Wind Power

Quick Facts

- Wind currently provides about 1 percent of America's electricity.
- Wind power was 19 percent of all U.S. electricity generation capacity added in 2006.[1]
- The U.S. Department of Energy found that generating 20 percent of U.S. electricity from wind by 2030 would avoid 825 million metric tons of carbon dioxide (CO_2) in 2030, a 25 percent reduction relative to a no-new-wind scenario.[2]
- Wind power is one of the least expensive renewable energy sources; it has become increasingly cost-competitive with fossil-fueled electricity generation and would be even more with a price on carbon.
- The levelized cost of electricity generation[3] (including tax incentives) from a new wind farm can range from 6-13 cents per kilowatt-hour (kWh).[4] Actual costs for wind power projects will vary depending on project specifics, and the cost of wind power is sensitive to tax incentives.

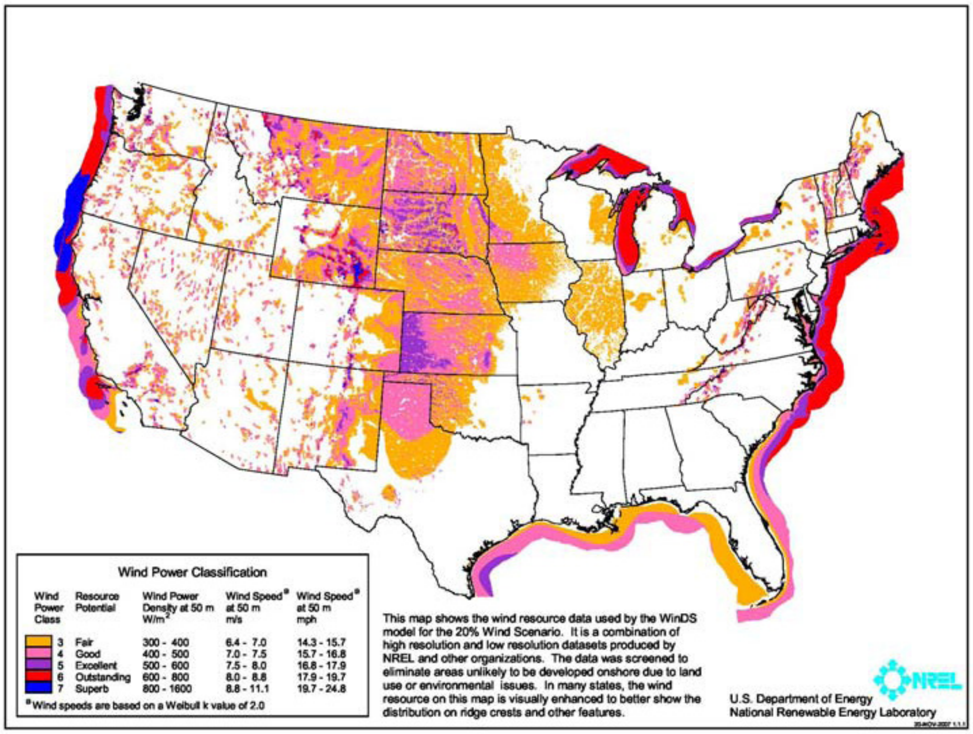
Background

Wind power harnesses the energy generated by the movement of air in the earth's atmosphere to drive electricity-generating turbines. Although humans have used wind power for hundreds of years, modern turbines reflect significant technological advances over early windmills and even over turbines from just ten or twenty years ago.

The wind resource potential varies significantly across the United States with substantial resources found in the Midwest and along the coasts (see Figure 1).

Winds generally blow more consistently and at higher speeds at greater heights. As wind speed increases, the amount of available energy increases following a cubic function,[5] so a 10 percent increase in speed corresponds to a 33 percent increase in the amount of available energy.[6] Modern turbines continue to grow larger and more efficient--two important factors that allow a single turbine to produce more usable energy. Improved materials and design have allowed for larger rotor blades and overall improvements in efficiency (measured as total energy production per unit of swept rotor area,[7] given in kilowatt-hours per square meter) and greater gross generation.

Figure 1. Wind resource potential at 50 meters (164 feet) above ground



Source: NREL, 20% Wind Energy by 2030.

Description

Wind technologies come in a variety of sizes (larger turbines can generally produce more electricity), and styles. Since wind is a variable and uncertain resource, wind turbines tend to have lower capacity factors than conventional power plants that provide most of the nation's energy. A power plant's "capacity factor" provides a measure of its productivity by comparing its actual power production over a given period of time with the amount of power the plant would have produced had it run at full capacity over that period. Coal- and gas-fired power plants have capacity factors of about 80 and 60 percent, respectively.[8,9] Wind turbines generally have capacity factors that are closer to 25 to 40 percent.[10] Wind turbine capacity factors have improved over time with advances in technology and better siting, but capacity factors are fundamentally limited by how much the wind blows.

Technologies to harness wind power can be classified into a number of broad categories:

- **Onshore, utility-scale turbines**
  A modern utility-scale wind turbine generally has three blades, sweeps a diameter of about 80-100 meters, and is installed as part of a larger wind farm of between 30 and 150 turbines.[11] An individual wind turbine can have a generation capacity of up to 3.5 megawatts (MW).[12]

- **Onshore, small wind**
  Small wind turbines are those with generation capacities of less than 100 kilowatts. Small turbines can be coupled with diesel generators, batteries, and other distributed energy sources for remote

use where there is no access to the utility grid.[13] Small wind remains a niche opportunity but is growing quickly within the overall wind market.

- **Offshore wind**
  Offshore wind technology has yet to reach full commercial scale and remains a relatively expensive technology. Even so, projects do exist and more are planned. Offshore wind installations could take advantage of higher sustained wind speeds at sea to increase electricity output by 50 percent compared to onshore wind farms.[14]

Environmental Benefit / Emission Reduction Potential

Wind power generates almost no net greenhouse gas emissions. Although electricity generation from wind energy produces no greenhouse gas emissions, the manufacture and transport of the turbines produces a small amount. Compared to conventional fossil fuel sources, wind energy also avoids a variety of environmental impacts, such as those pertaining to mining, drilling, and air and water pollutants.[15]

- **Emissions reduction potential in the United States**
  The U.S. Department of Energy found that generating 20 percent of U.S. electricity from wind by 2030 would avoid 825 million metric tons of carbon dioxide (CO_2) annually in 2030, a 25 percent reduction relative to a no-new-wind scenario.[16] This also represents a cumulative CO_2 emissions reduction of more than 7,600 million metric tons by 2030.

- **Emissions reduction potential globally**
  The International Energy Agency's aggressive technology scenario for reducing GHG emissions included a significant role for wind power—i.e., 2.1 gigatons of GHG abatement compared to "business-as-usual" in 2050, or 4.4 percent of total abatement from energy use, and about 12 percent of global electricity production in 2050.[17] Other analyses show an even greater role for wind power in the next several decades.

Cost

The cost of wind power has fallen significantly over the past few decades.[18] In 1981, the cost of generating electricity from a 50-kilowatt capacity wind turbine was around 40 cents per kWh. Technological and efficiency improvements (such as longer and stronger turbine blades from new advanced materials and designs) allow today's turbines to produce 30 times as much power at a much lower cost.[19] Technological improvements have the potential to further drive down costs over time.

Wind is cost-competitive with traditional power generation technologies in some U.S. regions. Recent analyses estimate the levelized cost of electricity[20] generation from a new wind power project to be 6-13 cents per kWh.[21] These costs, however, depend on project specifics (such as the wind turbines' capacity factor) and are sensitive to the inclusion of tax incentives for wind power. For example, the Federal Production Tax Credit for wind power lowers the levelized cost of electricity generation from wind by roughly 2 cents per kWh.[22] Recent estimates for the levelized cost of electricity generation from new coal-fueled generation run from 6.4 cents per kWh to 9.5 cents per kWh. [23,24] Similar estimates for the levelized cost of electricity from a natural gas combined cycle plant are in the range of 6.3-10 cents per kWh.[25]

At present, offshore wind turbines are approximately 50 percent more expensive than onshore installations, yet they produce about 50 percent more electricity due to higher wind speeds.[26]

Current Status of Wind

Wind capacity is growing fast and accounts for the largest share of added renewable energy capacity over the last several years.[27] Global wind capacity has grown at approximately 25 percent per year since 2003.[28]

- **Wind in the United States**
  Wind currently provides about 1 percent of America's electricity, but this relative share is growing quickly. Nineteen percent of all electricity generation capacity added in the United States in 2006 was wind power;[29] U.S. EIA data shows that new wind accounted for approximately 35 percent of new generating capacity in 2007 and early 2008.[30] Between 2006 and 2007, the amount of electricity generated from wind in the United States increased by 21 percent,[31] and in 2008 the United States increased its wind generating capacity by an additional 50 percent, overtaking Germany as the country with the largest installed wind capacity.[32]

  In October 2008, New Jersey announced its approval for the development of a 350 MW offshore wind farm to be completed by 2013.[33] Other U.S. states such as Rhode Island and Delaware are also considering such projects.

- **Wind at a global scale**
  Since 1990, global installed wind power capacity has grown by a factor of 50, reaching 94 gigawatts in 2007 and supplying approximately one percent of global electricity supply in 2006.[34] The United States accounts for about 18 percent of installed global wind power capacity.[35]

  Even assuming no new policy interventions – such as renewable portfolio standards or carbon emissions constraints – wind will continue to grow quickly, with installed capacity expected to quintuple in size by 2030.[36] Though some projections estimate it could account for as little as 2 percent of global electricity production in 2050, this share could be as high as 9-12 percent if policies are put in place to aggressively reduce greenhouse gas emissions and spur technological developments in renewable energy.[37]

A number of offshore wind farms are currently in development globally. Projects are underway in Denmark, Germany, and the United Kingdom; the London Array, the largest offshore development, is expected to have a capacity of 1,000 MW.[38]

Obstacles to Further Development or Deployment of Wind

A number of factors pose barriers to the further development of wind resources.

- **Variability and uncertainty**
  Wind power is inherently variable and uncertain due to weather factors, since winds vary in strength and sometimes do not blow at all. Wind power is uncertain insofar as wind speeds can be forecast with only limited accuracy. These issues can be overcome to some extent by developing better wind forecasting methods and addressing electricity grid interconnection issues between regions. The U.S. DOE estimates that the U.S. could generate 20 percent of its electricity from wind without any new energy storage.[39] To achieve even higher levels of generation, wind power will require enabling technologies such as energy storage and demand-response. Storage options for wind energy include pumped hydroelectric storage, compressed air energy storage, hydrogen, and batteries.[40]

- **Geographic distribution and transmission**
  Wind resources are unevenly distributed and many of the best wind resources are located far from the population centers that require electricity. New transmission infrastructure is necessary to bring electricity generated by wind resources in remote areas to end users.

- **Siting issues**
  Related to issues over geographic distribution of wind resources, siting of wind power projects can face opposition from local communities who see wind farms as a form of visual pollution that spoils views and property or have concerns about the potential impacts of the wind farm on wildlife (especially birds and bats) and habitat.

- **Investment uncertainty**
  Recent wind power growth rates in the United States have been volatile – largely driven by the cycle of lapses and reinstatements of tax policy support, namely the Federal Production Tax Credit. Such uncertainty hurts investment in wind power projects.

Policy Options to Help Promote Wind

- **Price on carbon**
  A price on carbon, such as that which would exist under a greenhouse gas cap-and-trade program, would raise the cost of electricity produced from fossil fuels, making wind power more cost-competitive.[41]

- **Tax credits and other subsidies**
  Stabilizing Federal Production Tax Credit cycles can help sustain investment and growth in wind power (for example, by putting into place incentive programs with longer periods before required Congressional renewal). Other forms of assistance include grant programs and loan guarantees to wind power project developers.

- **Renewable portfolio standards**
  A renewable portfolio standard (sometimes called a renewable or alternative energy standard) requires that a certain amount or percentage of a utility's power plant capacity or generation come from renewable sources by a given date. At present, 29 U.S. states and the District of Columbia have adopted an RPS. RPSs encourage investment in new renewable generation and can guarantee a market for this generation. States and jurisdictions can further encourage investment in specific resources, such as wind power, by including a "carve-out" or set-aside in an RPS, as is the case in Illinois, Minnesota, Montana, and New Mexico.

- **Development of new transmission infrastructure**
  One of the greatest barriers to investment in new renewable generation and tapping the full potential of resources such as solar and wind is the lack of necessary electricity transmission infrastructure. While estimated wind and solar resources are vast, frequently the areas with the most abundant concentrations of these resources are remote and far removed from end-users of electricity. Policies that promote the buildout of new electricity transmission lines allow access to these resources and can provide additional incentives for utilities to invest in them.

Related Business Environmental Leadership Council (BELC) Company Activities

- American Electric Power
- DTE Energy
- Exelon
- TransAlta
- WE Energies
- BP
- Duke Energy
- GE
- Ontario Power Generation
- Shell

Related Pew Center Resources

Electricity from Renewables: Challenges and Opportunities, 2009

Race to the Top: The Expanding Role of U.S. State Renewable Portfolio Standards, 2006

Further Reading / Additional Resources

American Wind Energy Association (AWEA)

- Wind Energy Basics, accessed 5 March 2009 http://www.awea.org/faq/wwt_basics.html#What%20is%20capacity%20factor
- *Home and Farm Wind Energy Systems: Reaching the Next Level*, 2005 http://www.awea.org/smallwind/documents/AWEA_SWT_Market_Study_6-05.pdf

Congressional Research Service

- *Power Plants: Characteristics and Costs,* by S. Kaplan, November 2008 http://www.fas.org/sgp/crs/misc/RL34746.pdf.
- *Wind Power in the United States: Technology, Economic, and Policy Issues*, by J. Logan and S. Kaplan, June 2008 http://fas.org/sgp/crs/misc/RL34546.pdf

"Federal Tax Policy Towards Energy" by G. Metcalf, *National Bureau of Economic Research Working Paper Series.* National Bureau of Economic Research, 2006 http://www.nber.org/papers/w12568

"The Future of Energy." *The Economist*, 19 June 2008 http://www.economist.com/opinion/PrinterFriendly.cfm?story_id=11580723

InterAcademy Council, *Lighting the Way: Toward a Sustainable Energy Future,* 2007 http://www.interacademycouncil.net/?id=12161

International Energy Agency (IEA), *Energy Technology Perspectives 2008: Scenarios and Strategies to 2050*, 2008 http://www.iea.org/Textbase/techno/etp/index.asp

"Levelized Cost of Energy Analysis," presentation by Lazard to the National Association of Regulatory Utility Commissioners, June 2008 http://www.narucmeetings.org/Presentations/2008%20EMP%20Levelized%20Cost%20of%20Energy%20-%20Master%20June%202008%20(2).pdf

U.S. Department of Energy (DOE)

- *20% Wind Energy by 2030: Increasing Wind Energy's Contribution to U.S. Electricity Supply,* 2008 http://www1.eere.energy.gov/windandhydro/pdfs/41869.pdf
- *Annual Report on U.S. Wind Power Installation, Cost, and Performance Trends: 2006*, by R. Wiser and M. Bolinger, 2007 http://www.nrel.gov/wind/pdfs/41435.pdf
- *The Role of Energy Storage in the Modern Low-Carbon Grid*, presentation by P. Denholm from the National Renewable Energy Lab, 2008 http://tinyurl.com/d4t4pu

[1] Wiser, R. and Bolinger, M. *Annual Report on U.S. Wind Power Installation, Cost, and Performance Trends: 2006*. Lawrence Berkeley National Laboratory, LBNL-62702. May 2007. http://www.nrel.gov/wind/pdfs/41435.pdf

[2] U. S. Department of Energy (DOE). *20% Wind Energy by 2030: Increasing Wind Energy's Contribution to U.S. Electricity Supply.* 2008. http://www1.eere.energy.gov/windandhydro/pdfs/41869.pdf.

[3] The levelized cost of electricity is an economic assessment of the cost of electricity generation from a representative generating unit of a particular technology type (e.g. wind, coal) including all the costs over its lifetime: initial investment, operations and maintenance, cost of fuel, and cost of capital. The levelized cost does not include costs associated with transmission and distribution of electricity. For all resources, levelized cost estimates vary considerably based on uncertainty and variability involved in calculating costs for electricity. This includes assumptions made about the size and application of the system, what taxes and subsidies are included, location of the system, and others.

[4] California Institute for Energy and the Environment (CIEE), *Renewable Energy Transmission Initiative (RETI): Phase IA.* Final Report prepared by Black & Veatch. April 2008. http://www.energy.ca.gov/2008publications/RETI-1000-2008-002/RETI-1000-2008-002-F.PDF

[5] The power (P) available in the area swept by the wind turbine rotor can be calculated using the following equation: P (in Watts = J/s = $(kg*m^2)/s^3$))= 0.5 * (air density, ~1.225 kg/m^3) * (area of rotor in m^2) * (wind speed in m/s) ^{3}. The 33 percent increase in power from a 10 percent increase in speed can be illustrated using a sample calculation (simplifying the equation to represent the first three variables on the left, which are simply multipliers, as X). At 10 meters per second (m/s), $P = X*(10)^3 = 1000X$. If we increase the wind speed by 10 percent, to 11 m/s, $P = X*(11)^3 = 1331X$. Windspeed has increased 10 percent, and available power has increased by 33 percent.

[6] DOE 2008.

[7] This is the area covered by the rotor blades as they make a rotation. More efficient turbines produce more energy for a given amount of area covered.

[8] Renewable Energy Research Laboratory, University of Massachusetts at Amherst. *Wind Power: Capacity Factor, Intermittency, and What Happens When the Wind Doesn't Blow?* Accessed 9 March 2009. http://www.ceere.org/rerl/about_wind/RERL_Fact_Sheet_2a_Capacity_Factor.pdf

[9] Note that natural gas power plants have lower capacity factors not due to technical limitations but because they are used for load-following and intermediate load duty rather than baseload generation, which is what coal plants are typically used to provide.

[10] American Wind Energy Association (AWEA). "Wind Energy Basics." Accessed 5 March2009. http://www.awea.org/faq/wwt_basics.html#What%20is%20capacity%20factor

[11] GE and Vestas product brochures.

[12] Ibid.

[13] The DOE provides a range of small wind resources at www.windpoweringamerica.gov/small_wind.asp.

[14] International Energy Agency (IEA), *Energy Technology Perspectives 2008: Scenarios and Strategies to 2050*. Paris: IEA, 2008. http://www.iea.org/Textbase/techno/etp/index.asp

[15] DOE 2008.

[16] Ibid.

[17] IEA 2008, BLUE Map scenario.

[18] IEA 2008.

[19] Schiermeier Q., J. Tollefson, T. Scully, A. Witze, and O. Morton. "Electricity Without Carbon." *Nature* 454 (2008): 816-822.

[20] See endnote 3.

[21] CIEE 2008.

[22] The PTC is currently 2.1¢/kWh, however one cannot simply add 2.1¢/kWh to cost estimates to yield a cost without the PTC, as the PTC is limited to 10 years and is furthermore not available to all investors. The analysis is further complicated by the 2009 stimulus bill, which extended the PTC and provided the option of an investment tax credit in lieu of the PTC. Nonetheless, a *rough* estimate is that the non-PTC price would be 2 cents per kWh higher than the PTC price.

[23] These, again, are levelized costs of generation, and do not include transmission and distribution costs.

[24] Low estimate taken from Logan, Jeff and Stan Mark Kaplan, *Wind Power in the United States: Technology, Economic, and Policy Issues*, Congressional Research Service, June 2008, see http://fas.org/sgp/crs/misc/RL34546.pdf. High estimate comes from communication with Jeffrey Jones (Energy Information Administration) regarding the levelized cost of electricity generation in the *Annual Energy Outlook 2009*.

[25] Low estimate taken from Logan and Kaplan 2008. High estimate taken from "Levelized Cost of Energy Analysis," presentation by Lazard to the National Association of Regulatory Utility Commissioners, June 2008.

[26] IEA 2008.

[27] InterAcademy Council (IAC), *Lighting the Way: Toward a Sustainable Energy Future*. Amsterdam: IAC, 2007. http://www.interacademycouncil.net/?id=12161

[28] Ibid.

[29] Wiser and Bolinger 2007.

[30] U.S. Energy Information Administration (EIA). Data available online at http://www.eia.doe.gov/cneaf/electricity/epm/epm_sum.html.

[31] EIA 2008. Figures available online at http://tonto.eia.doe.gov/energy_in_brief/renewable_energy.cfm.

[32] Global Wind Energy Council. "U.S. and China in race to the top of the global wind industry." E&E News, 2 February 2009.

[33] New Jersey Board of Public Utilities "Board of Public Utilities Approves Grant of $4 million for Offshore Wind Project Proposal." 3 October 2008.

[34] Ibid.

[35] Ibid.

[36] InterAcademy Council 2007.

[37] IEA 2008.

[38] IEA 2008.

[39] DOE 2008.

[40] InterAcademy Council 2007.

[41] "The Future of Energy." *The Economist*, 19 June 2008. http://www.economist.com/opinion/PrinterFriendly.cfm?story_id=11580723