# Alternative Renewable Energy Sources: Northern Great Plain Energy Station

An Interactive Qualifying Project Report

submitted to the Faculty

of the

WORCESTER POLYTECHNIC INSTITUTE

in partial fulfillment of the requirements for the

Degree of Bachelor of Science

by

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Date: July 02, 2004

Professor Mayer Humi, Advisor

1. Wind Energy
2. Hydrogen Fuel Cells
3. Alternative energy Sources

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# ABSTRACT

After careful analysis of growing future energy concerns, we have looked into providing a cost effective, renewable energy solution for the Western United States. We propose a wind farm in the Midwest and carry out cost analysis of this work site that will theoretically generate enough electrical energy to power the entire West Coast.

# EXECUTIVE SUMMARY

Our group investigated the future potential of various forms of alternative energy sources as a replacement for the current energy infrastructure consisting of polluting fossil fuels which are dominated by coal and oil. We first examined the current energy consumption trend which shows that fossil fuels will have been depleted by the mid-21st century. We then looked for ways to curb, and later construct a new infrastructure in place of the existing one, in favor of meeting the electrical needs of the future United Sates population through a series of renewable “green” energy sources. Our focus for the early part of our research centered around Hydrogen fuel cells, but then moved to Wind Energy in order to offer a more realistic approach to current concerns while bypassing the many existing problems that are currently faced by engineers working towards building cost-effective fuel cells.

Worcester Polytechnic Institute
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# Chapter 1

# Preliminary Research

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June 30, 2004

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## Summary and Critique

American Wind Energy Association FAQs:
http://www.awea.org/faq/index.html
Offshore Wind
Wind Energy Policy Issues
Wind Energy and the Environment

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May 20, 2004

Harnessing wind energy involves an initially expensive and historically challenging process, but theoretically has the potential to produce enormous energy prospects with no pollution, and little maintenance. Wind is a naturally occurring phenomenon that, if correctly controlled will supply cheap energy to worldwide power grids in the coming years. Compared with energy produced by burning fossil fuels, the interest in wind energy is backed by these statistics:

> “In 1997, U.S. power plants emitted 70% of the sulfur dioxide, 34% of carbon dioxide, 33% of nitrogen oxides, 28% of particulate matter and 23% of toxic heavy metals released into our nation's environment, mostly the air. These figures are currently increasing in spite of efforts to roll back air pollution through the federal Clean Air Act.” AWEA

Wind energy if implemented will purportedly drive down the cost of health insurance, reduce CO2 levels in the atmosphere (limiting greenhouse effects), and has minimal impact on being responsible for the killing of birds (far less statistically than major structures such as buildings and cats which are the main causes of unnatural deaths). The overall reduction of CO2 levels is dependant on the amount of energy supplied by green energy as a percentage and therefore inversely proportional to the percentage of traditional processes which account for the present CO2 levels.

There have been several planned proposals for offshore wind projects such as one near Cape Cod where higher wind speeds (than on land), and close proximity to a power grid in terms of laying transmission lines make such an endeavor feasible. Because each site is looked at carefully for projected erosion and environmental impacts beforehand, they end up not only having minimal “side effects” but are in fact helpful to the environment in the instance of creating shelter for fish.

Government policy is moving in the direction of making it easier and cheaper for renewable energy sources or so called “green energy” to gain ground in the near future. Theoretically speaking, the United States has the resources to become fully reliant on wind and solar power for several billion dollars worth of commitment to present technology. Sadly, only 20% of total energy output is expected to be “green” by the year 2020. Projected cost increases would in all actuality be saving taxpayers billions of dollars in the long run should this 20% (or greater) power transition take place (because they are naturally lower than the projected rising cost of traditional means when adjusted for inflation).

I personally think that wind energy and other renewable energy sources need to be looked at in depth as future investments.

It is no longer necessary to rely on oil for our energy needs. We have the ability to bypass OPEC and all major oil companies altogether and drive the cost of oil down (in turn driving the cost of RET’s down due to project construction and transportation costs) and providing for a more efficient and cleaner future.

Policy shifts in terms of energy-buying contracts and grid use will only make it easier in the future to sell energy on the open market for landowners such as farmers and cattle ranchers who plan on subsidizing their operations. Small businesses as well as large companies are positioned to take control of market share at a moment’s notice. The one thing left in the way of clean energy production is the government which openly supports the oil trade as a result of political ties.

I have no doubt that the future will provide the opportunity for cheaper, cleaner energy production and engineers will be at the forefront of this promising enterprise. Naturally, the more efficient renewable energy production is, the sooner it will come to be a reality.

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## Summary and Critique

Periodical Reference: Scientific American March 2002
Title: Blowing Out to Sea
Author:  Wendy Williams

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America’s first offshore wind farm is currently under construction five miles south of Cape Cod on a shallow sandbar known as Horseshoe Shoal and is expected to be completed by the year 2005. It will be capable of producing 420 Megawatts of power (the second largest in the world after Ireland’s proposed 520-megawatt farm.

Each of the 170 wind turbines will stand 260 feet above the water at the height of the turbine hub, and each blade will be 150 feet long. The turbines will be visible from Hyannisport, and laid out in a grid pattern over 25 square miles. Project developers say that at peak operation, the farm will satisfy the average energy need of Cape Cod in its entirety.

A Push towards developing offshore wind farms such as this one is being felt in Europe where there is not only a general public interest in environmental efficiency, but also the fact that such farms will not require land acquisition. For the most part, the turbines will be out of sight/earshot of residents, and fishermen are encouraged by studies that show that the anchored turbines are likely to increase fish populations by creating shelter. Although offshore wind technology has been around for the past decade, it is only now becoming more acceptable due to the increasing demand for clean, efficient energy in large supply (at competitive costs).

On the other hand, some question whether it is really worth the amount of money needed to fund such an endeavor.  Cape Wind, the company funding the project off Cape Cod, has already spent millions of dollars on initial studies, and anticipates spending a total of $600 million for it.  The company’s president claims that “We're creating a national model for America's energy and environmental future."  However, others have their doubts as to the success of the project.  "I'd be a little skeptical about starting with something that big," warns wind-farm engineering expert Tim Cockerill, a research fellow at the University of Sunderland in England.  In any case, the Department of Energy is paying close attention to the project as a whole to see if its benefits can outweigh its potential pitfalls (ability to generate projected amounts of energy at expected costs with relatively low maintenance or negative environmental impact).

I believe that with that much money and time invested in the project, it will achieve the majority of its goals, although I doubt that even if it is a huge success that the government will embrace such proposals in the near future.  Most of the research and field knowledge learned in these next few years however, will be worth their weight in gold once the United States decides that it should no longer look to be dependant on oil as its main source of energy.  This transition to green energy will not be a smooth move, but it will propel the next generation of power technology to a clear-cut efficient means of producing massive amounts of energy in demand.

Once the technology is evaluated and improvements are made to the system, not only will the U.S. benefit from production gains, but poorer countries will slowly begin to follow our lead.  Initially a wind farm project is very expensive, but over the years, even with maintenance, energy will be produced without the supply of fossil fuels and therefore be a much cheaper form of energy in the long run.

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## Summary and Critique

Periodical Reference: Physics Today April 2002
Title: “Hydrogen: The Fuel of the Future?”
Author: Joan M Oglen

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Hydrogen is a fuel that is widely appealing due to the fact that it is easily accessible, relatively cheap, clean burning, and a chemically potent alternative to gasoline.  It also has several other physical properties which make it appealing to engineers, such as detonability (the concentration of hydrogen/air at which it will combust).  These properties also pose problems to the current fuel infrastructure however.

Because hydrogen must be extracted and refined in a variety of complex manners, and either highly cooled or highly pressurized in order to exist in a usable liquid form, it ends up not being as truly cost efficient or environmentally friendly as one would think.  In a highly pressurized form, it is also difficult to work with, because it not only tends to corrode and embrittle various steels over time, but also lends itself to leaking (and combusts easily as mentioned earlier).  When hydrogen burns, it does so invisibly, making a leak not only difficult to detect, but dangerous in attempting to halt as well.

Needless to say, the challenges associated with leading industry in the direction of gasoline to hydrogen crossover is not only politically, but technically difficult.  One promising new technology is the use of carbon nanostructures to store hydrogen on the molecular level.  The hydrogen atoms encapsulated by these structures can then be released latter when need by simply passing a current through the medium.  Tests have shown that a relatively acceptable level of storage capacity can be achieved at room temperature more cheaply than using conventional techniques.

Most surprisingly perhaps is that small pockets of supporters and individual businesses are currently expected to make the transition to hydrogen full cell utilization rather than having governmental backing as previously believed.  One reason for this is the fact that demand needs to build before such a tremendous societal change is forced to take place.  Iceland has announced that it plans to convert to hydrogen fuel via electrolysis using off-peak power by the year 2030, but even this goal is unrealistic without continued research and development work to be conducted on creating viable fuel cells.

I believe that fuel cell research is more promising than the author since they ignore the fact that interest in this area has been gaining ground in recent years.  As soon as the public has vested interest in its development, research funding will advance the likelihood of groundbreaking technology in the refining, transportation, and safety of hydrogen.  Efficiency and power transfer will follow, producing a newly revitalized energy market that has not been seen since the discovery of oil. Fossil fuel reserves are quickly burning up, and producing dirty (and increasingly costly) environmental and widespread cultural problems.

Alternative energy sources are therefore not only a suggestive medium, but also an inevitable outcome with the possibility of hydrogen implantation leading the way. The next few years are crucial to the development of power production technologies which will ultimately shape the future of industry as a whole.

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# Chapter 2

# Preliminary Research

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## Summary and Critique

Periodical Reference: Physics Today, April 2002
Title: “Renewable Energy: Progress and Prospects”
Author: Samuel F. Baldwin

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Baldwin’s paper focuses on solar, wind, and biomass based renewable energy technologies (RETs). He states that efforts to harness RETs increased sharply as a direct result of the 1973-74 oil embargo, and that consequently the cost of wind-generated and photovoltaic electricity has been reduced by an order of magnitude. Baldwin outlines select energy capacity and usage figures starting with the increase in global wind-generated electric capacity from 4500MW to 18500MW in 2000. He continues by noting that global photovoltaic generating capacity was 396MW in 2001 representing an increase of 38% from 287MW in 2000. He also states that the United States RETs accounted for 6.6 quads (6.6E18J) of energy in 2000 which represents approximately 6.7% of the Unites States usage of 98.5 quads of energy and that of that usage only 0.07 quads and 0.05 quads were from wind and solar energy respectively.

Baldwin discusses photovoltaic technologies with respect to cost, application, and efficiency. He lists three categories of photovoltaics: single-crystal, thin-film, and concentrator with a maximum efficiency of 24.7% achieved as of his writing. He does not mention the theoretical max efficiency of 60% for Si technology and 70% for GaAs technology. Baldwin goes into some detail to explain the application parameters associated with each of these categories as follows: single crystal photovoltaics which are highly efficient but costly, thin-film photovoltaics with lower efficiency and cost and ease of adaptability to building integration, and finally concentrator photovoltaics, complex and costly, but suitable for high power applications. He notes that photovoltaic systems are very well suited to distributed systems and could aid in the reduction of peak loading of the power grid given the research and development efforts necessary to produce low cost, high-efficiency power inverter technology for grid connected distributed systems.

Baldwin states that current typical wind generator capacity is 900kW per unit representing a 1700% increase in capacity over the last twenty years. He goes to some length to convey the challenges faced in developing robust, high-efficiency wind generators which include modeling multidimensional stresses related to wind sheer, rotational dynamics, material fatigue, and power management. Baldwin notes that, using wind generator technology currently under development, wind farms constructed in the Great Plain states could, with minimal land covering, generate more electric power than is currently consumed by the country.

According to Baldwin, renewable biomass including wood, landfill gas, and ethanol produced from corn accounted for approximately

3.35 of the 98.5 quads of energy consumed by the Unites States in 2000. Biomass generated 11GW of electric power production, and augmented the nation’s fuel supply with approximately two billion gallons of ethanol or about 1.6% of the gallons of gasoline consumed. He explains that renewable biomass energy production is most efficiently accomplished in integrated biorefineries employing either enzymatic biochemical or thermo-chemical gasification in extracting the maximum usable resources from raw biomass and allowing biomass to be economically competitive with coal.

Baldwin writes, “After 25 years of dramatic technical progress RETs now have the potential to become major contributors…” with this statement Baldwin exemplifies and underscores humankind’s general state of apathy. We are on the very brink of the depletion of the medium that currently supplies the majority of our ever increasing energy needs, a resource currently consumed at a rate of almost 70 million barrels per day. Why the Chief Technology Officer of the Department of Energy’s Office of Energy Efficiency and Renewable Energy is using politically correct, saccharine verbiage is inscrutable. He should be writing, “After 25 years of devastating filibustering and legalized patent confiscation we find ourselves on the brink of irreversible damage to our planet and the imminent exhaustion of a non-renewable energy resource. The implementation of RETs, which should have begun decades ago, must be forcibly instituted immediately. Baldwin stops short of any admonition or recommendation that the windfall of corporate profits can no longer be allowed to lure us into specific energy technology decisions. Policy must be set with regard humankind's future on earth and the terra-forming technologies that will be demanded as mankind populates other planets. In his concluding paragraphs, Baldwin actually seems to attempt to convey the predicament future generations face but fails to instill any sense of urgency. Baldwin should state that enormous research and development efforts aimed at mass production and efficiency must be implemented with federal funding readily available to educational institutions and entrepreneurial endeavors and not obfuscated by the typical deluge of legal verbiage. Finally, Baldwin should be recommending that the immediate development and implementation of renewable energy technology power production must supply a minimum of 50% of the power requirements for all United States military installations throughout the world and that engineering and scientific specialists civilian, commissioned, and enlisted must be utilized to build and secure humankind's future.

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# Summary and Critique

American Wind Energy Association FAQs:
http://www.awea.org/faq/index.html
Small Wind Energy Systems
Wind Energy and the Economy
Wind Industry Statistics

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A grid-connected residential wind turbine is an excellent example of a small wind energy system. Such a system is a hybridization of a conventional residential electrical system with a small wind turbine power system. The wind turbine is essentially no more than a transducer that converts wind power into electric power. The system supplies the home with electric power from both the local utility connection and from the wind turbine. In wind conditions below a turbine specific speed, typically between seven and tem miles per hour, called the cut-in speed, no power is delivered to the system by the turbine and all the power required by the residence is purchased from the local utility. Above the cut-in speed, power is delivered to the system, from the wind turbine, proportional to the wind speed. Power generated by the wind turbine in excess of that required by the residence is sold to the local utility. Residences equipped with such systems typically realize a 50% or higher reduction in their annual electricity costs. Total savings generated by such a system is directly affected by usage and average annual wind speed.

The average American home uses about 10,000 kilowatt-hours per year and requires a wind turbine in the five to fifteen kilowatt range. The American Wind Energy Association (AWEA) recommends that a turbine owner should have at least a ten mile per hour average annual wind speed and a ten cent or higher cost per kilowatt-hour, for a wind turbine to be economical. Wind resource data published by the US department of Energy is sufficient for most residential applications but the AWEA recommends that those in very hilly or mountainous areas collect wind data independently prior to purchasing a wind energy system.

Questions and concerns regarding the installation, operation, and safety of small wind turbines are numerous. These turbines do make noise, typically less than that of a washing machine. Small wind turbines do not interfere with television reception. According to the AWEA bird collisions with small wind turbines occur as they do with other structures, rarely, and are known to have no impact on local bird populations. The question of avian mortality is often heard being voiced with regard to wind energy systems. It should be noted that house cats in the US are estimated to kill roughly one billion birds each year and that a single house cat is statistically a far greater threat to birds and the local bird population than a small wind energy system. Also statistically, a tree is more likely to fall than a properly installed wind turbine tower. These towers should be protected from curious children just like any similar structure. Another concern regarding the treat of ice being thrown from spinning blades is unfounded since ice buildup on blades reduces blade aerodynamic performance and therefore reduces revolutions per minute resulting in ice buildup typically dropping to the base of the tower rather than being thrown. The AWEA states that small wind energy systems do not adversely affect property values and may actually raise property values.

The incorporation of the benefit of wind power into a residence does not require rewiring of that residence and is further simplified by the *Public Utility Regulatory Policies Act* of 1978 which requires utilities to connect to and purchase power from small wind energy systems. Eighty to one hundred and twenty foot towers are usually supplied with wind turbine systems. Modest expenditures in tower height, within local regulations, can generate high rates of return since wind power goes as the cube of wind speed and wind speed aloft is higher and less turbulent than that closer to the ground. Wind energy systems can generate significant utility savings depending upon available wind power at the site of use and the application of available rebates and tax credits. Currently, small wind energy systems cost between $3,000.00 and $5,000.00 per kilowatt of generating capacity. Typical turbine lifetime can be up to twenty years with completely automatic operation and no regular maintenance. With the application of rebates and tax credits, a small wind energy system can pay for itself and generate free power during its typical operational lifetime. As with any major home improvement project, professional or self-installation must be considered and any offer that sounds to good to be true probably is. The AWEA can provide contact information for reputable dealers and satisfied customers to aid in the decision making process.

Currently available wind, photovoltaic, and diesel hybrid technology offer the lowest-cost centralized systems. Tax credits and rebates make these systems attractive for home owners and small businesses. Harnessing the inexhaustible supply of energy available to residences and small businesses benefits the economy with the addition of jobs, a free energy source, and the reduction of strains on the economy related to environmental pollution. According to the AWEA, sources of electric energy in the US include hydropower (7%), natural gas (16%), nuclear (20%), oil (3%), and coal (52%) the most polluting fuel and largest source of carbon dioxide. Clearly each percent of energy, currently produced using coal, which can be produced using turbines, is beneficial both economically and environmentally. As the demand for wind energy systems continues to grow the potential exists for the establishment of one of the largest sources of new manufacturing jobs needed to produce the integral and supporting components required for harnessing the wind power required to produce a significant percentage of the ever increasing global energy demand.

All current estimates point to world wide energy deficits without the establishment of an alternative and renewable energy resource infrastructure supplying an ever increasing percentage of global energy demands. According to the AWEA the fuel most likely displaced by wind farms is natural gas. This single fact is promising since the current natural gas shortage is in excess of three billion cubic feet per day. The Department of Energy has announced a goal of obtaining 5% of US electricity (about 240 billion kilowatt hours) from wind energy systems by 2020. As of January 2004, approximately 16 billion kilowatt hours of wind energy are produced in the US annually. Current world leaders in wind energy generating capacity are shown in the table below.

| **World Leaders in Wind Capacity**<br>December 2003 | |
|---|---|
| **Country** | **Capacity (MW)** |
| Germany | 14,609 |
| United States | 6,374 |
| Spain | 6,202 |
| Denmark | 3,110 |
| India | 2,110 |
| Netherlands | 912 |
| Italy | 904 |
| Japan | 686 |
| United Kingdom | 649 |
| China | 568 |

Table 2.1: http://www.awea.org/faq/tutorial/wwt_statistics.html

Great technological strides in wind power generation have been made since the early 1970s with average wind generating capacity increases of two orders of magnitude and concurrent cost reduction of an order of magnitude. These strides, along with available rebates and tax credits, have made small wind energy systems viable for residential and small business applications. Today’s energy costs, environmental concerns, and ever increasing energy demands only serve to underscore the necessity for the intelligent and deliberate implementation of hybrid energy systems with wind energy production being a primary component. Finally, alternative and renewable energy systems promise to provide not only the energy needed to meet future demands, but an infrastructure of energy production and energy technology development mankind needs for a prosperous future.

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## Summary and Critique

Periodical Reference: Scientific American February 2004
Title: “When Blade Meets Bat”
Author: Wendy Williams

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May 27, 2004

Wind power development faces an emergent issue with respect to wildlife conservation. Bird and bat deaths recorded on existing wind turbine installations threaten to delay or halt further development. Currently no single site underscores the need for concern more than that of FPL Energy’s 44-turbine installation on Backbone Mountain, in West Virginia. FPL energy is currently the largest producer of wind energy in the United States and is facing site expansion issues in West Virginia, Western Maryland, and South Central Pennsylvania due to a large number of bat deaths associated with the Backbone Mountain site.

The issue is that at least four hundred bats died, at the Backbone Mountain site between mid-August and October 2003 and it is currently unknown how or why this occurred. According to Williams, the deaths have generated public outcry as to the potential for decimation of bird and bat species as a byproduct of wind turbines. It is currently speculated that the collisions may be the result of the bats not using their echolocation, the turbines emission of, as of yet, undetected high-pitched sounds, or the bats being caught in the wind shear generated by the units.

One key concern of biologists is that many more than four hundred bats could have been killed and that their bodies which are very small and hard to find may have been overlooked or that scavengers may have removed them from the site prior to discovery of the four hundred animals found. Wildlife advocates are currently threatening legal action due to the deaths that have occurred at another FPL Energy wind turbine site located in Meyersdale Pennsylvania where they believe that the endangered Indian Bat may use the site for a seasonal habitat. Williams states that a letter from a university biologist contracted to examine the site, for FPL Energy, seems to support the advocate’s claims and recommended that a summer-long study might be appropriate. This concern has fueled the issue and generated a debate in the conservationist community regarding the time that needs to be devoted to preconstruction wildlife studies. Williams relates that some biologists currently recommend preconstruction studies of two year duration while others including wind power entrepreneurs disagree.

A more considered approach has been outlined by a university bat echolocation specialist and a member of Bat Conservation International. The gentlemen agree that the key issue is to find out how and why the bats are killed using techniques including infrared cameras. They suggest that there may be a simple way to solve the conservation issues currently faced.

The current electricity needs of the United States are in excess of 3.4 trillion kilowatt hours and it is estimated that this need will increase by 1.4 trillion kilowatt hours by 2020. The most optimistic geological studies, including studies done by the US Geological Survey indicate a world oil shortage no later than 2019 and most indicate closer to 2012. Renewable energy resources, including wind power generation, must be developed and implemented. A measured approach identifying the hows and whys of conservation issues and mitigating technologies should be used. This course of action is the responsible one and embraces the spirit of renewable energy technologies and provides for the energy production capacity that will be needed and must be added to provide for the requirements of the population.

# Worcester Polytechnic Institute
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## Summary and Critique

Periodical Reference: Financial Times
Title: “Scots Launch Rooftop Wind Turbine Trial”
Author: Mark Nicholson

Periodical Reference: New Scientist
Title: “Reach For the Sky”
Author: Simon Torok

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June 11, 2004

According to Mark Nicholson of the Scotland Correspondent, the Scottish executive[1] launched a pioneering trial of silent, roof-mounted wind turbines, on May 18, 2004. The trial includes five turbines created by Renewable Devices, an Edinburgh based company, mounted to the roof of a primary school in Fife, Scotland. Each turbine is capable of generating about 4500kWh annually which is approximately one third of the annual electric power consumption for an average home. An example of a typical electric power consumption distribution for an average home in a warm climate can be seen below.

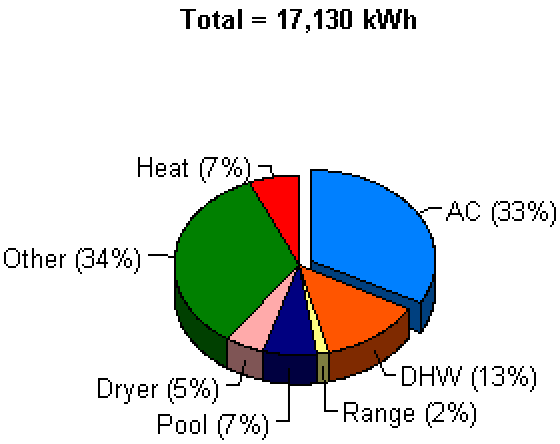

Figure 2.1: http://www.fsec.ucf.edu/bldg/pubs/PF369/

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[1] The Scottish Executive is the body that governs Scotland in relation to all devolved matters. The Scottish Executive is formed from the party or parties holding a majority of seats in the Parliament. The members of the Executive are collectively referred to as 'the Scottish Ministers'. All Ministers are MSPs. This means that they are part of two separate organizations: the Scottish Executive (Ministers) and the Scottish Parliament (MSPs). Ministers head up the departments, which are run by the Scottish civil service. The Scottish Executive is led by the First Minister.
http://web.ask.com/redir?bpg=http%3a%2f%2fweb.ask.com%2fweb%3fq%3dwhat%2bis%2bthe%2bscottish%2bexecutive%26o%3d0%26page%3d1&q=what+is+the+scottish+executive&u=http%3a%2f%2ftm.wc.ask.com%2fr%3ft%3dan%26s%3da%26uid%3d02A3F9494180A9C04%26sid%3d14D75A494180A9C04%26qid%3d83EEB6DCA64ED24AA5893B748531D6AC%26io%3d7%26sv%3dza5cb0db8%26o%3d0%26ask%3dwhat%2bis%2bthe%2bscottish%2bexecutive%26uip%3d44093005%26en%3dte%26eo%3d-100%26pt%3dAbout%2bScotland%26ac%3d3%26qs%3d0%26pg%3d1%26ep%3d1%26te_par%3d102%26te_id%3d%26u%3dhttp%3a%2f%2fwww.scotland.org%2f&s=a&bu=http%3a%2f%2fwww.scotland.org%2f&qte=0&o=0

According to Mr. Nicholson, one of Renewable Devices two co-founders claims that the company was the first to achieve the “holy grail” of a wind turbine – a smooth-running turbine quiet enough to be roof mounted. At first glance Renewable Devices claims seem to point to a revolution in wind power generation with respect to cost, installation, and returns with their roof-mounted, 4500kWh generators currently priced at about £10,000 ($18,200) and predicted price of £1,500 ($2,700) once mass production is underway.

The benefit to the consumer seems revolutionary at first glance, but is it? What Renewable Devices is offering is a “silent”, roof-mountable wind energy system capable of producing 4500kWh annually at a predicted cost of $2,700. According to the American Wind Energy Association (AWEA), Small wind energy systems cost from $3,000 to $5,000 for every kilowatt of generating capacity, or about $40,000 for a 10-kw installed system[2]. Renewable Devices 4500kWh roof-mountable systems have a generating capacity of 0.5-kW. At their current cost of $18,200, they are 910% of the cost of the typical 10-kw installed, residential system. Even at $2,700, Renewable devices systems

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[2] http://www.awea.org/faq/tutorial/wwt_smallwind.html#How%20much%20does%20a%20wind%20system%20cost

would cost a minimum 135% of the cost non-roof mounted, installed, residential systems.

Renewable Devices roof-mountable systems could be very attractive for residences and small businesses in high population density, metropolitan areas with class 3 or higher winds, if they can achieve a competitive mass production cost of $4,000 or less per kilowatt of generating capacity. These systems are not currently cost effective or applicable to large generating capacities needed for high energy consumption businesses and industries but there are other renewable technologies on the horizon that may lend themselves to such applications.

An engineer in Australia, Bryan Roberts, has been pioneering an effort to develop flying wind generators since the early 1970s. Simon Torok, of New Scientist, relates that Roberts plans for these flying wind generators to be tethered to the ground by 4500m cables and extract massive amounts of wind energy from the jet streams circling the globe. Roberts envisions building massive power stations comprised of dozens of these “gyromills” with hundreds of megawatts of total generating capacity. The prospect of harnessing the awesome wind power available in the jet stream is exciting. Wind power is proportional to the cube of wind speed. The wind power available in the jet steams is enormous. For comparison, the highest annual average wind speed recorded in the United States was 56.16 km/h on Mount Washington[3] while winds in the jet stream can attain a relatively constant 500 km/h, almost ten times the wind speed of the windiest places on the surface or about 1000 times the wind power that is available anywhere on the surface of the planet. Roberts claims that the power available in the jet streams “is up to 100 times the power available from any other energy source.”

The “gyromill” design of the technology is necessitated by the staggering cost of getting such large generators aloft. Conventional means of lifting the generators include balloons or gliders but either would have to be huge to meet the task. According to Roberts, using conventional aircraft to lift the generators into position would require “…something roughly the size of a jumbo jet” for a one megawatt generator and he envisions fleets of ten megawatt generators in any given “gyromill” power station. Robert’s teams have built and flown several gyromills over the years since the early 1970s, achieving craft stability in the 1990s. Since achieving stability Robert’s has focused on optimizing power-to-weight

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[3] http://www.sizes.com/natural/wind.htm

ratios and the administrational plans for his “gyromill” wind farms.

With the huge amounts of energy available in the jet streams over places like upstate New York in the United States of America and Northern New South Wales in Australia, 17kW/m$^2$ and 19kW/m$^2$ respectively, a subsidized trial of one or more of Robert’s “gyromills” seems like the only logical course of action. These machines could be included in hybridized “energy stations” coupled with land based hydrogen reformation systems and based in favorable locations throughout the Great Plain states. High voltage, low current power generated at the “gyromill” could be transmitted to the “energy station” with low $I^2R$ losses. These “energy stations” would be massive facilities integrating biomass, hydrogen reformation, hydropower, and photovoltaic technologies depending on location and could provide both grid power and hydrogen reformation during off peak hours when massive power excesses could be used to generate hydrogen. The hydrogen could then be shipped via freight, rail and tanker to all parts of the country.

Simon Torok relates that Concerns have been raised with respect to the danger to aircraft and the danger of having massive machines tethered to several cables flying four and one half kilometers overhead. Roberts has addressed maintenance and sever weather concerns with the proposal of an installation including winch systems capable of slowly pulling the “gyromills” back to the surface while simultaneously sending power to the machines to generate a controlled descent. This control and recovery system, coupled with diode lighting technology and on board collision avoidance transmitters on every “gyromill”, and cable markers could prove to provide the safety margins that must be considered.

All current estimates point to world wide energy deficits without the establishment of an alternative and renewable energy resource infrastructure supplying an ever increasing percentage of global energy demands. The Department of Energy has announced a goal of obtaining 5% of US electricity (about 240 billion kilowatt hours) from wind energy systems by 2020. As of January 2004, approximately 16 billion kilowatt hours of wind energy are produced in the US annually. [4] Though great technological strides in wind power generation have been made since the early 1970s, the average wind generating capacity increase of two orders of magnitude pales in comparison to Robert’s claims of his

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[4] Worcester Polytechnic Institute, Term E04, Interactive Qualifying Project, Summary and Critique, American Wind Energy Association: Small Wind Energy Systems, Wind Energy and the Economy, Wind Industry Statistics, Richard Ricci June 7, 2004

technology with its generating potential up to 100 times the power available from any other energy source.

Today’s energy costs, environmental concerns, and ever increasing energy demands only serve to underscore the necessity for the intelligent and deliberate implementation of hybrid energy systems with wind energy production being a primary component. Finally, alternative and renewable energy systems promise to provide not only the energy needed to meet future demands, but an infrastructure of energy production and energy technology development mankind needs for a prosperous future.

Worcester Polytechnic Institute
Term E04
Interactive Qualifying Project

# Energy Station: Cost Analysis

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June 22, 2004

## Energy Station: Rough Cost Analysis

Employ General Electric’s 3.6 megawatt wind turbines and future higher capacity wind turbines to produce one-quarter of the United State’s 6 trillion kWh demand estimated for 2020. Supply the entire west coast and adjacent states with sufficient power to meet demand through 2020.

Employ current and future reformation technologies to produce transportation scale quantities of hydrogen, using excess and off peak power.

The analysis scenarios that follow are based on:

- A per unit cost basis of (a) $1.8M or (b) $3.6M installed
- A turbine efficiency of 50%
- Allocation of $30B to $40B for workforce development fund

Figure 2.2: Utility Scale Wind Turbine

## Analysis 1a: 1.5 Trillion kWh

| | |
|---|---|
| Required Annual Production: | 1.5 E+12 kWh |
| Unit Capacity: | 3.6MW |
| Unit Efficiency: | 50% |
| Hours/year: | 8760 |
| Units Required: | 95000 |
| Per Unit Installed Cost: | $1.8 E+06 |
| Initial Cost: | $171 E+09 |
| Workforce Development: | $30 E+09 |
| Annual Maintenance: | $1.71 E+09 |
| Annual RET[5] R&D Budget: | $10 E+9 |
| Annual Mgmt and Transmission: | $30 E+09 |
| Annual Capital Loss[6]: | $8.55 E+09 |
| Annual Environmental Budget: | $1.71 E+09 |
| 20 Year Cost: | $1.240 E+12 |
| 20 Year Production | 30 E+12 kWh |
| Cost Per Kilowatt Hour: | $0.0413/kWh |

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[5] Renewable Energy Technology: Augment current national budget for the research and development of improved turbine technology, inverter technology, superconductors, hydrogen reformation, biomass energy generation, magnetic levitation rail systems, etc.

[6] Revenue escrowed for replacement and upgrade of all turbines every twenty years.

## Analysis 1b: 1.5 Trillion kWh

| | |
|---|---|
| Required Annual Production: | 1.5 E+12 kWh |
| Unit Capacity: | 3.6MW |
| Unit Efficiency: | 50% |
| Hours/year: | 8760 |
| Units Required: | 95000 |
| Per Unit Installed Cost: | $3.6 E+06 |
| Initial Cost: | $342 E+09 |
| Workforce Development: | $30 E+09 |
| Annual Maintenance: | $3.42 E+09 |
| Annual RET[7] R&D Budget: | $10 E+9 |
| Annual Mgmt and Transmission: | $30 E+09 |
| Annual Capital Loss[8]: | $17.1 E+09 |
| Annual Environmental Budget: | $3.42 E+09 |
| 20 Year Cost: | $1.658 E+12 |
| 20 Year Production | 30 E+12 kWh |
| Cost Per Kilowatt Hour: | $0.0550/kWh |

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[7] Renewable Energy Technology: Augment current national budget for the research and development of improved turbine technology, inverter technology, superconductors, hydrogen reformation, biomass energy generation, magnetic levitation rail systems, etc.

[8] Revenue escrowed for replacement and upgrade of all turbines every twenty years.

## Analysis 2a: 2.0 Trillion kWh

Required Annual Production: 2.0 E+12 kWh

Unit Capacity: 3.6MW

Unit Efficiency: 50%

Hours/year: 8760

Units Required: 126840

Per Unit Installed Cost: $1.8 E+06

Initial Cost: $228 E+09

Workforce Development: $40 E+09

Annual Maintenance: $2.28 E+09

Annual RET[9] R&D Budget: $12.5 E+9

Annual Mgmt and Transmission: $40 E+09

Annual Capital Loss[10]: $11.4 E+09

Annual Environmental Budget: $2.28 E+09

20 Year Cost: $1.637 E+12

20 Year Production 40 E+12 kWh

Cost Per Kilowatt Hour: $0.0409/kWh

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[9] Renewable Energy Technology: Augment current national budget for the research and development of improved turbine technology, inverter technology, superconductors, hydrogen reformation, biomass energy generation, magnetic levitation rail systems, etc.

[10] Revenue escrowed for replacement and upgrade of all turbines every twenty years.

## Analysis 2b: 2.0 Trillion kWh

Required Annual Production: 2.0 E+12 kWh

Unit Capacity: 3.6MW

Unit Efficiency: 50%

Hours/year: 8760

Units Required: 126840

Per Unit Installed Cost: $3.6 E+06

Initial Cost: $457 E+09

Workforce Development: $40 E+09

Annual Maintenance: $4.57 E+09

Annual RET[11] R&D Budget: $12.5 E+9

Annual Mgmt and Transmission: $40 E+09

Annual Capital Loss[12]: $22.9 E+09

Annual Environmental Budget: $4.57 E+09

20 Year Cost: $1.578 E+12

20 Year Production 40 E+12 kWh

Cost Per Kilowatt Hour: $0.0547/kWh

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[11] Renewable Energy Technology: Augment current national budget for the research and development of improved turbine technology, inverter technology, superconductors, hydrogen reformation, biomass energy generation, magnetic levitation rail systems, etc.

[12] Revenue escrowed for replacement and upgrade of all turbines every twenty years.

## Summary

Numerous factors included in the “energy station” cost analysis include an expected wind turbine efficiency of 50%, an expected wind turbine cost of $500 to $1000 per kW, a one-time workforce development allocation of $10 billion per 500 billion kilowatt hours of required production, an annual maintenance and environmental cost of two percent of the initial cost, an annual R&D budget of more than $3 billion per 500 billion kilowatt hours of required production, and an annual capital loss of 5% of the initial cost.

Factoring in all costs over twenty years results in the following end-user power costs:

Cost Scenarios

| Cost Scenario | Annual Production (kWh) | Installed Turbine Unit Cost | End-User Cost/kWh |
|---|---|---|---|
| 1a | 1.50E+12 | $1,800,000.00 | $0.0413 |
| 1b | 1.50E+12 | $3,600,000.00 | $0.0550 |
| 2a | 2.00E+12 | $1,800,000.00 | $0.0409 |
| 2b | 2.00E+12 | $3,600,000.00 | $0.0547 |

**Table 2.2: Cost Scenarios**

The installed per unit cost basis of $1.8M/$3.6M per wind turbine must be investigated, as well as, the 50% expected efficiency since these factors, particularly a lower turbine efficiency factor, would eliminate any competitive edge with respect to the cost of coal, if environmental damage and health care costs are not factored in.

Worcester Polytechnic Institute
Term E04
Interactive Qualifying Project

# Chapter 3

# Preliminary Research

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June 30, 2004

# Worcester Polytechnic Institute
# Term E04
# Interactive Qualifying Project

## Summary and Critique

Periodical Reference: Scientific American, 2004
Title: “The Hydrogen Economy Game”
Author: Wald, Matthew L.

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## May 31, 2004

In the race to reduce pollution and the consumption of gasoline, the government is initiating research for new reusable clean energy. There are several concept ideas for cars, which are the major consumer of gasoline, in which hybrid electric cars will replace gas guzzling combustion engines. Another idea being thrown around is whether hydrogen powered energy could be used to power cars. While looking for solutions to the gasoline problem, it is important too see if the alternatives are actually better than the original problem.

Toyota’s two concept cars, one being the hybrid gas and electric and the other being a hydrogen fuel cell car are among the top considerations for energy saving cutting edge technology. The hybrid car uses a gasoline fueled engine supplemented by a battery powered electric motor. The hybrid of the two motors ends up giving 50 miles per gallon of gasoline and half of carbon dioxide emissions. The hydrogen motor would emit only pure water as waste. The hydrogen motor sounds like a miracle to the ear for reduction of emissions, but looking at the total picture it might not be.

A few of the problems with the hydrogen motor are the fact that it costs about 100 times as much and is not completely environmental friendly like the façade portraits. The electricity for the hydrogen process has to come from energy sources. These sources could come from renewable energy sources like wind or hydroelectric or solar, but these sources of energy are either unaffordable or unavailable on a commercial scale. The cheaper source of energy would come from coal or natural gas. These energies as you can imagine are dirty and cause a lot of pollution therefore the hydrogen motor and the electric hybrid are becoming a little counter productive with the goals that they were originally set to accomplish. Shipping of hydrogen is extremely expensive as well. It would take about 15 trucks to deliver the hydrogen needed to power the same number of cars that could be served by a single gasoline tanker.

Other uses of hydrogen power could be found, not only for cars. Home use of hydrogen is a possibility in the future with fuel cell technology increasing greatly. One major thing though that we need to look into further in the future is the renewable energy resources such as solar and wind in order to save gasoline and hopefully make the earth a cleaner place for everyone.

# Worcester Polytechnic Institute
# Term E04
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## Summary and Critique

American Wind Energy Association FAQs:
http://www.awea.org/faq/index.html
Wind Energy Basics
Wind Energy Costs
Wind Energy's Potential

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June 7, 2004

## Wind Energy Basics

Wind is a form of kinetic energy that can be converted to electricity. Learning how to harness the energy has become a way to obtain energy for purposes that we can use. There are a couple types of energy that people can use to do work, mechanical and electrical. Mechanical wind use is usually used for pumping water or grinding grain. Wind electric energy can be used in people’s homes or businesses and possibly cars.

There are two basic designs of wind electric turbines: vertical-axis, or "egg-beater" style, and horizontal-axis (propeller-style) machines. Horizontal wind machines are most of the turbines uses today.

***Turbine subsystems include:***

- A rotor, or blades (made of fiberglass), which convert the wind's energy into rotational shaft energy;
- A nacelle (enclosure) containing a drive train, usually including a gearbox (but not all) and a generator;
- A tower( made of steal), to support the rotor and drive train; and
- Electronic equipment such as controls, electrical cables, ground support equipment, and interconnection equipment.

Today’s turbines have greatly increased in size compared to previous generations of turbines. Today the rotors are around 71 meters and have a rating of 1650 kilowatt and annually can produce 5600 megawatt-hours. This electricity is carried from the wind farms to customers through power lines. A megawatt of wind can generate about as much electricity as 240 -300 households to use. An annual average wind speed greater than four meters per second is required for small wind electric turbines. Larger scale wind power plants have a minimum average wind speed of 6 m/s. The power available in the wind is proportional to the cube of its speed. So by doubling the wind speed increases the available power by the factor of eight. Small increases in wind speed can mean a large difference in available energy and in the electricity that can be produced. Larger diameters of turbines are approaching 110 meters with the smallest home or business use turbines have rotor diameters of 8 meters or less.

Capacity factor is an element to measure the productivity of the wind turbine.

$$CapacityFactor = \frac{Actual\_Amount\_of\_power\_produced\_over\_time}{Max\_power\_that\_could\_have\_been\_produced}$$

Capacity factors of 25% to 40% are common although 65% to 80% is typical. The most electricity per dollar of investment is gained by using a larger generator and accepting the fact that the capacity factor will be lower as a result. This is much different from fueled power plants. Modern wind turbines have an availability of more than 98%--higher than most other types of power plants. This is because of refinement through engineering where high reliability and performance are on the forefront.

## Wind Energy Costs

The cost of utility-scale wind energy systems has dropped more than 80% over the last 20 years due to research of wing shape technology and lighter blade materials. Wind-generated energy did cost more than 30 cents per kilowatt-hour, but now electricity can be generated for less than 5 cents per kilowatt-hour. At the current price the wind generated electricity can now be comparable to gas or coal fired power plants. There are several factors that go into the cost of wind-generated electricity including the size, the wind speed, and cost of turbines. The size is important because the larger the farm, the lower the cost of energy, along with higher wind speeds. The less expensive construction cost mean lower costs of the energy. Transporting the energy from the farms is another consideration when dealing with the cost of producing the energy. The further it has to travel the more money it is going to cost.

Wind energy gets subsidized through the government. There is a 1.5 cent per kilowatt-hour production tax credit (PTC) for wind energy that was included in the Energy Policy Act of 1992. The Renewable Energy Production Incentive (REPI) consists of direct payment to a public utility installing a wind plant that is equal to the PTC, but it is hard to obtain these funds due to competing federal spending priorities. You might wonder why if wind energy is so competitive why it needs to be subsidized by the government. Wind energy is not obtained freely and with coal and oil having other costs such as medical cost for coal workers; therefore it is not shown in the price of coal electricity. The wind PTC was passed to give wind a level playing field. Another subsidized power source is nuclear power in which the government pledged to act as an insurer of last resort.

Looking at what it would cost an average home, using wind energy over regular electricity is starting to become almost the same price. In Austin, Texas the cost of natural gas produced electricity will cost 2.80 cents per kilowatt-hour compared to the cost of wind-generated electricity at the price of 2.85 cents per kilowatt-hour. This equates to roughly a 75 cents a month more for the average household. When the electric company sells the wind energy is also receives a PTC back so the price might be even less.

## Wind Energy’s Potential

Demand for electricity is all the time, whereas wind energy is not always constant like that of conventional plants. Even though production of the electricity is not always constant, it does increase the overall statistical probability that the system will be able to meet demand which gives wind energy a value. Using previous formulas dealing with capacity factor a 100 MW wind machine with a capacity factor of 35% would compare to a 35 MW conventional generator. The exact capacity value includes a number of factors including average wind speeds onsite and the match between wind patterns and utility load (demand) requirements. Diversification is important when supplying demand through wind power because if all the wind units are in the same area no power will be produced when that area has no wind. If the units are scattered geographically there is a greater chance that some of them will be producing power.

Now with all this diversification and with capacity factors expecting much less, how much energy is can realistically be produced for consumption. Estimates from the Battelle Pacific Northwest Laboratory predict about 20% of nation’s electricity could be generated from wind. Resources useful for generating electricity can be found in nearly every state where North Dakota alone is theoretically capable of producing one-third of U.S. electricity demand.

**THE TOP TWENTY STATES for Wind Energy Potential**

Measured by annual energy potential in the billions of kWh, factoring in environmental and land use exclusions for wind class of 3 and higher.

| | | **B kWh/Yr** | | | **B kWh/Yr** |
|---|---|---|---|---|---|
| *1* | **N.Dakota** | 1,210 | *11* | **Colorado** | 481 |
| *2* | **Texas** | 1,190 | *12* | **New Mexico** | 435 |
| *3* | **Kansas** | 1,070 | *13* | **Idaho** | 73 |
| *4* | **S. Dakota** | 1,030 | *14* | **Michigan** | 65 |
| *5* | **Montana** | 1,020 | *15* | **New York** | 62 |
| *6* | **Nebraska** | 868 | *16* | **Illinois** | 61 |
| *7* | **Wyoming** | 747 | *17* | **California** | 59 |
| *8* | **Oklahoma** | 725 | *18* | **Wisconsin** | 58 |
| *9* | **Minnesota** | 657 | *19* | **Maine** | 56 |
| *10* | **Iowa** | 551 | *20* | **Missouri** | 52 |

Source: An Assessment of the Available Windy Land Area and Wind Energy Potential in the Contiguous United States, Pacific Northwest Laboratory, August 1991. PNL-7789

**Table 3.1: THE TOP TWENTY STATES for Wind Energy Potential**

Wind’s potential is huge. Currently in the world wind energy supplies about 9 million average American households. According to the U.S. Dept. of Energy, the world’s winds could supply 15 times the current world energy demand. This resource seems almost untapped and underused with the data being presented.

Worcester Polytechnic Institute
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# Title: “History of the Wind”

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June 10, 2004

The potential of wind energy has been realized for generations. Harnessing of the energy can be traced from the ancient Egyptians more than 5000 years ago to the present sophisticated uses of the power. The capturing wind energy started off with simple motion concepts and now has evolved into the production of electricity for thousands of people. This long evolution has taken many innovations by engineers along with thousands of years of alteration to get to the point today. Looking at where we are today seems so far from where the research had started, but there is still much improvement for where the technology should go.

While looking at the primitive innovations that ancient cultures had achieved you can realize how many of the same concepts developed more than 5000 years ago still apply to the present time. The harnessing of wind energy notable by the Egyptians were inventions that lead to expansion and discovery. The primary use by the ancient Egyptians was for moving boats for trade purposes. The invention of the sail made of linen or papyrus began propelling small crafts as early as 3100BC. The Egyptians used the predominately Northern winds to flow south back up the Nile River in order to return from trade voyages. These sails lead to increased wealth and the ability to trade goods with other areas. The first windmill was developed in theory by Hero of Alexandria who constructed a small wooden windmill connected to an air pump to plan an organ. That first century idea had to wait until the tenth century where there is proof that windmills were turning in order to grind corner and raise water for irrigation of crops. Middle class people sick of paying taxes to the lords began building the windmills as a freedom from the water power, therefore building up their own little fiefs. The increased building of these windmills was almost a revolt against the aristocracies control over the water wheel power design. The wind power windmill that was used to do physical work lasted up until the nineteenth century, although some still exist today in remote sections.

As the use of windmills grew and revelations with design of these mills surfaced there became peaked interest in the technology. The discovery of the America’s and the settling of the new continent brought with it the need for reliable, renewable energy sources so that work could be performed. With this need came the windmill idea from Europe. Cape Cod, with its windy climate and its ability to support windmills, was a particularly ideal spot to build mills. These mills were used for grinding grain, pumping water, and for driving sawmills. Around the nineteenth century, America began to rely on coal and steam power and the windmill started to fade, but as any renewable reusable energy source it made a come back. Hand in hand with the building of the first railroad saw the resurgence of windmill production. The railroad builders placed windmills at watering places along the railroad to pump water for use. Although all these windmills were created to do physical work such as pumping and grinding, windmills and wind power was a precursor to the electricity producing machines of today.

In 1890 power source experiments by Charles Brown began providing electricity for his mansion. The windmill with a 56 ft. diameter produced energy to charged 408 secondary batteries in order to maintain electricity needs of his estate. The estate housed 350 incandescent bulbs, 100 of which were used every day. Another pioneer Professor Poul La Cour set up at test station in Denmark in order to try and have an economical construction for optimized performance using aerodynamic principles. His airfoil design helped increase the speed the windmills turned at harnessing more power. The first windmill erected in 1891 and the second erected in 1897 had slatted sails 75 feet in diameter which drove to dynamos in which each were 12 h.p. (9 kW). The windmill could generate 90 h.p. in strong winds with one dynamo able to charge a 60 cell battery with 150 volts and 50 amperes. The second dynamo produced 30 volts and 250 amps. Moving ahead to the 1920’s with technology increasing and many new people coming up with specific designs, companies started to form in order to grab a share of the market. Several machines including the Aerolectric system produced between 32 volts to 110 volts with costs between $1000 and $1200. The Jacobs Model designed by the Jacobs brothers was a main windmill from 1927-1957. The Jacobs Wind Electric Company produced more than 30,000 units with prices at $490 for base model and the deluxe model for $1030. This seemed like a huge investment for people during the time, but with electricity prices at that time of .055 cents per kilowatt hour, the investment could be justified.

When the 1960's and 1970's rolled around, everyone started using electricity and it became a commodity taken for granted. With increases in electricity uses hovering around 8% per year, more and more power plants were being used in order to meet the demand. Then in 1973 a crisis happened, an oil embargo that threw the international energy situation in chaos. The United States began looking at energy conservation and alternative energy resources again after realizing the vulnerability of relying on one source. Now with new research grants and promotions, wind energy was resurrected as a possible huge supplier of electricity. Several locations were developed for electricity production where 100kW standard units were tied into main transmission lines in order to supplement the power plants already in place. As time rolled on and technology increased, the constant battling of windmill reliability quickly downgraded the interest in the power source. The world needed reliable energy and with the machines breaking so frequently it was hard to obtain it. The Danish foreign market had built reliable strong wind units capable of generating 50kW to 70kW which was reasonably small but worthwhile.

Today new technology, such as lighter materials and better generator design, coupled with increased reliability is shining a promising future on wind energy and the potentials for electricity production. With increased cost justification and technology the potential for the energy supply is endless. This renewable reusable source of power will always be there as oil and gas will not always. It is important to realize how far we have come in windmill production and use, while also remembering how it can be used in the future.

# Worcester Polytechnic Institute
# Term E04
# Interactive Qualifying Project

# Chapter 4

# Introduction:
# Renewable Energy Station

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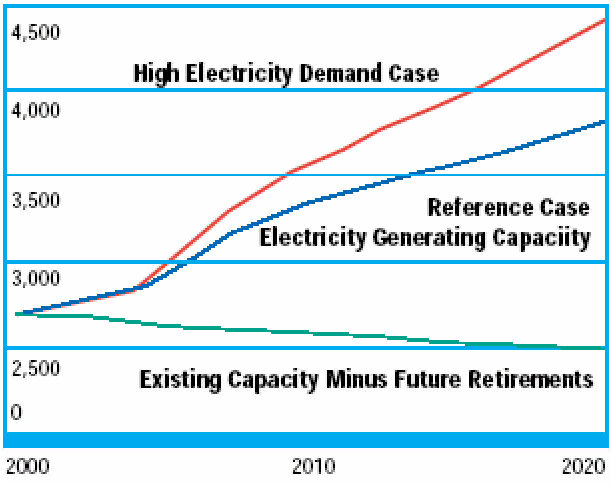
June 26, 2004

## INTRODUCTION

The current electric power consumption of the United States is in excess of 3.4 trillion kilowatt hours. At current rates of increase of consumption, the United States will consume approximately 5.0 trillion kilowatt hours per year by 2020. The sheer magnitude of this number must be understood in order to begin to comprehend the enormity of any proposal to revolutionize the production of electric power. Assuming the universe has existed for 15 billion years implies that the universe has existed for approximately 5 X $10^{17}$ seconds. Electric power consumption by 2020 is projected to be approximately 5 X $10^{15}$ watt hours per year.

**Figure 4.1: The U.S. Needs More Power Plants**



The nation is going to require significant new generation capacity in the next two decades. Depending on demand, the United States will need to build between 1,300 and 1,900 new power plants—or about one new power plant a week.

*Source: U.S. Department of Energy, Energy Information Administration.*

Coal is America’s most abundant fuel source. The United States has a 250-year supply of coal. Over 1 billion tons of coal were produced in 25 states in 2000. About 99.7 percent of U.S. coal production is consumed domestically, with electricity generation accounting for about 90 percent of coal consumption. [13]

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[13] Report of the National Energy Policy Development Group, May 2001

Therefore, in order to meet expected demands for 2020, we need to produce a number of watt hours per year representing one percent of the number of seconds the universe has existed. Obviously, the task is immense and any approach to meeting projected estimates requires expenditures in the range of hundreds of billions of dollars.

The fact that hundreds of billions of dollars will be expended in coming decades to meet electric power demands is not in question, but the manner in which that demand is met must be questioned. Recommendations included in the National Energy Policy Development Group’s May 2001 report, to the President, include the use of coal-fired power plants. Though a current economic justification of this recommendation can be outlined, including the existing industry infrastructure, technological advancement in cleaner coal consumption, and 250-year coal supply estimate; is it the wisest course of action for a nation and indeed a world facing increasingly severe environmental concerns.

> Thanks to thicker clouds and growing air pollution, much of Earth's surface is receiving about 15 percent less sunlight than it did 50 years ago, according to Michael Roderick, a climate researcher at Australian National University in Canberra.[14]

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[14] http://seattletimes.nwsource.com/html/nationworld/2001923726_globaldimming09.html

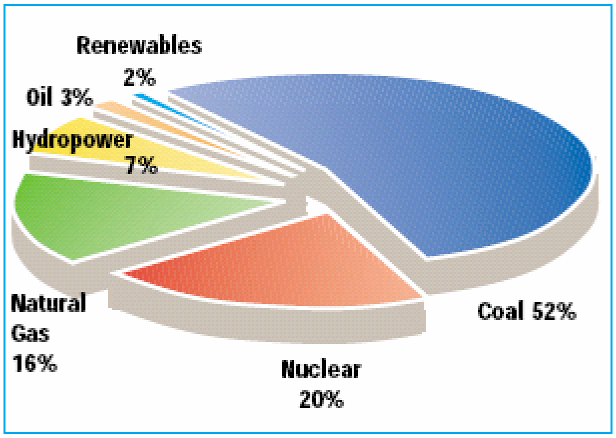
The solar-dimming effect is "about half as large as the greenhouse-gas warming," said James Hansen, director of NASA's Goddard Institute for Space Studies in New York.[15]

WASHINGTON-- Reducing carbon dioxide and other emissions blamed for global warming from coal-burning power plants would raise the cost of electricity an average of $9 billion a year over the next 20 years, the Energy Department said. By 2020, electricity from those plants will cost 33 percent more than it would if carbon dioxide continues to be treated as an unregulated non-pollutant, Mary J. Hutzler, acting head of the department's Energy Information Administration, told the Senate Environment and Public Works Committee.[16]

The Centralia plant owns the distinction of being the single largest air-polluter in the Pacific Northwest. According to recent figures from the Environmental Protection Agency, Centralia each year pumps out 16,100 tons of nitrogen oxides, 64,000 tons of sulfur dioxide and a staggering 9 million tons of carbon dioxide.[17]

Figure 4.2: Fuel Sources

**Fuel Sources for Electricity Generation in 2000**



Electricity is a secondary source of energy, generated through the consumption of primary sources. Coal and nuclear energy account for over 70 percent of U.S. electricity generation.

Source: U.S. Department of Energy, Energy Information Administration.

A typical (500 megawatt) coal plant burns 1.4 million tons of coal each year. There are about 600 U.S. coal plants. Coal pollutes when it is mined, transported to the power plant, stored, and burned.[18]

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[15] http://seattletimes.nwsource.com/html/nationworld/2001923726_globaldimming09.html

[16] http://www.enn.com/news/wire-stories/2001/11/11052001/ap_coal_45457.asp

[17] http://seattlepi.nwsource.com/opinion/cented.shtml

[18] http://www.ucsusa.org/CoalvsWind/c02c.html

> Today 52% of the capacity for generating electricity in the United States is fueled by coal, compared with 14.8% for nuclear energy. Although there are economic justifications for this preference, it is surprising for two reasons. First, coal combustion produces carbon dioxide and other greenhouse gases that are suspected to cause climatic warming, and it is a source of sulfur oxides and nitrogen oxides, which are harmful to human health and may be largely responsible for acid rain. Second, although not as well known, releases from coal combustion contain naturally occurring radioactive materials--mainly, uranium and thorium.[19]

Although the supply of coal is sufficient for 250 years, at current rates of consumption, the impact of the use of coal must be scrutinized. The National Energy Policy Development Group's recommendations to the President include the increased construction of relatively clean natural gas power plants and the statement that "Electricity generated by natural gas is expected to grow to 33% by 2020". Assuming this statement is accurate, factoring in projected increases in demand, assuming that electricity generated by coal will be directly offset by the increase in use of natural gas, and all other fuel source growth rates will remain constant; implies that coal-fired power plants will constitute 35% of the electric power produced in the united states representing a one percent reduction in the use of coal-fired power plants by 2020. While this seems promising, two major factors must be taken into consideration.

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[19] http://www.ornl.gov/info/ornlreview/rev26-34/text/colmain.html

First, the amount of pollution generated by the existing coal-fired power plants is staggering. In an average year, a typical coal-fired power plant generates:

- 3,700,000 tons of carbon dioxide ($CO_2$), the primary human cause of global warming -- as much carbon dioxide as cutting down 161 million trees.
- 10,000 tons of sulfur dioxide ($SO_2$), which causes acid rain that damages forests, lakes, and buildings, and forms small airborne particles that can penetrate deep into lungs.
- 500 tons of small airborne particles, which can cause chronic bronchitis, aggravated asthma, and premature death, as well as haze obstructing visibility.
- 10,200 tons of nitrogen oxide (NO), as much as would be emitted by half a million late-model cars. Nitrogen oxide leads to formation of ozone (smog) which inflames the lungs, burning through lung tissue making people more susceptible to respiratory illness.
- 720 tons of carbon monoxide (CO), which causes headaches and place additional stress on people with heart disease.
- 220 tons of hydrocarbons, volatile organic compounds (VOC), which form ozone.
- 170 pounds of mercury, where just 1/70th of a teaspoon deposited on a 25-acre lake can make the fish unsafe to eat.
- 225 pounds of arsenic, which will cause cancer in one out of 100 people who drink water containing 50 parts per billion.
- 114 pounds of lead, 4 pounds of cadmium, other toxic heavy metals, and trace amounts of uranium.[20]

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[20] http://www.ucsusa.org/CoalvsWind/c02c.html

The Development Groups recommendation implies the approval of the introduction of an additional 59 million tons of carbon dioxide, sulfur dioxide, airborne particles, nitrogen oxide, carbon monoxide, hydrocarbons, mercury, arsenic, lead, cadmium, other toxic heavy metals, and trace amounts of uranium into our environment. Second, the recommendation necessitates an enormous increase in the consumption of natural gas. Current predictions indicate a 50% increase in the consumption of natural gas from 22.8 to 34.7 trillion cubic feet per year[21], of which and ever increasing amount will be imported. Natural gas prices have increased sharply in the past several years and futures prices increased by 320% in 2000 alone. The worldwide consumption of natural gas introduced approximately 5.0 billion metric tons of carbon dioxide into the environment in 2002[22].

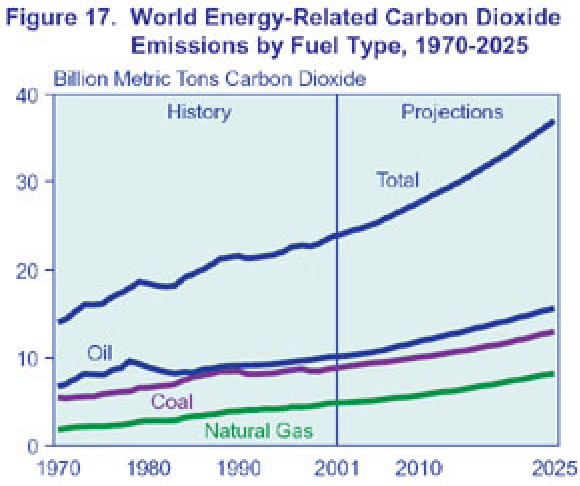
Figure 17. World Energy-Related Carbon Dioxide Emissions by Fuel Type, 1970-2025

Figure 4.3 Carbon Dioxide Emissions

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[21] Report of the National Energy Policy Development Group, May 2001

[22] http://www.eia.doe.gov/pub/international/iealf/tableh3conco2.xls

Globally, energy related emissions of carbon dioxide are predicted to exceed 30 billion metric tons per year by 2020[23].

The United States imports over 15% of the natural gas it consumes and increases in consumption generate increases in imports, almost exclusively from Canada. Clearly the data available underscore the need to scrutinize any plan that calls for a static approach to coal usage and an increase in the amount of imported primary energy sources such as natural gas. The destabilization of natural gas prices and the overall increase in the cost of all non-renewable primary energy sources will only be furthered by the increased energy demands of developing countries. The world needs a plan that embraces the best of what can be achieved, as opposed to the most readily achievable.

Plans for the future must be tempered by the harsh reality of the Chernobyl accident and Superfund sites. We as a global community need to strive to do what will be most beneficial to future generations of mankind, rather that what is most readily within our capabilities or most profitable to an ever decreasing number of individuals. With great power comes great responsibility and the United States must rise to the challenge

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[23] http://www.eia.doe.gov/oiaf/ieo/world.html

of employing its people, strength, and courage to create a prosperous world wherein technology and environment are integrated and ever improving. We must embrace the responsibility of the stewardship of the planet for future generations and the need for a global shift to not only increase the use of renewable energy technologies, but to aggressively work together to replace existing non-renewable energy production facilities to the extent possible.

All current estimates point to world wide energy deficits without the establishment of an alternative and renewable energy resource infrastructure supplying an ever increasing percentage of global energy demands. The Department of Energy has announced a goal of obtaining 5% of US electricity (about 240 billion kilowatt hours) from wind energy systems by 2020. As of January 2004, approximately 16 billion kilowatt hours of wind energy are produced in the US annually.[24] Today’s energy costs, environmental concerns, and ever increasing energy demands only serve to underscore the necessity for the intelligent and deliberate implementation of hybrid energy systems with wind energy production being a primary component. Finally,

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[24] Worcester Polytechnic Institute, Term E04, Interactive Qualifying Project, Summary and Critique, American Wind Energy Association: Small Wind Energy Systems, Wind Energy and the Economy, Wind Industry Statistics, Richard Ricci June 7, 2004

alternative and renewable energy systems promise to provide not only the energy needed to meet future demands, but an infrastructure of energy production and energy technology development mankind needs for a prosperous future.

In the spirit of the vision outlined above, We propose the construction of a massive Renewable Energy Station (RES) with nodes throughout Minnesota, North Dakota and South Dakota consisting of thousands of multiple megawatt capacity wind turbines and the establishment of hydrogen reformation facilities, occupying the same geographic area and using excess and off-peak electric power to generate transportation scale quantities of hydrogen, but specifically located with respect to established rail, freight, and shipping hubs.

Additionally, we recommend the Nationalization of this project for reasons of magnitude, security, regulation, and economic benefit, particularly to the sagging manufacturing sector. We propose congressional oversight of this 1.5 to 2 trillion kilowatt hour RES and the management and regulation of this and all future RES by the Department of Energy and the Federal Energy Regulatory Commission respectively. Additionally, we recommend that the Department of Defense and The Department of Homeland Security be mandated to contribute lands for dual-use purposes, extend no-fly zones over energy production nodes where feasible, and oversee the security management necessary for this and future RES.

We propose an integrated approach including the Department of Energy and the National Laboratories, the Department of Environmental Management, and The Department of the Interior managing the dual usage of all available land resources and leasing of hundreds of thousands of acres of land owned by farmers and ranchers in Minnesota, North Dakota, and South Dakota whose land has been decimated by leafy spurge. We propose the ongoing improvement of that land using environmentally sound practices to reclaim it for those same farmers and ranchers while continuing to lease 10% to 20% of that land for the proposed RES, once the land has been sufficiently cleared of leafy spurge. We propose additional leasing and management of farmlands throughout the Midwest for the production of vast quantities of corn derived ethanol and the use and improvement of existing heavy rail capacity throughout the Midwest to transport ethanol to the proposed hydrogen reformation facilities to be consumed in the production of hydrogen using Rhodium-Ceria reformation technology[25] and future reformation technologies.

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[25] http://www.ur.umn.edu/FMPro?-db=releases&-lay=web&-format=unsreleases/releasesdetail.html&ID=1155&-Find

Finally, we propose a revolutionary approach to power generation wherein massive RES with thousands of multiple megawatt wind turbines, hydrogen refineries, photovoltaic systems, integrated biorefineries, hydropower generating capacity, and all forms of renewable energy resources are integrated establishing new manufacturing growth and generating hundreds of thousands of jobs rekindling the spirit of this great country in a manner akin to the Apollo program and that the strength and courage of a great nation of pioneers is tapped to create an enduring legacy of courage, environmental responsibility, and foresight for our nation and our planet.

Worcester Polytechnic Institute
Term E04
Interactive Qualifying Project

# Chapter 5

# Justification for Technology Employed in our Wind Farm

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June 26, 2004

## Basic Operation

For the final outcome of our project, we decided on conducting our cost analysis and providing technical data based on the General Electric 3.6s MW model. This is not only the most powerful model available at the moment, but also comes form a well recognized, highly diversified company that would be able to support the project in its entirety if actually implemented.

To first understand why we chose the wind turbine model that we did, it is necessary to understand how one works. The hub, rotor, and shaft form the easily recognizable “propeller” on the front of a turbine. The shaft itself, connects to the gearbox for optimal efficiency in transferring mechanical power, and also contains hydraulic pipes as a first barrier to stressful wind speeds in enabling aerodynamic windbreaks to operate so that the gearbox does not become damaged. The other end of the gearbox is connected to a high speed shaft which performs rotations at much higher RPMs (Rotations Per Minute) and is fitted with an emergency mechanical disc brake in case the hydraulic system fails. Mechanical energy is then transferred to, and converted into electrical energy in the electric generator (usually an asynchronous generator), and the size of the generator determines how much energy is able to be produced.

Next to the generator, lies an electronic controller which senses movement and vibrations within the turbine. If the blades or “props” are becoming too stressed by the wind, then the controller is programmed to allow a yaw and pitch mechanism to move into a more suitable position. This allows not only for maximum benefit in regards to power production, but also protects the turbine from becoming damaged. Similarly, if there is a problem with one of the components, the controller will automatically shut down the turbine and alerts a maintenance station via a modem link. In this way, it is also possible for wind farm operators to monitor energy production, wind patterns, and a host of other valuable data through these control systems.

At the very back of the unit is a cooling fan for the internal components so that they don’t overheat, and this also houses an oil cooling system for the gearbox. Above the cooling fan is an anemometer and wind wane used to measure wind speed and direction. Naturally, this is connected to the electronic controller so that data can be collected and the turbine is only in operation when enough wind is present for an energy benefit. Lastly, there is the nacelle, which is the name of the casing that contains all of the major components.

Below is a diagram of the actual GE 3.6s MW model that we chose for our wind farm proposal.  This is followed by a picture of one in operation.

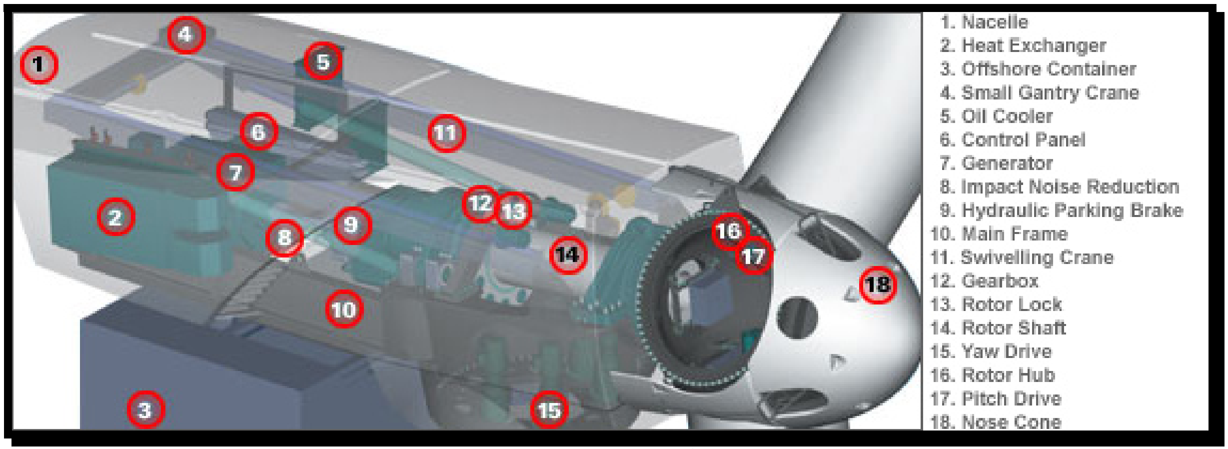

**Figure 5.1: Diagram of GE 3.6s MW**

**Figure 5.2: GE 3.6s MW in operation.**

## Aerodynamics

The aerodynamic design is obviously an important factor in the design of a wind turbine, but it is no longer the reliant factor in terms of maximum power. Advances in materials, manufacturing processes, and computer systems have had just as much a part in the advancement in wind turbine design in the past 20-30 years. However, it is a major factor in terms of design. The principle of Lift is the driving force behind wind power theory, and the little known fact for the reason why wind turbines have three props instead of a different number is because this is the most stable configuration without off balancing the machine (no even numbers allowed) or putting too much stress on the blades (five is too much in many cases).

The rotor blades are twisted in a way that reduces the ability to stall while providing a maximum amount of lift (just like on a prop airplane). The blades are made of glass fiber reinforced plastics (GRP) or glass fiber reinforced polyester/epoxy. Carbon fiber and Kevlar are also sometimes used, but are not feasible for large projects. In many cases, only these light-weight expensive materials will do, simply because steel is too heavy, aluminum too week, and wood too brittle. There is ongoing research into wood fiber epoxy composites, but these have not had a large impact on the market yet. For now, the higher and larger a windmill is built, the higher the price is expected to be as well, largely due to the materials necessary to withstand the growing weight and stress needs.

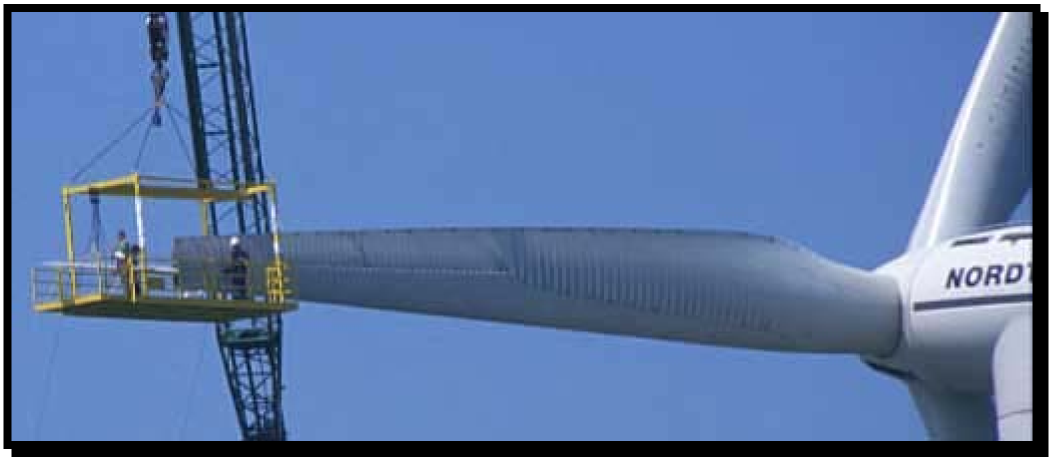

**Figure 5.3: Repairs being made to an industrial-size blade**

As mentioned earlier, the blades themselves are designed to break apart if wind speeds are in excess of the normal operating range. They achieve this by operating on both a hydraulic and spring loaded system, so that if one fails, the other insures that they will break and form an aerodynamic wind brake. They then automatically reattach once winds have died down, or maintenance work has been completed.

Below is a picture of one advancement made to the tips of the blades which is still not in widespread use. The small triangle cutouts make vortices which increase air pressure over the tips of the blade and slightly increases lift/ decreases the chance of stalling.

**Figure 5.4: Wind Vortices**

It is important to note that 100% of the power found in wind will never be able to be captured due to the nature of aerodynamic forces. However, we can maximize our prospects by understanding them. As a general rule, the energy content of the wind varies with the cube (the third power) of the average wind speed. Therefore, if the wind speed is doubled, it contains eight times as much energy as the original wind speed. For the purpose of harnessing this energy, wind can then be thought of as a cone. This is in relation to Betz’ Law which states that the mass of air streaming through the rotor in one second is: $m = \rho F (v_1 + v_2)/2$. The ratio between the power we extract from the wind and the power in the undisturbed wind is then:

$$(P/P_0) = (1/2)(1 - (v_2/v_1)^2)(1 + (v_2/v_1))$$

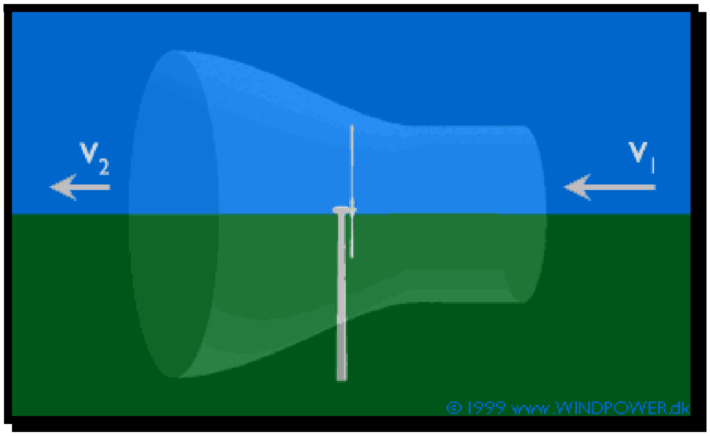

**Figure 5.5: Theoretical cone according to Betz' Law.**

This means that the power extracted from the wind only reaches 16/23 of its potential. Even with this loss, tremendous gains can be expected compared to other forms of energy, which is what makes this endeavor so worthwhile.

## Cutting Edge Materials and Processes

Present day-three phase technology is the most beneficial for converting mechanical power into something usuable and is "ramped up" to high voltages for transport, often within the wind tower itself. At high voltages (30,000V-40,000V) the electricity can me loaded into the grid fairly easily, and with little loss, if at a localized location.

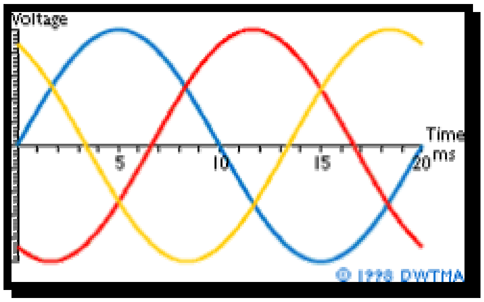

**Figure 5.6: Three-Phase Alternating Current**

Converting this energy from AC to DC and back to AC again (common practice) is a major problem faced by present day engineers, not only in wind power systems, but in all electrical industries. A recent article in Scientific American laments that only 60-70% of the 120V AC power supply is converted into useable energy; the rest is lost as heat. Converting back and forth throughout a grid from wind tower to residential house, therefore illustrated the great dilemma in building good inverters. Even a 5% change would bring about billions of dollars in energy savings across the country.

Possible areas of improvement do not end there however. Transmission lines have been a leading loss of energy for decades. As power plants, and grids are moved further and further away from the areas where most of the electricity consumption is set to take place, small loses over a given cross-sectional area become monumental in the kilometer range. The cure for this is a superconductor (which only exists in theory), but better materials are becoming available in building transmission towers capable of carrying more wires at a reasonable price.

This in fact was the main reason that our group decided to only power the West Coast and not the entire nation. The area that we decided to build our wind farm in lends itself nicely for implementation to the West Coast grid. On the other hand, transmission lines stretching from the wind farm to the East Coast Grid would experience far too much load loss in order to be feasible.

## Our Vision

Although, the manufacturing and design processes involved in making a wind turbine have come a long way in the last 20-30 years, they still have a long way to go. The GE 3.6s MW is currently the most powerful industrial version available in the United States. Other, European companies have also created turbines on this scale, but no company has yet reached the 5 MW mark set to be achieved by 2010. Until then, the 3.6 MW is the standard which we designed our project around in terms of cost, manpower, and sheer power generation. At approximately 57,000 units, our project takes on seemingly impossible odds, but we plan to make our vision more appealing by also implementing other technology.

We included billions of dollars into our yearly budget for the building of a hydrogen-refinement and shipping infrastructure set to inevitably be built over the oil infrastructure in the coming decades.  During off-peak hours, electrical energy is slated to be diverted into the refinement of hydrogen through the procurement of ethanol (processed by an up and coming Rhodium-Ceria device invented at the University of Minnesota). Ethanol (produced from corn) would be easy to transport into our wind farm site, being naturally located at the upper part of America’s Bread Basket.  Ethanol would be transported in by train and truck, and then the refined hydrogen would be taken out the same way to be used either in fuel cells, or in liquid form for long distance transport.

Several other technologies, unavailable today could potentially be retrofitted to our wind farm system as an allotted R&D cost (also already figured in) such as the use of carbon nanostructures used in the safe storage of hydrogen on the molecular level.  The addition of more powerful turbines could also be added to the system if needed as these turbines are phased out.

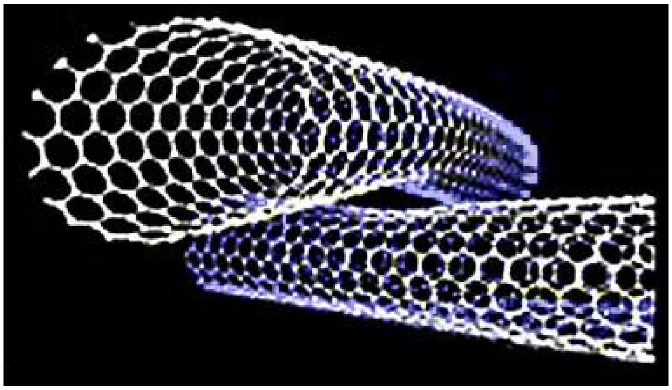

**Figure 5.7: Carbon Nanostructures**

The future is limitless as far as we are concerned, and perhaps one of the most gratifying aspects of this project has been to take a radical idea and illustrate how it could easily become reality. My justification for using the technology that we chose for this project is therefore not based on abstract theory, but proven examples that it does already work on a smaller if albeit simpler scale. The question then becomes: “Why wouldn’t the same technology be expected to function the same way on a larger scale if given the proper backing?

The power curve illustrations of this turbine model, do not show performance on par with smaller ones… the ones for the 3.6 MW model are far better. The technology required to manufacture a turbine on this level is a testament to the amount of expertise that went into its design. All of the components that are fitted into the nacelle of the GE 3.6s MW turbine simply could not fit, nor would they belong on commercial sized models. The closest thing to it would be the 1.5 MW and 2.6 MW versions which were reengineered for its creation. Choosing any other model for this project would not only be foolish in my estimation, but unrealistic in attempting to meet our far reaching goals.

Worcester Polytechnic Institute
Term E04
Interactive Qualifying Project

Chapter 6

# Renewable Energy Station: Site Justification

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June 28, 2004

## INTRODUCTION

The identification of a site within the contiguous forty-eight states, appropriate for the location of our proposed Renewable Energy Station (RES), required the juxtaposition of several factors including available wind resources, land resources, and environmental resources. Our objective required that the location be appropriate for the installation of tens of thousands of wind turbines installed in multiple nodes distributed across a large land area. The total installed turbine capacity was required to be sufficient to supply between 1.5 and 2.5 trillion kilowatt hours per year utilizing currently available technology. Additionally, the site was required to have an average annual wind power classification of no less than four. The location of the site was required to facilitate grid interconnection for power delivery to the west coast and adjacent states. The site was required to be located to facilitate in the delivery of both primary and re-formable energy resources and the shipping of transportation and energy scale quantities of hydrogen, generated by reformation, throughout the country. Finally, it was desired that the location of the site aid in the dual usage of land resources and the use of existing environmental management and security resources.

In accordance with our objective requirements, Minnesota, North Dakota, and South Dakota have been chosen for the site of our site. Our justification for the chosen site is outlined in this chapter.

## AVAILABLE WIND RESOURCES

As indicated, available wind resources, with an average annual wind power classification of no less than four, was a principle site component. Other wind resource factors included wind speed range and standard deviation.

Minnesota, North Dakota, and South Dakota encompass approximately 6000 square miles of land area of which more than 3000 square miles (1.9 million acres) has been identified as having an annual average wind power classification of no less than four, with a high degree of certainty.

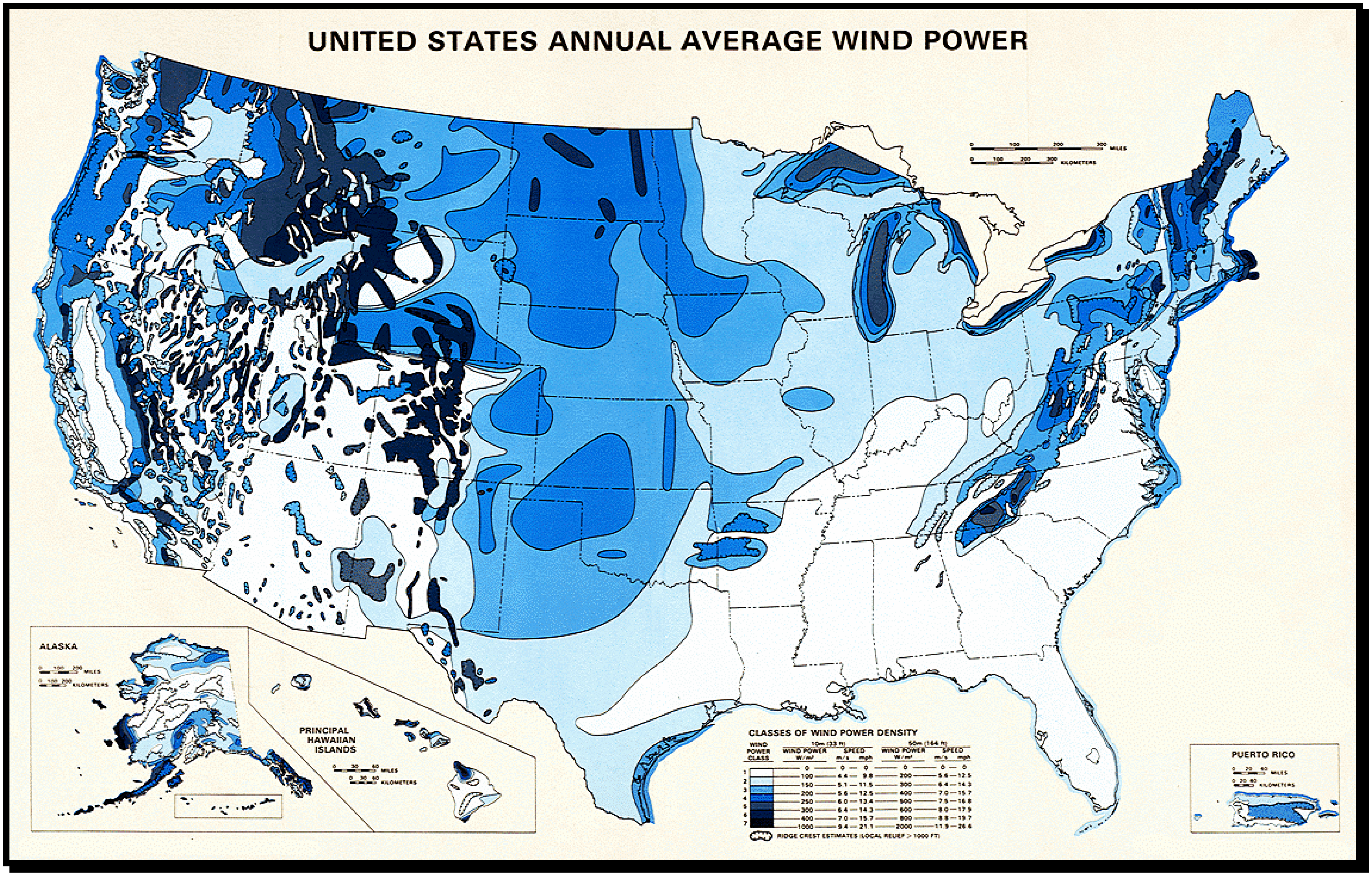

Figure 6.1: http://rredc.nrel.gov/wind/pubs/atlas/maps/chap2/2-01m.html

The map on the preceding page underscores the vast wind energy resources available through out the Midwest. Western Minnesota, North Dakota, and central South Dakota can be clearly seen to have thousands of square miles of land area with a wind power classification of no less than four. The three maps that follow detail those specific wind energy resources.

**MINNESOTA**

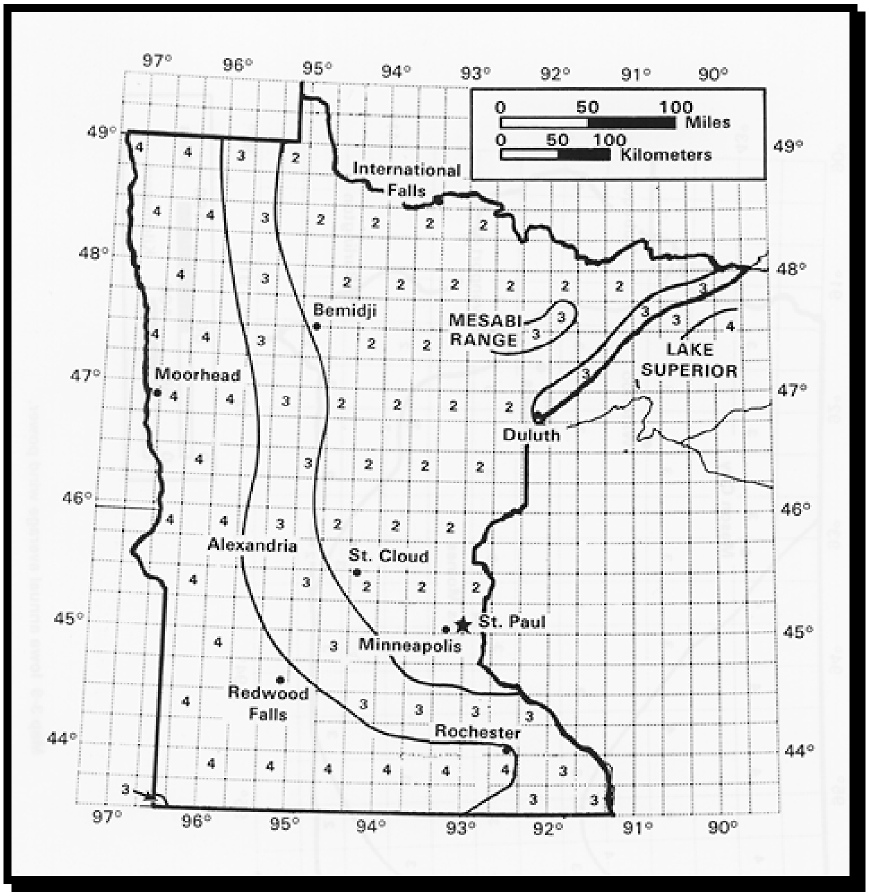

Figure 6.2: http://rredc.nrel.gov/wind/pubs/atlas/maps/chap3/3-10m.html

## NORTH DAKOTA

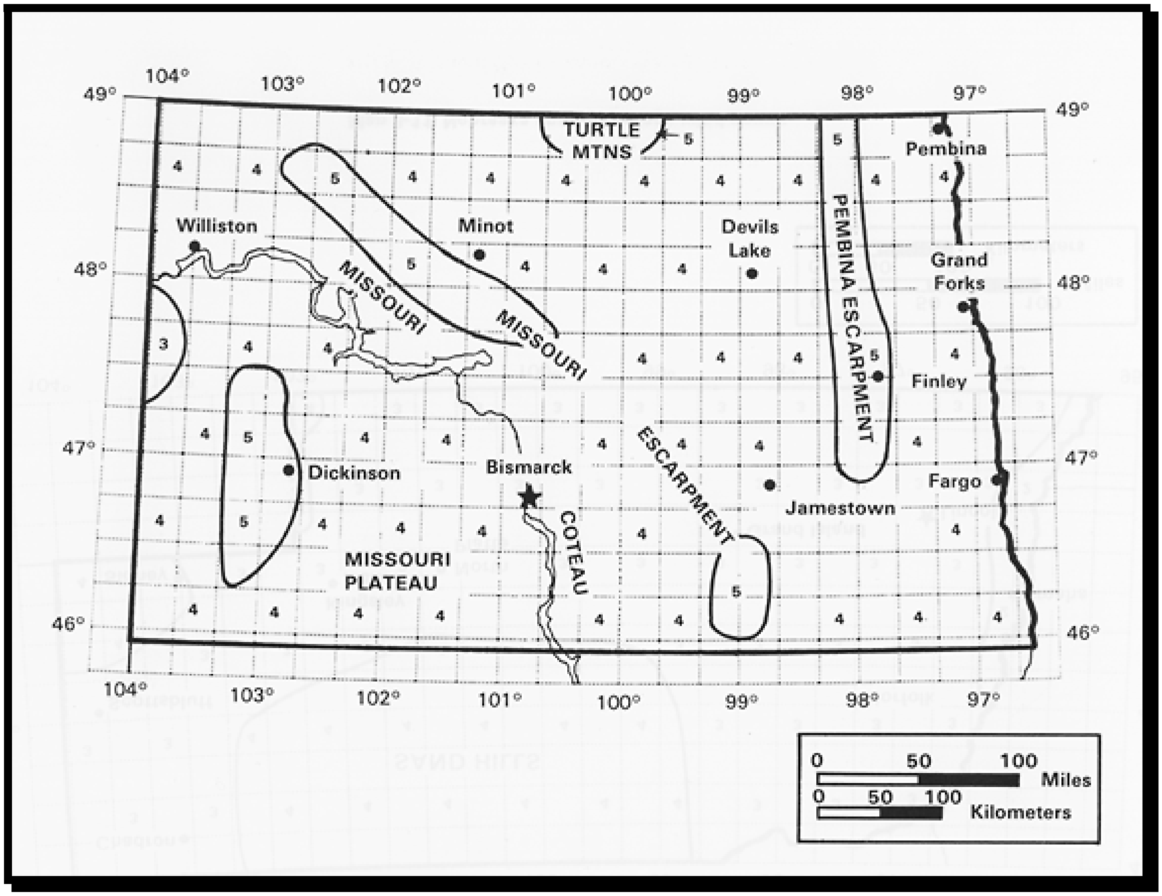

Figure 6.3: http://rredc.nrel.gov/wind/pubs/atlas/maps/chap3/3-12m.html

## SOUTH DAKOTA

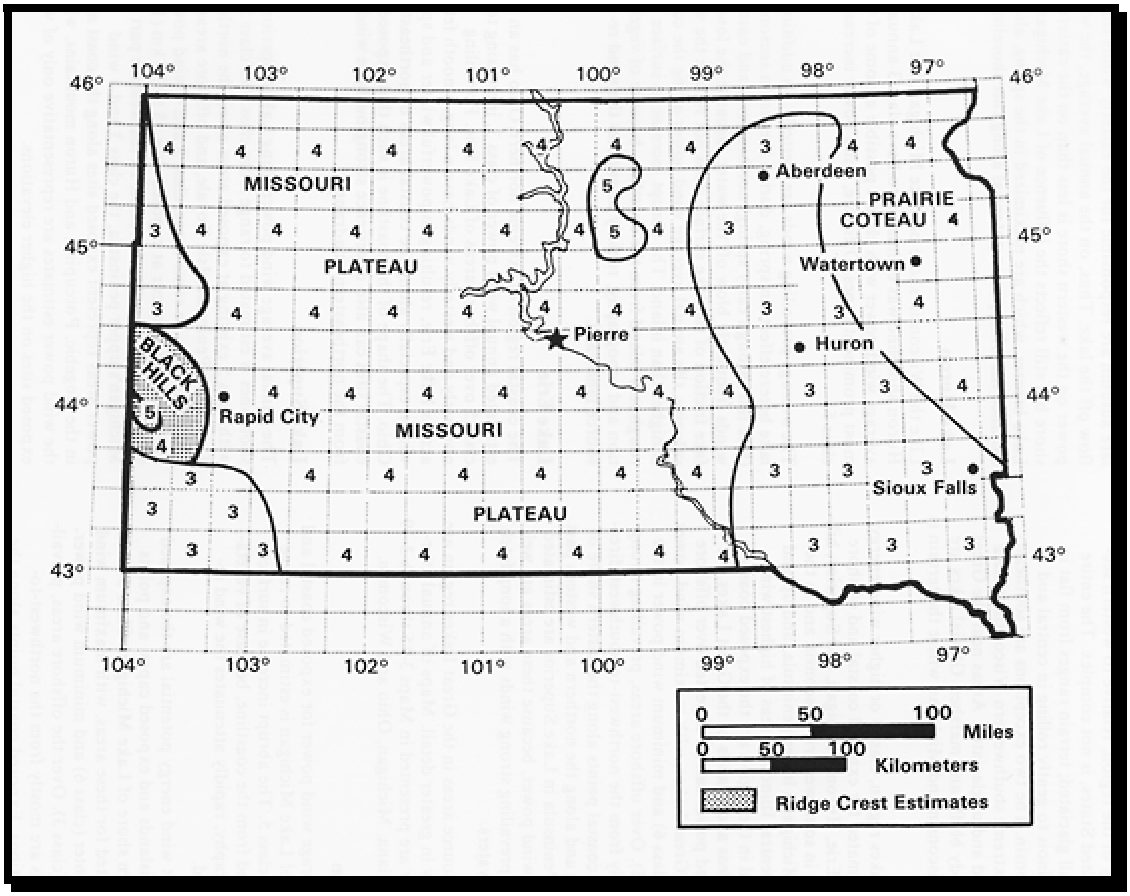

Figure 6.4: http://rredc.nrel.gov/wind/pubs/atlas/maps/chap3/3-13m.html

In addition to the availability of thousands of square miles of land area with a wind power classification of no less than four, the wind power classification has been determined with a high level of certainty as can be clearly seen on the map of “Certainty rating of the wind resource estimates for areas with Class 4 or higher wind power in the contiguous United States”, following page.

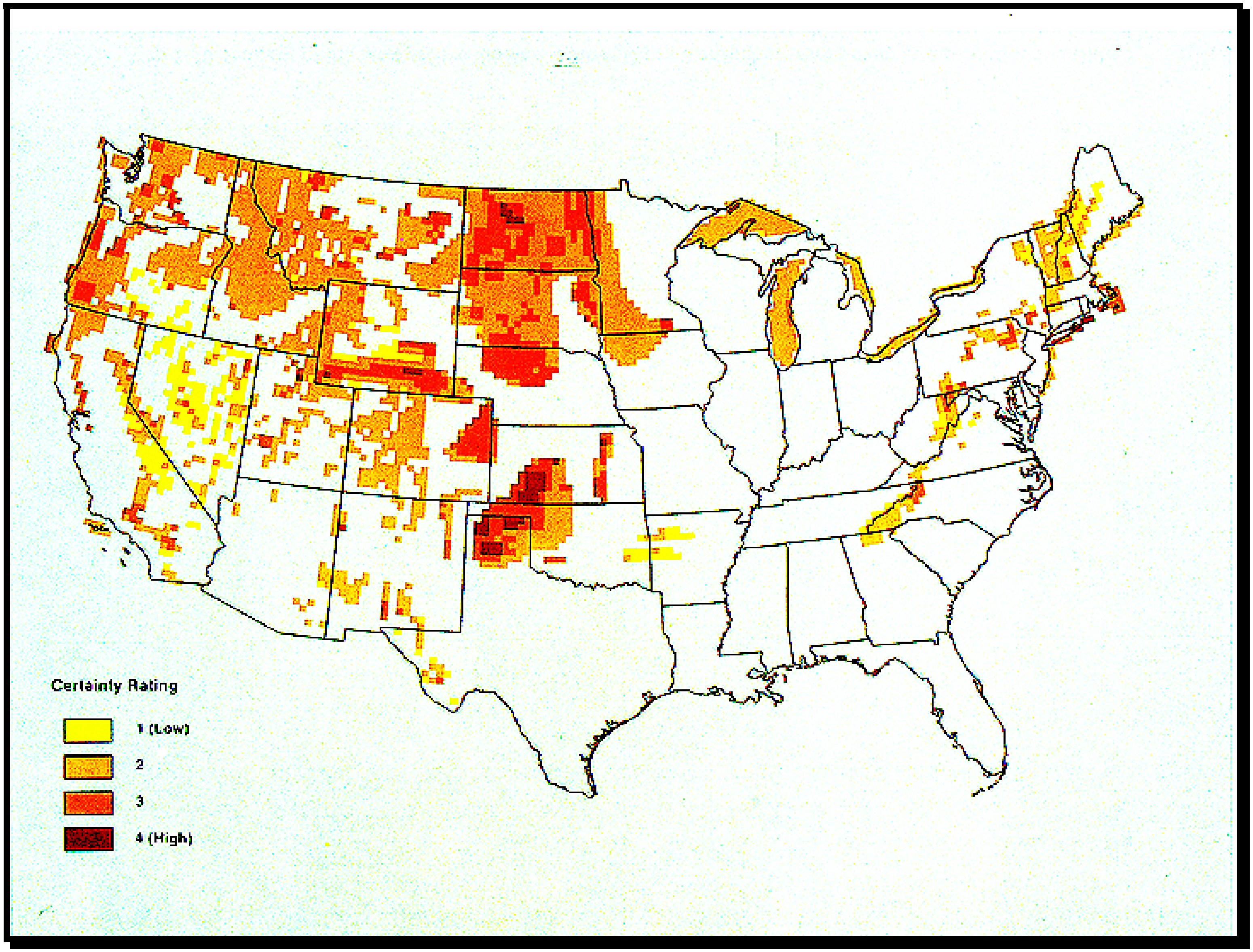

Figure 6.5: http://rredc.nrel.gov/wind/pubs/atlas/maps/chap2/2-09m.html

These two characteristics of the chosen site almost eclipse all other considerations for several reasons. First, wind turbine efficiency or turbine capacity factor is directly proportional to the available wind power and as can be clearly seen in the maps on the preceding pages, the area chosen certainly has vast, wind power resources. Second, wind power opponents typically claim that proposals are overly optimistic with regard to inflated claims of expected turbine capacity factor. The indicated certainty rating identified by the Pacific Northwest Laboratory for the Department of Energy effectively suppresses one of wind energy opponent’s most sited arguments.

Those same opponents typically argue that turbine capacity factors of 20% to 30% are accurate while proponents often argue that capacity factors of 60% TO 70%. A few simple assumptions and calculations can be used to explain why turbine capacity factor can be so readily used by experts and laymen alike to attempt to sway the general public’s opinion with regard to the prospect of utility scale wind energy production.

First, let us make the following assumptions, strictly based on readily available data. A turbine lifecycle is twenty years in duration; our nominal turbine capacity is one megawatt, our installed, grid connected, turbine cost is $5 million, and the cost of coal generated electric power is 5 cents per kilowatt hour ignoring all coal-associated environmental and healthcare costs, we can readily examine both our opponents and proponents capacity factor scenarios.

Based on our opponents worst case capacity factor claim of 20%:

(1000 kW)(20 yrs)(365 days/yr)(24 hrs/day)(20%)

Our 1MW generator will produce 35 million kWh of electric during its twenty year lifecycle, at a cost of $0.143/kWh, almost three times the cost of coal. Based on our proponents best case capacity factor claim of 70%:

(1000 kW)(20 yrs)(365 days/yr)(24 hrs/day)(70%)

Our 1MW generator will produce 123 million kWh of electric during its twenty year lifecycle, at a cost of $0.041/kWh, almost 20% less than the cost of coal. Clearly, assumptions of outlying capacity factors can easily be employed by the expert and layman in an attempt to prove or debunk the prospect of wind power.

In our judgment both capacity factor extremes are inaccurate. As can be seen in both of the chapters that follow, we have based cost analysis scenarios on a turbine capacity factor of 50%. As indicated we have recommended sites having average annual wind power classification of four or higher with a high certainty rating. Additionally, we have recommended the use of excess and off peak power to generate massive quantities of hydrogen using existing and future reformation technology effectively storing excess energy to stabilize output. Our approach is based on a realistically conservative, manufacturer supported capacity factor claim with built in energy reserve production.

As indicated initially, our site was required to have an average annual wind power classification of no less than four. Additional considerations with regard to wind power classification include the range and standard deviation of available wind power resources. Here again our site recommendation provides relatively consistent wind power classifications of four or higher throughout the year

> **Winter Wind Resource (December, January, February)**
>
> Over the northern Great Plains, class 5 wind resource is found in winter over portions of North and South Dakota. Class 4 wind resource covers a substantial part of the northern Great Plains, including much of the Dakotas, hilltops and uplands of eastern Montana, and the Sand Hills of Nebraska. The class 4 wind resource extends eastward into western and southern Minnesota and much of Iowa, hilltops and uplands in southwestern Wisconsin, and a portion of central Illinois.
>
> **Spring Wind Resource (March, April, May)**
>
> Over much of the central United States from eastern Montana to Minnesota and south to Texas, wind power reaches a maximum in the spring. Areas of highest wind resource over this region, class 6, occur in the northern Great Plains over elevated escarpments and uplands throughout North Dakota, near Rapid City in South Dakota, and uplands near Circle, 110 km (70 mi) north of Miles City in eastern Montana.

> **Summer Wind Resource (June, July, August)**
>
> …areas of class 3 or higher wind resource occur over much of the northern and southern Great Plains, the Great Lakes, the south Texas coast, the Pacific coast from south-central California northward to Oregon, southern Wyoming, the wind corridors in specific areas of California, Oregon, Washington, Montana, and Utah, and exposed mountain summits and ridge crests throughout the West.
>
> **Autumn Wind Resource (September, October, November)**
>
> In autumn, upper-air wind speeds increase as autumn progresses toward winter. Consequently, the mean wind power is considerably greater in November than in September over much of the country. Throughout most of the contiguous United States, the mean autumn wind resource is less than that of spring and winter but greater than that of summer.
>
> …most of the Great Plains from northern Texas to North Dakota and Montana; and high plains and wind corridor areas in Montana and Wyoming. Some of the wind corridors in California continue to have high wind resource into the autumn.[26]

Though data suitable to monthly standard deviation analysis could not be found, the seasonal standard deviation was found to be approximately one wind class rating per year with a wind speed range varying from class 4 to class 6 winds as identified in the table on the following page.

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[26] http://rredc.nrel.gov/wind/pubs/atlas/chp2.html#seasonal

**Table 1-1 Classes of wind power density at 10 m and 50 m[(a)].**

| Wind Power Class* | 10 m (33 ft) |  | 50 m (164 ft) |  |
|---|---|---|---|---|
|  | Wind Power Density ($W/m^2$) | Speed(b) m/s (mph) | Wind Power Density ($W/m^2$) | Speed(b) m/s (mph) |
|  |  |  |  |  |
|  |  |  |  |  |
| 1 | 0 | 0 | 0 | 0 |
| 2 | 100 | 4.4 (9.8) | 200 | 5.6 (12.5) |
| 3 | 150 | 5.1 (11.5) | 300 | 6.4 (14.3) |
| 4 | 200 | 5.6 (12.5) | 400 | 7.0 (15.7) |
| 5 | 250 | 6.0 (13.4) | 500 | 7.5 (16.8) |
| 6 | 300 | 6.4 (14.3) | 600 | 8.0 (17.9) |
| 7 | 400 | 7.0 (15.7) | 800 | 8.8 (19.7) |
|  | 1000 | 9.4 (21.1) | 2000 | 11.9 (26.6) |
|  |  |  |  |  |

Table 6.1: http://rredc.nrel.gov/wind/pubs/atlas/tables/A-8T.html

Finally, our recommendation clearly meets the requirement that the site have an average annual wind power classification of no less than four.

## AVAILABLE LAND RESOURCES

In our analysis, available land resource considerations were subordinate to available wind resources. Again Minnesota, North Dakota and South Dakota presented resources appropriate to meet requirements. Specifically, it was required that the location be appropriate for the installation of tens of thousands of wind turbines installed in multiple nodes distributed across a large land area, facilitate grid interconnection for power delivery to the west coast and adjacent states, facilitate in the delivery of both primary and re-formable energy resources and the shipping of transportation and energy scale quantities of hydrogen, generated by reformation, throughout the country, and it was desired that the location of the site aid in the dual usage of land resources and the use of existing environmental management and security resources.

The recommended site encompasses more than 1.9 million acres of land with an average annual wind power classification of four or higher. As outlined in our cost analysis, we propose the installation of between 90,000 and 150,000 wind turbines concentrated in thousands of units in each of multiple nodes, initially leasing and occupying between 180,000 and 300,000 acres throughout western Minnesota, and North and South Dakota.

Typically, wind turbine footprints claim 5% of the land they are installed on. Here again, we have chose a conservative estimate of 20% to include the augmentation of the existing transmission and transportation infrastructure, as well as, the installation of necessary additional transmission and transportation infrastructure and the footprint of the RES nodes themselves including hydrogen reformation and storage facilities.

An additional factor supporting our site recommendation is the current Leafy Spurge infestation in this part of the country.

> ***Damage***
> Leafy spurge is an aggressive weed that tends to displace all other vegetation in pastures and rangelands. The latex in leafy spurge is a skin irritant that can cause severe dermatitis in humans and grazing animals, and is unpalatable and toxic to cattle and horses. Cattle and horses generally avoid leafy spurge, but if ingested it causes scours and weakness that may result in the death of the animals. Sheep and goats are not affected by the toxin and can eat young leafy spurge plants (Muller et al. 1990).
>
> The presence of leafy spurge in pastures can reduce the livestock carrying capacity 50 to 75%. In North Dakota, South Dakota, Montana, and Wyoming, the economic damage done by this weed has been conservatively estimated at over $110 million per year due to losses of forage production and beef cattle production, plus the costs of herbicides and herbicide applications. There is an additional loss of over $11 million annually in North Dakota alone due to reduced wildlife habitat and associated recreational activities. Native prairie species, such as the western prairie fringed orchid, *Plantathera praeclara*, in Cheyenne National Grassland of North Dakota, show serious decline in association with leafy spurge infestations. It is also eliminating the vegetation that is the required habitat for the threatened northern prairie skink, *Eumeces*

> *septentrionalis septentrionalis* (Lym & Kirby 1987; Lym & Messersmith 1990; Bangsund & Leistritz 1991; Thompson et al. 1990; Wallace et al. 1992; Van Driesch & Bellows 1996).[27]

We propose the following mutually beneficial land resource management approach. Renewable Energy Station nodes including wind turbines will in all feasible cases be located on lands currently unusable to farmers and ranchers due to Leafy Spurge infestation. That same land will be leased at $1000 per acre per year, for the initial twenty years outlined in our introduction and cost analysis. During those twenty years the land will be managed and continuously improved using RES revenue effectively reclaiming the land from infestation. After thee initial twenty year lease term, as much as 80% but no less than 60% of leased lands will be returned to the respective farmers and ranchers, at no cost. Acreage necessary for RES operations will be leased at $2000 per acre per year increasing at a rate equal to inflation. The above outlined leasing, land improvement, and return will be non-negotiable and eliminate any and all legal obfuscation of the process.

Finally, the site lends itself to the grid interconnection and heavy freight transportation necessary to provide resources, raw material, and primary energy to the site during and after development and to provide for the transportation and

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[27] http://www.efn.org/~ipmpa/Noxlspur.html

transmission of power from the site once initial installation and development has been completed.

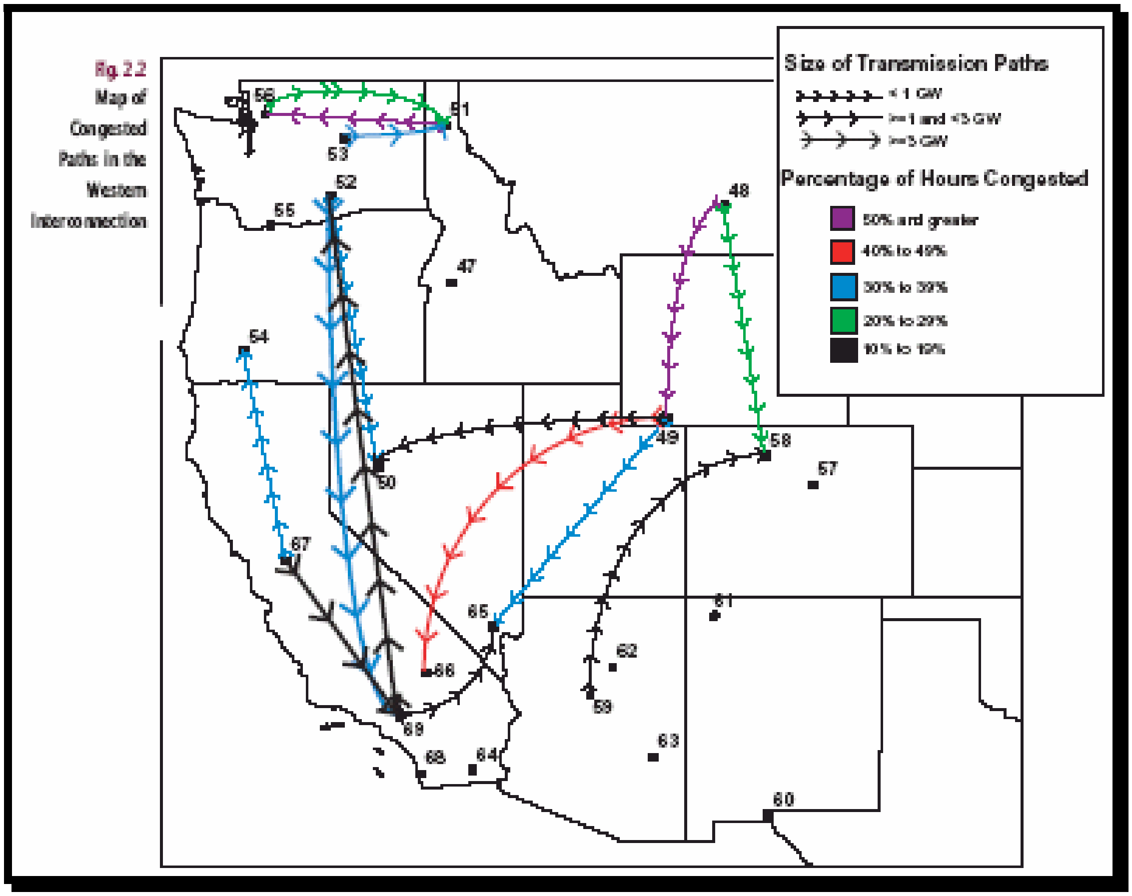

Figure 6.6: National Transmission Grid Study, DOE, May 2002

The figure above details current transmission grid congestion throughout the western section of the United States. The important concept to understand is that we have built tens of billions of dollars per year of working capital (Management and Transmission) into our cost analysis in order to address this very issue. While the transmission infrastructure currently exists, it is badly in need of both updating and augmentation. Our proposal provides for this multi-billion dollar necessity.

Finally, we have recommended the utilization of existing interstate and heavy rail infrastructure throughout the Great Plain states. Again, billions of dollars of working capital have been built into our cost analysis to provide for the necessary improvement and augmentation of these existing systems.

## ENVIRONMENTAL MANAGEMENT AND SECURITY

One of the most effective means of minimizing environmental impact is to develop systems that operate as harmoniously with the environment as is currently possible. Our recommendations and proposals outlined in the foregoing pages strive to accomplish this feat while generating trillions of kilowatt hours of electric power and transportation scale quantities of hydrogen. We desired that the location of the site aid in the dual usage of land resources and the use of existing environmental management and security resources. And again, existing resources and factors in western Minnesota, and North and South Dakota prove to be well suited to the task at hand.

Our approach has been to recommend systems that integrate with existing infrastructure and minimize the need for and impact upon unspoiled land. The primary method of power generation itself uses a vast renewable resource, wind, to produce electric power without pollution. Understanding that humankind must work to achieve harmony with the environment we have built in over one hundred billion dollars worth of additional working capital into our cost analysis scenarios. This additional working capital will be provided to the Department of Environmental Management, the Department of the Interior and the appropriate

National Laboratories specifically, for the purpose of comprehensive studies of and minimization of impact to habitats and research and development to aid in the minimization of habitat impact while increasing both electric power and hydrogen output. Our site location lends itself to our vision of the energy station of the future integrating existing and bold new energy production technologies to generate the energy resources demanded while minimizing environmental impact and to rise to the challenge put forth by our President.

> ***"America must have an energy policy that plans for the future, but meets the needs of today. I believe we can develop our natural resources and protect our environment."***
>
> — President George W. Bush

In the following chapter we recommend the use of hydrogen reformation technology designed to efficiently extract hydrogen from ethanol, a renewable fuel source made from corn. Again our location has been chosen to minimize the environmental impact and maximize efficiency of energy generation and transmission. The northern Great Plain states afford an ideal location for the reception and reformation of ethanol. The freight and heavy rail infrastructure exists and working capital to improve and augment the existing infrastructure has been provided for, in our cost analysis.

> MINNEAPOLIS / ST. PAUL (2/12/2004) -- The first reactor capable of producing hydrogen from a renewable fuel source - ethanol - efficiently enough to hold economic potential has been invented by University of Minnesota engineers. When coupled with a hydrogen fuel cell, the unit - small enough to hold in your hand - could generate one kilowatt of power, almost enough to supply an average home, the researchers said. The technology is poised to remove the major stumbling block to the “hydrogen economy”: no free hydrogen exists, except what is made at high cost from fossil fuels. The work will be published in the Feb. 13 issue of Science.[28]

Numerous studies have been conducted regarding migratory route impact, avian, and bat mortality with respect to wind turbine farms. Numerous studies have identified rare cases of atypical mortality rates with the conclusion that additional longer duration studies are required but not provided for. The migratory route map on the following page when compared to the

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[28] http://www.ur.umn.edu/FMPro?-db=releases&-lay=web&-format=unsreleases/releasesdetail.html&ID=1155&-Find

map of average annual wind power presented on page five clearly shows the intersection of migratory routes and our nation’s most abundant wind power resources.

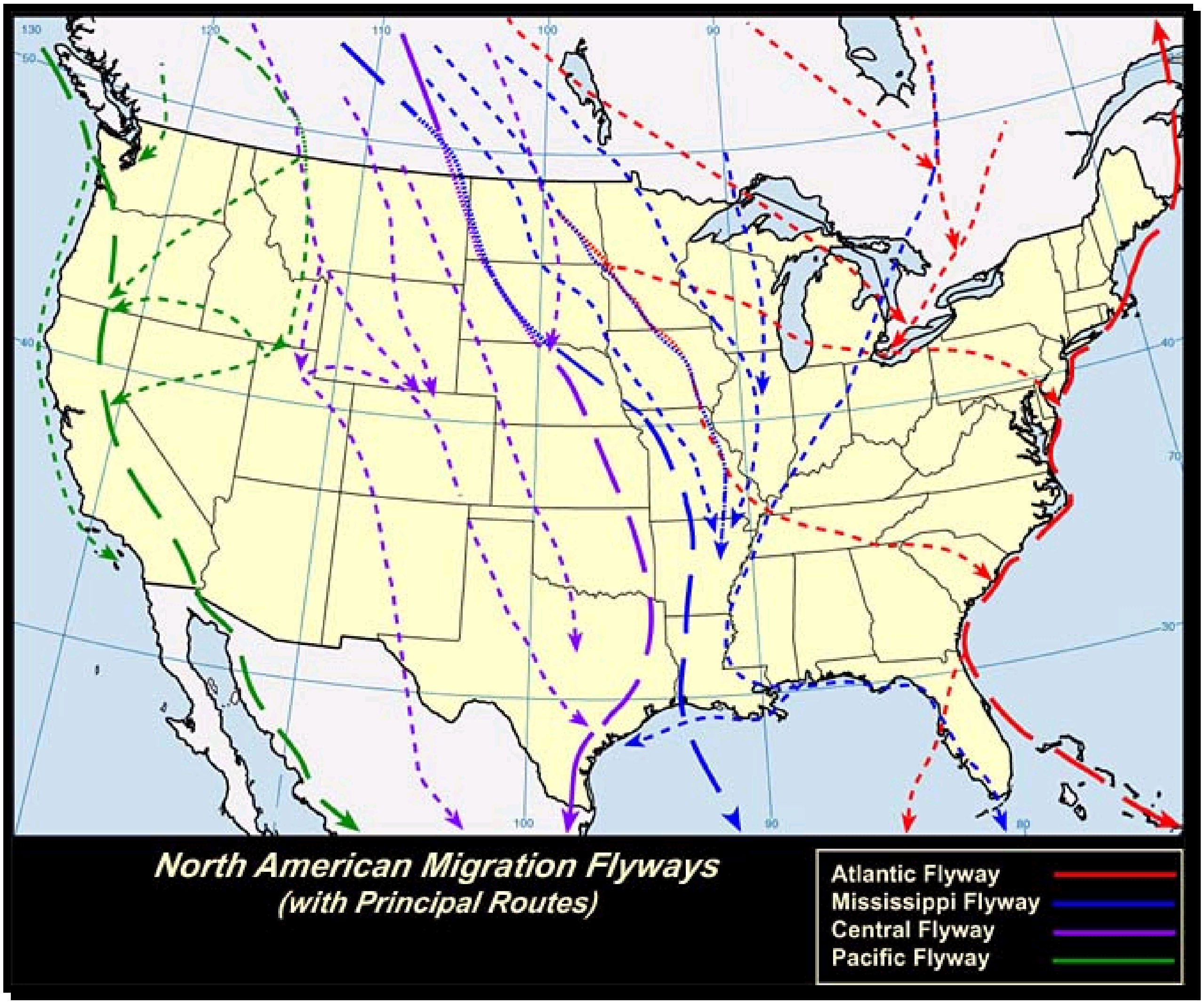

Figure 6.7: http://www.birdnature.com/flyways.html

Our recommendations provide billions of dollars of working capital to fund large scale conservation studies and generate environmentally responsible policies and technology to minimize the impact to all natural habitats, activities, and behaviors while providing the energy our nation needs in the most environmentally responsible manner currently possible. Additionally, we have recommended and provided for the continued improvement of those same policies and technologies.

Lastly, in recent years an appreciation of the stark reality of terrorism has been dramatically emphasized, here in the United States, and heightened throughout many other nations. Any proposal devoid of provisions for immediate and enduring security for such a large scale vision of revolutionizing utility and transportation scale energy production would be reckless at best.

Our proposal provides for the necessity of security by again augmenting and utilizing existing infrastructures rather than establishing new ones. Our recommended site lends itself to the extension of numerous Air Force base no-fly zones. Several established bases, outlined in the table below, are encompassed by or in close proximity to the land area recommended.

| BASE CODE | INSTALLATION | SERVICE | ACREAGE |
|---|---|---|---|
| MN002 | St. Paul IAP AGS | Air Force | 300 |
| ND001 | Grand Forks AFB | Air Force | 23100 |
| ND002 | Hector Field AGS | Air Force | 133 |
| ND003 | Minot AFB | Air Force | 22731 |
| ND004 | Cavalier AFS | Air Force | 650 |
| SD001 | Ellsworth AFB | Air Force | 25494 |
| SD002 | Joe Foss Field AGS | Air Force | 145 |

Here again we propose a mutually beneficial relationship with the local military installations and the Department of Homeland Security, wherein the working capital required for the effective augmentation of infrastructure necessary to provide for the security of such valuable national assets is provided for from management and transmission funds outlined in our cost analysis. Additionally, we propose that electric power and hydrogen fuel required by the bases is provided by the RES to the local military bases in whatever quantities are determined most appropriate.

In Short we propose a revolutionary approach to energy generation wherein massive Renewable Energy Stations with thousands of multiple megawatt wind turbines, hydrogen refineries, and all forms of renewable energy resources are effectively integrated. We recommend that this project be nationalized establishing new manufacturing growth the generation of hundreds of thousands of jobs and rekindling the spirit of this great country in a manner akin to the construction of the interstate system, the construction of the Hoover dam, and the Apollo program. Our vision is one in which the strength and courage of a great nation of pioneers is tapped to create an enduring legacy of achievement, environmental responsibility, and foresight for our nation and our planet.

Worcester Polytechnic Institute
Term E04
Interactive Qualifying Project

Chapter 7

# Renewable Energy Station: Cost Justification

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June 28, 2004

Calculating the cost of an enormous project like this is critical to the planning. The investment required to supply large amount of electricity to the country must be justifiable in order to begin undertaking the project. There are numerous variables when it comes to looking at the economics, but with wind energy costs decreasing production of this energy from the source seems like it will be a huge factor in the future. The costs that we are going to look at include actual cost per unit, maintenance costs, research and development initiatives, and management and transmission. With all these costs we hope to show that we will be able to supply the needed electricity while maintaining a competitive price while keeping future updating in mind.

We looked at two different scenarios when looking at the costs associated with electricity needs. The first scenario is the 1.5 trillion Kwh scenarios and the second is 2 trillion Kwh. Currently the United States is projected to consume around 6 trillion Kwh in the year 2020 which means 1.5 trillion Kwh would be a quarter of the total energy needs. This would mean our proposal would be able to give enough energy for the entire west coast and adjacent states where energy needs are great. While looking at our scenarios we were very conservative with assigning costs therefore trying not to make the mistakes of previous exploratory attempts concerning wind energy. Our allowance for programs such as workforce development and research and development greatly exceeds what needs to be allotted from out calculations.

Below are the cost terms that we used to gauge an accurate representation of our project:

Unit capacity: The generator that we have chosen is a 3.6Mw unit being one of the most powerful units on the market today. With our conservative ratings we gave a efficiency factor, explained in research, of 50% which is a reasonable estimate for the location in which we are putting these units. Competitors have similar units just not as large and without the support capabilities that come with a company such as GE.

Units required: With the estimates for electricity usage we were able to extrapolate numbers of units based on the unit capacity and the efficiecy factor

Per Unit Installed cost: Our per unit installed cost looks at the installation of the unit and takes into account a low prediction as well as a high estimate.

Initial cost: The initial cost is the total capitol cost associated with the building of the wind farm’s units

Workforce Development: This section of the cost analysis deals with a stipend for the production of the wind machines because of the large scale production needs

Annual Maintenance Costs: Maintenance Costs were taken at 10 percent of the initial cost of the project, these maintenance cost allotment allows sufficient room to any problems as more accurate maintenance costs are around 5 percent of the capitol cost based on AWEA research.

Renewable Energy Technology Research and Development: This allotment allows the research needed to bring wind energy to the next level with the end goal of producing more electricity through wind farms. Improved generators and lighter materials might give a way to produce more through the units.

Annual Management and transmission: With a wind farm of this magnitude managing and transmitting the energy once produced becomes a large task therefore the budget for the category needs to be able to cover the cost

Annual Capitol loss: Deals with revenue escrowed for replacement and upgrade of all turbines every twenty years as well as the deterioration of the capitol worth of the project

Annual Environmental Budget: Allowance for environmental research and studies as well as protection of species and prevention measures around the wind farm

| | 1.5 trillion kwh production | |
|---|---|---|
| *Per unit Cost* | $1,800,000.00 | $3,600,000.00 |
| *Unit Capacity* | 3.6 MW | 3.6 MW |
| *Capacity Factor* | 50% | 50% |
| *Hours/Year* | 8760 | 8760 |
| *Units Required* | 95000 | 95000 |
| *Initial Cost* | $171,000,000,000.00 | $342,000,000,000.00 |
| *Workforce Development* | $30,000,000,000.00 | $30,000,000,000.00 |
| *Annual Maintenance* | $1,710,000,000.00 | $3,420,000,000.00 |
| *Annual R& D* | $10,000,000,000.00 | $10,000,000,000.00 |
| *Management and Transmission* | $30,000,000,000.00 | $30,000,000,000.00 |
| *Annual Capitol Loss* | $8,550,000,000.00 | $17,100,000,000.00 |
| *Annual Environmental Budget* | $1,710,000,000.00 | $3,420,000,000.00 |
| *20 year Cost* | **$1,240,000,000,000.00** | **$1,658,000,000,000.00** |
| *20 year production* | 30000000000000 Kwh | 30000000000000 Kwh |
| *Cost per Kwh* | **$0.04140** | **$0.05500** |

| | 2 trillion kwh production | |
|---|---|---|
| *Per unit Cost* | $1,800,000.00 | $3,600,000.00 |
| *Unit Capacity* | 3.6 MW | 3.6 MW |
| *Capacity Factor* | 50% | 50% |
| *Hours/Year* | 8760 | 8760 |
| *Units Required* | 126840 | 126840 |
| *Initial Cost* | $228,312,000,000.00 | $456,624,000,000.00 |
| *Workforce Development* | $40,000,000,000.00 | $40,000,000,000.00 |
| *Annual Maintenance* | $22,831,200,000.00 | $45,662,400,000.00 |
| *Annual R& D* | $12,500,000,000.00 | $12,500,000,000.00 |
| *Management and Transmission* | $40,000,000,000.00 | $40,000,000,000.00 |
| *Annual Capitol Loss* | $11,400,000,000.00 | $22,900,000,000.00 |
| *Annual Environmental Budget* | $2,280,000,000.00 | $3,420,000,000.00 |
| *20 year Cost* | **$1,637,000,000,000.00** | **$1,578,000,000,000.00** |
| *20 year production* | 40000000000000 Kwh | 40000000000000 Kwh |
| *Cost per Kwh* | **$0.04090** | **$0.05470** |

**Table 7.1: Detailed Cost Analysis Breakdown**

This project, based on the costs shown above would need to be a partnership between the government and other companies in order for it to work.  There is a lot of space available for these windmills to occupy in the states that we have chosen and land costs which are included in the initial cost are almost negligible when looking at the scope of everything else.

One idea that shows promise if contractual agreements could ever be worked out would be an agreement between farmers in the mid west area and our project.  At the present time thousands of acres are not being used by farmland due to a leafy spurge problem making their land worth around a hundred dollars per acre.  Based on this we would go in and lease lots of the land, hundreds of thousands of acres if needed, and put the wind farm on the land.  For this small price we would be producing energy while efforts hired by our endeavor would rid the landscape of the leafy spurge in order to return the farmland to a useable state.  At that point we would release the land back to the owner and keep the minimal percentage, estimated at 10 percent of the original buy, in order to keep the production of electricity through our farm.

This situation would help out farmers in the area stricken with the leafy spurge problem, as well as supplying us a base to operate our farm.  Calculating the cost of the lease into our cost analysis would equate to no change from our current cost of Kwh to the public.

There are several ways in which savings for this project can occur, but mostly savings would have to occur in the production of the units themselves. The huge initial cost coupled by other budgeted programs centered on the production of the units take up a large portion of the allotted budget. Advanced production methods such as production lines with mechanical conveyors would have to be implemented for high scale production. With the work force supplementation worked into our model it would be appropriate to have this huge production schedule ready fairly quickly, that being around a few years for completion. Producing 35 units per day for 10 years would give you the quantity needed to meet the needed set forth above.

All in all little can change the prices that we have acquired, and the huge cost is out weighed by the valuable energy being supplied to a portion of the country where it is needed so badly. With help from the government and an initiative to look at cleaner, renewable energy resources is the future of energy needs of this country.

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Renewable Energy Technology: Augment current national budget for the research and development of improved turbine technology, inverter technology, superconductors, hydrogen reformation, biomass energy generation, magnetic levitation rail systems, etc.

Revenue escrowed for replacement and upgrade of all turbines every twenty years.

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[13] http://www.ur.umn.edu/FMPro?-db=releases&-lay=web&-format=unsreleases/releasesdetail.html&ID=1155&-Find

[14] The Scottish Executive is the body that governs Scotland in relation to all devolved matters. The Scottish Executive is formed from the party or parties holding a majority of seats in the Parliament. The members of the Executive are collectively

referred to as 'the Scottish Ministers'. All Ministers are MSPs. This means that they are part of two separate organizations: the Scottish Executive (Ministers) and the Scottish Parliament (MSPs). Ministers head up the departments, which are run by the Scottish civil service. The Scottish Executive is led by the First Minister.
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[15] http://www.awea.org/faq/tutorial/wwt_smallwind.html#How%20much%20does%20a%20wind%20system%20cost

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[17] Renewable Energy Technology: Augment current national budget for the research and development of improved turbine technology, inverter technology, superconductors, hydrogen reformation, biomass energy generation, magnetic levitation rail systems, etc.

[18] Revenue escrowed for replacement and upgrade of all turbines every twenty years.

[19] http://rredc.nrel.gov/wind/pubs/atlas/chp2.html#seasonal

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