1 Wind Energy

In This Section:

Market Status/ Overview

Large wind farms can produce electricity at 2.7 cents to 5.4 cents per kilowatt-hour (kWh)— including the federal production tax credit (PTC)—making wind power one of the lowest-cost renewable technologies. U.S. wind capacity reached about 9,000 megawatts (MW) at the end of 2005, which is a 35% increase over 2004. Almost all of this is so-called utility-scale wind, meaning multiple turbines of 1 or more MW each, installed in wind farms of 50 to 100 MW or more. These large wind farms take advantage of economies of scale, which drive down the costs per kilowatt and costs per kilowatt-hour.

Although the costs of electricity from wind have seen remarkable decreases in recent years, one must be careful in comparing these costs with those of electricity from fossil-fired or other types of power plants. Because of wind power's intermittency, it has a reduced capacity value and imposes costs (called ancillary service costs) on the rest of the electricity system. Wind undeniably can act as a "fuel saver," allowing fossil fuel plants to burn less fuel when the wind is blowing. However, it's not yet clear how much wind can replace "firm" capacity. As long as wind makes up only 1% or 2% of total generation, this generally isn't an issue, but when it exceeds that, it becomes important to carefully consider wind's impacts on system costs and operation.

Smaller wind turbines—5 to 200 kW—have also seen reduced costs, but these haven't been nearly as impressive as cost reductions for large turbines. Electricity produced from most smaller wind turbines is still considerably more expensive than wholesale electricity from large power plants. A very strong wind resource—with average annual wind speeds of more than 18 miles per hour (mph)—will lower costs per kilowatt-hour, but even with such wind, these projects are rarely cost-effective.

Wind Resource Assessment

Wind turbines require sustained winds. As shown in table 1.1, small (10 kW) turbines can start generating electricity at wind speeds as low as 8 mph, but they don't reach rated output until wind speeds reach 31 mph. Larger turbines have comparable start-up wind speeds. However, all turbines produce very little electricity at lower speeds; higher and sustained wind speeds are needed to produce enough electricity to make a turbine financially viable. This is due to the fundamental physics of the wind resource: The amount of energy in the wind is proportional to the cube of the wind speed; so, for example, a doubling of wind speed means the energy available in the wind increases eight times.

Specifics vary by project, but a rough rule of thumb is that a location with average annual wind speeds of 10 mph or more can support a small (10 kW) turbine (although generation will be limited). Utility-scale (1.5 MW) machines need average annual winds of at least 15 mph, and preferably more, to be financially viable.

Such locations are surprisingly prevalent. One analysis found sites with enough wind to justify large turbines in 45 states. This study looked at utility-scale turbines; sites for smaller turbines are even more numerous. DOE maps of the wind resource (see "For More Information on Wind Power") show that just about every state has multiple sites that can support small turbines. There are practical and economic limitations that make much of this resource unrealistic: Specific sites may be too far from loads or power lines; they may cause unacceptable visual clutter; power prices may be too low to make such projects financially realistic; the higher cost and lower average production per unit of capacity of small turbines increase the cost per kilowatt-hour; and so on. It is, however, important to recognize that the wind resource itself is vast and largely untapped.

Table 1.1. Required wind speeds for typical turbines, by turbine size

Turbine size	Wind speed to start (mph)	Wind speed to reach rated output (mph)
1 kW	6	25
10 kW	8	31
100 kW	9	34
1.5 MW	7 to 9	29

Source: E Source

Published maps can provide a general sense of the wind resource, but more specific data are required to determine whether a wind project is feasible. Airports and meteorological research stations often collect longer-term, site-specific wind data and should be contacted as a first step. (The weather reporter at your local television news channel, if you have one, may be able to point you to data sources.) The best data are on-site, long-term (one year or more), actual measured data on wind speed and direction. Such data are not inexpensive to collect; they require anemometers, data loggers, and subsequent analysis of the data. Some state energy offices have anemometer loan programs, which are sponsored by the DOE. To find out whether your state has such a program, start your search at www.naseo.org/members/states.htm. When planning its wind farm, for example, Lamar Light and Power (Lamar, CO) borrowed anemometers through the Western Area Power Administration's (Lakewood, CO) equipment loan program. For more information on this program, see www.wapa.gov/es/loan/default.htm.

Once you have good wind data for a specific site, it's straightforward to calculate the annual kilowatt-hour output you can expect to obtain from wind turbines. This is discussed below.

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How Does Wind Power Work?

A wind turbine converts the energy of the wind into electricity. The moving wind strikes the rotor blade, causing it to spin. The spinning rotor turns a generator, which creates electricity. The key elements of a wind turbine are the rotor (including the blades), the nacelle (which contains the gearbox and the generator), the tower, and the control and monitoring equipment. Wind turbines come in all sizes, from portable 100 W units to massive utility-scale units that produce up to 5 MW of power. In general, the larger the turbine, the lower the cost per kilowatt-hour of the electricity produced.

The average size of new turbines for utility-scale projects has been increasing rapidly. New utility-scale projects installed in 2005 typically use turbines in the 1 to 2 MW range—up considerably from the 750 kW turbines installed in the late 1990s and early 2000s.

The technological details of turbines vary quite a bit, depending on the size of the turbine; here we discuss two representative turbines: a 10 kW model and a 1.5 MW model.

A typical 10 kW turbine has three blades, with a 20-foot-diameter blade. Wind strength increases rapidly with height, so these turbines are typically placed on towers at least 80 feet high. As shown in table 1.1, these turbines start producing electricity at about 8 mph and reach their rated output—10 kW—at 31 mph. They can be wired to connect directly to the utility grid or to charge batteries for off-grid use. To connect to the grid, the wind turbine's output must be synchronized to the grid. This can be achieved by converting the wind's AC (alternating current) output to DC (direct current) and then converting it back to grid-compatible AC.

A typical 1.5 MW utility-scale turbine has three blades and a rotor diameter of about 230 feet. In comparison, a Boeing 747 has a wingspan of about 210 feet. The hub height (that is, the top of the tower where the nacelle is located and the rotor connects) is about 215 feet above the ground. It starts turning at about 7 to 9 mph (producing very little electricity at those speeds) and reaches rated output (1.5 MW) at 29 mph. Specialized equipment is needed to transport and assemble these huge devices. In fact, a growing constraint on turbine size is the practical challenge of transporting more than 100-foot-long blades from the manufacturer to the installation site.

These large turbines are rarely installed individually. The overall project economics are much more attractive when 20 to 50 turbines are installed as a wind farm. This allows economies of scale in purchasing, installation, maintenance, and operations.

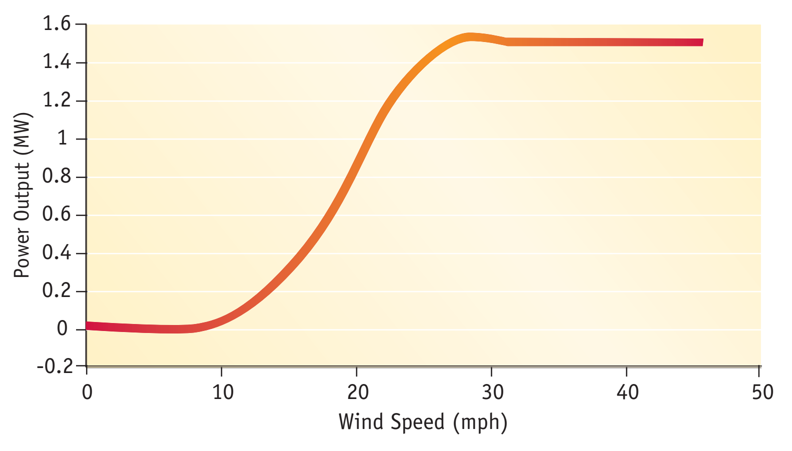
As a general rule, turbines should be spaced three to five diameters apart perpendicular to the wind in areas with a predominant wind flow direction. In areas with highly variable wind direction, turbines should be placed five to nine diameters apart. Note, however, that turbine placement and land requirements depend entirely on the specific location and should be based on monitored wind data, collected at turbine height.

The technical performance of wind turbines can be measured several ways, as described below.

ELECTRIC OUTPUT

The power (megawatts) and generation (megawatt-hours) output of a wind turbine is a direct result of the amount of wind it experiences. (This is why accurate wind resource data are so important.) Turbine manufacturers provide "power curves," which show power output as a function of wind speed (figure 1.1). Links to manufacturers' Web sites can be found at http://web.memberclicks.com/mc/page.do?orgId=awea.

Figure 1.1. Typical Power Curve for a 1.5 MW Turbine



Source: E. Source

Once one has a power curve and wind data, it's a straightforward process to calculate expected electricity output. For example, assume that the wind speed is 5 mph for 5,000 hours per year, 20 mph for 1,000 hours per year, and 35 mph for 2,760 hours per year. (This is very simplistic; actual wind speeds are much more evenly distributed.) From the power curve for the larger turbine in figure 1.1, it is evident that the 5 mph winds produce no electricity, the 20 mph winds produce 0.8 MW, and the 35 mph winds produce peak output of 1.5 MW. Therefore, the approximate electric output would be (0.8 MW x 1,000 hours) + (1.5 MW x 2,760 hours) = 4,940 MWh per year.

CAPACITY FACTOR

This is an important measure of wind technical performance. Capacity factor is defined as the actual output (megawatt-hours per year) divided by the theoretical maximum output, if the turbine operated at peak output for the entire year. For example, if the turbine in figure 1.1 actually produced 1.5 MW year-round, the output would be 1.5 MW x 8,760 hours/year = 13,140 MWh/year. However, the projected output as calculated above was 4,940 MWh/year. Thus, the capacity factor is (8,100/21,900) = 0.38, or 38%.

Capacity factor is mostly determined by the wind resource: The better the wind, the higher the capacity factor. In fact, if good long-term data on the actual wind resource are available, the capacity factor can be predicted with reasonable certainty. In 2004, Lamar Light and Power installed four 1.5 MW turbines adjoining a wind farm of 108 turbines. Rick Rigel of Lamar Light and Power noted only a slight difference between the 35.65% capacity factor the feasibility study projected and the turbines' actual 32.48% performance. However, this small change resulted in a production loss (and therefore revenue loss) of almost 9%.

A secondary influence on capacity factor is availability. Wind turbines are mechanical devices, and they suffer from both "planned outages" (for planned maintenance) and "unplanned outages" (for unplanned maintenance and repair). In modern turbines, the need for maintenance has been significantly reduced. Availability (defined as the fraction of time the turbine is available for use) typically exceeds 98% for today's utility-scale turbines. Note, however, that a turbine can have an availability of 100% and still produce no electricity if the wind is not blowing.

Co-op experience to date suggests that a short fine-tuning period in the first few months of operation is to be expected. "One of our units has a more than 95% availability rate, and even with start-up problems, the other two do better than 90%," reported Rigel. Newer large wind projects with on-site maintenance crews often experience availability consistently in the 95% to 99% range.

Smaller and older turbines can be a bit more temperamental. CD Kendall of Consumers Energy (Marshalltown, IA) reports that his company's 108 kW turbine occasionally has problems starting up when winds reach a speed at which the turbine should start generating electricity.

Understanding Intermittency

The electrical output of wind turbines fluctuates with the wind. Unlike fossil fuel power plants, wind turbines cannot be dispatched and cannot be directly controlled by grid operators. Wind turbines are not considered "firm capacity." In addition, wind turbines impose costs on the system; for example, they need to have some spinning reserves in case the wind stops blowing. Ongoing research to measure these ancillary service costs has found that they typically range from 0.1 cent to 0.6 cents per kWh. At low wind penetrations (that is, when wind supplies 5% or less of total system electricity), these costs are at the low end of the range. As wind penetration increases, costs increase to the higher end of the range. However, a recent study by the National Renewable Energy Laboratory (NREL), "Wind Power Impacts on Electric Power System Operating Costs," (Smith et al., March 2004, www.nrel.gov/docs/fy04osti/ 35946.pdf) concluded that "it is now clear that, even at moderate wind penetrations, the need for additional generation to compensate for wind variations is substantially less than one-for-one and is generally small relative to the size of the wind project." This statement addresses the amount of generation that must be available to respond to sudden changes in the wind, not the amount of other generation the wind will displace. Although wind has some ability to displace other resources (known as "capacity value"), that capacity value is typically considered to be less than 20% of the nameplate rating of the project, unless unusual circumstances provide a basis for the local grid system to assume a higher value (i.e., reliable periodic winds during system demand peaks, nontechnical regulatory dictates, etc.).

How Much Does Wind Power Cost?

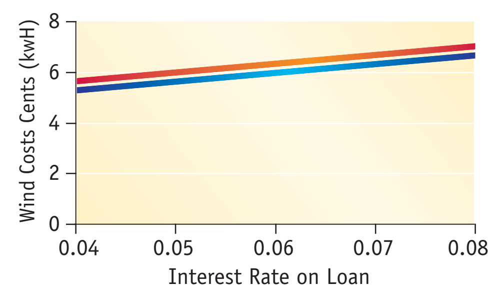
The cost of wind power depends on the wind resource, the details of the financing, various site-specific costs, and countless other factors. There is now enough experience with utility-scale wind, however, to allow for good predictions of large wind costs. Cost data with smaller turbines are more limited.

LARGE UTILITY-SCALE TURBINES

Capital (first) costs of large (1.5 to 2.5 MW) wind turbines are typically about $1,300 to $1,500/kW. As of late 2005, prices were at the higher end of this range, largely because of higher steel prices, a decline in the U.S. dollar that has increased the U.S. dollar prices of turbines produced in Europe and demand for new wind turbines outstripping supply. Over the last four years, the estimated cost of a large wind project has increased 30% to 40%. About 70% of the first cost is for the hardware—the blades, rotor, gearbox, generator, tower, and monitoring and control equipment; 20% is for construction and connection to the grid; and the remaining 10% is for legal, administrative, and other miscellaneous costs. Any needed transmission line installations or upgrades are not included in this initial cost estimate. Those costs can be significant, particularly if system upgrades are needed to provide the electrical transmission needed for the output of the project.

Operations and maintenance (O&M) costs are typically about 0.5 cents to 0.7 cents per kWh. Fuel costs are zero. Some O&M costs (such as equipment maintenance) are proportional to actual output (i.e., kilowatt-hours per year), whereas other costs (such as site security and road maintenance) are not. In addition, land lease costs need to be considered. Such leases are typically $3,000 to $5,000 per year per turbine. Additional costs, such as property taxes, insurance, and margins should also be added to the above costs.

Figure 1.2. Interest Rates and Wind Costs



Source: E Source

Capital costs and O&M costs can be combined into an overall levelized cost per kilowatt-hour. We estimate the levelized cost for large wind turbines at 2.7 cents to 5.4 cents per kWh, after allowances for the PTC. Because wind turbines—like most renewable technologies—are capital-intensive, levelized costs are strongly influenced by interest rates (figure 1.2).

This, however, is simply the amount of revenue one would have to receive to cover the capital and O&M costs. Actual market prices for wind can be very different for many reasons, notably the following:

- Availability of additional public funding, such as accelerated depreciation. Tax benefits can easily cover half or more of total project investment costs. For an up-to-date list of federal and state public wind subsidies, see www.dsireusa.org.
- Revenue from sales of green tags, also called renewable energy credits. The revenue from tag sales depends in part on whether they are sold to meet a renewable portfolio standard (RPS) or sold into voluntary markets. In general, tag prices are higher in regulatory compliance markets.
- Profit needed for investors to commit financing.
- Prevailing wholesale power prices.

SMALL TURBINES

A typical 10 kW turbine costs $25,000, which includes a voltage regulator or inverter but not a tower or batteries (this turbine costs $2,500 per kW). In addition to the cost of the turbines, towers are typically $8,000 to $12,000, depending on height and design, and not including installation. O&M costs are presumably low, but they are not well documented. Making a number of reasonable assumptions yields a levelized cost estimate of 10.5 cents to 17 cents per kWh, including the federal PTC.

Small turbine projects require careful design to ensure safety of utility personnel. Multiple disconnects, clearly labeled and easily accessible, should be installed.

Specific Questions to Ask When Considering Wind Power

Five essential steps, or components, must be in place for a wind project to go forward. If you can answer yes to ***all five*** of these questions, a wind project is worth considering in more detail. If you answer no to any of these questions, a wind project is not economically feasible.

1. Is there a sufficient wind resource?

A feasible wind project requires good wind data for a specific site, documenting that the wind resource is sufficient. For a small (10 kW) turbine, winds are needed of at least 10 mph for a minimum of 25% of the time (that is, 10 mph or more at least one full day out of every four days). Large, utility-scale turbines require winds of 15 mph or more for a minimum of 25% of the time. Ideally, long-term (one year or more), measured wind data are available. These data can then be assessed and combined with performance data from turbine manufacturers to yield predictions of kilowatt-hour output. Although such data collection and analysis can be time-consuming and expensive, it is essential to determine whether a wind project is viable (and lenders will likely require it in any case). Consultants can assist with this work; see http://web.memberclicks.com/mc/page.do?orgId=awea for a searchable database of wind consultants.

2. Is the land available for wind energy development?

A number of proposed wind projects have run into siting conflicts when neighbors opposed the wind farm for aesthetic reasons. Others have run afoul of zoning, environmental, or other considerations. If a co-op is considering a small, single turbine on private land, it may need to consider zoning restrictions. The county planning or land-use office is the best source for such information. Handbooks and further information on siting and permitting for large wind turbines and wind farms can be found at www.nationalwind.org/publications/siting.htm.

3. Is there a buyer/market for the wind electricity?

Wind power, like any commercial product, is commercially viable only if someone wants to buy it. A viable project requires a long-term power purchase agreement or other solid, low-risk commitment. There are several potential revenue streams that can result from a wind project, notably from wholesale power markets, from green tag sales, and from tax advantages. Green tags can be sold into regulatory or voluntary markets; a list of green tag marketers and brokers can be found at www.eere.energy.gov/greenpower/markets/certificates.shtml?page=2.

As discussed above, the economics of smaller, single-turbine projects are rarely compelling. If a co-op decides to offer net metering, such projects will look more attractive from the turbine owner's perspective.

4. Is there transmission access/capacity?

Large projects must tie in to the grid at higher voltages. Are there transmission lines near the proposed site and, if so, do these lines have unused capacity that is available? Access to transmission is a growing problem for wind power and one that sometimes cannot be solved with money: One cannot just create transmission capacity where none exists. Building new transmission capacity is very expensive, time-consuming, and politically sensitive. More information on transmission for large wind can be found at www.nationalwind.org/workgroups/transmission.

Smaller (10 kW) turbines can often tap directly into the distribution system. However, care must be taken to ensure that the distribu-

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tion system has the needed capacity to support the turbine.

5. Is capital available at a reasonable cost? Today, a large wind farm can typically cost about $1,400/kW, so a 20 MW (20,000 kW) wind farm will cost $28 million. Banks and other large lenders are increasingly comfortable with wind power, but they still must be convinced that the expected return outweighs the risks and opportunity costs. "Good performance and longevity are the biggest part of making wind energy affordable," said Rigel of Lamar Light and Power. "Our fuel costs are fixed—we don't have any. But we are paying on the bonds whether the turbines are generating or not."

Smaller turbines typically have first costs of $30,000 to $50,000, and traditional lenders (such as local banks or credit unions) will in most cases be unfamiliar with this technology. Self-financing, or loans secured by real property may be the only options for small wind projects.

Outlook for Wind Power

Continued rapid growth in large (more than 50 MW) wind farm installations is expected for the next two years, largely because of the extension of the PTC through the end of 2007 (see "The Energy Policy Act of 2005" in Section 10). Because demand for turbines and associated equipment currently exceeds the supply, hardware costs are up markedly from two to three years ago.

The outlook for smaller turbines is less promising. Costs are still high, and the PTC applies only to projects in which the electricity is sold to a third party (as opposed to used by the turbine owner). Small turbine projects make economic sense only in niche applications, such as off-grid use or when financially supported by grants or other forms of direct subsidy.

For More Information on Wind Power

For more information on wind power, please consult the following resources:

- A basic and thorough tutorial on wind energy is available at www.awea.org/faq/index.html.
- A rough first cut at wind resource data can be made by examining state-level wind data. See http://rredc.nrel.gov/wind/pubs/ atlas/maps.html.
- A concise source for small wind (usually defined as less than 100 kW) is www.awea.org/smallwind.
- A comprehensive and searchable database of the wind industry, including wind turbine manufacturers and dealers, consultants, and others, is available at http://web.memberclicks.com/mc/page.do?orgId=awea.
- A database of large U.S. wind projects—both installed and under construction—is available at www.awea.org/projects.