PROJECT NUMBER: PPM-0893

Worcester Academy Wind Turbine Feasibility Study

An Interactive Qualifying Project Report
submitted to the Faculty of
WORCESTER POLYTECHNIC INSTITUTE
in partial fulfillment of the requirements for the
Degree of Bachelor of Science
by

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Date: October 28, 2009

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Table of Contents

List of Figures

List of Tables

Abstract

The goal of the project was to perform a feasibility study to assess the potential for installing a wind power at a potential site at Worcester Academy. The methodology included a feasibility study of three wind turbines. This feasibility study included a series of investigations addressing wind data and energy, wind turbine selection, and financial feasibility. The wind study included estimation of amount of wind energy that could be generated, and the determination of the ideal site placement for the wind turbine. A financial projection was performed with consideration to a twenty year span in order to determine potential savings provided by a wind turbine. The overall conclusion was that there is potential for installation of a wind turbine to at Worcester Academy.

1. Introduction

The energy needs that are required in today's society are continuously growing and our reliance on energy is unavoidable. Nonrenewable energies such as the combustion and burning of fossil fuels have been the main source of energy worldwide since energy was first harnessed. Nuclear plants have also been able to provide another source of energy across the world and have proved to be viable sources of energy in less populated areas and areas with low amounts of fossil fuels.[1]

It is becoming evident however that fossil fuels and nuclear plants are not the only forms of energy that we should be using to get us through day to day life. Research into renewable energies began decades ago and the availability of it today is the highest ever.[2] Also, the fact that energy costs are reaching prices never recorded before and the expense of installing renewable energy concepts are decreasing gives reason for an increased effort to move towards renewable energy sources.[3]

One school that is planning to start using renewable energy as a way to power its campus is Worcester Academy. Worcester Academy is a boarding college-preparatory school that boards 140 high school students and has another 640 day students in grades 6-12. The school, located in Worcester, Massachusetts has created a list of standards that they plan on being able to set in place by 2014. One of these standards is to "assess, support, and sustain its community and educational programs through exemplary institutional systems and practices" which they hope to complete in part by "developing and adopting a school-wide plan for environmental responsibility and civic management".[4] This plan has created the need to expand from addressing day to day sustainability issues to a larger scale project.

[1] (AWEA, 2007)
[2] (Why Clean Energy is Important: Overview)
[3] (Swift-Hook, 1989), *pg. 3*
[4] (Worcester Academy: Strategy)

Accordingly the objective of this project to assess the feasibility of adding a wind turbine to the Worcester Academy campus in order to cut power costs and continue the academies efforts to turn its campus into a more sustainable entity. To determine the feasibility, social and regulatory implications as well as the financial feasibility in the process in installing the wind turbine on the campus of Worcester Academy must be considered. The proposed location of the wind turbine is on a six-acre plot of land owned by Worcester Academy to the South of their main campus. The goal for the project is to devise a three pronged financial approach to the construction of a wind turbine on this part campus to serve Worcester Academy's energy sustainability needs. In reaching our goal we will provide our sponsor necessary steps in regards to regulatory conditions, Massachusetts sustainability laws, and local laws that need to be followed.

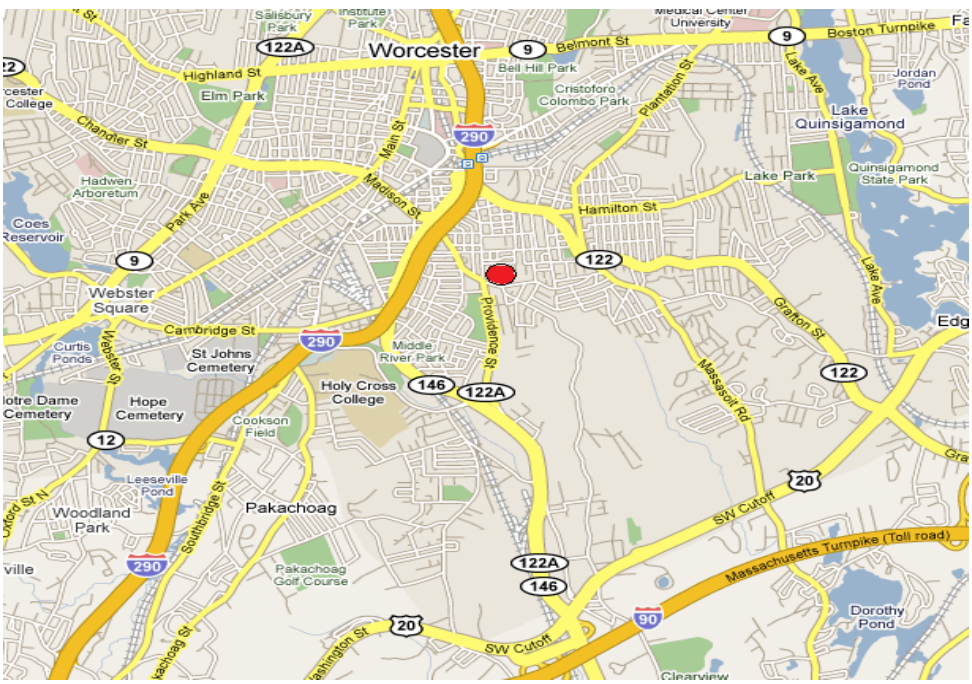

Figure 1: Proposed Site Indicated by Red Dot

In order to come up with a proposal for a suggested wind turbine research into wind turbines and wind energy had to be completed. This began with the usage of general available text on background information and recently completed projects in the area. With understanding of what it would take to complete such a project as we would be proposing, the feasibility of the project being successfully completed was determined. The look into the feasibility included the location of the site, available funding and grants, passing or local regulations, and projected savings.

2. Background

In order to complete a successful report it is necessary to have a strong understanding of the material you are discussing. The research that was conducted to provide the background included information on wind energy, wind turbines, generators. Research was done to look into Worcester Academy, the proposed site, and wind data collection including the mapping software, ArcGIS.

2.1 Wind Energy

Renewable resources are the wave of the future. With depleting fossil fuels in the world, nations need to start to turn to renewable and alternative resources in order to fulfill the increasing need for electricity and power. Various different types of renewable energies include wind power, wave power, tidal power, solar power, hydro power, geothermal, biomass, and biofuels. Each of these forms of renewable energy helps to save on the use of fossil fuels, and other nonrenewable resources such as coal, oil, and natural gas. The uses of these renewable resources also help to cut down on pollution of the atmosphere, depletion of the ozone layer, lower greenhouse gas emissions, and reduce the growing global warming crisis.[5]

There were many uses since the beginning of time involving wind energy. These original uses were to propel sailing ships across the water and also to use the energy and convert this into mechanical energy in order to pump water or to grind grain. In the present time, the primary objective for wind power is to generate electricity, using what is known as a wind turbine. For large energy generation these turbines are arranged in large quantities called wind farms. These wind farms can be as small as a few dozen turbines, or have as many as 100 turbines.

Over time the overall design of wind turbines have changed dramatically. The older turbines, or windmills, used to consist of four blades, which were made of wood, each of the sails on the blades

[5] (Diversifying Sources of Electricity)

were made of some type of strong fabric. These turbines used to be used for two main reasons; one was to crush up stone, corn, and other things, into a fine powder in order to crush them using a big wheel inside of the turbine. The newer turbines are typically three bladed, metal structures. These turbines are very high in efficiency, have a fairly low amount of torque, have tip speeds, speed of the tip of the blade, of up to six times the wind speed, and are also extremely reliable.[6]

2.1.1 Global Interest in Wind Energy

There are many countries that are starting to focus their efforts in wind power. In 2007 the top 5 countries for wind power capacity were Germany (22,247), United States (16,818), Spain (15,145), India (8,000), and China (6,050). Each of these 5 countries consumes a certain percentage of their total electricity usage in wind power. Germany had a 6.8% usage, United States .77%, Spain 9.7%, India 1.9%, and China .172%. Each percentage is the amount of their total electricity usage that was based from wind power. With the efforts that the nations are putting in, the world is on track to be saving 10 billion tons of CO_2 by 2020, which would turn out to producing 12% of the world power from wind power.[7]

Table 1: Countries Contributions to Wind Power from 2005 and Future Estimates (Ankhmatov 2008)

Country	Present Wind Power	Projected Wind Power
Spain	10 GW	12 GW by 2010
Germany	18.4 GW	30GW by 2030
Great Britain	1.1 GW	6.2 GW by 2010
Netherlands	1.2 GW	6 GW by 2020
Sweden	500 MW	2.7 GW by 2015
USA	6.4 GW	10 to 84 GW depending on Legislation
Australia	250 MW	6.7 GW proposed

As of the end of 2008, the United States had 25.1 GW (25,100 MW) of wind energy capacity, this caused them to surpass Germany to become the world's leading wind energy market. In 2008 the United

[6] (Darling, 2008)

[7] GWEC. *Global Wind Energy Outlook 2008.* 2008.

States wind capacity increased a total of 50%, which is vastly higher compared to the average growth of the world's capacity at 28.8%[8]

2.1.2 Local Interest in Wind Energy

On a state level, the amount of funding for research and development of wind energy is increasing at a consistent rate. To ensure that the Commonwealth of Massachusetts was doing the most it can to develop and use renewable energy the state government created Massachusetts Technology Collaborative (MTC) in 1982. The MTC's purpose since its beginning has been to create "a cleaner environment for Massachusetts" and "improve the quality of life throughout the state".[9] MTC now offers the largest grant program for renewable energy projects in Massachusetts including the Large Onsite Renewables Initiative (LORI) grant that award up to $400,000 per project.

In the last couple of years the amount of wind turbines being constructed and proposals created for more in Massachusetts has been on the rise. One project that was funded in part by the MTC was the Holy Name Jr/Sr High School wind turbine constructed in Worcester. The construction of this turbine was completed in 2007 and included a 600 kW wind turbine. MTC contributed $575,000 to the completion of the project which covered partial costs of a feasibility study as well as the turbine and its construction.[10]

A second project that received the LORI grant from MTC is the wind turbine constructed at Massachusetts Maritime Academy in Bourne. This project completed in 2006 is similar to the Holy Name project and included the installation of a 660 kW turbine on MMA's campus. This project cost MMA $1,344,500, $520,808 of which came from MTC in the form of grants.[11]

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[8] (Energy Sector Research)
[9] (MTC History (2005))
[10] (Holy Name Central Catholic Jr/Sr High School, 2007)
[11] (Massachusetts Maritime Academy, 2006)

A third wind turbine project that received the LORI Grant is a 10kW turbine located on the location of Upper Cape Cod Regional Technical School also in Bourne. This turbine is the smallest allowable to still apply for a LORI grant. To help aid in the financing of the turbine and the feasibility study that went along with the construction the school received $428,000 in grants from MTC. As noted in the project overview, Upper Cape Technical has also received other grants from MTC for their renewable energy curriculum and photovoltaic cells.[12]

One site in Worcester that has also received the LORI Grant is the location of The Christopher House. The Christopher House is a nursing and rehabilitation center that is located to the north of Worcester Academy. So far, The Christopher House has received $37,782 from MTC for a wind power feasibility study that was given out in May 2008. With the study finishing in the next few months The Christopher House will become eligible for up to $400,000 more from MTC is their site is found a viable wind energy source.[13] If a wind turbine is added to the site it will be the second wind turbine installed south and east of Route 290 in Worcester, the first being at Holy Name High School. This leaves an opportunity for Worcester Academy to install the third turbine in the area. Figure 2 below shows the location of Holy Name High School's turbine site as a black circle at the bottom of the figure, The Christopher House's proposed site as a green circle at the top of the figure, and Worcester Academy's proposed site in red on the left side of Figure 2.

[12] (Upper Cape Cod Regional Tech School - Wind Feasibility Study, 2007)
[13] (Christopher House Feasibility Study, 2008)

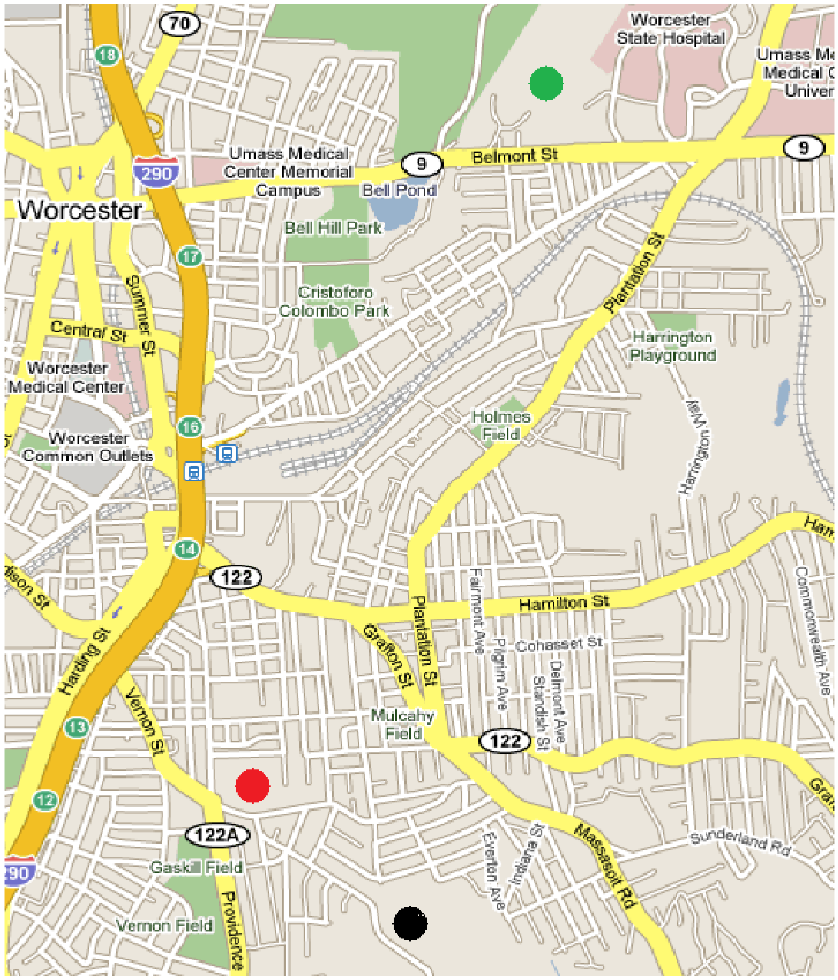

Figure 2: Sites Investigated for Viable Wind Energy in Worcester

2.2 Wind Turbines

2.2.1 History

Wind energy was first harnessed circa 200 BCE by the Persians in the form of a panemone, a simple drag device powered by the wind. The first “Dutch Windmill” however was not first documented until 1180 ACE in Normandy, France. The Dutch Windmill then spread throughout Europe in the following centuries and later into Asia. It is estimated that by the nineteenth century China was using nearly 500,000 windmills, the equivalent to the amount used across the entire continent of Europe. The first windmills started to cross the Atlantic Ocean into the United States around 1850.[14] According to historian Walter Prescott Webb, the windmill was one of the most important inventions in allowing the spread of farms across the Great Plains as it allowed farmers access to water for herds that was otherwise unattainable.[15]

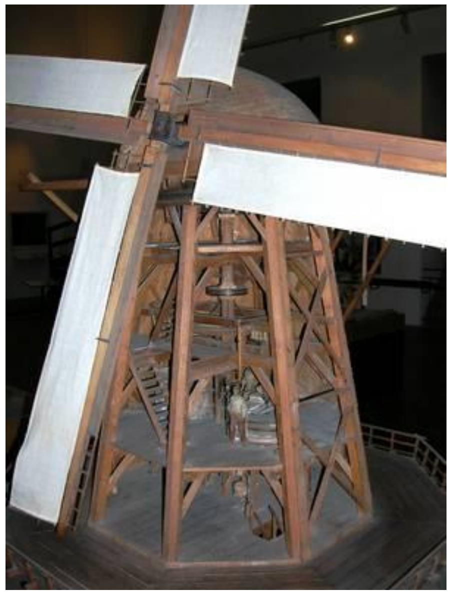

Figure 3: Dutch Windmill circa 1880

The first modern wind turbines that used generators to power them were created in the 1930s to help backup machines on military bases in Europe. The first modern turbine to be constructed in the United States was the WF-1; a three-bladed, 25 kW turbine constructed by US Windpower of Burlington, Massachusetts. The WF-1 was built in 1971 and was used as a teaching tool for the construction of turbines throughout the 1990s. [16]

2.2.2 Specifications and Requirements

Wind Turbines can vary tremendously in size, and also in shape. Each turbine has a specific kilowatt (kW) output that is generates. This wattage is normally based upon the size of the turbine, the

[14] (Gipe, 1995), pg. 118
[15] (Gipe, 1995), pg. 122
[16] (Manwell, McGowan, & Stoddard)

smaller the turbine the smaller the wattage output, the bigger the turbine, the larger the wattage output. There is an equation that states how the power of a turbine is determined, this shows how the power transferred to the turbine itself is directly proportional to the density of the air, to the area that rotors turn, and to the cube of the wind speed.

$P=1/2\ \alpha\rho\pi r^2 v^3$.

P is the power in watts, α is an efficiency factor that is determined by the design of the turbine itself, ρ is the density of the air in kilograms per meters squared, r is the radius of the turbine in meters, and v is the velocity of the air in meters per second.[17]

In order to place a wind turbine, there are multiple factors that need to be considered. First of the necessities is determining what size of a turbine that is to be used. The size could vary anywhere from a 100 kW turbine to a 1 MW turbine. The determination of size depends on the power demand that must be met. Second, and probably most important, finance must be considered. One option to seek funds is through grants that are given by the state and federal governments. Also the elevation plays a part in deciding where to put a turbine. Higher elevations are associated with faster wind speeds, and lower elevations imply lower wind speeds. Turbines can be place at various elevations and can be placed in water or on land. When placing a turbine, it is often helpful to take advantage of the funnel effect associated with the landscape in the area. This effect essentially concentrates the wind in one specific area, which results in higher wind speeds in a given area. Other factors that come into account are the temperature. Areas that have extremely low temperatures (e.g. below -20°C) open up the possibility of ice accumulation on the rotor, or motor. The accumulation of ice can cause high loads on certain areas and possible damage to areas of the turbine. The ice problem can be fixed with

[17] (American Wind Energy Association)

different lubricants, different alloys that the turbine is made out of, and even including internal heaters inside of the turbine.[18]

Finally there are also requirements associated with the turbines that must be addressed in order for the turbine to be built. The minimum wind speed needed in order to power a turbine is typically 10 mph, or 4.5m/s. The ideal conditions for a spot to install a turbine include in an area with a relatively constant wind flow, and relatively few turbulent gusts of wind. This is because turbulent winds can damage or even knock over a wind turbine. Figure 2 shows the average wind speeds in the nation.[19]

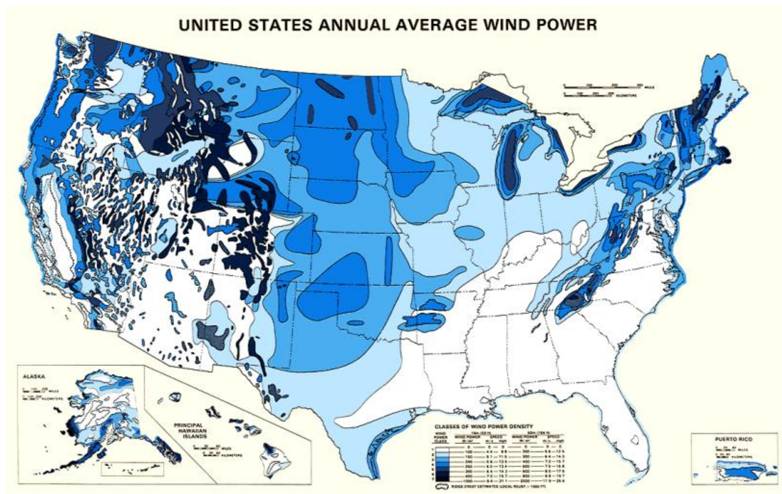

Figure 4: U. S. Annual Wind Power

This is determined by various different shading of blue. The darker that the area is the higher the average wind speeds are for that given area.

[18] (American Wind Energy Association)

[19] (Massachusetts Technology Collaborative)

2.2.3 Turbine Construction and Grid Connection

There are many preparations that must be completed before a wind turbine can be installed. The wind turbines themselves occupy less than one percent of the total area of a wind farm but there are quite a few other considerations such as roads, power lines, trees and the ground bellow a turbine. While a turbine may appear to extend straight up there is a general rule of thumb that recommends for every ten feet of tower height, a one foot increase in concrete pier depth. This means that if a tower is one hundred feet tall there is typically assumed to be a concrete pier roughly ten to fifteen feet deep. This requirement could cause problems while building in a city because of possible existing sewers or electrical lines underground.

The next consideration to installing a wind turbine involves the surrounding landscape. To prevent any problems with a turbine's operation, the surrounding area must be cleared of trees and brush. It is estimated that roughly an acre must be clear to allow the turbine to work properly and installations to take place. [20]

Once the area is clear of all brush and trees the next step is to install the transmission lines. There are two ways to locate the transmission lines. The first way is to place the wires underground; the second way is to run the lines above ground with a series of poles. There must also be access roads so that trucks and other installation vehicles can reach the area to install and maintain the turbine.

There are two different methods to connecting a wind turbine to the electric grid. The first method is a direct connection. This option is to connect the generator output directly to the grid. The way direct connection is done is to use asynchronous generators, when connected to a nearby 3 phase AC power grid. [21]

The second method is an indirect connection. An indirect grid connection is completed when the turbine outputs a variable AC voltage, which depends on the speed at which the turbine is moving. The

[20] (Gipe, 1995)
[21] (Gipe, 1995)

AC is output from the turbine and then converted to a fluctuating DC. The conversion is done using a large power transistor. The next step is to convert the DC back to usable fixed frequency AC. This process is also done using the same transistor. Once the voltage is in the form of fixed frequency AC voltage, the fixed AC voltage needs to be pissed through filters to reduce of the spikes and sags. The filters shape the wave into exact form the utility companies use.

There are many advantages to using the indirect method for grid connection. The first advantage of indirect method is that it allows the turbine to harness more possible power because the turbine is now allowed to use the full power of a gust of wind. This method also helps reduce the wear and tear of the turbine because it relieves the stress, allowing the tower and rotor to operate peak torque. The biggest advantage is that modern power electronics facilitates the use of voltage phase shifting and the reactive power can be controlled much easier. This technique helps improve the quality of power being put into the grid. The main disadvantage that associated with the indirect grid connection is the energy loss and the power and high cost of electronics systems. The conversion from AC to DC back to AC also reduces the overall efficiency.

While in some cases the indirect grid connection might be more expensive, it gives the best overall power output.

2.2.4 Types of Turbines

The new modern turbines are generally grouped into two types of categories; Horizontal-axis wind turbines (HAWT) and Vertical-axis wind turbines (VAWT). There are advantages and disadvantages to both of these types. HAWTs are what people typically think of when they think of a wind turbine. These names refer to the main rotor shaft and the direction in which it is arranged. HAWTs have their motors/electrical generators at the top of the tower, whereas the VAWTs have theirs at the base of the tower. HAWTs generally fall into one look of the turbine itself, whereas VAWTs have three main types; Darrieus wind turbine, which looks similar to a very large egg beater, the Giromill is a similar to the

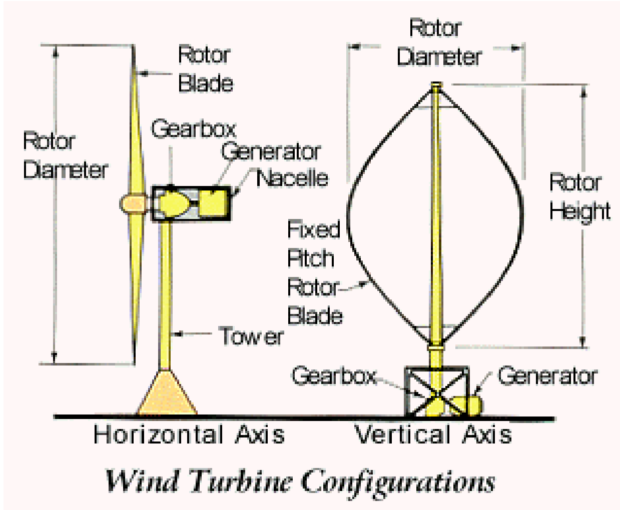

Figure 5: Wind Turbine Configuration (Darling 2008)

Darrieus except that the blades are straight instead of curved, and the last is a Savonius wind turbine which uses drag devices with scoops.[22]

2.2.4.1 Horizontal-Axis

Horizontal-axis wind turbines have their own advantages and disadvantages. HAWT advantages include the fact that they can have a variable blade pitch to them which allows the turbine to collect the maximum amount of energy depending on how the wind changes. HAWTs also have high towers which allow them to have access to areas that experience wind shear. Wind shear means that as you go up in increments into the air wind speed can increase. In some places, wind speed can increase by 20% which would cause power output to increase around 34%, every ten meters up you go. HAWTs also have their own disadvantages. HAWTs don't function very well in turbulent winds. The transportation of some of the taller towers can cost up to 20% of the equipment costs as well as be extremely hard to put up because they need large cranes and skilled operators which will also increases the cost. The tower to the turbine has to be able to support the weight of the gearbox, generator, and the large blades, along with being able to undergo the torque that the blades put on it. The turbines also require a mechanism

[22] Danish Wind Industry Association. *Windpower.org.* May 10, 2003. http://www.windpower.org/en/tour/wtrb/comp/index.htm.

called a yaw which is used to keep the rotor facing the wind to ensure that the maximum amount of energy is being absorbed. The large structures tend to be very obtrusive and stick out in the landscape which can cause local people to get aggravated with looking at it. The larger turbines can also be very hard to repair if something happens to break on or in them.[23]

2.2.4.2 Vertical-Axis

Vertical-axis wind turbines also have their own advantages and disadvantages. Some of the advantages include but are not limited to the following items. First, there is no yaw since the blades are vertical, and therefore do not need to turn to face the wind. VAWTs are not required to be high in the air; they can be located close to the ground if needed. This makes it so that there is no massive structure that is needed. VAWTs have a lower start up speed starting at 6 mph, as well as having a lower tip speed ratio so turbulent winds are less likely to break them. The structures can be built in areas where height might be a limiting factor. Vertical-axis wind turbines also have disadvantages as well. They are 50% less efficient as HAWTs because, in order to catch the wind, the blades rotate in a manner that creates additional drag in the air. Some VAWTs use guy-wires in order to hold the structure in place, this puts all the weight of the rotor on the bottom bearing. Also since VAWTs are located on the ground they have the entire structure on top of the motor, this causes it to be very hard to repair if something happens to break.[24]

2.2.5 Maintenance

A wind turbine usually is given an estimated life span of 20-30 years. It is estimated that a maintenance cost for a turbine should be roughly 2% of its total turbine cost. To keep a turbine running

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[23] Danish Wind Industry Association. *Windpower.org.* May 10, 2003. http://www.windpower.org/en/tour/wtrb/comp/index.htm.

[24] Danish Wind Industry Association. *Windpower.org.* May 10, 2003. http://www.windpower.org/en/tour/wtrb/comp/index.htm.

at the peak of its potential it is suggested that the entire turbine be checked annually. There are some general specific tasks that are asked to be done such as greasing bearings, changing transmission oil, braking systems, checking rotor blades and testing the wiring and connections. The turbine must also have all its mechanical parts checked and all of the supporting structures around the turbine as well as the wiring between the output of the turbine and wherever the energy is being routed to. The tower must also be checked for any signs of damage that may have occurred over the year. All of these precautions done at least once a year will keep the turbine running at optimal efficiency and keeps it running for its full lifespan.

2.3 Induction Generators

Induction generators are what a typical turbine uses in order to generate power. This induction generator is used to convert the mechanical power of the rotor into the electrical power that is then put into the grid. There are multiple different types of induction generators; these include fixed-speed generators, dynamic rotor resistance generators, doubly-fed generators, full-rating converter generator. Each of these types of inductors have a different way in which the generate power, and is converted into electrical power. Each of these inductors are used to supply the grid with the converted electrical power, but at the same time the generators also absorb some power from the grid. This power is used to excite the generator in order to get it going. [25]

[25] (Ankhmatov, 2005)

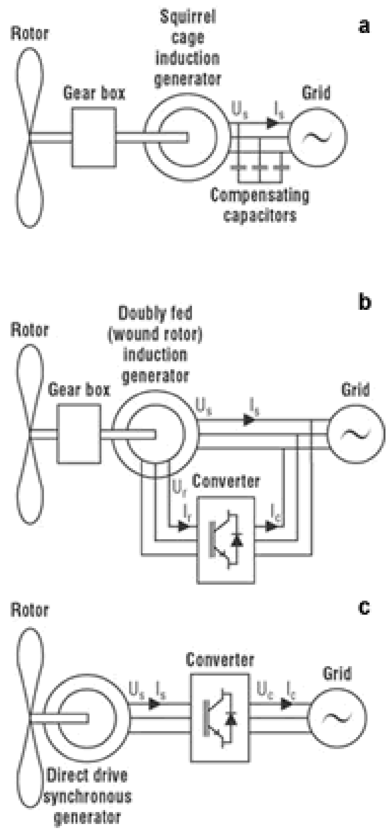

Figure 6: Different Types of Induction Generators

2.3.1 Fixed Speed

The first and oldest commercial wind turbines were equipped with a short-circuited rotor circuit. This means that the wind turbine rotor is connected to the generator rotor through a shift type system. This is known as a fixed-speed generator, because the range of variation in the speed of normal operation only varies by up to 2%. In this concept the generators have no way of controlling the reactive power that is taken from the grid, which requires the grid voltage to be kept at around the rated voltage of the generator. This also means that the generators usually have to be fully compensated with the use of a set of capacitor banks, this controls and reduces the overall reactive power that is taken from the grid, which thus improves the overall power generator by the generator itself. [26]

[26] (Ankhmatov, 2005)

The shaft system is comprised of a low-speed shaft that is connected to a three bladed rotor, and a high-speed shaft that is connected to the generator rotor and the gearbox. The purpose of the gearbox is to allow transformation between the slow and fast rotating generator rotors. The normal range of the turbine rotor speed is anywhere from 15 to 20 rev./min. Along with that the speed of the generator is normally 1500 rev./min for two-pole pairs and 1000 rev./min. for three-pole setups. This also means that the mechanical gear ratio of these turbines is around 100.

In this concept, the turbines are either fixed-pitch or they are blade-angle controlled. Another name for the fixed-pitch is called stall-controlled, this is because the mechanical power of the system is controlled and limited to the rated power which occurs during rated wind conditions. This means that the blades are simply secured to the rotor hub at a given fixed pitch angle. With this at higher wind speeds it can cause the rotor system to stall. The purpose of this design is simply for a very robust, and cheap solution.

With blade-angle controlled turbines the blades can be adjusted at a given angle. The purpose of this is in order to improve the low rated speeds which can cause the turbine to stall and also to keep the power up at high rated wind speeds. When the speed of the turbine gets high, the angle of the blades become steeper creating a lower speed at which the high stall point would hit. When the speed of the turbine gets low, the angle of the blade gets shallower in order to prevent the low stall point. This active-stall control provides a reduction of flickering emission from the turbines themselves and is characterized by limitation of the turbines power, when the wind exceeds the rated wind speed. [27]

2.3.2 Dynamic Rotor Resistance

The concept of dynamic rotor resistance is based upon having the rotor circuit connected to a power electronics converter. This power electronics converter is controlled using the Insulated Gate Bipolar Transistor (IGBT) switches, which also ads an external resistance in series with the rotor circuit.

[27] (Ankhmatov, 2005)

This external rotor resistance allows continuous operation of the generator rotor slip because you have dynamic control of it. 2% is the normal slip range of a short- circuited rotor circuit. Instead this allows up to 10% because this allows for operation at partly variable speeds. The benefit of this control is to reduce flicker emission that is put into the grid; this is similar to the fixed speed concept as well.

The partly variable speed wind turbines that are equipped with this type of induction generation use a pitch control. This pitch control is used in order to optimize the power output of the rotor at speeds below the rated wind, and to keep the rated power steady in situations of high wind speeds. The pitch works as follows; when it is applied, the blades are turned away from the wind when the output becomes excessive. This reduces the angle and limits the mechanical power. The opposite also applies for when the output is too low, the angle is increased in order to improve mechanical power. The use of this pitch control also helps to compensate for the variations that can occur in maximum steady-state power that are caused by changes in air density.

The use of the power electronics converter does not influence the induction generator excitation. The generator absorbs power from the grid, reactive power. This is then compensated the same way as the fixed-speed concept. The use of a capacitor bank is used to improve the power of the turbine. [28]

2.3.3 Doubly-Fed Generators

The concept of the use of doubly-fed generators is a very popular concept among many manufacturers. The turbines that use these are usually variable speed, pitch controlled. The way this works starts with a slow rotating rotor that is connected to a fast rotating generator. This is done through a geared shaft system, which has a gear ratio of up to 100. The generator stator is AC connected to the power grid. The generator rotor however, is connected through an AC/DC/AC frequency converter back to the grid. This frequency converter is comprised of two back to back voltage

[28] (Ankhmatov, 2005)

sourced converters (VSC) that are connected through a DC link. The grid side VSC uses a smoothing inductor and transformer to feed the power into the grid, and the rotor side VSC is connected to the rotor circuit through slip-rings. These two VSCs are controlled by IGBT-switches.

The generator rotor along with the wind turbine rotor, do not require that there be a fixed speed in order to operate. However the rotor speed can be adjusted via the dynamic control of the rotor VSC. This provides a much wider speed range at which the turbine can operate, which is why they are known as variable speed. These variable speed turbines typically are able to operate within the speed range of -40% to 15% (dynamically up to 30%) of the synchronous speed. This can have the possibility to increase energy production anywhere from 5% to 10% depending on the overall power and functioning speed.

The VSC also allows for power fluctuations, caused by wind fluctuations and gusts, to be converted into kinetic energy of the rotor and smoothly converted to electrical energy that is supplied to the grid. [29]

2.3.4 Full Rating Converters

The concept of full-rating converters starts with the following block setup; Dynamic wind, Aerodynamic rotor, shaft system, induction generator operating at full-variable frequency that is set by the generator VSC, generator VSC including control and interfacing the simulation tool, grid-side VSC including control and interfacing the simulation tool, DC link, protective system, and pitch control. The frequency converter uses IGBT- switches; these must be protected against over-voltage, over-current, and thermal impact. The converter protection model with restart and converter blocking has to be maintained in the dynamic wind turbine model, so this control can be arranged in a couple different ways. The first is b completely blocking voltage in the DC link, this interrupts the power supply to DC link from the generator VSC. This allows the voltage to stabilize to within the acceptable range, then the

[29] (Ankhmatov, 2005)

converter starts again with normal operations. The second way is to apply an immediate frequency change at excessive over-voltages. In this the power of the generator VSC is reduced, or even set to negative, which results in an immediate frequency change at the generator terminals and this interrupts the active power supply. Another piece that can be present is a "chopper", this acts like an electronic crow bar. This chopper short circuits the DC link capacitor through a resistance at an excessive DC voltage. The grid side VSC is designed with this in mind, and has to withstand the impact of the grid during short circuit faults that may cause blocking of the generator VSC. The means that grid side VSC control should be at full-rating capability, to control the reactive power of the grid and to supports the grids voltage during short circuiting. An important note is that if the grid side VSC has to block, the turbine must not stop so this causes the VSC to have to restart very quickly after the grid fault is removed. [30]

2.4 ArcGIS

GIS stands for geographic information system. GIS is a way to capture, store, analyze, manage, and present data that has a way to be linked to a specified location. ArcGIS is a computer program that uses GIS data maps in different given layers. These layers can be placed on top of each other to achieve the look of any given map that you want. These maps can be made for anything from street maps, to river maps, to topography maps, to contour maps, or anything that one can find in data layer form that they want to make a map of. The possibilities for the program are endless. In this map design the layer images that were used were raster images. These are images that are in a series of bits of information that are translated into pixels in the image itself. For the maps for Worcester Academy, the data for these layers were derived mainly from data that were collected by Massachusetts Technology Collaborative, in combination with numerous other companies.

[30] (Ankhmatov, 2005)

2.5 Wind Data Collection

The power of wind sources varies with the time of day, season, height above the ground and type of terrain. All of these things must be looked at and considered before a wind turbine can be established. The best way to consider these factors and estimate monthly wind speeds and direction is with an anemometer. An anemometer is a weather instrument used to measure the speed of the wind. There are a few different types of anemometers ranging in complexities.

A spinning cup anemometer measures wind speed only.[31] It is the most common type of anemometer and is the most basic. The anemometer has three or four cups positioned at 45 degree angles and mounted to a pole. When the wind blows the cups catch the wind and it forces the anemometer to spin. As the anemometer spins the pole it's spinning on counts the rotations over a period of time and then concerts it into an average wind speed.

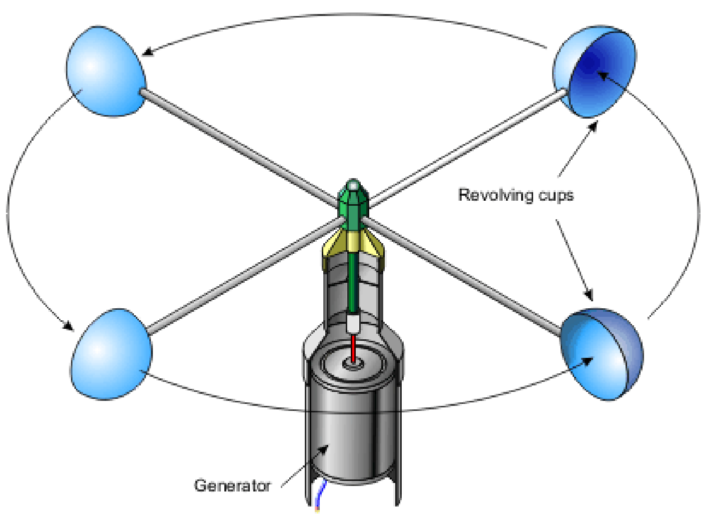

Figure 7: Spinning Cup Anemometer

[31] (Anemometers)

The next type of anemometer is a much more complex type known as a sonic anemometer. The sonic anemometer uses ultrasonic sound waves to measure the wind speed, as well as the direction. Two pairs of ultrasound transducers are positioned approximately 4 to 8 inches apart facing one another. It then measures the wind and direction by sending sound waves across to each other. If the wind is blowing behind the anemometer the sound waves will reach the other side much faster. If the wind is blowing from the side the sound waves will be slightly off giving off not only the wind speed but direction that the wind is being produced. Along with the types of anemometers there are there are also a few approaches that can be implemented. [32]

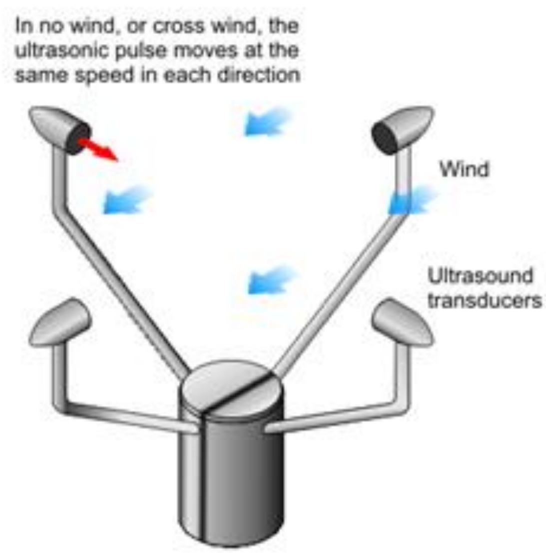

Figure 8: Sonic Anemometer

The first approach is a single meteorological tower roughly 50 meters high. The tower would have two different heights of measurements. This type of tower would help estimate how the turbine would work because it would help get the wind speeds from blade to blade. With a blade to blade estimate of wind, the estimates for power produced can be much more accurate than a single

[32] (Anemometers)

anemometer.

The next approach would be to place several anemometers mounted at different heights or at several locations. This would give a more detailed data and give a much higher confidence level in the data. This data can be recorded on strip charts or computer data loggers. The data recording can be done either by yourself or a hired professional.

The best approach for Worcester Academy would be a single wind anemometer. The best type of anemometer to pick would probably be the sonic anemometer because it will not only give the wind speed but also the direction. This would be the best approach because of the size of the project and the expenses that would go into setting up multiple anemometers or a meteorological tower. This would be the slightly less accurate approach but because the site is limited there is no need for multiple towers and because of cost reasons two anemometers on a single tower would not be necessary. [33]

Once the wind data is collected for a year the production of a wind turbine can be estimated very close to its real production. The wind does not fluxuate enough in a year to drastically change the production. With an anemometer in place Worcester Academy can fully understand the potential of a wind turbine on their site.

2.6 Major Turbine Companies

There are numerous top companies when it comes to making wind turbines over the past number of years. A list of the top 8 Companies that contributed to the United States Wind energy growth are GE, Vestas, Siemens, Gamesa, Mitsubishi Heavy Industries, Suzlon, Clipper Wind Power, and Nordex. As of world wide, in 2007 the top two companies to install turbines where Vestas, out of Denmark, who installed 4.5 GW, and GE Energy, out of the United States, who installed 3.3 GW.[34]

[33] (Wind Resource Assessment)

[34] (BTM Consult ApS, 2009)

Each of these companies has different types of turbines that they seem to design and each of these companies has different combinations of turbines and generators to make their product. The following table lists some of the larger companies in the world and the type of turbines that they design and put together.

Table 2: Largest Wind Turbine Manufacturers and Their Main Products[35]

Manufacturer	Wind Turbine Concepts
Vestas Wind Systems	Fixed-Speed with conventional induction generators OptiSlip with induction generators and adjustable rotor resistance Variable-Speed with doubly-fed induction generators
GE Wind Energy	Variable-Speed with doubly fed induction generators Variable-Speed with permanent magnet generators and full –rating frequency converters
Enercon	Variable-Speed with multi-pole synchronous generators and full-rating frequency converters
Gamesa Eolica	Variable-Speed with doubly-fed induction generators
Siemens	Fixed-Speed with conventional induction generators Variable-Speed with induction generators and full-rating frequency converters Variable-Speed with permanent magnet generators and full –rating frequency converters
RePower	Variable-Speed with doubly-fed induction generators
Nordex	Fixed-Speed with conventional induction generators Variable-Speed with doubly-fed induction generators
Others	Fixed-Speed with conventional induction generators Variable-Speed with doubly-fed induction generators

2.7 Worcester Academy Background

Worcester Academy is a private school which focuses on students grades six through twelve. The school services roughly 150 middle school students and 500 high school students; the school currently boards 141 of their students. Students of Worcester Academy are mainly from the Worcester area, but there is a global program that includes seventy-eight students from ten countries. Worcester Academy is located Union Hill in Worcester, Massachusetts. The campus is seventy-two acres with forty acres devoted to playing fields[36].

[35] (Ankhmatov, 2005), pg.
[36] (Worcester Academy: Strategy)

In these tough economical times Worcester Academy has been actively looking for ways to save money but stay environmentally conscious. One of the schools goals is “developing and adopt a school-wide plan for environmental responsibility and civic engagement.”[37] While the school has been reducing its energy consumption for the past few years by implementing simple things such as turning off lights when they are not needed and using energy saving light bulbs it still continues to look for ways to reduce the energy usage and total costs. Their current school electricity bill is roughly $175,000 a year. With their proactive approach to reduce electricity consumption this bill should follow their recent trend in reducing the cost of their bill.

Worcester Academy is also part of a pact that vows they will not increase their energy consumption at any time. This means if they look to expand the school they need to find ways to offset any potential energy production. One of the best ways to create an excess in energy would be to create a wind turbine. The wind turbine would create energy in an environmentally safe way while also giving Worcester Academy the ability to expand their school.

2.8 Site Information

The planned site of the wind turbine is located to the south of Worcester Academy’s main campus. This site is approximately six acres in area and is a Brownfield site that has been cleaned with the hopes of expanding the campus. The fact that this site was once contaminated creates a unique scenario that may cause issues with permitting through the city of Worcester. Since the site is only going to be used for the wind turbine and no regular traffic will be passing through the issues will be less, however it will be a topic that is discussed by the permitting committees. On the same lot of land as the proposed site is another six acres of land that is not owned by Worcester Academy. On this part of the site there is a building that is partially occupied and currently under construction.

[37] (Worcester Academy: Strategy)

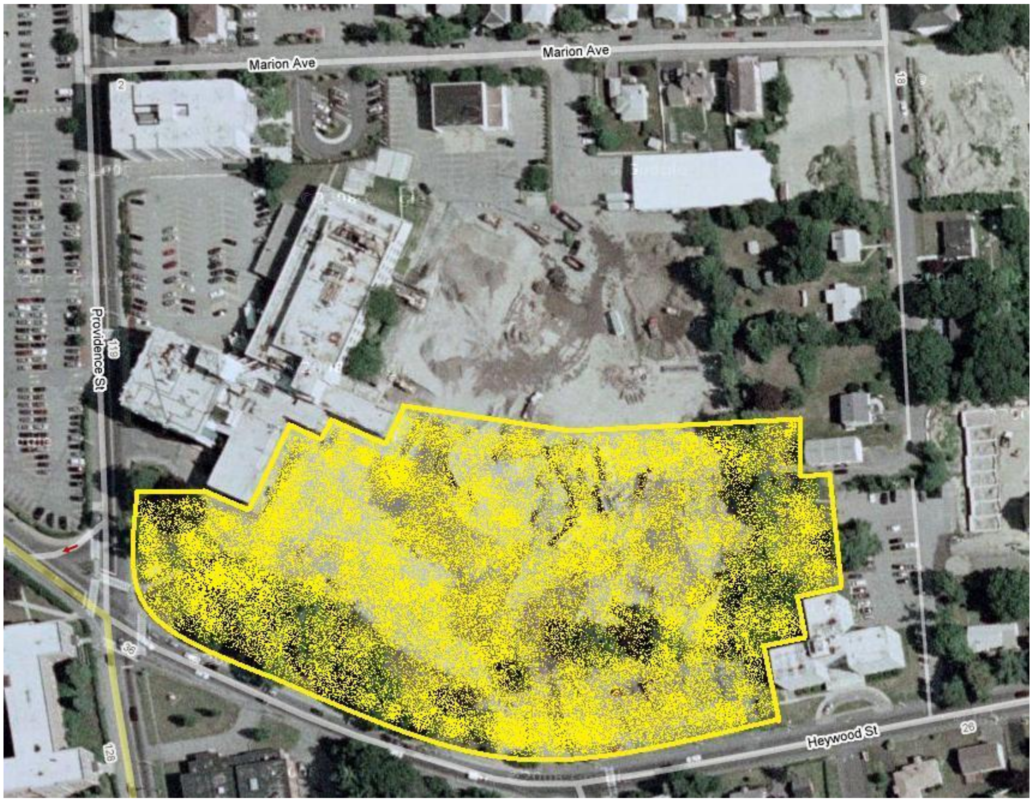

Figure 9: Site Layout - Shaded Area Shows 6 acre Site Currently Owned by Worcester Academy

The site is surrounded by Winthrop St. to the south, Providence St. to the west, and Shannon St. to the east. Other than the before mentioned building on the site there is a parking lot owned by Worcester Academy on the north side of the site. Although no official plans are in place, Worcester Academy does plan on buying the remaining land on the site eventually at which time the existing building will be removed. Based on topography maps that we have gathered the site is fairly level with the height of the area just below the parking lot being the tallest point as approximately ten meters taller than the area bordering Winthrop Street, the lowest part of the site.

2.9 Worcester Academy Energy Usage

Worcester Academy has high energy demands based on the usages of their buildings. Many would assume that the school would have significantly higher energy demands during school months, September through June, than in the summer months. However by looking at the table below of the energy demands of the school, it is clear that the campus uses relatively the same amount of energy throughout the calendar year with a slight decline in the month of July.

Table 3: Worcester Academy Electrical Usage

	Year		
	2006	2007	2008
Usage per Month			
1	161,371	160,923	151,473
2	159,313	158,075	149,072
3	164,684	158,209	136,715
4	156,006	137,007	137,428
5	155,078	146,930	133,216
6	147,499	142,942	141,938
7	124,575	125,030	114,963
8	149,125	143,583	142,930
9	142,200	141,287	128,776
10	143,498	150,686	
11	151,667	148,062	
12	166,555	176,078	
Total kWh/year	1,821,571	1,788,812	1,236,511

Worcester Academy has also been determined to limit the amount of electrical usage on their campus by using more energy conserving methods on their campus. They have been successful in doing this so far by holding events planned around making a more sustainable campus and replacing light bulbs with more efficient ones among other things. The school realizes the importance in decreasing total energy demand due to its commitment to carbon neutrality. The figure below is a chart of the data in Table 3, it shows the drop in usage of electricity (in kWh) on Worcester Academy's campus.

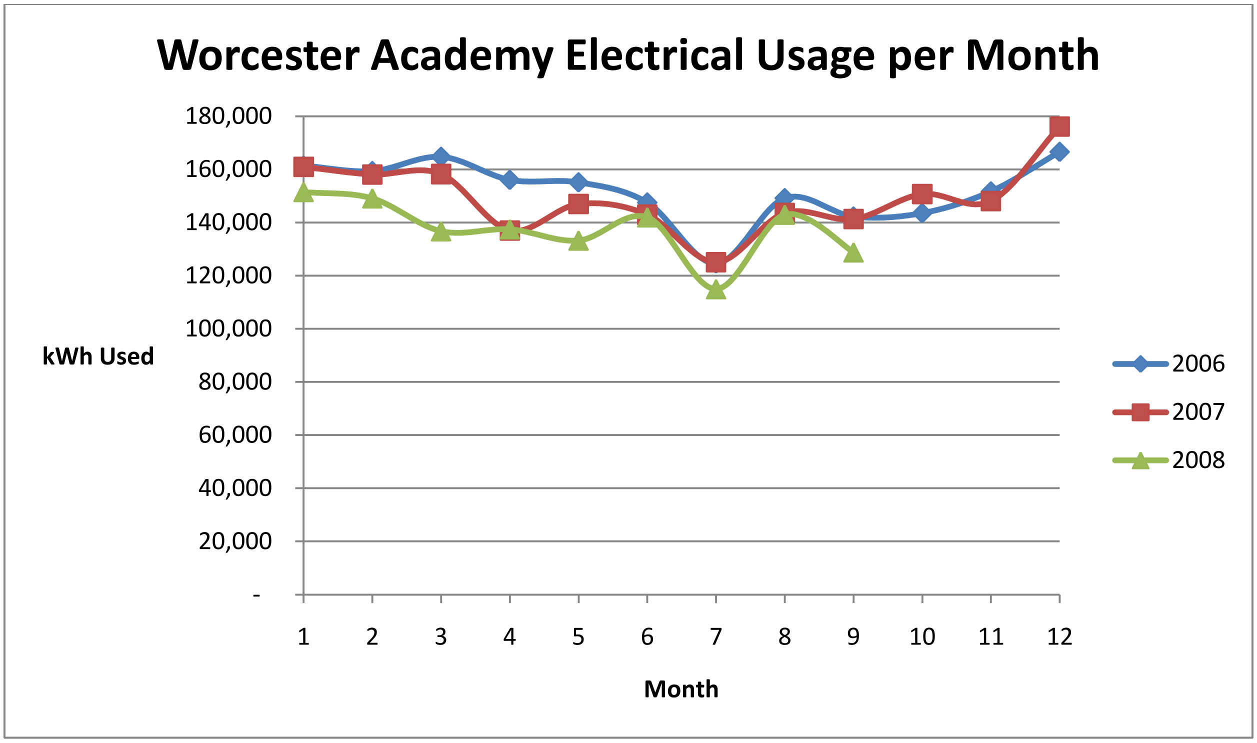

Figure 10: Worcester Academy Electrical Usage per Month

3. Methodology

Wind turbines are complicated systems with many factors. Regulatory, financial, and social factors all equally effect the construction of a wind turbine. In the case of Worcester Academy these three factors must all be carefully looked at to come up with the proper wind turbine recommendation that will not only help financially, but will also be within the social and regulatory limits that are set. The major tasks in our methodology include the following:

- Research
- Wind Turbine Simulation and Selection
- Energy Demand Characterization
- Financial Feasibility
- Regulatory Factors Impact
- Write-up recommendation

3.1 Research

To ensure Worcester Academy will get the proper recommendation started the process by researching windmills and all the laws and regulations that might affect the building process. The research started using books and journals on the basics of wind turbines as well as the effects and use of wind power in today's society. During this research period we also looked at previous projects in the state of Massachusetts and the process those wind turbines had to go through to be successful. One project that we will follow more closely than others will be a previously completed IQP at Holy Name High School. This project closely followed the steps that we will have to take as each had a similar goal in mind in their beginnings. One MQP that we used for our research is a project on the study of wind energy possibilities in New Hampshire. This project gave us a strong base on what needed to be researched to thoroughly understand the effects of wind and gave us some important sources that we can use to further expand our knowledge of wind power. Another benefit we found with this project is there was a good amount of simulation software used throughout which we used to try and get our own simulations started.

Outside of completed WPI projects we also researched a considerable amount on two separate renewable energy organizations. The first organization is the American Wind Energy Association (AWEA). The AWEA is a national organization that researches the capabilities of wind power by region and sets guidelines that are based on previous projects and professional research. The second organization we will research is the Massachusetts Technological Collaborative (MTC). This organization is similar to the AWEA except that it operates on a state level rather than a national. Through the MTC we have been able to acquire wind data charts and other local information of wind capabilities. We will also be proposing to Worcester Academy to apply for grant that is offered from the MTC which we have found through our research that could give them upwards of $400,000 in grants.

3.2 Wind Turbine Simulation and Selection

Once an idea of the general process for applying for loans and funding was understood, we looked into the technical aspects behind a windmill. This started by looking at wind and topographical maps of the Worcester area from the MTC. These maps gave us a general idea of the technical feasibility behind a wind turbine in Worcester and in particular the Worcester Academy proposed site. These maps gave us a rough estimate of the wind power in the area but to be more precise an anemometer must be put into place. Since it was not financially practical for us to install an anemometer, nor did we have the time before our projects end to complete the research we attempted to simulate the effects of wind at the proposed project site using a wind simulation program called Wind Farm. Wind Farm enables you to analyze, design and optimize a proposed wind farm.

However, in trying to get Wind Farm to work correctly for our project we ran into many issues. One issue that we could not overcome was that we could not get a file format that Wind Farm would accept and analyze our site from. This proved to slow our process of estimating the projected power from a selected wind turbine and be able to fully develop a wind rose to display the wind data graphically.

We planned on using this collected data to show the projected outputs of certain size wind turbines at the project site to calculate the amount of energy that can be created. Depending on what we found for possible energy outputs and comparing it to the energy usage distribution information we have for Worcester Academy would have allowed for a stronger argument to the selection of a specific turbine. Using formulas generated for wind power and wind turbine capabilities we were able to come up with another way to analyze turbine outputs without the program.

3.2.1 Wind Rose

The wind rose that was developed for this site was put together with the collected data from a wind anemometer that was at the Holy Name High School. This gave us numbers that we could work with in order to develop the working wind rose we now have. On the wind rose there is every direction that would be on a compass: north, north-northeast, northeast, east-northeast, east, east-southeast, southeast, south-southeast, south, south-southwest, southwest, west-southwest, west, west-northwest, northwest, north-northwest. The minimum time (frequency) and wind energy percentages, for the given data to matter are 2%. The wind rose shows the percent of the wind energy along with the percent of time the wind was in one of the previous given directions. This then sets up the normal flow of the wind on average.

3.2.2 Wind Data Charts

The wind charts were developed using the data that was collected from the wind turbine that was put up at Holy Name High School. This data was taken over the course of a given year. There were ten samples per day, for everyday out of the year. These samples per day were then averaged in order to get an average wind speed per given day. This was then developed into the first chart. Then the data was averaged again in order to achieve an average wind speed per month. This was then put into a second chart.

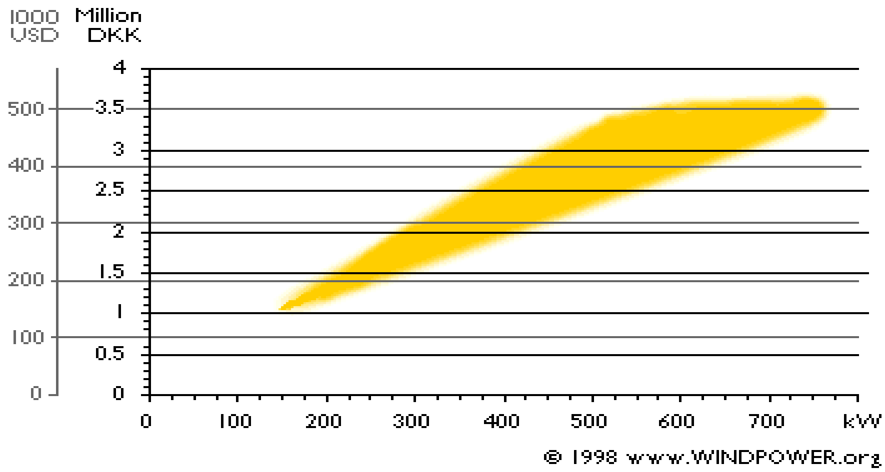

Figure 11: Wind Turbine Cost Trends

3.3 Financial Feasibility

With the proposed turbine simulation completed we then needed to check the financial feasibility of the project. We looked into the different grants and loans that could be used to build a wind turbine, most of which will be coming from MTC. Based on the successful acquirement for a Large Onsite Renewable Grant (LORI Grant) through the MTC, we proposed how much Worcester Academy will receive and the potential amount of money they will have to put into the project themselves.

Since the prices of wind turbines were not readily available from the manufacturers they had to be estimated from models and previous projects. By using models such as the one below, which give a general cost per kW, and local projects, a close estimation was created.

The projected savings was determined in the following fashion, for each of the three turbines that we chose; the Suzlon S52, the Enercon E33, and the Gamesa G58-850. We started with the overall purchase price of the turbine. Then the cost for shipping and installation was added to this price. Then the potential grants were subtracted from the total cost. Then from that total you take the overall kWh per year of each of the given turbines and you multiply it by the cents per kWh that you receive from rebates. This number is then multiplied by twenty, because it is a prediction over twenty years, and subtracted from the total cost after potential grants. Then you factor in the loan payment for the rest of the turbine, along with the interest that is accrued over the twenty year prediction span. This loan payment and interest payment are then added to the total. This then gives the overall savings, or deficit that you would receive over a twenty year span.

3.4 Regulatory Factors

With the completed simulation and financial feasibility checked, the biggest factor behind the successful proposal of a wind turbine is the passing of local and state regulations. We had to look into the zoning laws in Worcester and the special zoning laws that go into building a wind turbine. With those special zoning laws in account we have to look at the given area and find the exact location on the projected site and make sure it is acceptable.

Research into the regulatory laws of the city of Worcester showed that there are currently no laws in place that are related specifically to a wind turbine. This will make the guarantee of a proposed project uncertain. The proposal of the erection of a turbine will be sent to the planning board for the city first and if it passes as an acceptable project then it will go to the zoning board and regulatory commissions for the city.

It is expected that the wind turbine will have to meet the current laws set by the city of Worcester, if not exceed them. These laws that it will have to pass include noise disturbances, height requirements, and others.

3.5 Write-up Recommendation

The final aspect of the project is writing the project write-up. This was completed after all research, simulations, and proposals have been completed. In the write-up we include an abstract which will act a short introduction of our project that will outline our goals and a brief description of the steps it took us to reach them. The next section is an executive summary which will be a short summary of our results. This is followed by background information pertaining to our project. Topics covered in this section include wind power and turbine history, information of how turbines work, the funding that has become available for renewable energy projects, and information of Worcester Academy itself. The first part of our data section covered any laws and regulations that will need to be abided for the successful erection of the wind turbine. We then have a section of data results from our wind simulation that will give us the expected annual output of the turbine. This section will then go on to discuss the financial needs the project will require from Worcester Academy and projected profits that they can expect. The next section is a summary of the project's achievements and conclusions. To finish out our write-up is a list of sources for our research and an appendix of table and figures to better supplement our proposal of the best case for the erection of a wind turbine on the Worcester Academy's campus.

4. Results

The results of this project are intended to provide a breakdown on the feasibility of installing a wind turbine available at the site at Worcester Academy by considering the location, the laws & regulations, and the costs and financial benefits of a wind turbine. First, the appropriateness and location of the site is discussed outlining the rules and regulations as well as environmental impact of installing a wind turbine. Next, three different turbine models are reviewed and evaluated, each with varying outputs and costs. Also in this section the available wind data for the site are estimated and analyzed so that the wind output at specific heights is clear. Finally, the financial potions are reviewed and evaluated. These results are used to provide recommendations for the next steps to install a wind turbine.

4.1 Site Assessment

When analyzing the site for appropriateness for the installation of a wind turbine many factors play into the final decision. The current state and use of the site is important as a number of issues could arise from the existing conditions. Since there are currently no buildings where the proposed location of the wind turbine will be located, the amount of work that needs to be done will not be expensive as other locations requiring further site preparation would be more costly.

Also since the site has not been constructed there should be no major utility lines through the proposed project site. The only building on the same location is not owned by Worcester Academy but it may have public utilities such as sewer or electricity that run under the site of construction. To determine if utilities will have to be avoided or moved maps from the city of Worcester outlining public utilities will have obtained. Also before construction takes place a service such as Dig Safe will have to be contacted to make sure that no utilities are going to be struck during excavation. Other areas with the site that still need to be addressed is its location in respect to neighboring properties and Worcester Airport as well as the environmental impact of building on the site.

4.1.1 Governing Laws and Regulations

As often happens with new technologies, the laws or regulations on the state or local level do not fully clarify the requirements that pertain specifically to wind turbines. Since, at the moment, there are not any laws in place, all interpretation to the functionality of a wind turbine, is highly dependent on the planning board and zoning board of the city of Worcester. After allowing a wind turbine to be installed at Holy Name, the city made a point that all similar cases would be heard on an individual basis. For a proposed wind turbine to be approved it still must fall within certain regulations and suggestions set up by the AWEA and MTC.

One of the most common issues with proposed wind turbines is the height of the turbine. Since the height of an average 600 kW turbine from its base to the top of the tallest point reached by a blade is 250 feet, it will need special approval from the city for its erection.[38] Also, with the Worcester Regional Airport nearby height restrictions will also have to pass FAA regulations. Since the proposed site is similar to the site used at Holy Name High School we expect no issues in regards to the height of the turbine as the one constructed there is 262 feet tall and passed all city boards.

Another issue that needs to be followed closely is the noise generated by the wind turbine. Although current turbines emit noises much quieter than older turbines, they are still not completely quiet. The generators that power them as well as noises caused by blades in the wind can prove to be very noisy if not installed or accounted for properly. It is recommended by the AWEA to keep turbines approximately two times the distance of their total height from neighboring properties. Since the proposed site is surrounded by private property not owned by Worcester Academy the location of the

[38] (Resources, 2009)

turbine on the site is limited by this buffer zone. In Figure 12 the site owned by Worcester Academy is

Figure 12: Allowable Location of Turbine Shaded in Green

shaded in yellow and the area that can it can be erected on based on sound buffering is shaded in green.

4.1.2 Wind Turbine Location

For this site, it does not appear the specific location of the wind turbine within the site will greatly alter the amount of power that it can generate. The reason for this is the site is almost perfectly flat from one side to the other; the southwest corner of the site is about five meters higher than the northeast corner and there is a gradual slope across the span of the site. Another factor that was considered in determining the location of the wind turbine was the fall zone. The fall zone of a wind turbine is a safety consideration taken that limits the amount of damage that the turbine could cause if it were to fall over. In an ideal situation there would be no structures or roadways for a turbine to hit if it were to fall. However, being in an urban area there is not a lot of room to work with so minimizing the amount of damage is the best that can be done.

Using the shaded area in Figure 12 as the possible location of the turbine, it was determined that it would be best to place the turbine towards the southeast corner of the area. By locating the turbine in this location it clears all fall zone worries in regards to buildings on the site and roadways. Also, since there is minimal height difference across the site the amount of power generated by a turbine in either side would have little difference. A reason why it was preferable not to locate the turbine to the west side of the shaded area was that if Worcester Academy does buy the rest of the land on the site they possibly plan on tearing the existing building down. Although there is nothing suggesting the turbine would be damaged in any way during the alteration of the site, having it further from any form of construction will ensure its safety. A number of locations the turbine can have are possible but one location is recommended here. The exact proposed location of the turbine is represented by the white dot in Figure 13. Also in Figure 13 the fall zone that a 600 kW turbine would have (with a central

Figure 13: Proposed Turbine Location and Fall Zone

location) is denoted by the black shading. This area has a radius of approximately 250 feet.

4.1.3 Environmental Impact

It is unlikely that installation of a wind turbine on the site will have a very large impact on the environment around it. Being an urban location and a site close to major roadways there is most likely little wildlife that will be affected by erecting a turbine on the site. One concern with a wind turbine is birds. Many people believe that the flight paths of birds will be greatly altered by a wind turbine. However others feel that the turbines take up just as much area in the sky as high rise buildings and skyscrapers. Issues with birds tend to arise when wind farms of multiple turbines are being installed as they can take up miles of land. An example of this is the Altamont Pass in northern California that consists of over 4900 wind turbines. [39] It is expected that since the site is similar to the site used for the wind turbine installed at Holy Name that there will be no issues with endangering wildlife.

Another issue than wildlife that will be considered is the effects on water runoff from the site. This is investigated by the EOEA, Executive Office of Environmental Affairs, under the National Pollution Discharge Elimination System. Since the site under investigation was a contaminated site there is still a possibility of contamination in the soil even if it is not noticeable at the surface. Since the turbine will be placed on footings that will be on foundations, the ground in the area will be altered to make the turbine stable. The footings will most likely be a concrete footing as in other turbine construction and will alter water runoff. Since the foundations and footings for a wind turbine are not as large as those for a building there should not be an issue, nevertheless a drainage plan should be put together to show how the draining of water from the site will happen to make sure it will not be overburdening other areas causing local flood scenarios.

[39] (Altamont Pass, California, 2008)

4.2 Turbine Selection

During the turbine selection process a wide range of turbines covering different models and sizes were considered. Each company has its positives and negatives behind their specific turbines. After taking a close look at the different designs for each turbine we selected three companies that will each give a different benefit. The three companies are Suzlon, Enercon, and Gamesa.

4.2.1 Suzlon S52

The first turbine for consideration was the Suzlon S52, a 600 kW turbine. There are a few special qualities that Suzlon prides itself on that made us take a close look at the Suzlon S52. The turbine is specially designed to deliver high-performance in a low to medium range of wind. This would be good for the particular site because there is not a high wind range. With such low wind speeds on our site a turbine that performs high with a low wind speed would be very beneficial.

Figure 14: Suzlon S52 in Germany

Suzlon has a few custom designs to the turbines to ensure it will work with low wind speeds. These designs first start with the blades which are made using state-of-the-art Vacuum Assisted Resin Infusion Modeling technology. The next big design is a unique Micro Pitch system along with advanced controls, which helps make the produce grid-friendly and generate efficient energy. [40] The last big design difference between Suzlon and its competition is its high hub-height for its class. This helps get the most out of the wind energy in the given area.

4.2.2 Enercon E33

The next turbine we decided to look into was the Enercon E33. The Enercon E33 is a 330 kW turbine. The first difference between Enercon and other turbines is it takes a better look at the power curve for particular wind turbines. It calculates in more factors making the estimates for how well the turbine works much more accurate. This will help us in picking a turbine knowing that the measurements we might be taking are much more accurate than the competitions. Enercon also has designed a special storm control system that helps the turbine work more effectively in times of storms.[41]

Figure 15:Enercon E33 in Use

[40] (Suzlon S52)

[41] (Product Overview)

The storm control system helps the turbine become more effective in gusty wind conditions. A normal turbine will shut down when the maximum wind speed is exceeded and won't turn back on for a considerable amount of time if the storm keeps going. With the storm control system the wind turbine does not shut down automatically but instead it reduces the power output by lowering the rotational speed. They do this by turning the rotor blades slightly out of the wind. Once the gusty wind stops the turbine is put back instantly into full power. This feature helps the turbine produce energy during some of the best times to be collecting energy.

4.2.3 Gamesa G58-850

The final turbine selected for consideration is the Gamesa G58-850. The Gamesa G58-850 is an 850 kW turbine. The features that set Gamesa turbines apart from the competition are its full lightning protection. This means that if the turbine is struck by turbine the electrical components are protected from damage. The Gamesa G58-850 also has a SMP predictive maintenance system which helps detect potential deterioration or malfunctions in the wind turbine. This is a very helpful feature because it will help keep the turbine running in its best shape for as long as possible. With as much money going into a wind turbine it is helpful to have a feature that will detect any problems earlier than most other turbines. The final design feature that Gamesa has is its control system. The doubly fed machine it has helps increase efficiency and production. It also helps prolong the working life of the turbine, low harmonic content and minimal losses, and active and reactive power control. All of these things help separate Gamesa turbines from the competition. [42]

[42] (G58-850)

Figure 16: Gamesa G58-850 Wind Farm

4.2.4 Summary and Comparison of Turbines

The table below gives a comparison of the specifications of the three turbines that we have selected. The biggest differences in the models are their outputs, their hub heights and rotor diameters. Since the Enercon E33 is the smallest output it has the smallest hub height and the smallest rotor diameter. Also, the cut in speed is the amount of wind that is needed to make the turbine begin to spin, therefore the lower cut in speed the better.

Table 4: Turbine Model Comparison

Model	Output (kW)	Hub Height (m)	Rotor Diameter (m)	Cut-in Speeds (m/s)
Suzlon S52	600	75	52	4
Enercon E33	330	36-50	33.4	3
Gamesa G58-850	850	44-71	58	3

The averages of kWh produced that are calculated in the table below are the result of using a formula available online from the Danish Wind Industry Association. This formula was used as a basis to compare the turbines against one another in a like environment. Since the formula is an estimation, it does not give a perfect representation of the capacity of the turbines. The formula table used to find the values in the table can be found at www.windpower.org/en/tour/wres/pow/index.htm.

Table 5: Average kWh Produced

Model	Average kWh produced using speeds based on hub height
Suzlon S52	1,284,538
Enercon E33	921,649
Gamesa G58-850	1,366,468

4.2.1 Turbine Cost

Determining the cost of the turbines required both estimation and research. Most turbine companies, including the ones used, do not have the costs of their turbines available to the public. To get the costs you usually have to be in the process of a feasibility study and demonstrate a desire to use that company's product. To determine the costs of the turbines we are proposing Worcester Academy prior projects were researched and used to create an estimate.

The Suzlon S52, a 660 kW turbine, would cost Worcester Academy around $1.35 million. This value was calculated by looking at the Holy Name project which cost around $1.3 million for a 600 kW turbine and the Massachusetts Maritime Academy project that cost $1.35 million for a Suzlon S47, an older version of the S52. The Enercon E33, a 330 kW turbine, will have an estimated cost of $900,000. Even though this turbine is only half the output of the S52, it costs almost two thirds as much still. This is because there are costs such as permitting, site excavation, and other preparatory steps that will cost the same no matter the size of the turbine being installed. The final turbine, the Gamesa G58-850, an 850 kW turbine, will have a cost of $1.6 million. For the same reason why the E33 is as expensive relative to output is why the G58-850 is cheaper relative to output.

4.3 Wind Data Review and Analysis

4.3.1 Wind Data Available from Mass GIS

In order to come up with wind speeds for the desired area data from Mass GIS was used in a set of maps. There were four different maps that were designed for the showing of wind speeds across the desired area. They involve full color along with the streets, schools, and elevation contours of the area. The location of Worcester Academy's Brownfield site is located inside the block of Winthrop St, Marion Ave, Sharon St, and Providence St. The following paragraphs list the description of wind speeds in regards to the maps. Each wind speed map is the average wind speed at the site at four different elevations; thirty, fifty, seventy, and one hundred meters. In order to devise these maps there were various different layers, which were placed on top of each other using the ArcGIS program. The road layout of the area was placed on top of the wind speed map in order to find the exact area and layout of the Brownfield site. Along with the streets, each of these maps had a contour layer for the area laid on top of the map in order to show the wind speed to elevation relationship. In addition to the four wind speed maps, there was another map that was designed to show the wind power density at fifty meters. This also had a layer of streets and schools in the area, along with a contour layer placed on top to show the area. The second set of maps is similar to the color map set. This however is a grayscale map, varying shades of grey on a scale from pure white being zero to pure black being a desired/set value. This set of maps also has a road and contour layer placed on top. The grayscale maps tend to have a more exact value rather than a range of values for a given area.

Each of the maps indicates the speed range at the Brownfield site. At thirty meters the average wind speed for the Brownfield site is 11.2-12.3 mph, or 5.0-5.5 m/s. At fifty meters the average wind speed for the Brownfield site is 12.3-13.4 mph, or 5.5-6.0 m/s. At seventy meters the average wind speed for the Brownfield site is 13.4-14.5 mph, or 6.0-6.5 m/s. At one hundred meters the average wind speed for the Brownfield site is 14.5-15.7 mph, or 6.5-7.0 m/s. The wind power density at fifty meters for the Brownfield site is 300-400 watts/square meters. When looking at the grayscale maps, they have an exact value for a block rather than a generalized range that the values fall in.[43]

The grey scale maps (shown in the appendix) offered a more exact number for the wind speeds, rather than an average wind speed over the area. At thirty meters (Figure 19), above the ground the average wind speed for the Brownfield site is 12.341 mph, or 5.52 m/s. At fifty meters (Figure 20), above the ground the average wind speed for the Brownfield site is 12.81 mph, or 5.73 m/s. At seventy meters (Figure 18), above the ground the average wind speed for the Brownfield site is 14.42 mph, or 6.45 m/s. Finally, at one hundred meters (Figure 17), above the ground the average wind speed for the Brownfield site is 15.292 mph, or 6.84 m/s. Averaging these together, for any given height the average wind speed is 13.716 mph, or 6.135 m/s. [44]

[43] (Holy Name Central Catholic Jr/Sr High School, 2007)
[44] (Holy Name Central Catholic Jr/Sr High School, 2007)

Figure 19: Wind speeds at a Height of 30m

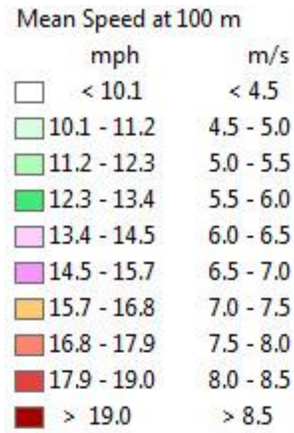

Figure 20: Wind speeds at a Height of 50m

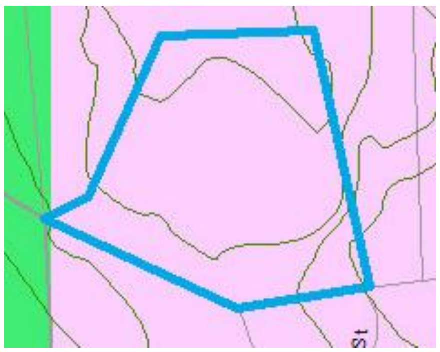

Figure 18: Wind speeds at a Height of 70m

Figure 17: Wind speeds at a Height of 100m

With the summary of these values, this states that on the location that has been chosen to put up the wind turbine for Worcester Academy, there is enough wind energy on average to be able to sustain a wind turbine, and allow it to maintain power. This information helps to provide the location for the placement of a given turbine location, based upon the areas that have the highest overall potential wind speeds. There are a variety of place on the lot of land at which the turbine could be place, but based on wind speed data, the place on site is in the southern part of the lot.

4.3.2 Wind Data and Wind Rose

Table 6: Frequency and Velocity of Wind in a Given Direction

Direction	Frequency (%)	Average Wind Speed At 50m (m/s)
North	5	5
North-Northeast	5.6	5.2
Northeast	4.7	4.8
East-Northeast	4.7	4.8
East	3.4	4.1
East-Southeast	2.9	3.5
Southeast	2.3	3.7
South-Southeast	1.5	4.1
South	3.9	4.8
South-Southwest	7	6.3
Southwest	11.8	6.3
West-Southwest	12.6	6.8
West	9.9	6.2
West-Northwest	11.7	6.5
Northwest	7.3	5.9
North-Northwest	5.6	5

The magnitude and direction of this site was determined by a wind rose. These data were taken from a similar site located at, Holy Name High School. This wind rose was developed by using the wind speed data that is collected by a wind anemometer. This anemometer collects the winds velocity and the winds direction, and inputs it into a table that is collected as its data. These data were then put into what is called a wind rose, shown in Figure 21. The minimum time, frequency, for the given data to matter is 2%. A wind rose shows the direction, divided into forty-five degree increments, along with the total wind energy and the total time that the wind was in a given direction, shown in percentages. For this wind rose the general direction that the wind is moving for the majority of the time, is west-south-west, WSW.

The overall conclusion of the wind data is that the speed of the wind is traveling on average 13.716 mph, or 6.8 m/s, in the west south west direction. [45]

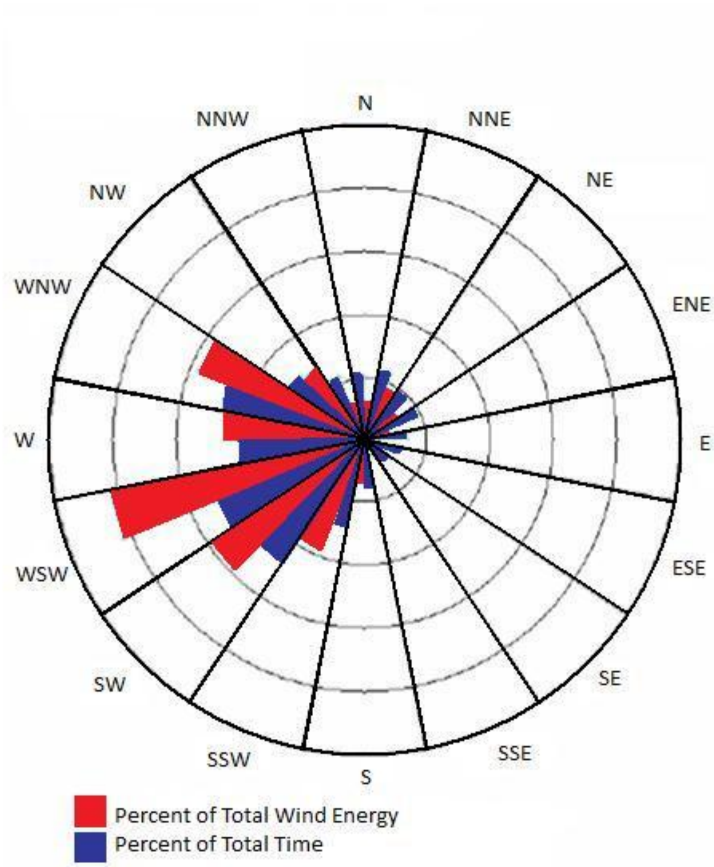

Figure 21: Wind Rose for Proposed Site

[45] (Holy Name Central Catholic Jr/Sr High School, 2007)

4.3.3 Wind Data Charts

The following data is the data that was collected from the Holy Name High School's wind turbine. Each day for a year there were ten data collections per day, for each of the 365 days of the year. Figure 21 shows an average per day of those ten data collections, along with Figure 22 which shows the average of each of the days of each month.

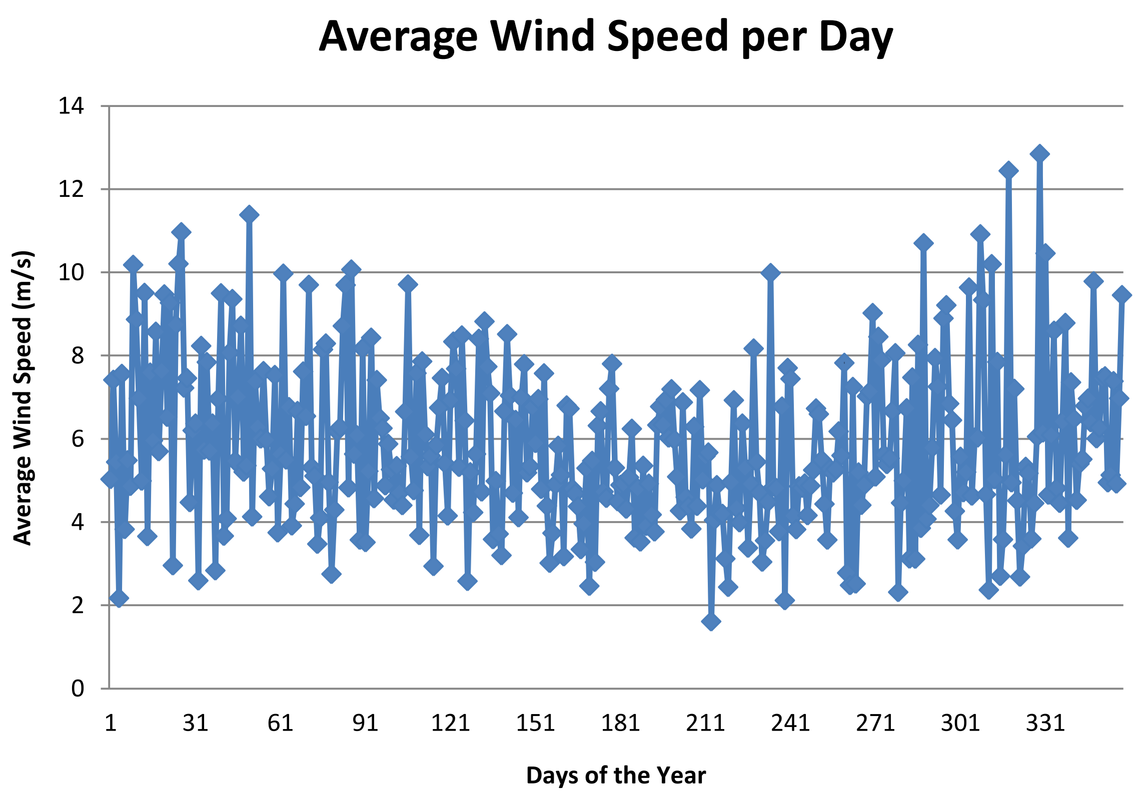

Figure 22: Average Wind Speed per Day[46]

[46] (Holy Name Central Catholic Jr/Sr High School, 2007)

Table 7: Average Wind Speed Values per Month[43]

Month	Wind Speed/Month
January	6.815949863
February	6.298734063
March	6.153330287
April	5.857549336
May	6.083710362
June	5.013855234
July	5.164177341
August	4.927672232
September	5.53075061
October	5.928549115
November	6.257784297
December	6.458265936

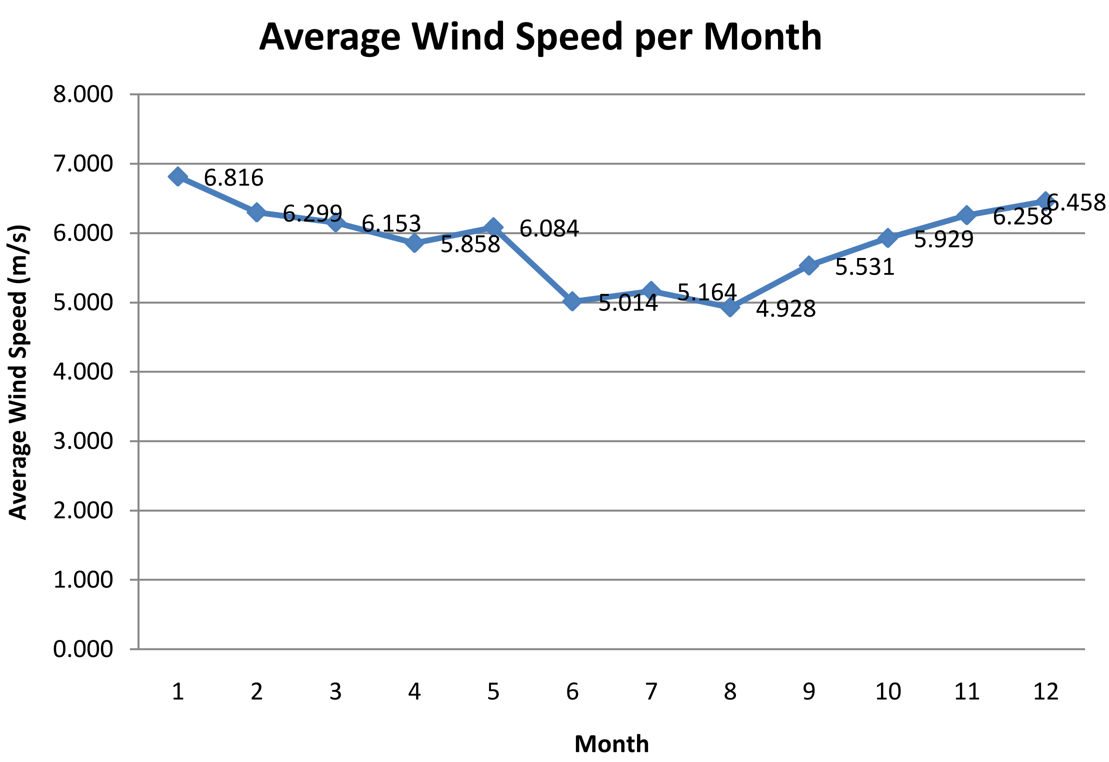

Figure 23: Average Wind Speed per Month[47]

Figures 22 and 23 show the average change of the wind speeds over the course of a given year. Figure 22, even though there is a lot of data in it, illustrates the general trend of the wind over the given year.

[47] (Holy Name Central Catholic Jr/Sr High School, 2007)

Figure 23 illustrates much more clearly the trend of the winds' speeds by breaking the data down by month. This allowed us to see the minimum and maximum value of the average wind speed per month. The maximum value of the wind data occurred in January and it was 6.816 m/s, the minimum value of the wind data occurred in August and it was 4.928 m/s. [48]

4.4 Financing

Since the expense of wind turbines can be quite high, it is not expected that the installation cost can be paid in full by their buyers. To help pay for renewable energy initiatives there are many national and state agencies set up to help with the cost by offering grant and loan programs. Also, electricity companies offer tax incentives and other rebates to those who put energy back into the company's grid through renewable energy. These programs are used to offset the costs and help encourage more renewable initiatives to be undertaken.

4.4.1 Grants

There are a few possible ways to help the costs of installing a wind turbine. The biggest and maybe the most important is a grant given by the Massachusetts Technology Collaborative or MTC. The MTC gives out a grant bi-yearly for the design and construction of wind turbines and other renewable energy sources. The grant given by the MTC is called the Large Onsite Renewable Initiative or LORI and its main purpose is to expand the production and use of distributed renewable energy technologies in Massachusetts. The LORI grant has two areas in which an applicant my try and seek grants these two studies are the Feasibility Study Grants and the Design and Construction Grants. The Feasibility Study Grants are for people who have already done a pre-feasibility study and ready to move into hiring a wind consultant to help estimate the costs and benefits to installing a wind turbine. This grant is capped at $40,000 with a cost-share of at least 20% or $5,000, whichever is less. The Design and Construction

[48] (Holy Name Central Catholic Jr/Sr High School, 2007)

Grants are for people who have already done a feasibility study and are ready to move into design and construction. Design grants are capped at $75,000 or 75% of actual cost whichever is less, and the construction grant is capped at $500,000 or 75% whichever is less. Anyone who wishes to apply for the grant is subjected to a competitive selection process. There are a few requirements that must be met for the grant to apply. The renewable energy project must have a nameplate capacity of greater than 10 kilowatts and are located on commercial, industrial, institutional, and public facilities that will consume more than 50% of the renewable energy generated by the project on-site. The next requirement is that the applicant and project site must be a consumer of a Massachusetts investor-owned electric distribution utility. [49]

4.4.2 Tax Incentives

There are a variety of tax incentives that can help offset costs and even make a wind turbine a more profitable investment. These incentives range from production of energy incentives to income and sales tax exemptions for any individuals and organizations in Massachusetts. The two tax incentives that will effect Worcester Academy the most are the 'Production Tax Credits', 'Renewable Energy Equipment Sales Tax Exemption' and the 'Property Tax Incentive'.

The Production Tax Credits or PTC is one of the most important tax credits to receive. As of recently the PTC is running and gives 2.1 cents per kilowatt to any wind turbine for a span of 10 years from its building date. The PTC has yet to get a long term deal and continually goes off for a year then back on. The current deal is set to end in 2010. This greatly affects the wind turbine market. When the PTC is on there is a roughly a 40% increase in wind turbine production, when it is off there is a drastic decrease. Since the PTC is underway until at least 2010 there is plenty of time for Worcester Academy to get the 2.1 cents/kWh[50].

[49] (Large Onsite Renewables Initiative)
[50] (Production Tax Credit for Renewable Energy, 2009)

A second tax incentive is the Renewable Energy Equipment Sales Tax Exemption. This tax incentive gives any renewable energy equipment such as wind turbine, solar power, and heat pump systems the ability to bypass the standard Massachusetts sales taxes[51]. There is no maximum amount associated with this incentive and gives Worcester Academy a huge way to save money. It would save 5% of the initial cost which would be thousands because of the excessive amount of money turbines cost.

The final tax incentive that would give Worcester Academy even more economical relief would be the Property Tax Incentive or the PTI[52]. The PTI would give Worcester Academy a property tax exemption from local property taxes for a 20-year period. The only requirement to get this tax incentive is that the wind or solar energy system must be used for heating or supplying energy to taxable properties.

4.4.3 Projected Savings

The projected savings were determined using three different types of turbines. The predicted total cost consists of the turbine, along with the excavation cost, and the shipping and installation cost. Then the expected return is determined by per year rebates, two were chosen. The first was a .02 dollar per watt and the second was a .06 dollar per watt, chosen based upon of the power was returned to the grid or fed directly, respectively. Along with this the expected return also included the grants, which only apply with MTCs energy consumption standards, a proposed donation and/or fundraiser, and tax incentive return. There is no difference for nonprofit organizations such as Worcester Academy, versus profitable organizations. It seems that there is no major benefit for money spent or not spent up front other than the fact that the loan that has to be gained will be substantially less and thus there should be

[51] (Massachusetts Incentives for Renewable Energy, 2009)

[52] (Renewable Energy Property Tax Exemption, 2008)

more benefit and profit over time. Each of these was calculated out for each of the three chosen turbines; the Suzlon S52, the Enercon E33, and the Gamesa G58-850. All of the data for the following section is represented in the appendix under the Projected Savings section.

First the Suzlon S52 is a 600 kW turbine. The projected cost of this turbine is $1.35 million. Along with that is the projected excavation cost which has a total cost of $15,000 and the installation and shipping with a cost of $5,000. This comes to a total cost of $1.37 million. Then factor in the expected grants and the proposed donation, which have the potential to come to a total of $1,115,000. This brings the overall total to $255,000. Along with that are the rebates that they would receive annually which is $26,975.30 with return to the grid, and when not returned to the grid is $77,072.28. When you factor in the excess loan that would need to be taken out and the interest of that loan and the yearly maintenance cost of $27,000, your total cost over twenty years would be $1,053,215. Then subtract total cost over twenty years from the total rebate cost over twenty years. This gives a deficit of -$513,709 when the energy is put back into the grid, and the benefit of $488,230 when fed directly to the site.

Second is the Enercon E33 is a 330 kW turbine. The projected cost of this turbine is $900,000. Along with that is the projected excavation cost which has a total cost of $15,000 and the installation and shipping with a cost of $5,000. This comes to a total cost of $920,000. Then factor in the expected grants and proposed donations, which have the potential to come to a total of $1.115million. This brings the overall total to -$195,000. Along with that are the rebates that they would receive annually which is $19,354.63 with energy returned to the grid, and $55,298.94 when not returned to the grid. When you factor in the excess loan that would need to be taken out and the interest of that loan and the yearly maintenance cost of $18,000, your total cost over twenty years would be $165,000. Then subtract total cost over twenty years from the total rebate cost over twenty years. This gives a benefit of $222,092 when the power is returned to the grid and $940,978 when the power is directly fed to the site.

Third is the Gamesa G58-850 is a 850 kW turbine. The projected cost of this turbine is $1.6 million. Along with that is the projected excavation cost which has a total cost of $15,000 and the installation and shipping with a cost of $5,000. This comes to a total cost of $1.62 million. Then factor in the expected grants and proposed donation, which have the potential to come to a total of $1.115 million. This brings the overall total to $505,000. Along with that are the rebates that would be received annually, which is $28,695.83 when power is returned to the grid, and when power is directly fed is $81,998.08. When you factor in the excess loan that would need to be taken out and the interest of that loan and the yearly maintenance cost of $32,000, your total cost over twenty years would be $1,403,215. Then subtract total cost over twenty years from the total rebate cost over twenty years. This gives a deficit of -$829,298 when power is returned and $236,546 when the power is directly fed to the site.

Each of these predictions are based on the fact that there is a need to take out the complete and total loan after grants are factored in. If this is not the case you would obviously remove whatever cost is being paid out of pocket from the cost after grants. The expected savings would obviously be more substantial if payment of the loan wasn't needed. The significant portion of the overall cost of the turbine is the yearly maintenance, which is 2% of the turbines original cost.

Another change that could be made to alter the cost and benefits would be if the power didn't have to be put back into the grid. If power was taken directly from the turbine to the site then there would be a much more substantial value of the power they were receiving. Those savings could be possibly three, four, or five fold.

5. Project Conclusions and Recommendations

The goal of this project was to investigate a site proposed by Worcester Academy for the suitability of erecting a wind turbine. With the location considered three different turbines, with three different outputs and costs were investigated to create a best case scenario for the site. Our assessment of the site, the turbine costs and projected savings, as well as the wind data collection aided us in our conclusions.

The proposed site is a suitable site for a wind turbine to be set up. There is enough wind at the height that a turbine would sit at to operate correctly and the site is large enough so that there will be no interference with neighboring properties. It cannot be determined if there will be issues with permitting and zoning regulations, but based on the passing of the Holy Name project no issues are predicted.

The next step for Worcester Academy to fulfill their vision of erecting a wind turbine on their campus is to apply to the Massachusetts Technology Collaborative for a feasibility grant under the Large Onsite Renewable Initiative (LORI). The feasibility grant is capped at $40,000 with cost-share of at least 20% or $5000, whichever is less. This grant would give Worcester Academy the money to set up an anemometer which is essential to figuring out exactly how well a turbine will fair at the given location. The money can also be used to hire a wind turbine consultant who can help with the process of figuring out how well a turbine will do.

Currently the deadline for the LORI is over and a new date has yet to be set. Once a date is set there are a few documents that must be signed and sent along with information about your site, budget, technical requirements, and general terms and conditions. These forms can be found on the Massachusetts Technology Collaborative site under the LORI grant section. Once the information is presented to the advisors they will look it over and on a set date announce who will be receiving the grants.

Once a feasibility study has been conducted the next step is to apply for a Design and Construction Grant also under the LORI. The Design and Construction Grant is used to help lower the financial burden of buying and constructing a turbine. This grant is broken up into two parts. The design grant is capped at the lesser of $75,000 or 75% of actual cost, and construction grants are capped at the lesser of $500,000 or 75% of actual cost. The same processes are used to apply for the Design and Construction Grant that is used for the Feasibility Grant.

Once these grants have been applied for and accepted the turbine should be ready to be placed. The grants and studies will take roughly a year to complete. It will take at least 6-12 months of anemometer studies before the turbine can be truly considered by the LORI. Once the studies have been conducted it should be as simple as getting the grants and building a turbine.

There are two scenarios that were run through. This is based upon the turbines falling under the Class II net-metering specifications for renewable energy. The first scenario is with the power from the turbine being returned to the grid because of the fact that there is no direct route to be able to route power from the turbine to campus. The second scenario is that when or if buildings are built on the southern campus that the power is returned directly to the southern or main campuses. In the first scenario the return of dollar per watt is .021 dollars/watt. In the second scenario the return of dollar per watt is .06 dollars/watt. It seems that there is no major benefit for money spent or not spent up front other than the fact that the loan that has to be gained will be substantially less and thus there should be more benefit and profit over time.

The overall cost, for the first scenario, of the installation and maintenance of any of the given three wind turbines with our conclusions seems to not be beneficial for the installation of a wind turbine. The turbine that gives the least deficit is the Enercon E33, which gave a deficit of only -$513,709 after 20 years. The turbine that gave the greatest deficit was the Gamesa G58-850, which gave a deficit after twenty years of -$829,298. The only way that this would be beneficial is for the loan to be substantially less money taken, so that there is less interest and an overall loan to pay back. The other way is for there to be a direct line from the turbine location to the Worcester Academy campus, so that it is not put back into the grid. This allows complete savings of the power that the turbine is producing, drastically cutting the cost of electricity. The turbine that actually gave benefit was the Enercon E33 which gave a benefit of $222,092.

This overall cost of this second scenario is vastly superior to that of the previous one. This also includes the installation and maintenance of a given wind turbine, however cost of electricity is greatly reduced. The turbine that gave the least benefit was again the Gamesa G58-850 which had an overall benefit of $236,546. The turbine with the greatest benefit was the Enercon E33, which had a benefit of $940,978. From the compilation of data that was collected and the analysis of wind and the analysis of the three specified turbines we can safely draw our conclusion. Based on these statistics we can safely conclude that it is feasible to put a wind turbine, Enercon E33, on the Southern Campus of Worcester Academy.

6. Appendices

Wind Maps

Image 2: Grey Scale Map for Height of 30m

Image 1:Grey Scale Map for Height of 50m

Image 3:Grey Scale Map for Height of 70m

Image 5:Grey Scale Map for Height of 100m

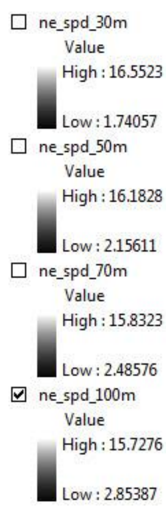

Image 4:Legend for Grey Scale Maps

Wind Turbine Specifications

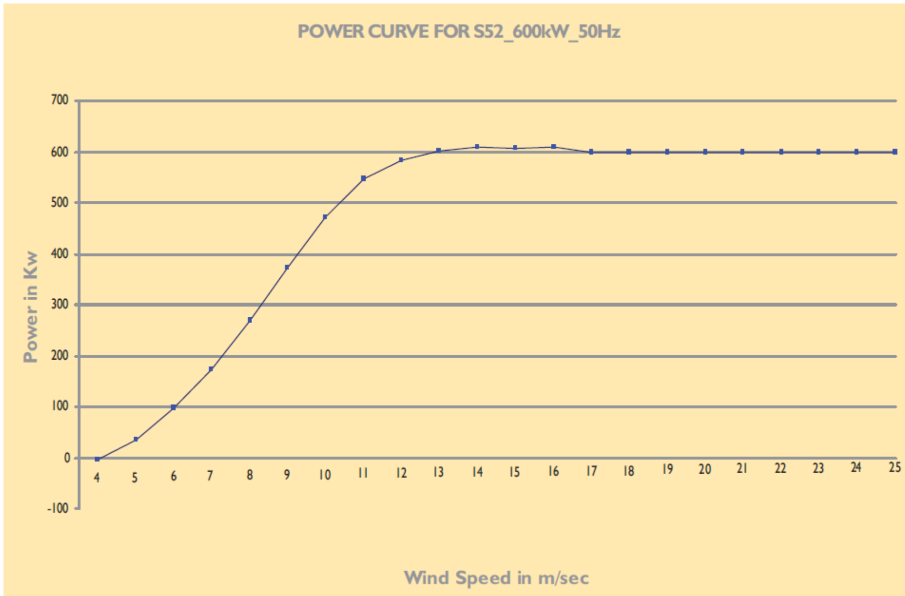

Image 6: Suzlon S52 Published Power Curve

Wind speed m/s	Power output [kW]	Wind speed m/s	Power output [kW]
4	1	17	600
5	34	18	600
6	96	19	600
7	173	20	600
8	269	21	600
9	372	22	600
10	471	23	600
11	546	24	600
12	584	25	600
13	600		
14	600		
15	600	Power curve data at air density 1.225 kg/m^3	
16	600		

Image 7: Suzlon S52 Published Power Output

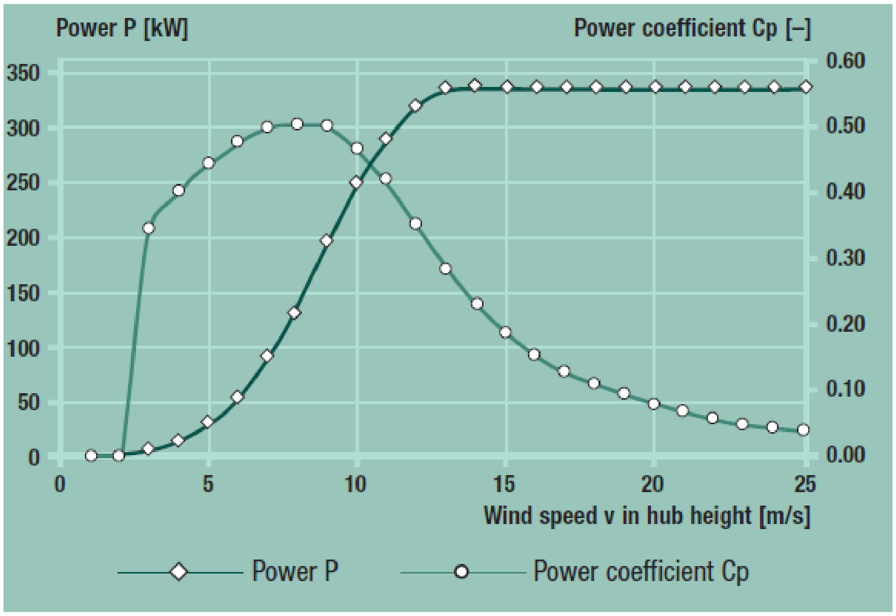

Image 8: Enercon E33 Published Power Curve

Wind [m/s]	Power P [kW]	Power coefficient Cp [-]
1	0.0	0.00
2	0.0	0.00
3	5.0	0.35
4	13.7	0.40
5	30.0	0.45
6	55.0	0.47
7	92.0	0.50
8	138.0	0.50
9	196.0	0.50
10	250.0	0.47
11	292.8	0.41
12	320.0	0.35
13	335.0	0.28
14	335.0	0.23
15	335.0	0.18
16	335.0	0.15
17	335.0	0.13
18	335.0	0.11
19	335.0	0.09
20	335.0	0.08
21	335.0	0.07
22	335.0	0.06
23	335.0	0.05
24	335.0	0.05
25	335.0	0.04

$\rho = 1.225\ kg/m^3$

Image 9: Enercon E33 Published Power Output

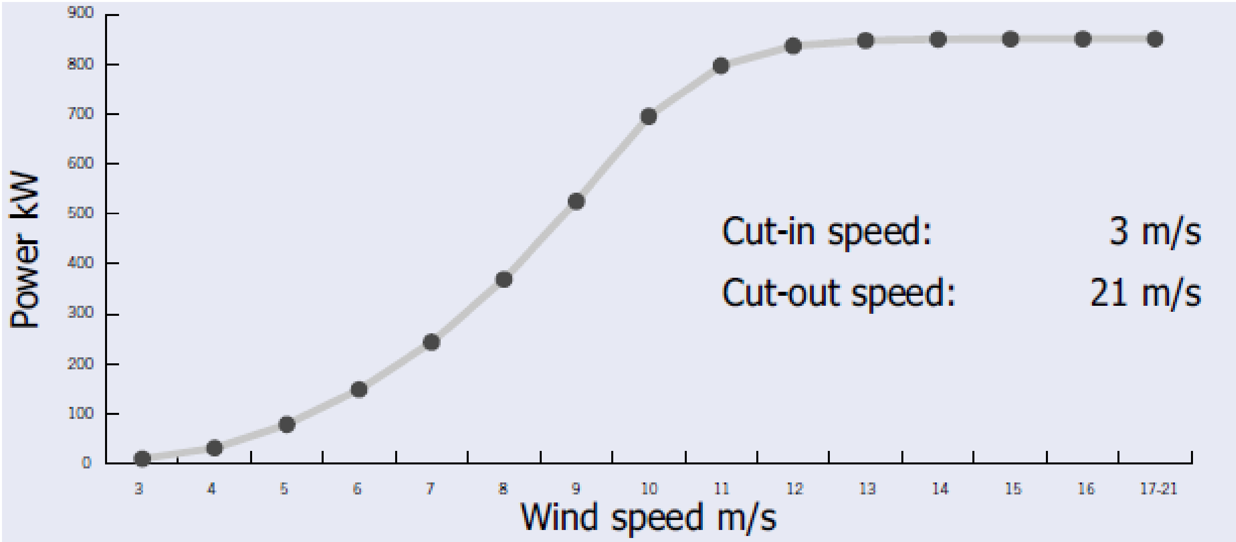

Image 10: Gamesa G58-850 Published Power Curve

SPEED (m/s)	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17-21
POWER (kW)	9.7	31.2	78.4	148.2	242.7	368.8	525.3	695.0	796.6	853.9	846.8	849.3	849.9	850.0	850.0

Image 11: Gamesa G58-850 Published Power Output

Projected Savings

Table 8: Turbine Savings Estimation for .02dollar/watt

Suzlon S52						
	Cost of Turbine			Suzlon S52	1,284,538	kWh/year
Turbine	$1,350,000.00					
Excavation	$15,000.00					
Shipping	$5,000.00					
Grants	$615,000.00					
WA Donation	$500,000.00					
Total cost	$1,370,000.00				**Tax Incentives**	
Total Expected Cost	**$255,000.00**			Energy returned to Grid	1,284,538	watts
				Rebate	$0.0210	Dollar/watt
	Loan Repayment					
Original Cost	$255,000			**Total Rebate Annually**	**$26,975.30**	
Repayment Time	20	years				
Monthly Payment	$2,325.93			**Total Rebate over twenty years**	$539,505.96	
Overall Interest	$258,215.23					
Yearly Maintenance Costs	$27,000			**Total Benefit**	($513,709.27)	
Total Cost (over 20 years)	**$1,053,215**					

Enercon E33						
	Cost of Turbine			Enercon E33	921,649	
Turbine	$900,000.00					kWh/year
Excavation	$15,000.00					
Shipping	$5,000.00					
Grants	$615,000.00					
WA Donation	$500,000.00					
Total cost	$920,000.00				**Tax Incentives**	
Total Expected Cost	**-$195,000.00**			Energy returned to Grid	921,649	watts
				Rebate	$0.0210	Dollar/watt
	Loan Repayment					
Original Cost	($195,000)			**Total Rebate Annually**	**$19,354.63**	
Repayment Time	20	years				
Monthly Payment	N/A			**Total Rebate over twenty years**	$387,092.58	
Overall Interest	N/A					

Yearly Maintenance Costs	$18,000			**Total Benefit**	$222,092.58	
Total Cost (over 20 years)	**$165,000**					

Gamesa G58-850						
	Cost of Turbine			Gamesa G58-850	1,366,468	
Turbine	$1,600,000.00					
Excavation	$15,000.00					
Shipping	$5,000.00					
Grants	$615,000.00					
WA Donation	$500,000.00					
Total cost	$1,620,000.00				**Tax Incentives**	
Total Expected Cost	**$505,000.00**			Energy returned to Grid	1,366,468	watts
				Rebate	$0.0210	Dollar/watt
	Loan Repayment					
Original Cost	$505,000			**Total Rebate Annually**	**$28,695.83**	
Repayment Time	20	years				
Monthly Payment	$2,325.93			**Total Rebate over twenty years**	$573,916.56	
Overall Interest	$258,215.23					
Yearly Maintenance Costs	$160,000			**Total Benefit**	($829,298.67)	
Total Cost (over 20 years)	**$1,403,215**					

Table 9: Turbine Savings Estimation for .06dollar/watt

Suzlon S52						
	Cost of Turbine			Suzlon S52	1,284,538	kWh/year
Turbine	$1,350,000.00					
Excavation	$15,000.00					
Shipping	$5,000.00					
Grants	$615,000.00					
WA Donation	$500,000.00					
Total cost	$1,370,000.00				**Tax Incentives**	
Total Expected Cost	**$255,000.00**			Energy returned to Grid	1,284,538	watts
				Rebate	$0.0600	Dollar/watt
	Loan Repayment					
Original Cost	$255,000			**Total Rebate Annually**	**$77,072.28**	
Repayment Time	20	years				
Monthly Payment	$2,325.93			**Total Rebate over twenty years**	$1,541,445.60	
Overall Interest	$258,215.23					
Yearly Maintenance Costs	$27,000			**Total Benefit**	$488,230.37	
Total Cost (over 20 years)	**$1,053,215**					

Enercon E33						
	Cost of Turbine					
Turbine	$900,000.00			Enercon E33	921,649	kWh/year
Excavation	$15,000.00					
Shipping	$5,000.00					
Grants	$615,000.00					
WA Donation	$500,000.00					
Total cost	$920,000.00				**Tax Incentives**	
Total Expected Cost	**-$195,000.00**			Energy returned to Grid	921,649	watts
				Rebate	$0.0600	Dollar/watt
	Loan Repayment					
Original Cost	($195,000)			**Total Rebate Annually**	**$55,298.94**	
Repayment Time	20	years				
Monthly Payment	N/A			**Total Rebate over twenty years**	$1,105,978.80	
Overall Interest	N/A					
Yearly Maintenance Costs	$18,000			**Total Benefit**	$940,978.80	
Total Cost (over 20 years)	**$165,000**					

<u>Gamesa G58-850</u>						
	Cost of Turbine					
Turbine	$1,600,000.00					
Excavation	$15,000.00			Gamesa G58-850	1,366,468	kWh/year
Shipping	$5,000.00					
Grants	$615,000.00					
WA Donation	$500,000.00					
Total cost	$1,620,000.00				**Tax Incentives**	
Total Expected Cost	**$505,000.00**			Energy returned to Grid	1,366,468	watts
				Rebate	$0.0600	Dollar/watt
	Loan Repayment					
Original Cost	$505,000			**Total Rebate Annually**	**$81,988.08**	
Repayment Time	20	years				
Monthly Payment	$2,325.93			**Total Rebate over twenty years**	$1,639,761.60	
Overall Interest	$258,215.23					
Yearly Maintenance Costs	$32,000			**<u>Total Benefit</u>**	$236,546.37	
Total Cost (over 20 years)	**$1,403,215**					

Energy Usage Information

2007-2008	Jul	Aug	Sep	Oct	Nov	Dec
Usage (kwh)	125,030	143,583	141,287	150,686	148,062	176,078
Cost	$ 3,905.15	$ 4,484.09	$ 4,762.19	$ 4,658.09	$ 4,910.13	$ 5,088.25
	$ 0.031	$ 0.031	$ 0.034	$ 0.031	$ 0.033	$ 0.029
Usage (kva)-Central only	308	340	313	348	330	306
Cost	$ 1,400.49	$ 1,547.91	$ 1,425.06	$ 1,583.40	$ 1,501.50	$ 1,392.30
	$ 4.55	$ 4.55	$ 4.55	$ 4.55	$ 4.55	$ 4.55
Usage (kw) - Kingsley only	24	25	29	40	39	38
Cost	$ 159.60	$ 164.92	$ 191.52	$ 266.00	$ 258.02	$ 250.04
	$ 6.65	$ 6.65	$ 6.65	$ 6.65	$ 6.65	$ 6.65

	Jan	Feb	Mar	Apr	May	Jun	Total
	151,473	149,072	136,715	137,428	133,216	141,938	1,734,568
	$ 4,267.66	$ 4,239.59	$ 3,571.89	$ 4,503.13	$ 4,371.49	$ 6,843.99	$ 55,605.64
	$ 0.028	$ 0.028	$ 0.026	$ 0.033	$ 0.033	$ 0.048	$ 0.032
	306	294	282	282	275	265	3,649
	$ 1,392.30	$ 1,337.70	$ 1,272.20	$ 1,149.84	$ 1,209.01	$ 1,161.59	$ 16,373.30
	$ 4.55	$ 4.55	$ 4.51	$ 4.08	$ 4.40	$ 4.39	$ 4.49
	37	34	35	33	32	33	398
	$ 244.72	$ 228.76	$ 231.16	$ 217.14	$ 214.49	$ 219.78	$ 2,646.15
	$ 6.65	$ 6.65	$ 6.64	$ 6.62	$ 6.62	$ 6.62	$ 6.64

2006-2007	Jul	Aug	Sep	Oct	Nov	Dec	
Usage (kwh)	124,575	149,125	142,200	143,498	151,667	166,555	
Cost	$ 11,188	$ 13,606	$ 13,295	$ 13,485	$ 14,449	$ 16,095	
	$ 0.090	$ 0.091	$ 0.093	$ 0.094	$ 0.095	$ 0.097	
Usage (kva) -Central only	281	302	319	336	297	294	
Cost	$ 1,305.72	$ 1,406.16	$ 1,481.49	$ 1,562.40	$ 1,381.05	$ 1,367.10	
	$ 4.65	$ 4.65	$ 4.65	$ 4.65	$ 4.65	$ 4.65	
Usage (kw) - Kingsley only	$ 24.40	$ 24.00	$ 43.60	$ 43.60	$ 41.20	$ 41.20	
Cost	$ 162.26	$ 159.58	$ 289.94	$ 289.94	$ 273.98	$ 273.98	
	$ 6.65	$ 6.65	$ 6.65	$ 6.65	$ 6.65	$ 6.65	
	Jan	Feb	Mar	Apr	May	Jun	Total
	160,923	158,075	158,209	137,007	146,930	142,942	1,781,706
	$ 15,791	$ 15,639	$ 15,573	$ 13,700	$ 17,815	$ 17,762	$ 178,399
	$ 0.098	$ 0.099	$ 0.098	$ 0.100	$ 0.121	$ 0.124	$ 0.100
	302	318	302	297	297	324	3,670
	$ 1,406.16	$ 1,478.70	$ 1,397.82	$ 1,351.35	$ 1,351.35	$ 1,474.20	$ 16,963.50
	$ 4.65	$ 4.65	$ 4.62	$ 4.55	$ 4.55	$ 4.55	$ 4.62
	$ 41.20	$ 44.80	$ 43.60	$ 40.00	$ 42.80	$ 39.20	$ 469.60
	$ 273.98	$ 297.92	$ 289.93	$ 266.00	$ 284.62	$ 260.68	$ 3,122.81
	$ 6.65	$ 6.65	$ 6.65	$ 6.65	$ 6.65	$ 6.65	$ 6.65

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