Fossil Fuels and Wind Power:
Feasibility Analysis of Wind Power in Massachusetts and Worcester

An Interactive Qualifying Project Report

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1. Energy and Resources
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Abstract:

The place of wind power in the renewable energy economy is discussed and the current state of wind power is explored through research. Wind turbine effectiveness and barriers to wind power installation are also explored. Ultimately, wind power's potential contributions to the city of Worcester, the state of Massachusetts, and the United States as a whole are considered.

Acknowledgements:

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1. Introduction

The world energy demand is steadily rising. Over the last 25 years, the average annual increase in world wide energy consumption has been around 5.9 quadrillion Btu/year[1]. In 2002, 86% of this energy worldwide came from the non-renewable fossil fuels, including coal, natural gas and petroleum[2]. Not only are these energy sources diminishing at an ever increasing rate with rising demand, but in large quantities they are also generating harmful pollutants. As our society has felt the growing effect of pollution and the scarcity of both oil and natural gas, measures to change the modern energy economy have been increasingly sought. In America, the environmental hazards and decreasing reserves of fossil fuels are not the only problem; our dependence on foreign oil is also a significant concern.

As humanity has passed through the 20th century we have begun to understand the importance of sustainability, both in terms of resources and on a sociological level. Looking at the supply and effects of fossil fuels, sustainability and independence are at the focus of the energy situation. As our country once again enters a new era, the energy crisis we are facing has long reaching implications on the international scale. Renewable energies have the greatest prospect for the future of our country and the world.

As a result of this increasing need for sustainable energy sources, a new energy economy needs to be developed. Ideally, this new energy economy will include a variety of renewable energy sources; one of these renewable energies is wind power. This Interactive Qualifying Project centers on the role of wind power in the new energy economy, and its ability or inability to become an alternative to fossil fuels.

Because wind power is currently such a controversial issue in many areas, the social implications of an expanding wind infrastructure are a determining factor in the feasibility of wind power as a large scale alternative energy source. Because wind resources are also an unevenly distributed resource, an analysis of wind power capacity centered around the energy density of wind in specific locations is also necessary. Several primary methods are used to investigate both the social and practical aspects of wind power. These methods include a study of current wind farm sites, taking into account the social issues surrounding these projects, as well as an independent study of the technology and net wind resources available in certain areas.

2. Current US Energy Economy and Outlook

The current and projected future production of oil, coal, and natural gas will have an enormous effect on what the US and worldwide energy economy will look like in the next 20 to 30 years. Though there are many different views on when worldwide peak production of oil will occur, it is widely agreed that oil is the least abundant of the three fossil fuels and will become depleted first[3]. Estimates on when this peak production will occur, range from the end of 2005[4] to 2047[5]. Even though petroleum is not used in a significant way in the US electrical system a significant drop in production will affect our entire society.

Petroleum is almost the exclusive fuel of the transportation industry, delivering 99% of the energy for both cars and air travel, in addition to being used widely in America's plastics industry. Unless the "62 million registered vehicles in the U.S."[6] are going to be replaced in the very near future, another source of high grade gasoline may be needed. Other methods for producing gasoline and sustaining our oil driven economy include using plant oils to create diesel and coal gasification using the Fischer-Tropsch process. The Fischer-Tropsch process can be used to make aviation fuel and gasoline to power the US transportation industry. However, coal is the dirtiest of the fossil fuels and the Fischer-Tropsch process requires a reserve of hydrogen to crack larger hydrocarbons; today the largest industrial production of hydrogen comes from natural gas or coal gasification. Coal and natural gas already supply 65% of US electrical energy, if coal gasification is used to produce gasoline for our transportation industry, the 200 year estimated reserves for coal will be cut significantly. Using plant oils to create diesel would also require a major restructuring of American agriculture and land use. A better generator of electricity could be found in renewables.

The pollution and environment hazards of fossil fuels are significant. Some of the better known forms of this pollution are chemical smog, global warming, acid rain, and the environmental disruption of oil drilling and coal mining. Other hazards include mercury dispersion and the release of particulate matter from burning coal. It is true that the US and the world have decreased harmful pollution through technological measures in the past several decades. However, if we continue to burn coal and other fossil fuels for the next hundred years, the consequences may include more drastic global effects that are difficult to predict. Besides global environmental problems, chemicals released into the atmosphere from power plants and industries can lead to “asthma, bronchitis, emphysema and other respiratory problems”[7]. Mercury is also a dangerous chemical, able to bio-accumulate in fish and wildlife and cause neurological diseases when exposed to humans[8].

In addition to the problems of scarcity and pollution, the US should also be concerned with its dependence on foreign sources of energy, not just oil. As mentioned previously, when oil production starts to drop, alternative energy sources will begin to be implemented most likely from both domestic and foreign sources. The US has an abundance of coal (and natural gas, less so); however, these are still non-renewable resources and demand for them may increase greatly in the next 30 years as oil production begins to decrease. The U.S also has an abundance of wind resources, more than enough to power the whole country’s energy needs[9]. There are, however, economic and social factors that dampen the possible growth of wind power that must be overcome. Many economic barriers are being overcome through technological innovation and government programming. Social barriers are also receding as wind power becomes more prevalent.

2.1 Short and Long Term Solution

Whether oil production begins to decline in the next year or thirty years from now, a major restructuring of the sources we get our energy from will occur, including a restructuring of the energy distribution system. Though it is difficult to say how we might be prepared for this crisis in thirty years, if technological breakthrough is expected to become an energy silver bullet we may not be much better off. Many of the technologies that have the ability to reduce our dependence on fossil fuels, or at the very least allow us to get more fossil fuels out of current known reserves, already have decades of research and development spent on them.

Unconventional reserves of both oil and gas could double the time before we run out of fossil fuels. The amount of natural gas stored in gas hydrates (Gas hydrates are a complex of natural gas and water, where the natural gas dissolves in the water and the water crystallizes; they are found in solid form.)[10] is estimated to be up to 100 times the conventional natural gas reserves in the world. Gas hydrates are common in the far north 600-3000 feet below permafrost trapped in ice and also outside the oceanic continental shelf 2000-8000 feet below the surface[11]. There has only been one production facility for gas hydrates, in Siberia, and that was discovered by accident. It is possible that a production method for oceanic gas hydrates could be developed, but the extent of gas hydrates has been known for some time and no company has been able to extract it economically.

Oil shale and heavy oil sands also hold more oil than all the conventional oil reserves of the world. Heavy oil sands are basically a conventional oil reserve that didn't have a non-porous cap rock to keep the oil in the earth. They can be strip mined from the surface and refined into lighter oils with a reserve of hydrogen. Currently heavy oil sands accounts for 33% of Canada's total oil production, and future production looks hopeful, but may be slow[12]. Oil shale, like heavy oil sands, is simply oil trapped in rocks. If the rock is heated the oil will come out and the energy loss of heating the shale is not significant enough to make the process uneconomical. Both oil shale and heavy oil sands are hopeful prospects to replace conventional reserves. Even if oil sands and oil shale are able to carry our society after production drops from conventional reserves, pollution will be an even greater problem since heavy oil sands require more refining than conventional oil reserves and also require cracking, for which hydrogen from either natural gas or coal is needed.

Coal and nuclear plants are likely short term solutions to the energy crisis. As mentioned previously, however, coal and natural gas may be required to replace substantial amounts of petroleum. Other sources of electricity, either nuclear or renewable, may be the best choices for making up the difference. Currently, there is quite a bit of controversy over the future of nuclear power in America. The Department of Energy is developing two programs to outline a roadmap for the deployment of new nuclear generation facilities. One program is designed to support and facilitate near-term deployment by 2010, and these reactors are called Generation III+ reactors[13]. The other program is designed to promote nuclear reactor technology that may be used by 2030, these reactors are called Generation IV reactors[14]. Generation III+ reactors include some improved older models and also a selection of new innovative designs, both of which are planned primarily around better fuel efficiency, passive safety measures, and higher thermal efficiency. Generation IV reactors continue with these basic ideas and try to add long term sustainability of fuels into the picture by expanding the number of consumable fuels and by burning past nuclear waste into material with shorter half-lives.

Ultimately, however, renewable energy and usage efficiency are the only long term solutions for our energy needs. The renewable energy solution will most likely incorporate many different renewable energy sources. These sources include any methods that allow the relatively quick conversion of solar energy into a fuel or electricity. Broadly, these include hydroelectric, geothermal, tidal, photovoltaic, bio-fuels, and wind power. Each of these sources has the capacity to convert solar radiation into a fuel or electricity quickly and sustainable without net pollution.

Many alternative energy sources today contribute very little to total energy consumption of America and the world. Geothermal and tidal systems are only used in a few countries, though they can be extremely significant. Currently, geothermal energy in Iceland heats 85% of the nation's houses and provides 5.8% of their electricity[15]. In 2002, worldwide hydroelectric production accounted for 17% of total world electrical energy production which is roughly equivalent to worldwide production from nuclear sources[16]. Hydroelectric energy is the leading producer of energy in the renewable energy field.

Several other IQPs including Akinci[17] and Degen et al.[18] examined bio-fuels including bio-diesel and bio-hydrogen. Degen, Ehnstrom and Baxter examined the possible use of fermentation reactors using different substrates to produce hydrogen. Their analysis concluded that although it is possible for a bio-hydrogen reactor to produce enough hydrogen for an average house, the amount of substrate needed is unreasonable. To power Worcester using dark fermentation, 25.7% of the sugar produced in America would be needed[19]. Both projects examined the potential for using plant derived oils to create bio-diesel. Akinci and Degen et al. agreed that using micro algae to create bio-diesel could support a large portion of America's transportation energy needs. Using conservative estimates, Akinci found that 3.4% of US land area would be needed to supply the motor vehicle energy consumption of the US using micro algae derived bio-diesel[20]. Difficulties with bio-diesel include the need for a constant warm temperature and sunlight. However, the energy production estimate provided by Akinci includes only energy derived from oils, if micro algae derived bio-diesel were produced on a large scale "energy stored in the protein and carbohydrates should be used as well."[21]

3. Wind Energy History

Wind has been used for human benefit since early in the history of civilization. Sailing craft were among the first devices to harness the power of the wind. The first actual proof of windmills being used as a device to make life easier is from 10th century Persia in the form of wind-powered mills that were used to raise water for irrigation and grind corn[22]. These windmills rotated around a vertical axis unlike stereotypical windmills, which rotate around a horizontal axis. The efficiency of this early design was much lower than the more modern design but did not need to be raised off the ground significantly, thereby making its construction much easier.

In the 13th century, Europeans began using the modern construction type to build windmills for the same purpose of grinding grain. Hundreds of years of development eventually optimized the windmill design with many features that still remain on modern windmills including several modifications of the blade design[23].

When Europeans traveled to America, they brought their windmill designs with them. Many early colonies (especially those in New England) made significant use of windmills to grind grain as well as to power sawmills[24]. Most importantly, windmills that were designed for raising water out of the ground were used in settling the West. Without these, there would have been significant shortages of water, making farm life in the West very difficult. A huge number of these windmills were installed (reportedly, around six million units between 1880 and 1930)[25].

The first windmill designed to produce large-scale electricity was built in 1888 by Charles Brush. It had a rotor approximately 17 meters in diameter and produced around 12 kW; comparably sized modern turbines produce between 70 and 100 kW[26]. This shows the progress that has been made in efficiency since these early electricity-producing windmills.

Smaller systems were being developed by the 1920’s, but became unpopular very quickly as a result of the Great Depression; the resulting extension of the electrical grid due to public works projects, while very important on its own, also caused a decline in small wind system sales. Prior to World War II, however, several large-scale turbines were erected in the United States as well as in Europe. Most of the actual design work during this era was conducted in Europe—specifically, in Germany and Denmark. Several parts of the traditional design were modified in order to make large-scale turbines possible, including the addition of protective features (which were largely German modifications) and the use of alternative materials (which were used mostly in the Danish designs).

The oil crisis in 1973 gave the United States a new reason to study alternative energy sources, including wind power. German and Danish design modifications were implemented in a variety of new installations with varying degrees of success, but due to a number of changes in United States research goals, there were few notable successes. A number of new systems were developed in the following decades, and as expected many were simply modifications of or improvements upon existing designs. As a result of this research, modern designs are much more efficient.

4. Why wind energy?

Each alternative energy source has certain areas in which it is most valuable (for example, direct solar energy is a good choice in areas that receive large amounts of sunlight). The reason wind energy is so important is that it, like solar energy, is essentially unlimited and contains great amounts of power that can be readily harnessed, especially in areas with high wind speeds.

Wind energy is important because there are some areas that have high-speed winds and thus can benefit significantly from the installation of wind turbines. Another reason why wind energy is often one of the first choices among renewable energy sources is that the technology to harness wind is already mostly developed due to its long history. Technological modifications are still in progress but the efficiency is much higher than it was in previous years and as a result. There is no expectation of much further improvement upon the basic designs of modern wind turbines. This means that it currently can be cost effective to install wind turbines, and that new models will not supplant the current technology very quickly.

5. Wind Availability

When considering wind power as an alternative energy source, it is important to analyze the worldwide, national, and local wind that is available. This makes it possible to determine some areas that could be used for the construction of successful wind farms as well as areas where wind power would not be a high renewable energy contributor. Additionally, this section includes an analysis of the Worcester area as well as Massachusetts in general in order to establish whether or not wind energy could be significant to the state's renewable energy needs.

5.1 United Kingdom, Germany and Europe:

In many ways, Europe's energy problems are similar to those of Northeastern America. With high population densities and the need for non-polluting and domestic energy supplies, a comparison between how different countries in Europe have successfully made wind power an integral part of their energy system is valuable for creating a future outlook on wind power's role in the Northeast.

As seen in Figure 5.1 and Figure 5.2, the northeastern United States has a comparable population density and wind capacity to Western Europe. Though population density is not always a critical factor in other sources of energy, it is many times a crucial factor in how well wind power can be implemented in a certain area. Wind power has one of the largest social effects on the local population surrounding the generation site—more than any other energy source. This factor can be seen in the conflicts surrounding wind power in Massachusetts especially in Princeton and on Cape Cod. The United Kingdom is beginning to encounter similar resistance from local residents affected by new wind farm sites. In the United Kingdom, many current projects are facing "opposition from local activists, who claim that wind farms are unsightly and destroy local bird populations."[27] This sociological factor is one of the major roadblocks for wind power in highly populated areas.

Europe is also dealing with many of the same environmental implications of fossil fuels as America and the northeast are: both pollution and energy dependence. With the introduction of the Kyoto Protocol, CO_2 emissions in Europe are now required to be reduced by a significant amount also. The United Kingdom must reduce its 1990 level of CO_2 emissions by 12.5% by 2012. Also, many countries continue to be dependent on foreign sources of energy, especially oil. Germany imported 94% of its oil supply and 63% of its total energy supply in 2002.[28] By comparison, in 2004 only 58% of oil products in America came from imports.

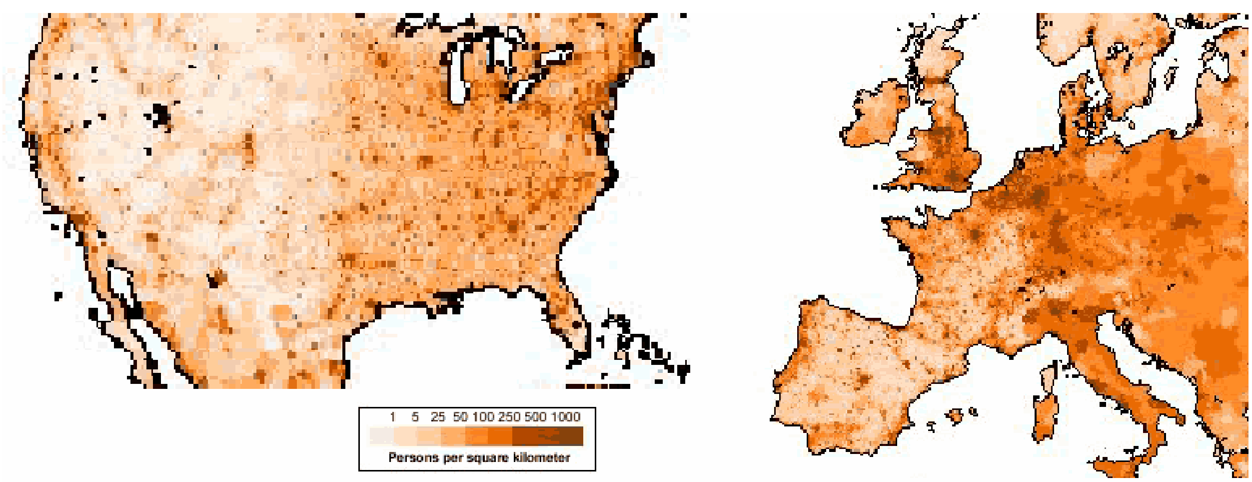


Figure 5.1– Population Density
This figure compares the population density of the northeastern United States with central and Western Europe. Dark red is high population density. Not to Scale.29

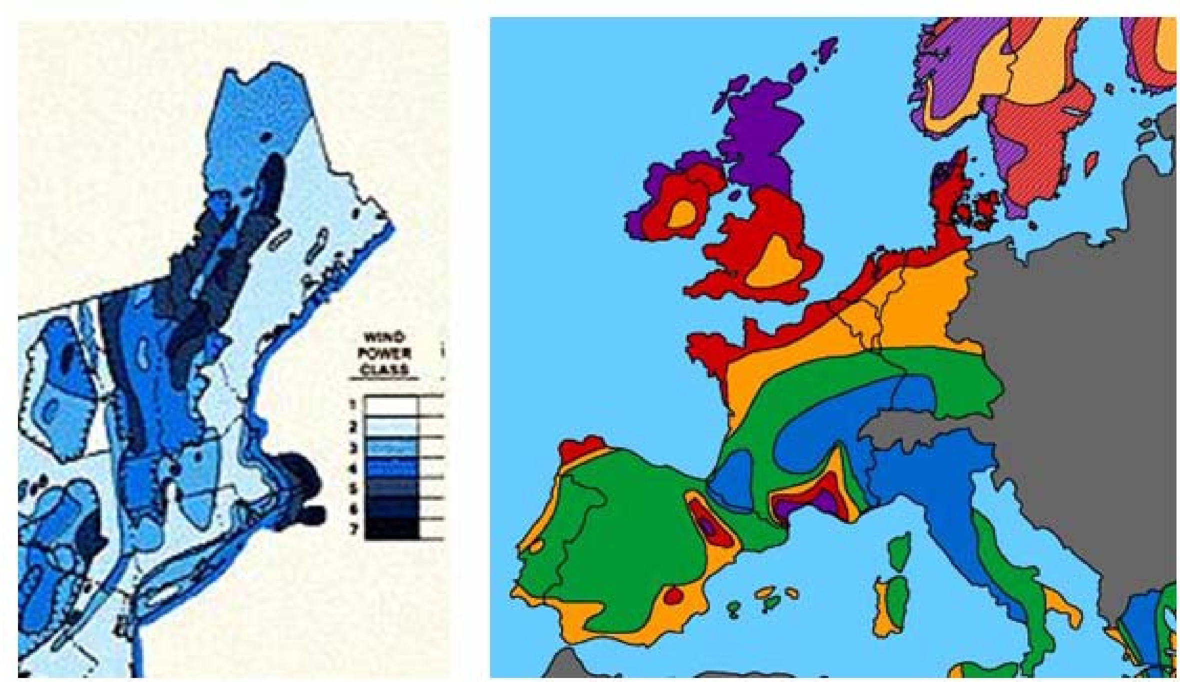


Figure 5.2 – Wind Resources
Although the scale is obviously different in both these figures they are qualitatively the same. Black correlates to purple, and the various shades of dark blue correlate with red and orange. As can be seen, there are very good wind resources in Maine, Vermont, New Hampshire, and northern Europe.[30]

5.2 Wind Power in Germany and the United Kingdom:

Among the European countries, the United Kingdom and Germany are unique in that they are leaders in the world in terms of their innovative approach to implementing wind power: Germany is the world leader in operational wind capacity, and the United Kingdom is making strides in utilizing its land and wind resources efficiently. Both these countries also have high population densities, similar to New England. Table 5.1 compares the top wind power producing countries in the world.

Country	Additional capacity in 2003 (MW)	Rate of growth in 2003 (%)	Total capacity installed end of 2003 (MW)
Germany	2,608.1	21.7	14,609.1
USA	1,685.0	36.0	6,370.0
Spain	1,372.0	28.4	6,202.0

Denmark	230.0	8.0	3,110.0
India	408.0	24.0	2,110.0
Italy	119.0	15.2	904.0
The Netherlands	187.0	27.3	873.0
United Kingdom	97.0	17.6	649.0
China	99.0	21.2	567.0

Table 5.1 – World energy leaders in wind power[31]

In Germany there is a large push toward renewable energy in the hope that it will pull the country out of the short term economic recession in which it found itself during 2003. Large investments are being made to enlarge sectors of the economy in addition to reducing Germany's dependence on foreign energy sources. Because of its almost complete lack of oil reserves, Germany has also focused heavily on long term, in addition to short term, goals. The Renewable Energy Sources Act that was passed in 2000 hopes to "increase the amount of renewable energies in the power supply to 12.5 % by 2010."[32] This Act also sets goals of 20% and 50% of the country's energy supply from renewable by 2020 and 2050, respectively. The Act works by requiring electrical grid operators to buy from renewable sources in addition to setting maximum prices for renewable energies.

According to the Germany Association for Wind Energy, the "government aims to develop large wind parks offshore"[33] now that land is becoming scarce. However, with a high population density, Germany has been able to install more than twice the wind power capacity of the entire United States on a land area less than 4% the size of the US. As can be seen from Figure 5.3, Germany is continuing to support a thriving wind energy economy.

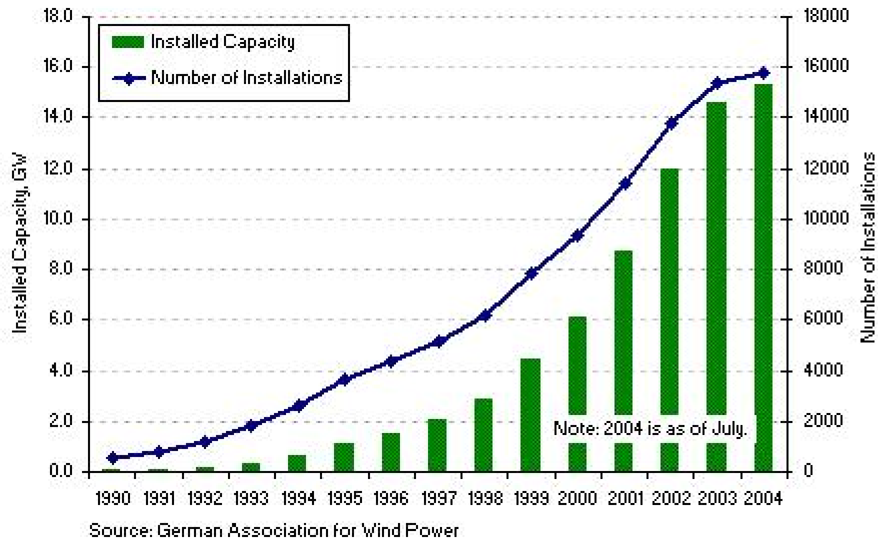


Figure 5.3 – Growth in German wind capacity and number of installations[34]

The United Kingdom is working in a similar way to Germany in its use of national legislature to support renewable energy. Currently, electricity suppliers are required to obtain 3% of their power from renewable sources, this is expected to increase to 10% by 2010[35]. In addition to this, the United Kingdom focuses on mid-size projects. Following is a compilation of data from the 94 grid connected projects in Britain[36]:

Average Number of Turbines	Average Capacity (MW)	Average Homes Supplied
12.6	9.45	6,156

Table 5.2 – Average Size and Capacity of Wind Turbines in the UK[37]

As can be seen, many of these projects are larger than the projects at Princeton and Hull, MA. However, they are much smaller than the Cape Wind project. These statistics portray a focus on using land economically and to its full capacity where available. The range of average wind farm capacity and average number of turbines is 60MW and 102, respectively. In areas where a small farm could supply a population of people, it was implemented. Likewise, large wind farms were also used.

In the US, in many cases legislation regarding renewable energy has been left to individual states. Several states have adopted Renewable Energy Portfolios, however, a National Renewable Portfolio (NRP) may encourage larger investment in sustainable energy. The Energy Information Administration recently completed an analysis of how a NRP would affect energy prices[38]. According to this analysis, a national renewable portfolio designed to meet 10-20% of US electricity consumption by 2020 would have little effect on consumer electricity prices, raising prices by less than 1%. Over the past decade, the United States has supported renewable energy through a Production Tax Credit (PTC) which grants tax credits (to the producer of the renewable energy, which could be the owner of the turbines) for creation of electricity from renewable means. The 2004-2005 PTC granted a tax credit of 1.8 cents for every kWh of renewable energy produced[39]. This bill, however, is being extended on a bi-yearly basis causing major spurts and lulls in America's renewable energy industry. As many countries consider their energy supply 20 to 30 years in the future, long term commitments and legislation are becoming more common.

The Energy Information Administration NRP analysis also examined the effect of pollution control legislation. The report estimates that without the US government playing a role in emissions caps or a Renewable Portfolio, renewable sources will only account for 2.8% of electrical energy by 2020[40]. If a CO2 cap of 7% below 1990 levels is implemented that the renewable energy sector could account for 6.4% of electricity production[41]. However, it is believed that emissions caps will merely transfer production from one fossil fuel and renewable sources will always be more expensive unless a NRP is instituted.

5.3 Global Wind Resources and Infrastructure:

Both the advantages and disadvantages of fossil fuels are felt on a global scale. As many of the disadvantages of fossil fuels become apparent, countries are trying more and more to utilize renewable sources of energy. Two countries in the world that follow this description to a greater degree than many others are India and China. These countries have some of the worst pollution in the world and also have some of the fastest growing economies and need for additional energy.

5.3.1 China

In 2005 the Chinese Renewable Energy Industry Association (CREIA) met with the European Wind Energy Association (EWEA) and Greenpeace to develop a blueprint for wind power production in China. The blueprint is called *Wind Force 12 – China* and outlines expectations and possible production plans for wind power in China. The report is mainly a feasibility estimate exploring the potential of wind power in China by 2020. According to the report, by 2020 China could have 170 GW of installed capacity powering 12% of the country[42]. This is the upper limit of what China could achieve in the next 15 years with an estimated investment of 105 billion euros. A more realistic estimate is given by the US National Renewable Energy Laboratory as 20GW[43]. China has more than doubled its wind capacity since 1998 and all indications point to even a greater commitment in coming years. China's plans are further discussed in Appendix C.3.

5.3.2 India

India is also moving forward towards wind power. India is confronting many of the same problems as China including pollution, population growth and increased energy consumption at levels the country is currently not prepared for. Electrical production in India is falling behind demand to an extent that "power outages are common, and the unreliability of electricity supplies is severe enough to constitute a constraint on the country's overall economic development."[44] Currently, India has the fifth largest installed capacity for wind energy in the world and in 2003 India expanded their capacity by 400MW, more than any other country ever has in a single year.[45] The Indian Government's plans to support wind power include extensive tax rebates and a system of nationwide government sponsored monitoring stations designed to site wind turbines efficiently.

5.4 New England Wind Analysis

New England has some of the highest areas of electricity consumption in the United States due to large cities, densely populated suburbs, and frequent use of heat in the winter and air conditioning in the summer. Due to transmission losses, it is most effective to generate power in the New England area for use in the New England area. For an analysis of the wind power available in New England, the wind speed needs to be measured to determine which areas will be used as wind power sites.

Worcester County only has “fair” wind conditions according to the National Renewable Energy Laboratory (NREL)[46]; this translates roughly to an average wind speed of about 5 m/s which provides a wind power density of 160 (W/m^2)[47] (all wind statistics in this section are evaluated at 50 meters above ground). The city of Worcester used roughly 1,507,000 MWh over the course of 2004, including residential, commercial, and other uses. Given that usage number and the average wind power density from above, it would take more than 200 - 2.3 MW wind turbines to power the city of Worcester [48]. If 3.2 MW turbines were used instead, roughly 120 turbines would be needed. These numbers are enormous, but they are largely due to the low wind power density in the Worcester area; however, a smaller number could be used to make an impact on the city’s energy needs.

Due to these statistics, placing wind turbines in most parts of Worcester County would be a waste of time and money; however, there is a small area that could provide a wind power density of roughly 300 W/m^2 in Paxton—only a few miles from Worcester. Additionally, there is an area in Westminster—north of Worcester—that has wind power densities nearing 600 W/m^2. There is no way at present to know whether or not the land is available for turbine usage, but the mere fact that there is wind available in the immediate vicinity indicates the possibility of using wind to power Worcester. There are also a few decent-sized areas in Western Massachusetts that have very high wind availability (some sites with close to 650 W/m^2 of wind power density). The electricity from this area that is not used by the local population could be used to contribute to the needs of other cities in the area (particularly, it could contribute to Worcester’s needs).

There is currently a proposal to put a wind farm with 130 – 3.6 MW turbines in Nantucket Sound (between Cape Cod and the Islands)[49]. Ideally it will produce a maximum output of 420 MW—roughly 113 million barrels of oil per year—which will be enough to power three quarters of the Cape’s and the Islands’ electricity[50]. This could save the state of Massachusetts an estimated $800 million in energy costs over the next 20 years[51]. The wind in the Cape Cod area, both on-Cape and offshore, are spectacular for wind farms. The average wind speeds in the onshore areas of the Southern Cape are in the area of around 6 to 7 m/s, providing power of roughly 220 to 370 W/m² while the offshore wind is roughly 9 m/s which would provide power of around 700 W/m². The offshore sites are better for raw power generation, but there are a number of complaints regarding potential tourism drops from offshore sites; it might be a good idea to consider having some small onshore turbines in more remote locations to lower the number of offshore turbines necessary to power the Cape. One such location was discussed in an interview with State Representative Jeffrey Perry. The State of Massachusetts has set aside much of the area around the Camp Edwards Army Base—part of the Massachusetts Military Reservation—as a reserved area; the State is capable of leasing this land to private contractors, who in turn could build a small wind farm on the site[52].

It also is important to consider the entire state of Massachusetts in the wind power analysis. Due to the relatively low levels of wind in the state (with the exception of Cape Cod and a few areas in western Massachusetts), it would be an exercise in futility to attempt to power the entire state with wind turbines—it is possible, but at massive expense in both money and space consumption; however, the idea of putting wind farms in remote areas of other nearby states is quite plausible. Northern New Hampshire, Vermont, and Maine have significant wind resources and low population densities. Using these resources (depending upon the amount of reservation areas and a number of issues regarding the population of the area) it would be possible to contribute greatly to the energy needs of these states as well as Massachusetts and possibly other states in the Northeast. This possibility is discussed further in the next section.

5.5 Western and General United States Wind Analysis

The Midwestern and Western areas of the United States are prime areas for the use of wind power. They have large stretches of open fields and regions of extremely low population density (see Figure 5.4). As a result of these low population densities, it would be easy to install a number of wind farms in these areas and send the electricity to nearby areas with higher population (for example, cities within their own state or areas in the Midwest that use more power).

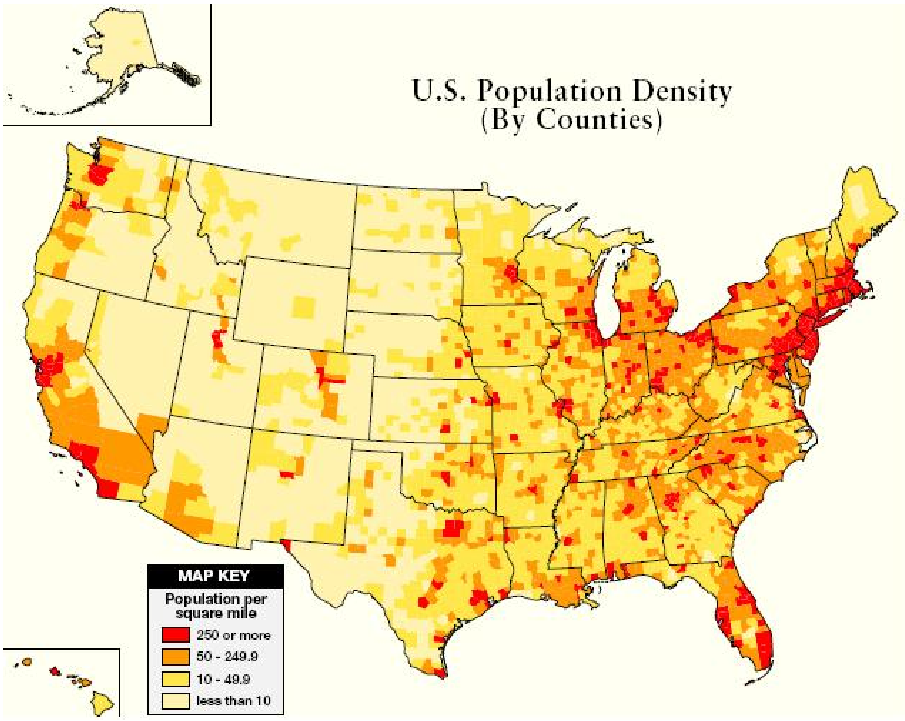


Figure 5.4 – United States Population Density Chart[53]

The wind availability actually matches the lower population density areas relatively well. Most states in the West have at least some areas that are listed as "outstanding" (the second best possible rating) by the National Renewable Energy Laboratory (NREL)[54]. This means that there are some areas that have significant amounts of wind available and are sparsely populated, and thus it would be effective to install wind turbines in those areas. The wind map in Figure 5.5 shows the approximate amounts of wind throughout the United States; some of the areas of interest are the dark section of the map—indicating very high winds—in the region of Montana, Idaho, and Wyoming, the spaced high-wind sections in Nevada and parts of Utah, and the moderately high wind areas of the Midwest (especially in the Dakotas and Minnesota). According to the American Wind Energy Association (AWEA), the top five states for wind (measured by the total annual potential for the entire state) are North Dakota, Texas, Kansas, South Dakota, and Montana[55].

It is also important to take note of areas with very low wind amounts; states such as Arizona and New Mexico would most likely not be able to take much advantage of wind power on their own, but other states in the area that have high wind speeds could provide these states with power from their own wind. However (although it is not in the scope of this project), those states have high volumes of sunlight and thus could take advantage of the use of solar power as a supplement to their current energy sources. Another area with exceptionally low wind is the Southeastern United States. These states would not be able to use wind power very successfully but again could benefit from the usage of other alternative energy sources. It is at this point that it becomes obvious that wind power cannot be used to power the entire country simply for this reason (among a number of other reasons)—not all areas receive enough wind or are close enough to wind resources to be powered by the energy generated by turbines.

Some other areas that are also of special interest to this project are the high-wind sections of Vermont, New Hampshire, and part of Maine; while this area is not as big and is not quite the same wind power as some other parts of the United States, it is quite possible to take advantage of the high wind velocity in the more rural parts of northern Vermont, New Hampshire, and Maine, all of which have sections with relatively low population density as indicated above. This area could contribute significantly to the amount of renewable energy in New England, including Massachusetts.

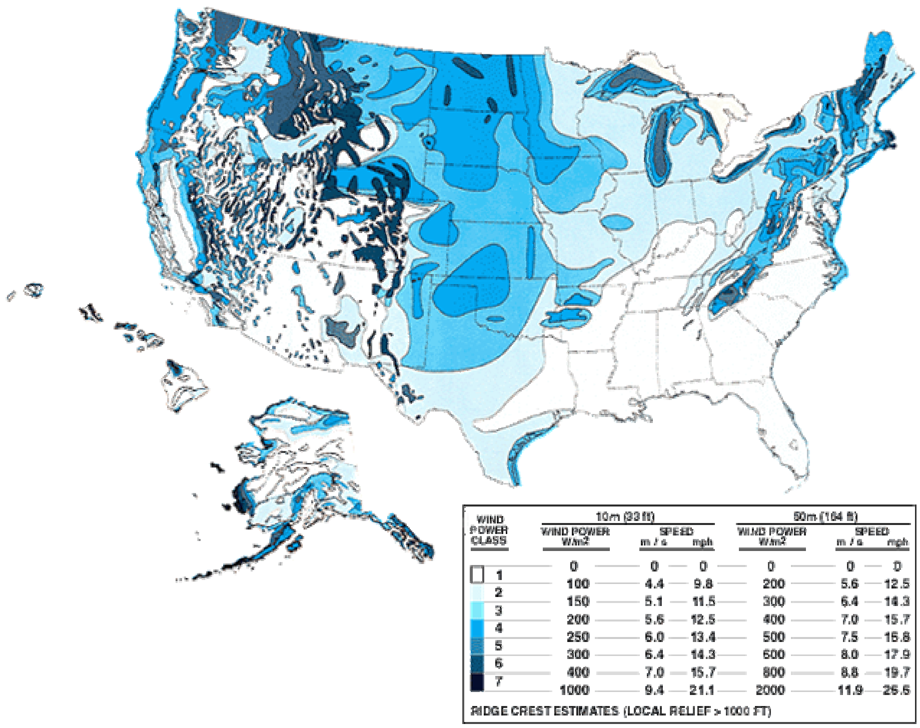


Figure 5.5 – Wind Availability in the United States[56]

There are currently many more wind farms in the Midwest than there are on the East coast primarily due to the above reasoning. A number of states in the Midwest and West are starting to make significant use of wind energy. Some states of interest (see Figure 5.6) are states like Texas which can make use of wind power "because the transmission line grid is not overloaded" and because of a number of sparsely populated areas in the state[57]. Part of why Texas has so much wind power installed already is because of hefty tax credits. In Iowa, one of the reasons wind power is often preferable to some other renewable energy sources becomes clear; due to the amount of sun and wind in the state, as well as the prices for installation of both energies, wind energy is about half the price of solar energy on a kilowatt-hour basis[58].

California also has a large number of wind farms (despite having only moderate-quality wind resources); in fact, it is the state with the highest current wind power generation capacity. However, a lot of projects in California have been cancelled or postponed due to a number of the electric utility companies going bankrupt or nearly going bankrupt (including PG&E and Southern California

Edison)[59]. Despite this setback, a number of small (residential- or small-business-sized) turbines are still being installed. The State of California has put into action a bill that will provide “a state tax credit of up to 50% and is considering offering a 30% installation credit”[60]. This will continually increase the benefits that wind power has provided to the state.

As a result of the developments in these states, wind power is rapidly becoming more popular as a method of providing relatively inexpensive renewable energy to people in a variety of areas. The Midwestern and Western states are doing exceptionally well with this task and there is much that people in New England can learn from their progress.

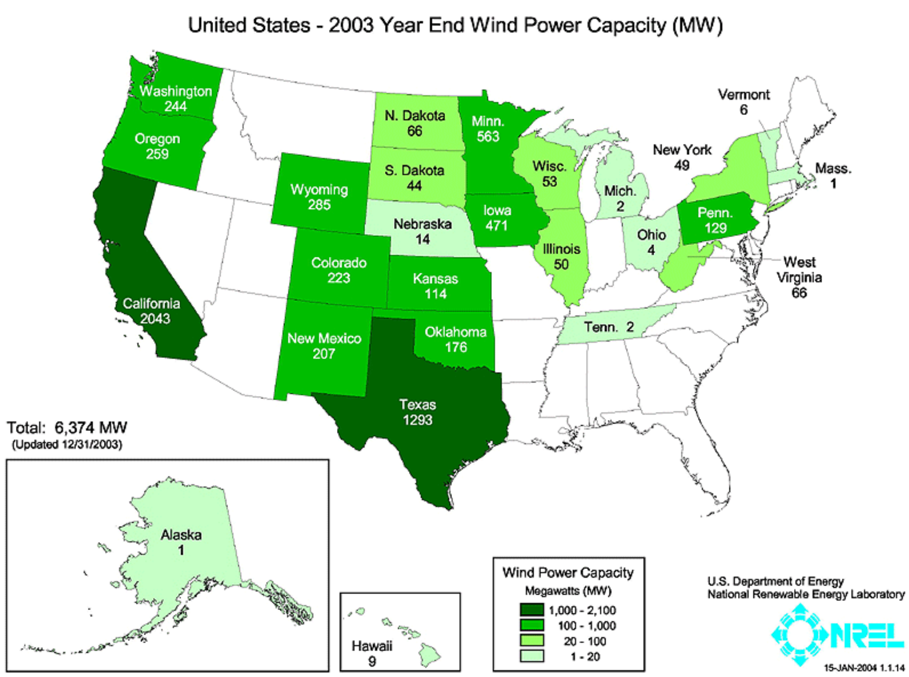


Figure 5.6 – United States Wind Power Generation, 2003[61]

6. Power Breakdown

In order to understand the immediate effects of power and the wind’s role in generating that power both the physical and electrical specifications of a wind turbine as well as the physical and electrical specifications of a single home are examined in the following sections.

6.1 Single Home and Worcester Analysis

To determine the feasibility of wind power, a single home and an apartment complex were analyzed for their electrical consumption. The analysis that was done was based on data from a three floor ~3200 square foot single family house in Holden, Massachusetts. This house has partial electric heat, 2 wood stoves, insulated roofs and walls and no air conditioning units of any kind. It is for this house that twelve month electrical consumption data was available[62]. The single family house's average monthly electrical consumption was found by taking the total kWh usage for the year (9714 kWh) and dividing it by the number of months in a year (12) to find the monthly average electrical consumption. Below is the average electrical consumption per month (809.5 kWh / Month)[63].

$$\frac{Total\ kWh}{Months\ in\ a\ year} = Monthy\ Average\ kWh\ usage$$

$$\frac{9714\,kWh}{12\,Months} = 809.5\,\frac{kWh}{Month}$$

A 7.5 kW turbine will produce 600 – 1500 kWh per month and a 10 kW turbine will produce 800 – 2000 kWh per month (see Section 12.4).

6.2 Wind Turbine Usage

Now that an estimate is known for a single family house, it is possible to find the necessary turbine rating to power a home and the number of homes a turbine can power can be found. In order to complete this analysis the ratings for individual wind turbines must be known and then compared to the usage of both the home and the apartment building. Two companies, Bergey Wind Power Co.[64] and WESTWIND[65], were found to supply wind turbines for homes and small businesses.

6.2.1 The Home

For the single home the Bergey 7.5 kW[66] and 10 kW[67] turbine packages[1] were rated to supply the single home with all of its electricity assuming that the weather is constantly favorable.

As indicated on the specification sheets (see Appendices B.3.1 and B.3.2) there are some major differences between these two setups. The 7.5kW turbine is

[1] A package includes all equipment needed to hook up the turbine to a home and either the batter back-up or electrical grid

designed to provide a battery back-up in case there is little to no wind, the turbine breaks, or if any grid dependant electricity is cut off (a black or brown out), however it does not allow the user the opportunity to sell surplus electricity back to the grid.

Unlike the 7.5 kW turbine, the 10 kW turbine does not include a battery backup system; it instead is designed to be connected to the electric grid to allow for the sale of any extra electricity which may be generated. Since the 10 kW turbine is connected to the grid to sell back electricity, safety precautions are set up to prevent damage to either the turbine or the grid. The disadvantage to this safety feature is that if there is a black or brown out on the grid, the wind turbine will stop generating electricity, including that which is sent to the house.

The cost for the 7.5 kW turbine with the battery backup is $48,140.00[68] and the 10kW turbine with resale capabilities is $33,550.00[69]. Based upon the electric bill for the single home described above, the cost for electricity is about $0.1247[2] per kWh used[70]. From this an estimated average monthly bill of about $100 was calculated. By taking each of the turbine costs and dividing by the monthly bill it was determined that to pay off the 7.5 kW turbine, it would take about 39.5 years and about 27.5 years for the 10 kW turbine[71] (see Appendix B.4.1). After this time the user would begin to see a return on investment[3]. Depending on the care given to the turbines, the dedication the owner has for renewable energies, the monthly cost for electricity, and the wind available, the owner can potentially see a return sooner than estimated. However, if this is not the case then the owner may never see a return and may end up paying more money for repairs or having to purchase electricity from the grid.

6.2.2 City of Worcester

After looking at the single family home, larger wind generators were analyzed in order to get a general idea for the overall capacity of a single turbine and how much electricity it can produce. Hull, Massachusetts has a 660kW turbine which was used as a model for this portion of the analysis. The table below outlines the

[2] This includes various other costs rolled into the monthly bill

[3] This does not include any accrued maintenance costs or potential profit made from selling electricity back to the grid

calculations that were made based upon information available from the Hull wind project[72]. The wind density of Worcester is half of that in Paxton and a quarter of that in Westminster (both of which were briefly examined in Section 5.4), therefore the estimated yearly production was calculated by taking the known yearly production in Hull, MA (1597963 kWh) and multiplying it by the wind density ratio of Paxton to Hull (300/377 W/m^2) [73]; this was then repeated for the wind density ratio of Westminster to Hull (600/377 W/m^2)[74]. Both of these calculations were done in order to arrive at a projection for the number of Worcester homes that one 660 kW turbine could power.

HOMES PER TURBINE			
Model Based on Hull, MA Turbine			
Location for Turbine		Paxton	Westminster
Hull Wind Ratio Density		300 / 377	600 / 377
Company-Model:		Vestas-V47	Vestas-V47
Rotors		3	3
Rating		660kW	660kW
Up Front Cost		$700,000.00	$700,000.00
Fees		Maintenance, Interest	Maintenance, Interest
Est. Yearly Production (kWh)		1271588	2543177
Est. Monthly Production (kWh)		105965	211931
Avg. Home kWh usage		825	825
Homes to be powered		128	257
Capital investment per Home		$5,468.75	$2,723.74
Cost / kWh[4]		$0.125	$0.125
kWh		105965	211931
Electric Cost / Month		$13,245.63	$26,491.38
% reduced		100%	100%
Grid Cost Reduction (GCR) / Month[5]		$13,245.63	$26,491.38
GCR / Unit / Mo[6]		$103.12	$103.12
Time to Pay off[7]			
	Months	52.85	26.42
	Years	4.40	2.20

Table 6.1 – Potential use of the Hull Wind Turbine

[4] This value is rounded up from the $0.1247 in the single home analysis.
[5] After the turbine is paid off, this will be the money saved per month.
[6] After the turbine is paid off, this will be the money saved per month.
[7] The payoff time is calculated assuming that there is no interest and/or maintenance on the turbine, Hull officials have reported that the turbine will be paid off in 4.1years (See section 7.3)

Earlier calculations show that this turbine can power about 200 homes. The reason that there is a difference between the 234 and the 200 is due to the assumptions made about the power generation for the turbine. The method used previously is based upon the yearly average electrical generation of 1,600MWh and assuming that a single home uses 8000kWh in a given year[75].

By comparing the costs of the single home generators (7.5kW and 10kW) to the community generator (660kW) it is obvious that it is much more cost effective for a group of people (i.e. gated community, small town), to erect one large community tower instead of many small individual towers.

7. Transmission Lines [8]

One key selling point for wind power projects is that the most energy dense winds are often located in fairly remote areas (ridges, miles off shore, mountains, woods, etc.) and as a result, the turbines won't be seen by their users. However much of a selling point remote locations may be for wind power users, they are a deterrent to the developers and managers of the projects. Being located in remote areas allows for some major maintenance problems, increases transmission line lengths, and reduces production efficiency. All of these factors are looked down upon by management since each one leads to the same result—increased project and overall maintenance costs.

With an increased length of the transmission lines comes a higher startup cost. This is due to the cost for extra materials and manpower required to install the lines into remote areas. If a wind farm is placed off shore there is the added cost of having to account for increased wire sheathing to protect against oceanic corrosion and the equipment to lay the wire.

Increased length not only has an increased startup cost; it also results in a higher yearly maintenance cost. This concept can be demonstrated by looking at

[8] The information in this section was largely taken from a discussion with Professor Alexander E. Emanuel, a Professor of Electrical and Computer Engineering at WPI whose specialty is power electronics.

state roads. Each year a state will have to pay a set amount of money to maintain those roads. However, if the state were to increase either the number of roads or the length of the existing roads, the yearly cost would increase to maintain these additions.

Another drawback to the increased lengths is transmission loss. Due to the inherent resistance of cables, there will be some loss along every transmission line. By using better materials and increasing the cross-sectional area, it is possible to minimize this resistance, but again, there will always be some resistance. Additionally, this resistance and the respective power loss increases linearly as a transmission line gets longer; that is, the resistance and loss are directly proportional to the length of the transmission line.

Ideally, less than 5% of the voltage should be lost in the transmission from one point to another; whether or not this occurs depends upon the quality of the transmission line which in turn determines the cost per foot of the line. The most important issue is that in order to transport electricity very long distances, the lines must be very high quality and thus cost much more to produce; at a certain point these lines become uneconomical.

Due to these numerous drawbacks of having turbines far from civilization, placing them near locations that use significant amounts of power would seem to be the logical conclusion. It is occasionally possible to place wind turbines close to high power-usage areas such as cities, but there are a number of problems with doing this.

The first problem in placing wind turbines close to populated areas is simply that there is less available space to install turbines. Even if there is available space, it is often not in ideal locations; for example, hill tops are often taken up by buildings. Roofs of buildings can occasionally be used but there is a cost for structural reinforcement and as a result, placing large wind turbines on the roofs of buildings becomes economically inefficient. Additionally, there is (understandably) often negative sentiment about placing anything of that size on top of a building in the middle of a highly populated area.

Naturally, people would be concerned about having a wind turbine on the building they live in or on a nearby office building. This is the other main reason that it is difficult to install wind turbines in urban areas—the NIMBY principle, in one of its more logical incarnations. As a result of their concern over property value and (not least of all) their safety, many citizens would likely oppose construction in densely populated areas and thus getting approval for construction of the turbines would be difficult at best.

There are problems in locating turbines far from densely populated areas, but it is often very difficult to locate them in densely populated areas. Therefore, in spite of the problems resulting from rurally sited turbines, placing them in sparsely-populated areas often makes the most sense. One of the most logical locations to place a wind farm based upon population is off shore, but this is not as easy a fix as it may sound. Since the turbines are in the middle of the ocean the transmission lines need to be laid under water to prevent damage from boats. The shielding which is placed around the underwater lines must be able to withstand the corrosive nature of the ocean. The lines also need to be laid extremely carefully to prevent any damage from occurring to them. One of the measures used to prevent the transmission lines from getting damaged is to pump oil between the lines and the shielding. This does a couple of things to the line: 1) it allows wind farms to monitor the pressure on their transmission lines and thus detect if there is any damage, 2) it allows for an easy way to find breaks in the lines, and 3) since the oil pressure inside the lines is kept higher than that of the ocean water, the oil will flow into the ocean and reduce or even eliminate damage to the lines themselves if there are any breaks in the lines.

With lines being placed in locations which have limited accessibility, the lifespan of transmission lines must be relatively long in order to prevent costly maintenance. The life of transmission lines is hard to predict and is based upon the materials' stress-strain analysis; it is expected that they will last at least as long as the turbines which they are connected to; otherwise they will accrue immense maintenance costs. This is especially true of the underwater cables as it is very costly, both in time and money, to work on the lines under water.

8. Obstacles to Wind Power

Wind power installation numbers have been growing significantly in recent years in the United States; however there are many reasons why, despite its easily recognizable potential, wind power is unpopular in certain circles. These include a number of environmental principles as well as some sociological concerns.

The primary concern about wind power is that it disturbs the environment. Wind farms on land or offshore can potentially cause the disruption of bird flight patterns or occasionally bird deaths. At sites in Spain where the casualties were numbered, roughly 7000 birds were killed in one year by 368 turbines[76]. Changes in underwater environment can also be an issue for offshore wind farms; the installation (as well as, to some degree, the constant action above water) of the turbines in an offshore farm can cause changes in the local ecosystem that could adversely affect aquatic species.

Land usage is an issue that falls into both environmental and sociological areas. If land is selected properly, it does not adversely affect the environment (other than in the areas discussed above) any more than the construction of a small building would. Additionally, if arable land is selected to be used for turbine placement, the land can also be used as farmland or for grazing land; only a small portion of the land is actually necessary for the turbine itself. Offshore wind farms are even less of a worry if they are put out of the way of large water traffic routes. If placed in the proper locations, therefore, wind power actually does not consume much space or affect the environment.

The primary sociological issue regarding wind power is the so-called “NIMBY” principle (an acronym for “not in my back yard”). This is one of the most common responses for people to oppose the construction of wind farms in their area; it is especially prevalent in more rural and scenic areas, which, ironically, are often the best places to put wind turbines since they generally have better wind resources, disturb fewer people, and have the unused land area necessary for construction. People are often concerned not only about the appearance of their town, but also about the possibility of damage that could be caused by the turbines. There is often a fear of ice being thrown from turbine blades and of turbines actually collapsing;

however, modern engineering has minimized these risks, so the concern for safety is not much of a reason to protest the construction of wind turbines.

8.1 Current Cost of Large Scale Wind Projects

Currently, wind generated power from large farms (greater than 5 MW) costs about 1.5-2 cents more per kWh than power created from fossil fuel power plants[77]. The cost of wind power is obviously highly dependent on what sort of wind resources are available at the location where the wind farm will be built. As seen in Figure 8.1, a majority of the cost of wind power is capital investment in the turbines themselves, electrical infrastructure and financing costs. This is consistent with the cost break down of the original Princeton wind farm. In Princeton, 50% of the total cost was principal (including the cost of the turbines and installation), 27% was financing interest, and 17% of the total cost before the turbines were shut down was for operation and maintenance.

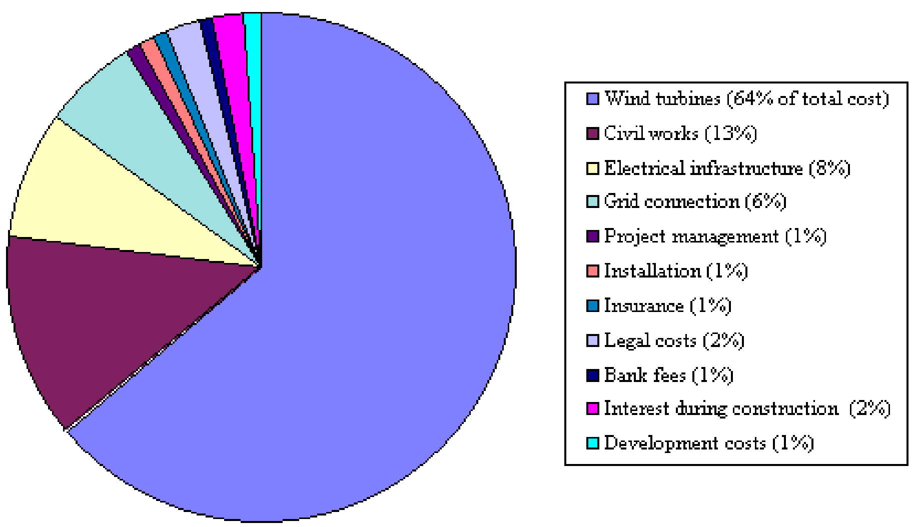


Figure 8.1- Breakdown of wind farm costs[78]

Different schemes have been used to decrease the cost of wind power including national tax incentives, changes in financing, and utilizing economies of scale. A National Production Tax Credit (PTC) exists that currently grants 1.8 cents per kWh of tax credit to any producer of renewable energy, including wind.[79] This credit is designed to bridge the cost gap between power derived from fossil fuels and renewable power. (The tax credit was specifically tailored for wind power, though it applies to all renewable sources.) Differences in financing also have distinct effects on the net cost of wind power for medium scale wind power. As seen for Princeton, 27% of the total cost of that project was interest on the original loan that was used to purchase their eight turbines. If a large electric utility (instead of a local municipality) owned and financed a medium to large scale project, the total cost of power could be significantly reduced[80,81]. If Worcester were to install a medium sized wind farm, financing options could be a major part of the total cost. For very large wind farms and offshore wind farms (greater than 50 MW) extra-large turbines are becoming more economical. Extra-large turbines producing up to 3.2 MW per turbine can be used in areas with excellent wind resources to allow the producer to save on capital costs.

8.2 Future Costs of Large Scale Wind Projects

As fossil fuel prices rise and the wind industry grows, the price of wind power will continue to decrease. Large wind turbines are already making better use of material capital costs, and as the wind industry grows, better and cheaper manufacturing will stimulate wind energy. In addition to industry trends, international agreements like the Kyoto protocol will also spur the wind industry.

8.3 Seasonal Fluctuations and other Transiencies

The wind resources of any given area can fluctuate greatly from season to season; this is one disadvantage of wind power. The most useful example of this is the Princeton wind farm. The original wind farm in Princeton (before it was shut down completely) was turned off in the summer because the wind speeds were so low. The turbines were stopped to prevent the need for maintenance when the turbines were not producing[9]. Princeton, however, like many cities in New England also had a winter-peaking consumption, so when the town was using its greatest amount of energy, its turbines were producing their greatest annual output[82].

In addition to seasonal changes in production, wind power also has short term (minute or hourly) fluctuations that require special equipment to stabilize the electrical grid and maintain a constant capacity by balancing conventional power generation and wind power. It is estimated that if Germany continues to increase its wind energy capacity, the cost of electricity could nearly quadruple due to the need to update their grid and outfit conventional electricity-producing plants with new equipment[83]. Short-term fluctuations usually only have to be taken into account when wind power penetration approaches 10-12%[84]; most areas of New England would not need to be concerned about this.

9. Reactions to Local Wind Power

A number of communities in Massachusetts have either installed wind turbines or have started planning installations. In many locations (especially when a number of turbines will be installed in an area) there has been some level of protest; regardless of some people's lack of approval, there also has been a great degree of support in many instances, especially in areas that have installed wind turbines in the past.

9.1 The Cape Wind Project

The largest planned wind farm construction in Massachusetts is the proposed wind farm in Nantucket Sound—the aptly named Cape Wind project—which, if built, will be one of the largest offshore wind farms in the world as well as the first offshore wind farm in the United States. There have been many objections regarding the installation of the wind farm, especially from people on southern Cape Cod. The primary reasoning is not exactly due to the resulting change in the natural ocean view, but an indirect result of the modified view. Much of the economy of Cape Cod relies on the tourism industry directly (in guided tours of certain areas) as well as

[9] To prevent undue wear or damage to the turbines, they are prevented from operating during low wind periods

indirectly (in beach fees, restaurants, and many small businesses); most of the small business owners on Cape Cod believe that a less natural view will cause a reduction in tourism and thus problems for the economy of Cape Cod[85]. This belief could be somewhat warranted, but it is also possible that many tourists would not care about the addition of the wind turbines to the scenery or even that some tourists would be interested in visiting the Cape solely to see the wonder of the wind turbines. A simulated view of the wind farm from a beach in Cotuit (approximately 6.0 miles away from the edge of the farm) is shown below in Figure 9.1; this is one of the closest shores to the proposed wind farm.

Figure 9.1 – Simulated Wind Farm View from Cotuit[86]

Overall, there is little opposition to the Cape Wind proposal except, as one would expect, in the areas most affected by the wind farm. A recent poll of people who live in Massachusetts shows that 47% of people approve of the farm proposal, 13% oppose it, and 39% are undecided; surprisingly, 65% of the people polled (throughout Massachusetts) knew about the proposal for the wind farm, despite the fact that it will affect a much smaller percentage[87]. Some on-Cape proponents of the wind farm call people who oppose the farm backwards and selfish, saying that the farm will make the Cape more popular simply because it sparked a wind energy revolution throughout the United States[88]. Another reason that some people on the

Cape support the wind farm is that there is an oil-fired power plant on the Cape already; many in the area of the plant hope that the power from the wind turbines will reduce the amount of oil the plant has to burn. (Surprisingly, the plant on the Cape is one of the few oil-burning power plants in the country.)

Many people who hear complaints about the wind farm from Cape residents would assume the opposition to the farm to simply be a case of NIMBY (not in my back yard) syndrome; however, after a brief analysis, it is clear that "NIMBY-ism" would not be the only reason to oppose the farm. Cape Cod (if a bit of land off the Cape is included) already has 2 power plants on their soil and are producing more electricity than they use[89]. Cape residents thus would not be selfish in saying they don't want something else producing power in their area when they are all ready overproducing.

One of the major arguments against the wind farm (other than the loss of tourism argument) is that the wind farm could harm wildlife and damage the fishing business. One article states that "many local fishermen make up to 60 percent of their income on Horseshoe Shoal"—the proposed location for the wind farm installation[90]; however, there are no studies that state that the fish will migrate away from the shoal if wind turbines are installed there, and ships can easily still get in and out of the area of the shoal between the turbines (which are between a third and a half mile apart)[91].

The Cape Wind proposal will be is interesting as a political issue because the state and local governments have no sway over the final decision because the farm will be situated in Federal waters [92]. Many local and state politicians such as Sandwich, MA Representative Jeffrey Perry are working to ensure that Cape Cod residents and the citizens of Massachusetts in general are not slighted by the construction of the farm; Representative Perry especially wants to make sure that the people on the Cape are given some compensation (probably in the form of tax breaks) for any negative effects that might result from the existence of the wind farm, should the wind farm actually be installed[93]. Due to the large number of possible negative effects from the Cape Wind proposal, it is still one of the most controversial wind farm proposals in the state and it is unclear whether installing the wind farm is a good or bad idea at this time.

9.2 Princeton Wind Farm

The residents Princeton, MA decided to put 7 wind turbines on a hill in their town in 1984; an additional turbine was installed a few years later. The farm is known locally as the Richard F. Wheeler wind farm. Recently the turbines were turned off due to the fact that they were no longer economical; however, the town is considering (and has mostly decided on) the idea of replacing the 8 turbines with 2 newer—and much larger—turbines.

The current turbines, if they were still operational, would be rated at a total of roughly 320 kW; while active, they provided 1 to 2 percent of the town's electricity. The proposed turbines would be rated at a total of around 3 MW and, due to the differences in efficiency and height, would produce 20 to 40 times the electricity of the old turbines, thus providing an average of 40 percent of the town's electricity. As a result of this number, it would take a total of 5 of these turbines to power the entire town (assuming constant wind).

The currently installed turbines were not very economical during their entire time, averaging roughly 27¢ / kWh, as shown below in Figure 9.2; it is also easy to notice that after the principle and interest costs were paid, the prices per kilowatt-hour were much better, nearing the current prices of electricity from nonrenewable sources. There were not many studies performed prior to the installation of the original farm and thus the estimates for the amount of power generated was too high; this resulted in higher costs per kilowatt-hour than expected. The idea of a new farm was studied much better; a number of independent wind speed studies were performed for the Princeton Municipal Light Department (PMLD)—the organization responsible for the maintenance of the turbines—in order to get more accurate estimates of the amount of power that will be delivered by the new turbines. The plans for the upgraded farm have a much better predicted cost per kilowatt-hour; additionally, the new turbines' performance is guaranteed at least to some degree by the company that builds the turbines[94]. This will ensure that town will be able to predict their cost per kilowatt-hour better than before.

Financial History of 320kW Wind Farm

Year	Principle	Interest	Capital	Salvage	O&M	Total Cost	Annual kWH	$/kWH
1984	$ -	$ -	$ -	$ -	$ -	$ -	140,000	$ -
1985	$ 55,000.00	$ 52,938.00	$ -	$ -	$ 11,992.00	$ 119,930.00	359,033	$ 0.33
1986	$ 55,000.00	$ 47,644.00	$ -	$ -	$ 11,543.00	$ 114,187.00	314,956	$ 0.36
1987	$ 55,000.00	$ 42,350.00	$ -	$ -	$ 3,478.00	$ 100,828.00	122,405	$ 0.82
1988	$ 55,000.00	$ 37,056.00	$ 80,712.00	$ -	$ 11,479.00	$ 184,247.00	288,897	$ 0.64
1989	$ 55,000.00	$ 31,763.00	$ -	$ -	$ 10,450.00	$ 97,213.00	253,480	$ 0.38
1990	$ 55,000.00	$ 26,469.00	$ -	$ -	$ 8,916.00	$ 90,385.00	285,171	$ 0.32
1991	$ 55,000.00	$ 21,175.00	$ -	$ -	$ 6,963.00	$ 83,138.00	244,227	$ 0.34
1992	$ 55,000.00	$ 15,675.00	$ -	$ -	$ 7,184.00	$ 77,859.00	292,930	$ 0.27
1993	$ 55,000.00	$ 10,450.00	$ -	$ -	$ 13,740.00	$ 79,190.00	276,543	$ 0.29
1994	$ 55,000.00	$ 5,225.00	$ -	$ -	$ 6,126.00	$ 66,351.00	287,215	$ 0.23
1995	$ -	$ -	$ -	$ -	$ 14,677.00	$ 14,677.00	154,769	$ 0.09
1996	$ -	$ -	$ -	$ -	$ 16,708.00	$ 16,708.00	217,948	$ 0.08
1997	$ -	$ -	$ -	$ -	$ 14,161.00	$ 14,161.00	252,829	$ 0.06
1998	$ -	$ -	$ -	$ -	$ 6,964.00	$ 6,964.00	146,305	$ 0.05
1999	$ -	$ -	$ -	$ -	$ 21,990.46	$ 21,990.46	232,499	$ 0.09
2000	$ -	$ -	$ -	$ (12,500.00)	$ 9,233.00	$ (3,267.00)	264,712	$ (0.01)
2001	$ -	$ -	$ -	$ -	$ 5,330.00	$ 5,330.00	83,068	$ 0.06
2002	$ -	$ -	$ -	$ -	$ 3,000.00	$ 3,000.00	75,778	$ 0.04
2003								
Total	$ 550,000.00	$ 290,745.00	$ 80,712.00	$ (12,500.00)	$ 183,934.46	$ 1,089,891.46	4,292,765	**$ 0.2712**

Figure 9.2 – Finances of Original Princeton Wind Farm[95]

Despite the great benefits that the installation of these turbines would bring, a few people in the community have expressed some concerns regarding the turbines; due to the lack of validity of some of these claims, it seems like the majority of these people simply do not want the larger turbines for visual reasons or extreme environmental conservatism, but it is also important to understand these concerns. The primary opponent of the wind turbine upgrades, Mr. John P. Mollica, stated some important issues; some of these are merely semantics, but a few are partly legitimate and thus are important to address.

One of the major concerns is the safety of the turbines, and one of the most discussed aspects of the safety of wind turbines in northern climates is the possibility of “ice throws”—ice being flung from the tips of the wind turbines. Mollica calculated that the force of a small chunk of ice flung from the tips of one of the new wind turbines (spinning at full speed) will have the energy of a rifle bullet[96]; the fallacy in this calculation is the neglect of wind resistance and the assumption that the pieces of ice are thrown directly at anything that can be damaged. Additionally, according to the PMLD there have been no reported cases of ice throws from the current Princeton turbines in their 20 year history. Mollica reports that there some of the sheds near the wind turbines have been damaged by ice throws[97]; during our investigation of the turbine site, only one shed was damaged (all the others were undamaged and did not have new roofing). The “shed” that was damaged—which resembled the figure in Mollica’s document—had a thin plastic roof, was less than 6 feet in height, and was more of an equipment storage container than a shed; additionally, the shed was directly under the rotor of one of the turbines which indicates that the damage was more likely caused by falling ice than a high-velocity ice throw.

Another main complaint from Mollica’s comments is the possibility of structural failure; however, with modern turbine designs, structural integrity is not much of an issue, even with multiple elements that can cause degradation of the materials used in the turbine construction. If properly maintained wind turbines can last for an almost indefinite amount of time and are very safe[98]. In our investigation of the turbines that are currently present in Princeton only one had broken and that was apparently after the shutdown of the turbines (and apparently the resulting negligence in maintenance). The other turbines appeared to be in decent condition considering their age although, as previously noted, they had been shut off due to increasing maintenance costs.

The last major complaint specifically about the turbines is the amount of noise that the turbines generate. It is commonly known that turbines resonate at a low frequency and produce other noises (commonly described as a whooshing sound); in certain cases the resonance can be extremely powerful, as was the case with an experimental large-scale wind turbine[99]; however, this turbine was not properly designed for acoustic resonance and had some other problems as well. According to Jonathan Fitch, the general manager of the PMLD, there have been no complaints about noise of the current wind farm to the PMLD until the idea of a wind farm expansion was proposed[100]. We spoke to a few residents who lived very close to the wind farm regarding this problem; none of the people that we spoke with said that they were affected negatively by the noise of the wind farm (or even the visual aspects)[101].

Additionally, we performed a survey in Princeton in order to determine the general approval of the previous wind farm as well as the sentiment regarding the proposed expansion; details from this survey are included in Appendix B.2. Out of the people that we interviewed, nobody expressed any significant negative sentiment towards the previous wind farms. (A few people said that they wished they had known about the lower-than-expected efficiency ahead of time but still expressed positive or neutral feelings about the wind farm as a whole.) Almost all of the people that we surveyed had very positive feelings towards the proposal to expand the wind farm. Charts showing the results of the survey are shown below in Figure 9.3.

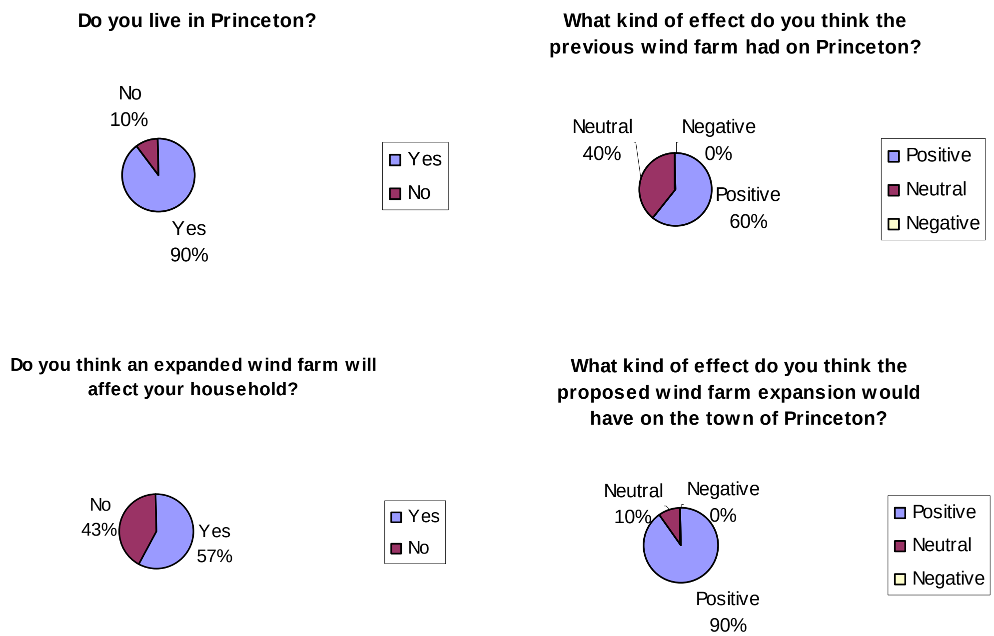


Figure 9.3 – Results of Princeton Survey[102]

9.3 Hull Wind

The town of Hull, MA installed a 40 kW wind turbine near the local high school in 1985; the turbine broke in a storm in 1997 due to wind speeds of up to 70 mph. (Modern wind turbines can withstand these speeds without any problems.) Though (like the original Princeton wind farm) the original turbine did not live up to expectations due to inadequate testing and more-than-average amounts of maintenance, the wind turbine actually helped the town. Over the course of its life, the turbine provided a net savings of roughly $45,000 in addition to about $17,000 worth of maintenance work (and thus additional work for people in the business of mechanical repair)[103], thereby helping the town in the long run.

History aside, after the wind turbine broke, residents rallied to install a new turbine. The new turbine was commissioned in 2001 and is rated at 660 kW; the current capacity factor (what percentage of the capacity is being used) over the life of the turbine is roughly 27% which is a respectable number considering low wind periods and energy conversion losses[104]. This high efficiency has resulted in a calculation that the cost of the turbine will be paid back 4.1 years from the initial installation date; the calculated cost of electricity from the turbine in the first few years was roughly $0.053/kWh[105]. The turbine generates roughly 1,600 MWh yearly[106], which, assuming the wind is completely constant, could provide the power for approximately 200 homes, given an average annual consumption of 8000 kWh (or 165 homes, using the 9714 kWh from the Worcester house example).

Reportedly, there are few to no complaints about the turbine and people even enjoy sitting and watching the turbine blades spin. In fact, there has been so much general approval regarding the current turbine that there have been suggestions and something of a proposal to install another turbine in the town. A survey taken in Hull recently showed that, of the 499 responses, 475 approved installing additional turbines; 11 people responded that they would be opposed to adding another turbine, but some of those 11 were not opposed to the original turbine[107]. The need for more power in the town of Hull is important right now, because there is a proposal for a town desalination plant which will require significant amounts of electricity.

10. Conclusions

It is clear that alternative sources of electrical energy will soon become essential to our energy economy. Due to the rapid depreciation of our fossil fuel reserves, there will soon be a deficit in the energy resources of the United States and the world if something is not done soon. Wind power is important to consider as a part of the renewable energy economy since any of the potential renewable energy sources could be used to contribute significantly to the United States energy economy.

Although ideally wind power could be used to power the entire world using offshore and rurally located wind farms, this is not possible. Due to the erratic nature of wind, it is not possible to expect more than around an average of 10 or 15 percent of the power for any area to be derived from wind power (without using massive energy storage facilities which would be cost-prohibitive); otherwise, blackouts and brownouts would be daily occurrences. This percentage is high enough to be a significant contributor to reducing the use of fossil fuels, but low enough that during periods of low wind other sources of energy could quickly be used to take the place of the wind energy. Contributions from wind power would often be higher during certain periods of the year than others due to seasonal effects, but this average of around 10 to 15 percent is a reasonable expectation, especially since other sources of power can be used during periods of low wind.

Additionally, this power can be achieved with little actual land consumption; since the footprint of the modern horizontal-axis wind turbine is relatively small, the land around the turbines can be used for farming or for raising livestock. This will help keep land available for farming while contributing significantly to a renewable energy economy.

The United States used 3481 billion kWh of electricity in 2003[108]; assuming constant wind and a capacity factor of roughly 30%, the United States could be completely powered by just over 575,000 - 2.3 MW wind turbines. Given the land area of the United States as roughly 3,537,438 square miles[109], this gives approximately 6.15 square miles per turbine, assuming that no turbines are placed offshore (as they likely would be). Obviously, as stated before, it would not be logical to try to power the entire country with wind energy alone, so this number is quite high. If the plan was to create 15% of the country's power with wind energy, there would be an average one turbine every 41 square miles; for comparison's sake, the city of Worcester has a land area of 37.6 square miles[110]. However, as discussed earlier, the city of Worcester does not have the wind quality that is necessary to make a significant impact; it would take more than 200 - 2.3 MW wind turbines to power the city of Worcester if the turbines were sited in the city. Locating the turbines in areas near the city with higher wind power density would definitely improve this number. As was discussed previously, Paxton and Westminster respectively have an average wind density of double and quadruple that of Worcester and are near enough to the city that running transmission lines would be possible. For the most part, though, large-scale wind power in Massachusetts would be most effective in the western part of the state and the Cape and Islands.

In many situations, for wind power to be economically competitive with energy derived from fossil fuels, governmental emissions restrictions or production tax credits are necessary. A long term National Renewable Energy Portfolio could be very useful. On a local scale, however, Hull, Princeton and Worcester Massachusetts are taking strides in the right direction. Local government support of municipally run renewable energy sources and encouraging legislation to aid the production of wind power is imperative for the growth of wind energy.

Through our research we have found that wind power is an important aspect in the renewable energy economy that will be essential in the next few generations. It is clear that although any one energy source will not provide enough energy to power the entire country, each source can make a significant contribution, and wind power is one of the best-developed renewable energy technologies so far. As a result, it is our strongest opinion that it is essential that in the immediate future the United States government and individual state governments make all steps to remove any illogical barriers to the construction of wind turbines.

11. APPENDIX A: Interviews and correspondences:

The following appendices include all correspondence involved with this project.

11.2 Jonathan Fitch Interview:

Jonathan Fitch is the director of the Princeton Municipal Light Department—the organization responsible for the Princeton wind turbines, among other things. This interview was conducted on the afternoon of April 7, 2005 at the Princeton Municipal Light Department offices in Princeton, MA by Kurt Ferreira and Darren Bell. The interview was recorded; all questions asked appear below.

F – Jonathan Fitch

K – Kurt Ferreira

D – Darren Bell

K: Do you mind if we record some of our question?

F: No. No I don't mind.

K: Alright, thank you. So, I guess we can just start right in on the questions. Have the repair frequency and cost [of the turbines] increased in recent years?

F: Yeah, that's why we turned them off.

K: Are they still adjusting themselves?

F: Yes, they are on yaw bearing[s] so they always swing downwind.

K: Does it automatically spin or do they have motors in them?

F: Automatically.

K: Have there been any complaints about the noise from the current wind farm?

F: Not really. I say not really because the opponents of the new project say they didn't like the noise from the old one but they didn't bring it up till we proposed the new ones. So in 20 years we haven't had any complaints that I can think of. The old ones were noisy though, much noisier than the new ones. 70 rpm down to 14-19 rpm—that's much slower.

K: Have there been any injuries from ice throws from the current turbines?

F: I don't know what he [John Mollica] is talking about. There has been no record of ice throws.

K: How were the benefits of the wind farm distributed among the people of the town?

F: Really it has been shared equally. What happens is we use it as a load reducer and as a town we measure our energy usage from a single point. So that energy is used to reduce the entire town load, so effectively it means that everyone profits. Technically speaking that energy gets consumed by the folks right there, but mathematically I can say generation amount of this is X consumption is Y therefore cost wise [the amount of energy the town needs to buy is distributed depending on how much each household uses].

K: How far into litigation is the current proposal for the new turbines?

F: Well, we have requested summary judgment and that is underway, so we're in the summary judgment phase. We're saying that these lawsuits have no fact, there is nothing they have stated that we have violated as far as zoning by-laws, regulation, permitting processes. We're pretty confident we'll get through it, it's just a matter of time. So we're definitely in the pre-trial phase, we're in the summary judgment phase.

K: So do you have any approximation of when the turbines will be up and running?

F: Hopefully this fall. This has been going on for 3 years, so it's been a long time coming.

K: Are their any official estimates on how much power the turbines will produce in kilowatt hours? I know it's not the actually mega-watt capacity of the turbines.

F: Oh yeah, estimated amounts from various sources are 8-9 million kWh. That's about 800 homes in the town. That's 40% of the town's energy requirements.

K: As a citizen, do you have any personal views on the turbines?

F: Oh I love them, they're great. I think they're beautiful, they're energy efficient. You only have to look at them and you'll see them, but one thing you won't see from them is pollution. Maybe they might prevent some of the news on the world scene that we see by having more of this in our own country. This is how technology starts, it starts small—it starts on a small size like ours with two turbines. And then you might see Cape Wind which is much larger at 130 turbines, then you might see a national wind farm out west even more so. This is the beginning of, hopefully, an energy independent nation. I know that sounds kind of corny, but that's it, that's why we do it.

K: Is there anything else that you would like to share?

F: Really, the project as presented by PMLD is based on the support of this community. The community of Princeton fully supports this project; there is very little opposition—it's almost negligible. Although, it only takes one person to put a lawsuit in and become a plaintiff. In general the entire town supports the project. In fact the entire town supported it through a town-wide vote and so this is just another means of meeting the mandate of the town and getting the power they want. It's not PMLD's project, it's the community's project, that's very important.

D: How much fluctuation is there, seasonal fluctuation and then difference between daytime production and night time production?

F: Nighttime and daytime I am not too familiar or knowledgeable about whether there is a difference and I really don't think there is. But summer and winter there is definitely a variation. We are a winter peaking load [consumption], so our general load is pretty high in the winter. But also our wind resources are fairly high in the winter. And so most of our wind will occur in the winter, and in the summer—especially June and July—we'll have very little wind resource; in fact, those turbines will be stopped. But that's all included in that energy estimate I gave you. We definitely have a winter peaking wind resource here.

11.3 Lewis Evangelidis Interview

Lewis Evangelidis is a state representative in Massachusetts; his district includes Princeton. This interview was conducted on the afternoon of April 13, 2005 at Mr. Evangelidis' Worcester law offices – 44 Front Street, Suite 400 Worcester, MA by Kurt Ferreira and Darren Bell. The interview was recorded, all questions asked appear below.

L – Lewis Evangelidis

K – Kurt Ferreira

D – Darren Bell

K – Have your constituents voiced any opinion regarding the Princeton wind farm?

L – My role as a state representative as far as I am concerned, and I think it's an accurate one, is that I'm there to represent the people in my district, including the town of Princeton. To effectuate the will of the people in each town I represent if there is a way I can assist them as a state representative. The wind farm issue is exclusively a town issue. The town of Princeton has to decide whether or not they wish to proceed with a wind farm on Wachusett Mountain. So, frankly, I stay out of that conversation because I am not a resident of Princeton and I have no influence, and shouldn't have any influence, on that decision. Jonathan Fitch runs the Princeton Light Department; I have talked to him numerous times and I said to him if there was the will of the people to proceed with the wind farm and you needed assistance with the state as far as getting access to the site through the MDC or the Department of Conservation and Recreation then I would be more than happy to help them. But I did not get directly involved in the decision making because it's not my role.

K – Yeah, we figured as much.

L – I have had people contact me and said "please oppose this" "please support this" and my response has been, "if the town wants to proceed and they vote to proceed, I will assist you if possible." If you decide not to proceed than I will not assist the town. It's the decision by the voters, not for me to decide. There were other folks actually who had adjacent properties that were concerned about safety issues with the wind farm itself. I directed people who had safety concerns to the Department of Conservation and Recreation, who own the property, so they could divulge and explain their safety concerns because some of these turbines will be extremely high and that there are some issues with possible icing and the falling debris could fall onto hikers because it also goes through a hiking area. So anywhere I can assist people. I don't have a particular side I'm on. If people are trying to stop it and they have a state issue that they'd like to address, I will help them. Someone's trying to support it and theirs a state issue involved, I'll help them. That's the way I look at my role.

K – How is the state government involved in decision about not local issues but more regional wind farm type issues or any renewable energy type issues?
L – I'm not real familiar. I mean if you have anything in particular. I know the Cape Cod wind farm; I thought that was a local decision of the people on Nantucket and around Nantucket sound. As far as I know, most of the issues we're talking about, lets say wind turbines for instance, I believe are local decisions. I don't think the state makes any general determination. We probably have programs that will assist and offer some sort of financial assistance. Because I know that we support renewable energy wherever possible. So I think it's important that we as a state have programs and assistance to help people who want to investigate the possibility of using it. But I am not familiar with any direct involvement.

K – Are their any plans to increase the amount of renewable energy in MA that have been proposed by the statewide congress? Or, if you're not directly involved in the building, do you have any initiatives that you're trying to increase the amount of renewable energy in MA?
L – There are so many issues we deal with up at the state house that I kind of deal with the ones that are right in front of me. I haven't had anybody come up to me with anything particular on renewable energy sources; particular line items in the budget that I am aware of right now. I know that there is a general consensus among nearly

everyone that renewable energy sources, ways to save fuel from supporting cars; these are more national issues. But for instance there should be tax policy on supporting hydrogen operating cars or electric cars or these hybrid cars like the Prius. There should be tax policies that reward people for purchasing these types of vehicles. There was some discussion about having hybrid cars having a fast lane to get in and out of Boston. Those are the sort of proposals we could look to support. For instance, you know they have the zipper lane and people who have multiple passengers, you know what I am talking about? There might be a hybrid car lane, something like that. Nothing that I'm aware of I can tell you this right now is a big issue, or this line item, I couldn't tell you.

K – Okay. So there's nothing right now that really big on the agenda.

L – Not that I'm aware of, no. There could be other people who that's their primary focus up there and they could tell you right away we're trying to get a million dollars of R&D money for this project, I don't know.

K- I guess if you're not aware of it this isn't a totally relevant question, but is there anything you think the state government could do differently about renewable energy?

L – Well, I said, I would like to think that we are going to be progressive in trying to find ways to reduce our dependence on oil, especially. Right now you see the oil prices just going through the roof. I think everybody's concerned about how do we do this, how do we get away from 1, the cost of oil for instance. Number 2, the international ramifications of oil dependency. So, that being said, what should we do? Yeah, we should look for any ways we can promote less consumption of oils, electricity by creating solar, wind, hybrid engines, hydrogen vehicles any way . . . But I also have a concern about the role of state government vs. private funding. I always think when you get into business propositions, that private funding is the primary way to go. But, frankly, some of this is a little bit difficult as far as its cost effectiveness right now for private industry. And state and federal government probably should help support this type of research. I see it more as probably a federal issue than a state as far as research 'cause its talking big money. So all I can say is we should break down any barriers we have for state regulations that slow down or make it difficult for renewable energy sources. Anything we can do to make it easier for them. That's a general answer but, I mean, if you have a specific question and ask me on it whether I'll support this or not, I'll tell you.

K – Are you from anywhere near the Princeton area

L – Born and raised in Holden.

K – Do you have any opinions about the wind farm?

L – I love the idea of wind powered electrical creation. There are some questions about how much of the towns energy can be derived from these turbines. I've heard somewhere from 2 percent to 10 to 20 percent. Generally I'm very favorable of it, I think it's hard not to be if its something that can reduce costs, clean the environment. I understand that there are some issues with the beauty of the landscape, that's something to consider. But I think that in the world we are in today I think we have to put a priority on streamlining processes that would make this available even at some cost to the environment unless it's an egregious situation. So I generally support it.

K – Is there anything else you would like to share just on renewable energy or wind particularly?

L – Not really. I've been following the stories around Cape Cod. What's the latest consensus on what's going to happen down there, are they gonna go?

K – They're still in litigation I think. Right now I don't think they're ready to go for it at all.

L – Well I think Princeton is a go. So it's going to be one of the first wind farms that I'm aware of that going to be going up, the new fangled wind farms with the 250ft turbines not the old 100. I'm excited about it; I'd like to see how the results are. I'm curious to see how much energy can be created from them. I hope the safety issues aren't an issue, I'm concerned about that but I'll assume for the moment that's been looked at. And I believe it has been and it has been determined safe. I hope it works out, I'll be watching it just like you will.

12. APPENDIX B: Data:

12.2 Worcester Wind Maps

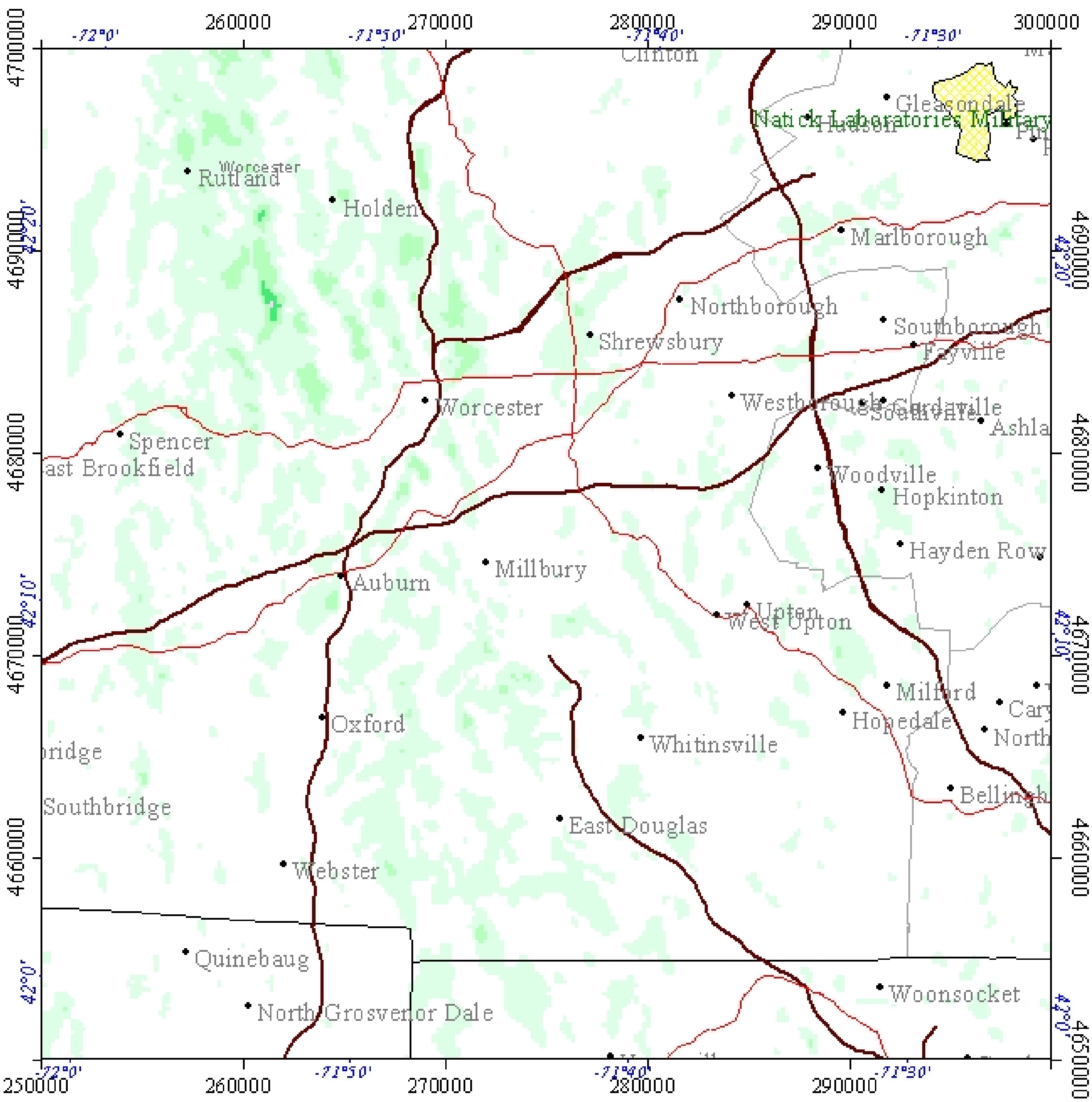


Figure 12.1– Wind Map of Worcester (1), Paxton is between Worcester and Rutland[111]

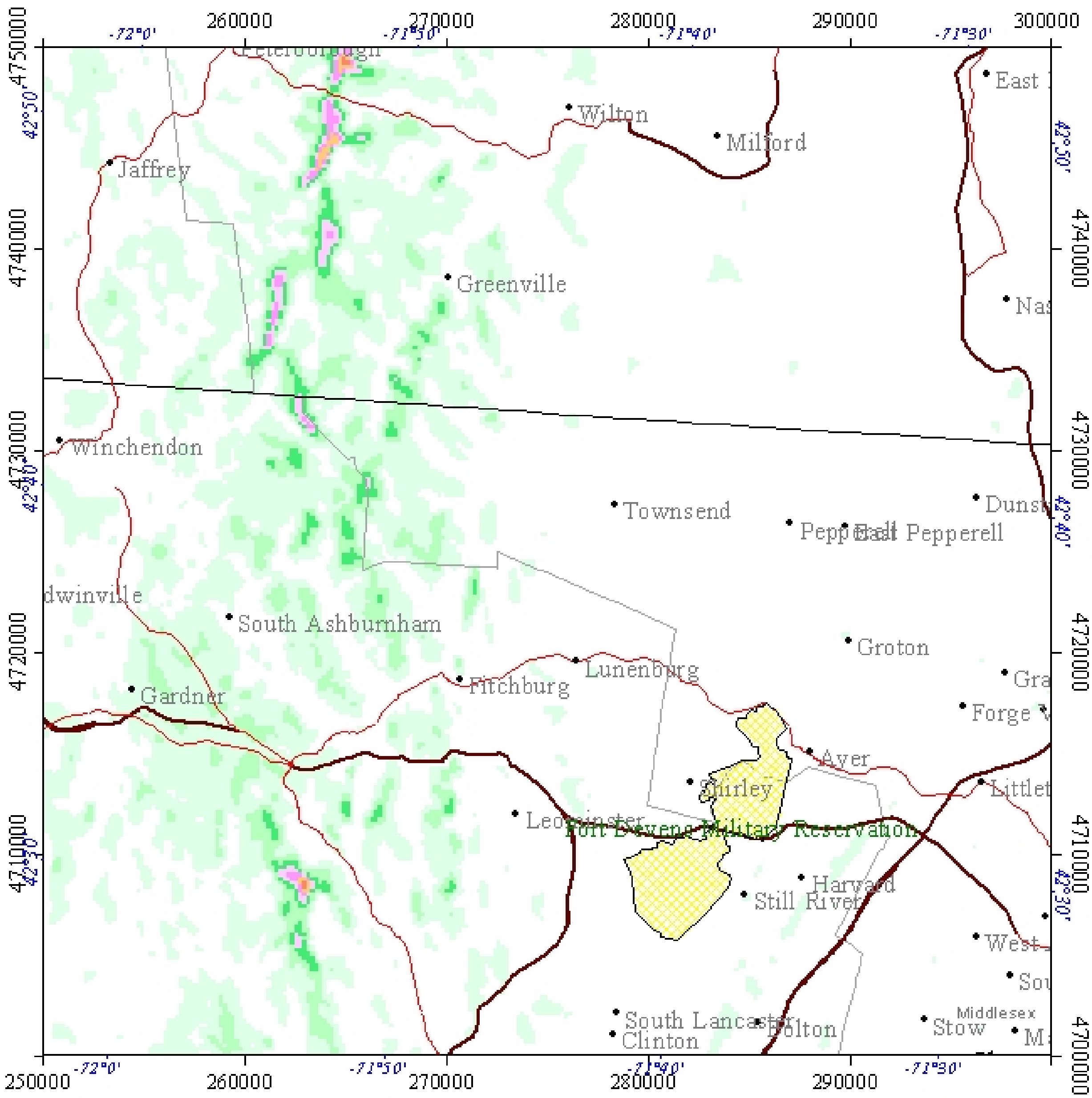


Figure 12.2 – Wind Map North of Worcester, Westminster is in Pink[112]

12.3 Princeton Survey

The survey in Princeton, MA was performed by Darren Bell and Kurt Ferreira on Wednesday, April 7, 2004 between 2 pm and 4 pm near the Princeton post office. Darren surveyed people while Kurt wrote down the results. The weather was partly cloudy and warm for the time of year. Due to the time of day, it was possible to survey almost every person that stopped at the post office; less than ten people were not surveyed either due to the fact that we were already surveying someone when they approached us, or because they were in a hurry. The questions were:

Question 1: Do you live in Princeton?

Question 2: What kind of effect do you think the previous wind farm had?

Question 3: Do you think an expanded wind farm will affect your household directly?

Question 4: What kind of effect do you think the proposed wind farm expansion would have on the town of Princeton as a whole?

In total, 20 people were surveyed for questions 1, 2, and 4. Question 3 was modified partway through the surveying, so the first 6 responses were not tallied; the question with usable data is shown above. The results of the survey on a person-by-person basis are shown below with one line per person who responded (Table 12.1) and in tabulated form (Table 12.2). Questions 1 and 3 were rated on a simple "yes" or "no" basis since they were straightforward questions. Questions 2 and 4 were rated from 1 (a negative response) to 3 (a positive response); if people were not aware of the proposal, they were asked if they would support an expansion. If there was a neutral or ambivalent response, the response was designated as a 2, but this rarely occurred in the course of the survey. Notes are included on the lines corresponding to people who had interesting comments.

Individual results:

Q1	Q2	Q3	Q4	Notes:
Y	3	n/a	3	Not in Princeton during previous wind farm
Y	2	n/a	3	
Y	3	n/a	3	
Y	3	n/a	3	Not a current resident, but lived in Princeton 13 yrs
Y	3	n/a	3	
Y	3	n/a	3	
Y	2	N	3	

Y	2	N	3	
Y	2	N	3	New resident, not aware of proposal
N	3	Y	3	
Y	2	Y	3	
Y	3	Y	3	Wind farm neighbor
Y	3	Y	3	
Y	3	Y	3	
Y	3	Y	3	
Y	2	Y	2	
Y	3	Y	3	
Y	2	N	2	Positive effects for all people but farm neighbors
N	3	N	3	
Y	2	N	3	

Table 12.1 – Individual responses for Princeton survey

Tabulated Results:

Q1	Q2	Q3	Q4
Yes	Positive	Yes	Positive
18	12	8	18
No	Neutral	No	Neutral
2	8	6	2
	Negative		Negative
	0		0

Table 12.2 – Tabulated results from Princeton survey

This shows a positive response towards the old wind farm despite its numerous problems and, more importantly, a desire to go ahead with the new wind farm. There were no negative responses with the exception of a response that expressed positive sentiment in general, but some concern for the neighbors of the farm. This shows that in communities that have become accustomed to wind turbines there is a positive sentiment towards them.

12.4 Single Home Turbines

Below are projected invoices for a 7.5 kW and a 10 kW Bergey wind turbine. These turbines are designed for homes and small businesses.

12.4.1 7.5 kW Wind Turbine

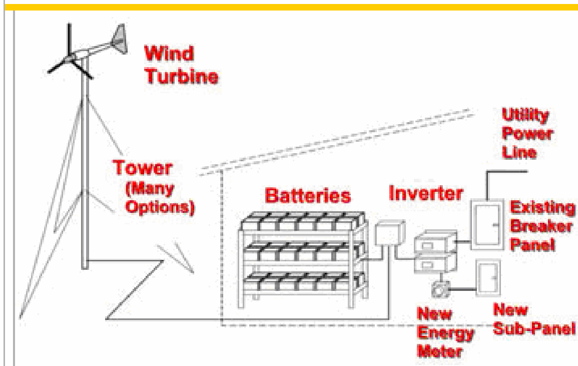
7.5 kW Home.**Sure** Package

Performance: 600 - 1,500 Kilowatt-hours (kWh's) per month (depending on wind resource), 24 hours to over a week of back-up power (depending on load and wind)

Recommended for:

- Areas where power outages are a problem
- Homes or businesses that use at least 800 kWh's per month
- Property sizes of 1 acre or more
- Wind Class 2 or higher

Note: This system contains batteries and can provide essential household power during power outages.



We recommend this package for homeowners and small businesses that want protection from extended power outages. This capability requires the addition of batteries and more sophisticated inverters.

The Home.Sure system keeps the batteries charged up and during an outage home power is supplied by both the batteries and the wind turbine. In regular (non-outage) operation any excess energy, once the batteries are charged, is sold to the utility company or "stored" by utilities offering net metering. The Guyed-Lattice tower is the least cost tower type and a 100 ft. tower is tall enough for most locations. Shorter towers reduce performance and increase the payback time.

The batteries are Trojan L-16's, the workhorse of the home power industry. A total of 40 individual batteries are connected in five parallel strings of eight batteries in series (48 VDC nominal). This large battery bank will support essential loads (lights, radio, TV, refrigerator, freezer, water pump, and blowers) for two to seven days without wind energy input. The dual Trace SW5548 sine-wave inverters provides 240 VAC (or 230 VAC, 50 Hz at 9 kW) with enough capacity to start difficult motor loads. A back-up engine generator can be easily added.

In addition to the equipment costs given below, a complete installation will typically include the following costs: shipping, sales tax, permit costs, foundation and anchoring, wire run, turbine and tower erection, battery racks or vault, electrical hook-up, and inspection fees. Some homeowners also incorporate a back-up gas, propane, or diesel generator into the system for maximum protection. Your dealer or Bergey WindPower can assist you in budgeting these additional costs. For budgeting purposes, these costs typically range from $5,000 (customer installed, no sales tax, etc) to $20,000 (Certified Dealer, sales tax, diesel generator, etc).

7.5 kW BWC Excel-R/48, with VCS-10	$20,900	**Options:**
100 ft. Guyed-Lattice Tower Kit (XLG30)	$7,800	Special Paint: $400
Tower Wiring Kit (XTWK30)	$1,000	Corrosion Pkgs: $520
DC Power Center Option, 7 circuit (XVPC-7)	$690	E-Meter: $430
84 kWh, 5 String, Battery Bank (5 x B350-8)	$9,720	50 Hz: No Charge
11 kW Inverter System (2 x SW5548)	$8,030	Other Towers
Total Cost:	$48,140	

Figure 12.3 – 7.5 kW Home and Small Business Turbine, with Battery Back-up[113]

12.4.2 10 kW Wind Turbine

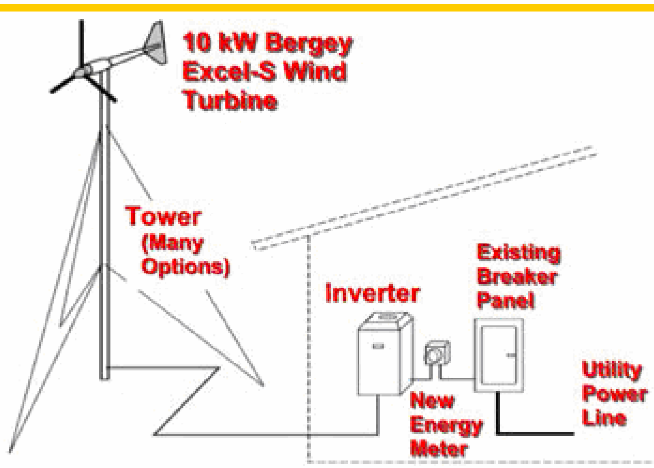
10 kW GridTek Package

Performance: 800 - 2,000 Kilowatt-hours (kWh's) per month (depending on wind resource)

Recommended for:

- Homes or businesses that use at least 1,000 kWh's per month
- Property sizes of 1 acre or more
- Wind Class 2 or higher

Note: This system does not provide back-up power during utility power outages. It automatically shuts off to protect the safety of utility repair crews.



We recommend this package for most homeowners and small businesses. The 10 kW Excel-S wind turbine with the GridTek power processor costs less than a BWC HomeSure system and provides the most favorable economics. Excess energy is sold to the utility company or "stored" by utilities offering net metering.

The GridTek Power Processor converts the wind power to utility power at 240 VAC (or 230 VAC, 50 Hz). Its output connects directly to your circuit breaker panel. The Guyed-Lattice tower is the least cost tower type and a 100 ft. tower is tall enough for most locations. Shorter towers reduce performance and increase the payback time.

In addition to the equipment costs given below, a complete installation will typically include the following costs: shipping, sales tax, permit costs, foundation and anchoring, wire run, turbine and tower erection, electrical hook-up, and inspection fees. Your dealer or Bergey WindPower can assist you in budgeting these additional costs. For budgeting purposes, these costs typically range from $6,000 (customer installed, no sales tax, etc) to $15,000 (Certified Dealer, expensive permits, sales tax, etc).

10 kW BWC Excel-S, with GridTek 10	$24,750	**Options:**
100 ft. Guyed-Lattice Tower Kit (XLG30)	$7,800	Special Paint: $690
Tower Wiring Kit (XTWK30)	$1,000	Corrosion Pkgs: $700
Total Cost:	**$33,550**	50 Hz: No Charge
		Other Towers

Figure 12.4 – 10 kW Home and Small Business Turbine, with Grid Connection[114]

12.5 Holden Single Family Home Analysis

Bill Date	kWh	Cost	Cost / kWh	kWh / Day	kWh / hr	Cost / Day	Billing Days
21-Mar	1122	144.44	0.12873	32.05714	1.33571	4.12686	35
14-Feb	728	94.42	0.12970	38.31579	1.59649	4.96947	19
26-Jan	1530	196.24	0.12826	56.66667	2.36111	7.26815	27
27-Dec	1334	171.35	0.12845	39.23529	1.63480	5.03971	34
23-Nov	435	54.42	0.12510	17.40000	0.72500	2.17680	25
29-Oct	591	73.22	0.12389	18.46875	0.76953	2.28813	32
27-Sep	757	93.22	0.12314	23.65625	0.98568	2.91313	32
26-Aug	711	87.68	0.12332	24.51724	1.02155	3.02345	29
28-Jul	884	108.52	0.12276	21.56098	0.89837	2.64683	41
17-Jun	449	56.11	0.12497	19.52174	0.81341	2.43957	23
25-May	448	53.74	0.11996	16.00000	0.66667	1.91929	28
27-Apr	725	85.74	0.11826	20.71429	0.86310	2.44971	35

Table 12.3 – Holden, MA: Single Home, Twelve Month Electrical Consumption Data[115]

12.5.1 Single Home Turbine Cost breakdown

SINGLE HOME TURBINES			
Bergey Models		Home.Sure	Gridtek
Rating		7.5 kW	10 kW
Up Front Cost		$48,140.00	$33,550.00
Fees		Maintenance, Interest	Maintenance, Interest
Features		Battery Back-up	Grid Connection
Est. Monthly Production (kWh)		600-1500	800-2000
Avg. Monthly kWh usage		825	825
houses to be powered		1	1
Cost per unit		$48,140.00	$33,550.00
Cost / kWh		0.1247	0.1247
% reduced[10]		100	100
Cost Reduction / Unit / Month		$102.88	$102.88
Time to Pay off			
	Months	467.9237947	326.1080871
	Years	38.99364956	27.17567392

Table 12.4 – Side-by-Side Turbine Comparison, (7.5 kW vs. 10kW)

[10] May fluctuate based on monthly load and wind supply

12.6 Worcester Power Consumption

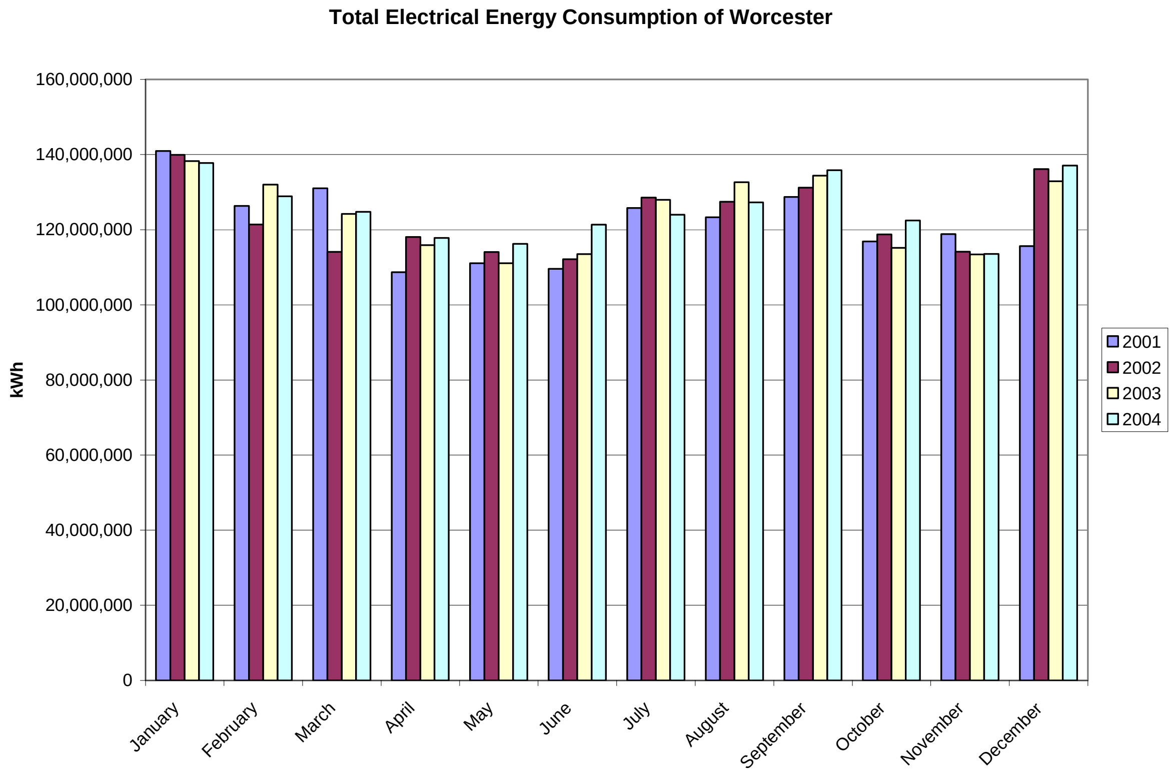


Figure 12.5 – Total Electrical Energy Consumption of Worcester[116]

2001												
	January	February	March	April	May	June	July	August	September	October	November	December
residential	44555656	37261368	37501443	31691179	26914934	27349151	31727644	31106572	32192466	27758643	28743288	34431308
commercial	95141554	88063027	92585073	76133028	83472449	81481684	93364883	91515149	95680971	88175570	89045118	79997996
street lights	1247050	1004309	933567	824786	710002	715811	668987	688528	870412	935607	1029933	1173249
total	**1.41E+08**	**1.26E+08**	**1.31E+08**	**1.09E+08**	**1.11E+08**	**1.1E+08**	**1.26E+08**	**1.23E+08**	**1.29E+08**	**1.17E+08**	**1.19E+08**	**1.16E+08**
2002												
	January	February	March	April	May	June	July	August	September	October	November	December
residential	42002800	37315691	32309408	32069906	28762774	26697689	33427456	35328105	33556488	28016134	31679393	42655307
commercial	96653142	83014381	80894774	85205661	84506735	84759231	94483993	91388648	96860563	89814071	81365764	92316353
street lights	1258572	1049770	875341	819321	758477	666791	669488	737301	794945	932643	1104274	1140836
total	**1.4E+08**	**1.21E+08**	**1.14E+08**	**1.18E+08**	**1.14E+08**	**1.12E+08**	**1.29E+08**	**1.27E+08**	**1.31E+08**	**1.19E+08**	**1.14E+08**	**1.36E+08**
2003												
	January	February	March	April	May	June	July	August	September	October	November	December
residential	44643932	43118215	39033361	33423828	28802339	29492193	32624664	36571524	36065656	27312458	30666008	40109755
commercial	92356067	87832265	84271638	81588358	81549461	83354506	94605324	95368532	97512689	86937328	81630331	91594508
street lights	1261147	1055199	880701	869901	713352	665202	715275	695308	822965	914358	1106235	1148145
total	**1.38E+08**	**1.32E+08**	**1.24E+08**	**1.16E+08**	**1.11E+08**	**1.14E+08**	**1.28E+08**	**1.33E+08**	**1.34E+08**	**1.15E+08**	**1.13E+08**	**1.33E+08**
2004												
	January	February	March	April	May	June	July	August	September	October	November	December
residential	45409012	43098653	37691610	33848659	29956226	29805216	31581348	34002142	34401099	30444824	31302538	40214805
commercial	91107138	84776839	86149092	83092860	85559120	90808149	91685726	92573872	1.01E+08	91119945	81193369	95671062
street lights	1216813	996379	912116	878597	713816	705096	706664	688803	900198	900352	1034316	1204772
total	**1.38E+08**	**1.29E+08**	**1.25E+08**	**1.18E+08**	**1.16E+08**	**1.21E+08**	**1.24E+08**	**1.27E+08**	**1.36E+08**	**1.22E+08**	**1.14E+08**	**1.37E+08**

Figure 12.6 – Worcester Monthly Electrical Consumption, 2001 – 2004, by Category.[117]

13. APPENDIX C: Other Analyses:

This section contains analyses not included in the body of the paper.

13.2 Wind Turbine Specifications

A wind turbine can be described by breaking its components into three major categories: the tower or shaft, the rotors or blades, and the generator. By making adjustments to any of those components engineers are able to create wind turbines that come in a wide variety of shapes, sizes, and electrical capacities.

13.2.1 The Tower

The height of a wind tower plays a major role in the production of the generator. Generally there is more wind at higher elevations, so towers are often hundreds of feet high. Most commercial towers vary between one and four hundred feet tall, as dictated where it is to be built and the needs or wants of the customer.

The physical construction of the tower can also vary between three distinct designs. One such design is a lattice structure, similar to those of a stereotypical oil well. Lattice towers are manufactured using welded steel profiles. The basic advantage of lattice towers is cost, since they require only half as much material as a freely standing tubular tower with a similar rigidity (**Error! Reference source not found.** – Left). Though these are often seen on older wind farms, for residential turbines, and some shorter turbines, they are not exclusively used in these areas.

The second design is the tubular steel tower (Figure 13.1 – Right). Most large wind turbines are delivered with tubular steel towers which are manufactured in sections of 20-30 meters with flanges at either end and bolted together on the site. The towers are conical in order to increase their strength and to save materials at the same time. Some of the larger tubular steel towers have stabilizer lines attached at various heights along the tower in order to help prevent the tower from falling over.

The third type of tower is called a Guyed tubular tower but it is only used for small towers meant to either charge batteries, or to act as a short term back-up generator.

Figure 13.1 – Wind Towers[118]

13.2.2 The Rotor

The cross-sectional area of the disc covered by the moving rotor, combined with wind speeds, determines how much energy which can be harvested in any given year. A typical turbine with a 600 kW electrical generator will typically have a rotor diameter of 44 meters (144 ft.). If the rotor diameter is doubled, the cross-sectional rotor area is four times larger. Consequently the rotor is able produce four times the power in the generator due to an increased torque. Rotor diameters may vary somewhat from those in Figure 13.2 below. This is due to the fact that many manufacturers calibrate their machines to be optimized for local wind conditions.

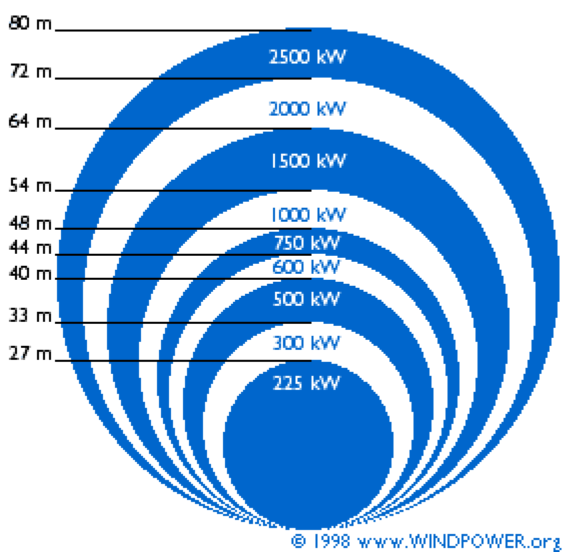


Figure 13.2 – Rotor Diameters[119]

A larger generator requires more wind to turn, so if a wind turbine were to be installed in a low wind area, a smaller generator for a given rotor size (or a larger rotor size for a given generator) will actually maximize annual output. For example a 600kW turbine can have a rotor diameter ranging from 39 to 48 meters and based on the wind analysis of the location for the turbine, the specific rotor size will be chosen to maximize the output. The reason that the output of a smaller generator will produce more electricity annually is because its rotors will be moving for more hours throughout the course of a given year. It is this increased rotor activity which enables the production of more electricity.

Additionally, the rotors may vary based upon the number of blades which they may have. Each rotor manufacturer determines how many blades are to be used for the wind turbine. This decision is typically based upon the customer's requests and the availability of the wind in a given area. Wind turbines can have anywhere from one to five blades, with three blades being the most common.

13.2.3 Generator

What really defines the "brand" of a wind turbine is the design of the generator and how it produces electricity. The rating, however, of each generator is held standard across manufacturers. All generators are rated based on the maximum number of kilowatts that they can produce at any given time, with commercial generators being rated between 10kW and 3.6MW and residential generators being rated between 1kW and 10kW. With larger generators placed in locations that are abundant with wind, the overall cost for electricity with be reduced and there will be an increase in electricity production.

13.3 Analysis of Oil Reserves and Production

Petroleum is the most heavily used energy source in America and the world (Figure 13.3). Petroleum is also estimated to be the first fossil fuel to become depleted, most likely in this century. The most important factors in determining the future role petroleum will play in the world are the estimated amount of reserves left in the ground, and the anticipated production rate. The amount of estimated reserves along with a model of how production is affected by demand and a shrinking reserve size can hopefully produce a scenario of how production of oil will increase and decrease over the next 50 years. The two most well known analyses of this type are the Hubbert analysis and the US Energy Information Administration analysis.

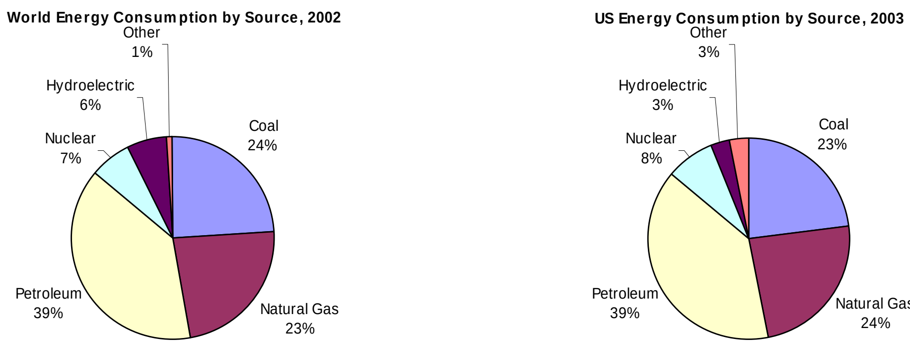


Figure 13.3 – US and World Energy Consumption by Source[120,121]

Because oil holds such a critical place in our society, a reduction in oil production could cause great changes to many different sectors of our economy and lifestyle. Our economy is centered around individual transportation. Suburbs are a good example of this. Many communities "sprawl" outward in order to get their own land and space assuming that they can make a short drive into town, to their jobs or any other place they need to be. Businesses as well as individuals will be shaken as gas prices continue to increase and eventually as gas diminishes. Some researchers propose moving to an entirely electrical economy with battery operated cars[122], others propose the use of hydrogen as the fuel of the future, and still others believe the only long term solution is a renewed concern and stewardship for our environment[123].

13.3.1 Hubbert's Analysis

This type of analysis is based on a 1956 paper by M. King Hubbert entitled "Nuclear Energy and the Fossil Fuels"[124]. In this paper Hubbert predicted that oil production in the United States would peak around 1970, which it did. This is the real basis for the validity of Hubbert's analysis—that he was able to correctly predict the US oil production peak at a time when the majority of scientists completely disregarded him. If Hubbert failed to correctly predict the US oil production peak, then his analysis would not be used to predict the world production peak today. The following analysis of the United States and the world were performed with methods from Kenneth S. Deffeyes' *Beyond Oil*[125] using independent data from the US Energy Information Administration[126]. They follow the Hubbert method and his assumptions, but all analysis was done by the IQP group.

United States Oil Production Peak

Hubbert originally formulated his analysis by looking at the United States. The central assumption of Hubbert's method is that production of any finite resource, when it becomes scarce, is eventually a function of *only* the remaining reserves. In the US, when there was quite a bit of oil in the ground, production could be a function of many different factors, therefore untapped reserves were not the limiting variable. However, as oil became depleted, regardless of technological innovations and economic demand, oil production became a function of only the amount of oil left in the ground. The United States oil production still is only a function of un-produced reserves.

Hubbert put this assumption into analytical form by plotting the "cumulative oil production on the horizontal axis and the ratio of annual production to cumulative production on the vertical"[127]. The assumption that production is dependent only on remaining reserves is accomplished by fitting this graph with a straight line. This straight line *is* the Hubbert analysis. This can all be seen in Figure 13.4.

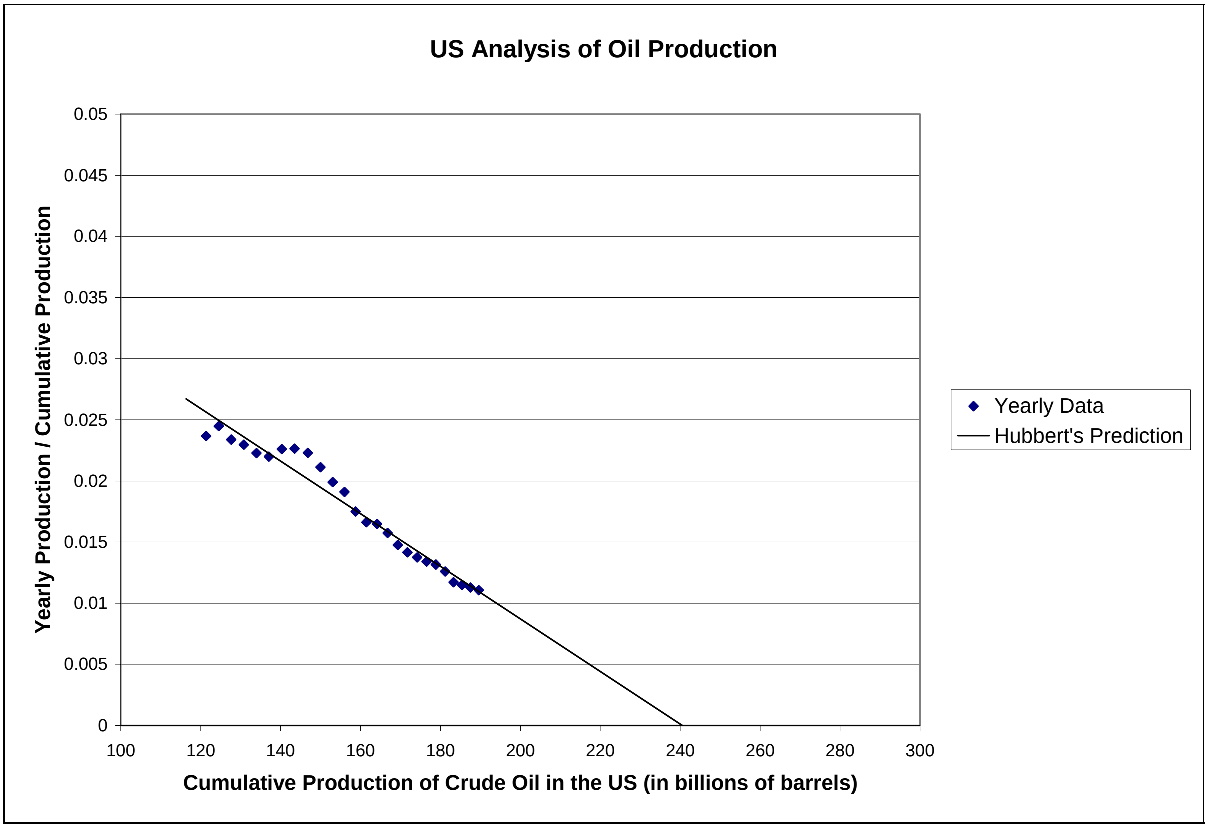


Figure 13.4 – Linear dependence of yearly production on cumulative production

The line obtained is of the form:

$$\frac{P}{Q} = a - \left(\frac{a}{Q_t}\right)Q$$

where *a* is a constant and the other terms are defined as:

P – Yearly Production of Crude Oil in the US

Q – Cumulative Production of Crude Oil in the US

Q_t – Total Crude Oil Reserves in the US, x intercept

The cumulative production of crude oil in the US, *Q*, is the total amount of oil taken out of the ground from the first oil well till now. The total crude oil reserve is the estimation of how much oil will ever be produced from the US regardless of technological advances or economic factors. By multiplying both sides of the above equation by *Q*, a quadratic equation for yearly production as a function cumulative production is obtained:

$$P = a\left(1 - \frac{Q}{Q_t}\right)Q$$

where $(1- Q/Q_t)$ is the fraction of remaining reserves.

Using data for the United States, this equation becomes:

$$P = 0.0517\left(1 - \frac{Q}{240}\right)Q$$

and can be plotted, as shown in Figure C.3.

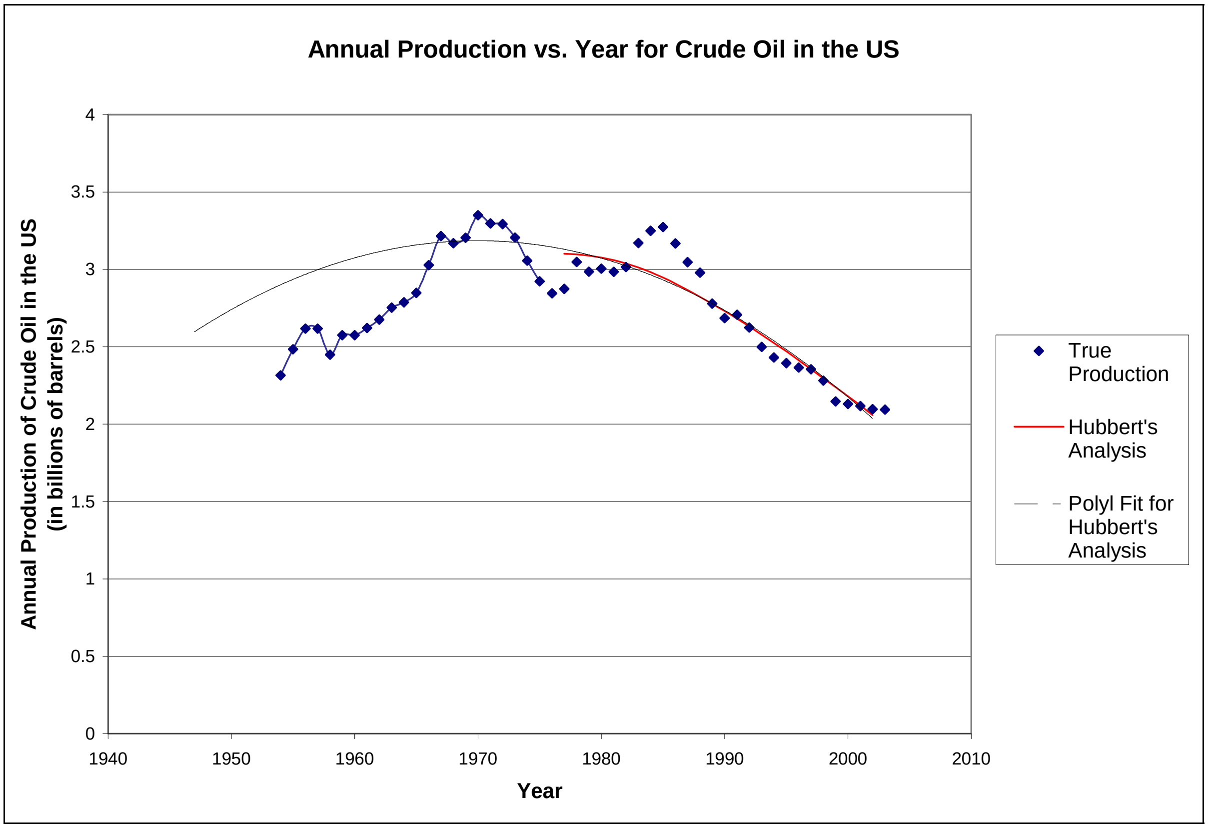


Figure 13.5 – Hubbert's Peak for the United States

This analysis predicts that the United States oil production peaked right around 1970, which it did. This same figure performed with more extensive data is included at the end of this section.

World Oil Production Peak

Obtaining an estimate of when world oil production might peak was done in a similar way. Using independent data and the methods of Hubbert, the IQP group was able to formulate consistent predictions on world oil production. Cumulative oil production is plotted on the horizontal and the ratio of yearly production to cumulative production is plotted on the vertical axis. This is shown in Figure 13.6.

The equation obtained from this linear best fit line is:

$$P = 0.0531\left(1 - \frac{Q}{2.1}\right)Q$$

with production in trillions of barrels this time.

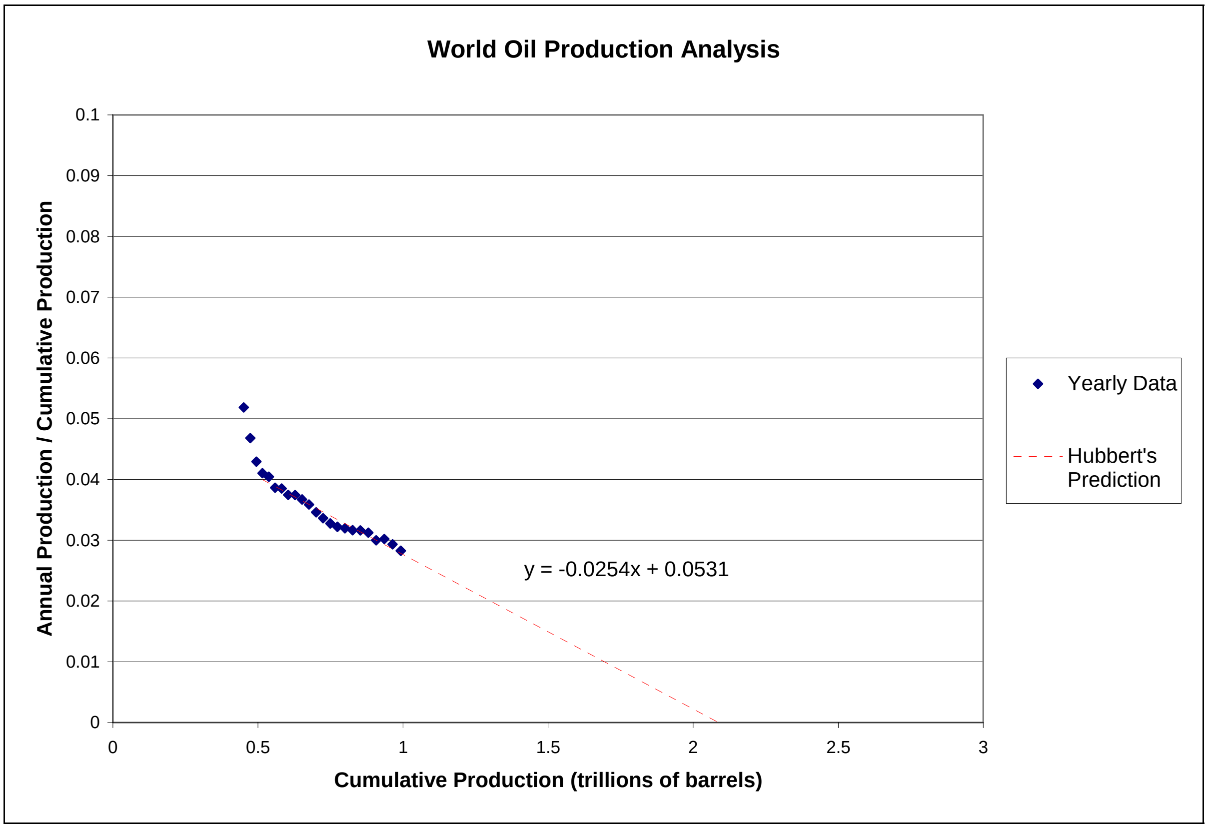


Figure 13.6 – Linear Dependence of Yearly Production on Cumulative Production

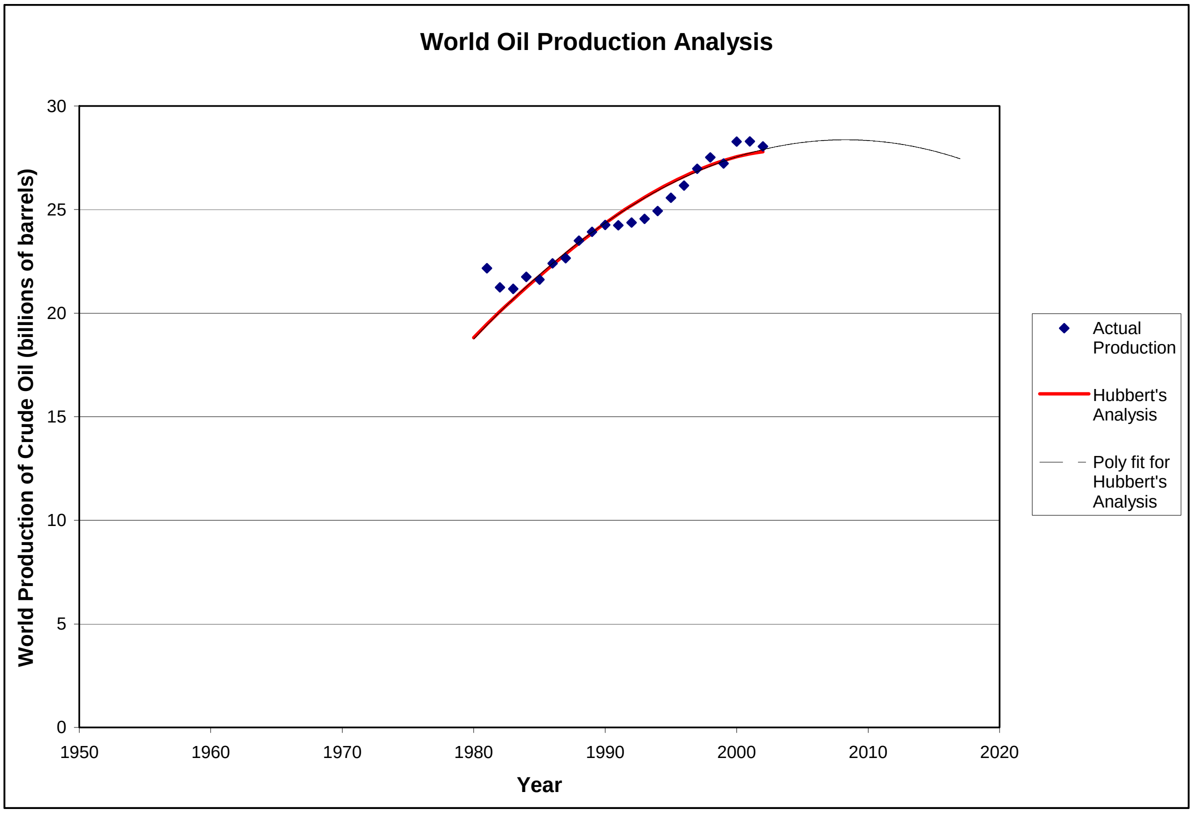


Figure 13.7 – Hubbert's Peak for World Oil Production

This equation is plotted in Figure C.7. As can be seen from this figure, our Hubbert analysis predicts that world oil production will peak sometime between 2005 and 2010. From this point, according to Hubbert, world oil production will continue to decrease. Q_t obtained from this analysis is around 2.1 trillion barrels. In 2003, the world cumulative production passed 1 trillion barrels meaning there is around 1.1 trillion barrels of remaining reserves. This result is consistent with analysis done by British Petroleum, the *Oil & Gas Journal* and *World Oil*[128].

13.3.2 U.S. Energy Information Administration and Other Methods

Although Hubbert's hypothesis that production of oil, because it is a finite resource, will eventually be controlled only by remaining reserves proved to be accurate for the US, it is still unclear what role sociological and economic issues will play in the future for the world oil supply. In the US, when domestic production declined, it was still possible to import oil. There is no such solution for the world oil supply. The US Energy Information Administration (EIA) believes that other factors will intercede such that oil production will not begin to decline in the next several years. There is uncertainty as to what these factors may be but they most likely will arise from the fact that the there is no external supply of oil for the world. Many

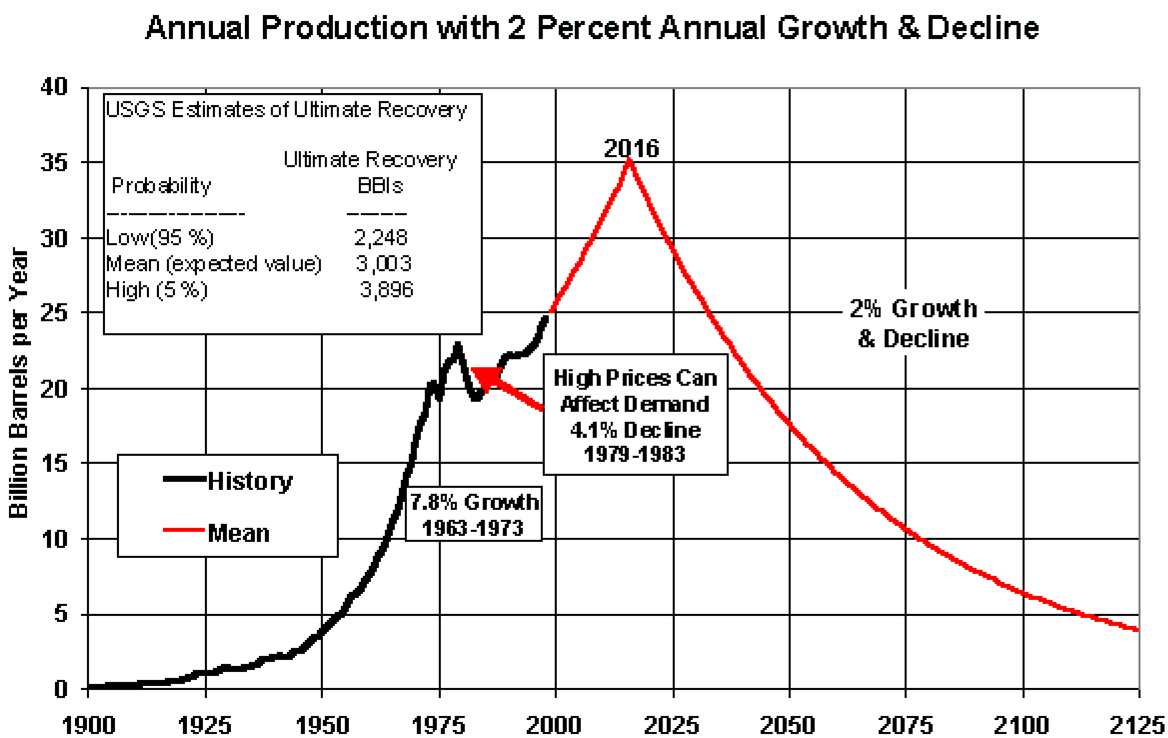


Figure 13.8 – EIA peak oil production estimate[129]

countries, however, including several in Europe, are becoming very forceful in developing solutions to this problem[130,131]. The United States seems to be late in developing petroleum alternative solutions[132,133].

The EIA used an empirical growth rate model to predict when world oil production will peak which can be seen in Figure C.6. Though based somewhat on current trends the data expressed in this graph only goes through 1999 and neither takes into account recent developments or the annual variation of production. Data from 1999 to 2004 shows both decreases and increases instead of a consistent 2% growth rate. Growth data for this time period is given in Table 13.1, which reflects an average growth rate per year of 1.61%[134]. The high variability of oil production from year to year is similar to the US experience in the 1970s. This can be seen in Figure

13.5 – Hubbert's Peak for the United States. These high fluctuations are produced because oil is reaching its production limit[135].

In addition to this, several of the major world oil producers have announced that they are producing at peak capacity. OPEC was formed with the goal of stabilizing oil prices and establishing power in the Middle East. In the 1990s OPEC aimed at keeping oil prices between $22 and $28 per barrel by increasing or decreasing production as a whole organization. During this period "OPEC members, one by one, ran out of surplus production capacity until Saudi Arabia was the last man standing"[136]. In March of 2003 the Saudi government announced that they were producing oil at maximum production. It is unlikely that production capacity will increase until 2020, as suggested by the EIA analysis.

Year	Annual Increase
1991	-0.08%
1992	0.54%
1993	0.76%
1994	1.52%
1995	2.55%
1996	2.32%
1997	3.10%
1998	2.03%
1999	-1.09%
2000	3.89%
2001	0.04%
2002	-0.85%
2003	3.39%
2004	4.42%

Table 13.1 – Annual Increase in world oil production, 1991-2004[137]

13.4 Analyses of Wind Power in China

In addition to America's search for alternative sources of energy in the form of electricity and fuels, many other countries are also coming to view their dependence on fossil fuels in a negative light. For many reasons, the countries that are pursuing renewable energy in the form of wind power to the greatest extent include many European countries, America, India and China. According to the World Wind Energy Association, these countries installed a combined capacity of 30,892 MW in 2003, which is 79% of the total installed capacity that year[138]. Similar driving forces are at work behind both western and eastern nations in their search for alternative energies, pollution reduction, and sustainability.

As of 2002, China's total electrical production capacity was 338.3 GW[139]. This is the second highest production capacity in the world; only America has a higher capacity with 848.3 GW. However, with a population of 1.3 billion people and a real GDP growth rate of 9.1% in 2003 (The US had 3.0%), China has one of the largest economic growth rates in the world and is also emerging as one of the largest energy consumers.

13.4.1 Current Energy Status

In 2003, China's energy infrastructure lost pace with its economic growth. This has caused major brown outs in some areas and could have an effect on China's future economic growth. Though the increased growth rates of 2003 were somewhat unexpected, China's economy has been steadily growing between 7-10% over the last 20 years and is expected to have continued growth at this rate for the next ten to fifteen years[140]. During the 1990's the Chinese government went through a major consolidation effort in state owned industry, especially the electrical power supply. During most of the 1990's, China's electrical system actually experienced an oversupply due to the closure of many government corporations around this period. The consolidation eventually led to less energy waste and greater monetary efficiency.

As already mentioned, China's economic growth has led to large leaps in energy consumption and production. The current energy deficit is leading to major investment in future electrical production, including recent plans for a large wind power sector. One of the most significant signs of China's increase in energy consumption as an industrialized nation is their in crease in petroleum consumption due to the use of cars. In the ten years between

1990 and 2000, Chinese petroleum consumption doubled from 2,296 to 4,796 thousand barrels a day[141]. For reference to how fast this growth is, America is consuming twice as much petroleum now as it was in the early 1960s[142]. During this same 10 year period, China also more than doubled its electrical energy consumption from 550.9 to 1200.2 billion kilowatt-hours[143]. Around three-quarters of this electricity was generated by coal fired power plants. China's dependence on coal fired power plants is one of the primary driving forces behind its new energy policy which was included in China's 10th 5 Year Plan.

13.4.2 Turn Toward Alternative Energy Sources

Pollution is a pressing problem in China today. China has very large reserves of coal and this source of energy has helped to fuel China's economic growth. As seen in Figure C.9, China experiences severe acid rain in many parts of the country due to sulfur emissions from coal powered power plants. According to the World Health Organization, China has 7 of the

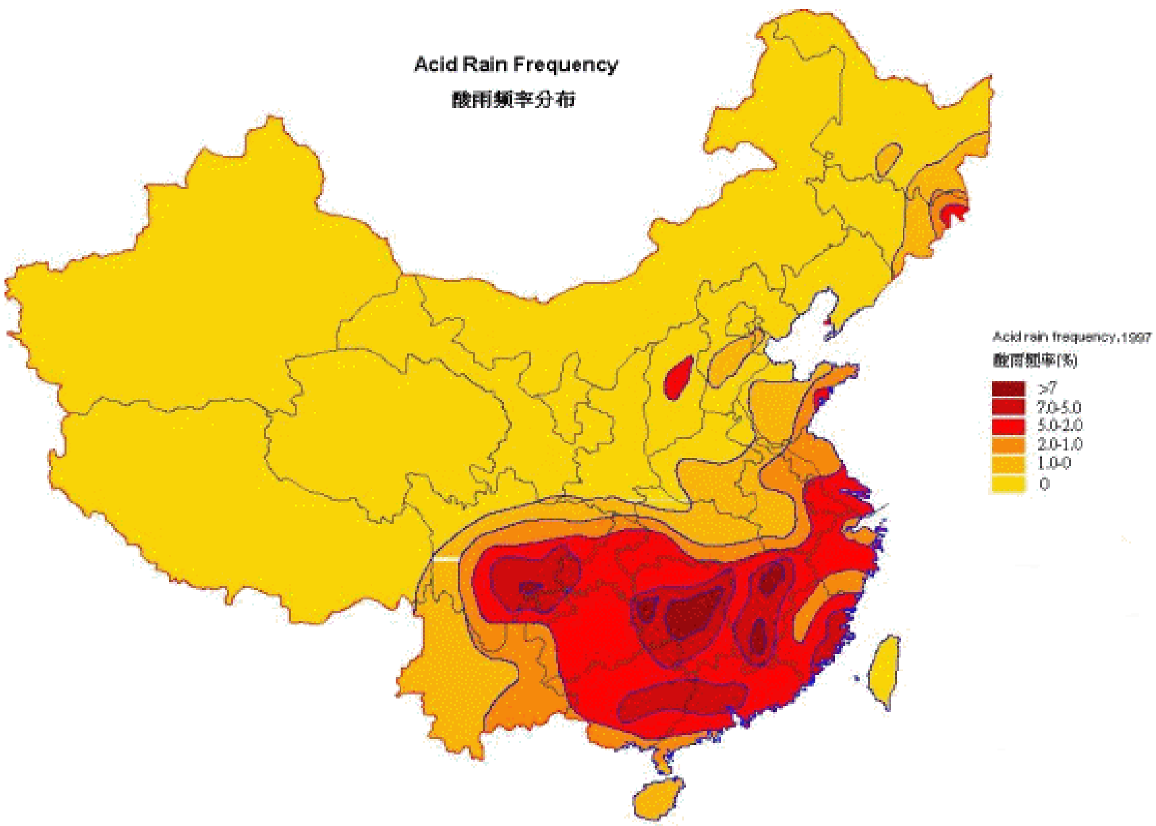


Figure 13.9 – Areas of high pollution in China[144]

ten most polluted cities in the world[145]. China's pollution problem, however, has even gone beyond a state of chemical hazard. China may be the first country severely affected by global warming; more than "60 percent of Chinese glaciers are anticipated to disappear by 2050, threatening the fresh water supply for more than 250 million Chinese."[146] In the last five years, China has not backed away from these problems. China's government has paved the way for renewable energies including wind and hydroelectric in addition to a proposed decrease in the consumption of coal power to be replaced by natural gas.

China's 10th Five Year Plan calls for major increases in hydroelectric and nuclear power. In 2005, however, China passed a Renewable Energy Act that proposes a goal of 10% total energy production from renewable sources by 2020. The Chinese government itself expects hydroelectric, wind and bio-fuels to play a major role in this goal. China has large resources of both hydroelectric and wind capacity, both wind and hydroelectric total energy capacities are estimated to be around 300GW each. As a testament to this goal, China is planning the two largest hydroelectric facilities in the world.

The Chinese government also believes wind power will help to power the future energy needs of the country. In 2005 the Chinese Renewable Energy Industry Association (CREIA) met with the European Wind Energy Association (EWEA) and Greenpeace to develop a blueprint for wind power production in China. The blueprint is called *Wind Force 12 – China* and outlines expectations and possible production plans for wind power in China. The report is mainly a feasibility estimate exploring the potential of wind power in China by 2020. According to the report, by 2020 China could have 170 GW of installed capacity powering 12% of the country[147]. Though this is the upper limit of what China could achieve in the next 15 years with an estimated investment of 105 billion euros. A more realistic estimate is given in Figure C.8 at 20GW. China has made a strong commitment to wind power since 1990 and all indications point to even a greater commitment in coming years.

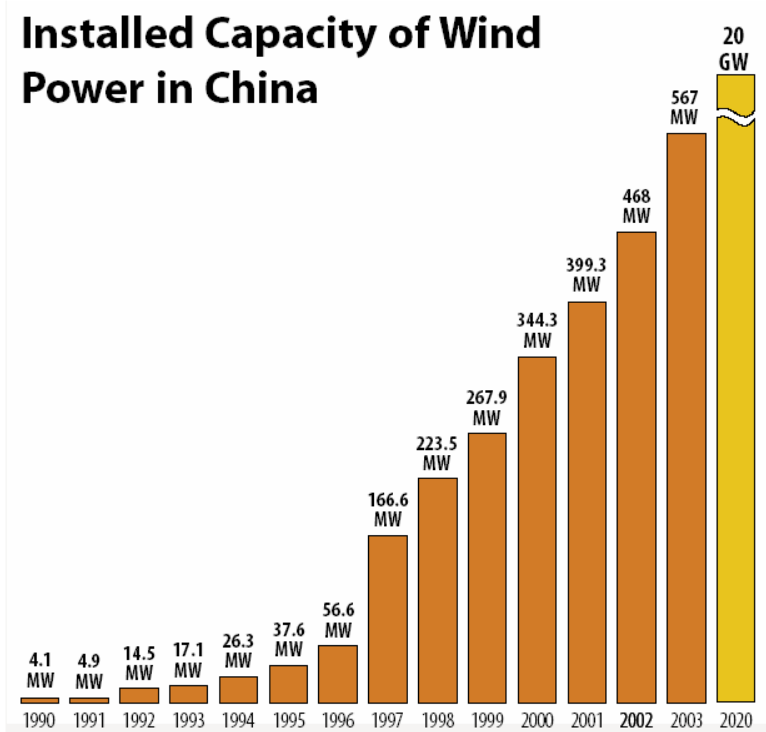


Figure 13.10 – Installed capacity of wind power in China, and predicted 2020 capacity[148]

[1] Based on a linear trend line using data from:
Energy Information Administration: World Total Primary Energy Consumption, http://www.eia.doe.gov/pub/international/iealf/tablee1.xls. Last Accessed: May 2, 2005.

[2] Energy Information Administration: World Consumption of Primary Energy by Energy Type and Selected Country Groups, http://www.eia.doe.gov/pub/international/iealf/table18.xls. Last Accessed: May 2, 2005. Also see Figure A.2

[3] See Appendix A for analysis of oil reserves; also refer to Deffeyes, Kenneth. *Beyond Oil.*

[4] Deffeyes, Kenneth S. *Beyond Oil.* New York, Hill and Wang, 2005.

[5] Energy Information Administration Long Term World Oil Supply Power Point – "Annual Production Scenarios with 2% Growth Rates and Different Resource Levels," http://www.eia.doe.gov/pub/oil_gas/petroleum/presentations/2000/long_term_supply/sld016.htm. Last Accessed: May 2, 2005.

[6] FAQfarm: How Many Cars are There in the United States?, http://www.faqfarm.com/Q/How_many_cars_are_there_in_the_US. Last Accessed: May 2, 2005.

[7] Nayak, Navin. "Redirecting America's Energy: The Economic and Consumer Benefits of Clean Energy Policies." U.S. PIRG Education Fund (2005) 3. http://www.apolloalliance.org/docUploads/redirectingamericasenergy%2Epdf. Last Accessed: May 2, 2005.

[8] Nayak, Navin. "Redirecting America's Energy: The Economic and Consumer Benefits of Clean Energy Policies." U.S. PIRG Education Fund (2005) 3. http://www.apolloalliance.org/docUploads/redirectingamericasenergy%2Epdf. Last Accessed: May 2, 2005.

[9] Johnson, Jeff. "Blowing Green." *Chemical & Engineering News.* http://pubs.acs.org/cen/coverstory/8108/8108energy.html. Last Accessed: May 4, 2005.

[10] Natural Gas Hydrates, http://sts.gsc.nrcan.gc.ca/beaufort_dcp/index_e.asp?CaID=8&PgID=41. Last Accessed: May 2, 2005.

[11] Deffeyes, Kenneth S. *Beyond Oil.* New York, Hill and Wang, 2005 p. 73.

[12] Deffeyes, Kenneth S. *Beyond Oil.* New York, Hill and Wang, 2005 p. 104.

[13] McConnell, Tony Co-Chairman and Long, Louis Co-Chairman et al. "A Roadmap to Deploy New Nuclear Power Plants in the United States by 2010: Volume II." Prepared for the U.S. Department of Energy (2001). http://www.ne.doe.gov/nerac/NTDRoadmapVolII.PDF. Last Accessed May 2, 2005.

[14] Technology Goals for Generation IV Nuclear Energy Systems, http://gen-iv.ne.doe.gov/pdf/finalgenivgoals_may01.pdf. Last Accessed: May 2, 2005.

[15] Ragnarsson, Árni. "Iceland Country Update." Proceedings of the World Geothermal Congress 1995, Florence, Italy. http://geoheat.oit.edu/bulletin/bull17-4/art25.htm. Last Accessed: May 2, 2005.

[16] Energy Information Administration: World Consumption of Primary Energy by Energy Type and Selected Country Groups, http://www.eia.doe.gov/pub/international/iealf/table18.xls. Last Accessed: May 2, 2005. Also see Figure A.2

[17] Akinci, Berk. "Biomass Conversion to Liquid Fuels: Using Plant Oils." Worcester Polytechnic Institute Interactive Qualifying Project, 2002.

[18] Degen, Bradfors; Ehnstrom, James and Baxter, Michael. "Alternative Energy: Bio-hydrogen and Bio-diesel." Worcester Polytechnic Institute Interactive Qualifying Project, 2004.

[19] Degen, Bradfors; Ehnstrom, James and Baxter, Michael. "Alternative Energy: Bio-hydrogen and Bio-diesel." Worcester Polytechnic Institute Interactive Qualifying Project, 2004 p. 12.

[20] Akinci, Berk. "Biomass Conversion to Liquid Fuels: Using Plant Oils." Worcester Polytechnic Institute Interactive Qualifying Project, 2002 p. 18.

[21] Akinci, Berk. "Biomass Conversion to Liquid Fuels: Using Plant Oils." Worcester Polytechnic Institute Interactive Qualifying Project, 2002 p. 18.

[22] Righter, Robert W. *Wind Energy in America*. (University of Oklahoma Press, Norman, OK. 1996), 7.

[23] Early Wind History Through 1875, http://telosnet.com/wind/early.html. Last accessed: May 3, 2005.

[24] Righter, Robert W. *Wind Energy in America*. (University of Oklahoma Press, Norman, OK. 1996), pp 21.

[25] Righter, Robert W. *Wind Energy in America*. (University of Oklahoma Press, Norman, OK. 1996), pp 28.

[26] 20th Century Wind Developments. http://telosnet.com/wind/20th.html. Last accessed: May 3, 2005.

[27] Energy Information Administration Country Analysis Sheets: United Kingdom, http://www.eia.doe.gov/emeu/cabs/uk.html. Last Accessed: May 2, 2005.

[28] Energy Information Administration Country Analysis Sheets: Germany, http://www.eia.doe.gov/emeu/cabs/germany.html. Last Accessed: May 2, 2005.

[29] Continental Population Density Maps 1995, http://sedac.ciesin.columbia.edu/plue/gpw/index.html?europe.html&2. Last Accessed: May 2, 2005.

[30] Wind Map of Western Europe, http://www.windpower.org/en/tour/wres/euromap.htm. Last Accessed: May 2, 2005.

[31] Press Release: Worldwide Wind Energy Capacity at 39,151 MW. http://www.wind-energie.de/englischer-teil/topics/050307-press-release-wwea-pdf.pdf. Last Accessed: May 2, 2005.

[32] Promoting wind energy through the Renewable Energy Sources Act (EEG), http://www.wind-energie.de/englischer-teil/topics/topics.htm. Last Accessed: May 3, 2005.

[33] Energy Information Administration Country Analysis Sheets: Germany, http://www.eia.doe.gov/emeu/cabs/germany.html. Last Accessed: May 3, 2005.

[34] Energy Information Administration Country Analysis Sheets: Germany, http://www.eia.doe.gov/emeu/cabs/germany.html. Last Accessed: May 3, 2005.

[35] Energy Information Administration Country Analysis Sheets: United Kingdom, http://www.eia.doe.gov/emeu/cabs/uk.html. Last Accessed: May 3, 2005.

[36] The British Wind Energy Association – Operating Wind Farms, http://www.bwea.com/map/list.html. Last Accessed: May 3, 2005.

[37] The British Wind Energy Association – Operating Wind Farms, http://www.bwea.com/map/list.html. Last Accessed: May 3, 2005.

[38] Energy Information Administration – "Analysis of Strategies for Reducing Multiple Emissions from Electric Power Plants," (2001) http://www.eia.doe.gov/oiaf/servicerpt/epp/pdf/sroiaf(2001)03.pdf. Last Accessed: May 3, 2005.

[39] Union of Concerned Scientists – "Renewable Energy Tax Credit Saved Once Again", http://www.ucsusa.org/clean_energy/renewable_energy/page.cfm?pageID=121. Last Accessed: May 3, 2005.

[40] Energy Information Administration – "Analysis of Strategies for Reducing Multiple Emissions from Electric Power Plants," (2001) http://www.eia.doe.gov/oiaf/servicerpt/epp/pdf/sroiaf(2001)03.pdf. Last Accessed: May 3, 2005.

[41] Energy Information Administration – "Analysis of Strategies for Reducing Multiple Emissions from Electric Power Plants," (2001) http://www.eia.doe.gov/oiaf/servicerpt/epp/pdf/sroiaf(2001)03.pdf. Last Accessed: May 3, 2005.

[42] Greenpeace - "Answer to China's Energy Future is Blowing in the Wind", http://www.greenpeace.org/international/press/releases/answer-to-china-s-energy-futur. Last Accessed: May 3, 2005.

[43] National Renewable Energy Laboratory – "Renewable Energy in China", http://www.nrel.gov/docs/fy04osti/35789.pdf. Last Accessed: May 3, 2005.

[44] Energy Information Administration Country Analysis Sheets: India, http://www.eia.doe.gov/emeu/cabs/india.html. Last Accessed: May 3, 2005.

[45] Wind Force 12, http://www.ewea.org/documents/WF12-2004_eng.pdf. Last Accessed: May 3, 2005.

[46] National Renewable Energy Laboratory – United States Annual Wind Resource Potential, http://mapserve1.nrel.gov/website/wind_resource1/viewer.htm. Last Accessed: May 3, 2005.

[47] The New England Wind Map, http://truewind.teamcamelot.com/ne/. Last Accessed: May 3, 2005.

[48] Calculation using the Siemens 2.3 MW turbine (http://www.powergeneration.siemens.com/en/windpower/products/index.cfm), which has a swept area of 5300 m^2; multiplying this with the 160 W/m^2 wind density of Worcester provides a power of 848 kW. With this number and the average need of roughly 172 MW at any given time for the city of Worcester (calculated from yearly usage), there is a need of 203 wind

turbines. The electrical conversion losses, transmission losses and other concerns are not factored into this calculation due to their inherent variability.

[49] Cape Wind: Energy for Life, http://www.capewind.org/. Last Accessed: May 3, 2005.

[50] Cape Wind: Energy for Life, http://www.capewind.org/. Last Accessed: May 3, 2005.

[51] Cape Wind: Energy for Life, http://www.capewind.org/. Last Accessed: May 3, 2005.

[52] Perry, Jeffrey. Personal interview. April 21, 2005.

[53] U.S. Population Density, http://www.census.gov/dmd/www/pdf/512popdn.pdf. Last Accessed: May 3, 2005.

[54] National Renewable Energy Laboratory – United States Annual Wind Resource Potential, http://mapserve1.nrel.gov/website/wind_resource1/viewer.htm. Last Accessed: May 3, 2005.

[55] Wind Energy: An Untapped Resource, http://www.awea.org/pubs/factsheets/WindEnergyAnUntappedResource01-13-04.pdf. Last Accessed: May 3, 2005.

[56] U.S. Wind Resource Map, http://www.azsolarcenter.com/images/windpower.gif. Last Accessed: May 3, 2005.

[57] Fischbach, Amy Florence. "Wind Biz." (2001) http://ceenews.com/mag/electric_wind_biz_2/. Last Accessed: May 3, 2005.

[58] Fischbach, Amy Florence. "Wind Biz." (2001) http://ceenews.com/mag/electric_wind_biz_2/. Last Accessed: May 3, 2005.

[59] Fischbach, Amy Florence. "Wind Biz." (2001) http://ceenews.com/mag/electric_wind_biz_2/. Last Accessed: May 3, 2005.

[60] Fischbach, Amy Florence. "Wind Biz." (2001) http://ceenews.com/mag/electric_wind_biz_2/. Last Accessed: May 3, 2005.

[61] United States – 2003 Year End Wind Power Capacity, http://www.azsolarcenter.com/images/uswindmap03.gif. Last Accessed: May 3, 2005.

[62] Data from Robert Thompson. Data is included in Table B.3 in Appendix B.

[63] Data from Robert Thompson. Data is included in Table B.3 in Appendix B.

[64] Amall Wind Turbines for Homes, Businesses and Off-Grid, http://www.bergey.com/. Last Accessed: May 3, 2005.

[65] Westwind Wind Turbines, http://www.westwind.com.au/. Last Accessed: May 3, 2005.

[66] Utility Bill Reduction + Back-up Power Value Package, www.bergey.com. Last Accessed: May 3, 2005. See Figure B.3 in Appendix B.

[67] Utility Bill Reduction Value Package, www.bergey.com. Last Accessed: May 3, 2005. See Figure B.4 in Appendix B.

[68] Utility Bill Reduction + Back-up Power Value Package, www.bergey.com. Last Accessed: May 3, 2005. See Figure B.3 in Appendix B.

[69] Utility Bill Reduction Value Package, www.bergey.com. Last Accessed: May 3, 2005. See Figure B.4 in Appendix B.

[70] Data from Robert Thompson. Data is included in Table B.3 in Appendix B.

[71] Data from Robert Thompson. Data is included in Table B.3 in Appendix B.

[72] Hull Wind, www.hullwind.org. Last Accessed: May 3, 2005.

[73] Hull Wind Information Brochure, http://www.hullwind.org/Hull%20Brochure.pdf. Last Accessed: May 3, 2005.

[74] The New England Wind Map, http://truewind.teamcamelot.com/ne/. Last Accessed: May 3, 2005.

[75] Hull Wind, www.hullwind.org. Last Accessed: May 3, 2005.

[76] Murray, Iain. "Green Civil War." *Tech Central Station* (2003). http://www.techcentralstation.com/112603C.html. Last Accessed: May 3, 2005.

[77] U.S. Doe Energy Efficiency and Renewable Energy – "Wind Farms and Wind Farmers," http://www.eere.energy.gov/consumerinfo/factsheets/ad2.html. Last Accessed: May 3, 2005.

[78] The British Wind Energy Association – The Economic of Wind Energy, http://www.bwea.com/ref/econ.html. Last Accessed: May 3, 2005.

[79] Union of Concerned Scientists – "Renewable Energy Tax Credit Saved Once Again", http://www.ucsusa.org/clean_energy/renewable_energy/page.cfm?pageID=121. Last Accessed: May 3, 2005.

[80] "Wind Power Costs Depend on Ownership, Financing." *Wind Energy Weekly* #709, 12 August 1996. http://www.awea.org/faq/cost.html. Last Accessed: May 3, 2005.

[81] Wiser, Ryan and Kahn, Edward. "Alternative Windpoer Ownership Structures: Financing Terms and Project Costs." (1996) http://eetd.lbl.gov/ea/EMS/reports/38921.pdf. Last Accessed: May 3, 2005.

[82] Interview with Jonathan Fitch. Transcript and information about the interview can be found in Appendix A.1.

[83] Myer, Rod. "Germany's Wind Farms Blowing Out of Control" *The Age.* http://www.theage.com.au/news/Business/Germanys-wind-farms-blowing-out-of-control/2005/02/01/1107228697876.html?oneclick=true. Last Accessed: May 4, 2005.

[84] Myer, Rod. "Germany's Wind Farms Blowing Out of Control" *The Age.* http://www.theage.com.au/news/Business/Germanys-wind-farms-blowing-out-of-control/2005/02/01/1107228697876.html?oneclick=true. Last Accessed: May 4, 2005.

[85] Perry, Jeffrey. Personal interview. April 21, 2005.

[86] Cape Wind: Energy For Life, http://www.capewind.org/. Last Accessed: May 4, 2005.

[87] Brooks, Walter. “New Statewide Survey on Cape Wind,” *Cape Cod Today*, http://www.capecodtoday.com/modules.php?op=modload&name=News&file=article&sid=044. Last Accessed: May 4, 2005.

[88] Brooks, Walter. “New Statewide Survey on Cape Wind,” *Cape Cod Today*, http://www.capecodtoday.com/modules.php?op=modload&name=News&file=article&sid=044. Last Accessed: May 4, 2005.

[89] Perry, Jeffrey. Personal interview. April 21, 2005.

[90] Taylor, James. “Massachuesettes Wind Farm Threatens more than 100,000 Birds,” *Heartland Institute*, http://www.heartland.org/Article.cfm?artId=16204. Last Accessed: May 4, 2005.

[91] Perry, Jeffrey. Personal interview. April 21, 2005.

[92] Perry, Jeffrey. Personal interview. April 21, 2005.

[93] Cape Wind: Energy For Life, http://www.capewind.org/. Last Accessed: May 4, 2005.

[94] Fitch, Jonathan. Personal interview. April 7, 2005.

[95] Fitch, Jonathan. Personal interview. April 7, 2005.

[96] Wachusett Mountain Wind Site, http://www.princetonwindfarm.com/db/wind.nsf/newwind?readform. Last Accessed: May 4, 2005.

[97] Wachusett Mountain Wind Site, http://www.princetonwindfarm.com/db/wind.nsf/newwind?readform. Last Accessed: May 4, 2005.

[98] Riccardella, Peter C.; Licina, George J.; Rosario, Darryl A. and Bax, Richard L. “Failure Investigation of Large Wind Turbine Transmission Housings.” http://www.structint.com/tekbrefs/t99007r0.pdf. Last Updated: May 4, 2005.

[99] Government Sponsored R&D, http://telosnet.com/wind/govprog.html. Last Accessed: May 4, 2005.

[100] Fitch, Jonathan. Personal interview. April 7, 2005.

[101] Bell, Darren and Kurt Ferreira. “Wind Farm Neighbor Survey.” Survey. April 7, 2005.

[102] Bell, Darren and Kurt Ferreira. “Princeton Resident Wind Farm Opinions.” Survey. April 7, 2005.

[103] Manwell, J.F.; McGowan, J.G.; Rogers, A.; Ellis, A. and Wright, S. “Wind Turbine Siting in an Urban Environment: The Hull, MA 660 kW Turbine.” http://www.ceere.org/rerl/publications/whitepapers/AWEA_Hull_2003.pdf. Last Accessed: May 4, 2005.

[104] Hull Wind, http://www.hullwind.org/. Last Accessed: May 4, 2005.

[105] Manwell, J.F.; McGowan, J.G.; Rogers, A.; Ellis, A. and Wright, S. “Wind Turbine Siting in an Urban Environment: The Hull, MA 660 kW Turbine.” http://www.ceere.org/rerl/publications/whitepapers/AWEA_Hull_2003.pdf. Last Accessed: May 4, 2005.

[106] Hull Wind One, http://www.vma.cape.com/~relweb/Case_Study_Hull_Wind_One.pdf. Last Accessed: May 4, 2005.

[107] Manwell, J.F.; McGowan, J.G.; Rogers, A.; Ellis, A. and Wright, S. "Wind Turbine Siting in an Urban Environment: The Hull, MA 660 kW Turbine." http://www.ceere.org/rerl/publications/whitepapers/AWEA_Hull_2003.pdf. Last Accessed: May 4, 2005.

[108] Energy Information Administration Annual Energy Outlook 2005, http://www.eia.doe.gov/oiaf/aeo/electricity.html. Last Accessed: May 4, 2005.

[109] Land and Water Area of States-2000, http://www.infoplease.com/ipa/A0108355.html. Last Accessed: May 4, 2005.

[110] Worcester, MA Profile, http://www.idcide.com/citydata/ma/worcester.htm. Last Accessed: May 4, 2005.

[111] The New England Wind Map, http://truewind.teamcamelot.com/ne/. Last Accessed: May 3, 2005.

[112] The New England Wind Map, http://truewind.teamcamelot.com/ne/. Last Accessed: May 3, 2005.

[113] Utility Bill Reduction + Back-up Power Value Package, www.bergey.com. Last Accessed: May 3, 2005.

[114] Utility Bill Reduction Value Package, www.bergey.com. Last Accessed: May 3, 2005.

[115] Thompson, Robert. Personal interview. April 11, 2005.

[116] Sullivan, Craig. "kWh Central District." E-mail to Joseph Citro. April 12, 2005.

[117] Sullivan, Craig. "kWh Central District." E-mail to Joseph Citro. April 12, 2005.

[118] Danish Wind Industry Association, http://www.windpower.org/en/tour/wtrb/tower.htm. Last Accessed: May 4, 2005.

[119] Danish Wind Industry Association, http://www.windpower.org/en/tour/wtrb/size.htm. Last Accessed: May 4, 2005.

[120] *The New York Times*, November 2003 http://www.infoplease.com/ipa/A0920633.html. Last Accessed: May 3, 2005.

[121] Energy Information Administration International Energy Annual 2002: "World Consumption of Primary Energy by Energy Type and Selected Country Groups", http://www.eia.doe.gov/pub/international/iealf/table18.xls. Last Accessed: May 3, 2005.

[122] Shinnar, R.; "The hydrogen economy, fuel cells, and electric cars", Technology in Society, Volume 25, Issue 4, Pages 453-576 (November 2003).

[123] Huesemann, Michael H. "Can pollution problems be effectively solved by environmental science and technology? An analysis of critical limitations." Ecological Economics 37 (2001) 271-287.

[124] Hubbert, M. King. "Nuclear Energy and the Fossil Fuels." *Drilling and Production Practice* (1956). http://www.hubbertpeak.com/hubbert/1956/1956.pdf. Last Accessed: May 3, 2005.

[125] Deffeyes, Kenneth S. *Beyond Oil.* New York, Hill and Wang, 2005.

[126] Energy Information Administration, http://www.eia.doe.gov. Last Accessed: May 3, 2005.

[127] Deffeyes, Kenneth S. *Beyond Oil.* New York, Hill and Wang, 2005 (36).

[128] Energy Information Administration - World Proved Reserves of Oil and Natural Gas, http://www.eia.doe.gov/emeu/international/reserves.html. Last Accessed: May 3, 2005.

[129] Energy Information Administration Long Term World Oil Supply – "Annual Production with 2% Annual Growth and Decline", http://www.eia.doe.gov/pub/oil_gas/petroleum/presentations/2000/long_term_supply/sld014.htm.
Last Accessed: May 3, 2005.

[130] Wind Force 12, http://www.ewea.org/documents/WF12-2004_eng.pdf. Last Accessed: May 3, 2005

[131] Press Release: "Worldwide Wind Energy Capacity at 39,151 MW", http://www.windenergie.de/englischer-teil/topics/050307-press-release-wwea-pdf.pdf. Last Accessed: May 3, 2005.

[132] Union of Concerned Scientists – "Renewable Energy Tax Credit Saved Once Again", http://www.ucsusa.org/clean_energy/renewable_energy/page.cfm?pageID=121. Last Accessed: May 3, 2005.

[133] Nayak, Navin. "Redirecting America's Energy: The Economic and Consumer Benefits of Clean Energy Policies." U.S. PIRG Education Fund (2005) 3. http://www.apolloalliance.org/docUploads/redirectingamericasenergy%2Epdf. Last Accessed: May 2, 2005.

[134] Energy Information Administration - "World Oil Supply, 1990-Present", http://www.eia.doe.gov/emeu/ipsr/t14.xls. Last Accessed: May 3, 2005.

[135] Deffeyes, Kenneth S. *Beyond Oil.* New York, Hill and Wang, 2005 (31).

[136] Deffeyes, Kenneth S. *Beyond Oil.* New York, Hill and Wang, 2005 (44).

[137] Energy Information Administration - "World Oil Supply, 1990-Present", http://www.eia.doe.gov/emeu/ipsr/t14.xls. Last Accessed: May 3, 2005.

[138] Press Release: Worldwide Wind Energy Capacity at 39,151 MW – 7,981 Added in 2003. http://www.wwindea.org/default.htm. Last Accessed: May 2, 2005.

[139] Energy Information Administration International Energy Annual 2002 – "World Electricity Installed Capacity by Type", http://www.eia.doe.gov/pub/international/iea2002/table64.xls. Last Accessed: May 3, 2005.

[140] U.S. Department of Energy: An Energy Overview of the People's Republic of China, http://www.fe.doe.gov/international/EastAsia_and_Oceania/chinover.html. Last Accessed: May 3, 2005.

[141] U.S. Department of Energy: An Energy Overview of the People's Republic of China, http://www.fe.doe.gov/international/EastAsia_and_Oceania/chinover.html. Last Accessed: May 3, 2005.

[142] Energy Information Administration – "Energy Consumption by Source, 1949-2003", http://www.eia.doe.gov/emeu/aer/txt/stb0103.xls. Last Accessed: May 3, 2005.

[143] U.S. Department of Energy: An Energy Overview of the People's Republic of China, http://www.fe.doe.gov/international/EastAsia_and_Oceania/chinover.html. Last Accessed: May 3, 2005.

[144] U.S. Department of Energy: An Energy Overview of the People's Republic of China, http://www.fe.doe.gov/international/EastAsia_and_Oceania/chinover.html. Last Accessed: May 3, 2005.

[145] Environment New Service - "The Winds of China Could Solve Climate Dillema", http://www.ens-newswire.com/ens/sep2004/2004-09-17-02.asp

[146] Environment New Service. "The Winds of China Could Solve Climate Dillema", http://www.ens-newswire.com/ens/sep2004/2004-09-17-02.asp. Last Accessed: May 3, 2005.

[147] Greenpeace - "Answer to China's Energy Future is Blowing in the Wind", http://www.greenpeace.org/international/press/releases/answer-to-china-s-energy-futur. Last Accessed: May 3, 2005.

[148] National Renewable Energy Laboratory – "Renewable Energy in China", http://www.nrel.gov/docs/fy04osti/35789.pdf. Last Accessed: May 3, 2005.