Electric Bill

13.) National Grid Wholesale Price: Auburn Residence Electric Bill

14.) REC's by MA RPS Standards: ~ 55$/MWh = 0.055$/kWh

15.) Federal Tax Credit: RERL Study on Turbine
Economics

16.) Estimated Turbine Revenue: Annual
Energy Production * (National Grid Wholesale
Price + REC's + Federal Tax Credits)

19.) Operation and Maintanence Costs: US Department of Energy data ~ 30$/MWh = 0.030 $/ kWh
(insurance included) [20 year period]

20.) Transmission Lines: Windustry Community Wind Toolbox ~ $200,000/ mile

21.) Access Road: Cost Helper @ ~1-3$/ft² with a area of 39,600 ft²

22.) Site Clearing:

23.) Planning & Design: ~10% of Construction Cost?

24.) Estimated Installed Cost/kW:
- Princeton: $ 7,300,000/3,000 kW = 2,433.33 $/kW
- Hull: $ 3,310,109/ 1,800 kW = 1,838.95 $/kW
- Average = 2,136.14 $/kW
- Includes transportation & turbine assembly