THE AUBURN WIND PROJECT
Design for a wind farm in the Town of Auburn, MA

A Major 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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Abstract:

This Major Qualifying Project (MQP) presents recommendations for the installation and site design of two 1.5 mega-watt wind turbines on Granger Cliffs in Auburn, Massachusetts. This project, which was completed in collaboration with a group completing an Interactive Qualifying Project (IQP), addresses the following topics and issues: site selection, zoning, turbine selection, turbine cost estimate and payback period, access road design, environmental issues, social concerns and scheduling and delivery details. The project's outcome is a feasible wind farm site design and cost analysis for the Town of Auburn, Massachusetts.

MQP Capstone Design Statement:

The Accreditation Board for Engineering and Technology (ABET) requires all civil engineering programs to include a capstone design experience that incorporates engineering analysis with real world concerns in a final design. This MQP project meets the capstone design requirement because it provides a product that meets the requirements of economic constraints, environmental constraints, sustainable constraints, health and safety constraints and finally social constraints. The Auburn Wind Project also includes three potential wind farm design alternatives which are compared and contrasted in order to identify the best alternative for the Town of Auburn in terms or profit and payback period. Alternative One proposes the installation of two 1.5mW Fuhrlander wind turbines. Alternative Two proposes the installation of one 1.5mW Fuhrlander wind turbine at the highest point on the site. Finally Alternative Three proposes the installation of one 1.5mW Fuhrlander wind turbine at a lower point on site which would require a slightly lower construction cost since it is closer to the access point of the site.

The overall project design included consideration of economic constraints and a variety of other factors as well. The report included a cost analysis which was used to determine the most appropriate turbines to use on site to minimize the payback period while also maximizing the Town of Auburn's profit. This cost analysis included the wind turbine product cost, project infrastructure cost, construction cost and finally the maintenance cost. The sustainability aspect of the project was handled a number of ways. The project itself was based on the Town of Auburn's Alternative Energy Committee's desire to find a new source of income through the sustainable technology of a wind turbine. By research a number of sites and determining which site provided the best source for wind which would maximize the energy output from the wind which is a reusable source of energy.

The impact of the design on the environment was minimized by minimizing contact with any potential wetlands on site, while also incorporating stormwater management techniques. By incorporating these techniques the design lessens the impact of the project and its construction of the surrounding environment around the access road, as well as within the staging areas by allowing the area to return to its natural state following the project's completion.

This project's design includes several design criteria which are in place to avoid and potential safety hazards either on site or to the surrounding area. The site design includes a fall zone envelope, protecting the surrounding private properties, as well as including a set distance between turbines, which will minimize air turbulence created from one turbine and affecting another which could lead to structural failure. Finally, the project addressed potential issues with the construction and installation of wind turbines to the environment, public and surrounding area. The report addresses the effects of flicker from the turbines blades, noise created from vibration, visual impacts, danger to aviary populations and Federal Aviation Administration impacts. By addressing these five areas of constraints, this MQP report meets Capstone Design requirements with its design of a wind farm for the Town of Auburn, Massachusetts.

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Authorship:

The Abstract, Capstone Design Statement, and Introduction sections were all written by Michael Swanton. The background section was divided equally between the members of the MQP team of Cody McGregor and Michael Swanton as well as the IQP team of Kyle Boucher, Justin Guerra and Bryan Watkins.

The methodology was divided between the MQP team with Cody McGregor authoring the sections entitled Site Determination, Cost Characterization, Site constraints and Public Concerns, and Scheduling and Delivery. Michael Swanton authored the sections entitled Wind Energy Analysis, Turbine Selection, Turbine Siting, Access Road Design, and Staging Area.

The results and alternatives section was also divided between the MQP team. Cody McGregor authored the sections entitled Site Choice and Alternatives, Wind Information and Calculations, Cost Information and Calculations, Site Constraints and Public Concerns and finally Delivery and Scheduling. While Michael Swanton authored the sections entitled Turbine Selection and Alternatives, Access Road Information and Alternatives, and finally Turbine Sighting and Alternatives. It is important to note that the IQP team assisted in the Wind Information and Cost Information sections.

The recommendations section was divided in a similar fashion as the results alternatives section with Cody McGregor authoring the sections entitled Site Determination and Scheduling and Delivery. While Michael Swanton authored the sections entitled Turbine Selection, Turbine Siting, and Access Road Design.

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We would also like to acknowledge the IQP team of Kyle Boucher, Justin Guerra, and Bryan Watkins who assisted in the development of this MQP project while also handling several sections of our report.

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Chapter 1: Introduction

Today as corporations and governments begin to move towards sustainable practices, more emphasis has been 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 the reliance on natural resources that will not be replenished. For companies and towns, and more importantly the nation's population, electricity becomes a necessity that can be very expensive depending on your reliance on it. New sustainable technologies that create electricity and will potentially be paid for through grants from the state and federal governments are the perfect solution to the energy needs for cities and towns.

One of the modern sustainable technologies that has come to the forefront has been one whose history 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, hopes to harness the wind's energy to create electricity by building a wind turbine within the town. The Town of Auburn Alternative Energy Committee hired the Renewable Energy Research Laboratory in the spring of 2008 to conduct a site selection survey. This work was funded by the Massachusetts Technology Collaborative. In the fall of 2009 the Alternative Energy Committee sent out a Request for Qualifications for companies to conduct a wind turbine feasibility study, which is also expected to be funded by the Massachusetts Renewable Energy Trust (MTC-RET). The Auburn Energy Committee selected Sustainable Energy Developments, Incorporated to perform their feasibility study, and they have since submitted a grant requesting funding from the MTC. This Major Qualifying Project is a feasibility study which focuses on the design of a wind farm on Granger Cliffs, in the town of Auburn, Massachusetts. This site was selected by both the town and their hired contractor as the most appropriate site for a wind farm, which was our recommendation as well. The tasks in this project included:

- Identifying the size and number of turbines based on wind data collection and analysis, as well as a cost analysis
- Developing a preliminary site plan including access road, staging areas, wetland issues, and turbine siting

An additional aspect of this project was the coordination with an Interactive Qualifying Project team, which researched available wind turbine technologies that could be used to maximize the site's wind energy potential and conducted a cost analysis of wind power generation at the site

This report contains four main sections. The first section is the background section, and it provides information and background knowledge of the topics that are discussed throughout the report. The following section is the methodology section. This section details the steps the group went through to complete each task performed in order to complete the site determination, turbine selection, wind analysis, cost analysis and the site design. The next section is the results and alternatives section. This section provides all of the findings from the groups studies and research as well as all possible alternatives that could be taken in constructing Auburn's wind farm. The final section is the recommendations section. This section includes the results the group feels is the best use for all aspects of Auburn's Granger Cliff wind farm.

Chapter 2: Background & Literature Review

The background and Literature review section of this Major Qualifying Project report details the information that provides a solid foundation for the project. This research covers topics from town zoning and regulations to modern types of wind turbines.

2.1 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. 6) ("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.5) ("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.

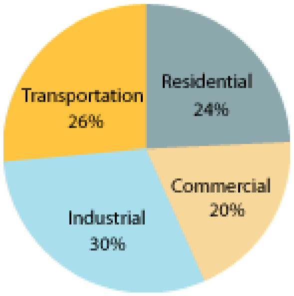


Figure 2: MA Energy Sources

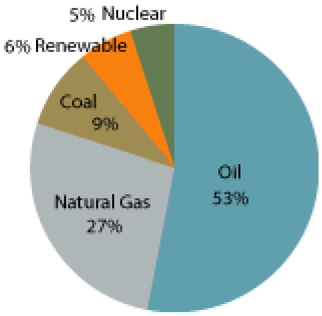


Figure 1 - Overall MA Energy Use(MTC, 2009)

2.2 Massachusetts Wind Potential

Massachusetts holds good potential for renewable energy, especially for offshore wind power as shown in figure 3. 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 would be able to supply the town with 40% of their power needs. 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 the University of Massachusetts (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).

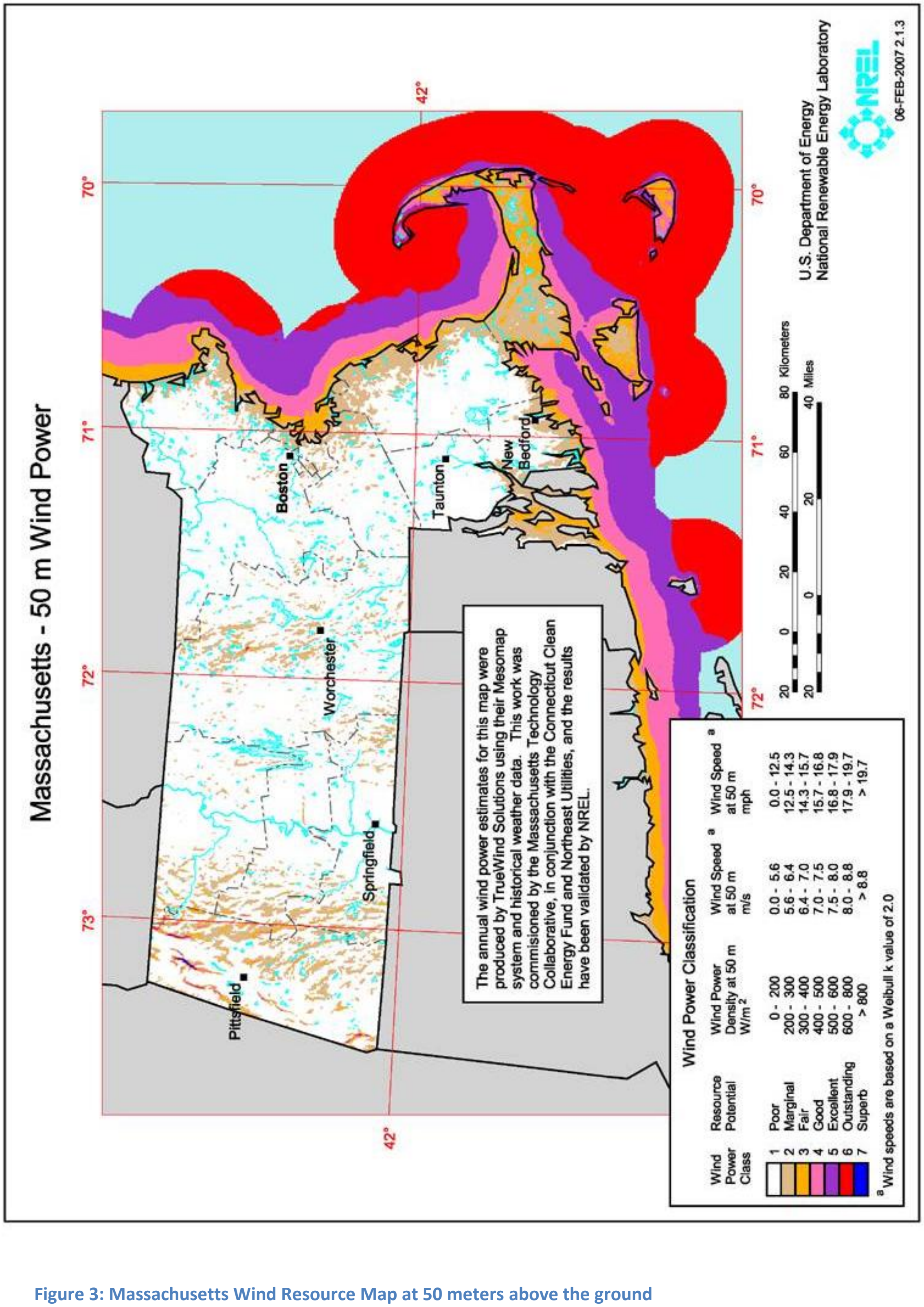


Figure 3: Massachusetts Wind Resource Map at 50 meters above the ground

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

2.3 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 the Massachusetts Clean Energy Center, which used to be the Massachusetts Technology Collaborative, the state's development agency for renewable energy as well as the economy ("MTC: What We Do," 2008). The Clean Energy Center takes credit for 25% of jobs in Massachusetts and has been in service to the state for 23 years.

CEC'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). CEC 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 4: Sites of existing and potential future wind turbine locations in Massachusetts

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

2.4 Current 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 5, 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).

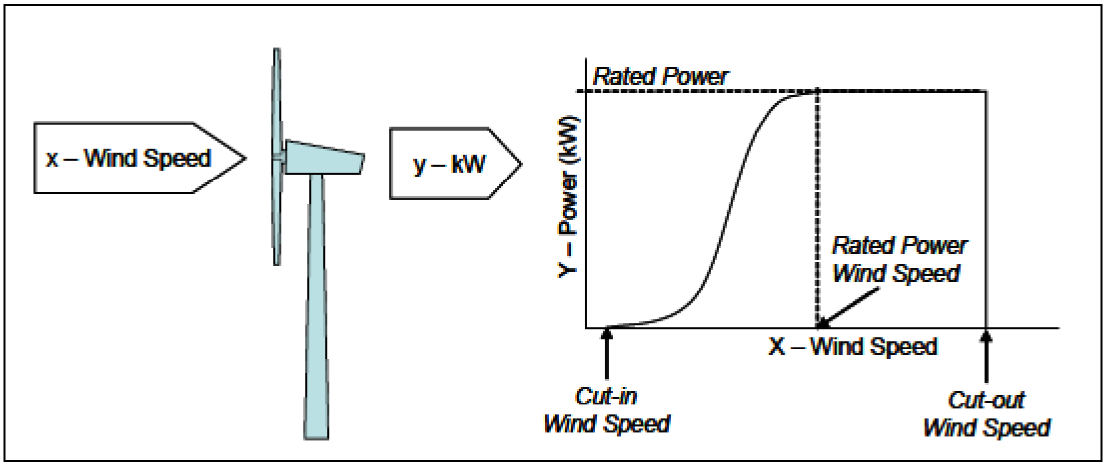


Figure 5: Speed and Power Production Relationship (Paterson, 2004)

As seen in Figure 6, 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.

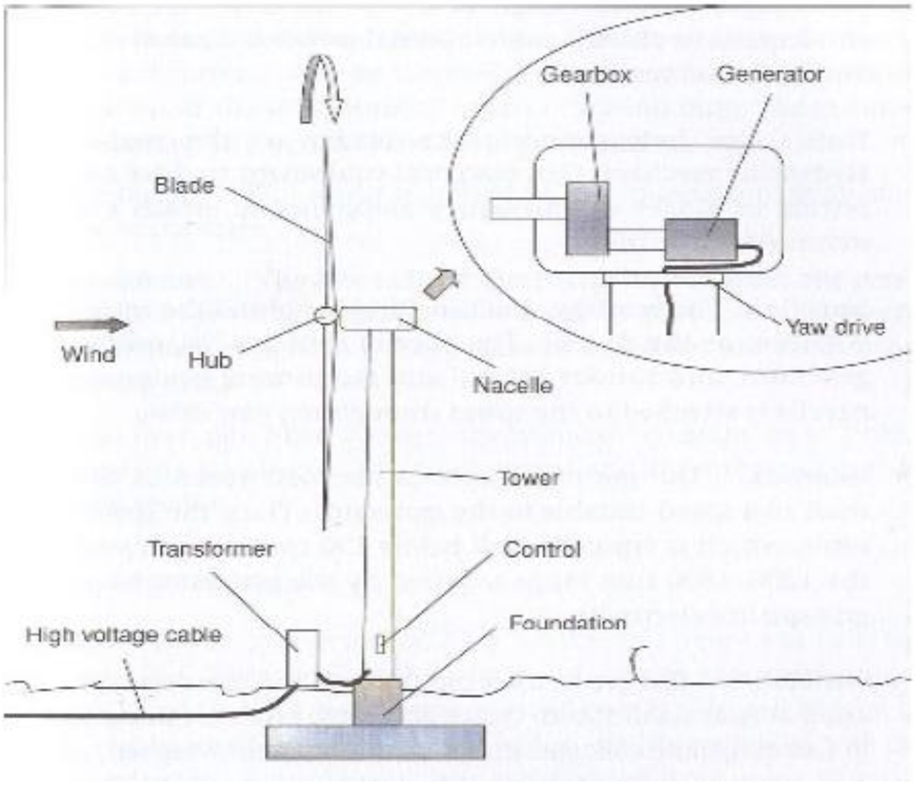


Figure 6: Wind Turbine Components

(Paterson, 2004)

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

Figure 7: Vertical Axis Wind Turbine

(Setting a Good Example)

2.5 Federal Regulations

There are several programs within the United States 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. While this handbook is only directly applicable to public lands, it provides a good model for regulations that could be developed by states and/or local governments. 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).

2.6 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 within Massachusetts are the Massachusetts Clean Energy Center (CEC) and the Massachusetts Renewable Energy Trust(MRET). The CEC administers the MRET which was developed by Legislature in 1997. The CEC 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 CEC 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 the 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)

2.7 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, the group 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, the group 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) The Town of Auburn is currently drafting aoning bylaws that directly relate to wind turbines to be added to their zoning regulations.

2.8 Renewable Energy Research Laboratories Auburn Study

In this section the group provides 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 #1: 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 by RERL.
3. Site 3: Upland Street: This site is located too close to residences by RERL. 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 as Determined by RERL Anemometer

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

Site 4	5.34 m/s

Wind Speeds for Medium Scale Turbines: 50 meters

B. 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.

C. Environmental Issues and Permitting

Take into consideration in site design and construction

- 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

D. Wind Turbine Component Transportation & Access

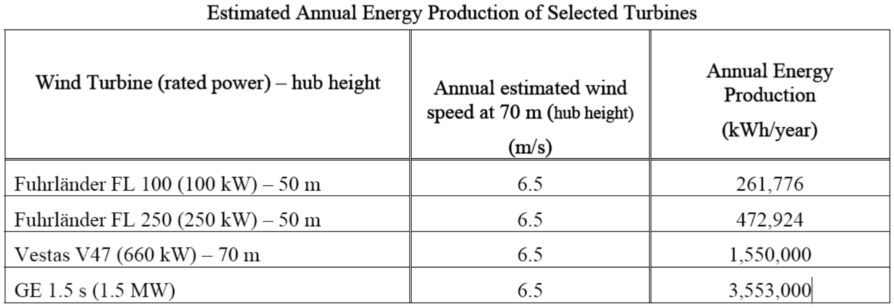
- Transportation and access in general
- Turning radius and truck length = 130ft
- Small/tight town roads could be an access issue

E. 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.

F. 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

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 Wing 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. Pay-back period is the length of time it takes for the savings made from producing electricity via wind turbine to equal 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. In the United States, wind turbine technology could supply about 20% of the nation's electrical needs. However, other sources are needed to produce the other 80% such as solar, geothermal or other renewable and non-renewable resources.

2.10 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" or residential facilities are generally defined as systems up to 60 kW in capacity." (Drupal, 2009) "Class II" or commercial 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" or utility 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)

Figure 8: Massachusetts Regulation Rules governing the reconstruction of the electric industry

2.11 Operation & Maintenance

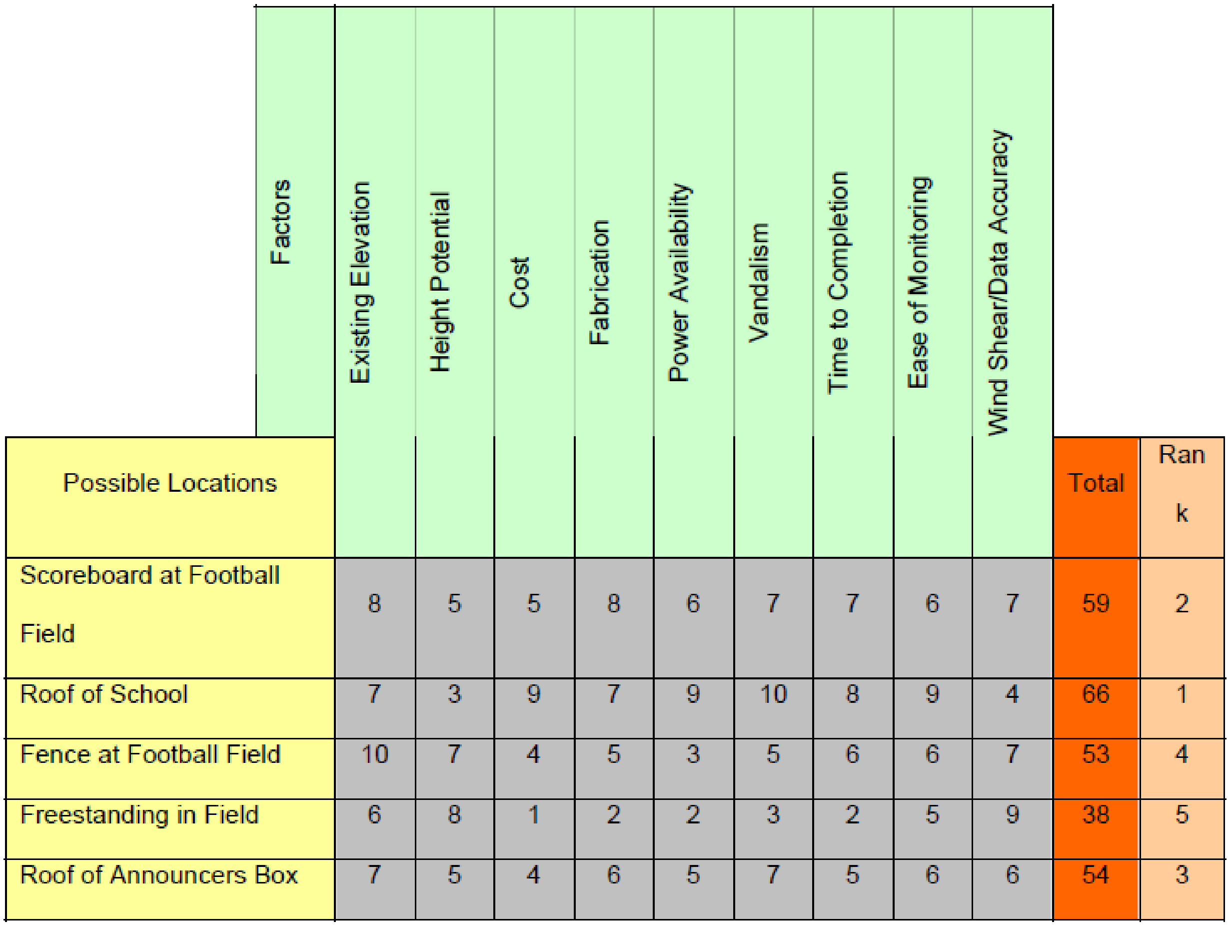
An important factor in balancing the budget for turbine installation and maintaining a reliable wind farm is operation and maintenance. Designing an effective operation and maintenance plan includes examining two major parameters; preventative and un-preventative maintenance. Preventative maintenance 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.

2.12 Holy Name High School Case Study

Holy Name is a private Junior/Senior High School located in Worcester, Massachusetts that contains 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 weighed out the best possible location seen in figure 9.



Possible Locations	Factors: 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 9: Matrix for Holy Name Anemometer Location

(Jensen, 2006)

The next step once a location found was installing the anemometer and collecting wind data from the site. The collected data was then put together 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 figure out what each turbine would output, 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. This case study along with the rest of the background section provides background information that will be useful in the development of the project and report.

Chapter 3: Methodology

This Major Qualifying Project's ultimate goal was the design of a wind turbine or farm at the site of Granger Cliffs, in the town of Auburn, Massachusetts. In order to achieve this result, the following steps were developed to ensure that the project maximizes its energy production based on the available wind at the site, while also completing a preliminary site design for Granger Cliffs. The methodology details the mean by which each task was accomplished in order to reach the projects ultimate goal.

- Site Determination
- Wind Energy Analysis
- Turbine Selection
- Cost Characterization
- Turbine Siting Options
- Access Road Layout
- Site Constraints & Public Concern
- Scheduling and Delivery

3.1 Site Determination

When deciding which site would be best suited for wind turbine or turbines, there were many factors that came into the decision making process. Initially the group reviewed the five (5) sites that were assessed in the RERL study. A preliminary review of the sites was conducted by this group to see if any of the sites had the potential for further consideration. The factors taken into consideration were:

- Reviewed wind speeds at an elevation of 50 meters from the ground in m/s, as published in the RERL Study to determine most appropriate siting.
- Distance from neighborhoods not only for Regulatory reasons, but also for consideration of potential noise impacts.
- Distance to nearest airport (Worcester Regional Airport). 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.
- Potential environmental impacts and associated permitting requirements. This group considered possible environmental impacts that could be affected by constructing a wind turbine.

- Transportation of the wind turbine to the site, as well as the need for an access road into and out of the site. The access road into each site must be carefully planned and must be able to provide a safe route for the turbine parts to and from the turbine site.
- The distance for the distribution and transmission lines. The group researched previous project's transmission lines usages and tried to follow their practices.
- Size of site to accommodate proper spacing for the possibility of constructing two wind turbines.

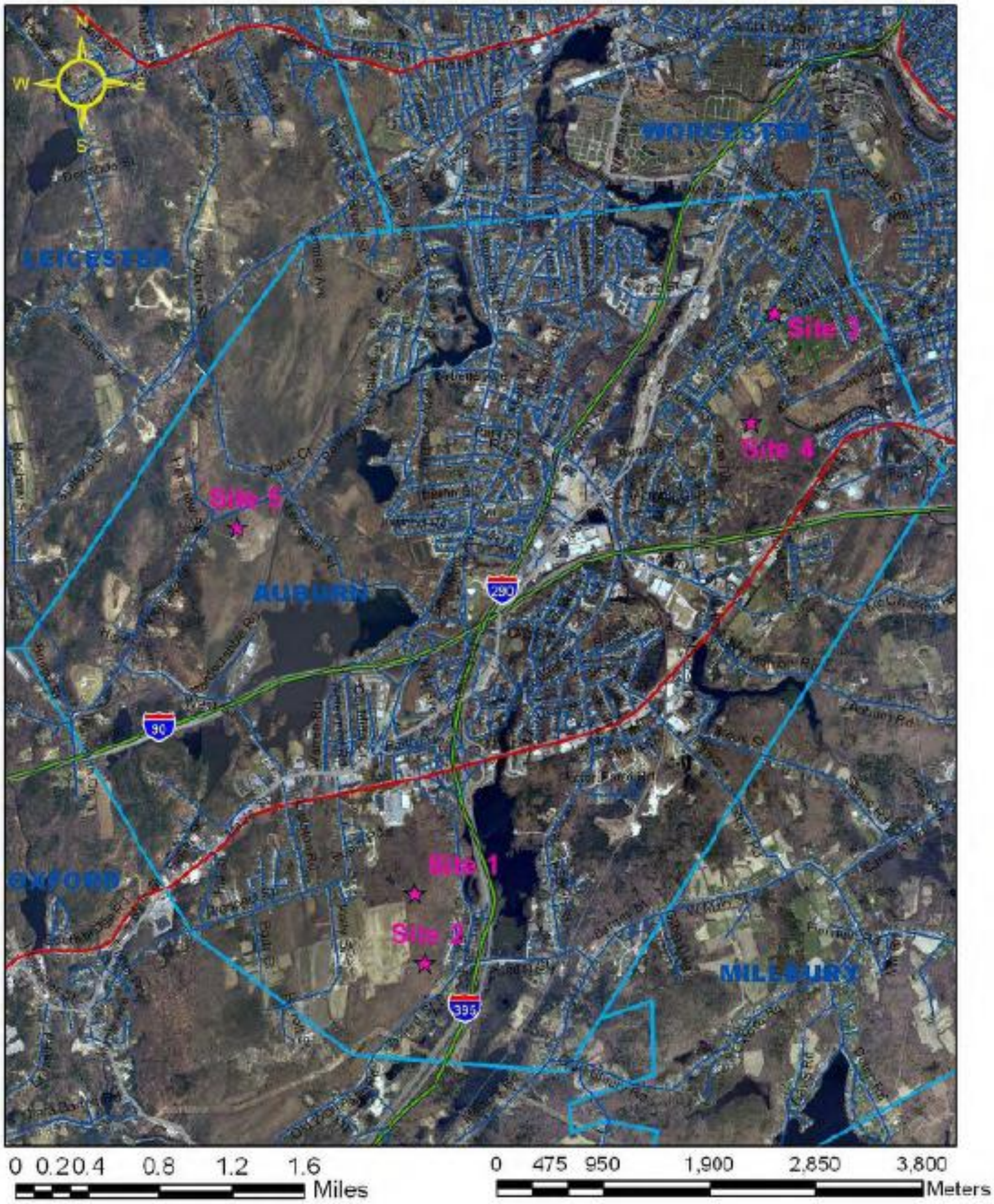


Figure 10 - Map showing 5 turbine sites in Auburn as identified by RERL

3.2 Wind Energy Analysis

When trying to create a wind farm, analyzing the wind at the proposed site is an important issue. Initially the group's plan was to place an anemometer on site in order to gain wind information from the site. Due to the access issue for setting up the anemometer, the group was forced to look into alternative sources of wind speed data. The sources for wind speed data used were the Associated Weather Services Wind Navigator Map System, Mass Geographic Information Systems, and a Renewable Energies Research Laboratory Anemometer in Paxton, Massachusetts. By using the data from each source at 100 meters, the group was able to create an average wind speed for the Granger Cliffs site.

3.3 Turbine Selection

3.3.1 Review Turbine Technology

In order to select the turbines for the wind farm atop Granger Cliffs, the group first reviewed the potential turbine technologies. The group looked at all possible turbine technologies, considering their height, energy output, cut-in speed and any other possible issues related to the turbines including the technologies lifecycle and maintenance needs. By reviewing all the technologies, it gave the group a starting point to compare the group's wind speed data in order to determine the most appropriate wind turbine.

3.3.2 Determining Technology

Based on the results from the group's wind measurements the group selected the most appropriate turbine or turbines to meet the town's energy needs while minimizing the turbines costs. The goal was to create the maximum amount of energy based on the winds available. The group used the several power curves from various turbine manufacturers and model to best maximize the electricity output based on the wind speeds available. This report also present alternative wind farm selections based turbine and construction cost implications.

3.4 Cost Characterization

This aspect of the project will be handled primarily by the Interactive qualifying team; however their results are critical to the overall project. A cost analysis process is critical in determining the most suitable wind turbine or turbines to be implemented on the site which maximizes the energy production while minimizing the cost. Also involved in the cost analysis, once the ideal turbines are selected, the group will begin to look at the technologies payback period.

Topics included in this section will be:

- Determining the Number and Size of Turbines
- Wind Turbines Payback Period
- Delivery and Construction
- Maintenance

3.4.1 Determining Number and Size of Turbines

After the group has finalized the wind measurements and researched the current prices for different turbines technologies the size and number of turbines will be determine. The goal will be to maximize the energy produced by the technology, while minimizing its cost. Factors that will be important in the group's decisions will include the height of maximum wind speed, the total costs of technologies of different sizes and the energy these turbines will produce. The ultimate goal for the Town of Auburn is to maximize the energy output from the turbines in order to generate the largest possible revenue from the project. We will develop several scenarios involving different sizes and numbers of turbines. From this point the group will be able to compare each scenarios project cost and the energy each will generate and select the most economically feasible option.

3.4.2 Turbine Payback Period

Once the team has identified the number, size and model of the turbines propose to be placed at Granger Cliffs, the group will determine the turbines payback period. The payback period of a green technology is the time it takes for the technology to create electricity that is worth more than the original cost of the total wind turbine project. This information can be helpful in identifying the feasibility of the project because if the technology has a very long payback period, it may not be worth the original investment by the town of Auburn.

3.5 Turbine Siting

There are several aspects involved in selecting the sites for the turbine towers themselves. We determined a series of constraints which the group had to work within, in order to find the most appropriate sites. The constraints the group dealt with included the fall zone, the slope of the land, and wetlands on site. The fall zone is an envelope which the turbine must be sited within so, if the turbine were to fall, it would not damage any private property bordering the site. This fall zoning ordinance will be included in Auburn's zoning by-law that deals directly with wind farms. The slope of the site represents an access issue for delivery and construction vehicles. The slope of the success road cannot exceed a 10% grade without the use of tractors to assist delivery vehicles. Wetlands are an important factor on any site and are often protected by the Department of Environmental Protection. The group minimized any contact with wetlands caused by the necessary construction of the access roads and the staging areas.

An additional factor in determining the most appropriate site for a wind turbine is trying to site the turbine on the highest available point of land. By maximizing this height, you are able to expose the turbines to higher and more powerful winds. The distance between turbines is a constraint in wind farms since siting wind turbines too close to one another can cause wind turbulence which can potentially damage wind turbine towers and rotors. These distances are often mandated by the turbine supplier and will be important in siting the second turbine in Auburn's proposed wind farm. All of these constraints will be used to determine the optimal wind farm design. In the following section, all possible wind farm designs will be investigated and three potential wind farm designs will be detailed. Finally in the recommendations chapter, the group will compare and contrast the alternative designs and present the best use for the Town of Auburn.

3.6 Access Road Design

The access road is an important aspect of Granger Cliffs' site design. This project recommends constructing the road leading from the entry point in the most direct path to the turbine sites, while trying to avoid wetlands. The materials from which the access road will be constructed will be basic gravel and fill materials. The group identified materials for the access road construction through research as well as identified the best practices in the construction of the road. The group also researched the necessary standards for the width and depth of an access road to support delivery and construction vehicles. The group worked to ensure that the designed access road would not exceed a 10% grade on the site, while still being able to access both turbine sites. To deal with wetlands issues, the group worked to minimize contact with the wetlands identified on Mass GIS and researched access road design techniques to allow water to flow with limited effect from the newly created access road. Storm water management practices were also analyzed and incorporated into the overall site design. The group identified the amount of clearing necessary for the construction of the access road as well. Finally, the group determined an alternative route for the access road while keeping in mind the slope, effect on wetlands and amount of clearing.

3.7 Staging Area

Staging areas are necessary in the development of a wind farm site plan. The staging areas will be used to store the equipment and wind turbine parts as they are delivered, as well as provide an area for the construction of the turbine itself. The group determined the appropriate size on location for the staging areas on the Granger Cliffs site. The amount of clearing required and the typical surface will also be researched and implemented into the site design.

3.8 Site Constraints and Public Concerns

There is always a lot of controversy when the construction of wind turbine, or anything for that matter. There will always be people who are for and against wind turbines. When coming up with the public concerns, showing the public that a lot of what they may think about wind turbines may not actually be fact, just here say. What the group needed to look into when figuring out what the site constraints and the public concern would be were a series of obstacles:

- Wetlands are an issue that needed to be addressed. Need to make sure that the access road on the site can be placed with minimal impact to wetlands.
- The visibility of the turbine is an issue that has surfaced in other wind energy projects. Site selection should consider the view of the turbine from other locations in the community.
- Noise is another issue that might cause public concern. A site with minimal houses in close proximity would be a preferred choice. .
- Potential impacts on birds have been another common concern. Research has shown, however, that wind turbines have very little negative impact. In fact, a wind turbine is only likely to kill a maximum of two birds a year. This information should be relayed to the public early in the process.
- Flicker is the effect on sunlight passing through the rotating turbine blades. Address the flicker problem which is a concern to houses in the area.

The way the group addressed the public concern issue is in this report the explanation of each public concern is described. Each public concern is explained and tells how each concern is nothing major to be concerned about.

Figure 11: Princeton access road on staging area

3.9 Scheduling and Delivery

The scheduling of the delivery and delivery of the wind turbine itself are two very important processes in the construction of a wind turbine. When completing the scheduling absolutely everything that is taking place in the process from the time the turbine leaves the company it is purchased from until the last piece of the wind turbine is put together.

The delivery process must be mapped out accordingly. This means that all routes the turbines blades, rotor, etc. will be taking need to be very carefully mapped out. This will in the end reduce time, which in the end is money. The better prepared the delivery process is, the faster the turbine will get there. Warning highway patrols and cities that many trucks will be passing through will reduce traffic time. Another important aspect of the delivery process is to make sure that none of the parts of the turbine get damaged. The parts are very expensive.

Scheduling is an important tool for manufacturing and engineering because it can have a major impact on the productivity of a process. In manufacturing, the purpose of scheduling is to minimize the production time and costs, by telling a production facility what to make, when, with which staff, and on which equipment. Accurate scheduling can maximize the efficiency of the operation and reduce costs.

Chapter 4: Results and Alternatives

The results and alternatives section of this report displays the findings from the investigations discussed in the methodology. This section will also include all potential alternative solutions to the turbine selections, access road design, and turbine sighting. The sections within this chapter include the following:

- Site Determination
- Wind Energy Analysis
- Turbine Selection
- Cost Characterization
- Turbine Siting Possibilities
- Access Road Design
- Site Constraints & Public Concern
- Scheduling and Delivery

4.1 Site Choice and Alternatives

There were initially five potential sites under consideration for the placement of the wind turbines. The first site this group investigated was Granger Cliffs by utilizing the results shown in the Renewable Energy Research Laboratory's report. Granger Cliffs was selected as the preferred alternative in the RERL study, and this group was in agreement with that study's findings. The location, the possibility of access road, distance from neighborhoods, turbine spacing are all much more suitable to this projects needs than the others. However, this group also reviewed the Crowl Hill Site. This site was a former landfill with wind speeds that were the lowest of all of the other sites. The third site at Upland Street was a site that was deemed to not be large enough to provide the proper distance of the turbines from residences. As such, this site was not visited. The next site was the Upland Street site. Similarly, this site was too close to residences and was not considered. The final site was Packachog Meadows. This site, along with Granger Cliff was considered in the initial stages of this project.

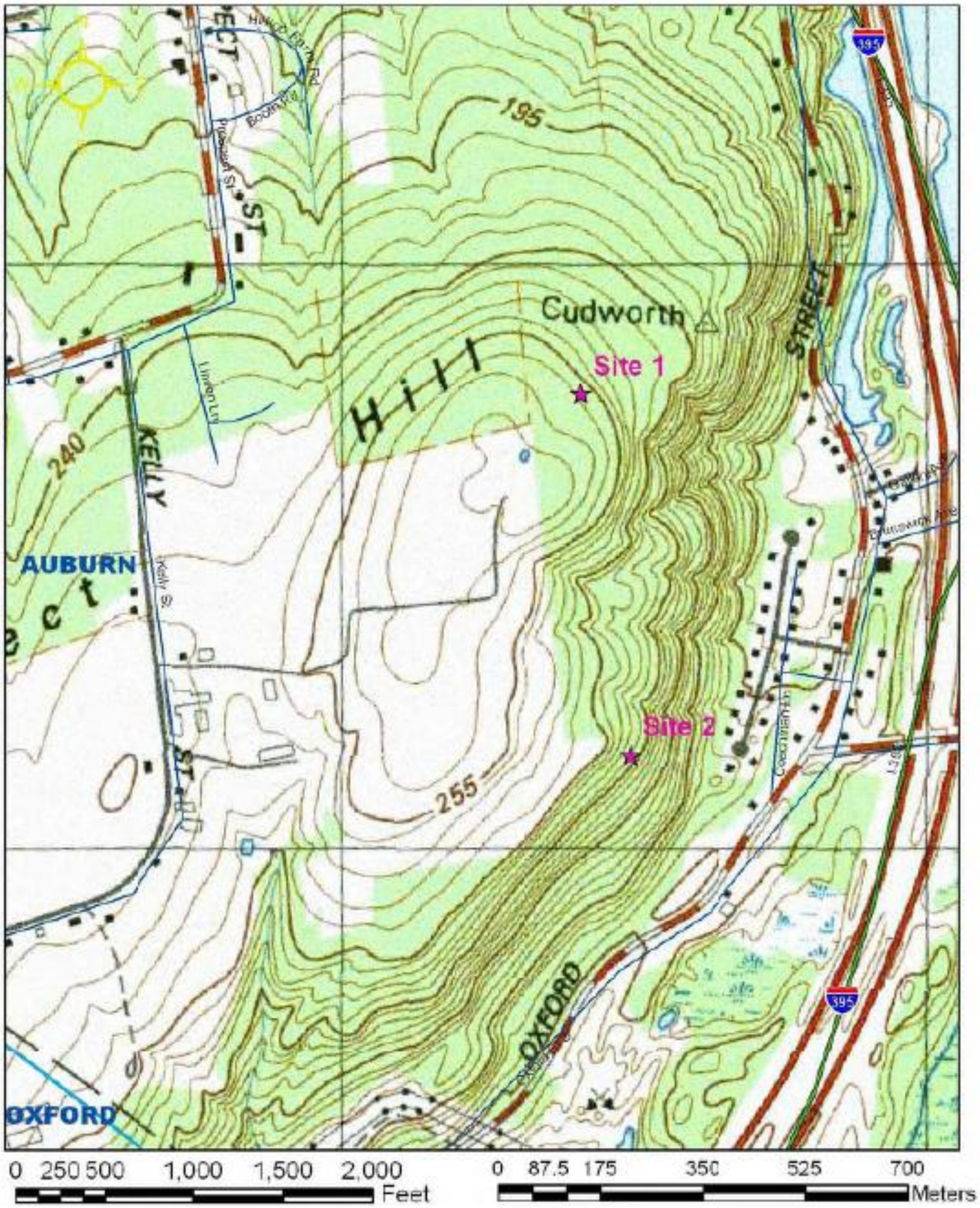


Figure 12 - Topographical map showing two sites at Granger CLiffs

4.2 Wind Information and Calculations

There were initially five potential sites under consideration for the placement of the wind turbines. The first site this group investigated was Granger Cliffs. Granger Cliffs was selected as the preferred alternative in the RERL study, and this group was in agreement with that study's findings. The location, the possibility of access road, distance from neighborhoods, turbine spacing are all much more suitable to this projects needs than the others. However, this group also reviewed the Crowl Hill Site. This site was a former landfill with wind speeds that were the lowest of all of the other sites. The third site at Upland Street was a site that was deemed to not be large enough to provide the proper distance of the turbines from residences. As such, this site was not visited. The next site was the Upland Street site. Similarly, this site was too close to residences and was not considered. The final site was Packachog Meadows. This site, along with Granger Cliff was considered in the initial stages of this project.

4.2 Wind Information and Calculations

When determining which site to choose, the group had to look closely as to which site would have the highest average of wind speed. The figure below shows the proposed site and its measured wind speed at that site, as presented in the RERL study. Possible measuring devices should be in a large open area away from possible interference such as buildings, trees etc. It is generally accepted that measurements are based on readings at 10 meters (33 feet) above ground. The distance between the anemometer and any obstruction is at least ten times the height of the obstruction. Site one which is Granger Cliffs provided the highest wind speeds at 5.83 meters per second @ 50 meters about ground level. The next site with the closest wind speed was Packachog Meadows where the wind speed was 5.77 meters per second.

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

Figure 13 - Shows wind speeds at potential sites at 50m

Figure 13 above represents the predicted wind speeds at 50 meters for the potential sites in Auburn. Site 1 represents the Granger Cliff's site, whose wind speed is shown as being the highest of the four. Since this wind data represents only one source, the team worked to gather other sources of wind information for the area. Figure 14 below displays wind speeds from other sources such as AWS Truewind, MassGIS, and the RERL Paxton anemometer. Overall, these wind data sources showed much higher wind speeds at 50 meters in height, which may be due to the seasons of the tests. However, these wind speeds average to 7.7 meters per second which is promising.

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

Figure 14 - Wind speed data calculated for Granger Cliffs site

4.3 Cost Information and Calculations

The team worked together to complete the Cost information and Calculations, however the IQP team handled most of the writing and calculations for this section. Their information is shown below.

The cost analysis of a wind turbine is calculated in three parts: the amount of electricity the turbine will produce the worth 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 or turbines 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 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, or the percentage of the maximum amount of electricity could produce. 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 group 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.

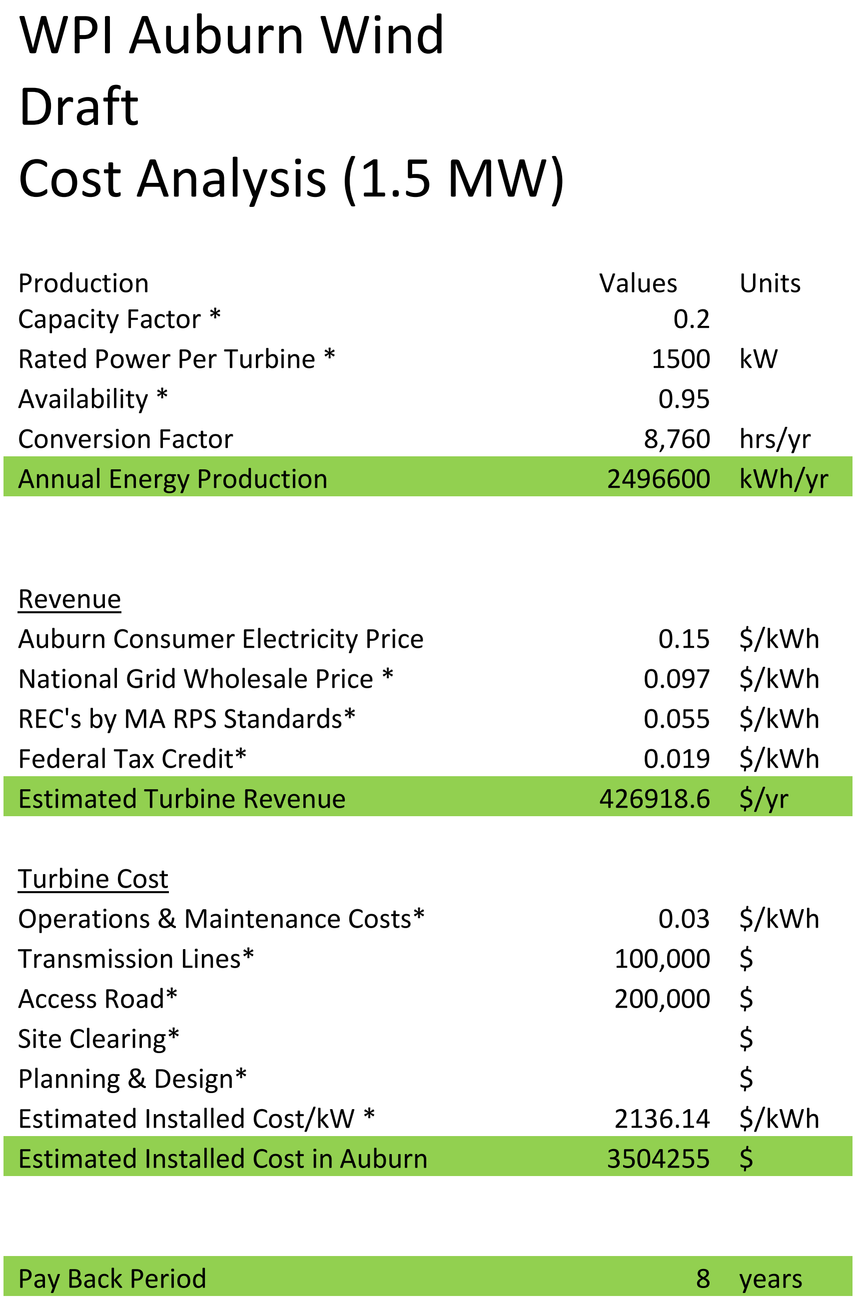
The payback period is the most important part of the cost analysis. The team determined a payback period by taking the estimated installation cost and dividing that by the estimated turbine revenue. This value is an estimation of how long it will take for the turbine to produce enough electricity to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

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 & Maintenance Costs*	0.03	$/kWh
Transmission Lines*	100,000	$
Access Road*	140,000	$
Site Clearing*		$
Planning & Design*		$
Estimated Installed Cost/kW *	2136.14	$/kWh
Estimated Installed Cost in Auburn	1521702	$
Pay Back Period	8.9	years

Figure 15 - Fuhrlander 600kW Turbine cost analysis

Figure 15 above shows the cost analysis of one 600kW wind turbine. The turbine's payback period is only 8.9 years which is roughly 1 year greater than the other turbine options. However, due to the low cost of the turbine and its construction, as well as the low revenue, the overall profit of the project is much lower than the other options.



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
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	426918.6	$/yr
Turbine Cost		
Operations & Maintenance Costs*	0.03	$/kWh
Transmission Lines*	100,000	$
Access Road*	200,000	$
Site Clearing*		$
Planning & Design*		$
Estimated Installed Cost/kW *	2136.14	$/kWh
Estimated Installed Cost in Auburn	3504255	$
Pay Back Period	8	years

Figure 16 - Fuhrlander 1.5mW Turbine cost analysis

Figure 16 above shows the cost analysis of a 1.5mW Fuhrlander wind turbine. This turbine creates much more electricity and revenue, yet also has a higher turbine cost than the 600kW option. This turbines payback period is 8 years and the values represent those the group would expect from

Alternative Two show in the wind farm designs later in the report. Not only is the payback period slightly better for this turbine, the increased revenue over that of the 600kW turbine means that over the life of the turbine it will generate more income. The only reason for similar payback periods is that the 1.5mW turbine had a higher cost that the 600kW turbine.

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 & Maintenance Costs*	0.03	$/kWh
Transmission Lines*	100,000	$
Access Road*	230,000	$
Site Clearing*		$
Planning & Design*		$
Estimated Installed Cost/kW *	2136.14	$/kWh
Transportation Cost	150,000	$
Estimated Installed Cost in Auburn	6888510	$
Pay Back Period	8.0677	years

Figure 17 - Cost analysis of two Fuhrlander 1.5mW Turbines

Figure 17 above shows the cost analysis of two 1.5mW wind turbines. This cost analysis represents that of Alternative One of the site design alternatives. This cost analysis has a much high annual energy production value as well as a much higher estimated turbine revenue, although it also has a higher cost for the Town of Auburn. This cost analysis has roughly the same payback period as a single 1.5mW. However like the situation comparing a 600kW turbine to a 1.5mW turbine, two 1.5mW turbines will ultimately provide more revenue for the Town of Auburn. The payback period is only similar due to the increased construction costs for two wind turbines as opposed to only one.

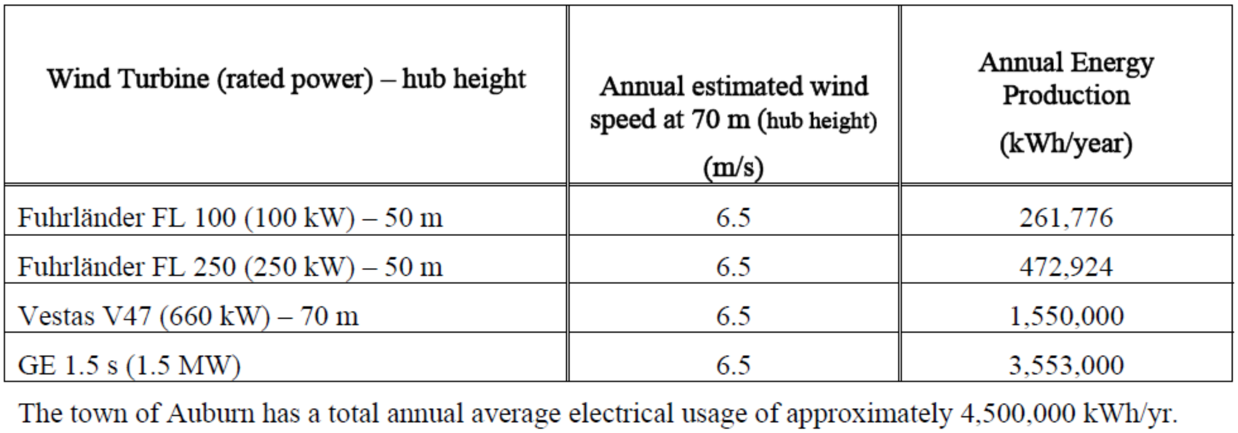
4.4 Turbine Selection and Alternatives

The turbine selection is based on several criteria. These criteria involve the turbine cost, payback period, energy efficiency, and finally the turbine size. Ultimately, the group wanted to select a turbine that will create the most potential energy while having the shortest payback period. The larger turbines will be able to reach higher winds and will generate a higher electricity output. However, if a turbine is is too large, the cut in speeds may be too high and the turbine may not be rotating at times, and will not generate all potential energy. The selected turbines, which are shown in Table 5, all do have fairly low cut in speeds of 3 to 3.5 meters per second. Larger turbines also often have higher rated wind speeds, meaning the wind speed required to create the maximum electricity output. By viewing the turbines below the Fuhrlander 1500 has one of the lower rated speeds while still producing 1500 kilowatts of electricity. These four turbines presented below were selected and investigated because the Fuhrlander FL 600 and FL 1500 as well as the GE 1.5 were identified in the RERL study. The 2.5 was selected in order to investigate the potential for a turbine which would create even more electricity than the other 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

Figure 18 - Shows a comparison of potential turbines which were identified by CEC and RERL

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.



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

The town of Auburn has a total annual average electrical usage of approximately 4,500,000 kWh/yr.

Figure 19 - Displays annual energy production of different technologies at .5m/s wind speed (Knipe & McClelland, 2008)

Figure 19, above, shows the estimated amount of electricity that can be produced annually by a 1.5 megawatt turbine as compared to Vestas' 660 kilowatt model turbine. Considering that Auburn's annual electrical usage is 3,553,000 kilowatt hours per year, having two 1.5 megawatt turbines would far surpass the electricity requirements, though the town will not being able to directly use the electricity, rather they will have to use net metering. Figure 20, below, shows the power curve of a Fuhrlander 1.5 megawatt turbine and it shows that at the annual estimated wind speed of 7.7 meters per second, which represents an average of all the wind speed data collected for this project, the turbine will meet the maximum electricity output of the 600 kilowatt turbines. This means that any wind speed above 7.7 meters per second, the 1.5 megawatt turbine will continue to generate even more electricity, while the 600 megawatt turbine will have reached a plateau. (Knipe & McClelland, 2008)

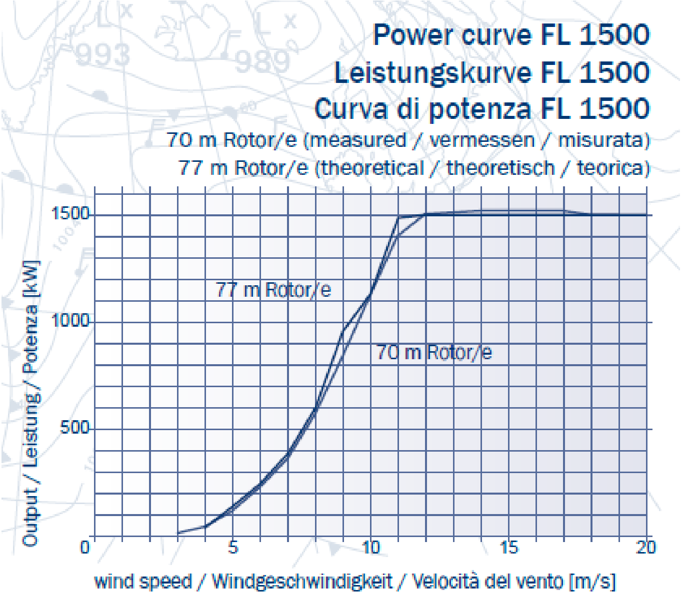


Figure 20: Fuhrlander FL 1500 Power Curve

(Fuhrlander Wind Turbines, 2009)

4.5 Turbine Siting Information and Alternatives

4.5.1 Constraints and Issues in Wind Turbine Siting

There are a number of goals and constraints associated with determining the siting for the turbines on the parcels of land on Granger Cliffs. The site constraints include the fall zone envelope, wetlands and the sites slope. The fall zone represents the area that the turbine must be constructed within so that if it were to fall it would not damage any surrounding private property. Wetlands represent an area which the design attempts to avoid or minimize contact with all together. Auburn's previous RERL study showed that there were no wetlands of concern on site according to the Department of Environmental Protection. However, both Mass GIS and the CADD drawings the town provided for the previously proposed high school on Granger Cliffs both showed wetlands on the northern end of the parcels. The group used the wetlands identified by Mass GIS in the final design. Slope represents more of an access issue in the design. Delivery trucks for materials and construction vehicles cannot travel up a slope greater than 10% without the assistance of a tractor. This factor effects the route of the access road which must avoid slopes on site greater than 10%. The slope will only be an issue on the northeastern end of the site, which is completely avoided by the staging areas and the access road.

Other important issues in determining the appropriate siting for the wind turbines is to construct them on the highest possible piece of land which will allow the turbines to reach higher and more powerful winds. By reaching higher winds, the turbines will be able to generate more electricity. The other issue with potentially sighting two wind turbines is the distance between the turbines. Turbine suppliers mandate a certain distance between turbines to avoid higher stresses due to wind turbulence created by receiving wind that had passed through the first turbine. The Granger Cliffs site also helps minimize this effect since the predominant wind direction is from the west. If the wind were from the north or south, the wind would pass through both turbines since one is sighted behind the other. However when facing the west, the turbines stand next to each other and do not come in contact with the same winds. For the Princeton wind farm, Fuhrlander proposed a distance of 1,000 feet between turbines. Since the turbines are the same model, the group used this distance in the site design.

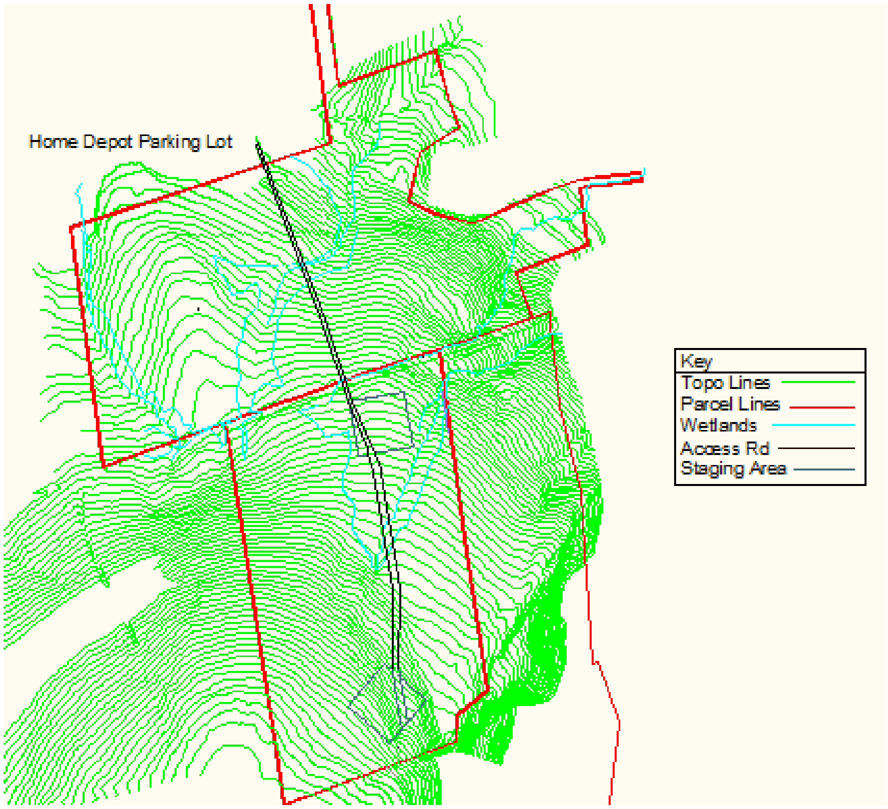


Figure 21 - Site design showing site constraints and proposed access road

4.5.2 Turbine Siting Alternatives

Three alternatives were considered for the wind turbine siting. These alternatives include:

- Alternative 1: Two 1.5mW Fuhrlander turbines at sites 1 and 2.
- Alternative 2: One 1.5mW Fuhrlander turbine at site 2.
- Alternative 3: One 1.5mW Fuhrlander turbine at site 1.

4.5.2.1 Alternative 1

Alternative 1 for the Granger Cliffs' site involves the siting of two wind turbines on the northernmost site (site 1) and the southernmost site (site 2). This wind farm design allows for maximum electricity output with two turbines producing electricity for the town. The Turbine at site 2 will generate more electricity since it is at a higher elevation of roughly 250 feet, which will allow the turbine to be exposed to higher and stronger winds. However, the turbine at site 1 is only roughly 50 feet lower and will also be exposed to winds in the range of 7 to 8 meters per second at 100 meters in height

4.5.2.2 Alternative 2

Alternative 2 for the Granger Cliffs' site involves the siting of one turbine at site 2. While this design only had one turbine, it uses the fact that site 2 is exposed to higher winds than any other possible siting on Granger Cliffs. This allows for maximum electricity output from a single turbine on site. This design also allows for the construction of a second turbine at site 1 in the future, if the town finds that funding two turbines will be an issue, they can fund one and then in the future start funding for an additional turbine. The future turbine site will be accessible by the previously existing access road and would not require the larger access road between the two turbines as would be required in alternative 1, which will be discussed later in the report.

4.5.2.3 Alternative 3

Alternative 3 for the Granger Cliffs' site involves the siting of one turbine at site 1. This wind farm design will site one turbine at the lower site which will not generate as much electricity as the other single turbine design of alternative 2. This design would, however, allow for a lower construction cost since the access road would run 1,164 feet to the turbine rather than running 2,217 feet as in alternative 2. This is 1,053 feet shorter and would save 14,742 square feet of necessary clearing and gravel for access road construction.

Figure 22: Overlay of the proposed turbine sites with site 1 to the north and site 2 to the south

4.6 Access Road Information and Alternatives

After reviewing several guidelines for access road construction the group was able to compile the group's findings into a results section where access road results for alternatives 1,2 and 3are presented.

4.6.1 Route

The obvious point of an access road is to provide access to the turbines themselves for construction and future maintenance. So the route of the access road is based on the siting of the turbine, since the access road must run to that point. Through discussion with the town of Auburn, access through the Home Depot parking lot has become that entry point of choice. Delivery vehicles will be able to access the site through the delivery entrance behind the existing BJ's. The major concern's involving the design of the access road deal with wetlands infringement and the slope of the road itself. We will plan for the access road to minimize contact with wetlands as well as avoiding steep slopes which may affect the construction and delivery vehicles ability to reach the turbine construction sites. We will also try to minimize construction along the side of slopes due to increased construction and gravel in these areas. The access road path will not differ between alternative 1 or alternative 2, with the only difference being that in alternative 1 it will pass though a staging area and be widened which will be discussed later in the report. For alternative 3 the route will follow the same path; however it will stop at site 1.

4.6.1.1 Alternative Route

Since the purpose of an access road is to provide access for construction and delivery vehicles to the turbine, there is only one design that fits all the criteria stated above. However, in Auburn's case, if the Home Depot/BJ's parking lot cannot be used as an access point there is a potential alternative access route. The town owns a parcel of land behind BJ's which could be potentially used as an access road. There are concerns about this access road however. The road length running from Route 20 to site 1 will be 2,416 feet in distance, which is 1,252 feet longer than the route running from the BJ's/Home Depot parking lot. Its total length would be 3,469 feet and would require over 50,000 square feet of clearing and gravel for the access road construction. This alternative route covers 16,000 square feet more than the originally proposed access road route. Also, there are marked wetlands in that area, which is an additional reason why it would be best if the BJ's lot could be used for the access road.

Figure 23: Shows an overlay of the proposed access road and staging areas

4.6.2 Materials:

Typical materials used in the construction of an access road are fill materials and gravel. A common practice is to use materials native to the area onsite as the fill material which is compacted for gravel to be placed on top and compacted. An important issue in the construction is the time of year that the access road is constructed. Avoiding severely cold, hot and rainy seasons is very important in ensuring a well constructed access road. Also, the best practice for construction is to spread and compact the gravel immediately while the sublevels of fill are still unsettled. This creates a stronger bond between the gravel and soils. (Tew, Price, Swift, & Riedel, 2005) A higher percentage of finer gravel should also be used as compared to the typical gravel that is used underneath pavement. Another important issue will be to ensure that the road is crowned to avoid siting water on the road itself. On a road the is not along a slope, the road can be crowned 3 to 4 inches on each side of the roads center. However, if the road is constructed along a slope, the entire road can be sloped towardsthat direction. (Commision, 2001)

Figure 24: the access road leading to Princeton's wind farm

4.6.3 Storm water Management

A concern in the construction of an access road is the creation of new impervious area which affects the flow of water. There are several steps that can be taken to lessen the effects of storm water on the surrounding areas from a construction stand point. The most major storm water management practice is the construction of a culvert running under the access road itself from a higher elevation to a lower elevation in an area on concentrated ground water. The culverts can be constructed with steel, concrete, aluminum or plastic piping, with steel and concrete being the best materials. (Commision, 2001)

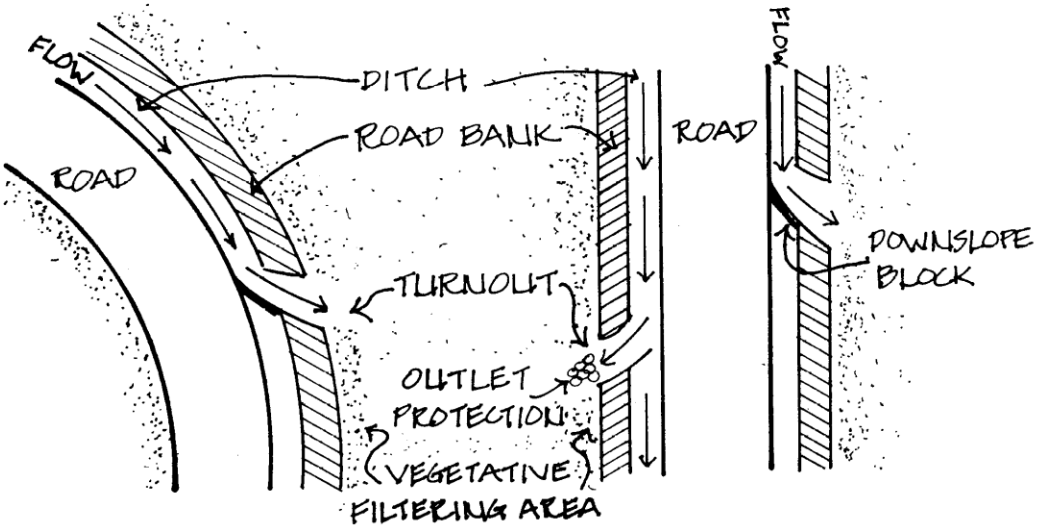


Figure 25 - Shows ditch and turnout design alongside an access road (Commision, 2001)

Another form of stormwater management is the use of roadside ditches which divert the water away from the road as shown in figure 29 above.. These ditches will have turnout areas that allow high flows of water to empty into an area of gravel of vegetation that will prevent erosion in the area. A practice that is also used is to create waterbars over the surface of the road. These waterbars will act as an area for water to pass over the road, while trying to limit the erosion created over the rest of the roadway. The goal of a waterbar is to make it high enough to divert water, yet low enough to drive over, which is shown in figure 30 below. (Commision, 2001)

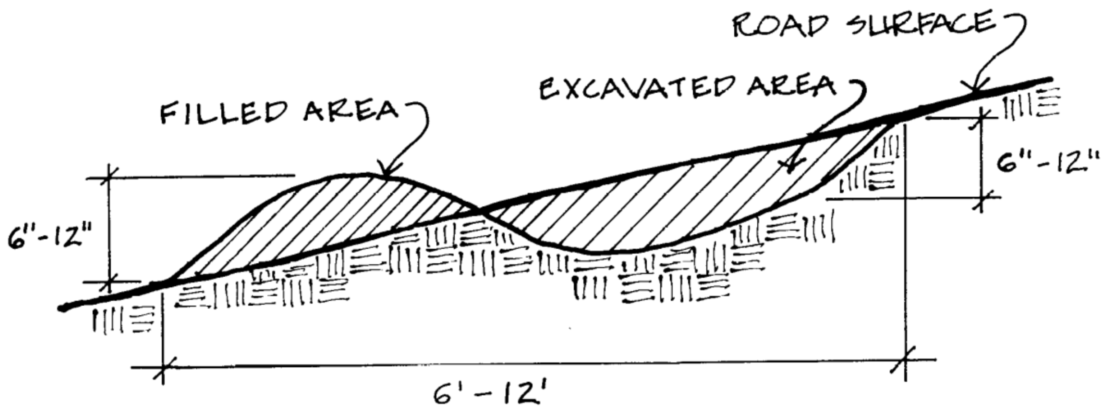


Figure 26 - A cross section of a waterbar constructed within an access road (Commision, 2001)

The final storm water management practice that can be applied to this project is the use of silt fence dikes and hay bale dikes, which is shown in figure 31 below. Both silt fence dikes and hay bale dikes area materials place in dikes to slow stormwater flows and prevent silt, sediment and other materials from traveling into the surrounding areas during construction. However, these two objects can be removes once construction has been completed, while the others will require maintenance through time. (Commision, 2001)

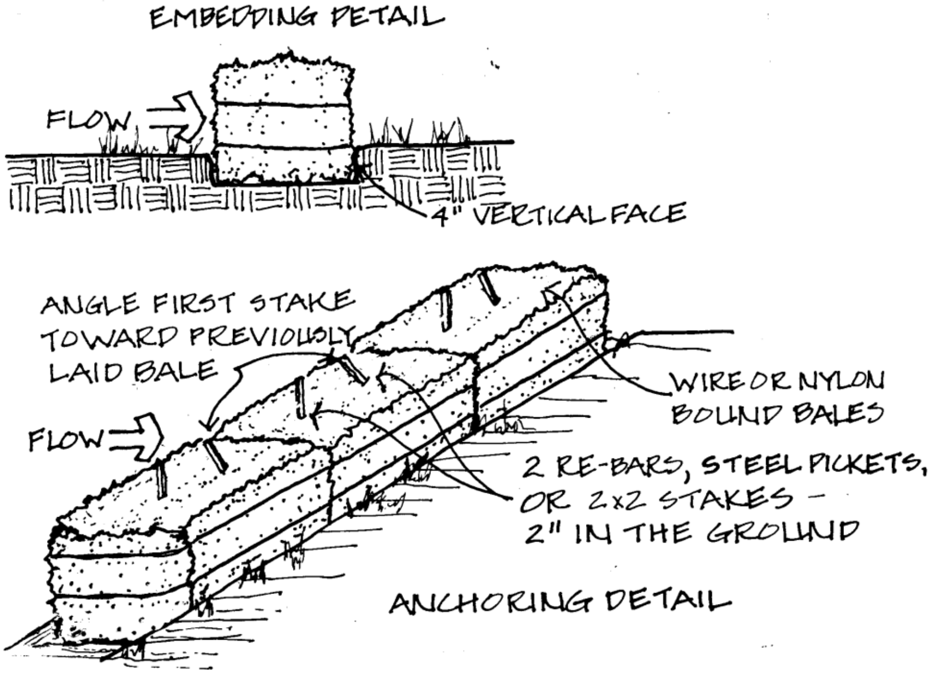


Figure 27 - Shows the design of a hay bale dike alongside an access road (Commision, 2001)

4.6.4 Width:

The necessary width of a wind farm access road is required to be at least 14 feet. This number in both reported in design guidelines, as well as being the width used in Princeton's wind farm access road design. This is the required width of the road from the entry point of the access road onto staging area 1. (Tew, Price, Swift, & Riedel, 2005) At this point the crane (most likely a Manitowoc) will be constructed, and will require an access road with a width of 26 feet running to the second staging area. (Fitch, 2006) After the construction of the second turbine, the crane can be taken down and placed back onto a delivery vehicle and taken off site.

Figure 28: Shows the Manitowoc 2250 Crane which requires a 26 foot width access road

4.6.5 Slope Construction:

When constructing on the side of a slope, there are certain design and construction practices that must be used to ensure that the access road can maintain its width and a level surface for passing trucks. On the uphill side of the access road, there needs to be a cut into the hill at a 3 to 2 ratio as shown in the image below. This cut maximizes the amount of surface area for the access road by creating area into the hill, while also preventing any erosion from the hill into the road itself. On the downhill side of the road, you must fill to a 2 to 1 ratio, also shown below. This will maintain the surface while preventing erosion of the newly constructed gravel road. This side-slope design will require more gravel on the downhill side than the typical access road, and will also require more construction to complete the uphill cut at a 3 to 2 ratio which will then be compacted to prevent erosion. The type of design will be required between turbine site 1 and site 2, as the access road begins running along the side of the slope.

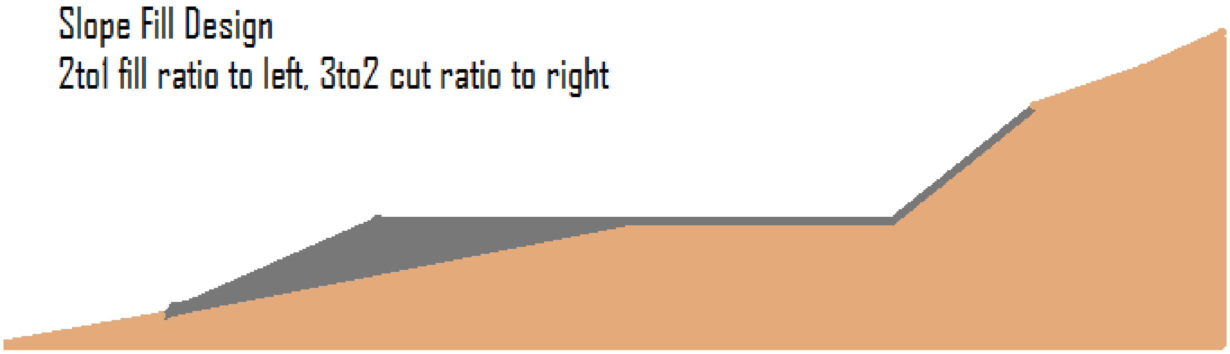


Figure 29: Access road design cross section when built into a slope

Figure 30 - Tree coverage on Granger Cliffs site

4.6.6 Access Road Construction Costs

4.6.6.1 Access Road Alternative 1

The figure below shows a cost analysis of the access road for Alternative 1. This access road construction cost is estimated to total about $230,000.

Alternative 1 Road Construction Costs			
Activity	Unit Cost	Amount	Actual Cost
Clearing and grubbing	1700/mile	.42 mile	714
Roller Compaction	.38/CY	14558 CY	5532
Excavation Base Cost	1.66/CY	14558 CY	24166.3
Aggregate	1.05/CY	14558 CY	15285.9
Agg. Compaction	1030/mile	.42 mile	432.6
Finishing Cost	570/mile	.42 mile	239.4
Outsloping Cost	1125/mile	.42 mile	472.5
	Subtotal		30914.2
40% Labor			77114.3
Silt Fencing	7-12/LF	2217x2 LF	44340
Haybales	7/LF	2217x2 LF	31038
Waterbar Construction	7-9 each	1/100 LF	176
		TOTAL	**229782.6**

Figure 31 - Alternative 1 Access Road Cost Estimate (Service, 2009)

4.6.6.2 Access Road Alternative 2

This access road construction cost is estimated at roughly $204,000. This estimate is $26,030 less than alternative 1, however it only has one turbine and will have a longer payback period on the initial construction cost. The figure below shows a cost analysis for the access road design of Alterative 2.

Alternative 2 Road Construction Costs			
Activity	Unit Cost	Amount	Actual Cost
Clearing and grubbing	1700/mile	.42 mile	714
Roller Compaction	.38/CY	10346 CY	3931.5
Excavation Base Cost	1.66/CY	10346 CY	17174.4
Aggregate	1.05/CY	10346 CY	10863.3
Agg. Compaction	1030/mile	.42 mile	432.6
Finishing Cost	570/mile	.42 mile	239.4
Outsloping Cost	1125/mile	.42 mile	472.5
	Subtotal		30914.2
40% Labor			64099.3
Silt Fencing	7-12/LF	2217x2 LF	44340
Haybales	7/LF	2217x2 LF	31038
Waterbar Construction	7-9 each	1/100 LF	176
		TOTAL	**203752.6**

Figure 32 - Alternative 2 Access Road Cost Estimate (Service, 2009)

4.6.6.3 Access Road Alternative 3

Although this project would be the most cost effective initially in terms of construction cost, having the turbine sited lower would cause for a longer payback period due to the lower electricity outputs. This siting alternative has the cheapest access road construction of $137009.20, which is $92,773.40 less than alternative 1 and $66743.4 less than alternative 2. These initial construction cost differences would be made up over time by the electricity produced by the other alternatives due to their elevation and having two turbines as in alterative 1. The figure below shows a cost analysis for the access road for Alternative 3.

Alternative 3 Road Construction Costs			
Activity	Unit Cost	Amount	Actual Cost
Clearing and grubbing	1700/mile	.22 mile	374
Roller Compaction	.38/CY	5432 CY	2064.2
Excavation Base Cost	1.66/CY	5432 CY	9017.1
Aggregate	1.05/CY	5432 CY	5703.6
Agg. Compaction	1030/mile	.22 mile	226.6
Finishing Cost	570/mile	.22 mile	125.4
Outsloping Cost	1125/mile	.22 mile	247.5
	Subtotal		30914.2
40% Labor			48672.6
Silt Fencing	7-12/LF	1164x2 LF	23280
Haybales	7/LF	1164x2 LF	16296
Waterbar Construction	7-9 each	1/100 LF	88
		TOTAL	**137009.2**

Figure 33 - Alternative 3 Access Road Cost Estimate (Service, 2009)

4.6 Staging Area Design

Staging areas will be necessary at the base of each turbine. These areas typically are around an acre in area, and will have to be cleared of all trees. However, unlike the access road, the ground does not have to be perfectly flat, or have one type of surface. On the Granger Cliffs site, it will be necessary to clear roughly two acres of trees and land or 87,120 square feet. There will be a continuation of the 26 foot wide road through the staging areas allowing for the crane to maneuver between the two sites. Otherwise, the staging area is simply used as an area to place the delivered turbine pieces, as well as an area in which the blades can be assembled before they are lifted and connected to the turbine tower.

Figure 34: Shows the terrain of the staging areas at the Princeton wind farm, in Princeton, MA

The figure above displays the one of the staging areas in Princeton. It shows that the area is not completely flat, nor compacted in the same way that an access road is. The terrain simply must be clear for the storage of materials and have an access road for the transportation of materials and construction vehicles.

Figure 35: Shows the construction of a wind turbine rotor on a staging area in Princeton, MA

The image above shows how Princeton minimized the necessary clearing space by using the slope which is larger than the one on Granger Cliffs, to their advantage by simply cutting into the trees rather than clearing them all together. Once the construction has been completed, the staging area should be reseeded and growth should be allowed to come back to the area to assist in storm water and return the area to its natural environment.

Staging area clearing cost:

1 mile of 14ft wide roadway= $1,700 (Service, 2009)

or 73,920 square feet of clearing = $1,700

1 staging area = 43,560 square feet = $1,002 clearing and grubbing/ staging area

4.8 Site Constraints and Public Concerns

4.8.1 Bird Fatalities

Often the safety of birds is considered when putting up wind turbines; however bird deaths from wind turbines are very low. Annually about 2.19 birds per turbine are killed. When compared to other sources of fatalities such as windows, house cats or vehicles. There are approximately 400 million bird fatalities per year due to these sources, while there are approximately 10,000-40,000 fatalities due to wind turbines. (Fitch, 2006)

4.8.2 Wetlands

In this project there was no real way to avoid infringing on areas marked as wetlands by MassGIS. We attempted to minimize this effect by routing the access through smaller areas of wetlands. The wetlands can be seen in blue in the following figure, while the access road is black. At the points where the access road directly passes over the wetlands a culvert passing underneath the roadway should be constructed tom minimize effect on the wetlands water flow. Another simple construction measure to assist in water flow is creating small dips in the roadway which will provide a channel for stromwater and other water to pass over the road. Auburn's town bylaw states that "No person shall remove, fill, dredge, or alter any area within one hundred (100) feet from any bank, fresh water wetland, flat, marsh, meadow, bog, swamp, creek, river, stream, pond or lake, or any land under said waters or any land subject to flooding." Due to this by law the project will require a special permit due to its infringement on wetalnds.

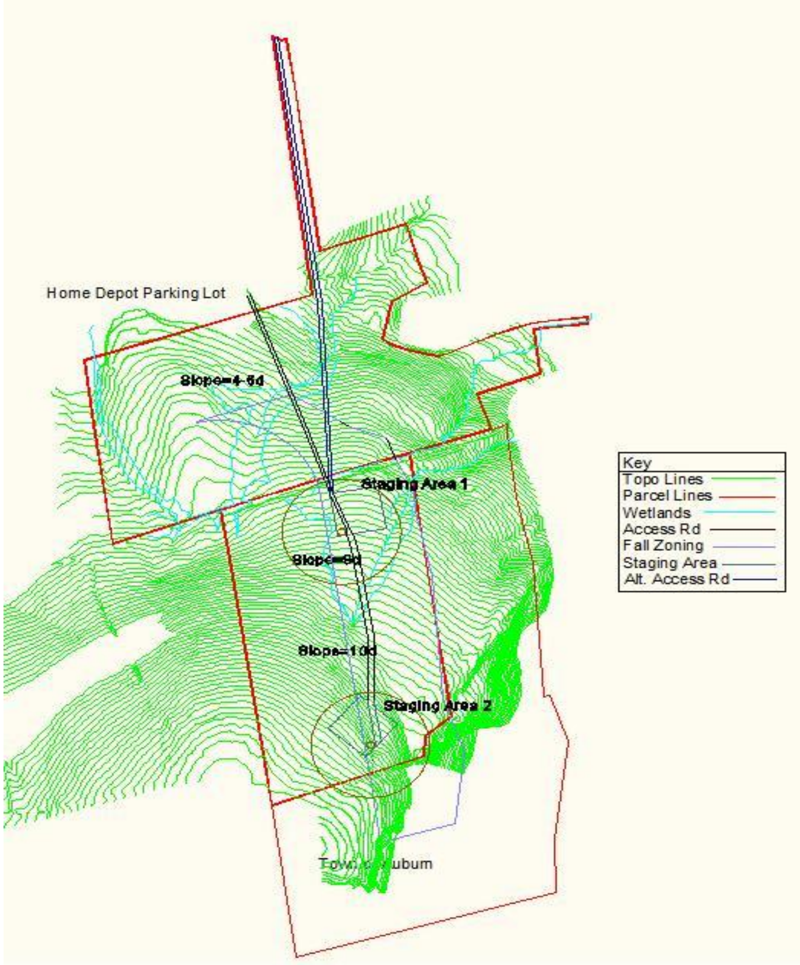


Figure 36 - Site design showing wetland areas

4.8.3 Noise

One important impact a wind turbine places upon the environment is noise pollution. Many people think wind turbines are a great idea, yet a large number of these people would oppose wind turbines close to their homes. The impact of noise pollution has the potential to lower property values within a varying radius of the construction. Wind turbines generate two types of noise: aerodynamic and mechanical. A turbine's sound power is the combined power of both. Aerodynamic noise is generated by the blades passing through the air. The power of aerodynamic noise is related to the ratio of the blade tip speed to wind speed. (Alberts, 2006)

Depending on the turbine model and the wind speed, the aerodynamic noise may seem like buzzing, whooshing, pulsing, and even sizzling. Turbines with their blades downwind of the tower are known to cause a thumping sound as each blade passes the tower. Most noise radiates perpendicular to the blades' rotation. However, since turbines rotate to face the wind, they may radiate noise in different directions each day. The noise from two or more turbines may combine to create a fluctuating or thumping effect. (Alberts, 2006)

Utility scale turbines must generate electricity that is compatible with grid transmission. To meet this requirement, turbines are programmed to keep the blades rotating at as constant a speed as possible. To compensate for minor wind speed changes, they adjust the pitch of the blades into the wind. These adjustments change the sound power levels and frequency components of the noise.

Mechanical noise is generated by the turbine's internal gears. Utility scale turbines are usually insulated to prevent mechanical noise from escaping outside the tower. Small turbines are more likely to produce noticeable mechanical noise because of insufficient insulation, so the Fuhrlander 1.5 MW will most likely not produce noticeable mechanical noise. Mechanical noise may contain discernable tones which makes it particularly noticeable and irritating. This is something that must be discussed with the community in the area of Granger Cliffs. (Alberts, 2006)

The amount of annoyance that wind turbine noise is likely to cause can be related to other ambient noises. One study in Wisconsin4 reported that turbine noise was more noticeable and annoying at the cut-in wind speed of 4 m/s (9 mph) than at higher wind speeds. At this speed, the wind was strong enough to turn the blades, but not strong enough to create its own noise. At higher speeds, the noise from the wind itself masked the turbine noise. This could be of significance to Michigan communities where the average wind speeds vary from 0 to 7 m/s (0–16.7 mph). (Alberts, 2006)

4.8.4 Visibility and Flicker

Another disadvantage regarding a wind turbine and its impact on the surrounding environment can be expressed with the term visual impact or visual pollution. On a sunny day, this will create flicker at a rate of 60 cycles per minute (2 blades X 20RPM) and when the sun is low in the sky, such as evenings and in the winter, this flickering can occur some distance from location of the turbine. At the top of Granger Cliffs the two proposed wind turbines will be visible to people in the area and flickering may be a problem. (Chautauqua Wind Power, 2004)

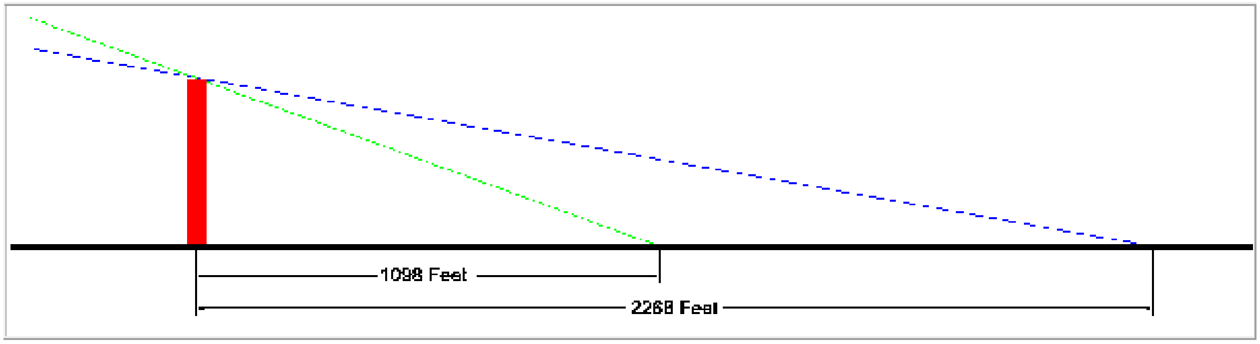


Figure 37 - Flicker distance based on angle of the sun (Chautauqua Wind Power, 2004)

The image above shows how long the shadows of a 400 foot tall object, like the tip of the turbine blades, would be with the sun at two different elevations. The vertical red line indicates the turbine location. The green line indicates where the shadow of the turbine blades would fall when the sun is at an elevation of 20 degrees from the horizon, which is close to the maximum elevation angle of the sun for many days during the winter. The blue line indicates the shadows when the sun is 10 degrees from the horizon. These elevations of the sun happen in the morning and evening in the summer and during the morning and afternoon in the winter. When the sun is at 10 degrees, there will be “60 flashes every minute or one every second at a distance of 2,258 feet or almost a half mile from the actual turbine.” As the sun rises to or sets below this elevation, the distance of the flicker from the turbine increases. This flicker is an annoyance to somebody who experiences it. At worst, flicker from wind turbines can trigger seizures in those who are susceptible. The flickering from the wind turbines are a very negative aspect of placing a wind turbine so close to homes. (Chautauqua Wind Power, 2004)

4.6.5 FAA Regulation

FAA Advisory Circular AC 70/7460-1K says that warning lights must be placed on the wind turbines. Choosing the least intrusive lighting system available will minimize the impact to the environment and to the surrounding community. We will use a strobe light placed near the generator enclosure of the wind turbine for both night, and daily use. The lighting system that should be chosen is one that allows for the light to be lit for the least amount of time, so it does not interfere with people in the community. (Fitch, 2006)

The placement of the light on top of the generator does not allow the light to shine downward, which will help block light from people in the community. The lights will be covered with clear cones that will also aid in the prevention of strayed light and keeping the light from impacting the community and environment. The FAA has strict rules about stray lighting so keeping it to a minimum is very important when installing the lighting system. When picking the lighting system, the system that will most likely be chosen is the system that emits the least amount of strayed light. (Fitch, 2006)

4.9 Delivery and Scheduling

4.9.1 Scheduling

The coordination process of shipping and delivering wind turbines is very extensive. Mass-Highway must be contacted to coordinate the route to take, and clearances along the highway. Also coordinating with the towns is very important, due to the amount of traffic that can be caused by a convoy of semi-trucks. One turbine usually takes between 8-10 semi-trucks. The breakdown of how each part of the turbine is transported is as follows; the tower is delivered in three pieces, each turbine blade is delivered separately on its own semi-truck, the generator, the hub, and other equipment involved in the erection process are delivered on 3 to 4 semi-trucks.

Figure 38 - Trucks delivering turbine parts to staging area

The figure above shows delivery trucks delivering turbine parts to the Princeton wind farm staging area. During the delivery process the blades are the most protected part of the turbine. They are handled very carefully because they are made out of expensive lightweight fiberglass and are delivered in one piece. Also it is important to contact the manufacturer in advance of the initial construction date to allow time for the turbine to be constructed and shipped. This will also be very important in clearing for the access road and staging area, as well as constructing the access road. Without access to the site, no materials can be delivered or erected.

4.9.2 Delivery

The proposed access road will obviously need to be constructed before any part of the delivery process occurs. With the removal of trees to create the access road, there will also be a vast amount of trees located adjacent to the access road will need to be cleared. Also there may be a need for a topcoat of crushed graded gravel may need to be placed where a crane will go in order to erect the wind turbines.

The crane the team decided to use is a Manitowac 2250 crane that will be used in the erection of the wind turbines. The crane itself will need approximately fifteen semi-trucks to transport it to the site, and will need to be assembled on site. While unassembled, the crane will only need between a 12-14 foot roadway to get the crane to the site. However, once the crane is assembled it will need a roadway no less than 26 feet wide in order to move from one turbine site, to another. In order to make this possible the land between the two turbines must be cleared and leveled to a certain degree in order for the crane to get from one turbine location to the other.

Wind turbine parts are very large, so planning as to where the parts will sit before the erection is a process in itself. If the rotors of the turbine are assembled before reaching the site, approximately an acre of land next to each turbine location will be needed just for one rotor. The slope of the area where turbine assembly occurs needs to be close to flat, so that both of the sites there may need to be some cut and fill in order to level out the land. The figures below display the individual turbine parts that must be delivered to the staging areas before construction can begin.

Tower Sections	***Weight***	***Length***	***Diameter(base)***	***Diameter(top)***
Embedded Section	7 tons	8’	14’	14’
Base	37 tons	58’	14’	14’
Middle	28 tons	65’	14’	14’
Top	27 tons	99’	14’	8’
	Weight	***Length***	***Width***	***Height***
Generator	51 tons	25’	10’	12’

	Weight	***Length***	***Diameter***
Blades	7.5 tons	131’	10.5’

Figure 39: Table of turbine parts sizes and weights

Chapter 5: Recommendations

5.1 Site Determination

After carefully comparing the five potential wind turbine sites considered for this project, the group selected a site that would provide the best location for the town of Auburn to place a wind turbine(s). The site the group is recommending to the town of Auburn is the Granger Cliffs site. Granger Cliffs from the beginning of the search has stood out above the other sites as the best choice. From the Table 13 presented earlier in this paper, you can see that Granger Cliffs site produced the most wind speed per m/s than the other four sites. The location, the possibility of roadway access, distance from neighborhoods, turbine spacing are all much more suitable to this projects needs than other sites could offer.

5.2 Turbine Selection

The wind turbine technologies recommended for the Granger Cliffs' wind farm are two Fuhrlander 1.5 megawatt turbines. The basis behind this decision was to generate the maximum amount of electricity possible from the wind turbines. The 1.5 megawatt turbine would surpass the maximum output of a 600 kilowatt turbine at the expected annual wind speeds, with the electricity output growing as the wind speeds increase according to the Fuhrlander 1500 power curve. The initial research dealt with smaller turbines, mainly a 600 kilowatt design which was also offered by Fuhrlander. Fuhrlander was chosen as the turbine manufacturer because while researching potential models, Fuhrlander offered choices in the range of smaller 600kw turbines through larger 1.5 megawatt turbines, while other manufacturers such as GE did not offer these smaller turbine models. Later in the project's development it was discovered that the Princeton Municipal Lighting Department had also chosen Fuhrlander as their turbine supplier which supported the group's findings.

5.3 Turbine Siting

The potential siting alternatives included Alternative 1 which was the siting of two 1.5mW turbines at both site 1 and 2, Altenrative 2 which was the siting of one 1.5mW turbine at site 2 and finally Alternative 3 which was the siting of one 1.5mW turbine at site 1. The alternative siting that was chosen for the Auburn Wind Project was alternative 1, which was the siting of two turbines on the northern and southern ends of the property at site 1 and site 2. This alternative was selected in accordance to the turbine selection of two 1.5 megawatt turbines. This site design allows for the siting of two turbines at a safe distance from each other of 1,000 feet, while staying within the fall zone envelope. These turbine sites are selected with the intention of trying to maximize the turbine heights while not infringing on wetlands. The final AutoCAD site design including both turbine sitings is shown below in figure 40.

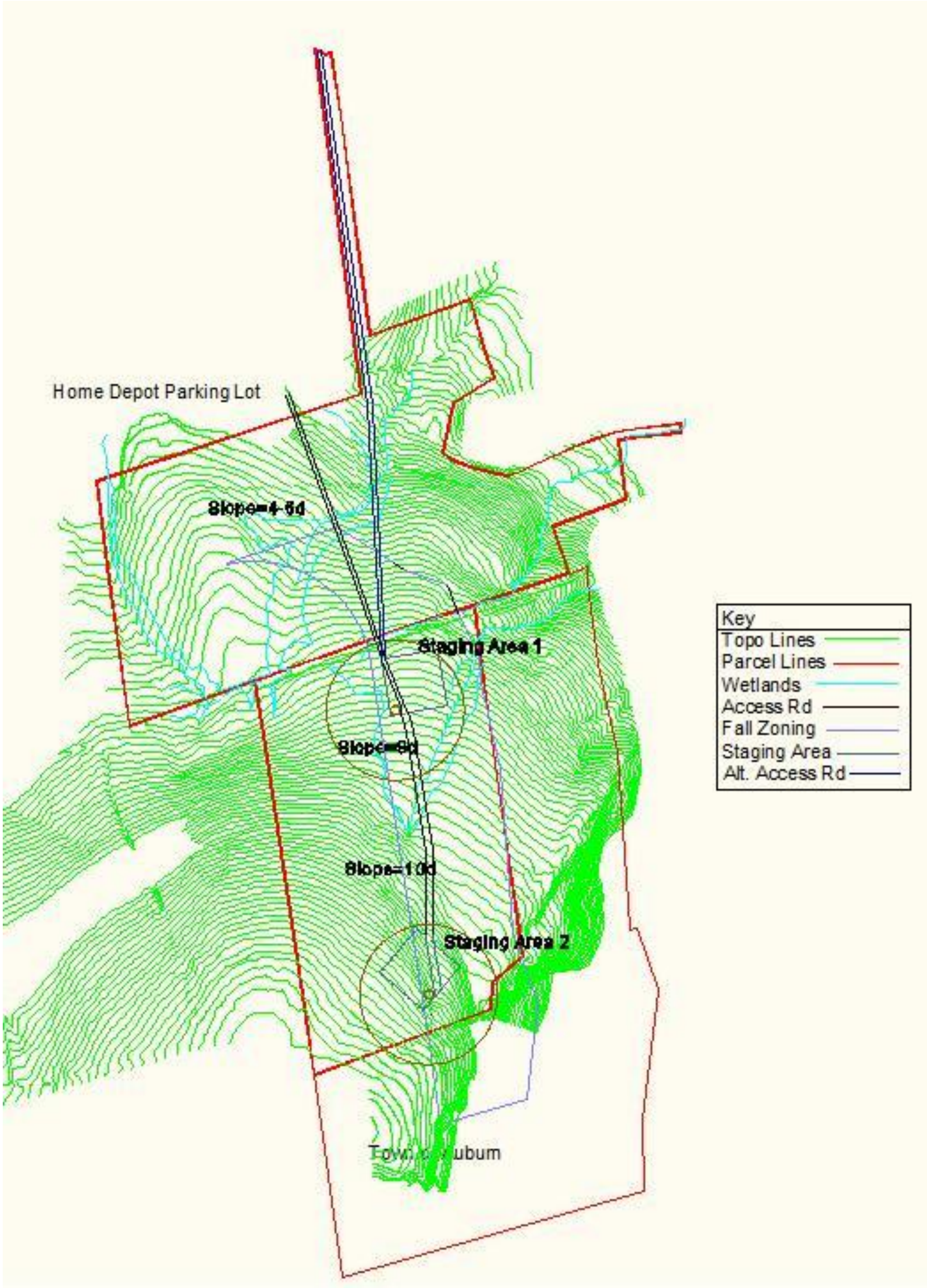


Figure 40 - AutoCADD Site Design

5.4 Access Road Design

The proposed access road design for the Auburn Wind Project will enter from the southeast corner of the BJ’s/Home Depot parking lot. This route was chosen since it reduces the effects on the surrounding wetland areas. The road alignment will cross two wetland areas Shower in light blue in figure 40 above. The access road could have entered further to the west; however, it would have had similar wetlands infringement while also having much more of the road running alongside a sloped area which would add to the construction costs of the access road. The width of the road will be 14 feet between the road entrance and first turbine, and 26 feet between the turbines for the transportation of the crane which will be erected on site. The road will be constructed with gravel over compacted soils, with finer gravel materials in the top layers. There will be several steps taken to minimize the effects of stormwater and wetlands. During the construction of the access road and the turbines, silt fence and hay bale dikes should be employed to reduce the damage to the surrounding areas from silt and other materials that could be washed into the surrounding vegetation. Other storm water management practices that can be applied are ditches alongside the road to control flow as well as turnouts which can direct the water flow into areas that will not damage the environment such as gravel for groundwater recharge. Culverts are generally used either for roads which cross streams or for runoff management. It is unlikely that the existing wetlands would produce enough runoff to require a culvert on site, so the application of turnouts and waterbars should provide sufficient runoff management. The figure below shows the use of a waterbar on the access road in Princeton which is shown running downhill at a diagonal. (Recommended Practices Manual, 2000)

Figure 41 - Imagine showing a waterbar on Princeton's access road

5.5 Scheduling and Delivery

The recommendations the group has for the scheduling and delivery is to have both been on time. In every project being constructed, time is money. So if the scheduling is precise that will lead to the delivery of the product being delivered on time. It is important to plan because planning and scheduling; helps to minimize the cost by optimum utilization of available resources, reduces irrational approaches, duplication of works and inter departmental conflicts, and encourages innovation and creativity among the construction managers. For instance, the planners must make sure that the access road has been completed before the delivery of the wind turbine has arrived. Again planners must be very precise in their planning in that in every project, time is money. So efficient planning that goes into this project will in turn cause for less time to complete the project and less money that may have been spent if the planning had not been done efficiently. The delivery of the parts needed to complete must be delivered on time. This again goes back to efficient planning in making sure that when construction of the turbines begins, all of the parts needed to begin construction are available for use.

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Appendix:

Appendix A: 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. 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.

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).

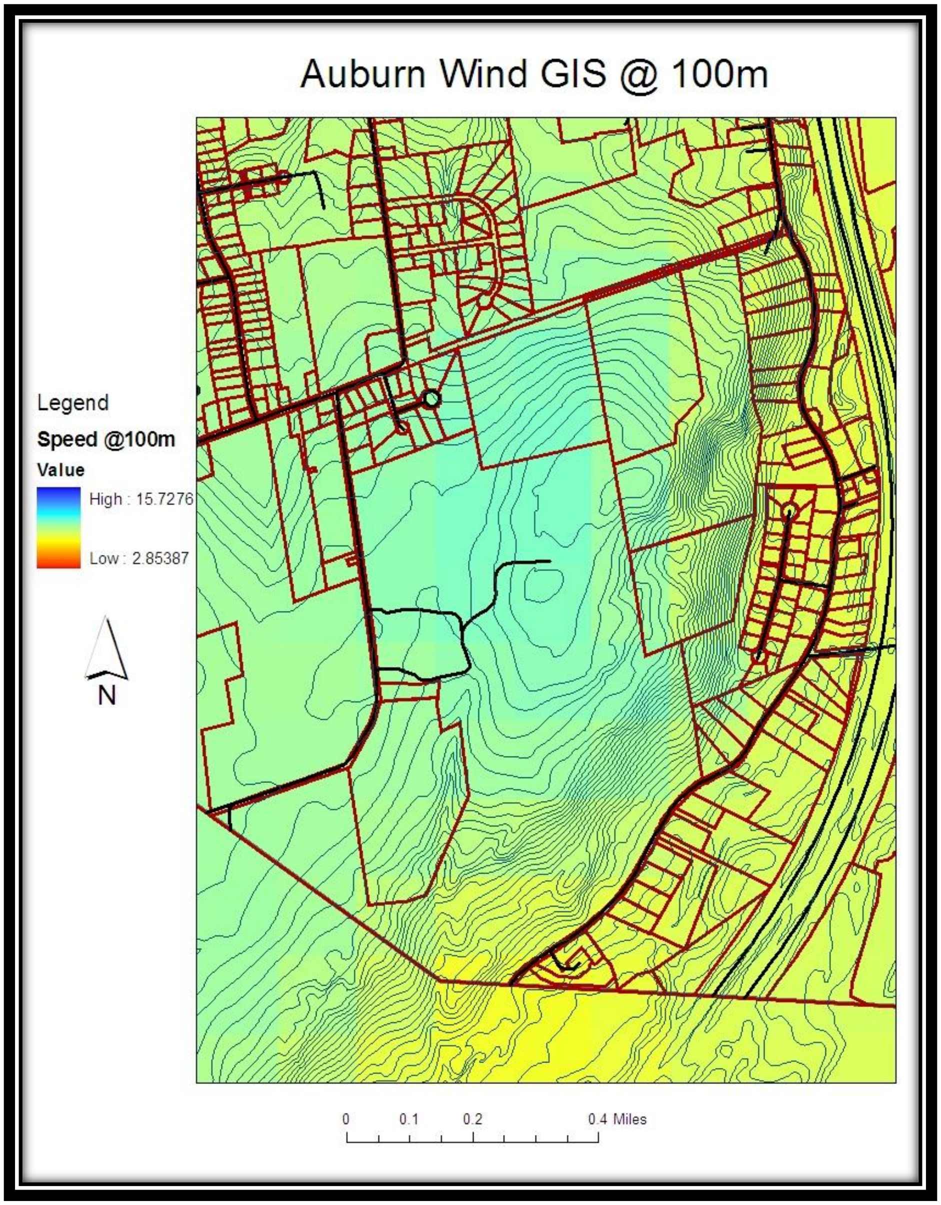
In the United States, the federal government's involvement in wind energy research and development began about two years after the so-called "Arab Oil Crisis" of 1973. The research from the Federal Government's development activities resulted in; the design, fabrication, and testing of 13 different small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

Appendix B: Wind Data Information



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	-	-

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

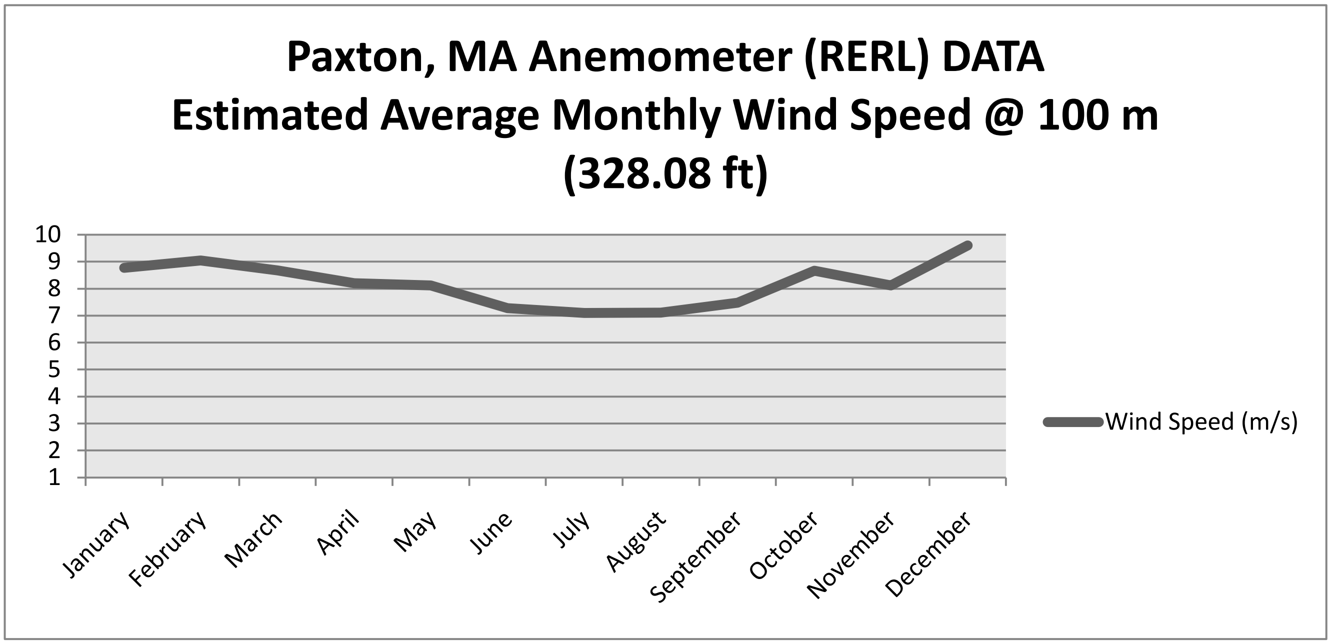
(University of Massachusetts Amherst, 2007)

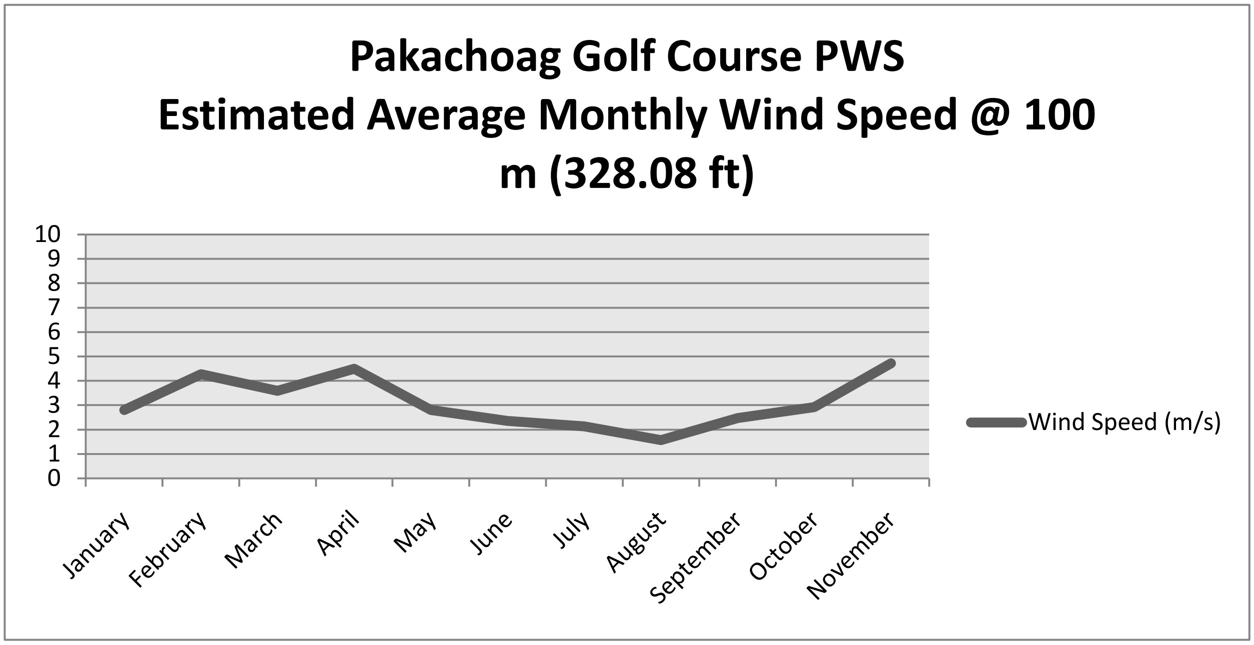
Estimated Average Monthly Wind Speed @ 30 m (98.4 ft)		
Time (month)	Wind Speed (m/s)	Wind Speed (mi/hr)
January	6.9	15.4
February	7.1	15.9
March	6.8	15.2
April	6.4	14.4
May	6.4	14.3
June	5.7	12.8
July	5.6	12.5
August	5.6	12.5
September	5.9	13.2
October	6.8	15.2
November	6.4	14.3
December	7.6	16.9

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 C: Complete Cost Analysis

Fuhrlander 600kW turbine

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
<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	170767.4	$/yr
<u>Turbine Cost</u>		
Operations & Maintainence Costs*	0.03	$/kWh
Transmission Lines*	100,000	$
Access Road*	140,000	$
Site Clearing*		$
Planning & Design*		$
Estimated Installed Cost/kW *	2136.14	$/kWh
Estimated Installed Cost in Auburn	1521702	$
Pay Back Period	8.9	years

ASSUMPTIONS (*)

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$/ft^2 with a area of 39,600 ft^2

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

Fuhrlander 1.5 mW turbine

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
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	426918.6	$/yr
Turbine Cost		
Operations & Maintainence Costs*	0.03	$/kWh
Transmission Lines*	100,000	$
Access Road*	200,000	$
Site Clearing*		$
Planning & Design*		$
Estimated Installed Cost/kW *	2136.14	$/kWh
Estimated Installed Cost in Auburn	3504255	$
Pay Back Period	8	years

ASSUMPTIONS (*)

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

Two Fuhrlander 1.5 mW turbines

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*	230,000	$
Site Clearing*		$
Planning & Design*		$
Estimated Installed Cost/kW *	2136.14	$/kWh
Transportation Cost	150,000	$
Estimated Installed Cost in Auburn	6888510	$
Pay Back Period	8.0677	years

ASSUMPTIONS (*)

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

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24.) Estimated Installed Cost/kW:

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- Hull: $ 3,310,109/ 1,800 kW = 1,838.95 $/kW
- Average = 2,136.14 $/kW
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