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The Future of Wind Energy Technology in the United States

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The Future of Wind Energy Technology in the United States

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1 Introduction

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

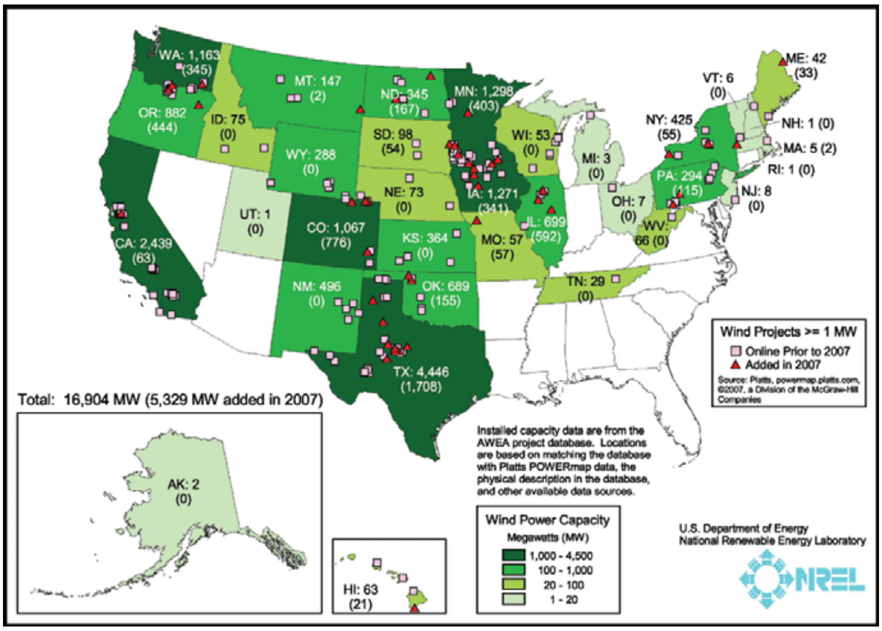
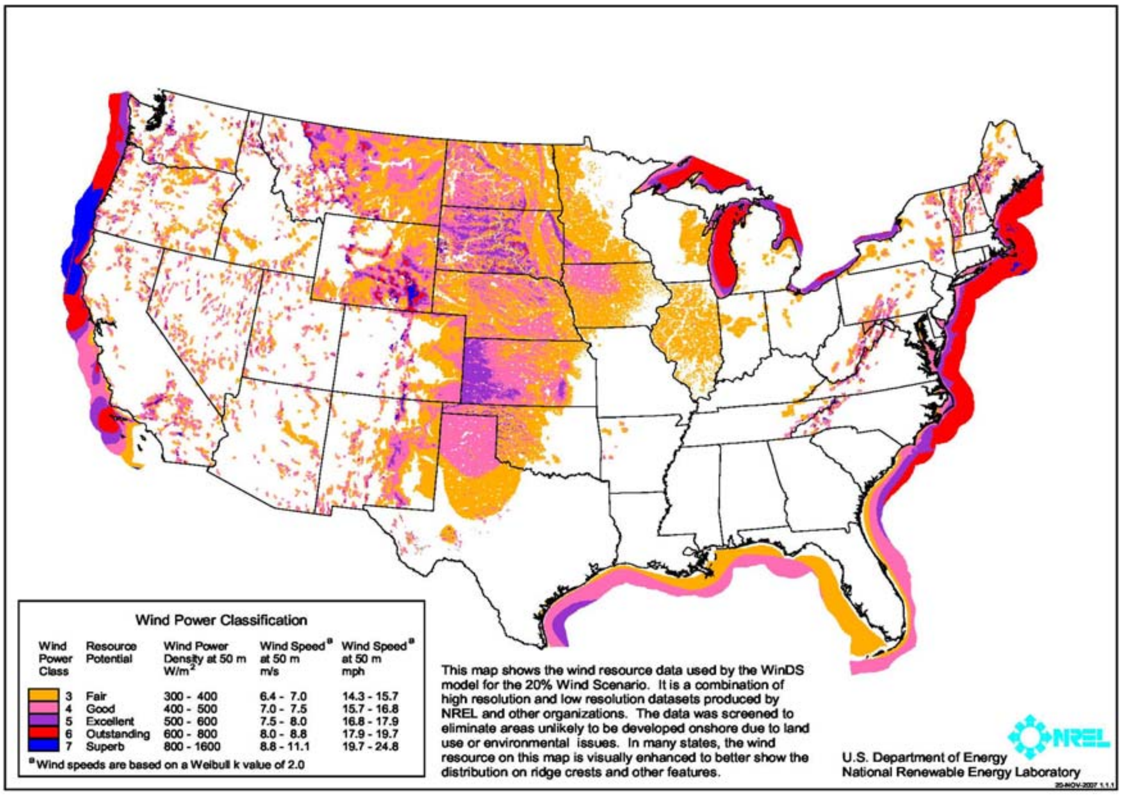


FIGURE 1. Installed Wind Capacity in the United States as of December 31, 2007.



Wind Power Classification

Wind Power Class	Resource Potential	Wind Power Density at 50 m W/m^2	Wind Speed[a] at 50 m m/s	Wind Speed[a] at 50 m mph
🟧 3	Fair	300 - 400	6.4 - 7.0	14.3 - 15.7
🟪 4	Good	400 - 500	7.0 - 7.5	15.7 - 16.8
🟪 5	Excellent	500 - 600	7.5 - 8.0	16.8 - 17.9
🟥 6	Outstanding	600 - 800	8.0 - 8.8	17.9 - 19.7
🟦 7	Superb	800 - 1600	8.8 - 11.1	19.7 - 24.8

[a] Wind speeds are based on a Weibull k value of 2.0

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 Wind Resource Potential at 50m on Land and Offshore.

Wind capacity in the United States and in Europe has grown at a rate of 20% to 30% per year over the past decade. Despite this rapid growth, wind only provides for about 1% of total electricity consumption in the United States.

The United States is blessed with an abundance of wind energy potential. The land-based and offshore wind resource has been 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.

2 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 a greater elevation 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.

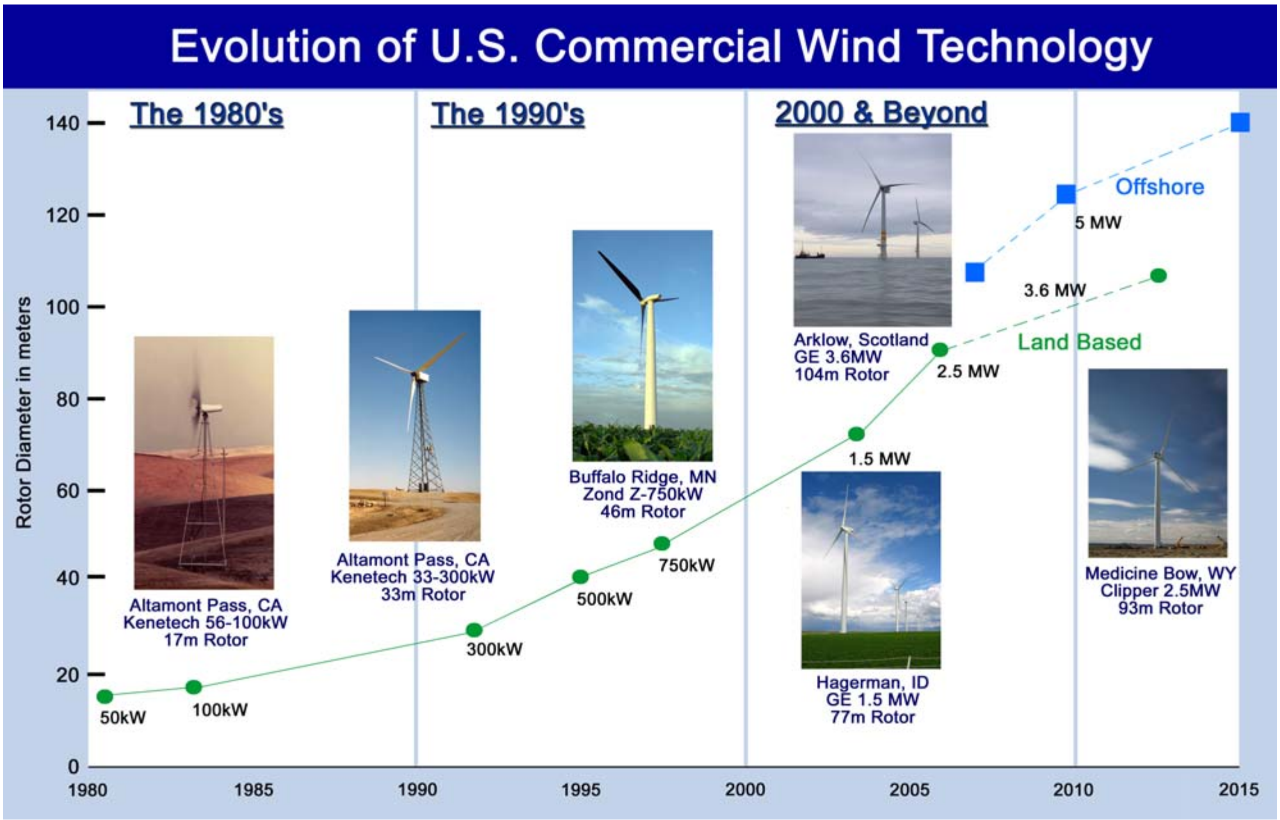
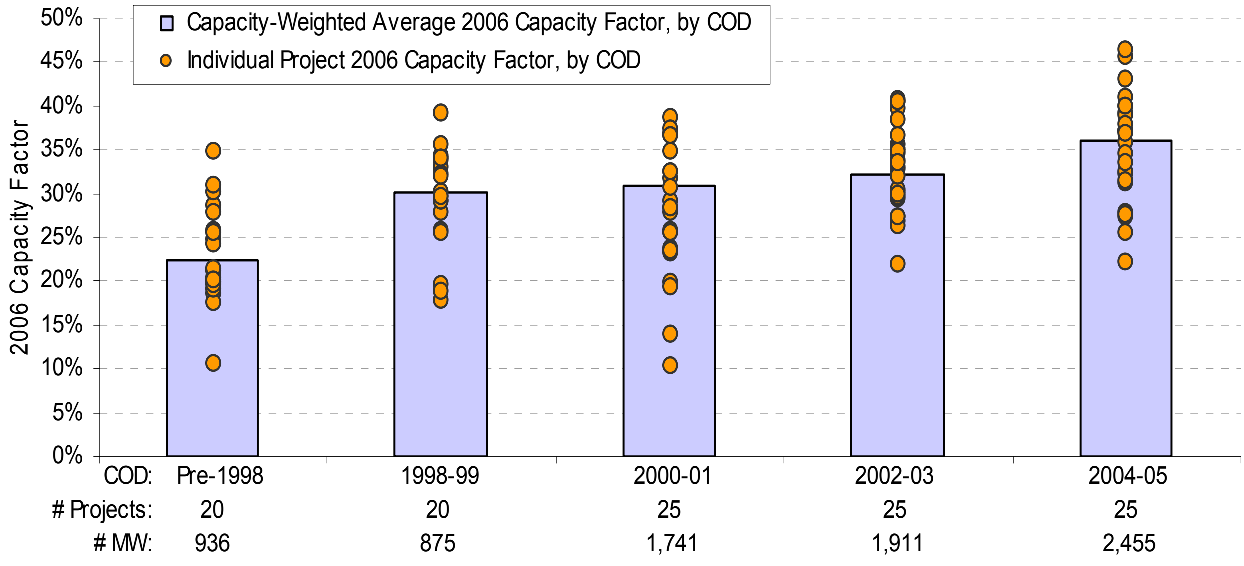


FIGURE 3. The Development Path and Size Growth of Wind Turbines.



Source: Berkeley Lab database

Figure 4. 2006 Project Capacity Factors by Commercial Operation Date (1).

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

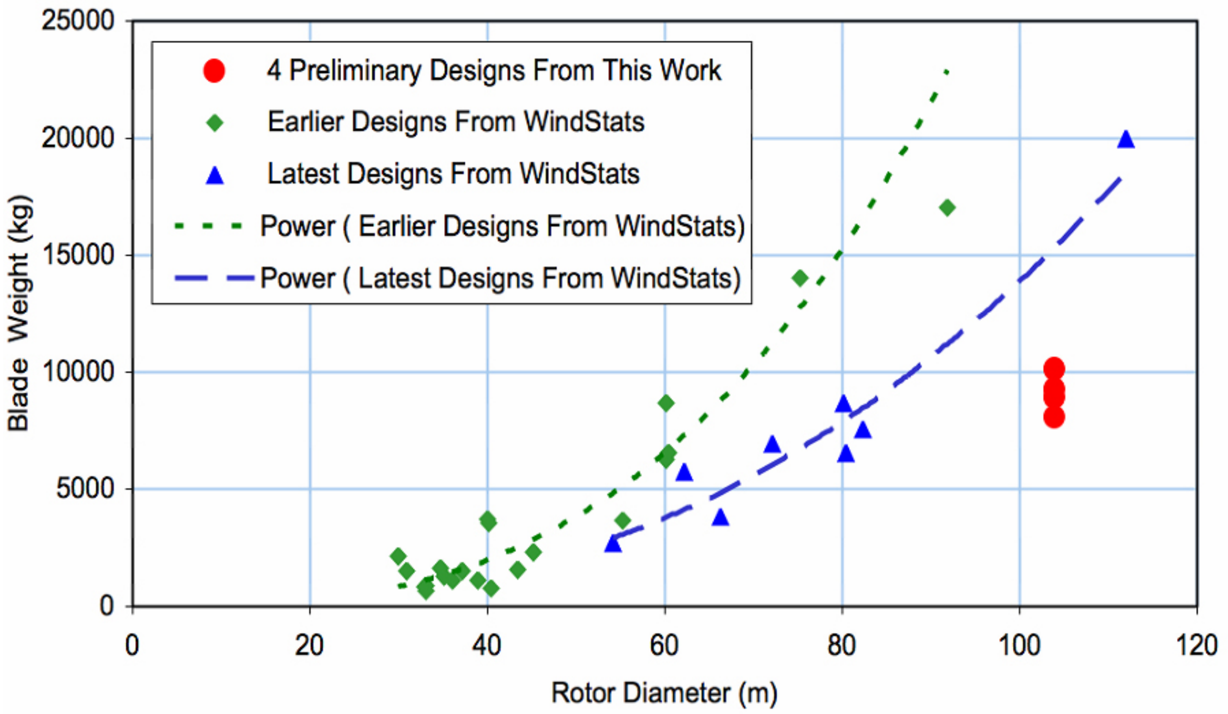


FIGURE 5. WindPACT (2) Study Results Indicating the Lowering of Growth in Blade Weight Due to the Introduction of New Technology

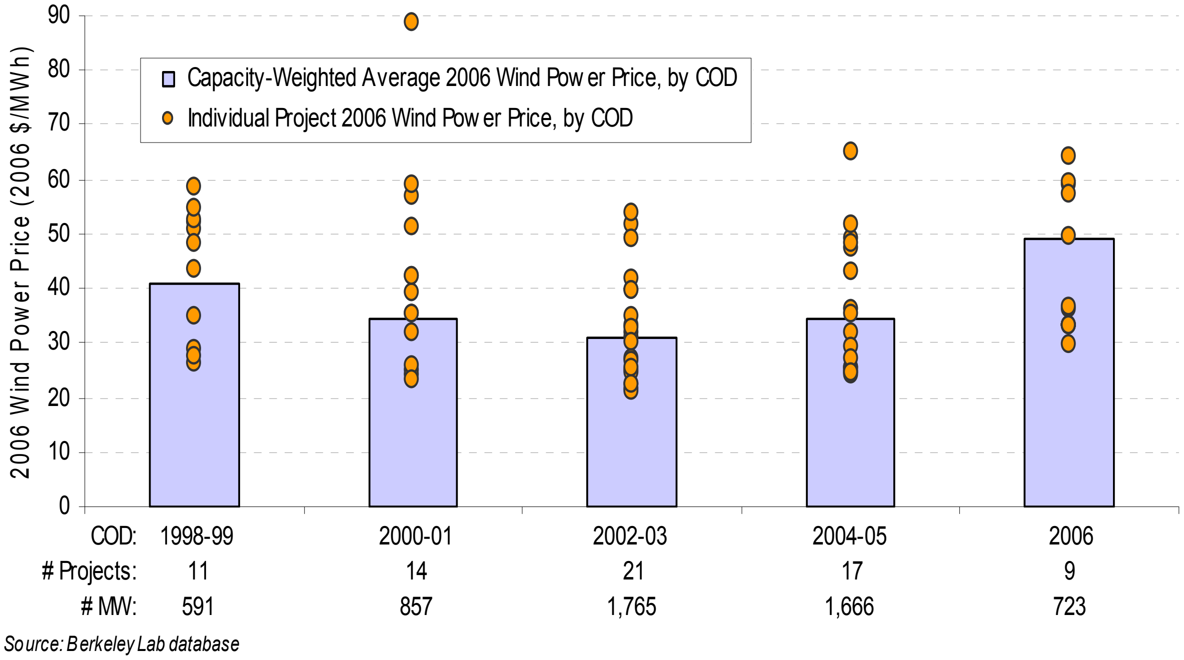
and removing material or by using material more efficiently to trim weight and cost.

Studies have shown that in recent years, blade mass has been scaling at roughly an exponent of 2.3 instead of the expected 3, as shown by the WindPACT blade scaling study[2]. This WindPACT study shows how successive generations of blade design have moved off the cubic weight growth
curve to keep weight down as illustrated in Figure 5. If advanced research and development were to provide even better design methods, as well as new materials and manufacturing methods that allowed the entire turbine to scale as the diameter squared, then 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 for turbines installed on land. 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.

3 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 for some more recent wind energy projects from public records. 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 1.9 cents per kWh, which is the value of the federal tax credit. Accounting for the tax credit, the unsubsidized cost for wind-generated electricity for projects completed in 2006 ranges from about 5 to 8½ cents per kWh.



Source: Berkeley Lab database

Figure 6 Wind Energy Price by Commercial Operation Date Using 2006 Data (1).

The reasons generally offered for the 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.

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

4 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, undertook a study[4] to explore the possibility of producing 20% of the nation's electricity using wind energy. This investigation attempts to estimate all aspects of this 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 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 price reductions, 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. 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.

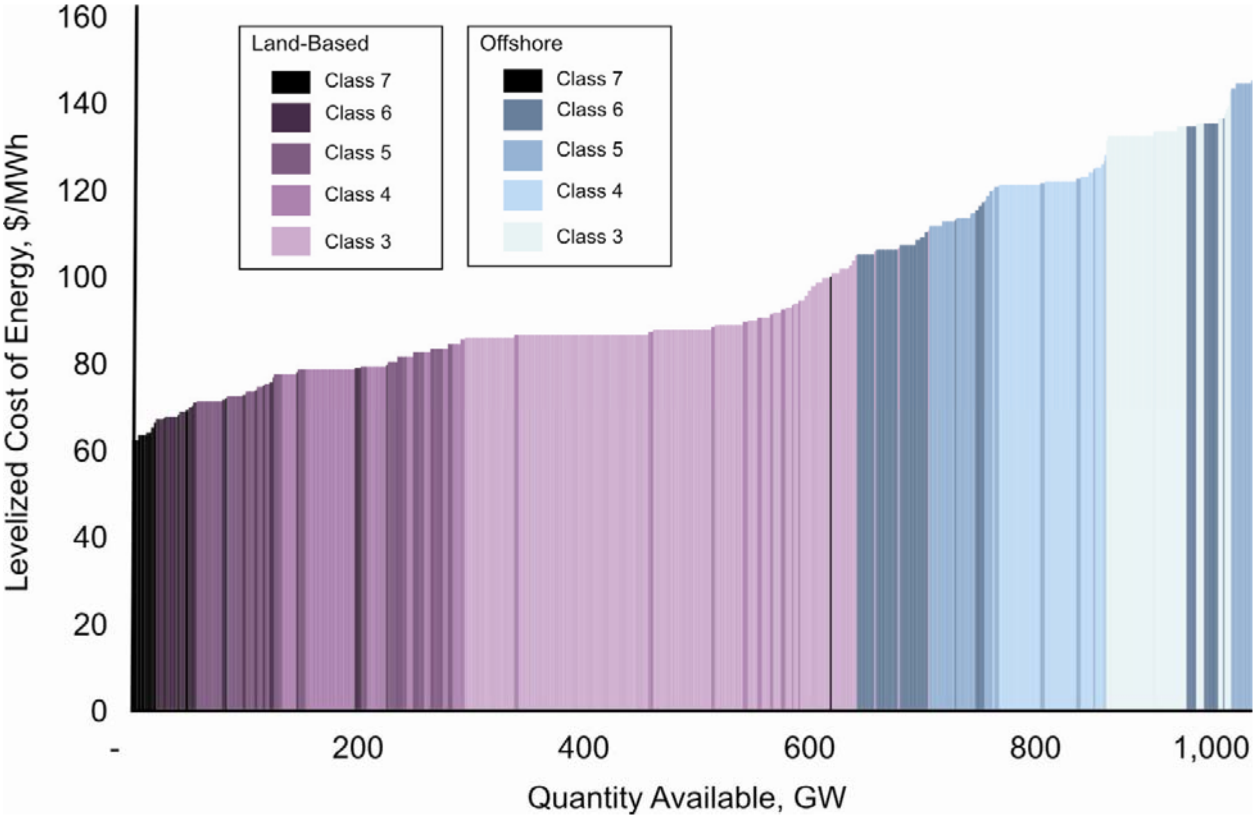


FIGURE 7. Wind Energy Supply Curve for the 20% Wind Scenario Modeling

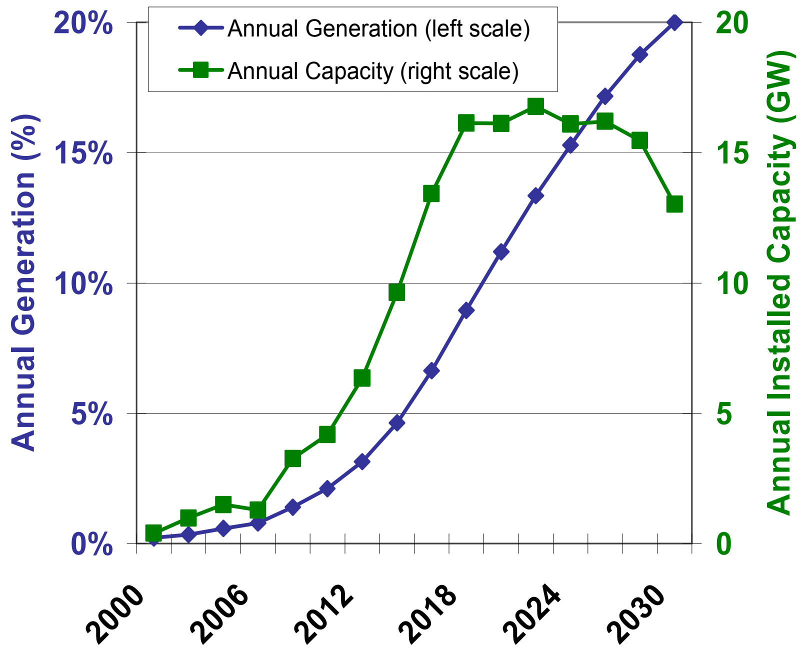


Figure 8. Prescribed annual wind generation and capacity additions

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 2020, and wind turbine performance, or capacity factor, is assumed to increase by 15 % from today's capacity factors of 35% by the year 2030. Although these increases do not appear to be particularly aggressive, they represent a significant technical challenge given the present situation where turbine costs are increasing with time not decreasing.

5 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 are being considered. Proposed locations span both state and federal waters and total more than 2,400 MW.

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.

Table 1: Areas of Potential Technology Improvement			
		Cost Increments (Best/Expected/Least, Percent)	
Technical Area	Potential Advances	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 already 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 in conjunction with a drop in the value of the dollar (Ref. 1). Therefore, working from a 2006 baseline, we can expect a more modest increase in capacity factor, but 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.

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. The much deeper water along the coastlines of the United States will not longer be able to use the concepts currently being installed in very shallow water.. However, 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).

6 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 probable scenario is a sizeable increase in capacity factor with a modest drop in capital cost from the 2002 levels.

7 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 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, free of 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 cost of wind-generated electricity ranges from about 5 to 8.5 cents/kWh for projects completed in 2006 (1). No major technical breakthroughs in land-based technology are needed for a broad geographic penetration of wind power on the electric grid. Advancement requires a systems development and integration approach, reflecting the high level of engineering already incorporated into modern machines. No single component improvement in cost or efficiency can achieve significant cost reductions or dramatically improved performance. Capacity factor can be increased 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. In addition, with continued R&D, offshore wind energy has great potential to allow the United States to greatly expand its electrical energy supply.

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13. **SUPPLEMENTARY NOTES**

14. **ABSTRACT** *(Maximum 200 Words)*

This paper describes the status of wind energy in the United States as of 2007, its cost, the potential for growth, offshore wind energy development, and the potential future wind energy technology improvements.

15. **SUBJECT TERMS**

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