ρ = air density (typically 2.70 lb/m^3 [1.225 kg/m^3] at sea level and 59ºF [15ºC]),

A = rotor-swept area, and

V^3 = cube of the incident wind speed.

The power coefficient of the rotor has a theoretical maximum value of 0.593, called the Betz limit or Lancaster-Betz limit. This value is based upon the physical reality that even the most aerodynamically efficient turbine blade disrupts the airflow of incident wind, even before the wind front reaches the rotating blade. In actuality, the air molecules within the cross-sectional area swept by the rotor slow down as they approach rotating turbine blades and thus lose kinetic energy proportional to the cube of that velocity loss.[5]

The power coefficient of the rotor can be thought of as a correction factor, introduced into the above power equation to reflect the reality that the rotor's power-capturing efficiency is less than perfect. To calculate the power coefficient of the entire wind turbine, one simply has to introduce additional correction factors to represent the mechanical inefficiencies of the entire turbine drivetrain. However, for the purpose of this discussion, the power coefficient of the rotor is the source of greatest turbine inefficiency to the extent that drivetrain inefficiencies need not be discussed in detail.

A comparison of the turbine efficiency equation above with the equation presented in Section D.3, which represents the power inherent in the wind, leads one to fully appreciate how energy is produced by wind turbines. The Betz limit actually reflects the impossibility of extracting all the energy from the wind. Because the theoretical limit of rotor efficiency is always considerably less than 100%, the power produced by a wind turbine is always less than the power contained in the wind cross section that the turbine is intercepting. And because the rotor's efficiency is the major contributor to the overall turbine efficiency, rotor design considerations are of paramount importance.

D.5.2 Turbine Power Curves

The graphical representation of a turbine's electric power output as a function of incident wind speed is known as the turbine's power curve. At a fixed rotor speed, the power production of a wind turbine is defined by the following equation:

$$P_{el} = c_p \times \rho/2 \times (v_w)^3 \times A \,, \qquad \text{(D.4)}$$

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[5] The Betz limit is named after Albert Betz, the German dynamicist who first identified and defined the phenomenon. A more detailed discussion of the influence of turbine blades on airflow and the derivation of the Betz limit is provided in Burton et al. (2001).

where

P_{el} = electric power (expressed in W, kW, or MW),

c_p = power coefficient of the turbine,

ρ = air density (kg/m^3),

v_w = wind speed (m/s), and

A = swept area of the rotor (m^2).

Turbine manufacturers routinely use the power curve as a representation of their wind turbine's official certificate of performance.

Certain design features can have minor influences on the exact shape of the power curve; however, these influences notwithstanding, the power curves of virtually all commercial wind turbines are strikingly similar. As incident wind speed increases from zero to the "cut-in velocity," the net power extracted from the wind becomes greater than that which is necessary to overcome the mechanical drag of the turbine's drivetrain, and the excess power is used to begin producing usable electric power. With increasing wind speed, power production increases rapidly until the "rated velocity" is reached. At this wind speed, the turbine has reached its maximum electric power production capability. Power production continues at this maximum level with further increases in wind speed until the "cut-out velocity" is reached. At the cut-out velocity, the wind's energy is so great that it can cause mechanical damage to major turbine components. To prevent such damage, designers introduce various controls (such as pitch and stall control on the rotor, mechanical braking of the rotor shaft, and clutching mechanisms on the rotor shaft) that can decouple the rotor from the remainder of the turbine drivetrain.[6] With the application of such controls, the electric power production drops precipitously to zero, and the turbine effectively becomes nonfunctional as a power source. The range of wind velocities over which the turbine can produce electricity is referred to as its operating range; however, the maximum electric power production (i.e., the turbine's nameplate rating) is achieved only at the upper end of the operating range. At incident wind speeds between the cut-in velocity and the rated velocity, power production is well below the nameplate rating. In general, commercial wind turbines have operating ranges between 2.5 and 25 m/s. (Table D-2 in Section D.6, which provides commercial wind industry profiles, has examples of operating ranges.)

A turbine's power output can be derived solely from engineering calculations. However, because the power curve represents the manufacturer's guarantee of a turbine's performance, theoretical calculations are also carefully validated with real-world measurements. To overcome myriad real-world variables that can affect power production, such empirical verifications of power output are based on the statistical evaluation of a large number of measurements.

[6] In practice, such controls can be applied at any point throughout the operating range of the turbine to maintain the quality of electric power being produced and to overcome the real-world variability in incident wind energy over time.

Hau indicates that measurements averaged over a minimum of 10 minutes are usually sufficient to account for the time variability of operating conditions (Hau 2000).

D.5.3 Capacity Factors

Although the power curve is an accurate measure of the turbine's ability to generate electricity from incident wind, it does not adequately describe expectations of real-world power production. Overlaying the relevant characteristics of a given wind regime (most importantly, the percentage of time the incident wind is at the uppermost portion of the operating range) and introducing additional correction factors that reflect the turbine's technical availability (i.e., periods when the turbine is fully functional and not down for maintenance or repairs)[7] yield the capacity factor, the most realistic and reliable prediction of the energy yield for a given candidate site. Capacity factors are dimensionless, expressed as a ratio in which the turbine's annual predicted energy production is divided by the energy it would produce if it operated at its nameplate rating continuously. Capacity factors are normally represented as annualized values to account for seasonal variations in wind regimes. In practice, the most efficient wind farms exhibit individual turbine capacity factors of 30 to 35% (EPRI 2001; DOE/TVA/EPRI 2003; Robichaud 2004). However, capacity factors as high as 45% have been observed (Manwell et al. 2002; EPRI 2001; McGowan and Conners 2000). Capacity factors of at least 25% are considered minimally necessary for a site to be considered economically viable (McGowan and Conners 2000).

Because it is rooted in the real world, the capacity factor becomes a much more valuable tool for supporting decisions about wind farm development than the turbine's power curve alone. The ideal site from a power production perspective is one that yields the highest capacity factor for each of the turbines. That being said, however, it is important to also recognize that power-producing potential, although important, is not the exclusive basis for site development decisions. Many other factors, including ease of site access, access to transmission lines, site development costs, the absence of sensitive ecosystems, and market price for energy, are always also considered in site selection decisions. Thus, it is often the case that the sites with the ideal wind regimes yielding the highest predicted capacity factors are not necessarily assigned the highest priority for development.

D.5.4 Rotor Tip Speed and Tip Speed Ratio

The rotor tip speed is the tangential velocity of the very end of the blade of a rotating rotor (i.e., the speed at which the tip of the blade moves around the circumference of the swept area of the rotor). Early wind turbine designs sought to match the rotor speed with the rotational speed requirements of the electric generator's rotor.[8] However, modern designs utilizing more

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[7] Hau (2000) cites studies from Denmark and Germany that support the claim that annualized availabilities of modern-day wind turbines can approach 98%.

[8] The center shaft, or rotor, of a typical induction generator rotates at 1,500 to 2,000 rotations per minute (rpm).

sophisticated and more reliable transmissions (Figure D-5) can adequately maintain the rotational speed of the electric generator's central shaft at much lower rates of rotor rotation. This results in substantial additional benefits, including reductions in the bending moments on the blades and reductions in the forces on the turbine drivetrain, by minimizing the effective weight of the rotor.

Wind turbine designers concern themselves not with the blade's tip speed but rather with the tip speed ratio, which is defined as the ratio of the angular velocity of the blade tip to the mean velocity of the wind entering the rotor. For a given mean wind velocity and a rotor with a given number of blades, the design objective is to select a tip speed ratio that maximizes the opportunity for the incident wind to interact with the turbine blades and impart aerodynamic lift while simultaneously minimizing the disruptions of airflow ahead of the rotor blades. A rotor spinning too fast will present a greater obstruction to incident wind. Conversely, a rotor revolution that is too slow will allow large amounts of air to pass through the rotor's plane without ever interacting with a turbine blade and imparting aerodynamic lift. At a given mean wind speed, the power coefficient of a turbine initially increases with an increasing tip speed ratio until a maximum is reached; beyond this point, performance actually decreases with further increases in the tip speed ratio. A more detailed discussion of this relationship and the influence of the Betz limit on turbine performance is provided by Burton et al. (2001). The ideal tip speed ratio is empirically derived and is inversely related to the number of blades. Because the rotor's (and the turbine's) power coefficient is directly related to the tip speed, controlling that ratio is a desirable objective. For a specific rotor operating in a given wind regime, the tip speed ratio at which maximum performance is achieved becomes the controlling design basis value.

In addition to the basic performance relationship between the blade's tip speed and the turbine's power coefficient, two impacting factors are directly related to rotor rotation and tip speed: aerodynamic noise and shadow flicker. Both can influence turbine design decisions. The aerodynamic noise generated by a wind turbine is proportional to the fifth power of the tip speed.[9] Thus, small variations in tip speed can dramatically affect the noise profile of a wind turbine. Empirical data have led turbine designers to limit the tip speed to no more than 213 ft/s (65 m/s). Limiting the tip speed (which is proportional to the rotor's rate of rotation and based on the swept area of the rotor) and limiting the distance to the nearest habitation to at least 1,312 ft (400 m) are expected to result in a turbine noise level at or near ambient levels (Burton et al. 2001). However, other factors, such as the height of the rotor and the topography of the site, can significantly influence the propagation of sound energy.

In addition to the mathematical and geometric relationships between the rotor's rate of revolution and the tip speed and the relationships between the tip speed ratio and the power coefficients, rotor revolution can also cause a visual phenomenon unique to wind turbines known as "shadow flicker." Shadow flicker refers to the shadows that a wind turbine casts over structures and observers at times of the day when the sun is directly behind the turbine rotor from an observer's position. Shadow flicker is most pronounced in northern latitudes during winter months because of the lower angle of the sun in the winter sky. However, it is possible to

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9 The angle at which the airfoil of a rotor blade faces the wind, sometimes known as the angle of attack, can also influence the production of aerodynamic noise.

encounter shadow flicker anywhere for brief periods after sunset and before sunrise. Empirical data suggest that shadow flicker can have a disorienting effect on a small segment of the general population. Empirical data also suggest that limiting the frequency of rotor rotation to below 2.5 Hz can mitigate the deleterious effects of shadow flicker.[10] Burton et al. (2001) indicates that limiting a (three-bladed) rotor revolution to 35 rpm will result in a blade passing frequency of 1.75 Hz (i.e., where the passing is between the sun and the observer). Increasing the spacing between a turbine rotor and the nearest observer to at least 10 rotor diameters also dramatically mitigates shadow flicker effects.

Finally, another closely related phenomenon is “blade glint,” which is the reflection of sunlight off the surfaces of rotating blades. Such glint can also have a disruptive effect on some observers. However, as discussed elsewhere, the trend in the industry is toward longer blades. To control the resulting weight (and provide better aerodynamic properties), modern blades are now constructed almost exclusively of carbon composites or plastics, the natural surfaces of which are quite dull, especially relative to the steel and aluminum blades of the past. In the majority of cases, this technological development has made blade glint a relatively moot point with regard to modern turbines.

D.5.5 Blade Length and Tower Height

Because the speed of the incoming wind cannot be controlled, attaining and maintaining the ideal tip speed ratio involves controlling the tip speed. There are two paths to this objective: changing the rate of rotor rotation or increasing the blade length. Increasing the blade length is often the preferred option for a number of engineering reasons. However, the law of diminishing returns is also at play here. Larger rotor diameters result in additional bending moments on the blades that must be accounted for. Longer blades mean additional rotor weight and increased strain on the mechanical drivetrain components. Research on alternative materials and fabrication procedures is being conducted by turbine manufacturers and under government sponsorship. (See Section D.7 for more details on blade research.) Preliminary DOE-sponsored research on the technological impediments to scaling up current blade designs has identified the need to modify construction materials and processes (Griffin 2002) and the need to take a fundamentally different approach to airfoil design for extremely long blades (TPI Composites, Inc. 2002).

To accommodate longer blade lengths, the turbine support towers have to be taller and more substantial. Irrespective of blade length, taller towers allow the rotor to operate in geostrophic wind regimes above the interferences introduced by surface topography. Principal performance factors affecting tower height selection include the wind profiles of the candidate site and the blade length of the turbine model selected. Costs of fabrication and erection are balanced against the performance advantages. Other factors related to site conditions can also influence tower height selection. These include access to the site by the larger equipment needed to transport towers (or tower segments), longer blades, and lifting/erection equipment; temporary

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[10] One hertz, or one cycle per second, is equal to 1/60th rpm.

amendment of site surface conditions to accommodate erection activities; and subsurface conditions that could affect the difficulty and the cost of constructing sufficient foundations for larger towers.[11] Installation costs, site access, and transportation logistics are important limiting factors with regard to tower height, and all factors must be considered in calculating improved performance with height. Developers are not likely to erect towers any taller than necessary to achieve economic power production (Steinhower 2004).

The principal impacting factors that directly relate to a rotor's geometry and the elevation at which it operates are listed below:

- Larger rotors require higher, more formidable towers that are more expensive to fabricate and erect.

- Higher towers, in turn, are visible from greater distances, increasing the size of the impacted viewshed.

- Larger rotors allow for the economical capture of wind energy at slower rotor revolutions, which could lessen or completely eliminate the adverse viewshed impacts and bird-strike hazards.

- Larger rotors can rotate at frequencies less than the frequencies that induce shadow flicker.

- Larger rotors operating at fewer rotations per minute produce less aerodynamic noise than their smaller counterparts, which must rotate faster to capture the same amount of wind energy.

D.5.6 Grid Interconnection Issues

The distance to an existing transmission line of suitable voltage and with reserve power-carrying capacity is a critical factor to consider with regard to future wind energy development projects, because the wind farm developer is expected to absorb the cost of establishing the physical link from the wind farm to the nearest existing transmission grid.[12] However, connecting to the grid is not necessarily a straightforward process. In reality, many factors related to grid interconnectivity can influence site development costs, design selection, initial installation and subsequent operating costs, and ROI schedules.

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[11] However, innovative tower designs can dramatically influence erection costs and simplify transportation logistics. See Section D.7.1 for additional discussion.

[12] Detailed discussions on the development of interconnecting links to existing transmission lines are provided in the cumulative impacts portion of this PEIS. Nevertheless, the development of power links between any wind farm and existing power transmission lines will receive separate National Environmental Policy Act (NEPA) evaluations, which are outside the scope of this PEIS.

To prevent disrupting the grid, the electric power generated at the wind farm must first be conditioned. This requires installing various power management and conditioning devices. Other devices are required to automatically isolate a wind farm from the grid during certain disruptive events. Sophisticated supervisory control and data acquisition (SCADA) systems are also required to ensure that the operating conditions of both the individual turbines and the overall wind farm and any rapid changes to grid interconnections are adequately controlled, in order to prevent the effects of potentially damaging disruptive events at the wind farm from cascading onto the grid.

Although power management and control devices and SCADA systems certainly affect site development costs and the ability of the wind farm to interconnect to the grid, they represent only an incremental change to the footprint of the wind farm, and most have little or no direct or cumulative environmental impacts.[13] There are two notable exceptions, however: "voltage flicker" and lightning protection.

If not adequately conditioned and controlled, wind farm power introduced onto the grid can result in voltage flicker. Voltage flicker occurs when changes to the network voltage occur faster than steady-state voltage changes that exist within the transmission system. Voltage flicker can cause perceptible changes to the brightness of incandescent lights that draw power from the grid. Such changes, in turn, can have a disorienting effect on certain individuals. Transmission grid operators can be expected to require wind farm operators to establish power management systems capable of eliminating conditions leading to voltage flicker.

Lightning protection is also required for wind farm components to prevent catastrophic impacts to the grid. Each individual turbine tower on the wind farm, as well as the electrical substation, must be protected, and control systems must be capable of isolating the wind farm from the grid during upset conditions caused by lightning. Although lightning protection technologies are available, their application in some wind farm settings may appreciably increase site development costs. Conventional lightning control involves providing a low-impedance path for the lightning's electrical energy to pass to ground.[14] To establish adequate lightning protection for wind farms developed on rocky ground where there is no soil mantle, it may be necessary to drill one or more wells into which a current-conducting metal rod is inserted to extend the grounding path to the nearest aquifer. Moreover, the aquifer must be continuous over a large area rather than perched to provide reliable protection. In some western states within the study area, the nearest appropriate aquifer may be thousands of feet below a candidate wind site. Installation of such grounding wells will increase costs — not only costs directly related to well

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[13] Although many issues associated with power management and control and interconnection to the grid are outside the scope of this PEIS, they are, nevertheless, expected to be stipulations to any agreement between a power transmission company and a wind farm operator regulating grid interconnection.

[14] Where the soil mantle provides adequate grounding capacity, lightning protection systems routinely involve one or more grounding rods. For electrical substations, this grounding path is often enhanced by the installation of a grounding grid of wire located below the entire footprint of the substation and at some depth below the ground surface.

installation, but also costs to support the hydrogeologic studies that may be required to identify appropriate aquifers.[15]

D.5.7 Variable versus Fixed Rotor Rotation

Wind turbines can be designed to operate at both fixed and variable rotor rotation speeds. Of the two systems, variable-speed systems are preferred for a number of reasons related to overall wind turbine performance. However, while variable-speed machines can take fuller advantage of variations in the incident wind speed, the alternating current (ac) electricity they produce has a variable frequency that cannot be safely delivered to existing power transmission grids without conditioning. Variable-speed wind turbines are routinely connected “indirectly” to the grid to allow this power conditioning to occur at the wind farm. The majority of modern turbines include transmissions, clutches, and rotor shaft braking systems or aerodynamic stall features that act on the rotor blades to maintain the variations in a rotor shaft’s rotation within prescribed design limits. Such turbines are also equipped with SCADA systems that can adjust operating conditions (e.g., aerodynamic stall and blade pitch) to changing wind conditions. Variable-speed capability allows the turbine to operate at ideal tip speed ratios over a larger range of wind speeds. The most dramatic increase in performance is realized at lower wind speeds.

Wind turbines with either a fixed or variable rotor rotation speed can be outfitted with either synchronous or asynchronous electric power generators.[16] In general, initial installation costs for asynchronous generators are lower, and the generators are generally very reliable. More important, asynchronous generators have mechanical properties that make them very suitable for wind turbine applications, including good overload capabilities and a relatively small generator slip.[17] Asynchronous generators can easily accommodate changes in the torque applied by the wind turbine’s rotor shaft (through the transmission), thus reducing overall mechanical wear and tear over the generator’s operating life. Because of the relatively constant operating conditions of asynchronous generators, turbines equipped with such generators are normally directly connected to the grid with little additional conditioning.

The use of synchronous electric generators rather than induction generators improves the wind turbine’s overall power generating performance and reduces the likelihood that the turbine will be a source of harmonic electric currents that can be disruptive to the power grid. However,

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[15] Properly designed and installed “grounding wells” have no potential to adversely impact groundwater quality.

[16] Asynchronous generators are also commonly called induction generators. Expanded discussions on electric generators are available in appropriate engineering textbooks. A simplified discussion regarding generators used in wind turbines can be found in DWIA (2004).

[17] The difference in rotational speeds of the generator at idle and at peak load is called the generator slip, expressed as a percentage of the synchronous speed. Thus, the rotational speed of the generator’s center shaft (called the stator), which is turned by the action of the turbine rotor, varies little over the entire operating range of the generator.

initial installation costs are higher, and the power produced by synchronous generators must first be conditioned before delivery to the grid, further increasing installation and operational costs.

As rotor diameters increase, the turbine's rated power increases proportionally to the square of the rotor diameter. The amount of torque produced by the rotor shaft also increases markedly, placing significant operating demands on transmissions and generators. Industry and government researchers are now exploring the use of multiple generators or the use of multipole generators as a way of distributing torque and reducing its damaging effects on mechanical systems (Cotrell 2002). The use of multiple generators operating at different shaft speeds is also being investigated as a means of producing optimal levels of power at more widely varying rotor rotational speeds. Regardless of turbine and generator design choices, the attendant power-conditioning prerequisites do not themselves have additional environmental impacts of any significance.

Operation at variable rotor speeds increases the complexity of the initial turbine design as well as the SCADA system required. However, it also promises to increase the overall longevity of major system components and to reduce O&M costs. Thus, turbines with variable-speed rotors can be expected to have less of an environmental impact over their operating lives than would their fixed-speed counterparts.

Wind farms could consist of a mixture of fixed-speed and variable-speed turbines. Although the development costs of such a wind farm would be incremental, the increased sophistication of power management systems and SCADA systems and the expected greater O&M costs of such a configuration make such a wind farm unlikely. Wind farms consisting of identical turbines operating at different rotor elevations in order to take the fullest advantage of existing wind profiles are still a conceivable option, however.

The following impacting factors relate to rotor operation at a variable rotation speed:

- Reducing the dynamic forces on the turbine drivetrain, extending the operating lives of major components, extending the maintenance intervals, and reducing the incidence of breakdowns, all of which will result in a smaller environmental impact over the life of the wind farm;

- Allowing the turbine to be "elastic" with respect to its interaction with the grid, thereby reducing the generation of power harmonics that can be disruptive to the grid; and

- Allowing the turbine to efficiently generate power at lower wind speeds, thus reducing the aerodynamic noise signal of the blades.

D.5.8 Micrositing and Site Development

Once a candidate site has been selected and more detailed meteorological data have been gathered for a minimum of 1 year, site developers have the data necessary to make micrositing decisions (i.e., determine the precise location on the site at which the wind turbines will be located). The natural turbulence at the site due to the surface topography and obstructions and the induced turbulence of each wind turbine tower are the primary factors that govern turbine micrositing. Empirically derived nomographs[18] exist that indicate the necessary minimum distances for turbine placement from natural obstructions; however, they are often imprecise. Improving the methods for characterizing site-specific turbulence and understanding the influence of turbulence on site development make up a major ongoing R&D initiative (Section D.7). It is possible that site developers may find it appropriate to remove some natural obstructions (e.g., trees) to mitigate turbulence caused by natural obstructions.[19] It is also reasonable to conclude, however, that the extent to which natural features of the site will be altered to improve the wind regime will be limited by site development costs. Thus, while tree removal is a feasible step associated with site development, major alterations of the existing grade over a large scale are not.

It is also reasonable to expect that a site developer will seek to take advantage of economies of scale and develop a candidate site to its fullest potential. Thus, multiple turbines will likely be erected, and turbulence considerations will again be the primary factor governing their number and interspatial relationships.[20] Empirical nomographs that describe the induced turbulence of a wind turbine and its tower and that indicate the minimum distance of separation needed to avoid such interferences will likely be used to support micrositing decisions. (Research is ongoing to develop more precise modeling tools for characterizing the wind regimes on a site; see Section D.7.) Avoiding the wind shadow of turbines will probably be a first priority in siting multiple turbines, and access to the indicated micrositing location will be of secondary importance. Pursuing economies of scale in site development will amortize site characterization and site development costs. However, the extent to which a site will be developed can have additive affects on many of its impacting factors.

Primary impacting factors related to site development and micrositing include the following:

- Potential for ancillary activities, such as tree and vegetation removal, that will result in surface scarring and additional impacts to the viewshed beyond the impact of turbine visibility itself;

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[18] A nomograph is any chart representing numerical relationships. In this case, the relationship is between the degree of turbulence and the distance from a wind turbine to any natural or human-made wind obstruction, including other turbines.

[19] However, for wind turbines operating on very tall towers with their rotors largely within the geostropic wind regime, even mature trees represent relatively inconsequential ground-level obstructions to winds at the turbine hub's elevation.

[20] The rotation of both a turbine rotor and the support tower induce turbulence in the downwind direction. Spacing of wind turbines to avoid turbulence effects is usually represented by rotor diameters. Normally, a distance of 10 rotor diameters is considered to be the minimum downwind distance for spacing turbines in the downwind direction.

- Increased potential for fugitive dust, proportional to the area of disturbed ground surface;
- Potential for invasive species being established in disturbed areas before indigenous vegetation can be reestablished;
- Potential for bird strikes, generally proportional to the number of turbines installed;
- Increased time required for construction, with proportional increases in both the magnitude and duration of impacts related to construction;
- Potentially additive impacts from individual turbines, including noise and viewshed impacts; and
- Proportional increases in O&M costs, including costs to deal with wastes associated with system maintenance and repair.

D.6 COMMERCIAL WIND ENERGY INDUSTRY PROFILES

This section provides an overview of the existing commercial wind energy industry within the study area. AWEA compiles and maintains data on commercial wind farms.[21] The review and analysis of these data provide a reasonable basis from which to anticipate the characteristics of future wind farms.

Industrywide reviews of the commercial utility-scale wind energy industry have identified the following important trends, each of which will greatly influence future wind farms.

- In general, average individual wind turbine power-generating capacities have steadily increased in North America, from 500–750 kW in the late 1990s to megawatt-capacity turbine installations beginning in 1999, resulting in typical wind farm generating capacities of 50 MW or larger (Kaygusuz 2004).
- The (worldwide) average growth rate of the cumulative installed wind energy power-generating capacity over the period 1998–2004 has been about 30% per year (Kaygusuz 2004).
- As the understanding of aerodynamics has been increasing and as designs have been defined, wind turbine efficiencies have been increasing, especially for turbines with larger rotor-swept areas. Average annual yields per unit of rotor-swept area have increased by more than 50% as rotor diameters have increased from 66 to 262 ft (20 to 80 m) (Milborrow 2002).

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[21] The text box on the next page describes AWEA and information compiled by AWEA regarding the wind energy industry.

- Wind turbines now have power-generating capacities of as much as 600 W/m^2 of rotor-swept area.
- Three-bladed, upwind turbines dominate the commercial utility-scale market (Milborrow 2002).
- The majority of wind turbines run at fixed rotor speeds and utilize induction generators. However, newer models equipped with sophisticated electric power conditioning controls have rotors that run at a variable rotational speed (Milborrow 2002).
- Newer-model turbines tend to run at slower rotor rotational speeds but have relatively high energy capture/conversion efficiencies (Milborrow 2002).

About AWEA

The American Wind Energy Association (AWEA) is a national trade association that represents wind power plant developers, wind turbine manufacturers, utilities, consultants, insurers, financiers, researchers, and others involved or interested in the wind energy industry. AWEA provides up-to-date information on wind energy projects operating worldwide and projects under development, and it conducts technology and policy development activities related to wind energy.

AWEA compiles and regularly updates relevant domestic and worldwide statistics on the wind energy industry and makes them available to industry participants, the interested general public, and the news media. These data are available at the association's Web site at http://www.awea.org. Also available on the AWEA Web site is access to various wind-energy-related information resources, including wind energy fact sheets and a catalogue of related publications. AWEA also publishes a weekly newsletter devoted to wind energy news and hosts an annual national conference, WINDPOWER. Detailed information on AWEA activities and services can be obtained by visiting the Web site.

Information developed by AWEA has been incorporated into this PEIS without independent verification. The Bureau of Land Management (BLM) does not endorse AWEA and does not make any warranty regarding the accuracy or completeness of the data it provides.

Although the commercial wind energy market in the United States has existed for some time, it has only recently (since 1999) begun to experience substantial growth, with calendar years 2001 and 2003 witnessing the two largest single-year's growth. Figure D-6 graphically depicts the rise in wind energy capacity (nameplate ratings in megawatts of electricity; the bars in the foreground represent capacities added annually; the bars in the background represent cumulative power capacity) over the period from 1981 through 2003. Data published by AWEA indicate that the total installed capacity for all domestic commercial wind energy as of December 2003 was 6,374 MW, with 1,687 MW coming on line in 2003, which was a 36% increase from the capacity at the previous year's end (AWEA 2004d). Calendar year 2003 compared favorably with the previous year, showing a worldwide increase in capacity of 6,868 MW to reach a total of 31,128 MW and a U.S. increase of 410 MW to reach a year-end total of 4,685 MW, which represents 15% of the world's market (AWEA 2003a). Of the current total domestic capacity of 6,374 MW, 2,999.7 MW (or 47%) is being produced in the 11-state study area of this PEIS. The increase in overall generating capacity has been accompanied by a steady increase in individual turbine proportions and capacities. In the late 1980s, average turbine power outputs averaged 450 kW. Outputs increased to an average of 600 to 750 kW by the late 1990s. Now, individual turbines with ratings greater than 2 MW (2,000 kW) are commonplace (McGowan and Connors 2000).

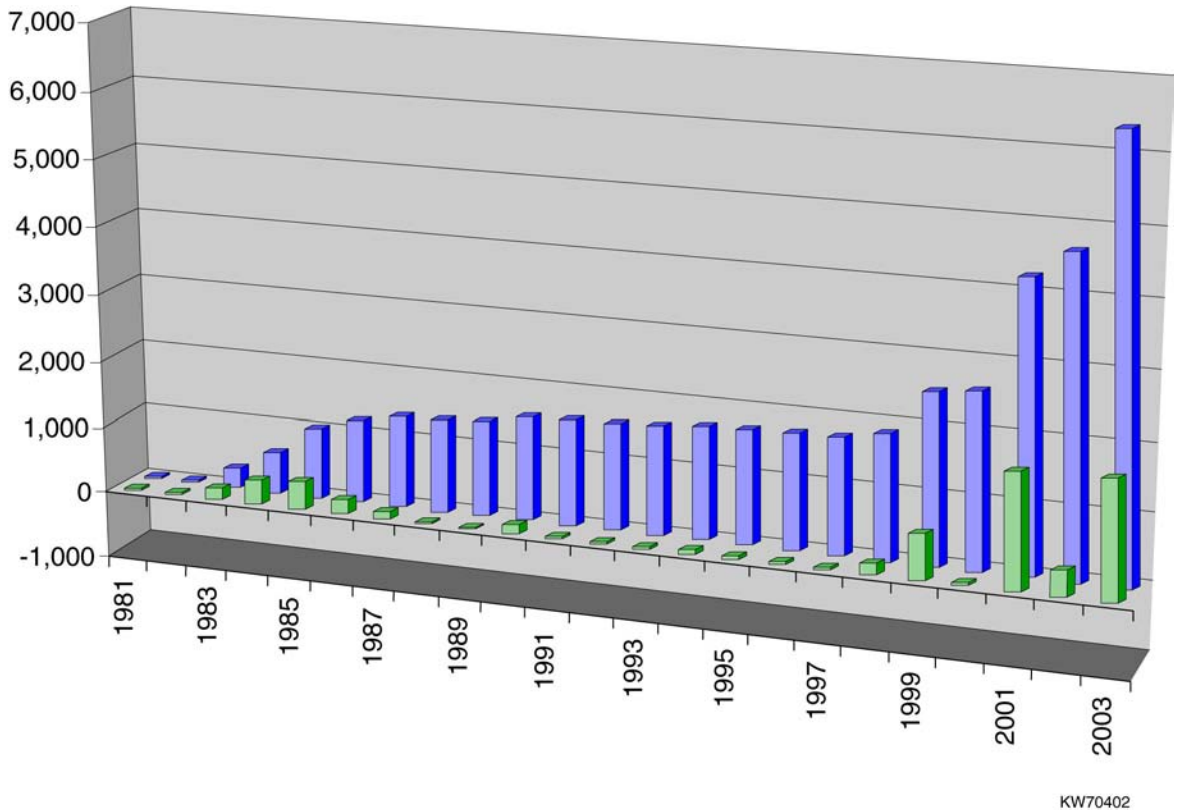

FIGURE D-6 U.S. Installed Capacity (MW) for 1981 through 2003 (Source: AWEA 2004d. Reprinted with permission. Courtesy of the AWEA.)

Figure D-7 shows the distribution of wind energy power-generating capacity across the United States. The numbers represent power capacities of utility-scale wind farms only, all of which deliver power directly to the electric power transmission grid. Additional power capacities from distributed energy systems are not included. The power capacities represent nameplate ratings and are rarely realized in practice. (See the discussion on typical capacity factors in Section D.5.2.) Within the 11-state study area for the PEIS, the total installed wind energy capacity is 2,999.7 MW.

Table D-1 lists the commercial wind energy projects completed in 2003. Projects completed within the 11-state study area are in bold type. The projects listed in the table represent new wind farms and phased expansions, or "repowering," of existing wind farms (i.e., replacing existing turbines with ones of newer design). Facility expansions and repowering activities are not expected to have the same array and magnitude of impacting factors as would a completely new facility. By definition, such site modifications are outside the scope of this PEIS.

In general, the number of manufacturers of wind turbines has greatly decreased from earlier years. In fact, a number of manufacturers have gone out of business. However, also represented in this decline are a number of mergers among manufacturers.

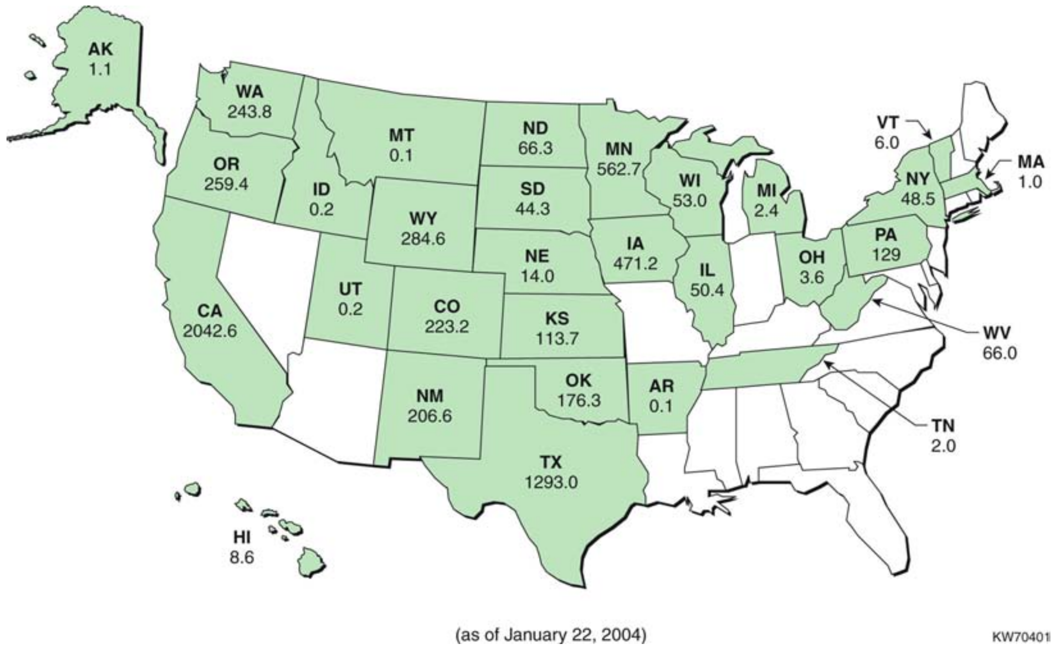

FIGURE D-7 Wind Energy Projects in the United States (Source: Adapted from AWEA 2004a. Reproduced with permission. Courtesy of the AWEA.)

Table D-1 lists the manufacturers of commercial wind turbines whose products were installed in U.S. wind farm projects in 2003. Although there are many other manufacturers, those listed in Table D-1 nevertheless represent a cross section of vendors. One should therefore take a more careful look at the turbine models offered by these vendors. Table D-2 lists the ranges of values for critical parameters of wind turbines installed in 2003. Although it is assumed that installations in 2003 constitute a reasonable representation of the most current facility installations and expansions, there is still a possibility that future wind farms will utilize turbines from other manufacturers. Nevertheless, it is reasonable to assume that the turbines installed in 2003 met the technical requirements of the sites at which they were installed. It is therefore also reasonable to assume that future developments at sites with similar wind regimes may also utilize turbines with these approximate specifications.

It is not BLM's intention to endorse any specific equipment manufacturer.[22] Consequently, rather than present the specifications of individual turbines, the table displays a range of values for each parameter that is addressed. Only design specifications that were readily available from manufacturers' Web sites are included in the range calculations. Not always accurately reflected in the range value displayed, but nevertheless important for anticipating future wind farm characteristics, is the fact that many manufacturers offer modules rather than complete turbines, providing a number of options for each major component. Thus, the developer can custom build a turbine that is precisely suited to a particular site's wind conditions and to the

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22 For a comprehensive list of turbine manufacturers, consult AWEA (2004b) or commercial business source guides such as Momentum Technologies, LLC (2004).

TABLE D-1 Wind Energy Projects Installed in 2003[a]

State	Project Name	Location	Capacity (MW)	Developer	Turbine Manufacturer	No. of Wind Turbines
Alaska	Selawik Wind Project	Selawik	0.2	Kotzebue Electric Association	AOC	4
Arkansas	Bitworks	Prairie Grove Industrial Park, Washington County	0.1	Bitworks, Inc	NEG Micon	1
California	**High Winds**	**Solano**	**162**	**FPL Energy**	**Vestas**	**90**
California	**Mountain View III**	**San Gorgonio**	**22.44**	**PPM Energy**	**Vestas**	**34**
California		**Sacramento**	**9.9**	**SMUD**	**Vestas**	**15**
California	**CalWind II CEC-repower**	**Tehachapi**	**8.58**	**CalWind Resources, Inc.**	**Vestas**	**13**
California	**Whitewater expansion**		**4.5**	**Cannon Power Corp.**	**GE Wind**	**3**
California	**Karen Avenue II**	**San Gorgonio**	**4.5**	**San Gorgonio Farms**	**GE Wind**	**3**
Colorado	**Colorado Green**	**Near Lamar**	**162**	**GE Wind**	**GE Wind**	**108**
Idaho	**Lewandoski wind farm**		**0.216**	**Bob Lewandoski**		**2**
Illinois	Mendota Hills	Lee County, near Mendota	50.4	Navitas Energy	Gamesa Eolica	63
Iowa	Flying Cloud	Near Spirit Lake	43.5	PPM Energy	GE Wind	29
Iowa	Henry Hills	Osceola County, near Sibley	3.6	Northern Alternative Energy	Gamesa Eolica	2
Iowa	Lenox	Lenox	0.75	Lenox Municipal	NEG Micon	1
Iowa	Wall Lake	Wall Lake	0.66	Wall Lake Municipal	Vestas	1
Iowa	Sibley Hills	Near Sibley	0.66	Northern Alternative Energy	Vestas	1

TABLE D-1 (Cont.)

State	Project Name	Location	Capacity (MW)	Developer	Turbine Manufacturer	No. of Wind Turbines
Minnesota	Chanarambie	Murray County	85.5	enXco	GE Wind	57
Minnesota	Moraine Wind Power Project	Pipestone & Murray Counties	51	PPM Energy	GE Wind	34
Minnesota	Farmers' cooperative corporations		22.8	DanMar & Associates	Suzlon Energy	24
Minnesota	McNeilus	Near Minn. Highway 56	22.8	Garwin McNeilus	NEG Micon	24
Minnesota	McNeilus		16.5	Garwin McNeilus	NEG Micon	11
Minnesota	Viking	Murray County	12	Project Resources		8
Minnesota	McNeilus		6	Garwin McNeilus	NEG Micon	4
Minnesota	Fairmont	Fairmont	1.9	SMMPA	NEG Micon	2
Minnesota	Missouri River Energy Systems	Worthington	1.9	Missouri River Energy Systems	NEG Micon	2
Minnesota	Shaokatan Power Partners	Lincoln County, near Hendricks	1.6	Northern Alternative Energy	Gamesa Eolica	2
Minnesota	McNeilus		1.65	Garwin McNeilus	NEG Micon	1
Minnesota	Don Sieve Wind Farm	Lincoln Co.	0.95	Diversified Energy Solutions	NEG Micon	1
Minnesota		Lincoln Co.	0.9	Diversified Energy Solutions	NEG Micon	1
Minnesota	Pipestone School District		0.75	Pipestone School District	NEG Micon	1
New Mexico	**New Mexico Wind Energy Center**	**Quay, DeBaca Counties**	**204**	**FPL Energy**	**GE Wind**	**136**
New Mexico	**Llano Estacado Wind Ranch at Texico**		**1.32**	**Cielo Wind Power**	**Vestas**	**2**

TABLE D-1 (Cont.)

State	Project Name	Location	Capacity (MW)	Developer	Turbine Manufacturer	No. of Wind Turbines
North Dakota		Near Edgeley	40.5	FPL Energy	GE Wind	27
North Dakota		Near Kulm	21	FPL Energy	GE Wind	14
Ohio		Bowling Green	3.6	Bowling Green Municipal	Vestas	2
Oklahoma	Blue Canyon Wind Power	North of Lawton	74.25	Zilkha Renewable Energy & Kirmart Corp.	NEG Micon	45
Oklahoma		Near Woodland	51	FPL Energy	GE Wind	34
Oklahoma		Near Woodland	51	FPL Energy	GE Wind	34
Oregon	**Combine Hills**		**41**	**Eurus**	**Mitsubishi**	**41**
Pennsylvania	Waymart	Clinton & Canaan Township	64.5	FPL Energy	GE Wind	43
Pennsylvania	Meyersdale	Somerset	30	FPL Energy	NEG Micon	20
South Dakota	Highmore	Near Highmore	40.5	FPL Energy	GE Wind	27
South Dakota	Rosebud Sioux		0.75	DisGen	NEG Micon	1
Texas	Brazos Wind Ranch	90 miles south of Lubbock	160	Cielo Wind Power/Orion Energy	Mitsubishi	160
Texas	Sweetwater	Sweetwater	37.5	DKR/Babcock-Brown	GE Wind	25
Texas	Hansford County, Texas		3	FPL Energy	Vestas	1
Texas	Indian Mesa		3		Vestas	1
Washington	**Nine Canyon, phase II**	**Benton County**	**15.6**	**Energy Northwest**	**Bonus**	**12**
Wyoming	**Evanston**	**Evanston**	**144**	**FPL Energy**	**Vestas**	**80**

[a] Bold type indicates projects within the 11-state study area.

Source: Adapted from AWEA (2003b). Reprinted by permission. Courtesy of the AWEA.

TABLE D-2 Specifications for Wind Turbines Installed in 2003[a]

Parameter[b]	Ranges for Available Options[c]
Power (nameplate rating)[d]	200 kW–3.6 MW
Turbine type	Upwind HAWT
Cut-in speed (m/s)	2.5–4.0
Nominal wind speed (m/s)	11–16
Cut-out speed (m/s)	25
Rotor diameter (m)	30–104
Rotor-swept area (m^2)	706–8495
Rotor speed (rpm)	8–46
Rotor hub height (m)[e]	30–120
Tower construction material	Cylindrical or tubular steel, hot-dip galvanized lattice steel, combination concrete and tubular steel
Tower weight (kg)[f]	<30,500–216,780
Nacelle weight (excluding rotor) (kg)[e,f]	<19,954–55,329
Rotor weight (kg)[g]	<9,070–30,839
Total weight (kg)[h]	<37,188–158,300

[a] Data presented in this table represent the range of options offered by the manufacturers listed in Table D-1 for which data were readily available. No attempt was made to identify the specific turbine models used in the 2003 projects. Instead, all available models of the manufacturers listed were used to compute the ranges. Additional information on individual turbine models is available at that turbine manufacturer's Web site. Web sites are listed here as follows:

Atlantic Orient Corp.	http//www.aocwind.net/specs.htm
Bonus Energy Products	http//www.bonus.dk/uk/produkter/
Gamesa Eolica	http//www.gamesa.es/ingles/nucleos_negocio/gamesa_eolica/presentacion/presentacion.htm
GE Energy	http//www.gepower.com/businesses/ge_wind_energy/en/products.htm
Mitsubishi Electric	http//www.global.mitsubishielectric.com/bu/windpower/index2_b.html
NEG-Micon	http//www.neg-micon.com (Only limited data are available; data are not included in ranges presented in the table.)
Suzlon Energy	http//www.suzlon.com/technical_data
Vestas Wind Systems A/S	http//www/vestas.com/produkter/

[b] By industry convention, all specifications are presented in metric units.

[c] Range does not include data from AOC Model 15/50 turbine, the use of which has been confined to distributed energy systems in remote locations.

[d] Range represents individual turbine nameplate ratings. Additional specifications for power generation and management devices are available at the manufacturers' Web sites. However, since these devices have little or no influence on the environmental impacts of an operating wind turbine, they are not represented here.

[e] Rotor hub height is considered to be approximately equivalent to tower height, measured from ground elevation.

Footnotes continued on next page.

TABLE D-2 (Cont.)

[f] All weights are approximate; the weight range is based on models manufactured by Vestas Wind Systems A/S and Bonus Energy Products only. The weight of the smallest tower option was not available.

[g] Rotor weight includes active pitch control equipment, if present.

[h] Nacelle weights may differ as a result of drivetrain component selection.

Source: Derived from AWEA (2003b).

stipulations of a particular interconnection agreement with the transmission line operator. For the reader's convenience, the Web sites for the manufacturers whose turbines are represented in the range of values displayed are provided as footnotes to Table D-2.

The data displayed in Table D-1 appear to support the following conclusions about the characteristics of future wind farms. Notwithstanding the fact that calendar year 2003 was an exceptional year for industry growth, a reasonable assumption is that the projects that went on line in 2003 reflect the state of the technology with respect to commercially available wind turbines. Another reasonable assumption is that the wind turbine models installed in 2003 offered operating parameters that matched well with the specific conditions at the sites at which they were installed. A further assumption is that future sites with wind characteristics similar to those at sites developed in 2003 will utilize turbines with operating parameters similar to those displayed in Table D-2.

Following a strategy of extracting the maximum potential wind energy from a given site will minimize the overall environmental impacts. However, phased site development can cause changes to some impacting factors related to site development and operation. Some of the impacts in phased development will simply be additive over time. For example, the noise levels from individual turbines will be logarithmically additive for each turbine installed; however, because of the expected distances between turbines in a typical wind farm, the addition of each turbine will increase the area potentially impacted by noise, but it will not substantially increase the average or maximum noise levels throughout that area. Site topographic features can also greatly influence noise levels at a given distance from a noise source. See Section 4.5 for a detailed discussion on noise generation and propagation and Section 5.1.5 for a discussion on potential noise impacts from wind farms. Impacting factors associated with turbine foundations and erections will also be additive within a given phase of development and then reoccur during subsequent development phases, although not necessarily at the same magnitude or for the same duration. Other impacts related to initial site development may not reoccur at all during subsequent site expansions. For example, if it is assumed that the initial site development plan accounts for all future site expansions, a single main site access road can be selected and constructed as part of initial site development, and it can continue to serve as the site access road for subsequent phases of development. In such a scenario, only the expansions of on-site roads would be impacting factors in later development phases.

D.7 WIND ENERGY TECHNOLOGY RESEARCH AND DEVELOPMENT

A review of the current state of the commercial wind turbine market can provide a basis for predicting the types of turbines that are likely to be installed at future sites. However, it is also reasonable to predict that future site developers will avail themselves of technological advances and improved performance models. Therefore, a brief review of wind energy industry R&D activities is warranted. Although much of the R&D effort has been undertaken by the equipment manufacturers, the federal government also provides support. The discussions below are confined to R&D activities unique to the commercial wind energy industry. Note that R&D efforts to improve the design and performance of many of the major components of a wind turbine, such as transmissions and electrical generators, are also ongoing within the respective industry sectors. Likewise, R&D efforts in the general area of monitoring and control systems continue as well. Although these R&D efforts are not discussed here, it is assumed that wind farm developers and/or equipment manufacturers will incorporate technological advances from these other sectors into their wind farms and turbines at appropriate times.

D.7.1 Industry-Sponsored Research and Development

Leading equipment manufacturers are already engaged in R&D on many aspects of their products. Their primary objective is to maintain or improve their competitive positions in the markets in which they operate. R&D can also help them conform to quality standards (Section D.8).

Industry research focuses on improving the reliability of major components, improving overall efficiency, reducing manufacturing costs, and mitigating the adverse aspects of individual products. For example, manufacturers who hope to participate in the European wind energy market are exploring ways to mitigate the noise signals of their equipment. Because most wind farms in Europe are located close to inhabited areas, controlling noise is critical to maintaining market position. In its overview of worldwide wind energy industry trends, Shikha et al. (2003) found that continuous improvements were being made to applied technologies in the expanding wind energy industry. They found that energy output capacities of individual turbines increased 100-fold in the 15 years ending in 2003, while the overall weight of turbines was halved in the 5 years ending in 2003, and the noise emitted was halved over the 3-year period ending in 2003. Steady gains were attributed to a number of factors, including improved aerodynamics, improved structural dynamics, and improved micrometeorology, which resulted in precise turbine siting at the most ideal location. Additional improvements were attributed to the increase in rotor size and improved blade performance. Together with the benefits derived from reduced rotor weight, overall improvements in the drivetrain design and the reliability of individual components also resulted in a reduction in O&M costs. It is estimated that O&M costs constitute as much as 10 to 15% of the unit energy costs of a new wind farm; however, O&M costs increase to 20 to 30% near the end of the farm’s design life (McGowan and Connors 2000). However, O&M costs are also expected to rise slightly over the design life of the turbine. Steady improvements in drivetrain design and efficiency are expected to reduce O&M costs from a U.S. average of $0.01/kWh in 1997 to $0.005/kWh by 2005 (McGowan and Connors 2000).

Manufacturers are also adopting modular design strategies that allow the replacement of individual turbine drivetrain components, thereby reducing downtime and costs. Often such strategies are further enhanced by equipping towers with internal lifting devices that allow the replacement of individual components without the necessity of bringing heavy-duty lifting devices to the site to remove the rotor assembly and/or the entire nacelle.

FIGURE D-8 Lattice-Type Wind Turbine Tower in South Dakota (A Vestas Model V17 wind turbine mounted on a lattice-type tower in Gary, South Dakota. Photo credit: Energy Maintenance Service, Inc., Sept. 1, 2002. Source: Photo # 12449, NREL 2004b.)

Although the majority of industry R&D initiatives focus on improving the design and efficiency of rotors and turbine drivetrain components, some innovative tower designs and materials can also affect future wind farms. Early wind farms utilized lattice-type towers (Figure D-8). However, smooth-skinned, tapered steel towers now dominate the commercial utility-scale market. The size and weight of the steel towers required for larger turbines increase installation costs and create significant problems related to the transportation of both the tower segments and the cranes required for their erection. A number of innovative tower designs and erection methodologies have been developed to overcome these impediments. Towers that can be erected by using mobile, temporary elevators have been developed, obviating the need for independent cranes and thus greatly simplifying erection costs and reducing transportation logistics (e.g., see Valmont 2004). A government-sponsored study completed in May 2001 identified a number of unique tower erection strategies and evaluated each against its impact on the overall cost of energy produced (Global Energy Concepts, LLC 2001). Two technologies were evaluated in depth and compared with conventional crane technologies. The study concluded that one of the two alternative erection methods compared favorably to conventional cranes for 1.5-MW and larger turbines, but it was more expensive than conventional cranes for smaller turbines. The study further postulated that alternative erection methodologies might be favored over conventional cranes for sites with complex terrain or difficult access, but they could be at a disadvantage at sites with significant wind shear. Other developments include constructing towers of tubular carbon composites in an integrated pyramidal shape, resulting in stronger and substantially lighter towers (e.g., IsoTruss Structures, Inc. 2004). Again, such lighter towers can substantially reduce transportation logistics and reduce site development costs.

D.7.2 Government-Sponsored Research and Development

Government-sponsored research and government-industry partnerships also account for a major portion of ongoing R&D efforts. DOE/EERE is the principal funding agency for government-sponsored research. Government participation also includes the personnel and facilities of NREL in Boulder, Colorado, and Sandia National Laboratories in Albuquerque, New Mexico. Government-industry partnerships proceed under the auspices of DOE's Cooperative Research and Development Agreement (CRADA) program. Under CRADA programs, government and industry collaborate to identify and better understand the fundamental science and engineering issues critical to technology advancement. Government personnel also conduct tests on prototypes and develop software that aids designers. Industries then have access to the published reports on CRADA research and use their contents to shape their own additional technology R&D. The government-industry partnership in DOE's Wind Energy Program is known as the Wind Partnerships for Advanced Component Technologies (WindPACT).[23]

DOE's R&D objectives and strategies are outlined in *Wind and Hydropower Technologies Program; Wind Energy Program Multi Year Technical Plan for 2004–2010* (EERE 2003). The overall strategic objective is to protect the nation's energy security by fostering the development of technologies that utilize a diverse supply of affordable and environmentally sound energy. Specific research objectives are defined in terms of reducing the ultimate costs of electricity generated by wind energy. Individual research initiatives, or technology improvement opportunities (TIOs), are distributed throughout all segments of the wind energy industry. The research initiatives of greatest importance to the utility-scale sector of the industry include improving the viability of low-wind-speed technology and facilitating the application of technologies and technological advances by engaging in fundamental research, developing quality standards and certification programs, conducting field verification tests, and analyzing and addressing technological and market impediments.

Researchers have identified a number of TIOs, including the following:

- Advanced drivetrain designs that use rare-earth permanent magnets for excitation, reduced gear box stages, and low- and medium-speed generators;

- Advanced power electronics that allow variable-speed operation while improving overall power capture/conversion efficiencies;

- Advanced rotors that use adaptive blades; and

- Advanced tower designs and materials that either reduce erection costs and simplify transportation logistics or are fabricated completely on site.

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[23] Many of the WindPACT technical reports may be accessed electronically at the NREL and Sandia Web sites; see NREL (2004a) and Sandia National Laboratories (2004d).

Research critical to the advancement of utility-scale turbines, especially in lower wind power classes,[24] includes the development of (1) advanced rotors; (2) a more complete understanding of a site's atmospheric dynamics; (3) improved generator, drivetrain, and power management subsystems; and (4) better integrated operational controls.

Turbines harvesting wind at lower wind classes are expected to need larger rotor-swept areas and operate at higher hub elevations. Rotor development focuses on the development of blades that are stiffer and stronger but also more slender, lighter, and more flexible (i.e., more adaptive to the dynamic forces they will encounter during operation). These apparently mutually exclusive characteristics hold the key to the successful advancement of large turbines. Although blade technology has already advanced significantly, it is thought that new materials and fabrication methods, as well as new design philosophies and criteria, will be necessary to support further substantial technological advances. Prototype blades made of long-fiber carbon composites are being tested for durability, and manufacturing processes are being refined.[25] If successful, this research will lead to turbines with greater rotor-swept areas and power-capturing efficiencies. There are, nevertheless, technical and economic limits to blade length. Rotor weight increases by the cube of its swept area, while the rated power efficiency increases by the square of the swept area. Consequently, there are some diminishing ROIs in the development of extremely long blades. Furthermore, with regard to extremely long blades, gravitational forces and torsional forces on the hub and the rotor shaft will become controlling forces in turbine design. Finally, as noted earlier, the torque produced by the rotor shaft increases with the square of the rotor diameter, thus significantly increasing the demand on transmissions and generators to withstand such increased torque moments. Some anticipate that the point at which these adverse forces will preempt rotor size expansions will be reached at rotor diameters of 256 ft (200 m), although the introduction of lightweight composites, such as fiber-reinforced plastics, may extend the practical rotor diameter to even greater values (Milborrow 2002).

Other possible dividends from increased blade length include lower operating costs and less aerodynamic noise. However, another real-world consequence of the use of very long blades is significant transportation logistics. Research conducted by Sandia and its contractor has explored the possibility of manufacturing turbine blades at the wind farm location (TPI Composites, Inc. 2003). The research concluded that on-site manufacturing was fraught with significant quality control issues and not feasible at this time. However, fabrication of the blades at nearby manufacturing sites (i.e., sites specifically constructed to support blade fabrication for use at a particular wind farm) was still considered feasible, since such a strategy would significantly reduce transportation distances and, if located judiciously, would significantly simplify transportation logistics. Other scaling and related logistics issues associated with transportation and erection also accompany any consideration for significantly enlarging wind turbines. WindPACT research initiatives will identify these obstacles and evaluate ways to overcome them.

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24 Within the context of the WindPACT program, DOE defines lower wind classes as Class 4 and below ($\leq$ 5.8 m/s [13 mpg] at a height of 10 m [33 ft]).

25 See Sandia National Laboratories (2004c) for access to published reports of blade research being conducted by Sandia.

Up to this point of development, rotor aerodynamic design criteria have borrowed heavily from aerodynamic codes[26] developed in the aircraft industry. However, these codes do not reflect the aerodynamic conditions in which a wind turbine operates to a sufficiently high level of precision. New code development efforts are necessary to better understand the aerodynamic forces affecting both the performance and reliability of turbine rotor blades. Newly developed and validated codes will expedite the development of design criteria for longer, lighter, and more slender adaptive blades that can withstand dynamic forces and also impart minimum loads on the turbine drivetrain.

A more complete understanding of aerodynamic forces impinging on turbine blades will also allow designers to mitigate aerodynamic noise impacts. Another facet of research is the development of a semiempirical noise prediction code to be used by rotor and blade designers to ensure that new rotor systems have acceptable noise signatures.

As turbines become larger and operate at higher rotor hub heights, additional information about the atmospheric dynamics at these higher altitudes will be necessary to support design and micrositing decisions. It has already been established that the tallest turbines may be influenced by jet stream turbulence, especially by what are known as nocturnal jets (DOE 2002). Such turbulence is routinely present in low wind power classes, especially in the Great Plains regions. Successful advancement of wind turbines in such areas, especially in lower wind power classes, requires a much more complete understanding of jet stream turbulence and candidate site aerodynamics.

Other research initiatives on improving the power generation and management performance of the electric generator will have a direct impact on the interconnectivity of turbine power into the electrical grid but are expected to have little impact on environmental factors. Nevertheless, such improvements in overall turbine performance efficiency can be expected to reduce the mechanical noise emanating from the turbine blades and drivetrain components, as well as to reduce the number of breakdowns and maintenance shutdowns.

Finally, research on the advancement of integrated systems and controls attempts to enhance the precision with which turbines are monitored and controlled, promising better control of yaw and blade pitch to maximize performance. Such research pays its greatest dividends by improving the interconnection opportunities for wind farms. However, maintaining the turbine's operation at the highest performance level is also expected to improve overall reliability and reduce unwanted impacts that are manifestations of inefficiency (such as aerodynamic noise).

D.8 TESTING AND VERIFICATION PROGRAMS

DOE sponsorship of wind energy R&D also extends to field testing and verification programs. NREL and Sandia personnel, in collaboration with representatives of the Electric Power Research Institute (EPRI), other wind energy industry participants, and individual wind

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[26] Aerodynamic codes are an industry convention that describe the geometries of differently shaped airfoils.

farm operators, conduct evaluations of wind project development experiences and conduct field verifications of critical aspects of operational wind farms. The verification efforts help to identify issues related to site development, as well as design and operation, and provide the empirical basis for additional research on how to address or eliminate those issues. Published reports provide the opportunity for transferring lessons learned to other interested parties. Additional details about these verification programs and the published reports are available on the NREL and Sandia Web sites (NREL 2004c; Sandia National Laboratories 2004d).

D.9 STANDARDS AND CERTIFICATIONS

One clear indication of the maturation of the wind energy industry is the development and application of quality standards. International standards are already largely in place. Analogous U.S. standards are under development. Standards related to wind energy turbines promulgated by the International Electrotechnical Commission (IEC) are listed in Table D-3. AWEA is the U.S. industry representative to this international standard-setting body. Many turbine manufacturers voluntarily conform to these standards to maintain their competitive position in the marketplace and to better guarantee the connectivity of wind-generated electric power to transmission grids. Conformance with international standards is a requirement for some wind farms in Europe.

U.S. wind energy industry consensus standards have been under development since 1974. AWEA is the lead organization in domestic standard development. The development process involves the participation of various industry organizations, including the American Society of Mechanical Engineers (ASME), American Society for Testing and Materials (ASTM), American National Standards Institute (ANSI), National Fire Protection Association (NFPA), American Gear Manufacturers Association (AGMA), and Institute of Electrical and Electronics Engineers (IEEE). Personnel from NREL and Sandia also participate in standards development. Domestic standards are expected to parallel and be compatible with IEC standards in order to ensure that American manufacturers maintain their access to European markets.

TABLE D-3 International Wind Turbine Standards

Standard No.	Title
IEC 61400-1	Wind Turbine Safety and Design
IEC 61400-1 Ed 2	Wind Turbine Safety and Design Revision
IEC 61400-2	Small Wind Turbine Safety
IEC 61400-12	Power Performance
IEC 61400-11	Noise Measurement
IEC 61400-13	Mechanical Load Measurements
IEC 61400-22	Wind Turbine Certification
IEC 61400-23	Blade Structural Testing
IEC 61400-21	Power Quality

In addition to quality standards for the design and construction of major turbine components, international standards are in place for the certification of turbines and ancillary systems by independent third-party auditors. Leading equipment manufacturers routinely submit their products and systems to such certifications so that they have evidence that their quality and performance goals have been met. Personnel from NREL are working in collaboration with Underwriters Laboratories, Inc. (UL) to develop analogous domestic certification standards and processes. Until those are in place, U.S. manufacturers are submitting their products and systems to certification against the international standards.

As the wind energy industry continues to mature, it is reasonable to expect that future wind farm developers and their equipment vendors will conform to applicable quality standards and submit their products and systems to third-party certifications. Conformance to quality standards and certifications provides a better guarantee of safe design and construction and generally increases both the reliability and performance of major wind turbine components. Given the levels of participation that already exist, it is reasonable to conclude that proposals for future wind farms and the equipment represented in those proposals will involve a commitment to conform to all applicable quality standards and to submit to all relevant third-party certifications.

D.10 IMPACTING FACTORS RELATED TO REASONABLY FORESEEABLE SITE DEVELOPMENT ACTIVITIES

The data in Tables D-1 and D-2 provide a reasonable representation of commercially available turbines and allow a reasonable prediction of the types of turbines that will be used in future sites. They are less adequate, however, in supporting further conclusions regarding site development. Nevertheless, past project experiences, together with the current state of wind energy technology and the advances expected from ongoing R&D activities, lend support to the following likely future site development scenarios.

- Business plans for future sites will involve developing candidate sites to their fullest wind energy potential as a means of quickly amortizing initial site development costs.

- The majority of large or extensive wind farms will probably be developed in phases, with the schedule of development being based largely on available development capital, as well as on myriad electric power market conditions. It is less likely that development will be speculative (i.e., built in advance of electric power sale agreements with transmission line operators) (Osborne 2004).[27]

[27] Nevertheless, speculative construction (sometimes referred to as a merchant plant) in advance of electric market agreements has occurred in the past.

- Sites developed in phases will not necessarily consist of the same turbine model throughout the site, and portions of the site may be owned and operated by more than one business entity.[28]

- Future sites are likely to take advantage of state-of-the-art wind turbine technology, leading to larger and taller but fewer turbines at a given site.

- It is possible that existing sites will expand into less-ideal areas that cannot, at this time, be economically farmed for wind energy by state-of-the-art turbine technologies.

- Sites may be repowered by replacing original turbines with technologically advanced models.[29]

- Modular construction of turbines will allow for their customization to address site-specific characteristics. Modular construction, together with sophisticated SCADA systems, now make it technically feasible for future farms to consist of various models of turbines operating at different elevations on the basis of site-specific wind regime characteristics.

- Site development strategies will take fullest advantage of economies of scale. Activities will be grouped by type (e.g., foundations for all planned turbines will be installed over the same period), thereby simplifying logistics.

- Although the majority of wind turbine construction will still occur at the manufacturer's facility, larger turbines, longer and more slender adaptive blades, and taller towers will impose unique problems related to the transportation of those components and may result in additional subassembly work being conducted on site during site construction.

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[28] The Foote Creek Rim site, located near Arlington, Wyoming, is an example of one possible wind farm development scenario. This project, which was initiated on BLM-administered land and has subsequently been expanded to adjacent non-BLM-administered lands, represents one of the most ideal wind regimes in existence, with average wind speeds in excess of 23 miles per hour or mph (37 km/h). Four separate wind farms have been developed by two separate developers, delivering electric power to three separate utilities. The first farm, completed in April 1999, involved the erection of sixty-nine 600-kW turbines built by Mitsubishi (Model 600) and distributed over a land area of 2,156 acres (872 ha). The footprints of the turbines, control buildings, and other structures make up less than 1% of the land area in the parcel. A second farm completed in June 1999 added an additional three Mitsubishi turbines and 1.8 MW of generating capacity. A third farm, also completed in June 1999, added 33 NEG Micon turbines, representing a capacity of 24.8 MW. A final phase of development, completed in October 2000, involved an additional 16.8 MW of capacity from an additional 28 Mitsubishi Model 600 turbines. The remainder of the parcel continues to be used for ranching, as was the case before the wind farm was constructed.

[29] Repowering is already occurring. Many of the wind farms constructed in California in the early 1980s have been repowered. See the attachment to this appendix.

- The use of innovative, self-erecting towers constructed of lightweight composite materials may dramatically minimize problems related to transportation logistics and site development times and costs. Reduced transportation requirements may expand the array of candidate sites to some that were previously excluded because of access difficulties.

- Equipment manufacturers can be expected to conform to international quality standards for manufacturing and operation (and to analogous U.S. standards as they are promulgated) as a way of maintaining market competitiveness. This conformance to standards will, in turn, lead to higher quality and greater reliability of major turbine components. Maintenance intervals are expected to increase as maintenance procedures become more regimented and are based on empirically derived isochronal factors rather than elapsed time.

- Sophisticated SCADA systems will allow wind turbines at a given site to operate independently of one another, enabling the economical development of sites with different wind regimes throughout.

- It will become increasingly feasible for wind farms to include ancillary technologies, such as battery charging and elevated water storage, which will allow for the delayed delivery of wind-generated electricity to the transmission grid.

- The expanded capabilities and operating ranges of turbines will allow economical harvesting of wind energy at sites with Class 3 wind regimes.

D.11 REFERENCES FOR APPENDIX D

AWEA (American Wind Energy Association), 2003a, *Record Growth for Global Wind Power in 2002*, news release, March 3. Available at http://www.awea.org/news/news030303.gbl.html. Accessed March 2004.

AWEA, 2003b, *Projects Completed in 2003 (Preliminary)*. Available at http://www.awea.org/projects/summaries/2003projects.pdf. Accessed March 2004.

AWEA, 2004a, *Wind Energy Projects throughout the United States of America*, Jan. 22. Available at http://www.awea.org/projects/. Accessed March 2004.

AWEA, 2004b, *Online Membership Directory*. Available at http://mcweb01.memberclicks.com/mc/prelogin.do?hidOrgID=awea.

AWEA, 2004c, *American Wind Energy Association*, home page. Available at http://www.awea.org.

AWEA, 2004d, *Boom: 2003 Close to Best Year Ever for New Wind Installations; Bust: Expiration for Key Incentive Lowers Hopes for 2004*, new release, Jan. 22. Available at http://www.awea.org/news040122r03. Accessed July 9, 2004.

Burton, T., et al., 2001, *Wind Energy Handbook*, John Wiley & Sons, Ltd., Chichester, United Kingdom.

Cotrell, J., 2002, "A Preliminary Evaluation of a Multiple-Generator Drivetrain Configuration for Wind Turbines," preprint, presented at the 21st American Society of Mechanical Engineers Wind Energy Symposium, Reno, Nev., Jan. 14–17. Available at http://www.nrel.gov/docs/fy02osti/31178.pdf.

DOE (U.S. Department of Energy), 2002, *Wind Power Today, 2002 Wind Energy Research Highlights*. Available at http://www.nrel.gov/docs/fy03osti/33149.pdf. Accessed March 2004.

DOE/TVA/EPRI (DOE, Tennessee Valley Authority, and Electric Power Research Institute), 2003, *Tennessee Valley Authority Buffalo Mountain Wind Power Project, First- and Second-Year Operating Experience: 2001–2003*, DOE-EPRI Wind Turbine Verification Program, Dec.

DWIA (Danish Wind Industry Association), 2004, *Wind Turbine Generators*. Available at http://www.windpower.org./en/tour/wtrb/electric.htm.

EERE (Office of Energy Efficiency and Renewable Energy), 2003, *Wind and Hydropower Technologies Program; Wind Energy Program Multi Year Technical Plan for 2004–2010*, U.S. Department of Energy, Nov. Available at http://www.nrel.gov/wind_meetings/2003_imp_meeting/pdfs/mytp_nov_2003.pdf.

EERE, 2004a, *Wind & Hydropower Technologies Program*, U.S. Department of Energy. Available at http://www.eere.energy.gov/windandhydro/wind_history.html?print. Accessed March 2004.

EERE, 2004b, *Wind Energy Resource Potential*, U.S. Department of Energy. Available at http://www.eere.energy.gov/windandhydro/wind_potential. html.

EERE, 2004c, *How Wind Turbines Work*, U.S. Department of Energy. Available at http://www.eere.energy.gov/windandhydro/wind_how.html. Accessed March 2004.

EPRI (Electric Power Research Institute), 2001, *Big Spring Wind Power Project, Second-Year Operating Experience: 2000–2001*, Final Report, DOE-EPRI Wind Turbine Verification Program, Dec.

GE (General Electric), 2004, *3.6 MW Wind Turbine Technical Specifications*. Available at http://www.gepower.com/prod_serv/products/wind_turbines/en/36mw/36mw_specs.htm. Accessed March 2004.

Gipe, P., 1995, *Wind Energy Comes of Age*, John Wiley & Sons, Inc., New York, N.Y.

Global Energy Concepts, LLC, 2001, *WindPACT Turbine Design Scaling Studies Technical Area 3 — Self-Erecting Tower and Nacelle Feasibility March 2000–March 2001*, NREL/SR-500-29493, prepared by Global Energy Concepts, LLC, Kirkland, Wash., for National Renewable Energy Laboratory, Golden, Colo., May.

Griffin, D., 2002, *Blade System Design Studies Volume I: Composite Technologies for Large Wind Turbine Blades*, SAND2002-1879, prepared by Global Energy Concepts, LLC, Kirkland, Wash., for Sandia National Laboratories, July.

Hau, E., 2000, *Windturbines: Fundamentals, Technologies, Application, Economics*, Springer-Verlag, Berlin, Germany.

IsoTruss Structures, Inc., 2004, *IsoTruss Structures, Inc.*, home page. Available at http://www.isotruss.com.

Kaygusuz, K., 2004, "Wind Energy: Progress and Potential," *Energy Sources* 26:95–105.

Manwell, J.F., et al., 2002, *Wind Energy Explained: Theory, Design, and Application*, John Wiley & Sons Ltd., Chichester, United Kingdom.

McGowan, J.G., and S. Connors, 2000, "Windpower: A Turn of the Century Review," *Annual Review of Energy and the Environment* 25:147–197.

Milborrow, D., 2002, "Wind Energy Technology — The State of the Art," in *Proceedings of the Institution of Mechanical Engineers*, *Part A, Journal of Power and Energy* 216:23–30.

Momentum Technologies, LLC, 2004, *The Source for Renewable Energy*, source guide. Available at http://energy.sourceguides.com.index.shtml.

NREL (National Renewable Energy Laboratory), 2004a. Available at http://nrel.gov/. Accessed March 2004.

NREL, 2004b, NREL Photo Archive, Photo #04688, #01671, and #12449. Available at http://www.nrel.gov/data/pix/.

NREL, 2004c, *National Wind Technology Center.* Available at http://www.nrel.gov/wind/.

NWCC (National Wind Coordinating Committee), 2004, *National Wind Coordinating Council*, home page. Available at http://www.nationalwind.org/.

Osborn, D., 2004, personal communication from Osborn (Distributed Generation Systems, Inc., Lakewood, Colo.) to R. Kolpa (Argonne National Laboratory, Argonne, Ill.), March 15.

Robichaud, R., 2004, personal communication from Robichaud (National Renewable Energy Laboratory, Golden, Colo.) to R. Kolpa (Argonne National Laboratory, Argonne, Ill.), March 11.

Sandia National Laboratories, 2004a, *What Is It?* Available at http://www.sandia.gov/Renewable_Energy/wind_energy/abstracts/brochure.pdf.

Sandia National Laboratories, 2004b, *Sandia National Laboratories*, home page. Available at http://www.sandia.gov/.

Sandia National Laboratories, 2004c, *Online Abstracts and Reports*. Available at http://www.sandia.gov/Renewable_Energy/wind_energy/topical.htm.

Sandia National Laboratories, 2004d, *Wind Energy Technology*. Available at http://www.sandia.gov/wind.

Shikha [no first initial given], et al., 2003, "Aspects of Technological Development of Wind Turbines," *Journal of Energy Engineering* 129(3):81–95, Dec.

Spera, D. (editor), 1994, *Wind Turbine Technology, Fundamental Concepts of Wind Turbine Engineering*, ASME Press, New York, N.Y.

Steinhower, S., 2004, personal communication from Steinhower (SeaWest, Inc., Oakland, Calif.) to R. Kolpa (Argonne National Laboratory, Argonne, Ill.), March 19.

TPI Composites, Inc., 2002, *Parametric Study for Large Wind Turbine Blades, WindPACT Blade System Design Studies*, SAND2002-2519, prepared by TPI Composites, Warren, R.I., for Sandia National Laboratories, Aug.

TPI Composites, Inc., 2003, *Blade Manufacturing Improvements: Remote Blade Manufacturing Demonstration*, SAND2003-0719, prepared by TPI Composites, Warren, R.I., for Sandia National Laboratories, May. Available at http://www.sandia.gov/Renewable_Energy/wind_energy/other/030719.pdf.

Valmont, 2004, *Valmont*, Web site. Available at http://www.valmont.com.

Attachment to Appendix D:

Commercial Wind Energy Projects
(as of January 2004)

Data on commercial wind energy projects in the western states that are within the scope of this draft programmatic environmental impact statement (PEIS) are displayed in the tables below. The American Wind Energy Association (AWEA) compiles and maintains all of the data displayed below. All data presented are current as of January 14, 2004. All data are accessible electronically from the AWEA Web site at http://www.awea.org/projects/index.html. Data presented in the tables below are updated quarterly by the AWEA.

The Bureau of Land Management (BLM) cannot guarantee the completeness or accuracy of these listings. Submission by wind farm developers or operators of project information to AWEA for inclusion in these listings is voluntary.

California

Major CA Wind Energy Resource Areas

Existing Project or Area	MW Installed*	Annual Energy Output (Yr of Est)	Power Purchaser/ User	Turbines
1. Altamont Pass	548.32	637 M kWh (1998)	Pacific Gas & Electric	Variety
2. Pacheco Pass	16.0	22.3 M kWh (1998)	Pacific Gas & Electric	Variety
3. San Gorgonio Pass	614.94	805 M kWh (1998)	So. California Edison	Variety
4. Solano County	176.16	N.A.	S.M.U.D	Kenetech & Vestas
	60.0	97.1 M kWh (1998)	Pacific Gas & Electric	U.S. Wind- power 100
5. Tehachapi	605.72	1.2 B kWh (1998)	So. California Edison	Variety
Others	0.675	N.A.	U.S. Navy	NEG-Micon

Wind Energy Projects in California

Project Name	Owner	Year	MW	Power Purchaser	Turbines / Units
Altamont Pass					
1985 Zond Windsystem Partners Series 85C	GE Wind	1985	18.0	PG&E	Vestas V-17 (200)
Venture Wind (old Los Vaqueros)	SeaWest	mid-1980's	2.89	PG&E	Polenko/ Wind-matic (38)
Altech Energy, Ltd	SeaWest	1981-1995	5.76	PG&E	Enertech (144)
C.W.E.S.	SeaWest	1981-1995	1.32	PG&E	Enertech (24)
SeaWest Energy Group (a)	SeaWest	1981-1995	0.065	PG&E	Micon (1)

		1995			(170)
Zond-PanAero Windsystems	GE Wind	1981-1995	29.9	So Cal Ed	Vestas V-15 (460)
Whitewater Hill (San Gorgonio Farms)	San Gorgonio Farms	1984 - 1994	31.0	So Cal Ed	DWT 400 (35), Bonus 120 (56), Vestas 500 (5), Bonus 65 (85)
Dutch Pacific	Dutch Pacific, LLC	1994	10.0	So Cal Ed	NedWind (20)
Karen Avenue (San Gorgonio Farms)	San Gorgonio Farms	1995	3.0	So Cal Ed	Vestas (6)
East Winds (formerly Altech III)	Nichimen America	1997	4.2	So Cal Ed	NEG-Micon (7)
Invest I-IX Project Web Site	K/S Whitewater	1999	10.0	So Cal Ed	Nordex (10)
Pacific West I	PacifiCorp	1999	2.1	SCE - Green Mt. Energy	NEG Micon - (3)
Cabazon (Re-power)	GE Wind	1999	39.75	So Cal Ed	Zond Z-750 (53)
Westwind (Re-power)	Cinergy & Caithness	May 1999	46.5	So Cal Ed	NEG Micon Project Info
GE Wind / Earth Smart/ Green Power	GE Wind	June 1999	16.5	Electricity Marketers	Zond Z-50 (22)
Westwind-Pacificorp (Re-Power)	Pacificorp/ GMER	May 1999	1.5	SCE - Green Mt. Energy	NEG-Micon (2)
Mountain View Power Partners II	PGE-NEG	Oct 2001	22.20	PG&E	Mitsubishi MWT600 (37)
Mountain View Power Partners I	PGE-NEG	Oct 2001	44.40	PG&E	Mitsubishi MWT600 (74)
Whitewater Hill	Shell Wind Energy	Dec 2002	61.50	Dept. of Water Resources	GE Wind Energy 1500 (41)
Cabazon	Shell Wind Energy	Dec 2002	40.92	Dept of Water Resources	Vestas V-47 (62)
Karen Avenue II	San Gorgonio Farms	June 2003	4.5	So Cal Ed	GE Wind Energy 1500 (3)
Mountain View III	San Diego Gas & Electric	4th Q 2003	22.44	San Diego Gas & Electric	Vestas 650 (34)

Solano County

Solano County/ Kenetech	NA	1985	60.0	PG&E	U.S. Wind-power (600)
Sacramento Municipal Utility District (SMUD)	SMUD	1994	3.6	Sac Mun Utility District	Kenetech (12)
SMUD	SMUD	1999	0.66	Sac Mun Utility District	Vestas (1)
SMUD	SMUD	2003	9.9	Sac Mun Utility District	Vestas 660kW (15)
High Winds	SMUD	2003	162	Sac Mun Utility District	Vestas 1.8 MW (90)

Tehachapi

Zond Systems	GE Wind	1986	0.2	So Cal Ed.	Vestas (1)
Victory Gardens, Phase IV	GE Wind	1990	22.05	So Cal Ed.	Vestas V-27 (98)
Sky River	GE Wind	1993	76.95	So Cal Ed.	Vestas V-27 (342)
Oak Creek Energy Systems	Oak Creek Energy Systems	2002	0.8	So Cal Ed.	NEG Micon (1)
Oak Creek Energy Systems	Oak Creek Energy Systems	1981-1995	3.45	So Cal Ed.	Micon (36)
AB Energy	NA	1981-1995	7.0	So Cal Ed.	Vestas V27 (31)
Calwind Resources	NA	1981-1995	14.1	So Cal Ed.	Bonus (217)
Calwind Resources	NA	1981-1995	8.7	So Cal Ed.	Nordtank (134)
Coram Energy Group	NA	1981-1995	1.9	So Cal Ed.	Aeroman (47)
Coram Energy Group	NA	1981-1995	4.0	So Cal Ed.	Aeroman (100)
Coram Energy Group	NA	1981-1995	6.8	So Cal Ed.	Aeroman / Tacke (110 / 4)
Mogul Energy	NA	1981-1995	4.0	So Cal Ed.	Mitsubishi (8)
Mohave 3, 4, 5	Tomen/ FPL	1981-1995	75.0	So Cal Ed.	Mitsubishi (300)
Mohave 16, 17, 18	Tomen/ FPL	1981-1995	85.0	So Cal Ed.	Mitsubishi (340)
Windridge	NA	1981-1995	2.34	So Cal Ed.	Windmatic (36)
Victory Gardens I & IV	NA	1981-1995	1.0	So Cal Ed.	Vestas (2)
Cannon	NA	1981-1995	13.46	So Cal Ed.	Micon, Vestas (8, 28)
Cannon (Various)	NA	1981-1995	4.54	So Cal Ed.	Micon, Vestas (42)
Ridgetop Energy	NA	1981-1995	32.6	So Cal Ed.	Nordtank, Micon (329)
Zond Systems	GE Wind	1982-1987	23.99	So Cal Ed.	Vestas (369)
Zond Systems	GE Wind	1982-1987	64.0	So Cal Ed.	Vestas (711)
Windland (Boxcar II)	Windland, Inc.	Mid-1980's	14.3	So Cal Ed.	Various (141)
Oak Creek Energy Systems	Oak Creek Energy	2002	1.35	So, Cal Ed	NEG Micon (1)

Oak Creek Phase 1 (ON Energy)	Nichimen & Oak Creek Energy	Sept 1997	4.2	So Cal Ed.	NEG Micon (7)
Oak Creek Phase 2A (Re-power)	Oak Creek Energy	June 1999	1.6	So Cal Ed	NEG Micon (2)
Pacific Crest	FPL Energy	Jun 1999	45.54	So Cal Ed	Vestas (69)
Oak Creek Wind Power Phase 2 (Repower)	Caithness	June 1999	23.1	So Cal Ed	NEG Micon-700 Project Info (33)
Cameron Ridge (Re-power)	FPL & Caithness	Mar 1999	56.0	So Cal Ed	NEG Micon (80) Project Info
Victory Gardens (Repower)	Enron Wind Corp.	Jun 1999	6.75	So Cal Ed	Zond Z-50 (9)

Others

U.S. Navy/ NEG Micon San Clemente Island	U.S. Navy	1998	0.675	U.S. Navy	NEG Micon (3)
Los Angeles Co.	Wind Turbine Company	2001	0.50	Southern Cal Ed.	WTC (1)

Planned Projects in California

Utility/Developer (Project)	Location	Status	MW Cap	Online date/ Turbine
PG&E/SeaWest (Venture Pacific)	Altamont Pass	Pending	25.6	2004 Mitsubishi
FPL/Green Ridge Power	Altamont Pass	Proposed Re-power	110.0	2004 NEG Micon - 700
Indigenous Global Development Corp.	Contra Costa	Proposed	22.50	NA / TBD
Pacific Ind Elec (San Clemente Is.)	San Clemente Is.	Under Dev	0.75	2004 NEG Micon
Mark Technologies (Alta Mesa IV)	San Gorgonio	Under Dev.	40.3	2004 Vestas - 660 kW
SMUD (Solano Wind Project - Phase I)	Solano	Under Development	9.24	2004 Vestas V-47
GE Wind (Victory Garden)	Tehachapi	Proposed	30.0	2004 GE Wind
Oak Creek Energy Sys (Jawbone)	Tehachapi	Proposed	52.5	2004

+ Uncertain completion dates

Colorado

Wind Energy Development

Project or Area	Owner	Date Online	MW	Power Purchaser/User	Turbines / Units
1. Ponnequin (EIU) (Phase I)	K/S Ponnequin WindSource & Energy Resources	Jan 1999	5.1	PSCo	NEG Micon (7)
1. Ponnequin (PSCo) Project Info	PSCo	Feb-June 1999	16.5	PSCo	NEG Micon (22)
1. Ponnequin (Phase III)	New Century (Xcel)	2001	9.9	New Century (Xcel)	Vestas (15)
Peetz Table Wind Farm	New Century (Xcel)	Sept 2001	29.7	New Century (Xcel)	NEG Micon (33)
Colorado Green, Lamar (Prowers County)	Xcel Energy / GE Wind Wind Corp.	Dec 2003	162.0	Xcel	GE Wind 1500 (108)

New Wind Projects in Colorado

Utility/Developer (Project)	Location	Status	MW Capacity	On Line By/ Turbines

None

Idaho

Wind Energy Development

Existing Project or Area	Owner	Date Online	MW	Power Purchaser/ User	Turbines/ Units
Boise	Bob Lewandowski	2003	0.216	NA	108 (2)

Planned Wind Projects in Idaho

Utility/Developer (Project)	Location	Status	MW Capacity	On Line By / Turbines

None

Montana

Wind Energy Development

Existing Project or Area	Owner	Date Online	MW	Power Purchaser/ User	Turbine
Blackfeet Reservation	Blackfeet Nation	1996	0.1	Glacier Electric Cooperative	Vestas V-17 (1)

New Wind Projects in Montana

Utility/Developer (Project)	Location	Status	MW Capacity	On Line / Turbine
Assiniboine & Sioux Tribes / Montana-Dakota Utilities (Fort Peck Reservation Wind Project	Fort Peck Res/ Poplar MT	Under Dev.	0.66	2004/ Vestas V-47 660kW

Nevada

Wind Energy Development

Existing Project or Area	MW Installed*	Annual Energy Output (Yr of Est)	Power Purchaser/ User
None			

New Wind Projects in Nevada

Utility/Developer (Project)	Location	Status	MW Capacity	On Line By/ Turbine
Global Renewable Energy Partners & BP Capital (Power Star) (Table Mountain)	Near Primm in Sandy Valley	Proposed	105.0	2004 / NEG Micon
Cielo Wind Power (Desert Queen Wind Ranch)	Clark County	Proposed	60.0	2005
Global Renewable Energy Partners (Ely Wind LLC)	White Pine County	Proposed	50.0	2005 / NEG Micon

New Mexico

Wind Energy Development

Existing Project or Area	Owner	Date Online	MW	Power Purchaser/ User	Wind Turbines
1. Curry County (Llano Estacado Wind Ranch at Texaco)		June 1999	0.66	Excel	Vestas V-48 (1)
SW Public Service (Clovis)	Texas Wind Power	June 1999	0.66	Southwestern Public Service	Vestas V-47
New Mexico Wind Energy Center	**FPL Energy**	2003	**204**	Public Service of New Mexico	GE Wind 1500 (136)
Llano Estacado Wind Ranch	**Cielo Wind Power**	4th Q 2004	**1.32**	PS of New Mexico	Vestas 660 kW (2)

New Wind Projects in New Mexico

Utility/Developer (Project)	Location	Status	MW Capacity	On Line By

None

Oregon

Wind Energy Development

Existing Project or Area	Owner	Date Online	MW	Power Purchaser/ User	Turbines/ Units
1. Vansycle Ridge (Helix, OR)	FPL Energy	Oct 1998	25.1	Portland General Electric	Vestas V-47 (38)
Condon Wind Project Phase I (Gilliam County)	TBA	Dec 2001	24.6	BPA	Mitsubishi MWT600 (41)
Klondike (Wasco)	Northwest Wind Power	Dec 2001	24.0	Northwest Wind Power	Enron 1.5MW (16)
Stateline Wind Project, (Umatilla)	FPL Energy; Vansycle	Dec 2001	83.16	PacifiCorp	Vestas V-47 (127)
Condon Wind Project Phase II (Gilliam County)	TBA	Dec 2002	25.2	Bonneville Power Administration	Mitsubishi MWT600 (42)
Stateline (Orphans)	FPL Energy Vansycle LLC	2002	37	NA	Vestas V47 (55)
Combine Hills	PacificCorp/ Eurus	Dec 2003	41.0	PacificCorp	Mitsubishi 1000 (41)

New Wind Projects

Utility/Developer (Project)	Location	Status	MW Capacity	On Line By / Turbines

None

Utah

Wind Energy Development

Existing Project or Area	Owner	Date Online	MW	Power Purchaser/ User	Wind Turbine/ Units
Camp Williams, Riverton	U.S. Gov't	May 2000	0.225		NEG Micon / (1)

New Wind Projects in Utah

Utility/Developer (Project)	Location	Status	MW Capacity	On Line By / Turbine

None

Washington State

Wind Energy Development

Existing Project or Area	Owner	Date Online	MW	Power Purchaser/ User	Turbines/ (Units)
Stateline Wind Project, Phase I (Walla Walla)	FPL Energy, Vansycle	Dec 2001	180.2	PacifiCorp	Vestas V-47 (273)
Nine Canyon Wind Farm	Energy Northwest	Sep 2002	48.0	Public Power Members of Energy Northwest	Bonus 1300 (37)
Walla Walla County	Stateline Wind	2002	39.6	NA	NA
Nine Canyon Phase II	Energy Northwest	4th Q 2003	15.6	Energy Northwest	Bonus 1300 (12)

New Wind Projects in Washington State

Utility/Developer (Project)	Location	Status	MW Capacity	On Line By
BPA / Pacific Winds (Maiden Wind Farm)	Benton & Yakima Co. near Presser	Proposed	150.0	2004
BPA / Pacific Winds (Horse Heaven Hills)	Benton Co.	Proposed	150.0	2004
Zilkha Renewable Energy (TBD)	Near Ellensburg / Kittitas County	Proposed	100.0	2004
BPA / SeaWest Wind Power (Roosevelt)	Klickitat County	Speculative	150.0	2004
BPA / SeaWest Wind Power (Six Prong)	Klickitat County	Speculative	150.0	2004
BPA / SeaWest Wind Power (Waitsburg)	Walla Walla / Columbia	Speculative	100.0	2004
BPA / Columbia Windpower (Columbia Wind Ranch)	Klickitat Co.	Speculative	80.0	2004

Wyoming

Wind Energy Development

Existing Project or Area	Owner	Date Online	MW	Power Purchaser/ User	Turbines/ Units
Medicine Bow	PRPA±	1996	0.065	PRPA	Nordtank (1)
1. Medicine Bow, WY	PRPA	1998	1.2	PRPA	Vestas (2)
1. Foote Creek Rim - I (Carbon Co.)	Pacificorp, Eugene Water & Elec.	April 1999	41.4	Pacificorp, EWEB	Mitsubishi (69)
1. Foote Creek Rim - II (Carbon Co.)	Cinergy Global (Part Interest)	June 1999	1.8	BPA	Mitsubishi (3)
1. Foote Creek Rim - III	Cinergy Global	June	24.75	Public Service	NEG Micon

(Carbon Co.)	Power	1999		Co of Colorado	(33) Project Info
1. Foot Creek Rim - IV (Carbon Co.)	Cinergy Global Power	Oct 2000	16.8	BPA	Mitsubishi 600 (28)
1. Medicine Bow	PRPA	Oct 1999	3.3	PRPA	Vestas V-47 (5)
1. Medicine Bow	PRPA	July 2000	1.32	PRPA	Vestas V-47 (2)
Arlington, Carbon Co. (Rock River I)	Shell Renewables	Oct 2001	50.0	PacifiCorp	Mitsubishi MWT (50)
Evanston	FPL Energy/Orion Energy	4th Q 2003	144.0	PPM Energy	Vestas 1800 (80)

+ Platte River Power Authority

New Wind Projects in Wyoming

Utility/Developer (Project)	Location	Status	MW Capacity	On Line By / Turbines
None				

Notes:
No commercial wind energy projects are operational or planned for Arizona.
Only those wind energy projects that interconnect to the electric transmission system are listed.
Unless otherwise specified, all data are current as of January 14, 2004.