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Wind Energy Status and Future Wind Engineering Challenges

Preprint

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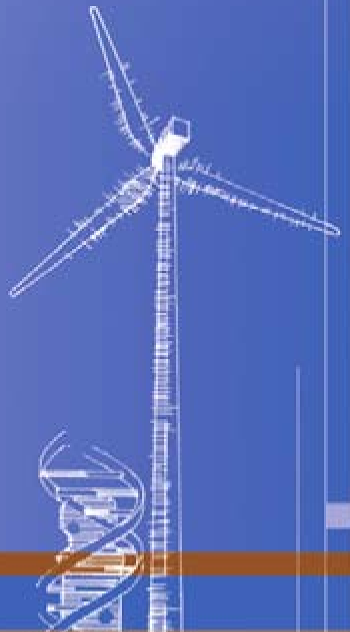

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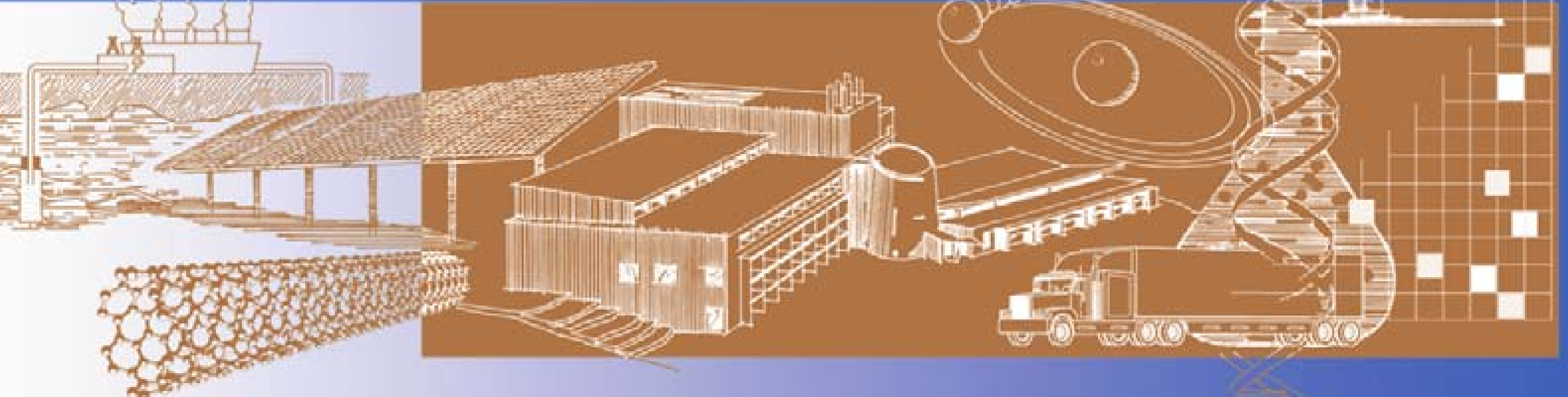

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Wind Energy Status and Future Wind Engineering Challenges[1]

Robert Thresher[2], Scott Schreck[3], Michael Robinson[4], and Paul Veers [5]

Introduction

Wind energy is one of the fastest growing electrical energy sources in the United States. The United States installed more than 5,300 megawatts (MW) of new wind energy capacity in 2007, and experts are forecasting for as much, or more, to be installed in 2008. The cumulative installed capacity in the United States as of December 31, 2007, was 16,904 MW. The state distribution of wind capacity is illustrated in Figure 1.

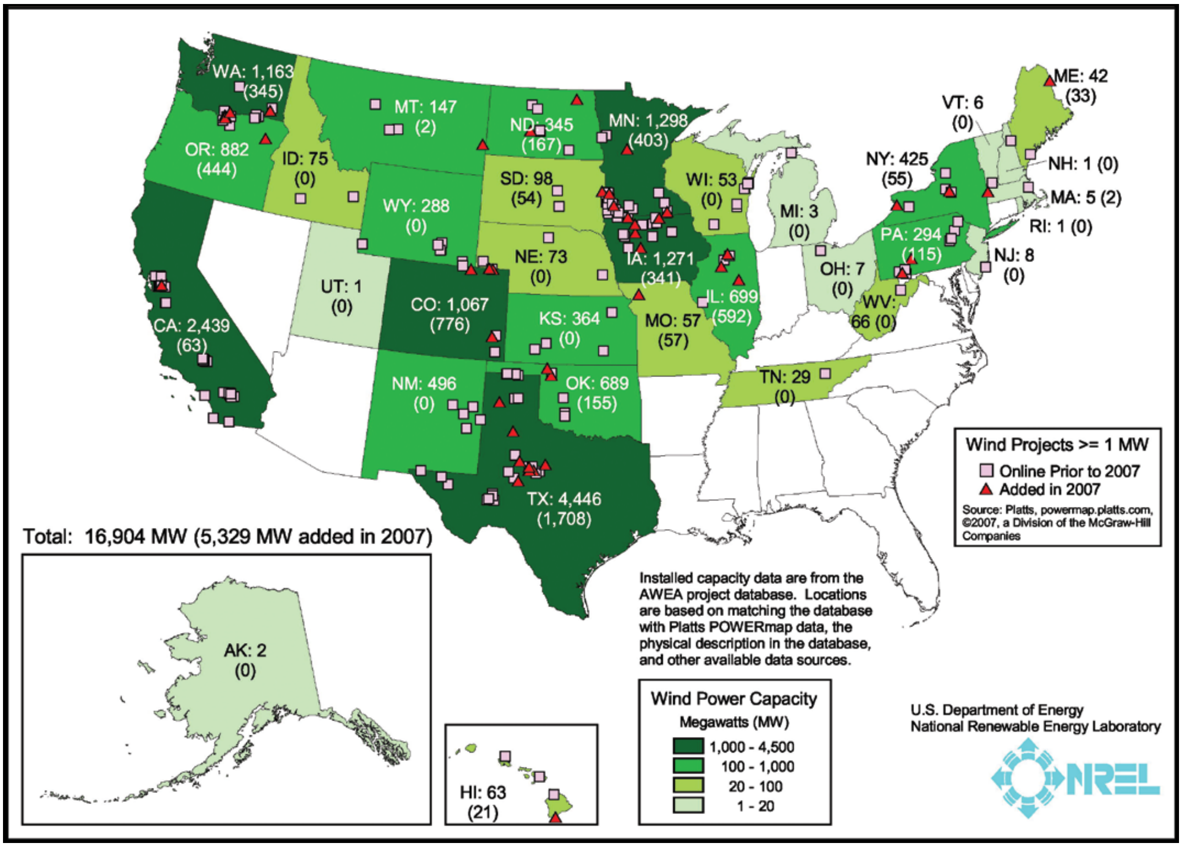

FIGURE 1. Installed wind capacity in the United States as of December 31, 2007.

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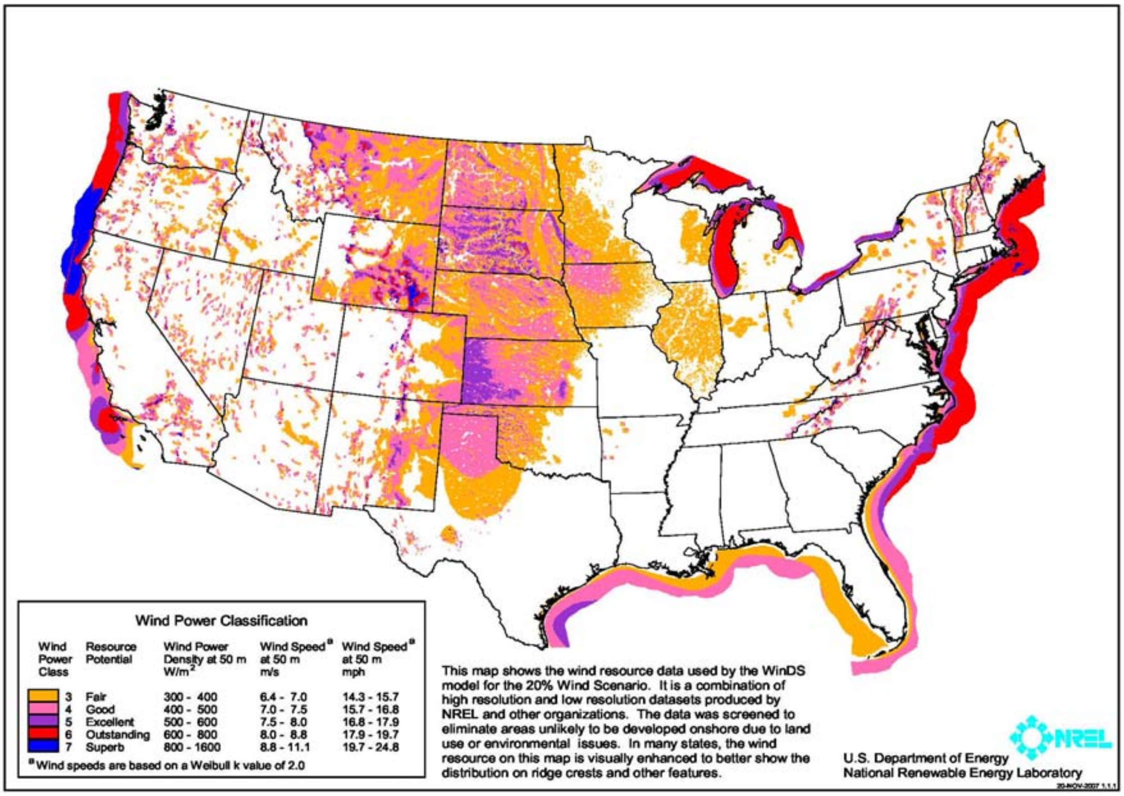
The United States is blessed with an abundance of wind energy potential. The land-based and offshore wind resources are estimated to be sufficient to supply the electrical energy needs of the entire country several times over. The Midwest region, from Texas to North Dakota, is particularly rich in wind energy resources, as illustrated in Figure 2. Wind capacity in the United States and in Europe has grown at a rate of 20% to 30% per year over the past decade. Yet, despite this rapid growth, wind only provides for about 1% of total electricity consumption in the United States.



This map shows the wind resource data used by the WinDS model for the 20% Wind Scenario. It is a combination of high resolution and low resolution datasets produced by NREL and other organizations. The data was screened to eliminate areas unlikely to be developed onshore due to land use or environmental issues. In many states, the wind resource on this map is visually enhanced to better show the distribution on ridge crests and other features.

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FIGURE 2. The land-based and offshore wind resource potential at 50 m.

The Current Status of Wind Energy Technology in the United States

During the past 20 years, average wind turbine ratings have grown almost linearly, as shown in Figure 3. Current commercial machines are rated at 1.5 MW to 2.5 MW. Each group of wind turbine designers predicted that their machines were as large as they will ever be. However, with each new generation of wind turbines, the size has increased along the linear curve and has achieved reductions in life-cycle cost of energy.

The long-term drive to develop larger turbines stems from a desire to take advantage of wind shear by placing rotors in the higher, much more energetic winds at greater elevations above ground (wind speed increases with height above the ground). This is a major reason that the capacity factor of wind turbines installed in the United States has increased over time, as documented by Wiser and Bolinger (1), and shown in Figure 4. However, there are constraints to this continued growth; in general, it costs more to build a larger turbine.

The primary argument for a size limit for wind turbines is based on the "square-cube law." Roughly stated, it says that "as a wind turbine rotor increases in size, its energy output increases as the rotor-swept area (the diameter squared), while the volume of material, and therefore its mass and cost, increases as the cube of the diameter." In other words, at some size the cost for a larger turbine will grow faster than the resulting energy output revenue, making scaling a losing economic game.

Engineers have successfully skirted this law by changing the design rules with increasing size and removing material or by using material more efficiently to trim weight and cost.

The WindPACT blade scaling study (2) shows that in recent years, blade mass has been scaling at roughly an exponent of 2.3 instead of the expected 3. The study also shows how successive generations of blade design have moved off the cubic weight growth curve to keep weight down as illustrated in Figure 5.

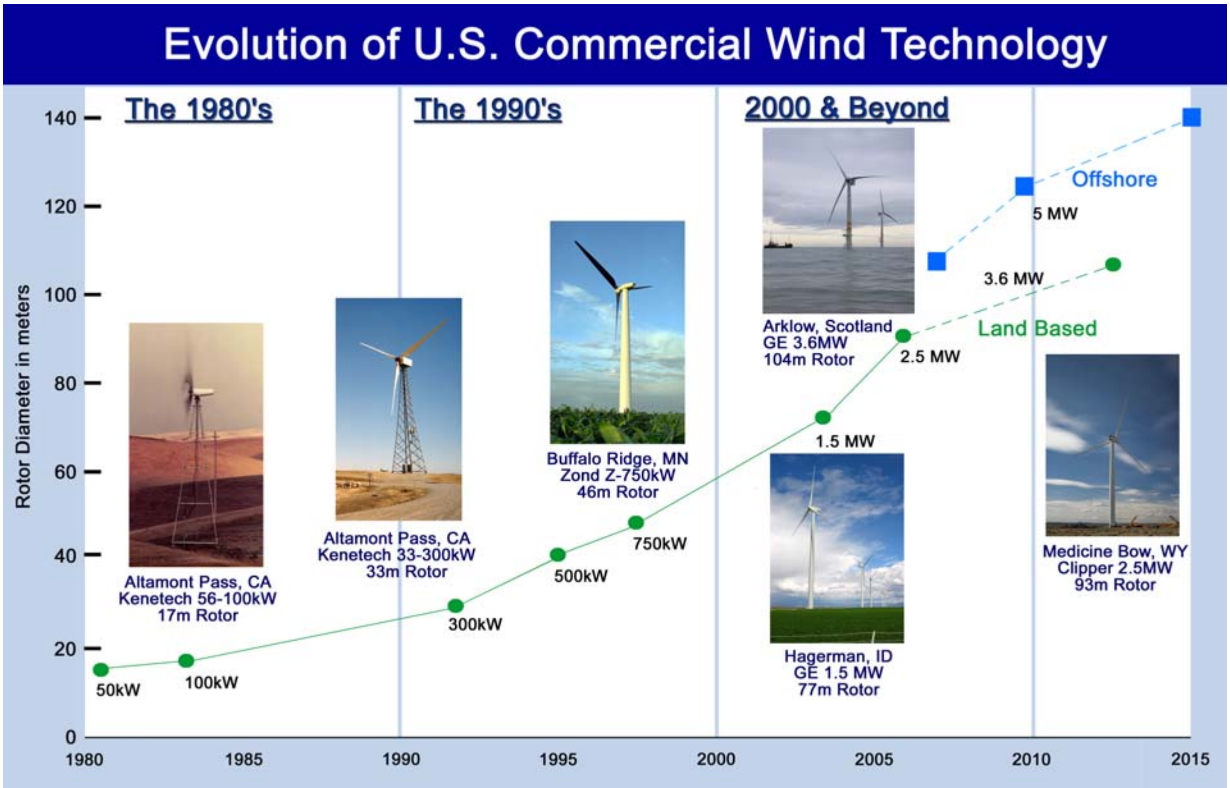
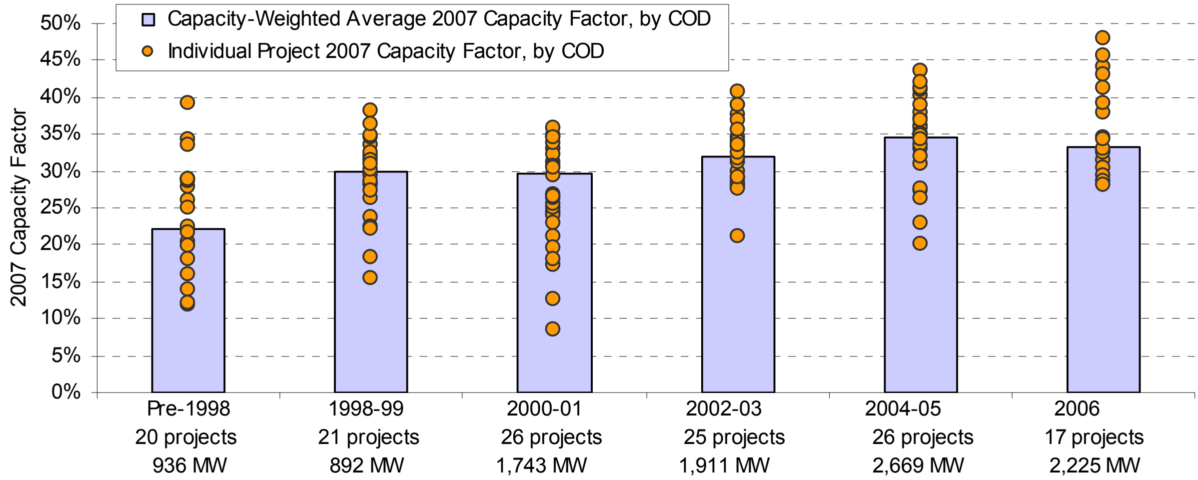


FIGURE 3. The development path and size growth of wind turbines.



Source: Berkeley Lab database

FIGURE 4. Project capacity factors for 2007 by commercial operation date (1).

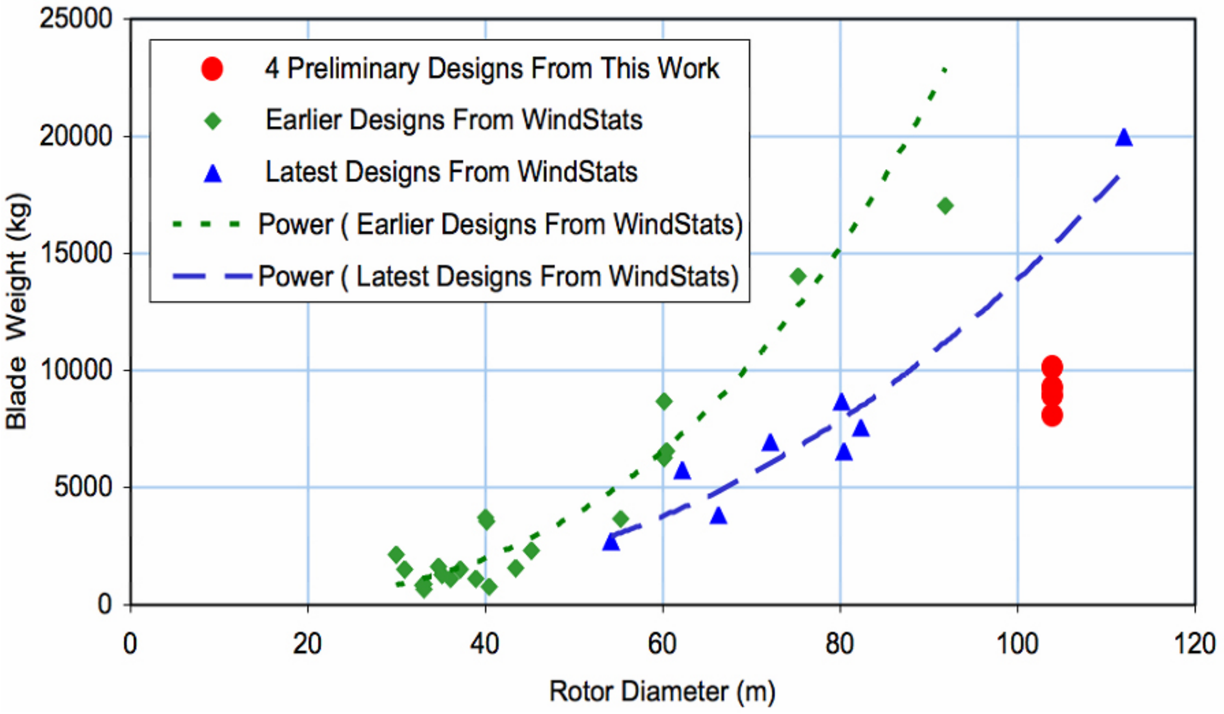


FIGURE 5. WindPACT study(2) results indicate lower growth rates in blade weight as a result of new technologies.

If advanced research and development provides better design methods, as well as new materials and manufacturing methods that allow the entire turbine to scale as the diameter squared, it would be possible to continue to innovate around this limit to size.

Land transportation constraints can also pose limiting factors to wind turbine growth. Cost-effective transportation can only be achieved by remaining within standard over-the-road trailer dimensions of 4.1 m high by 2.6 m wide. Rail transportation is even more dimensionally limited.

The Cost of Wind-Generated Electricity in the United States

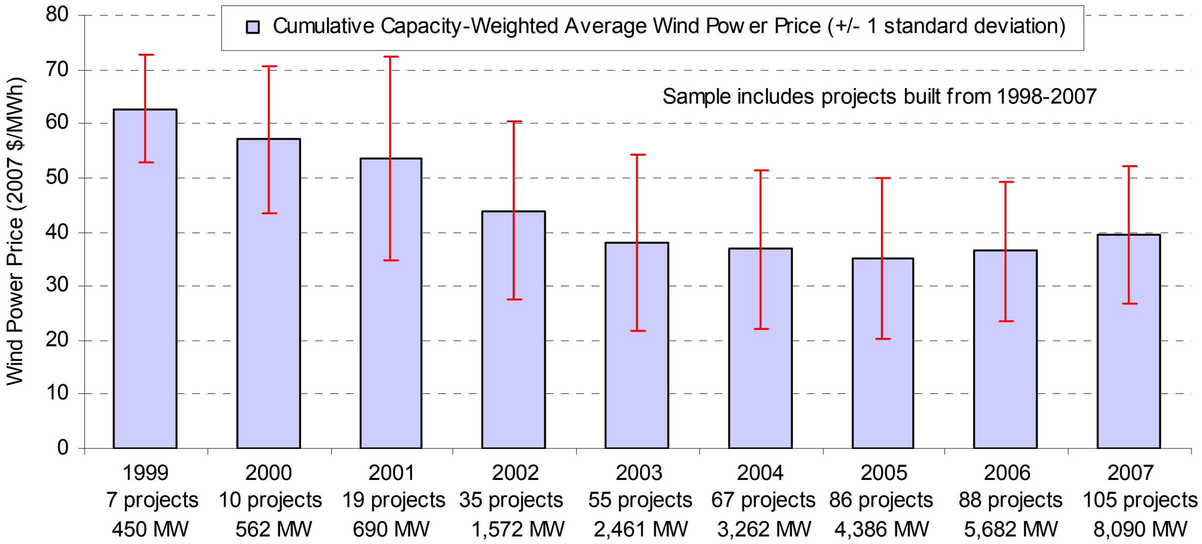
The cost of wind-generated electricity has dropped dramatically since 1980, when the first commercial wind plants began operation in California. Figure 6 depicts price data from public records for some more recent wind energy projects. This chart shows that in 2006, the price paid for electricity generated in large wind plants was between 3 and 6.5 cents per kilowatt-hour (kWh) with an average near 5 cents per kWh (1cent/kWh = 10$/MWh). These figures represent the electricity price as sold by a wind plant owner to the utility. The price includes the benefit of the federal production tax credit and any state incentives, as well as revenue from the sale of any renewable energy credits. Thus the true cost of the delivered electricity would be higher by approximately 2 cents per kWh, which is the value of the federal tax credit. The unsubsidized cost for wind-generated electricity for projects completed in 2006 ranges from about 5 to 8½ cents per kWh.

The reasons generally offered for the currently increasing price of wind-generated electricity after the long downward price trend of the past 25 years include:

- Turbine and component shortages due to the dramatic recent growth of the wind industry in the United States and Europe
- The weakening U.S. dollar relative to the Euro (because many major turbine components are imported from Europe) and relatively few wind turbine component manufacturers in the United States
- A significant rise in material costs such as steel and copper, as well as transportation fuels, over the past 3 years

- The on-again and off-again cycle of the wind energy production tax credit, which hinders investment in new turbine production facilities and encourages hurried and expensive production, transportation, and installation of projects when the tax credit is available.

Reducing wind energy costs to below the 2003 level will require further research and development efforts and will be considered later.



Source: Berkeley Lab database

FIGURE 6. Wind energy price by commercial operation date (1).

Potential Growth of Wind Energy in the United States

The vision of the wind industry in the United States and in Europe is to increase wind's fraction of the electrical energy mix to more than 20% within the next two decades. Recently, the U.S. Department of Energy in conjunction with American Wind Energy Association (AWEA), the National Renewable Energy Laboratory (NREL), Sandia National Laboratories, and Black & Veatch, published a study[4] that explores the possibility of producing 20% of the nation's electricity using wind energy. The study estimates all aspects of the 20% wind scenario, including the wind resource assessment, materials and manufacturing resources, environmental and siting issues, transmission and system integration, and public policy. It should be noted that several states have Renewable Electricity Standards that mandate comparable levels of renewable energy be deployed within the next 20 years.

The Wind Energy Deployment System model (3) developed at NREL was used to estimate the consequences of producing 20% of the nation's electricity from wind technology by 2030. This generation and transmission capacity expansion model selects from electricity generation technologies that include pulverized coal plants, combined cycle natural gas plants, combustion turbine natural gas plants, nuclear plants, and wind technology to meet projected demand in future years. Technology cost and performance projections, as well as transmission operation and expansion costs, are assumed. This study demonstrates that producing 20% of the nation's projected electricity demand in 2030 from wind technology is technically feasible, not cost-prohibitive, and provides benefits in the forms of carbon emission reductions, natural gas fuel savings, and water savings.

The United States possesses more than 8,000 gigawatts (GW) of wind resources that could be harnessed to produce electricity at reasonable cost if transmission expenditures are excluded. Considering some elements of the transmission required to access these resources, a supply curve that shows the relationship between wind power class and cost is shown in Figure 7, taken from reference (4). It includes the cost of accessing the current transmission system and shows that more than 600 GW of potential wind capacity is available for $60 to $100/MWh, without the production tax credit.

The relatively flat supply curve for wind energy clearly shows an abundance of modestly priced wind energy is available in the United States, even with limited transmission access.

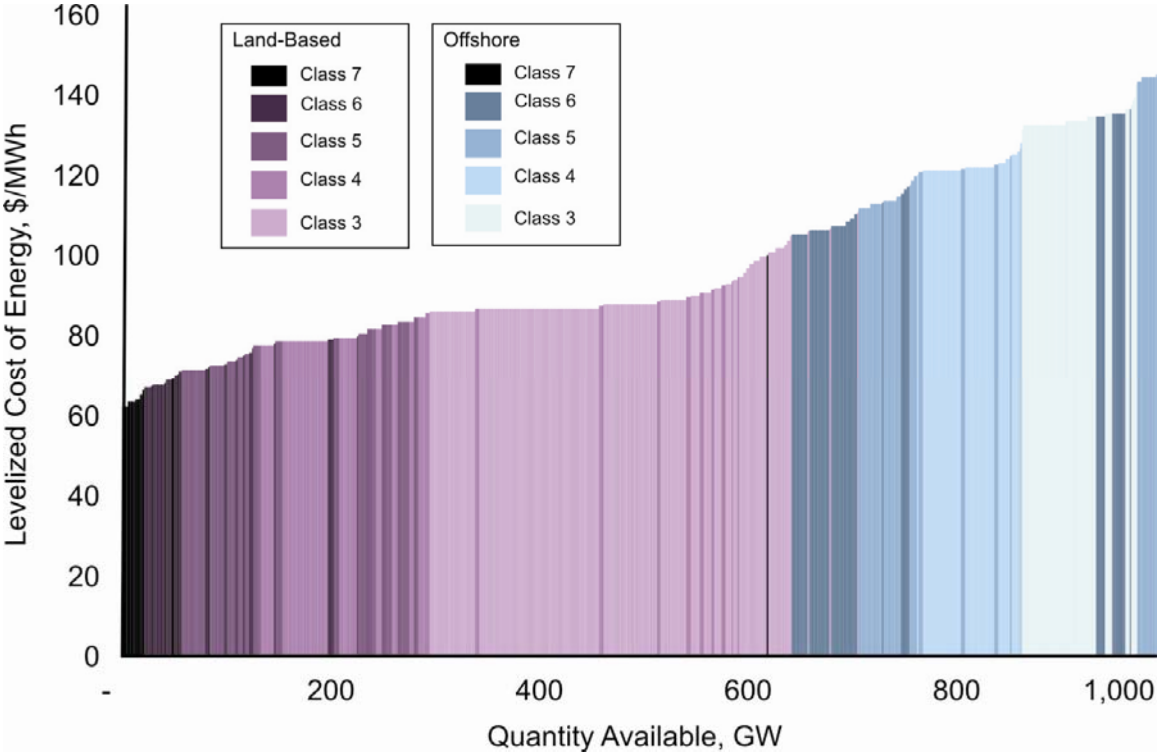


FIGURE 7. Wind energy supply curve for the 20% wind scenario modeling.

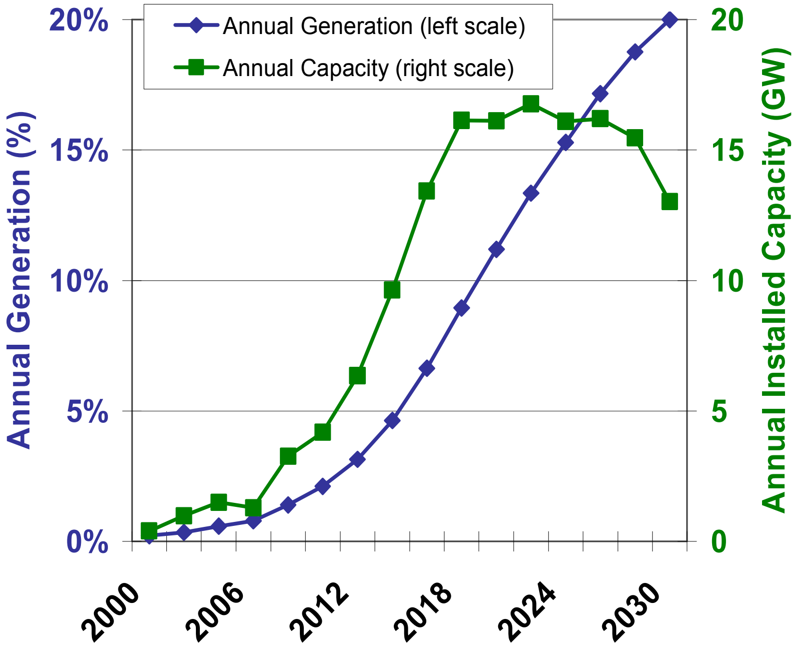


FIGURE 8. Prescribed annual wind generation and capacity additions

Figure 8 shows the wind capacity expansion necessary to reach 20% electricity generation by 2030. This trajectory was designed to produce an aggressive annual growth rate that reached a sustainable level of manufacturing by accounting for both demand growth and the repowering of aging wind plants. Based on the assumptions used in this study, the wind industry would need to grow from an annual installation rate of 5 GW/year in 2007 to a sustained rate of about 15 GW/year by 2018, which is a threefold growth over the next decade.

The scenario assumes a modest improvement of wind technology over the 20-year modeling period. Wind turbine costs are assumed to decrease by 10% to 12% between 2010 and 2030, and wind turbine performance, or capacity factor, is assumed to increase by 15 % from today's capacity factors of 35% by the year 2030.

Offshore Wind Energy Potential

U.S. offshore wind energy resources are abundant, indigenous, and broadly dispersed among the most expensive and highly constrained electric load centers. The DOE Energy Information Administration shows that 28 of the 48 contiguous states with coastal boundaries use 78% of the nation's electricity. In the United States, approximately 10 offshore projects totaling more than 2,400 MW are being considered for locations that span both state and federal waters.

Offshore turbines being considered for deployment range from 3 MW to 5 MW in size and typically have three-bladed horizontal-axis upwind rotors that are nominally 80 m to 126 m in diameter. Tower heights offshore are lower than land-based turbines because wind shear profiles are less steep, tempering the energy capture gains sought with increased elevation. The foundations for offshore wind turbines differ substantially from land-based turbines. Current estimates indicate that the cost of energy from these offshore wind plants is more than 10 cents/kWh and that the operation and maintenance costs are also higher than for land-based turbines due to the difficulty of accessing turbines during storm conditions.

The high cost of offshore wind energy and the need to develop a new regulatory process for permitting this unique technology has greatly slowed offshore wind development. Currently, there are no operating offshore wind plants in the United States. It is expected that during the next 5 years, one or more offshore wind farms will be deployed in the United States. They will be installed in shallow water and will supply electricity to nearby onshore utilities that serve large population centers. If they are successful, the technology will develop more rapidly. Most coastlines of the United States have much deeper water, and the shallow water technologies currently used for offshore installations in Europe will not be applicable. Therefore, the path toward deepwater floating systems must be supported by an extensive R&D program for at least a decade. For more information on the viability of offshore wind energy see reference (5).

Potential Future Turbine Technology Improvements

The DOE Wind Energy Program has conducted cost studies under the WindPACT Project that identified a number of areas where technology advances would result in changes to the capital cost, annual energy production, reliability, operations and maintenance, and balance of station. Many of these potential improvements, summarized in Table 1, would have significant impacts on annual energy production and capital cost. Table 1 also includes the manufacturing learning-curve effect generated by several doublings of turbine manufacturing output over the coming years. The learning-curve effect on capital cost reduction is assumed to range from zero in a worst-case scenario to the historic level in a best-case scenario, with the most likely outcome halfway in between. The most probable scenario is a sizeable increase in capacity factor with a modest drop in capital cost from the 2002 levels.

Table 1: Areas of Potential Technology Improvement

Technical Area	Potential Advances	Cost Increments (Best/Expected/Least, Percent)	
		Annual Energy Production	Turbine Capital Cost
Advanced Tower Concepts	* Taller towers in difficult locations * New materials and/or processes * Advanced structures/foundations * Self-erecting, initial or for service	+11/+11/+11	+8/+12/+20
Advanced (Enlarged) Rotors	* Advanced materials * Improved structural-aero design * Active controls * Passive controls * Higher tip speed/lower acoustics	+35/+25/+10	-6/-3/+3
Reduced Energy Losses and Improved Availability	* Reduced blade soiling losses * Damage tolerant sensors * Robust control systems * Prognostic maintenance	+7/+5/0	0/0/0
Drivetrain (Gearboxes and Generators and Power Electronics)	* Fewer gear stages or direct drive * Medium/low-speed generators * Distributed gearbox topologies * Permanent-magnet generators * Medium-voltage equipment * Advanced gear tooth profiles * New circuit topologies * New semiconductor devices * New materials (GaAs, SiC)	+8/+4/0	-11/-6/+1
Manufacturing and Learning Curve	* Sustained, incremental design and process improvements * Large-scale manufacturing * Reduced design loads	0/0/0	-27/-13/-3
Totals		**+61/+45/+21**	**-36/-10/+21**

Footnote: Since the 2002 baseline, there has been a sizeable improvement in capacity factor—from just over 30% to almost 35%—while capital costs have increased due to large increases in commodity costs and a drop in the value of the dollar (1). Therefore, working from a 2006 baseline, we can expect a more modest increase in capacity factor. The 10% capital cost reduction is still possible, although beginning from a higher 2007 starting point, because commodity prices are unlikely to drop back to 2002 levels.

Future Science and Wind Engineering Challenges

The very significant wind energy technology improvements and related cost reductions described above have been primarily enabled by the application of improved engineering analysis and design techniques transferred from related engineering fields combined with empirical relationships developed from laboratory and field testing of each new wind turbine component and system developed. However, wind energy technology has matured to a point where it will be difficult to sustain this rapid rate of improvement without a major advancement in our fundamental understanding of the basic physical processes underlying wind energy science and engineering. There are fundamental knowledge barriers to further progress in virtually all aspects of wind energy engineering. These barriers include our fundamental understanding of: atmospheric flows, unsteady aerodynamics and stall, turbine dynamics and stability, turbine wake flows and related array effects, and even climate effects caused by the large-scale use of wind energy.

To better understand these challenges and barriers a Research Needs for Wind Resource Characterization workshop, organized by DOE’s Office of Biological and Environmental Research and Office of Energy Efficiency and Renewable Energy, was conducted January 14 – 16, 2008, in Broomfield, Colorado. This workshop had two purposes. First, it brought together select researchers from the atmospheric science and wind energy engineering communities to identify and describe the most important challenges. Second, it solicited recommendations from these experts regarding productive approaches for the two communities to work together to address these barriers through a possible future DOE research effort. The workshop was attended by more than 120 atmospheric science and wind energy researchers from industry, academia, and federal laboratories in North America and Europe. For a more detailed account of the workshop results see reference (6).

To provide a framework for the workshop, four focus areas covering the fundamental challenges were delineated: 1) Turbine Dynamics, 2) Micrositing and Array Effects, 3) Mesoscale Processes, and 4) Climate Effects. These areas were introduced in four plenary presentations delivered by internationally recognized experts representing these fields. Participants then joined one of three problem definition breakout groups to address these focus areas. Each group included participants from the atmospheric science and wind energy engineering communities to promote knowledge exchange between the two. After the problem definition groups had addressed each of the four focus areas, participants then joined one of four recommendation breakout groups aligned with their individual expertise to distill the problem definition discussions into a cohesive set of research thrust recommendations.

Workshop discussions made it clear that research in each of the four focus areas had developed in relative isolation from the others. The nonlinear fluid mechanic character underlying these areas compelled this separation to achieve computational tractability, and the physical separation in spatial and temporal scales generally facilitated the current success of this separation. However, one major theme that emerged from the workshop was that continued progress in wind energy technology would require interdisciplinary reunification with the atmospheric sciences to exploit previously untapped synergies. A second major theme that emerged from the workshop was the need to apply experiments and observations in a coordinated fashion with computation and theory. In addition to these two comprehensive recommendations that were common to all four focus areas, specific recommendations were delineated for each focus area.

In the Turbine Dynamics focus area, detailed characterizations of inflows and turbine flow fields were deemed crucial to attaining the accuracy levels in aerodynamics loads that will be required for future machine designs. To effectively address the complexities inherent in this area, an incremental approach involving hierarchical computational modeling and detailed measurements was recommended, wherein the isolated turbine would be considered initially, and then the ingestion of a wake trailed from an upwind turbine would be addressed. In addition, a third thrust was recommended that would entail modeling extreme and anomalous atmospheric inflow events, as well as the aerostructural response of turbines immersed in these events.

The Micrositing and Array Effects focus area considered improved wake models to be important for more accurately characterizing energy capture losses and higher turbulence downwind of large multiple-row wind plants. Planetary boundary layer research was deemed necessary to achieve accurate, reliable determination of the inflow mean structure and turbulence statistics in the presence of various atmospheric stability conditions and complex land-surface characteristics. Finally, a requirement was identified for acquiring and exploiting large-scale wind inflow datasets for model verification, which will need to cover heights to 200 m and satisfy high spatial and temporal resolution requirements tailored to wind energy's unique needs.

The Mesoscale Processes focus area deemed improvements in fundamental understanding of mesoscale and local flows crucial to providing enhanced model outputs suited for wind energy production forecasts and wind plant siting. This improved understanding would be exploited by developing wind forecasting technologies well suited to wind plant siting and operations. Modeling approaches must be developed to resolve spatial scales in the 100-m to 1000-m range, a notable gap in current capabilities. Validation of these models will require development and deployment of new instruments and observational strategies, including additional analyses of existing measurements and additional longer-term measurements.

In the focus area of Climate Effects, theoretical, numerical, and observational work was recommended to identify and understand historic trends in the variability of wind resources to increase confidence in resource estimation for future planning and validation. For the same reasons, similarly multifaceted research was suggested to improve quantification of future changes in the mean and variability of wind climate and resources. Workshop participants also considered it important to characterize interactions between wind plants and local/regional/global climates through modeling and observations aimed at the physical link between wind plants and atmospheric boundary layer dynamics.

High-penetration wind energy deployment to meet long-range U.S. energy goals represents a daunting though attainable and crucial national objective. Meeting these goals will require an unprecedented ability to characterize the operation of large wind turbines deployed in gigawatt-scale wind plants that extract elevated energy levels from the planetary boundary layer. Success will demand accurate, reliable modeling computations and experimental measurements across an expansive scale that extends from microns to kilometers, as illustrated in Figure 9. Assets residing within the DOE national laboratory complex allied with researchers from industry and academia represent a formidable capability for realizing these objectives. Together, these resources will lay the foundations for a challenging collaborative research agenda of wind resource characterization in support of aggressive wind energy deployment to meet strategic U.S. energy needs.

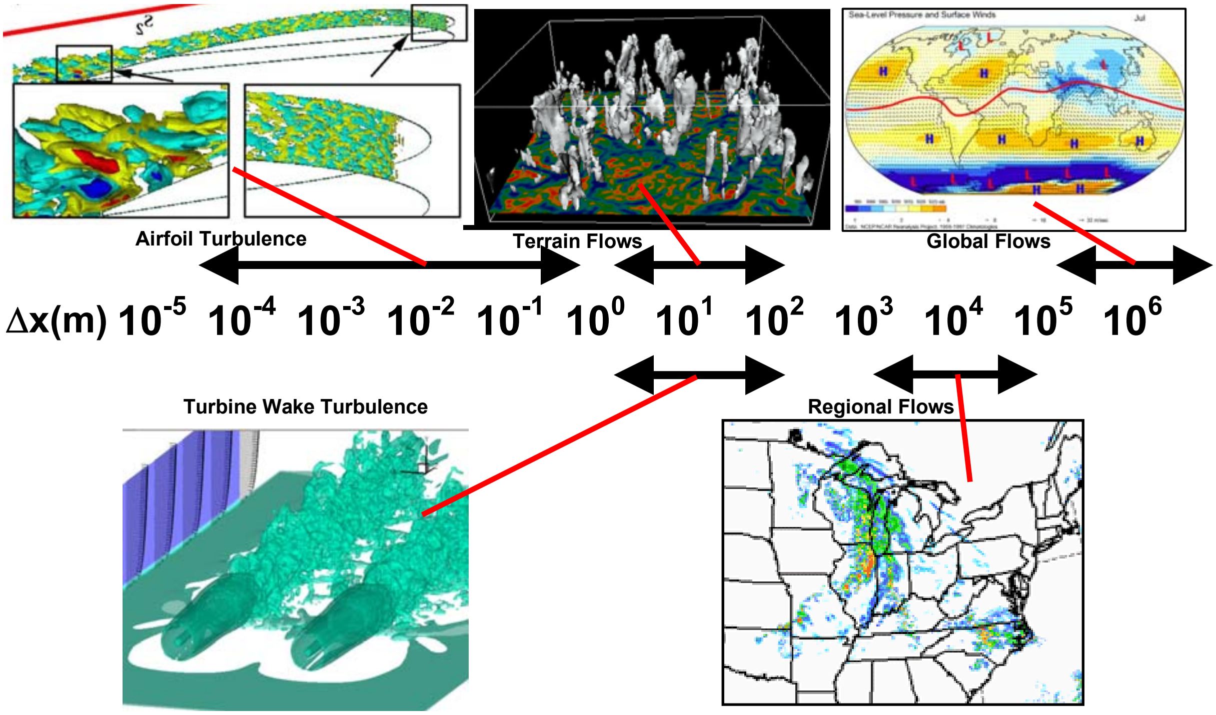


FIGURE 9. Wind energy computational scales range more than 10 orders of magnitude from the scale of airfoil generated turbulence, to rotor wake scales, to terrain flows, and then global scale flow.

SUMMARY

Power production from wind technology has evolved very rapidly over the past decade. Capital costs have plummeted, reliability has improved, and efficiency has dramatically increased, resulting in a robust commercial market product that is competitive with conventional power generation. Investments in R&D as well as the development of robust standard design criteria have helped to mitigate technology risk and attract market capital for development and deployment of large commercial wind plants. High-quality products are provided by every major turbine manufacturer, and complete wind generation plants are now being engineered to seamlessly interconnect with the grid infrastructure to provide utilities with dependable energy supply without the risks of future fuel price escalation inherent in conventional generation.

The cost-of-energy metric remains the principal technology indicator, incorporating the key elements of capital cost, efficiency, reliability, and durability. The unsubsidized (without the 2 cents/kWh PTC) cost of wind-generated electricity ranges from about 5 to 8.5 cents/kWh for projects completed in 2007 (1). No major technical breakthroughs in land-based technology are needed for a broad geographic penetration of wind power on the electric grid. No single component improvement in cost or efficiency can achieve significant cost reductions or *dramatically* improved performance. Capacity factor can be increased incrementally over time using enlarged rotors on taller towers. Market incentives are necessary to sustain near-term industry growth, but in the longer term, subsidies can probably be eliminated.

Major technology improvements require a systems development and integration approach with commensurate advancement in our fundamental understanding of the basic physical processes underlying wind energy science and engineering. This new physical understanding is needed to enhance our modeling capabilities in turbine dynamics, micrositing, mesoscale modeling for siting and forecasting, and to improve our prediction of larger scale climate effects. In addition, with continued R&D, offshore wind energy has great potential to allow the United States to greatly expand its electrical energy supply.

References

1. Wiser, R.; Bolinger, M. (2007). *Annual Report on U.S. Wind Power Installation, Cost, and Performance Trends: 2007*, May 2008. Department of Energy, Energy Efficiency and Renewable Energy; DOE/GO-102008-2590. Available at www.osti.gov/bridge.
2. Griffin, D. A. (2001). WindPACT *Turbine Design Scaling Studies Technical Area 1 -- Composite Blades for 80- to 120-Meter Rotor*. 44 pp.; National Renewable Energy Laboratory, Golden, CO. NREL Report No. SR-500-29492. Available at www.nrel.gov/publications/
3. Short, W.; Blair, N.; Heimiller, D.; and Singh, V. (2003). *Modeling the Long-Term Market Penetration of Wind in the United States***,** National Renewable Energy Laboratory, Golden, CO, NREL/CP-620-34469. Available at www.nrel.gov/publications/
4. U.S. Department of Energy (2008). *20% Wind Energy by 2030: Increasing Wind Energy's Contribution to the U.S. Electricity Supply.* National Renewable Energy Laboratory, Golden, CO. NREL Report No. NREL/SR-500-41869; DOE/GO-102008-2567. Available at www.eere.energy.gov/windandhydro
5. Musial, W.; "Offshore Wind Electricity: A Viable Energy Option for Coastal USA," *Marine Technology Society Journal*, Volume 41(3), Fall 2007; pp. 32-43; National Renewable Energy Laboratory, Golden, CO. NREL Report NO. NREL/JA-500-41338. Available at www.nrel.gov/publications/
6. Schreck, S., Lundquist, J., and Shaw, W. (2008) *U.S. Department of Energy Workshop Report: Research Needs for Wind Resource Characterization.* National Renewable Energy Laboratory, Golden, CO, NREL/TP-500-43521 June 2008. Available at www.nrel.gov/publications/

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14. ABSTRACT *(Maximum 200 Words)*

This paper describes the current status of wind energy technology, the potential for future wind energy development and the science and engineering challenges that must be overcome for the technology to meet its potential.

15. SUBJECT TERMS

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