Wind Power: A Clean and Renewable Supplement to the World's Energy Mix

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Abstract: Wind power harbors the potential to become a key contributor to the world's energy supply in years to come. Not only is it inexhaustible and free, but in comparison to fossil fuel sources, its environmental footprint is negligible. The major technical hurdles to wind power's growth relate to its remoteness and variability, but neither is an obstacle too great to be overcome. In many places, wind-generated electricity is already cost-competitive with traditional energy sources, and in those where it is not, capital investment is needed to prime the wind industry for competition.

This paper represents my own work in accordance with University regulations. M.B.T.

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Introduction

As the global community moves into the twenty-first century, its patterns of energy generation and consumption stand in urgent need of reform as the ability to sustain current trends appears increasingly implausible. With the world population growing rapidly and almost exclusively in less developed regions, demand for energy is greater now than ever before and will continue to rise. Concurrently, the outlook for traditional, non-renewable forms of energy to be able to meet this rising demand is gloomy as finite fossil fuel resources such as oil experience gradual depletion. Beyond this issue, the byproducts of fossil fuel incineration pose a significant threat to the environment: escalating atmospheric levels of carbon dioxide have contributed directly to global warming, while sulfur dioxide and nitrogen oxides have significantly exacerbated particulate air pollution and acid rain. Without a curbed reliance on fossil-fuel-based energy, the emission levels of these pollutants and their associated problems will soon become far more serious and more difficult to resolve than they are at present.

In every one of these capacities, the prospect of a larger proportion of global energy supply being derived from clean and renewable sources like wind offers not merely a glimmer of hope, but a realistic and straightforward response. The process of generating energy from wind gives rise to neither greenhouse gas emissions nor other harmful atmospheric pollutants. As to efforts aimed at alleviating poverty and enhancing standards of living worldwide, the construction and operation of wind farms create income and jobs for homes and businesses. On a separate note, nations concerned with the security of their energy supply benefit from the inclusion of wind in their energy mix because the cost of its electricity generation does not rely upon the price of a fuel which is typically imported, and because such diversification inherently promotes the stability of their energy portfolio.

A final and more complex matter is whether or not wind power can help substantively in the struggle to bring electricity to the 1.6 billion people currently living without the basic luxuries it provides, over 80% of whom live in less-developed countries (IEA, 2005). This question depends on several variables: the pace of technological advancement in wind turbine design; the ability of wind to compete cost-wise with established energy sources; and the extent to which policymakers support the progression of the wind power industry via legal, financial, and environmental channels. Following investigation of each aforementioned factor, this paper concludes that wind power indeed harbors the potential to extend the availability of electricity well beyond its present reach, and to do so while conforming to fundamental principles of sustainable development.

The paper begins with relevant background information about wind power and the role it presently occupies in satisfying the world's electricity demand. Next, it offers a perspective on the technical components of harnessing wind power, paying special attention to the areas in which there is considerable room for improvement. The economic side of wind energy is subsequently examined; general strategies for governments to create incentives for more immediate and widespread evolution of the wind industry are explored, as are costs of integrating and transmitting wind-generated electricity to the grid. The paper then shifts toward a case study of wind energy's future in a developed nation, the United States, as well as in a developing nation, China. Each of these sections includes a number of recommendations which seek to maximize wind energy's penetration into utility power pools in as prompt a fashion as is practicable.

Background Information on Wind Energy

"Wind energy is a form of solar energy that is created by circulation patterns in the Earth's atmosphere that are driven by heat from the Sun" (AWEA, 2005). The blades of a wind turbine are rotated by the kinetic energy of passing air; they spin the turbine's rotor, which in turn drives the shaft of a generator that ultimately converts kinetic energy into electricity. Kinetic energy is equivalent to ½ * (mass) * $(\text{velocity})^2$, and since the mass of an air flow through a cross-sectional area swept by a wind turbine's blades in a given period is itself dependent on the velocity of the wind, there exists a cubic relationship between potential wind energy generation and wind speed. The 'mass' term in the kinetic energy definition also correlates positively with the area swept by the blades and the density of the moving air. Clearly, though, wind velocity is the most influential factor in the calculation of hypothetical energy yield for an industrial-scale wind farm.

Wind power is classified as a renewable source of energy because it is generated via a source capable of being reused indefinitely, in contrast to the burning of a non-renewable fossil fuel. Similar to surveying and mining practices utilized to pinpoint the areas richest in fossil fuel reserves, extensive efforts to track wind quality, both in terms of its frequency and its velocity, are carefully performed by anemometers in order to assess the wind potential in a given locale. Unlike the fuel sources for non-renewable energies, wind has the quality of being extremely inconstant, and correspondingly, its usefulness for energy generation can fluctuate tremendously in even a very limited span of time. A graphical depiction of the distribution of wind velocities in a typical setting indicates that winds at high and very high speeds tend to occur at a much lower frequency than do winds at low and very low speeds [see Appendix Image 1.] Wind's intermittence has key ramifications for wind-generated power and the incorporation of wind energy into the blends of electricity sources employed by most major utilities.

In reality, natural wind speed variations afford a huge benefit to the business of wind energy production. If such variations did not exist, and wind instead gusted permanently at its arithmetic mean rate, far less energy would be attainable since a large fraction of wind energy capacity at a particular site is derived from its brief, high-speed winds. Generally, the amount of power which could be extracted if the wind at a site blew constantly at its average velocity is only about half of that procurable from a natural distribution of wind speeds in Earth's atmosphere (Windpower, 2006). This comparison demonstrates the degree to which high-speed winds contain energy relative to slower winds, and in so doing, allows the impact of the cubic relationship between wind energy and wind speed to come into still clearer focus.

A host of other factors can also have a bearing on energy generation from wind. Comparable to any loss of heat when two substances rub against one another, winds which must travel over rugged landscape experience a reduction in speed as a portion of their kinetic energy is converted to thermal energy by friction (Windpower, 2006). Not surprisingly, the less smooth a surface over which wind must pass, the greater the velocity (and energy) loss suffered on account of frictional heating. Another complication connected to wind energy arises from day-night discrepancies. This so-called diurnal variation in the wind occurs because wind's turbulence ordinarily peaks during the daytime hours. In many parts of the world, there is also an ample measure of seasonal flux in wind's behavior as temperature and weather changes serve to reconfigure local wind patterns throughout different parts of year.

Today, wind power remains a minor contributor to global electricity generation. The International Energy Agency estimated that 0.05% of total electricity production worldwide was created via wind power in 2003 (IEA, 2003). Despite wind power's seemingly inconsequential stake in the present arrangement of global electricity generation, several signals suggest it is lying right at the cusp of undergoing a critical transition period toward maturing into a major player in the world's energy production system. The price of wind-generated electricity has plummeted in recent history and is now on par with or cheaper than traditional sources (discussed later in detail). Also, global wind energy capacity grew 48.9% per year from 1971 to 2003, a rate unmatched by other energy sources (IEA, 2003). Coupling these merits with its environmental friendliness, there is every reason to expect wind power to occupy a burgeoning role in the global energy scene in coming years. Technological improvements and economic incentives to encourage wind energy generation would facilitate an even more secure position for wind power in the realm of electricity production worldwide.

Technical Issues Pertinent to Wind Energy

In order for wind power to realize its full potential to guide the world's population down a road toward sustainable development, technological advancement will need to help pave the way. It is incumbent upon the countries of the developed world to further explore and improve strategies ranging in scope from how to select the most valuable sites at which to build wind farms all the way to which wind turbine designs prove most efficient. All discoveries made will set the tone for wind power's progress in years to come, in particular as to how it may spread in the developing world.

Some of the world's windiest places are located in its most remote regions, an unfortunate fact since large-scale electricity generation is only as valuable as its connectedness to the grid. The search for areas suitable for wind farm construction is thus somewhat restricted. For instance, very cold regions often exhibit extremely windy conditions and witness increased air densities. To gauge the magnitude of air density discrepancies, the mass of a cubic meter of dry air at standard pressure and a temperature of 20°C is 1204 kg, whereas the same volume of air at -20°C has a mass of 1395 kg, a boost of more than 15% in air density (Windpower, 2006). Other considerations aside, this elevated air density would augur well for siting wind farms in frigid, blustery territory, as greater sums of energy can be extracted from heavier air. In actuality, though, very cold regions are rarely fit for wind farms owing to their remoteness as well as technical complications which arise upon exposure of turbines to freezing conditions (Lacroix, 2000).

Beyond cold weather regions, another high-wind area which may hold great promise for wind farms in the near future is the offshore setting. Wind blows faster and more uniformly at sea than on land; this means less wear on turbine components and more electricity generated per turbine (Ram, 2006). Although offshore wind farms would be somewhat more expensive than onshore farms in terms of construction, installation, and maintenance costs, it is very possible that such outlays could be compensated for by offshore sites' proximity to large populations. "Winds increase rapidly with distance from coast, so excellent wind sites exist within reasonable distances from major urban load centers, reducing the onshore concern of long distance power transmission" (Ram, 2006). In this way, the added expenses of developing a wind farm offshore could be defrayed by the associated reduction in transmission costs, which will be discussed later.

Offshore wind farms comprise a small fraction of total wind power at present, but are expected to soar in coming years. Additional offshore installations of 11 gigawatts (GW), nearly a fifth of the world's current wind energy capacity, are slated for completion by 2010, primarily by Germany and England (Ram, 2006). All will be anchored in shallow water no more than 20 meters deep. Technological strides are required before offshore wind farms can be cost-effectively constructed and operated above ocean waters beyond 20-meter depth. However, it is likely that the wind industry will quickly gain the ability to tap into such high-energy winds since offshore oil and gas drilling sectors have undergone analogous evolutions in the past (Ram, 2006). Enabling wind farms to be sited over increasingly deep waters will prove central to both the viability and value of offshore wind.

After settling upon a desirable location for wind farm construction, there are several additional factors which must also be considered in planning its layout. Because turbulence in the wind diminishes turbine lifespan, designers aim at reducing its impact when arranging a farm by spacing turbines at least three rotor diameters apart from one another (Windpower, 2006). Such a configuration enables turbines to function properly for as long a period as possible, thereby reducing the overall lifecycle cost of wind-generated power. An alternate objective in wind farm development is to counter the effects of transitory fluctuations in wind power because they impose a burden on the energy system to which the farm's electricity is supplied. This can be accomplished by dispersing clusters of turbines geographically "to create a smoothing effect on the aggregate power output with respect to time" (Milligan, 1999). Wind farm design must be tailored to the particular conditions of the surrounding site to allow for maximal efficiency in the collective effort to drive down wind energy prices.

A separate component of wind power's technical side is the perpetual refinement of the wind turbines themselves. It is not possible to extract all of the energy in the wind; the air which flows through the rotor's cross-section is not stopped completely, rather it is slowed down as it exits the opposite side. In 1919, German physicist Albert Betz proved that regardless of design, the ideal turbine decelerates passing wind by two-thirds its original speed, which allows for a theoretical yield of 59% of the wind's total energy to be convertible to electricity (Windpower, 2006). This upper bound should thus be approached as narrowly as possible if a turbine is to maximize its efficiency, but much work remains to be done on this front. Conventional propeller-style turbines often harvest less than a fifth of the wind's available energy and are constrained by a theoretical limit of 30% extraction, only half of the Betz Limit (Gorlov, 2001).

One novel approach which offers room for improvement in this regard is to orient blades about a vertical axis and hence reduce strain on turbine components—this adjustment could allow 43-45% of wind's available energy to be reaped (*Economist*, 2006). If accurate, this statistic means that about three-quarters of the theoretically obtainable (i.e. Betz Limit) energy in wind would be harnessed, representing a watershed in the field of turbine design. A related element of turbine effectiveness is its atmospheric efficiency rating, which computes the quantity of energy removed from the atmosphere and divides it into the quantity actually converted to electricity. For modern-day turbines the ratio is typically in the range of 0.47 to 0.57, but modifications to turbine design may be capable of yielding improvements on the magnitude of several tens of percents (Keith, 2004).

With little doubt, the era of improved turbine efficiency has dawned and will continue evolving as innovative designs are developed.

As alluded to earlier, wind velocity decreases considerably as it travels over rough topographical features due to frictional losses. Decreased wind speeds in turn reduce potential energy yield, so turbine designers strive to avoid this undesirable phenomenon. The basic solution is to construct turbines on taller towers to minimize the influence of surface effects. A generation ago, the towers on which turbines are mounted were less than 100 feet tall, but they have since doubled to average heights above 200 feet (Oklahoma, 2002). It is inevitable that turbine towers will climb even higher in the decades to come. Another important concept to grasp in relation to turbine efficiency is that of the drag force. Since rotor blades are continuously immersed in a stream of air, it is essential that they be designed aerodynamically to avoid efficiency losses from drag. This can be achieved by reducing the area of the blades which face into the wind and by ensuring blade surfaces are as smooth as possible (Windpower, 2006).

The issue of sound is a final technical hurdle in wind turbine design. Turbines used to produce bothersome broadband noise as their blades encountered turbulence, but advances in soundproofing and aerodynamics have so successfully addressed the problem that one can now stand beneath a whirring turbine and converse without raising one’s voice (AWEA, 2005). It is also worth noting that wind farms are sited in areas with above-average wind speeds that conceal the sounds produced by the turbine. Noise reduction constitutes a prime example of how advancing technical aspects of wind power can serve to propel the industry toward the forefront of the global energy order.

Economic Issues Pertinent to Wind Energy

The economic aspects of wind power are highly consistent with the tenets of a sustainable development framework. In recent years, the cost of wind-generated electricity has drawn level with and/or fallen beneath that of most non-renewable sources, illustrating the potential the wind industry has to help electrify impoverished regions of the underdeveloped world in future years. Governments have the ability to expedite this downward price trend and encourage the wind industry's continued growth, while ultimately standing to benefit from a number of positive consequences. The cost impacts of integrating wind power into larger energy mixes as well as transmitting wind energy from remote locations to densely populated demand centers are essential to the economic profile of wind energy. Yet another economic consideration is that employment opportunities are made available to those living in and around the spread of the wind industry. Sustainable development is well-served by efforts to enhance wind's role as a global energy producer and to continue its downward cost spiral into the future.

The chief contributing factors to the cost of wind-generated electricity are far different than those responsible for fossil-fuel-based electricity costs. First, there is obviously no cost associated with procuring wind itself, rendering wind energy a decidedly capital-intensive technology. This characteristic amplifies the degree to which wind energy costs suffer when there is insufficient principal for financing a wind power project. Next, larger wind farms provide economies of scale, for example: "A 3-megawatt (MW) wind plant generating electricity at 5.9 cents per kilowatt-hour (kWh) would, all other factors being equal, generate electricity at 3.6 cents per kWh if it were 51-MW in size" (AWEA, 2005). Wind-generated electricity costs are declining at a rate unparalleled by other energy sources. Over the past 20 years, onshore wind energy technology has experienced a ten-fold reduction in cost (Ram, 2006). [see Appendix Image 2.]

While electricity from wind may not have been competitive with fossil-fuel-based electricity in terms of nominal cost a decade ago, there were already indications that it would someday be able to compete. In a 1996 report issued by the California Energy Commission, energy technologies were compared based on levelized costing, and wind was found to be comparable in value to coal and gas (CEC, 1996).[1] The cost of wind-generated electricity was competitive because levelized costing took into account the full lifecycle of the energy plants, often overlooked by casual observers. Still, environmental costs attributable to the various energies' lifecycles were not included, effectively damaging wind's competitiveness since it is imposes a drastically lower cost upon the environment than do non-renewable energy sources.

This significance of this last point should not be understated, as relaxing or disregarding environmental effects allows fossil-fuel sources to appear deceptively cheap relative to renewables. In fact, "the hidden 'subsidy' that governments and markets give to polluting energy sources by partially or fully ignoring their health and environmental costs is typically much larger than direct subsidies to such energy sources" (AWEA, 2005). A 2001 study funded by the European Union found "the cost of producing electricity from coal or oil would double and the cost of electricity production from gas would increase by 30% if external costs such as damage to the environment and to health were taken into account" (Europa, 2001). It is evident that governmental agencies around the world could support the growth of the wind industry simply by requiring all energy

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[1] Levelized costing calculates (in 1993 dollars) all capital, fuel, operating and maintenance costs associated with the plant over its lifetime and divides the total cost by the estimated output in kWh over the lifetime of the plant. The typical lifetime utilized in these estimates was a 30 year time horizon.

plants to internalize (at least a portion of) both their environmental and health-related externalities. Wind power's lifecycle is not only completely free of emissions, but also of ecological hazards like mining, drilling, processing, and shipping fuel (AWEA, 2005). Nonetheless, there generally exists neither economic reward for wind's environmental cleanliness nor economic sanction for fossil fuels' pollution.

Since wind power normally functions as one of several energy forms which all supply a utility power pool, it is important to look at the cost effect wind is likely to have upon such a system overall rather than merely its stand-alone price. An electric utility system is responsible for maintaining the balance between aggregate demand for electric power and total power generated by all power plants feeding the system, a sophisticated task whose associated costs are referred to as ancillary-services (Smith, 2004). Wind's incorporation in the mix complicates the task of maintaining the system's balance due to the challenges of accurately forecasting wind and coping with its persistent fluctuations. Must the full capacity of wind energy supplying a power pool be backed up to keep from jeopardizing the utility's ability to match consumer demand? In truth, wind need not be backed with such a high quantity of dispatchable generation, for "even at moderate wind penetrations, the need for additional generation to compensate for wind variations is substantially less than one-for-one and is generally small relative to the size of the wind plant" (Smith, 2004). Thus, although ancillary-services costs attributable to wind rise in correspondence with its uncertainty and variability, neither of these facts necessitates precluding wind from participation in the powering of a utility electricity pool.

Another key economic issue pertaining to the wind industry is the cost of transmitting its electricity from wind farms to substations located near population centers.

Unlike other energy sources, wind's inherent intermittence prevents its plant operators from being able to precisely schedule the amount of electricity their plant will deliver to transmission lines in advance. This inability is problematic for the wind industry because utilities controlling transmission facilities often charge exorbitant fees for these so-called 'uninstructed deviations' regardless of whether they exceed or fall short of the scheduled use (Transmission, 2006). Other features of the transmission network can also prove particularly expensive for the wind industry. Often situated remotely, wind-generated electricity is disproportionately charged by utility practices such as basing transmission system usage fees upon the number of miles between generator and load center, or charging multiple access rates for transmission due to crossover of several lines of ownership, also known as 'rate pancaking' (Transmission, 2006). A final example of the wind industry incurring lopsided costs for transmission network usage is evidenced by the policy of some utilities to charge generators on the basis of peak rather than average use (Transmission, 2006). Once again, wind providers are helpless to guard against the natural fluctuations in wind and, as is the case with the other policies just discussed, will continue to be penalized undeservedly so long as government intervention fails to take place.

The last aspect of wind industry economics worth mentioning is the financial benefit it can yield to local communities. For example, creation of a 100-MW wind farm can generate 40 temporary construction jobs and 10 permanent skilled jobs (Oklahoma, 2002). And while it is sometimes contended that wind farms have a deleterious impact in terms of the attention they garner, they can also attract investment, infrastructure development, and tourism opportunities (WWEA, 2005). Wind power's economic status has seen dramatic improvement in the recent past, but can still be bolstered in years to come.

Future of American Wind Energy

The United States currently ranks third in the world in terms of installed wind capacity, with 9.149 gigawatts (GW) installed at the end of 2005, trailing only Germany and Spain (AWEA, 2005). In spite of this success, there still exists tremendous potential for further development of the American wind industry—beyond all the merits of wind power which have already been cited, the United States is fortunate to possess a vast resource of high-quality winds capable of providing clean, cost-competitive energy. To offer a perspective on its enormity, 24.8 billion kWh of electricity are anticipated to be generated from American wind in 2006, whereas the estimated potential annual yield is in excess of 10,000 billion kWh, a quantity more than double the country's overall present yearly electricity generation (AWEA, 2005). There are several, mutually-reinforcing ways that policymakers can facilitate increasing penetration levels of wind into the United States' total energy mix.

Recommendation #1: The Federal Energy Regulatory Commission (FERC) should ensure that wind-generated power does not suffer from unfair rules regarding access to the electricity transmission system in the United States. It is well-known that the nation's current grid system and associated policies were created with traditional energy sources in mind and, therefore, naturally favor non-renewables over their competitors. So long as these outdated vestiges of preferential treatment remain in place, the "burying of transmission investment charges in commodity power costs [will continue to] disguise the real cost of competing generation technologies" (Transmission, 2006). A brief glimpse at a map of United States wind power data highlights the importance of transmission concerns since the area in continental America endowed with the best quality winds (the Great Plains) is located far from major energy demand centers in coastal states. [see Appendix Image 3].

FERC itself has recognized this reality: "When purchasing firm transmission, a wind generator pays more for that transmission on a per unit basis" than do fossil-fuel generators (FERC, 2004). At least two major alternatives are available to confront this problem. The first option is to create an altogether new system in which transmission costs fall directly upon end-users of electricity rather than those generating it. This approach is sensible because 100% of embedded transmissions costs fall upon end-users irrespective of what system is in place, and it would provide a more 'level' playing field for all energy sources to compete (Transmission, 2006). A second option is to enact comprehensive reforms which would revamp the current transmission system by disallowing pricing practices that disproportionately charge wind on the basis of its remoteness and/or intermittence. Such an overhaul would necessitate the elimination of fees dependent on distance from load center, cross-over of multiple ownership lines, peak rather than average use level, and deviations from scheduled usage (Transmission, 2006). While the latter option probably requires more policymaking, either alternative could effectively support growth of the American wind industry.

Recommendation #2: The United States Department of Energy (DOE) should promote cooperation between the wind industry and the oil/gas sectors with prior experience in the offshore setting in order to expand wind farms over deep ocean waters that enjoy consistent, high-velocity winds in close proximity to major coastal populations. Such action would be beneficial to the American wind industry for a multitude of reasons. Foremost among them is the fact that the National Renewable Energy Laboratory has estimated the United States' offshore wind resource at a remarkable 1000 GW (over fifteen times current global wind capacity), 750 GW of which are located over ocean waters more than 30 meters deep (Ram, 2006). At present, however, turbines cannot be situated above depths greater than 20 meters due to technological impediments—this is the same challenge that faced offshore oil and gas companies in past decades. Coupling offshore wind development with veteran oil and gas industries would not merely offer a key to unlock massive amounts of potential wind energy, but could also work in unison with Recommendation #1 by easing wind power's dependency on transmission.

Recommendation #3: Elected officials in Washington should redouble their efforts to enhance wind power's cost competitiveness by expanding Renewables Portfolio Standards (RPS) nationwide and stabilizing the status of the Federal Production Tax Credit (PTC) for wind-generated electricity. As noted throughout this paper, economic considerations relevant to the wind-industry are unique in their overwhelming reliance on sufficient capital. RPS is a market mechanism which guarantees that a rising fraction of electricity be derived via renewable sources. It provides this assurance by mandating that every individual electricity generator possess a certain number of Credits at year's end in proportion to its total annual kWh sales (RPS, 1). Because there are no stipulations as to how the Credits are obtained, many generating companies will enter into long-term contracts with renewable generators, simultaneously providing incentive for cost-effective renewable generation as well as up-front financing needed for capital-intensive industries like wind to flourish. While twenty-one states have adopted an RPS of some sort, unifying and extending a single, sensible standard to all fifty states would strengthen the position of wind and other renewables and drive down their costs by supplying ample capital.

A second channel through which the American Government can increase cost-competitiveness for wind energy is by way of the Federal PTC, which "provides an inflation-adjusted 1.9 cents per kilowatt-hour tax credit for eligible technologies for the first 10 years of production" (DOE, 2005). Meant to counterbalance the inherent bias toward fossil fuel sources in federal energy tax code, the PTC has supported wind power since its inception in 1992, but to a limited degree. Its contribution to suppressing wind energy prices has been dulled by a series of near expirations, each of which was narrowly avoided by a temporary, last-minute extension of the PTC. This virtual "on-again, off-again" status has hobbled project development and deterred investment to the American wind industry (AWEA, 2005). Members of the U.S. financial community who still view wind power as novel and risky are only further disquieted by the PTC's erratic status (AWEA, 2005). Policymakers seeking to attract private capital to the American wind industry would strongly benefit from extending the Federal PTC beyond its present deadline of December 31, 2007 in order to foster a safe, steady environment for investing.

Future of Chinese Wind Energy

While the United States and China are an unlikely tandem in most ways, recent growth patterns of wind power in the two nations has been very similar. In fact, "China's wind power program has roots in a visit to the United States 18 years ago [when] a Chinese delegation witnessed modern wind turbines at work in Utah, then came back determined to adopt the technology at home" (French, 2005). China now ranks eighth in the world in wind power capacity with 1.260 GW, a sixty-fold increase from its 1990 level of just 20 MW (WWEA, 2005) & (Motavalli, 2005). This meteoric rise demonstrates the ability of a developing nation to borrow and implement technologies from more-developed nations and, in turn, use the newfound expertise to help meet its emerging needs in a sustainable framework.

Despite the similarities between the two, China's needs are certainly not identical to those of the United States. A major difference is that China generates over 70% of its total energy supply from coal, making the reduction of air pollution a chief priority for its policymakers: it leads to an estimated 400,000 deaths annually, not to mention the damage caused by acid rain, which affects two-thirds of the country (Motavalli, 2005). Ambitious goals have been set forth by Chinese authoritative bodies in response to this crisis, with the Ministry of Electric Power planning 3 GW of installed wind capacity by 2010 and the State Economic and Trade Commission projecting 7 GW by 2015 (Liu, 2002). High-quality wind availability will not be a limiting factor in achieving these objectives; China's wind resource is thought to exceed 600 GW (Motavalli, 2005). Instead, Chinese leaders will have to confront grid issues as well as economic barriers if they wish to maximize wind's penetration levels into their nation's overall energy supply.

Recommendation #4: China's State Planning Commission, its highest authority for energy project financing and approval, should renovate the nation's aging grid system so wind-generated electricity can be efficiently integrated into its power mix. If action is not taken in this regard, there is little hope for wind power to provide substantive relief to China's growing electricity needs. Its fragmented utility sector, which dates back to the age when provincial governments were in control, offers little or no connectedness between provinces (EIA, 2005). As such, it is inevitable that significant losses will be suffered if wind-generated power is introduced as a major component of China's electricity supply with the present grid in place. Wind's high variability requires a delicate balancing act as supply and demand levels fluctuate unremittingly, but China's antiquated grid is incapable of automatically rerouting power accordingly (French, 2005). Aside from integration difficulties, effective transmission of electricity from wind-rich, rural regions along the Mongolian border to densely populated cities on the Pacific Coast is doubtful. [see Appendix Image 4]. China's other high-velocity wind locale is the offshore setting (obviously lacking connectivity to the mainland) which would also need the State Planning Commission to oversee grid development in order for its energy potential to be realized.

Recommendation #5: The Chinese Government should drive down the price of wind-generated electricity so it draws as close to level as possible with the cost of coal-fired power. Unlike in the United States where wind is extremely cost-competitive with all sources of energy, wind in China remains unable to compete fully with coal. Two reasons for the gap in price are that the vast majority of equipment on Chinese wind farms is imported and that there is a shortage of trained personnel to manage and maintain the turbines' proper functioning (Hammons, 2004). A short-term response to these problems is for the Government to exempt the import tax on wind turbine components, which would decrease the cost of wind farm construction by 15% (Liu, 2002). In the long run, however, incentives should be provided to stimulate a homegrown Chinese wind industry which can offer real competition to the established coal-fired plants. The Government has already taken steps in this direction by providing tax incentives for alternative energy developers and by standardizing electricity rates—effectually subsidizing sources such as wind. Until wind power prices are truly on par with coal-fired ones, however, China will find it difficult to cut into air pollution in any meaningful way.

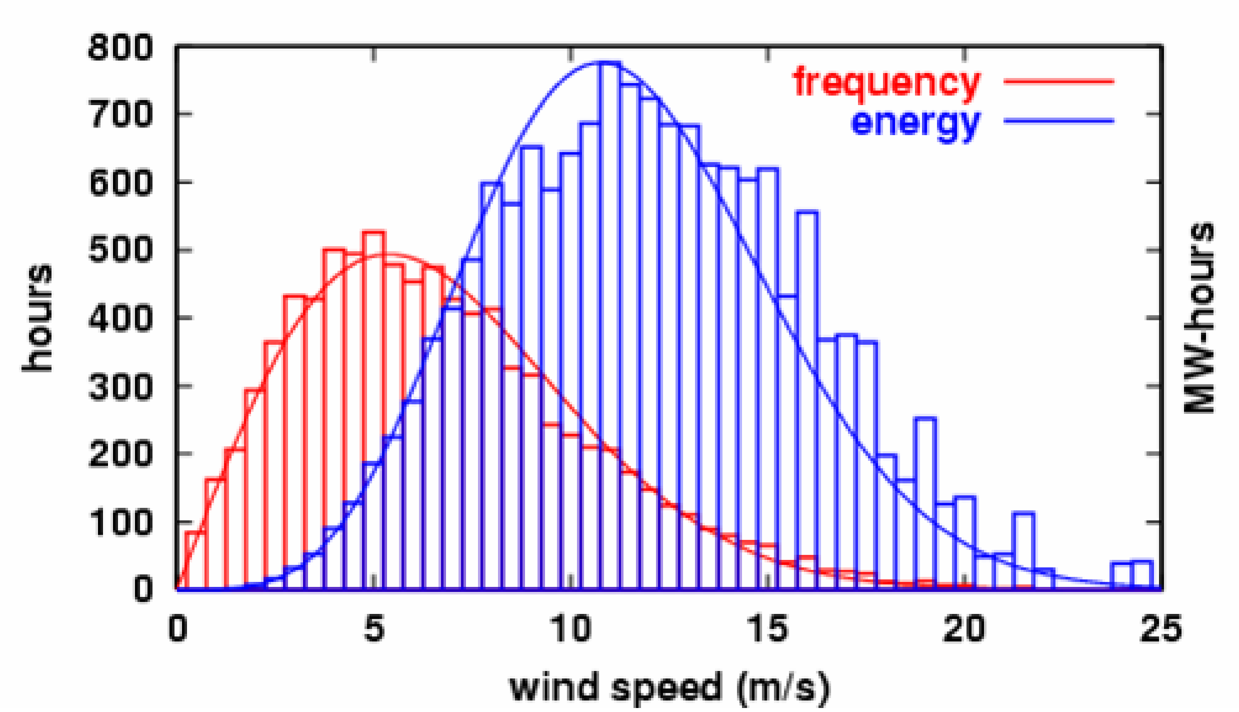
Conclusion

Wind power is a highly attractive source of energy for a host of reasons. Its fuel is free, its environmental footprint negligible, and it is incapable of being exhausted. In addition to these advantageous qualities, it is widely available and can generate electricity at a competitive cost provided it gusts at a sufficient velocity. Technological advancements in turbine design and progress in the offshore setting will only further enhance the utility of wind energy. Coupled with increased capital investment and policy measures which allow wind to compete fairly with traditional energy sources, there is every indication that wind power installations worldwide will continue to grow rapidly in the decades to come.

Whether a nation is seeking to combat global warming, reduce air pollution, provide affordable electricity to its people, or strengthen its energy portfolio through diversification, incorporating wind power into its blend of electricity can help achieve the desired aim. While intermittence and remoteness are unfortunate realities of wind, they do not overshadow the potential benefits which wind power offers to society. Governments around the globe are beginning to appreciate the many merits of wind energy and are implementing policies to encourage higher penetration levels of wind into their power mixes. The United States and China each have the potential to become world leaders on the wind energy scene owing to their enormous wind resources. With the proper support from their respective policy-making bodies, each nation will make wind power a substantial contributor to its energy portfolio.

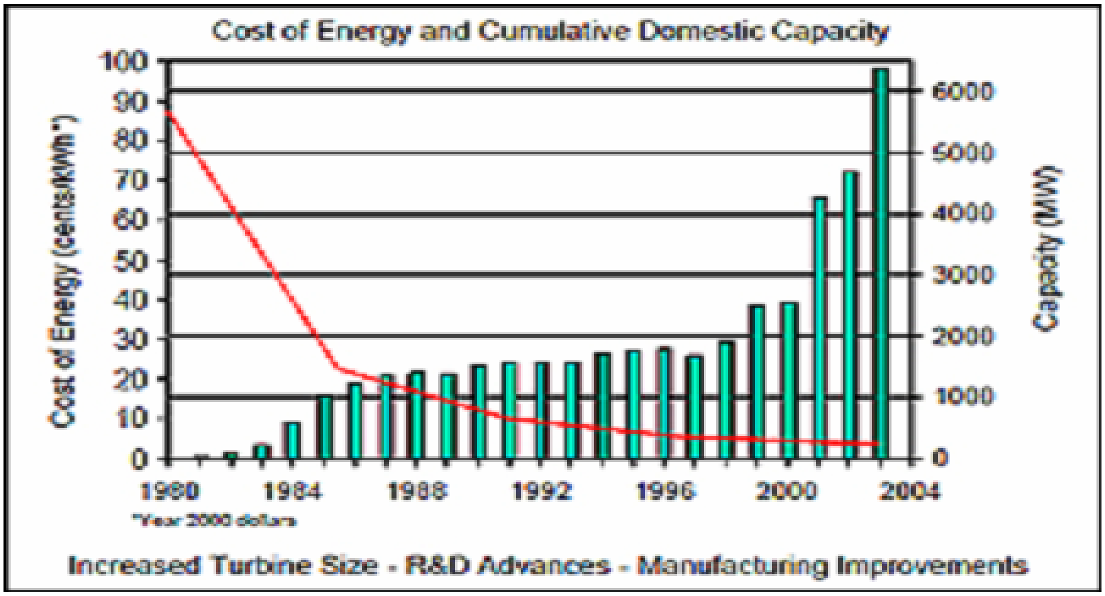
Appendix Images

Image 1. This graph depicts two phenomena simultaneously: in red, it shows a typical distribution of wind speed frequencies for a given locale; in blue, it shows the amount of energy derived at each speed across the full range of velocities experienced at the same site. It is clear that the highest levels of extractable energy occur at wind speeds around 11-12 m/s, or about double the site's mean velocity (~ 6 m/s). The highest speed winds (20-25 m/s) at the site do not furnish the highest levels of extractable energy because they are extremely infrequent.



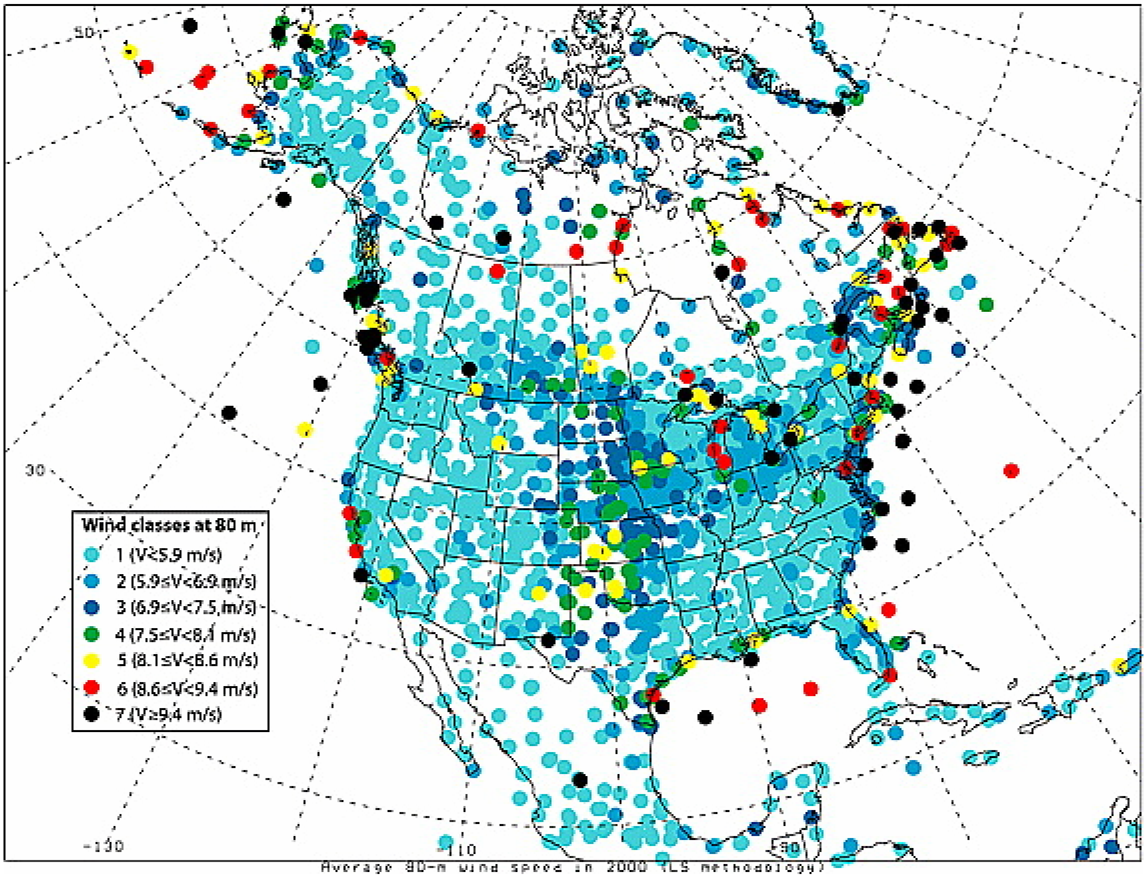
Source:
<http://www.answers.com/topic/wind-power-2>.

Image 2. This graph depicts two major trends which have occurred in the past quarter-century: the declining cost of American wind-generated electricity per kWh and the concurrent growth in total American wind energy capacity at years' end. The red line (cost) indicates a 1983 price of approximately 45¢/kWh, and a 2003 price of under 5¢/kWh, equivalent to a ten-fold reduction in cost (inflationary effects removed—constant 2000 U.S. dollars). Over the same period, the turquoise bars (total U.S. wind capacity) rose from a 1983 level of about 200 MW to a 2003 level of over 6000 MW, growth of more than 3000%.



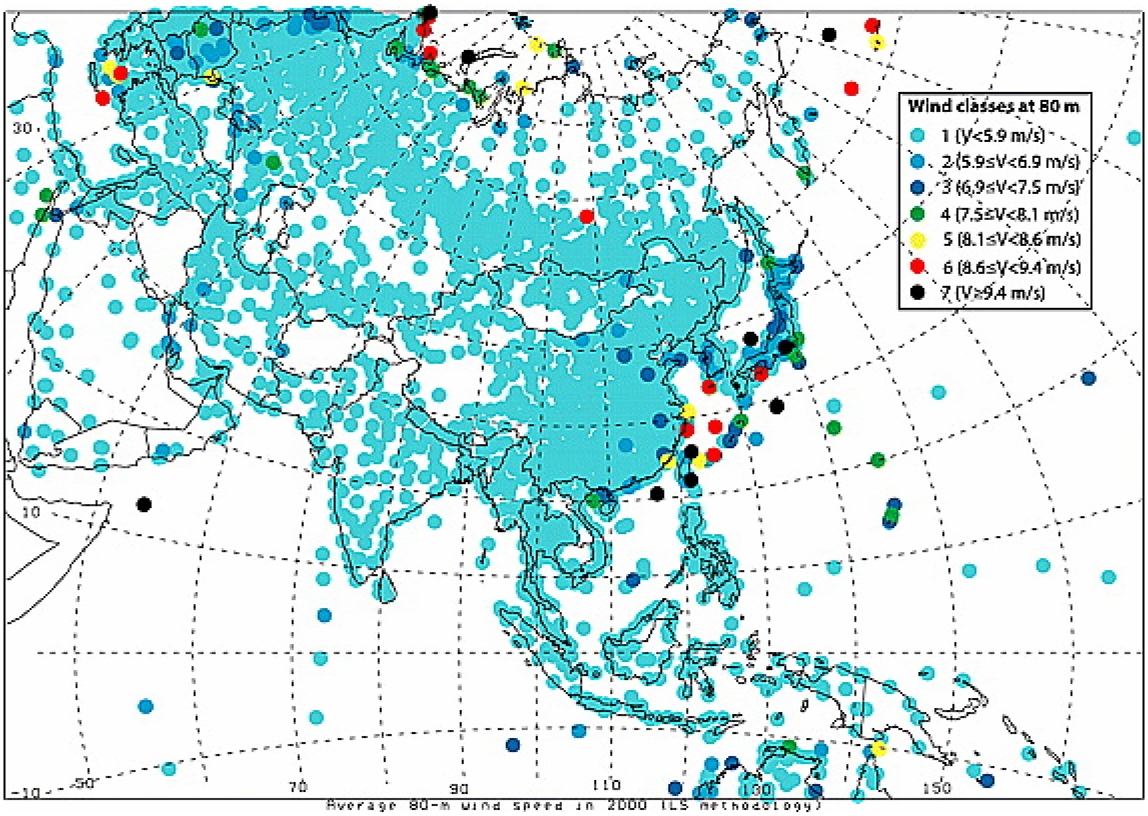
Source:
<www.eere.energy.gov/windandhydro/windpoweringamerica/ne economics.asp>.

Image 3. This image illustrates the quality of wind power across most of North America. Light blue dots represent areas which experience comparatively low average wind velocities, while black and red dots indicate regions with very powerful winds. Intermediate colors (Class 3 and above) are generally considered appropriate for wind farm siting; note the abundance of darkly shaded dots from the Dakotas south through Texas, as well as on and immediately off of the Atlantic Coast.



Source:
<http://www.agu.org/journals/jd/jd0512/2004JD005462/>.

Image 4. This image illustrates the quality of wind power across most of Asia. Light blue dots represent areas which experience comparatively low average wind velocities, while black and red dots indicate regions with very powerful winds. Note the two regions where Chinese wind potential is greatest: near its border with Mongolia as well as in the vicinity of its expansive coastline.



Source:
<http://www.agu.org/journals/jd/jd0512/2004JD005462/>.

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