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Chapter Six

Wind Energy

Background Article

INTRODUCTION

Wind energy is one of the oldest forms of energy generation. The growth of fossil fuel economies in the late nineteenth and early twentieth centuries led many energy consumers to view wind energy systems as inferior. Fossil energy was readily available and accessible on demand while wind systems were dependent on weather conditions. In a new era, hydrocarbon energy sources are beginning to show the strain of increasing global demand; costs and supply-related issues are making reliance on carbon-based energy sources less certain. Rising costs for energy combined with technological developments and government incentives that have effectively reduced direct costs to energy consumers are making wind energy an increasingly viable alternative to carbon-based energy sources.

Wind energy is one of the fastest-growing renewable energy sources in the United States. The cost of wind energy is declining in large part due to improved siting technology, wind blade control and structure, and improved wind generator systems. The oil shortages in the 1970s and early 1980s led to tremendous growth in research and development funding for wind energy in the United States, as suppliers and consumers sought an expansion of the energy supply base. While U.S. energy policy operated on a reduced commitment to alternative or renewable energy in the 1980s and 1990s, many Western European nations continued their development of wind energy technology. In the post–September 11 world of energy uncertainty and as petroleum prices rose to reflect growing global energy demand, the United States has renewed its commitment to the development of alternative and/or renewable energy systems.

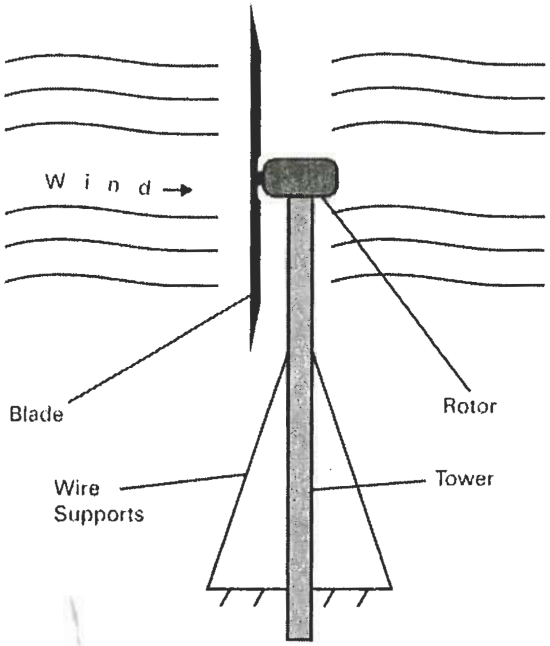

Figure 6.1. Wind Turbine Construction
Drawn by Christopher A. Simon.

WHAT IS WIND POWER? HOW DOES IT WORK?

Wind power technology is one of the oldest forms of energy generation in human civilizations. Early mechanical systems were used nearly seven thousand years ago in Egypt and the Middle East to operate windmills for grain processing. In the United States, windmills were used well into the twentieth century, but were rapidly replaced by steam and electrical power. Wind-powered water pumps were widely used, particularly in rural applications, in the United States for much of the nineteenth century and for several decades in the twentieth. The Rural Electrification Act of 1936 (7 USC 31) provided cheap and abundant hydropower electricity to many rural areas, making wind generation an inferior energy generation system for the modern age (see figure 6.1 and figure 6.2).

Wind power systems have at least three parts: propeller blades, rotors, and support towers. Blades for wind power systems use many of the same principles as are used to construct blades for propeller-driven aircraft and for engine propellers used on ships.

Important parts of a propeller:

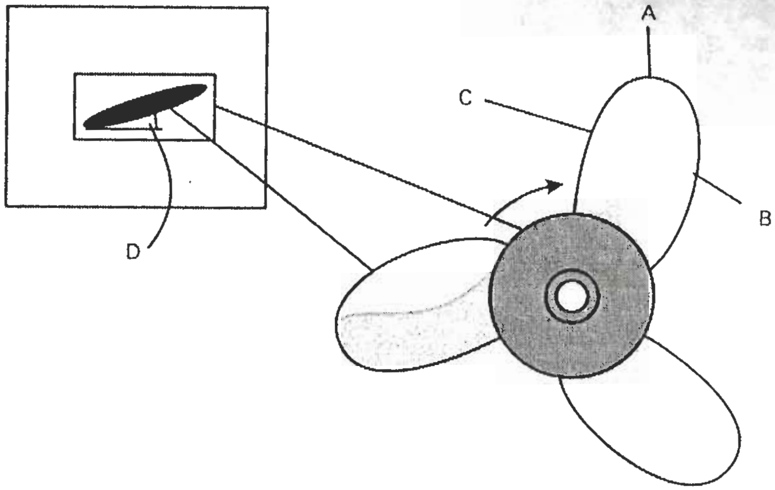

Figure 6.2. Wind Turbine Blades
Blade assembly portion of rotor drawn by Christopher A. Simon.

- blade tip (A): the very end of a propeller blade. Blade tip to center of rotor is one way to measure blade length. While the entire blade may be revolving twenty times per minute, the blade tip, due to the length of the blade, might be moving at 150 mph.
- leading edge (B): the part of the blade with which wind first comes into contact.
- Trailing edge (C): the part of the blade with which wind is last in contact.
- Pitch (D): the angle at which the blade sits, as measured by the imaginary perpendicular line in relation to the wind. Blade pitch depends on the strength of the wind in sustained wind speed as well in terms of wind gust speed. When the angle (D) becomes larger, the pitch of the blade is considered deeper, which is typical in wind systems operating in areas with high sustained winds and/or high-speed wind gusts. When the angle (D) is smaller, then the pitch of the blade is considered more shallow, which is often the case when sustained wind speeds are much slower and/or wind gusts are much lighter.

The rotor is the central feature of the blade assembly. At the rotor juncture, blades are attached to the wind power system. Within the rotor assembly, at least two different control and power take-off processes occur. First, blade pitch control exists within the rotor unit, allowing wind power user to adjust pitch depending on wind speed. At times, pitch control is automatically controlled by the wind power unit itself. Second, the rotor assembly contains a system of gears that mechanically increase the rotation speed of the electrical generator or other power take-off system—the nacelle. The nacelle also houses a generator for the production of electricity. Due to the system of gears, rotation speeds within the generator unit may exceed 1,500 rpms (revolutions per minutes) (see Energy Center of Wisconsin 2005). Within the nacelle, generated power fed onto the electrical grid must match the 60 hertz (or cycles per second) of conventional power systems in the United States. In contemporary wind power generation, power take-off is usually in the form of alternating current electricity. Even in light winds, properly designed propeller blades, often constructed from strong lightweight materials (e.g., aluminum or fiberglass), maintained at an optimum pitch, are capable of generating significant amounts of electricity.

Wind energy towers are particularly important in the energy generation process. Tower height is often a function of the length of propeller blades and size of rotor assembly. Additionally, wind speed analyses at various points above ground level may reveal optimum wind speed conditions; tower height and propeller blade length have to be properly sized and pitched so that efficient wind speeds are captured by wind generation systems, while simultaneously minimizing the impact of wind velocity and turbulence on tower and other wind turbine physical plant harmonics and load (see Larsen et al. 2005). Modern wind turbine towers are typically between 150 and 200 feet tall and 10 feet in diameter. Towers are either solid metal structures or are a lattice design. Towers are anchored into the ground and the strength of the anchoring depends on tower size and wind speed at generating site. Tower footings may be as much thirty feet deep. Cable support wires may be used to assist in supporting the tower and prevent torsion forces from causing damaging sway motion.

TECHNICAL FEASIBILITY OF WIND POWER SYSTEMS

Wind power is becoming increasingly feasible because of tremendous technological developments. Technological developments discussed in this section will relate to materials-related achievements that have increased the attractiveness of wind energy systems in a variety of locations. Additionally, the chapter will discuss location decisions that are becoming better informed because of wind-tracking data systems. Materials, technology, and informed decision making are important to nearly any power generation process.

Material accomplishments in wind power have impacted all aspects of the basic wind energy framework discussed in the previous section. Propeller technology continues to change because of material developments and generation system refinements related to the wider use of wind energy globally. Different locations require that energy systems meet different conditions and needs. For instance, in locations with very strong winds or particularly high wind gust regions, systems must be designed to resist propeller and tower damage, while simultaneously maintaining high levels of efficiency and properly meeting load requirements. Using a lightweight propeller might produce greater power; but in a high wind gust area it could be severely damaged. Material fatigue is another factor that could increase maintenance costs. Due to technological developments, wind energy systems can be footed in the ocean with propellers and rotor assemblies placed just above ocean level. In an ocean or sea air environment, proper materials must be used to resist the corrosive impact of salt water. Finally, low wind environments require the use of materials that will more easily capture the force of the wind and produce usable electrical energy.

Early propeller systems were constructed from wood or lightweight metals, such as aluminum. In some instances, aircraft propellers were used in wind energy systems. Wooden propellers pose many problems, such as cracking as well as material decomposition due to moisture, particulate matter, and other environmental conditions. Additionally, wooden propellers may be heavy, thus requiring stronger sustained winds. Although lightweight, propeller materials such as aluminum, fiberglass, and carbon fiber still require sustained wind to operate.

Early propellers were "fixed" at a particular pitch. Fixed propellers effectively reduce the range of usable winds for power generation. Light winds will not produce enough revolutions to operate rotors. Alternatively, heavier winds might actually result in very high rpms, which damage wind turbines and towers, or at least accelerate material fatigue.

Propeller engineering has addressed some of the aforementioned issues by creating stronger and lighter weight propellers out of new generation materials and using twenty-first-century production technologies. Propellers can be constructed out of hollow balsa wood frames with well-engineered internal support framing to prevent torque (or twisting) due to wind force impact. Balsa frames are covered with fiberglass to further strengthen the propeller and leading edge caps prevent fiberglass wear or propeller destruction due to impact with flying objects (e.g., birds). With computer wind simulations, it is possible to more efficiently place leading-edge caps to effectively protect propellers from damage while reducing material weight. Computer technology also helps engineers more effectively reduce unwanted wind drag on the propeller system. While drag is critical for the propeller spin, some forms of drag may actually lead to decreased propeller rotation, thus negatively impacting energy production (see Mohamed 2004).

Engineers are increasingly experimenting with the use of carbon fibers as a coating to be combined with fiberglass or used as a sole protective and strengthening layer over balsa wood framing. The logic behind the use of carbon fibers is twofold: (1) carbon fibers are lighter weight than fiberglass and its gel coating; and (2) carbon fibers are more resilient than fiberglass. Recent studies have shown that carbon fiber propellers exhibit some promising results and may reduce replacement and/or operation and maintenance costs for system propellers (see Veers et al. 2003).

Jackson, Zuteck et al. (2005) conducted extensive research, comparing the effectiveness of fiberglass and carbon fiber propeller blades, controlling for blade thickness, length, internal propeller stud support, and chord dimensions. The study found that increased internal supports reduce the required thickness of fiberglass or carbon fiber lamination; reduced thickness translates into reduced weight and material costs in blade manufacturing. Jackson, Zuteck et al. (2005) also studied the impact of various fiberglass and carbon fiber blades, controlling for the aforementioned characteristics, under clean and dirty blade conditions to compare power curves. Blade condition had noticeable impacts on longer blades operating under windy conditions.

Technology has also made it possible for propeller pitch to be adjusted automatically, depending on wind speed, so as to increase system energy production. This means that propellers must be connected to a rotor in a manner that prevents detachment but also permits pitch adjustment while the wind turbine is in operation. Studies have found that propeller fasteners (i.e., bolts) must be designed such that torque specifications are met, but that costs are constrained. Some forms of blade attachment—for example, fiberglass/metal hybrid t-bolts—may be cheaper yet equally effective. Materials analysis is conducted to relate costs to required wind energy system specifications (see Jackson, Zuteck et al. 2005).

Rotor size in relation to wind speed is another important factor in maximizing energy production. The rotor assembly is composed of the propeller blades and motor unit rotated by the impact of wind force on the blades. Rotors on many commercial-grade wind turbines are between approximately 40 and 110 meters in diameter and range in rated power production of between 0.6MW (megawatts) and 4.2MW. The impact of wind on these rotors varies as well, ranging from 312W per one meter squared of wind force to nearly 500W per meter squared of wind force (Jackson, Van Dam et al. 2005). Rotor size is positively related to power production and may reduce the need for larger generators within the rotor assembly (see Jackson, Van Dam et al. 2005). The authors found that the tailoring of wind turbine parameters (e.g., rotor and generator size) to load demands creates greater system efficiency, reduces costs, and increase power generation revenues. Technology is making it increasingly possible for wind turbine peak production periods to match peak load demand through proper turbine placement.

Nevertheless, Griffin (2001) found that rotor sizes are pushing the limits of current wind energy system materials. As blades become larger, some exceeding 60 meters (197 feet) in length, blade materials and blade tip caps must be made thicker, thus increasing blade weight. Heavier blade materials translate into more wear on rotor assemblies and taller and heavier support towers. In order to maintain system efficiency, lighter weight materials must be developed that can withstand the increased demands on wind generation systems as they become larger. As noted in Malcolm and Hansen (2003: 12), an optimum wind tip speed/wind speed ratio is between 7.5 and 8.0; this ratio cannot be maintained using existing materials as rotor radius is increased.

Larger and cheaper energy systems require more than simply identifying next generation materials. New tools and manufacturing processes must be developed to build the next generation of wind energy systems. Thus, the path toward increased use of wind energy systems, particularly large wind energy systems, will require continued commitment to research and development. New-age materials will only come to fruition with increased availability of money needed to support development. Cash resources will either come from existing sales of wind energy systems or from government or privately sponsored research. The transition to large-scale wind energy will require time to develop the next generation of materials, manufacturing processes, and operational design (see Griffin 2001).

At times, new materials and system design are at odds with one another, and a new synthesis on the interaction of design and materials must be completed. In his holistic analysis of wind systems, Ahlstrom (2006) points out that lighter, more flexible materials used in the construction of towers and blades may decrease system efficiency. Flexibility in construction may reduce costs and the impact of wind on equipment failure, but it can also lead to reduced energy generation. There is an interaction effect of blade design and other critical parts of wind turbine systems. Effective designs cannot deal with the individual parts in isolation but must consider the whole requiring the use of computer simulation analysis to isolate the dynamic qualities of wind turbines under different operating conditions and to determine optimum system design and adjustment. Simply put, "A wind turbine is a complex system working a complex environment. It is composed of subsystems working a tightly coupled way" (Diveux et al. 2001: 153).

Beyond the complexities of the individual wind energy system, there is the larger issue of how many wind systems should be deployed at any given generation site. In a study conducted in Scandinavia, Holttinen (2005) found that increasing the number of turbines in a single location does not necessarily improve the ability of wind systems to meet peak load demand. Rather, more turbines in a single location produces greater variation in wind energy production—variation roughly translates into greater uncertainty about the ability of wind generation at a particular site to meet demand. Through a longitudinal study of hourly wind power variations, Holttinen (2005) found that smoothing energy generation, thus reducing variation in expected wind energy production, is best accomplished through greater geographical diversity in wind turbine sitting. Single-site wind energy production methodologies make variation in wind speed, and hence energy production levels, an often variable and unmodeled cost that must be borne by wind energy producers. Conversely, multiple wind energy production sites take advantage of the variability that naturally exists in wind speeds over a large geographical area. Additionally, a smaller number of turbines at any given energy production site reduces the "footprint" of production operation.

Another technological solution to wind speed variation[1] and its impact on wind energy production is energy storage and selective release on demand. Energy storage generally means battery storage. Over-sizing wind turbines to not only meet live-time peak load demand, but to also meet battery storage load demands, is an efficient wind energy design. Large variation in wind speeds, however, will not necessarily be compensated for by over-sizing a wind turbine system or by adding additional turbines. A more effective method of reducing load variations requires an enlarged energy storage capacity (i.e., increased battery storage). In small wind energy systems, Paatero and Lund (2005) found that energy storage reduced power fluctuations by 10 percent, simply by using a small 3kWh (kilowatt hour) storage device.

Wind energy turbines are increasingly located in a variety of different locations, such as coastal waters and mountainous terrain. The advantage of the using these out-of-the-way locations is that they are out of the way. Placed in locations that are not close to homes and businesses, wind turbines are less likely to be opposed by property owners. A major technical difficulty in placing the turbines in these locations, beyond the initial construction issues, relates to the ability of wind energy engineers to correctly site wind turbines. Wind patterns along coastal waters may be difficult to measure. The confluence of wind and ocean currents and water temperatures impact wind patterns. Similar problems face wind energy development in high mountain locations, which may be impacted by wind following mountainous ravines and impacted by air temperature variations.

Technology has made it possible for wind engineers to overcome the obstacles faced by nonconventional energy sites. In Hasager et al. (2005), the authors identify four major remote sensing technologies employed in measuring wind patterns for offshore wind farm siting and development:

1. passive microwave
2. scatterometers
3. radar altimeters
4. synthetic aperature radar (SAR)

In all cases, the systems are not active methods of measuring wind speed. Analog systems usually involved a rotating device and the analysis of revolutions per second to measure wind speed. Passive wind speed measurement evaluates other dynamics related to wind speed without directly measuring the wind itself. Passive microwave, for instance, can be used to measure the impact of wind on a "wind driven ocean surface" from several different measurement points. A data matrix is created to analyze data patterns to determine speed of wind and direction of wind currents (see Piepmeier and Hass 2002). Scatterometers use satellite tracking to measure movement in small waves along ocean surfaces; using known mathematical algorithms for wave movement and wind speed, it is possible to determine wind speeds at different locations. Altimeters measure pressure changes associated with changes in altitude or high or low pressure fronts moving in a particular area. Data measurements on pressure changes in a particular area can be applied to a mathematical algorithm that gauges wind speed as a function of atmospheric pressure changes.

Imaging SAR has frequently been used to measure the topography of various locations on the Earth's surface. Radar signals are directed at the target location and Doppler returns are measured to determine image topography. When used to measure the topography of ocean currents and small wind-waves, some of the radar signal energy becomes "backscattered"—in other words, the signal return measured has been scattered across the surface being studied. Empirical analysis of backscatter is used to measure instantaneous wind speed along the ocean's surface. Hasager et al. (2005) found that imaging SAR was a valuable method of measuring wind speeds over the ocean, where other forms of wind speed measurement are not readily available.

High-altitude mountain locations also face wind direction and strength analysis challenges. Western regions of the United States are characterized by high-altitude mountain areas, many of which have excellent wind resources. Internationally, both Turkey and countries located in the central Asian region have high-altitude mountain regions with significant proven wind energy capacity. As with ocean wind resources, mountain wind resources require high tech approaches to analyzing wind patterns and sustained wind gusts. Several programs have been developed to measure surface temperature and wind patterns controlling for topographical characteristics (see Eidsvik et al. 2004, Eidsvik 2005). Understanding turbulent air flows around mountains is a critical part of understanding wind energy turbine placement in mountainous regions. Turbulence studies in fluid dynamics have demonstrated that air currents and water currents share similar dynamic qualities (see Belcher and Hunt 1998). Modeling of wind patterns for turbine siting is increasingly feasible, which will increase opportunities for remote wind farm locations and increased energy production.

ECONOMIC FEASIBILITY OF WIND POWER SYSTEMS

The economic feasibility of wind power has improved due to technological advancement in wind energy systems and lighter and stronger materials. Economic efficiencies are also improved by increased demand for wind energy systems. Initial costs are spread over more units produced. This assumes, of course, that a large number of devices of a similar type are produced using standard production techniques and tools. However, as wind systems become more prevalent, there will likely be greater variation in local wind conditions and terrain that will impact the efficiencies of wind energy production. To overcome efficiency limitations, wind energy system producers will have to adapt to more varied demands and fewer wind systems of any particular type will have to be produced; thus, production costs for any particular wind energy system will be spread over fewer units produced. In some cases, wind energy system manufacturing will involve original equipment manufacturing production to meet local wind energy site conditions, as would likely be the case for many sea- or mountain-based wind energy systems. Market forces, government incentives, and/or regulations will likely shape wind energy system producers' choices to produce and price levels for items produced as well as the level of demand for specialized one-of-a-kind wind energy systems. As market demand expands, tools and materials will become more numerous as well as multiple fabrication processes, thus potentially reducing costs for a wider demand. At this point, however, "blade mass and costs scale as near-cubic of rotor diameter" (Griffin 2001: ii).

As noted in figure 6.3—reproduced from Griffin's 2001 study of materials costs associated with different sized wind energy systems—the costs for larger wind energy systems scale up quite rapidly because of the increased need for stronger systems to respond to wind impacts. While energy production increases, blade mass and blade costs increase at an even faster rate. Rotor costs do not increase appreciably in relation to the size of wind energy system.

Radius (m)	Rating (kW)	Area* (m²)	Mass (kg)		Average Cost per Blade			Rotor Costs	
			Blade	Root	Fixed	Prod.	Total	S/kW	S/MWh/yr
23.3	750	66.3	1,577	111	$115	$19,100	$19,215	$76.9	$25.1
32.9	1500	132.6	4,292	243	$520	$51,850	$52,370	$104.7	$31.4
38.0	2000	176.8	6,528	336	$970	$79,230	$80,200	$120.3	$34.9
40.8	2300	203.3	8,010	388	$1,320	$97,495	$98,815	$128.9	$36.6
46.6	3000	265.2	11,783	515	$2,350	$144,910	$147,260	$147.3	$40.8
53.8	4000	353.6	17,961	681	$4,405	$224,395	$228,800	$171.6	$46.0
60.2	5000	442.0	24,869	851	$7,180	$316,590	$323,770	$194.3	$50.8

Figure 6.3. Blade Mass and Cost of Rotors

The mass (in kg) of the blade and root assembly (the portion of the blade which attaches to the turbines in the rotor assembly) increases quite substantially as the power rating (in kW) increases. While power rating increases by approximately five-fold in the chart above, the combined mass of the blade and root increases by fourteen-fold. In other words, system materials tend to increase nonlinearly, as do blade costs as function of power rating. Smaller systems tend to be more efficient than larger systems. Economic feasibility of large-scale wind power systems, therefore, will largely depend on the ability of technical experts to devise cheaper methods and material for constructing high power rating wind energy blades.

The cost of wind energy in an optimum wind scenario of twelve meters per second will produce energy at approximately 5.1¢ per kWh, which is competitive with the costs of conventional power generation. The caveat to this price estimation, however, is that it assumes that the optimum wind is sustained on a twenty-four-hour basis, which is generally not possible. For grid power generation, this poses a smaller problem, since other forms of power generation can take over when wind energy systems are not meeting load demands. Stand-alone wind power systems, however, will require appreciable extra capacity to produce surplus energy to be stored in batteries or other energy storage systems. The surplus stored power can be used to meet load demand during periods when wind energy systems are not meeting load demands. A wind farm requires housing for power storage devices, such as batteries. Servicing storage devices, buildings, and additional wind turbines will require a staff of employees as well as the costs of disposing of worn storage devices, which may contain environmentally harmful substances, such as acid and lead. These requirements will add a substantial cost to the relatively optimistic 5.1¢/kWh. It should be noted that conventional power generation also produces environmental damage and public health problems, which are generally not added into the "true" cost of carbon-based energy.

FEDERAL WIND ENERGY PROGRAMMING: HIGHLIGHTING WIND POWER AMERICA

The most recent development in federal wind energy policy is Wind Power America (WPA)—a U.S. Department of Energy renewable energy policy initiative that first emerged in 1999. Consistent with other policy initiatives in the 1990s, WPA is designed as a collaborative policy. It does not impose a rigid top-down policy on states, local governments, and businesses. Rather, it promotes cooperation focusing on the varied energy needs throughout the nation. At the national level, the policy goals are to promote state level policy innovations, protect the energy infrastructure of rural America, improve the "green" energy portfolio at the national level, particularly in relation to defense-related activities, and help build partnerships between utilities across local regions and states (Flowers and Dougherty 2002: 1).

The four major goals listed above reflect future-oriented thinking as well as preserving the best aspects of historically important energy goals—namely, production feasibility and broad distribution infrastructures. The energy paradigm under which the United States currently operates was first formed in the 1930s. Private power generators and providers were producing limited amounts of electrical power. Although demand was lower at the time, the price of electricity was quite high. Under Franklin D. Roosevelt (FDR), massive programs to build an energy infrastructure in the United States increased the supply of fairly cheap electrical energy. FDR's policy initiative was top down. Referring back to early chapters, Ted Lowi might label it "distributive" policy. Albeit costly (particularly in terms of workers' lives), the 1930s paradigm was to a significant degree built on hydropower. Dams were built where hydropower was most feasible and energy distributed across the national electrical grid.

The new energy paradigm is expensive and rapidly evolving. There is potential for a centralized approach, by placing large wind farms on vast acreages of open public lands, but it is more likely that energy policy will be tailored to specific state and local needs, in many instances using existing private land resources. Additionally, the expense of renewable/alternative energy systems means that caution and pragmatism must guide infrastructure choices to create efficient renewable/alternative energy plans.

Of historical energy policy importance, the need to promote rural economic development is an important part of WPA. Rural areas are the source of our domestic food supply. Without a ready supply of reasonably priced electricity, agricultural commodity prices will increase dramatically, damaging many sectors of domestic food production and preparation. Rural economic development, however, has broader implications. Rural areas are microcosms of the suburban and rural/urban interface communities throughout the United States. WPA clearly recognizes the need to promote community efficacy in moving into a collective and individual vision for the future. Energy availability and policy programming are important parts of making future social and economic goals a reality.

Providing for the common defense is a basic principle of government embedded in the U.S. Constitution. Perhaps due to the current war on terrorism and the awareness that military force strength is stretched over many national and international commitments, U.S. policymakers have become increasingly aware of the need to have ready access to energy resources in the effort to maintain national autonomy. In the spirit of promoting continued availability of energy resources for purposes of national defense, WPA seeks to promote renewable energy for appropriate defense policy purposes.

Finally, the promotion of utility partnerships are crucial to the development and maintenance of a more unified energy infrastructure, particularly as energy demand continues to rise and supply issues remain a critical issue for utility suppliers and consumers alike. Energy deregulation is intended to help promote energy efficiency and to open the process to a more diverse group of energy suppliers, such as small renewable/alternative energy concerns as well as individual green energy producers seeking to sell green energy through net metering programs (see Wan and Green 1998).

According to Flowers and Dougherty (2002), there are twelve major operating principles undergirding WPA (see figure 6.4). First, WPA works at the "margins" to promote wind energy. Rather than using a "one size fits all" approach, WPA determines the potential policy environment for wind energy and "should avoid investing in markets that are fully commercial and active" (Flowers and Dougherty 2002: 1). Second, WPA helps state and local governments fully "leverage" their existing energy policy resources so as to best promote community vision (Principle 2) and to develop new partnerships at the local, state, and national levels (Principle 3). Not unlike the so-called reinventing government paradigm principles, WPA works to promote strategic vision and the pursuit of "strategic opportunities" (Principle 4) and to fund innovative pilot programs—the foundation of the policy paradigm promoted during the Clinton presidency (Flowers and Doughtery 2002: 2; Osborne 1990; Osborne and Gaebler 1992). In pursuing opportunities to build new local and state initiatives, WPA promotes efforts to replicate successes through best practices policymaking techniques (Principle 6) and to provide needed education and other resources to make collaborative

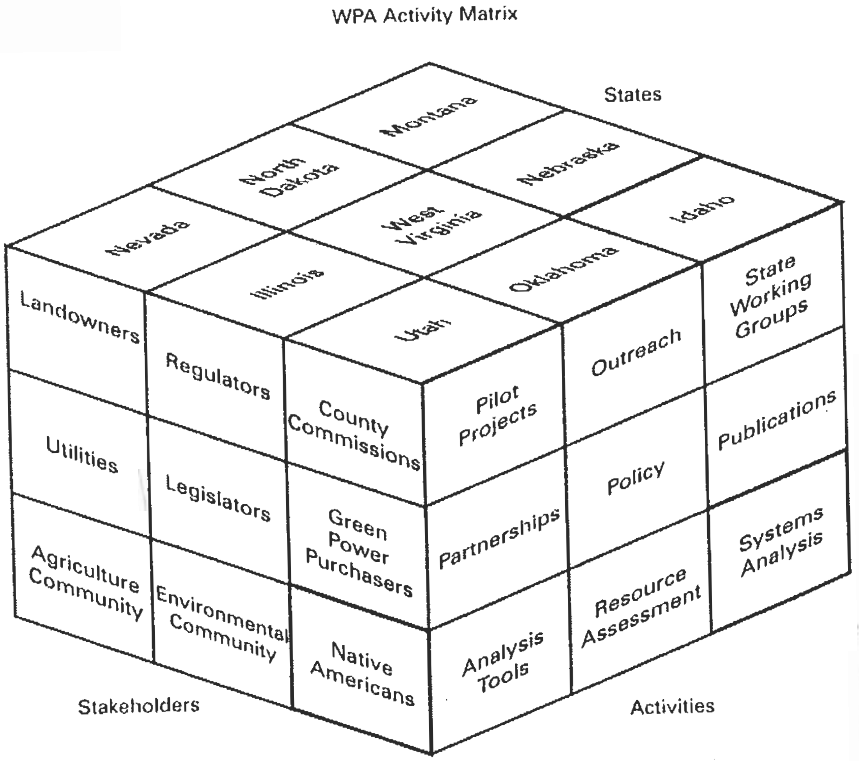

Figure 6.4. WPA Activity Matrix
Adapted from Flowers and Dougherty (2002: 3).

efforts feasible (Principles 7, 9, 10, 11, and 12), the latter is consistent with the need to promote democratic and inclusive policy initiatives and outcomes (see Pierce and Lovrich 1987). Finally, WPA identifies particularly "challenging . . . markets" (Principle 8) to promote best solutions to the specific energy needs of a particular state or local area (Flowers and Dougherty 2002: 2).

The rubric presented above best summarizes the WPA model for wind energy. The federal program recognizes the tremendous complexity facing the implementation of effective wind energy programs nationwide. It has a clear goal of producing 5 percent of all electrical energy by 2020, but there is no unified roadmap to reach that goal. Unlike the 1930s energy policy paradigm, this twenty-first-century paradigm accurately reflects the goals of a more pragmatic public-private-intergovernmental model of public policy. There is no one best way; limiting participation and narrowing solution options will not produce better outcomes, and active involvement recognizes complexity

and the sense that the energy problem is nationwide and the solutions should reflect the diverse nature of the obstacles that are faced.

STATE AND LOCAL POTENTIAL AND EFFORTS

According to *Wind Energy Potential in the United States* (Elliott and Schwartz 1993), the states with the greatest wind energy resources are in the upper midwest, Texas, and the mountain region. North Dakota has the greatest wind energy potential at 1,210 billion kWh. Texas's (which is #2) and Montana's potential capacity stand at 1,190 and 1,020 billion kWh per year, respectively. Wind energy potential, however, does not necessary equate to wind energy development maximizing potential capacity. California, which has the greatest wind energy development, produces a little over 1 percent of its power needs with wind energy.

Top Ten States in Wind Capacity (in billions of kWh per Year)

North Dakota	1,210	Nebraska	868
Texas	1,190	Wyoming	747
Kansas	1,070	Oklahoma	725
South Dakota	1,030	Minnesota	657
Montana	1,020	Iowa	551

Source: Elliot et al. 1991.

Three challenges facing wind resource development are: establishment of wind farm infrastructure, power transmission, and political/public support. Wind farm infrastructure relates to the costs associated with the transportation and assembly of wind turbines in remote locations. While the quality of wind resources in the mountain states and upper Midwest is quite substantial, wind energy equipment is shipped long distances from coastal ports and industrial centers to remote sites in these states. For each commercial wind generation unit, large turbine blades, rotors, and tower assemblies arrive disassembled and final assembly must be done on-site, requiring human resources and equipment. Mountain and upper midwestern states work with the WPA program to overcome some of the challenges associated with establishing a wind energy infrastructure. With a lower population density and abundant wind resource potential, developments could prove to be very beneficial in the long run.

Power transmission issues will arise as wind power infrastructure impinges on other policy priorities. If wind resources are developed in remote mountain sites, transmission will require the development of power lines crossing wilderness areas, which would pose serious challenges to environmental quality priorities. Rural areas in the western United States frequently abut public lands; wind power systems might pose risks to the plant and animal species living in public spaces.

Political/public support poses one of the most serious challenges to the development of wind power in the United States. In the mountain state region, for instance, Montana and Idaho have passed state laws supporting private wind turbine development by restricting construction near wind turbines that would negatively impact turbine performance. Wind and solar energy laws in many states provide tax and direct cash incentives to individuals and businesses that develop wind energy infrastructure.

Public support becomes more of a challenge when it comes to property values. For instance, the California coastal region north of Los Angeles has some of the best wind resources in the state, yet the scenic beauty of the region makes wind energy development unlikely; real estate development benefits are greater than the power generation benefit. Coastal areas in Washington, Oregon, Michigan, Maine, Massachusetts, and North Carolina face similar public support challenges.

The greatest wind resource development has occurred in California, but generally not along the California coast. California wind energy capacity is approximately 2,096mW installed wind energy systems. Wind energy development in the top wind capacity states is relatively uneven. North Dakota and Montana have developed only a tiny fraction of their wind resources, while Texas, Iowa, and Kansas are progressing more rapidly toward fully developing their wind energy infrastructure.

In 1981, the United States had only 10MW wind energy generation capacity. By 1982, the capacity had increased to 70MW, a 600 percent increase in wind energy generation capacity. Wind energy capacity stands at 6,740MW as of June 24, 2005 (see www.awea.org/projects/, accessed July 7, 2005]).

CHAPTER SUMMARY

Wind energy capacity in the United States is substantial. The technical feasibility of wind energy development is a function of the materials and engineering capable of meeting the various wind and environmental factors. Large-scale wind turbines are limited by current material strengths. Economic feasibility is a function of capital costs and operations and maintenance expenses. As wind energy increasingly explores challenging environments, such as high altitude mountainous and ocean siting, the technical feasibility that allows for wind energy development impacts the costs associated with establishing a wind farm. Political feasibility constraints may impact access to optimum wind power locations for wind power generation development.

NOTE

1. See Elliott and Schwartz (2005). In the United States, the National Renewable Energy Laboratory actively seeks to improve measurement of wind resources and maximize efficiencies of siting and wind generation plant dimensions related to site-specific conditions. Tower height, for instance, is particularly important in understanding wind resources as well as efficient access.

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