Online-PDH©

Online Continuing Education for Professional Engineers
Since 2009

Wind Power Basics and Small Wind Systems

PDH Credits:

3 PDH

Course No.:

WPT101

Publication Source:

US Dept. of Energy (EERE)

"Wind Power Today" – Pub. #DOE/GO-102007-2424
Small Wind Electric Systems – Pub. #DOE/GO-102005-2095

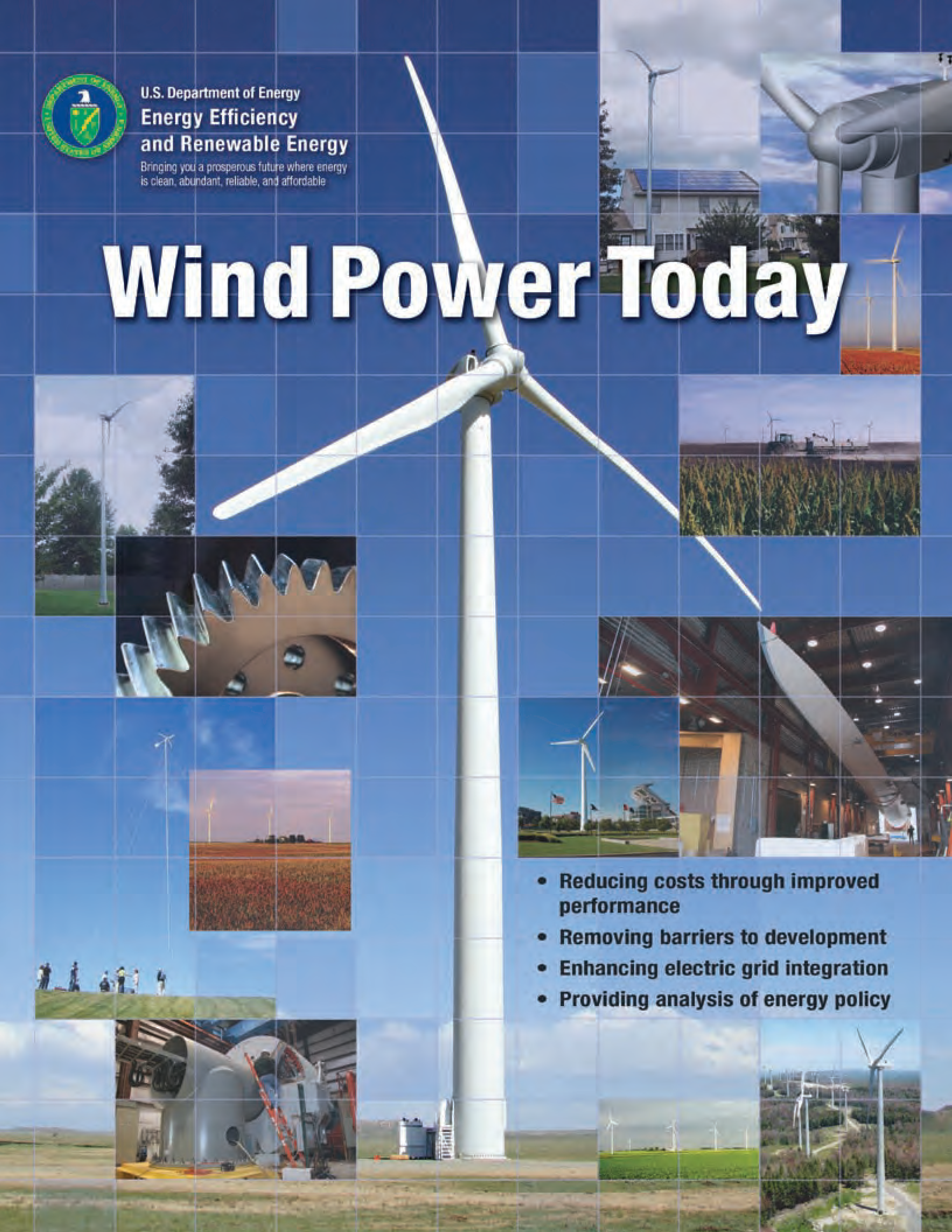
Release Date:
May, 2007 and March, 2005 (respectively)

1265 San Juan Dr. - Merritt Island, FL 32952
Phone: 321-501-5601

U.S. Department of Energy
Energy Efficiency and Renewable Energy

Bringing you a prosperous future where energy is clean, abundant, reliable, and affordable

Wind Power Today



- **Reducing costs through improved performance**
- **Removing barriers to development**
- **Enhancing electric grid integration**
- **Providing analysis of energy policy**

Leading the Nation's Wind Energy R&D

Wind energy technology has come a long way over the past decade. In 1996, the average utility-scale wind turbine was almost as tall as a 12-story building and it produced enough electricity to power about 125 average American homes. At the time, these turbines were considered by some to be quite large, but by today's standards, they would be considered small for utility-scale production. The average turbine installed in 2006 (rated at 1.5 MW) was twice as tall as the '96 model. It is almost as tall as the Statue of Liberty and has a rotor large enough to sweep a football field. A 1.5-megawatt (MW) turbine produces enough electricity to power almost 500 homes, and again, that might be considered small when compared to the 3- to 5-MW machines being developed today that will generate enough power for more than 1,300 homes. A 3.6-MW machine has a rotor diameter large enough to park 24 cars in end to end, and a 5-MW machine is as tall as the Space Needle in Seattle, Washington.

The U.S. Department of Energy (DOE) has worked with industry for more than 25 years to bring the technology to where it is today, developing larger machines that are more efficient and that capture more energy from the wind. As the machines have increased in size and performance, the cost of producing energy has dropped—from $0.80 (current dollars) per kilowatt-hour (kWh) in 1980 to about $0.04/kWh today—so that in some areas of the Nation, utility-scale wind power is the most cost-effective form of new generation available.

DOE has also been working to improve the performance and reduce the costs for small and distributed wind energy systems. These systems show great potential for engaging local populations in addressing America's energy future. Advances in small wind technology have produced quieter and more reliable systems that are easier to install and cost less to operate.

The wind energy industry has become the fastest growing utility-scale energy resource in the Nation, growing from 1,800-MW of capacity in 1996 to more than 11,600 MW in 2006. 2006 was a record-breaking year with new installations of more than 2,400 MW and a 27% annual growth rate. The new generating capacity installed in 2006 represents a capital investment of almost $4 billion, more than 10,000 new job-years nationwide (10,000 one-year jobs or 1,000 ten-year jobs), and more than $5 to $9 million in annual payments to landowners. The land payments and jobs provide a much needed economic boost to America's struggling rural economies.

As a clean, domestically produced renewable energy resource, wind energy also contributes to our Nation's energy security and environmental quality. The current capacity will generate more than 30 million megawatt-hours (MWh) and displace approximately 18 million metric tons of carbon dioxide per year.

Although 11,600 MW is enough capacity to power about 3 million average homes, it still constitutes a very small share of the total U.S. generation. According to the Energy Information Administration,

600'

500'

400'

300'

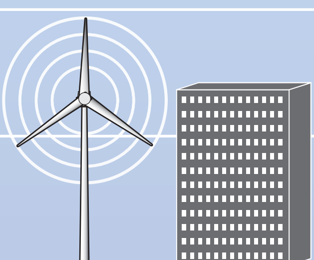
200'

100'

0'

1996

The 550-kW Zond Z-40, commonly installed in 1996, has a 131-ft (40-m) hub height and is as tall as a 12-story building.



2006

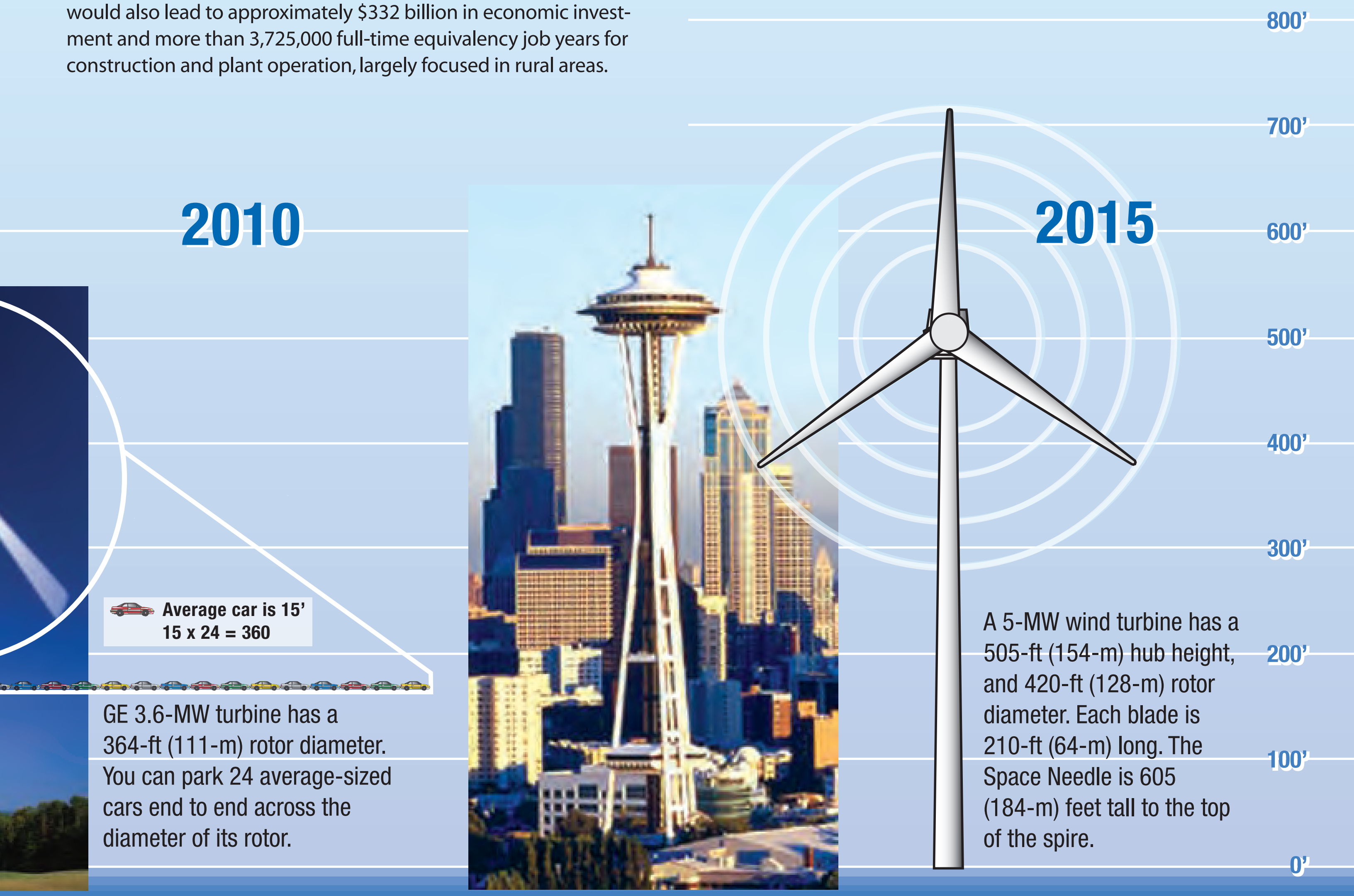
The GE 1.5-MW wind turbine, commonly installed in 2006, has a 275-ft (84-m) hub height and is almost as tall as the Statue of Liberty, which is 305 feet (93-m) tall from the ground to tip of torch.

as of October 2006, wind accounted for only 0.7% of the national electric supply. Coal-fired plants generate the majority (48.5%) of the Nation's electrical energy, followed by natural gas (20.5%) and nuclear plants (19.2%). Conventional hydroelectric, petroleum-fired plants, and other renewables constitute the remaining generation sources.

To accelerate the development and use of advanced clean energy technologies, President George W. Bush launched an Advanced Energy Initiative in 2006. According to the Initiative, areas with good wind resources have the potential to supply up to 20% of the electricity consumption of the United States. The DOE Wind Energy Program is collaborating with industry and stakeholders to analyze credible scenarios for high levels of wind energy use, and determine what actions will best address the technology, market, and policy challenges to maximizing the Nation's opportunity for harnessing its immense wind resources. To provide 20% of the Nation's electricity supply, U.S. wind capacity would have to increase from its current 11,600 MW to more than 325,000 MW. Incorporating this amount of wind generated electricity in the Nation's electricity portfolio could avoid emission of 3,500 million metric tons of carbon equivalent through 2050—equivalent to the amount of carbon produced by the entire transportation sector over 3-1/2 years. This would also lead to approximately $332 billion in economic investment and more than 3,725,000 full-time equivalency job years for construction and plant operation, largely focused in rural areas.

To provide greater support for the President's initiative, in 2006, the DOE Wind Energy Program shifted the emphasis of its activities to accelerate the market penetration of wind technology. Shifts in program activities include:

1. Supporting the development of 20% U.S. energy by wind.
2. Increasing the program's efforts to overcome near-term deployment barriers to wind projects.
3. Collaborating with the DOE Office of Electricity Delivery and Energy Reliability to ensure that wind energy is appropriately represented in grid expansion and modernization efforts around the Nation and conducting outreach to Federal, state, and local organizations and utilities.
4. Expanding work in the area of turbine performance and reliability to mitigate risk to investors, developers, and operators.
5. Expanding program activities in the distributed wind technology market sector (residential, farm, small business).



WIND ENERGY PROGRAM SUPPORT

Sandia National Laboratories developed an advanced data acquisition system (ATLAS II) on a GE Wind 1.5-MW wind turbine. The turbine is part of a cooperative activity involving SNL, GE Wind, and NREL.

Sandia researchers work with industry partners to develop the advanced materials and manufacturing processes required by longer blades.

The NWTC's resonance blade test system uses a 1000-pound (454-kg) weight housed in a stand attached to the end of the blade. The system allows researchers to apply 3 million cycles of fatigue test to a blade in 50 days rather than the 116 days required by the previous test system.

The NWTC has two dynamometer test facilities—a 2.5-MW and a 225-kW—to help its industry partners conduct a wide range of tests on wind turbine drivetrains and gearboxes.

The DOE Wind Energy Program is one of 10 clean energy technology programs within the Department of Energy. It is managed by program staff at DOE Headquarters in Washington, D.C., and its Project Management Center (PMC) in Golden, Colorado, manages the financial assistance, provides program support, and conducts outreach activities. The program provides funding to a wide range of public and private sector partners, with primary focus on the National Renewable Energy Laboratory's (NREL) National Wind Technology Center (NWTC) near Boulder, Colorado, and Sandia National Laboratories (SNL) in Albuquerque, New Mexico. NREL and SNL conduct wind energy research with industry partners and researchers from universities nationwide to advance wind energy technologies. Each laboratory is extensively equipped with a unique set of skills and capabilities to meet industry needs.

As the lead research facility for the program, NREL's NWTC conducts research across the complete spectrum of engineering disciplines that are applicable to wind energy, including: atmospheric fluid mechanics and aerodynamics; dynamics, structures, and fatigue; power systems and electronics; and wind turbine engineering applications. The center also provides design reviews and analysis; dynamometer, field, and blade testing services; and field verification for wind turbines that range in size from 400 watts to 2.5 MW. The NWTC is the Nation's only wind energy technology test facility accredited to International Electrotechnical Commission (IEC) standards. Industry partners may use the center's facilities to conduct atmospheric, static-strength, and fatigue tests on turbines and components, including its 2.5-MW dynamometer, to conduct lifetime endurance tests on a wide range of wind turbine drivetrains and gearboxes. In addition, the NWTC completed construction of a 225-kW dynamometer in 2005 that will aid development of advanced generators and power electronics for small wind systems. The NWTC also has two permanently installed advanced wind turbines to test new control schemes and equipment, and sites for testing industry prototype wind turbines.

SNL specializes in all aspects of wind-turbine blade design and system reliability. Activities at SNL focus on reducing the cost of wind generated electricity and improving the reliability of systems operating nationwide. Research disciplines include: materials, airfoils, stress analysis, fatigue analysis, structural analysis, and manufacturing processes. By partnering with both universities and industry, SNL has advanced the state of knowledge in the areas of materials, structurally efficient airfoil designs, active-flow aerodynamic control, and sensors. Researchers at the laboratory are currently investigating integrated blade designs where airfoil choice, blade planform, materials, manufacturing process, and embedded controls are all considered in a system perspective. By collaborating with operators, developers, and manufacturers, SNL evaluates known reliability problems and develops tools and methods to anticipate and investigate future reliability issues.

TECHNOLOGY ACCEPTANCE

In support of Advanced Energy Initiative objective to expand the use of wind energy, the Wind Energy Program is increasing its efforts to overcome near-term deployment barriers to wind by enhancing public acceptance, promoting supportive public policies, engaging key stakeholders, and addressing siting and environmental issues.

In 1999, only four states boasted more than 100 MW of installed wind capacity. By the end of 2006, 16 states had more than 100 MW and six more states are expected to reach that capacity by the end of 2007. The goal of the DOE Wind Powering America (WPA) project is for 30 states to have 100 MW of wind installed by 2010.

To achieve its goal, WPA supports the formation of state wind working groups, providing stakeholders with timely information on the current state of wind technology, economics, state wind resources, economic development impacts, and policy options/issues. Group members include landowners and agricultural sector representatives, utilities and regulators, colleges and universities, advocacy groups, and state and local officials. In 2006, WPA launched four new state wind working groups in Illinois, Indiana, Missouri, and New Jersey, bringing the total number of state wind working groups to 29. WPA also supported events in 11 states and convened its 5th annual All-States Summit in Pittsburgh, Pennsylvania. The summit provided participants with an opportunity to share strategies and lessons learned and to visit with experts on topics such as avian and wildlife issues, siting, transmission, community wind, small wind, Native American projects, operating impacts, utility myths, regulators, radar, interconnection, and wind resources and mapping.

Rural Economic Development

Rising fuel costs, low commodity prices, and a lack of jobs are just a few of the economic issues faced by rural communities nationwide. To address these issues, WPA works with rural community leaders, U.S. Department of Agriculture local and national representatives, state and local officials, the Farm Bureau, the Farmers' Union, representatives of growers associations, agricultural schools, and the local financial community to explore wind development options, benefits, and barriers. Achieving the goals of WPA during the next 20 years will create $60 billion in capital investment in rural America, provide $1.2 billion in new income for farmers and rural landowners, and create 80,000 new jobs.

Wind Power for Native Americans

The United States is home to more than 700 Native American tribes located on 96 million acres (39 million hectares), much of which have excellent wind resources that could be commercially

The new wind generating capacity installed in 2006 (2,454 MW) represents $5 to $9 million in annual payments to rural landowners.

developed to provide electricity and revenue to the reservations. Before these resources can be fully realized, many issues need to be resolved. These include the lack of wind resource data, tribal utility policies, sovereignty, perceived developer risk, limited loads, investment capital, technical expertise, and transmission to markets.

To support the development of Native American wind resources, WPA provides a wide range of technical assistance and outreach activities to more than 20 tribes from 13 states. To help tribes understand their wind resource and potential development options, WPA administers a Native American Anemometer Loan Program. In 2006, WPA helped install four 40- to50-m (130 to 165 ft) towers and one 20-m (65 ft) tower. Installation of two to four more of the tall towers is anticipated in 2007.

WPA also provides wind energy training for Native Americans through the DOE-supported Wind Energy Applications and Training Symposium (WEATS) at the NWTC. Training sessions in the 2006 symposium included Wind Applications, Wind Fundamentals, Small Wind (on- and off-grid applications), Site Selection and Wind Resource Assessment, Land Agreements/Environmental Review, Permitting, Interconnection and Transmission, and Wind Integration. Participants also toured the NWTC and the Ponnequin Wind Farm.

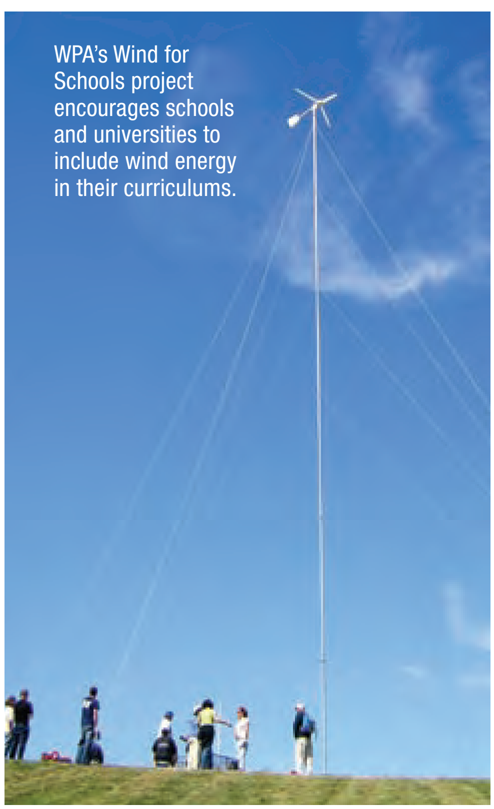
Wind for Schools

At a grass-roots level, WPA is engaging rural America in a discussion of wind energy while developing a knowledge base through its Wind for Schools (WfS) project. The objectives of the project are to:

1. Engage rural school teachers and students in wind energy education
2. Equip college students in wind energy applications and education to provide the growing U.S. wind industry with interested and equipped professionals
3. Introduce wind energy on a small scale in rural communities, starting a discussion of the benefits and issues in using wind energy

To accomplish its objectives, the WPA team at NREL assists schools with the installation of a small wind turbine through a coordinated community effort. Team members include a WfS facilitator within each state; a wind application center at a state-based university or college to provide technical assistance; a school, science teacher, school administration, and community to host or own the wind turbine; a green tag marketer to assist with the sale of the green attributes of the turbine to defray system costs; a wind turbine manufacturer to provide the wind turbine system; the local utility or energy cooperative; and the state energy office.

WPA launched it first WfS project in Colorado in 2006 and plans to replicate the process in Nebraska, Kansas, South Dakota, Montana, and Idaho in 2007-2008.


WPA's Wind for Schools project encourages schools and universities to include wind energy in their curriculums.


The Grassland Shrub Steppe Species Collaborative – a 4-year effort to study the impact of wind turbines on prairie chicken habitats in Kansas, is one study being conducted with program support to help understand wind-wildlife interactions.

Environmental Assessment

WPA also works with universities and non-government organizations to address wind turbine siting issues such as aesthetics, radar interference, and wind-wildlife interactions. In 2006, the program worked with AWEA, the National Wind Coordinating Committee (NWCC), and other federal agencies on wind power-radar interaction issues that affected more than 1000 MW of planned installations.

Wind power-radar interaction issues gained national attention in 2006 due to the potential for radar operations to be affected by wind turbines. Interference occurs when radar signals are reflected back by wind turbines causing clutter on the radar screens. In July, more than 100 experts, including representatives from AWEA, DOE, the Department of Defense, and the Federal Aviation Administration attended a Wind Power and Radar Issue Forum brief convened by the NWCC to discuss the influence of wind energy on aviation radar and possible mitigation strategies. This collaboration and follow-on interaction helped facilitate the approval of 950 MW of wind projects.

To help resolve wind-wildlife interactions, the program supported two collaborative efforts, the Grassland Shrub Steppe Species Collaborative—a 4-year effort to study the impact of wind turbines on prairie chicken habitats in Kansas—and the Bat and Wind Energy Collaborative that investigates bat and wind turbine interaction. In addition, the NWCC hosted its sixth Wildlife Research Meeting in Texas. The purpose of the meeting was to bring participants up-to-date on research being conducted to understand the interaction of birds, bats, and other wildlife with wind energy development, examine what has been learned about ways to minimize or mitigate wind energy's impacts on wildlife, and identify gaps in knowledge and research needs.

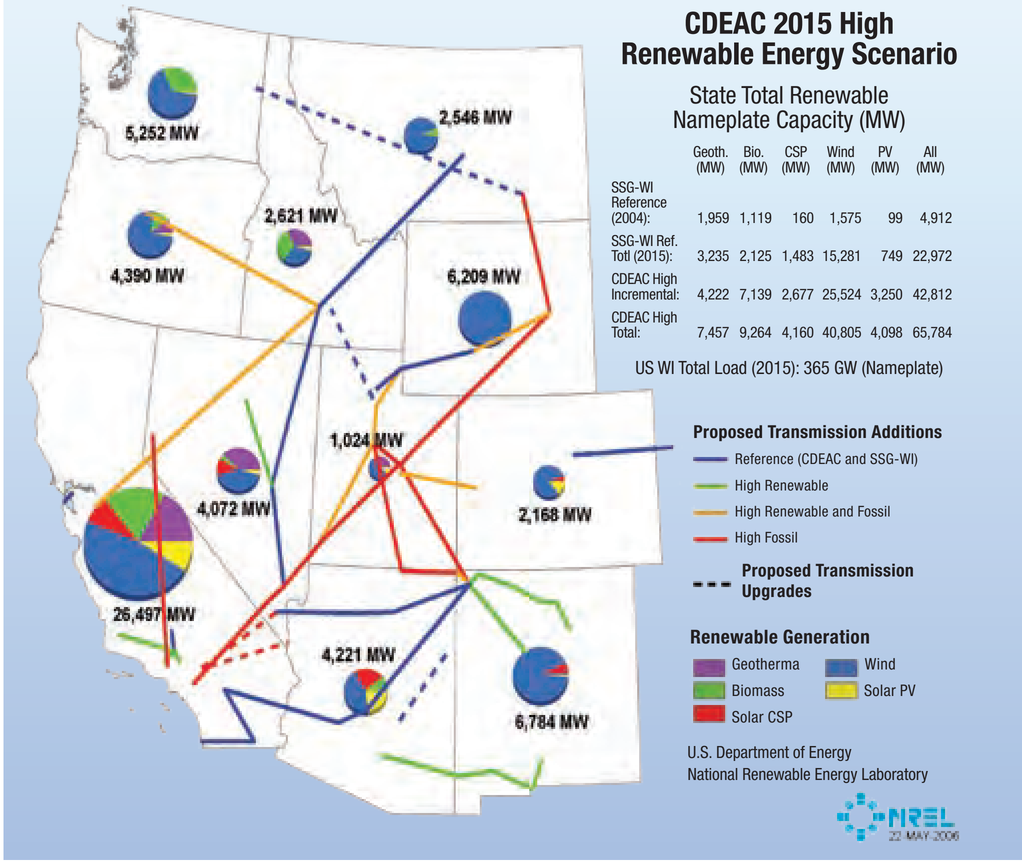
FACILITATING INTEGRATION OF WIND ON THE GRID

Systems Integration

The natural variability of the wind resource can present challenges to grid system operators and planners with regard to managing regulation, load following, scheduling, line voltage, and reserves. While the current level of wind penetration in the United States and around the world has provided substantial experience for successful grid operations with wind power, many grid operators need to gain a better understanding of the impacts of wind on the utility grid before they can feel comfortable increasing the percentage of wind in their energy portfolios. The goal of the program's systems integration research is to address interconnection impacts, electric power market rules, operating strategies, and system planning needed for wind energy to compete without disadvantage to serve the Nation's energy needs.

In 2006, the Wind Energy Program conducted a number of studies to provide states and utilities with the information and tools they need for wind energy development. For example, the program provided extensive GIS-based wind resource and transmission data to help the Western Area Governors Association (WGA) and the Clean and Diversified Energy Advisory Committee (CDEAC) to identify 30 GW of clean power that could be developed by 2015. In 2006, the CDEAC Wind Task Force developed a set of supply curves based on this data. The findings of the study indicate that the wind resource in the WGA region is more than enough to economically achieve the WGA 30-GW target for clean energy development.

Additional 2006 system integration activities included a study that provided the Western Farmers Electric Cooperative with a systems integration and wind power data analysis, a wind integration study for the state of Minnesota, and a study for Xcel Energy in Colorado that provided the company with the data it needs to assess the technical and economic impact of adding a significant amount of wind generation to its energy portfolio.



The Wind Energy Program provided the Western Area Governors Association and the Clean Diversified Energy Advisory Committee with extensive wind map GIS and transmission data to help them determine if there is enough wind resource to help them achieve 30 GW of clean power by 2015.

NREL Supplies WAPA with Wind Farm Training Simulator

The Western Area Power Administration (WAPA) provides electric power system operations training to power system operators and dispatchers throughout the United States and Canada at its Electric Power Training Center (EPTC) in Golden, Colorado. A significant portion of this training is performed with the Miniature Power System (MPS), an actual power system consisting of three synchronous generators (scaled up to 500 MW total), five loads, two ties to the western electrical grid, and a simulation of more than 500 miles of transmission lines. To enable WAPA to integrate wind energy into its training program, NREL's NWTC supplied WAPA with a wind farm simulator in 2006 that successfully simulated power delivery to the MPS grid from a time-series file of real wind-farm data for a 50-MW wind farm.

Enhancing Critical Energy Infrastructure

Transmission is a key energy infrastructure element critical to tapping our national wind resource and moving electricity to market, much as the interstate highway system does for the Nation's transportation needs. Much of the Nation's best wind resources cannot be tapped to meet our increasing energy demands without new transmission system capacity. The development of new transmission is challenged by many regulatory, jurisdictional siting, and cost allocation barriers. The program is working with state and Federal energy offices as well as regional organizations and utilities to support appropriate representation of wind energy characteristics and opportunities in energy infrastructure planning processes underway across the nation.

The development of new transmission corridors requires the coordination of many different organizations and groups from the Federal, regional, state, and local levels. Upgrading the Nation's transmission system, like upgrading the interstate highway system, will have substantial costs and will cross many organizational boundaries.

The Wind Energy Program is working closely with the DOE Office of Electricity Delivery and Energy Reliability to effectively coordinate the Department of Energy's contributions to the transmission planning efforts. This joint program effort will focus on linking remote regions with low-cost wind power to urban load centers, allowing thousands of homes and businesses access to abundant renewable energy

REDUCING COSTS THROUGH IMPROVED PERFORMANCE

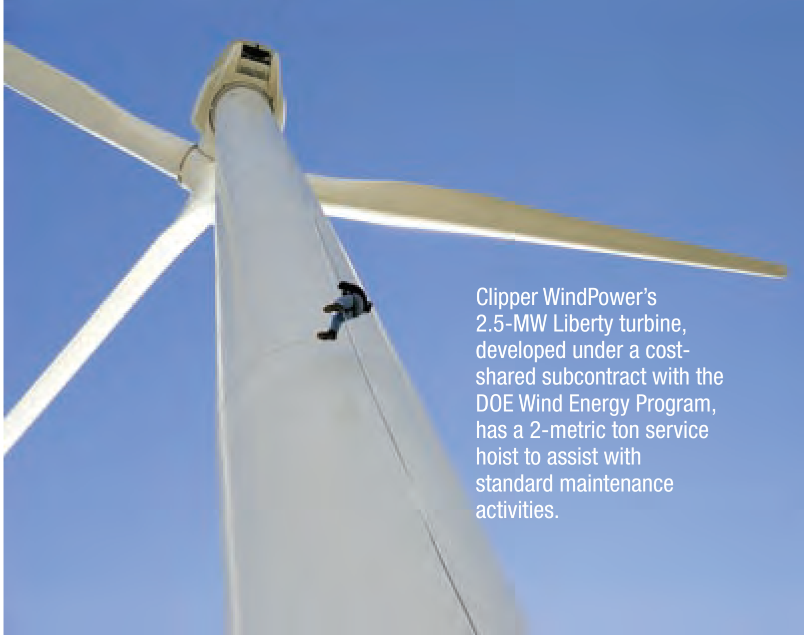
Large Wind Technologies

Although research efforts for the past two decades have led to dramatic reductions in the cost of wind energy, continued incremental improvements to wind turbine performance will lower system costs even further while improving system integration and enhancing technology acceptance.

The Wind Energy Program focuses its cost energy reduction efforts on improving wind turbine components. For example, gearboxes comprise 35% to 40% of the total wind turbine system cost. To help industry identify opportunities for improved gearbox design, the program initiated a long-term industry collaboration. NREL sponsored a drivetrain workshop in 2006 to jointly identify research needs under a multilateral industry-driven test program at the NWTC. For more information, contact Sandy Butterfield at 303-384-6902 or sandy_butterfield@nrel.gov.

Extending the fatigue life of system components like the drive-train, blades, and tower will play an important role in reducing system costs. As wind turbines become larger and taller, they become more flexible and susceptible to fatigue. To design fatigue-resistant wind turbines, the program is investigating ways to gain better control of the way the components interact and move. Control systems that regulate turbine power and maintain stable closed-loop behavior in the presence of turbulent wind inflow are critical to today's large wind turbine designs. NREL is developing and testing control systems that maximize energy capture while reducing structural dynamic loads that cause turbine parts to wear out thus increasing the cost of operation and maintenance.

To better understand improvement opportunities for wind turbine availability, SNL hosted a Wind Turbine Reliability Workshop in Albuquerque, New Mexico in October, 2006. More than 90 participants, representing wind farms, service companies, consultants, manufacturers, universities, and laboratories listened to presentations on topics ranging from hardware reliability (gearboxes, generators, pitch systems, blades, and condition monitoring) to stakeholder perspectives (owners, operations, maintenance, and user groups). The workshop also addressed planning for the characterization and reduction of operating and maintenance costs, data information sharing, and the establishment of user groups to address pressing common issues. SNL is planning another technical session in September 2007, and is currently working with the American Wind Energy Association (AWEA) Operations and Maintenance Working Group and others to begin a systematic data collection effort to collect, analyze, and report on issues affecting turbine reliability and availability. For more information contact Roger Hill, (505) 844-6111, rrhill@sandia.gov.



Clipper WindPower's 2.5-MW Liberty turbine, developed under a cost-shared subcontract with the DOE Wind Energy Program, has a 2-metric ton service hoist to assist with standard maintenance activities.

To help increase the performance of wind turbine blades, program researchers have tested new blade designs and materials at NREL's NWTC for the past decade using fatigue and static strength tests. However, the rapid growth in wind turbine size has recently out-stripped the capacity of the blade test facilities. In 2006, the program announced a CRADA seeking partners to design, construct, and assist in operating wind turbine blade test facilities capable of testing blades up to at least 70 m (230 ft) in length. The Wind Energy Program will contribute capital equipment and provide NREL staff and expertise to help develop and operate the facility. Massachusetts and Texas were chosen as the two finalists from six applications. The partners in Massachusetts include the Massachusetts Technology Collaborative, the University of Massachusetts, and the Massachusetts Executive Office of Economic Development. In Texas, the Lone Star Wind Alliance, led by the University of Houston and the Texas General Land Office, is partnering with Texas A&M University, Texas Tech University, University of Texas-Austin, West Texas A&M University, Montana State University, Stanford University, New Mexico State University, Old Dominion University, and the Houston Advanced Research Center.

Distributed Wind Technologies

Distributed wind systems have been traditionally defined as wind turbines rated at 100 kW or less installed at remote locations. The Wind Energy Program has supported efforts to increase the reliability and performance of distributed wind turbines with a goal of producing electricity at between 10 and 15 cents/kWh in a Class 3 wind resource (5.3 m/s at 10 m) by 2007. As achievement of the program's distributed wind technology (DWT) goal draws near, the program is expanding its activities and its definition for distributed applications to include wind turbines that are installed remotely or connected to the grid at the distribution system, including behind the customer meters. An independent assessment of the various segments of the distributed wind market is in progress.

NWTC team member, Garth Johnson, works in the rotor's hub after it is installed on the turbine.

The Controls Advanced Research Turbine (CART) at the National Wind Technology Center (NWTC) received a facelift in 2006 when an NWTC team replaced its 2-bladed rotor with a new 3-bladed rotor obtained from GE. The new 40-m rotor (trimmed down from 47 meters to fit the machine) will allow NREL researchers to test new control schemes applicable only to 3-bladed machines. Control schemes are used to reduce wind turbine loads and increase energy capture. Although many of the schemes tested in the past at the NWTC are applicable to both 2 and 3-bladed machines, because most of the turbines in commercial use today are 3-bladed, the upgrade to the CART will enable NREL to better meet industry research needs.

Successful 2006 LWT Projects

One program R&D project that shows potential for demonstrating a significant increase in overall system performance is the 2.5-MW Liberty wind turbine developed by Clipper Windpower. Clipper completed its prototype in 2005 after only 3 years of R&D. The new machine's innovative distributed-path powertrain design incorporates four permanent-magnet generators, and advanced variable-speed controls. According to U.S. Department of Energy Secretary Samuel W. Bodman, "Clipper's Liberty Turbine is not only one of the most advanced wind turbines ever produced, it may well be the most efficient wind turbine in the world." Successful field-tests conducted by Clipper with assistance from NREL and intensive component testing at the NWTC helped Clipper put the Liberty series turbine into production in the summer of 2006. Clipper's 2006 transaction announcements represent firm commitments of 875 MW of turbines and more than 5,000 MW of contingent orders for delivery through 2011.

Northern Power Systems (NPS) produced an award-winning power electronics package that can be scaled for use in a wide range of wind turbines, from small to multimegawatt systems. According to NPS, the new converter improves wind turbine reliability, energy capture, and grid performance. The project team was chosen by the American Wind Energy Association for its 2006 Technical Achievement Award. Tests completed in 2006 on both the converter and a 1.5-MW direct-drive generator, also developed with program support, demonstrated high-quality power output.

Knight & Carver is developing a 27.5-m (90-ft) replacement blade for a 750-kW turbine. The "STAR" (which stands for sweep twist adaptive rotor) blade is the first of its kind ever built. Its most distinctive characteristic is a gently curved tip, which prompts the blade to respond to high winds such that adverse loads are attenuated. This allows the blade length to be extended with no weight penalty and augments energy capture in low-wind-speed resource areas.

Global Energy Concepts (GEC) worked with program researchers to fabricate a 1.5-MW, single-stage drivetrain with a planetary gearbox and a medium-speed, permanent-magnet generator. The simple gearbox design and moderate-sized generator show potential for reducing tower-head weight and drivetrain costs. The company completed initial testing of this drivetrain at NREL's 2.5-MW dynamometer test facility. The generator is currently being upgraded, and a second phase of testing is planned for 2007.

Genesis Corporation is testing a new tooth form for gearboxes that promises major improvements in power density while reducing the costs of these devices. The company completed the first round of testing with positive results and is now working to refine its design through further targeted testing.

Knight & Carver's new blade design is curved to take maximum advantage of all wind speeds while passively reducing loads.

International Collaborations

International Research

The Wind Energy Program supports international wind energy research efforts as a member of the International Energy Agency (IEA) Wind Energy Executive Committee and by providing operating agents for several IEA Tasks. The United States participates in the five tasks listed below, is the operating agent for three of the tasks, and provides technical experts for the Topical Expert meetings held under Task 11: Base Technology Information Exchange.

- Task 19: Wind Energy in Cold Climates
- Task 20: HAWT Aerodynamics and Models from Wind Tunnel Measurements – Operating Agent
- Task 21: Dynamic Models of Wind Farms for Power Systems Studies
- Task 23: Offshore Wind Energy Technology and Deployment – Operating Agent
- Task 24: Integration of Wind and Hydropower Systems – Operating Agent
- Task 25: Power System Operation with Large Amounts of Wind Power

For more information on IEA activities, visit the IEA web site at www.ieawind.org

International Standards

NREL also plays an active role in the development of international standards by working with AWEA and the International Electrotechnical Commission Working Groups. International standards provide a critical link to cutting edge research which forms the basis for and harmonization of international design requirements. NREL's participation in the working groups provides consistent representation for U.S. industry, thus ensuring that standards to do not impede international industry development and trade opportunities while ensuring that environmental, safety, and health interests of industry employees, utility personnel, and the general public are maintained. NREL participates in the following active IEC Working Groups:

IEC 61400-1, Wind Turbine Safety and Design Requirements

IEC 61400-2, Small Turbine Safety and Design Requirements

IEC 61400-3, Offshore Design requirements

IEC 61400-4, Wind Turbine Gearbox Requirements

IEC 61400-11, Wind Turbine Noise Measurement

IEC 61400-12, Wind Turbine Power Performance Measurement

IEC 61400-21, Power Quality

IEC 61400-22, Certification Requirements

IEC 61400-23, Blade Structural Testing

IEC 61400-24, Lightning Protection Guidelines

IEC 61400-25, Communications and SCADA

The program is also continuing its efforts to increase the performance and reliability of small wind turbines. In 2007, the program will launch an effort to establish a small turbine testing and certification program. The program will partner with industry to test a number of small turbines to International Electrotechnical Commission (IEC) and draft AWEA standards. The project will provide high-quality, detailed, and independent test results and allow small businesses the opportunity to earn a certification granted by an independent certification body. The certification body is in the process of being formed by the Interstate Renewable Energy Council (IREC)—the Small Wind Certification Corporation.

Successful 2006 Small Wind Projects

Southwest Windpower conducted performance optimization and blade-fatigue tests at the NWTC on its new Skystream wind turbine. The 1.8-kW turbine, developed in partnership with DOE, won the Best of What's New Award from *Popular Science Magazine* and was listed as a best invention for 2006 by *Time* magazine. The new turbine has fully integrated electrical components, costs less, is easier to install, and more quiet to operate.

Northern Power Systems (NPS) is reconfiguring its 100-kW cold weather turbine for agricultural and community applications in temperate climates. The company began building its new machine in 2007 and plans to start testing the prototype at the NWTC before the end of the year. The machine will cost less to produce, and it shows good potential for filling a market gap in mid-sized wind turbines.

Windward Engineering produced a new 4.25-kW machine called the Endurance. The turbine is sized to offset the energy consumption of an average U.S. home (~11,000 kWh/yr) when installed in a Class 3 wind regime (5 m/s at a height of 10m). It employs an induction generator to simplify grid compatibility and a brake that is capable of stopping the rotor on command in any wind condition—a unique feature for a small wind system. Windward used off-the-shelf components from other industries to reduce system cost. The Endurance is currently being tested at the NWTC to IEC standards for duration, power performance, and acoustics.

Southwest Windpower's 1.8-kW Skystream turbine.

Windward Engineering's 4.25-kW Endurance wind turbine

WIND ENERGY FOR THE NEXT DECADE

For the past two years, the wind industry has enjoyed record-breaking growth, and industry experts predict that with the extension of the PTC through 2008, the next two years will be record-breakers as well. The challenge for industry is to maintain the long-term wind energy growth required to fulfill the expectations of the President's Advanced Energy Initiative. AWEA and the Wind Energy Program have formed a collaborative with 75 participating companies and organizations to evaluate credible scenarios for providing 20% of U.S. electric demand with wind and identify strategic actions that include:

- Participating in collaborative partnerships with industry that will result in turbine technology with higher reliability, expanded performance and a more competitive cost of energy
- Increasing its outreach and education efforts
- Investigating ways to increase and make transmission more accessible
- Addressing environmental issues
- Providing support for national and state policies that enable robust growth of wind energy.

The program also supports the development of expanded testing capabilities to support larger wind turbine R&D. The CRADA issued in 2006 that seeks partners to build a blade test facility capable of testing blades up to at least 70 m (230 ft) in length is one area targeted for expansion. The program is also exploring options for construction of a new drivetrain test facility of at least 11 MW in capacity.

For distributed wind technologies, the program will support potential markets by investigating applications such as off-grid water pumping for crop irrigation, residential-scale wind turbines, community wind, and hybrid wind/diesel applications.

To ensure long-term wind growth, the program is also investigating emerging applications for wind energy such as offshore installations, hydrogen production, and the production and delivery of clean water.

Hydrogen production offers an opportunity for wind to provide low-cost, clean energy for the transportation sector. NREL, in partnership with Xcel Energy, launched a wind-to-hydrogen demonstration project at the NWTC that will investigate the potential of using wind energy to produce hydrogen. The project will use two wind turbines (a 10-kW and a 100-kW), two proton-exchange membrane electrolyzers, and one alkaline electrolyzer to produce hydrogen from water. The hydrogen will be compressed and stored for later use in a hydrogen internal combustion engine where it will be converted into electricity and fed into the utility grid during peak demand hours. For more information visit http://www.nrel.gov/hydrogen/proj_wind_hydrogen.html

The program is also investigating wind energy applications that can ease the demands on the Nation's water resources. As the U.S. population grows, it places greater and greater demands on water supplies, wastewater services, and the electricity needed to power the growing water services infrastructure. Water is also a critical resource for thermoelectric power plants. Wind offers an energy source that uses limited water when compared to thermoelectric generation, and it can play a role in supplying energy for municipal water supplies and processes.

All of these applications present new challenges to the wind community, and cost and infrastructure barriers are expected to be significant. The program's vision is that this evolution pathway will begin to have an impact on the marketplace in the post-2020 timeframe.

This wind-to-hydrogen animation at http://www.nrel.gov/hydrogen/proj_wind_hydrogen.html demonstrates how electricity from wind turbines is used to produce hydrogen at NREL's National Wind Technology Center.

Key Contacts

Steve Lindenberg
Acting Program Manager
Office of Wind and Hydropower Technologies
Energy Efficiency and Renewable Energy
1000 Independence Ave., SW, Washington, D.C. 20585

Robert Thresher, Director
National Renewable Energy Laboratory
National Wind Technology Center
1617 Cole Blvd, MS. 3811
Golden, Colorado 80401

Brian Smith, Technology Manager
Wind and Hydropower Technologies
National Wind Technology Center
1617 Cole Boulevard, Golden, CO 80401

Jose R. Zayas, Manager
Sandia National Laboratories
Wind Energy Technology Department
P.O. Box 5800, Albuquerque, NM 87185-1124

Wind Energy Web Sites

U.S. DEPARTMENT OF ENERGY WIND AND HYDROPOWER TECHNOLOGIES PROGRAM
http://www1.eere.energy.gov/windandhydro/

AMERICAN WIND ENERGY ASSOCIATION
http://www.awea.org/
windmail@awea.org

NATIONAL RENEWABLE ENERGY LABORATORY NATIONAL WIND TECHNOLOGY CENTER
http://www.nrel.gov/wind/

SANDIA NATIONAL LABORATORIES
http://www.sandia.gov/wind/

NATIONAL WIND COORDINATING COMMITTEE
http://www.nationalwind.org/

UTILITY WIND INTEGRATION GROUP
http://www.uwig.org

WIND POWERING AMERICA
http://www.eere.energy.gov/windandhydro/windpoweringamerica/

A Strong Energy Portfolio for a Strong America

Energy efficiency and clean, renewable energy will mean a stronger economy, a cleaner environment, and greater energy independence for America. Working with a wide array of state, community, industry, and university partners, the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy invests in a diverse portfolio of energy technologies.

For more information contact:

EERE Information Center
1-877-EERE-Inf (1-877-337-3463)
www.eere.energy.gov

Produced for the

U.S. Department of Energy
Energy Efficiency and Renewable Energy
Bringing you a prosperous future where energy is clean, abundant, reliable, and affordable

1000 Independence Avenue, SW, Washington, DC 20585

By the National Renewable Energy Laboratory, a DOE National laboratory

DOE/GO-102007-2424

May 2007

Printed with renewable-source ink on paper containing at least 50% wastepaper, including 10% postconsumer waste.

Available electronically at www.osti.gov/bridge

Available for a processing fee to U.S. Department of Energy and its contractors, in paper, from:

U.S. Department of Energy, Office of Scientific and Technical Information, P.O. Box 62, Oak Ridge, TN 37831-0062
phone: 865.576.8401 • fax: 865.576.5728 • email: reports@adonis.osti.gov

Available for sale to the public, in paper, from:

U.S. Department of Commerce, National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161
phone: 800.553.6847 • fax: 703.605.6900 • email: orders@ntis.fedworld.gov • online ordering: www.ntis.gov/ordering.htm

PHOTO CREDITS: Cover photo: L. Fingersh, NREL/PIX 14650; Southwest Windpower/PIX 14933; Jenny Hager Photography/PIX14914; Massachusetts Technology Collaborative/PIX14872; L. Fingersh, NREL/PIX 14691; Southwest Windpower/PIX 14936; Jenny Hager Photography/PIX 14913; Jenny Hager Photography/PIX 14915; L. Fingersh, NREL/PIX15005; Tom Maves/PIX 14827; Todd Spink/PIX 14811; Todd Spink/PIX 14816. Page 2: Courtesy of American Electric Power/PIX 13884; GE Wind/PIX 12424. Page 4: Sandia National Laboratories/PIX11071; Sandia National Laboratories/PIX 13957; W. Gretz, NREL/PIX 12895; W. Gretz, NREL/PIX 13216; L. Fingersh, NREL/PIX 15004. Page 5: Jenny Hager Photography/PIX 14915; Todd Spink/PIX 14958. Page 6: Massachusetts Technology Collaborative/PIX 14872. Page 8: Clipper Windpower/PIX 14930. Page 9: L. Fingersh, NREL/PIX 14902; L. Fingersh, NREL/PIX 14899; Sandia National Laboratories/PIX 15007. Page 10: Southwest Windpower/PIX 14933; NREL/PIX 15006.

Small Wind Electric Systems

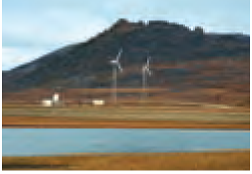
A U.S. Consumer's Guide

U.S. Department of Energy

Energy Efficiency and Renewable Energy

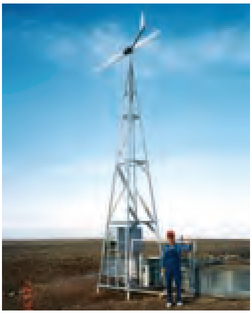
Bringing you a prosperous future where energy is clean, abundant, reliable, and affordable

Location—A home in Charlotte, Vermont
Capacity—10 kilowatts
Turbine manufacturer—Bergey Windpower Company
Photo credit—Trudy Forsyth, NREL/PIX09123



Location — Wales Wind Energy Project, Wales, Alaska
Capacity — 0.1 MW
Turbine manufacturer — Atlantic Orient Corporation
Developer — Kotzebue Electric Association
Photo credit — Steve Drouilhet, NREL/PIX09674

Capacity—10 kilowatts
Turbine manufacturer—Bergey Windpower Company
Photo credit—Bergey Windpower Company, NREL/PIX02102



Location—A ranch near Wheeler, Texas
Capacity—1 kilowatt
Turbine manufacturer—Southwest WindPower
Photo Credit—Elliott Bayly/PIX07169

Location — A farm in western Kansas
Capacity — 10 kilowatts
Turbine manufacturer — Bergey Windpower Company
Photo credit — Warren Gretz, NREL/PIX09618

Location—A cabin in South Park, Colorado
Capacity—600 watt
Turbine manufacturer—Southwest WindPower
Photo credit—E. McKenna, NREL/PIX04712

Small Wind Electric Systems

A U.S. Consumer's Guide

Introduction

Can I use wind energy to power my home? This question is being asked across the country as more people look for affordable and reliable sources of electricity.

Small wind electric systems can make a significant contribution to our nation's energy needs. Although wind turbines large enough to provide a significant portion of the electricity needed by the average U.S. home generally require one acre of property or more, approximately 21 million U.S. homes are built on one-acre and larger sites, and 24% of the U.S. population lives in rural areas.

A small wind electric system will work for you if:

- There is enough wind where you live
- Tall towers are allowed in your neighborhood or rural area
- You have enough space
- You can determine how much electricity you need or want to produce
- It works for you economically.

The purpose of this guide is to provide you with the basic information about small wind electric systems to help you decide if wind energy will work for you.

Why Should I Choose Wind?

Wind energy systems are one of the most cost-effective home-based renewable energy systems. Depending on your wind resource, a

Bergey Windpower/PIX01476

Homeowners, ranchers, and small businesses can use wind-generated electricity to reduce their utility bills. This grid-connected system installed for a home in Norman, Oklahoma, reduces the homeowner's utility bill by $100 per month.

Contents

Introduction . . . 1
First, How Can I Make My Home More Energy Efficient? . . . 2
Is Wind Energy Practical for Me? . . . 3
What Size Wind Turbine Do I Need? . . . 4
What are the Basic Parts of a Small Wind Electric System? . . . 5
What Do Wind Systems Cost? . . . 7
Where Can I Find Installation and Maintenance Support? . . . 8
How Much Energy Will My System Generate? . . . 9
Is There Enough Wind on My Site? . . . 11
How Do I Choose the Best Site for My Wind Turbine? . . . 14
Can I Connect My System to the Utility Grid? . . . 15
Can I Go "Off-Grid"? . . . 19
Glossary of Terms . . . 21
For More Information . . . 22

small wind energy system can lower your electricity bill by 50% to 90%, help you avoid the high costs of extending utility power lines to remote locations, prevent power interruptions, and it is nonpolluting.

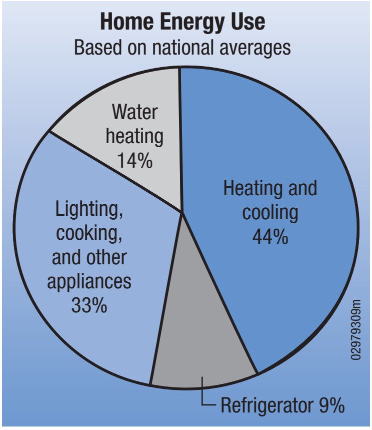
How Do Wind Turbines Work?

Wind is created by the unequal heating of the Earth's surface by the sun. Wind turbines convert the kinetic energy in wind into mechanical power that runs a generator to produce clean electricity. Today's turbines are versatile modular sources of electricity. Their blades are aerodynamically designed to capture the maximum energy from the wind. The wind turns the blades, which spin a shaft connected to a generator that makes electricity.

First, How Can I Make My Home More Energy Efficient?

Before choosing a wind system for your home, you should consider reducing your energy consumption by making your home or business more energy efficient. Reducing your energy consumption will significantly lower your utility bills and will reduce the size of the home-based renewable energy system you need. To achieve maximum energy efficiency, you should take a whole-building approach. View your home as an energy system with interrelated parts, all of which work synergistically to contribute to the efficiency of the system. From the insulation in your home's walls to the light bulbs in its fixtures, there are many ways to make your home more efficient.

- Reduce your heating and cooling needs by up to 30% by investing just a few hundred dollars in proper insulation and weatherization products.



The largest portion of a utility bill for a typical house is for heating and cooling.

- Save money and increase comfort by properly maintaining and upgrading your heating, ventilation, and air-conditioning systems.
- Install double-paned, gas-filled windows with low-emissivity (low-e) coatings to reduce heat loss in cold climates and spectrally selective coatings to reduce heat gain in warm climates.
- Replace your lights in high-use areas with fluorescents. Replacing 25% of your lights can save about 50% of your lighting energy bill.
- When shopping for appliances, look for the ENERGY STAR® label. ENERGY STAR® appliances have been identified by the U.S. Environmental Protection Agency and U.S. Department of Energy as being the most energy-efficient products in their classes.
- For more information on how to make your home energy efficient, see Energy Savers in the For More Information section.

Is Wind Energy Practical for Me?

A small wind energy system can provide you with a practical and economical source of electricity if:

- your property has a good wind resource
- your home or business is located on at least one acre of land in a rural area
- your local zoning codes or covenants allow wind turbines
- your average electricity bills are $150 per month or more
- your property is in a remote location without easy access to utility lines
- you are comfortable with long-term investments.

Zoning Issues

Before you invest in a wind energy system, you should research potential obstacles. Some jurisdictions, for example, restrict the height of the structures permitted in residentially zoned areas, although variances are often obtainable. Most zoning ordinances have a height limit of 35 feet. You can find out about the zoning restrictions in your area by calling the local building inspector, board of supervisors, or planning board. They can tell you if you will need to obtain a building permit and provide you with a list of requirements.

In addition to zoning issues, your neighbors might object to a wind machine that blocks their view, or they might be concerned about noise. Most zoning and aesthetic concerns can be addressed by supplying objective data. For example, the ambient noise level of most modern residential wind turbines is around 52 to 55 decibels. This means that while the sound of the wind turbine can be picked out of surrounding noise if a conscious effort is made to hear it, a residential-sized wind turbine is no noisier than your average refrigerator.

World Power Technology/PIX07168

In Clover Valley, Minnesota, this 3-kW Whisper H175 turbine on a 50-foot tower is connected to the utility grid to offset the farm's utility-supplied electricity.

What Size Wind Turbine Do I Need?

The size of the wind turbine you need depends on your application. Small turbines range in size from 20 watts to 100 kilowatts (kW). The smaller or "micro" (20- to 500-watt) turbines are used in a variety of applications such as charging batteries for recreational vehicles and sailboats.

One- to 10-kW turbines can be used in applications such as pumping water. Wind energy has been used for centuries to pump water and grind grain. Although mechanical windmills still provide a sensible, low-cost option for pumping water in low-wind areas, farmers and ranchers are finding that wind-electric pumping is a little more versatile and they can pump twice the volume for the same initial investment. In addition, mechanical windmills must be placed directly above the well, which may not take the best advantage of available wind resources. Wind-electric pumping systems can be placed where the wind resource is the best and connected to the pump motor with an electric cable.

Elliott Bayly/PIX09681

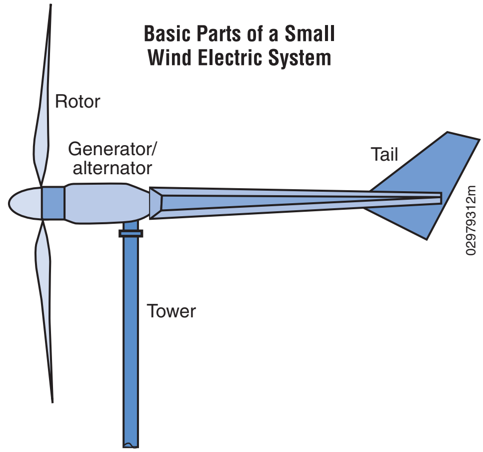
This 1-kW Whisper turbine provides direct AC power for the water pump for stock tanks on a ranch in Wheeler, Texas.

Turbines used in residential applications can range in size from 400 watts to 100 kW (100 kW for very large loads), depending on the amount of electricity you want to generate. For residential applications, you should establish an energy budget to help define the turbine size you will need. Because energy efficiency is usually less expensive than energy production, making your house more energy efficient first will probably be more cost effective and will reduce the size of the wind turbine you need (see How Can I Make My Home More Energy Efficient?). Wind turbine manufacturers can help you size your system based on your electricity needs and the specifics of local wind patterns.

A typical home uses approximately 10,000 kilowatt-hours (kWh) of electricity per year (about 830 kWh per month). Depending on the average wind speed in the area, a wind turbine rated in the range of 5 to 15 kW would be required to make a significant contribution to this demand. A 1.5- kW wind turbine will meet the needs of a home requiring 300 kWh per month in a location with a 14-mile-per-hour (6.26-meters-per-second) annual average wind speed. The manufacturer can provide you with the expected annual energy output of the turbine as a function of annual average wind speed. The manufacturer will also provide information on the maximum wind speed at which the turbine is designed to operate safely. Most turbines have automatic overspeed-governing systems to keep the rotor from spinning out of control in very high winds. This information, along with your local wind speed and your energy budget, will help you decide which size turbine will best meet your electricity needs.

What are the Basic Parts of a Small Wind Electric System?

Home wind energy systems generally comprise a rotor, a generator or alternator mounted on a frame, a tail (usually), a tower, wiring, and the "balance of system" components: controllers, inverters, and/or batteries. Through the spinning blades, the rotor captures the kinetic energy of the wind and converts it into rotary motion to drive the generator.



Wind Turbine

Most turbines manufactured today are horizontal axis upwind machines with two or three blades, which are usually made of a composite material such as fiberglass.

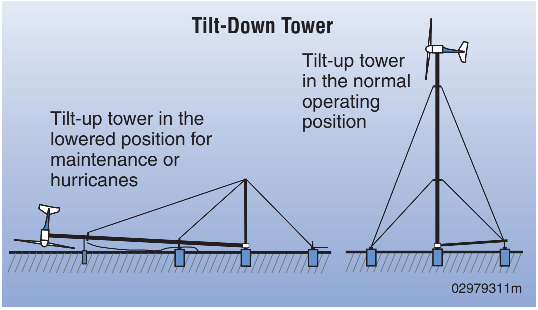
The amount of power a turbine will produce is determined primarily by the diameter of its rotor. The diameter of the rotor defines its "swept area," or the quantity of wind intercepted by the turbine. The turbine's frame is the structure onto which the rotor, generator, and tail are attached. The tail keeps the turbine facing into the wind.

Tower

Because wind speeds increase with height, the turbine is mounted on a tower. In general, the higher the tower, the more power the wind system can produce. The tower also raises the turbine above the air turbulence that can exist close to the ground because of obstructions such as hills, buildings, and trees. A general rule of thumb is to install a wind turbine on a tower with the bottom of the rotor blades at least 30 feet (9 meters) above any obstacle that is within 300 feet (90 meters) of the tower. Relatively small investments in increased tower height can yield very high rates of return in power production. For instance, to raise a 10-kW generator from a 60-foot tower height to a 100-foot tower involves a 10% increase in overall system cost, but it can produce 29% more power.

There are two basic types of towers: self-supporting (free standing) and guyed. Most home wind power systems use a guyed tower. Guyed towers, which are the least expensive, can consist of lattice sections, pipe, or tubing (depending on the design), and supporting guy wires. They are easier to install than self-supporting towers. However, because the guy radius must be one-half to three-quarters of the tower height, guyed towers require enough space to accommodate them. Although tilt-down towers are more expensive, they offer the consumer an easy way to perform maintenance on smaller light-weight turbines, usually 5 kW or less.

Tilt-down towers provide easy maintenance for turbines.



Tilt-down towers can also be lowered to the ground during hazardous weather such as hurricanes. Aluminum towers are prone to cracking and should be avoided. Most turbine manufacturers provide wind energy system packages that include towers.

Mounting turbines on rooftops is not recommended. All wind turbines vibrate and transmit the vibration to the structure on which they are mounted. This can lead to noise and structural problems with the building, and the rooftop can cause excessive turbulence that can shorten the life of the turbine.

Balance of System

The parts that you need in addition to the turbine and the tower, or the balance of system parts, will depend on your application. Most manufacturers can provide you with a system package that includes all the parts you need for your application. For example, the parts required for a water pumping system will be much different than what you need for a residential application. The balance of system required will also depend on whether the system is grid-connected, stand-alone, or part of a hybrid system. For a residential grid-connected application, the balance of system parts may include a controller, storage batteries, a power conditioning unit (inverter), and wiring. Some wind turbine controllers, inverters, or other electrical devices may be stamped by a recognized testing agency, like Underwriters Laboratories.

Stand-Alone Systems

Stand-alone systems (systems not connected to the utility grid) require batteries to store excess power generated for use when the wind is calm. They also need a charge controller to keep the batteries from overcharging. Deep-cycle batteries, such as those used for golf carts, can discharge and recharge 80% of their capacity hundreds of times, which makes them a good option for remote renewable energy systems. Automotive batteries are shallow-cycle batteries and should not be used in renewable energy systems because of their short life in deep-cycling operations.

Trudy Forsyth, NREL/PIX09122 and PIX09123

A Bergey XL.10, 10-kW wind turbine is part of a grid-connected wind/photovoltaic hybrid system that reduces the utility power used by this home in Vermont. The balance of system (upper right) includes from left to right, a Trace inverter for the PV system, a breaker box, and a Powersync inverter for the wind system.

Small wind turbines generate direct current (DC) electricity. In very small systems, DC appliances operate directly off the batteries. If you want to use standard appliances that use conventional household alternating current (AC), you must install an inverter to convert DC electricity from the batteries to AC. Although the inverter slightly lowers the overall efficiency of the system, it allows the home to be wired for AC, a definite plus with lenders, electrical code officials, and future homebuyers.

For safety, batteries should be isolated from living areas and electronics because they contain corrosive and explosive substances. Lead-acid batteries also require protection from temperature extremes.

Grid-Connected Systems

In grid-connected systems, the only additional equipment required is a power conditioning unit (inverter) that makes the turbine output electrically compatible with the utility grid. Usually, batteries are not needed.

What Do Wind Systems Cost?

Installation costs vary greatly depending on local zoning, permitting, and utility interconnection costs. A small turbine can cost anywhere from $3,000 to $50,000 installed, depending on size, application, and service agreements with the manufacturer. (The American Wind Energy Association [AWEA] says a typical home wind system costs approximately $32,000 (10 kW); a comparable photovoltaic [PV] solar system would cost over $80,000.)

A general rule of thumb for estimating the cost of a residential turbine is $1,000 to $5,000 per kilowatt. Wind energy becomes more cost effective as the size of the turbine's rotor increases. Although small turbines cost less in initial outlay, they are proportionally more expensive. The cost of an installed residential wind energy system with an 80-foot tower, batteries, and inverter typically ranges from $15,000 to $50,000 for a 3- to 10-kW wind turbine.


Southwest Windpower/PIX09156

A Southwest Windpower Air 303, 300-watt turbine is the sole source of electricity for this remote home in northern Arizona.

Although wind energy systems involve a significant initial investment, they can be competitive with conventional energy sources when you account for a lifetime of reduced or avoided utility costs. The length of the payback period—the time before the savings resulting from your system equal the cost of the system itself—depends on the system you choose, the wind resource on your site, electricity costs in your area, and how you use your wind system. For example, if you live in California and have received the 50% buydown of your small wind system, have net metering, and an average annual wind speed of 15 miles per hour (mph) (6.7 meters per second [m/s]), your simple payback would be approximately 6 years.

Warren Gretz, NREL/PIX09615

Small wind turbines like this 10-kW Bergey XL.10 provide electricity for home, farm, and ranch applications.

Things to Consider When Purchasing a Wind Turbine

Once you determine you can install a wind energy system in compliance with local land use requirements, you can begin pricing systems and components. Comparatively shop for a wind system as you would any major purchase. Obtain and review the product literature from several manufacturers. As mentioned earlier, lists of manufacturers are available from AWEA, (see For More Information), but not all small turbine manufacturers are members of AWEA. Check the yellow pages for wind energy system dealers in your area.

Once you have narrowed the field, research a few companies to be sure they are recognized wind energy businesses and that parts and service will be available when you need them. You may wish to contact the Better Business Bureau to check on the company's integrity and ask for references of past customers with installations similar to the one you are considering. Ask the system owners about performance, reliability, and maintenance and repair requirements, and whether the system is meeting their expectations. Also, find out how long the warranty lasts and what it includes.

Where Can I Find Installation and Maintenance Support?

The manufacturer/dealer should be able to help you install your machine. Many people elect to install the machines themselves. Before attempting to install your wind turbine, ask yourself the following questions:

- Can I pour a proper cement foundation?
- Do I have access to a lift or a way of erecting the tower safely?
- Do I know the difference between AC and DC wiring?
- Do I know enough about electricity to safely wire my turbine?
- Do I know how to safely handle and install batteries?

If you answered no to any of the above questions, you should probably choose to have your system installed by a system integrator or installer. Contact the manufacturer for help or call your state energy office and local utility for a list of local system installers. You can also check the yellow pages for wind energy system service providers. A credible installer will provide many services such as permitting. Find out if the installer is a licensed electrician. Ask for references and check them out. You may also want to check with the Better Business Bureau.

Although small wind turbines are very sturdy machines, they do require some annual maintenance. Bolts and electrical connections should be checked and tightened if necessary. The machines should be checked for corrosion and the guy wires for proper tension. In addition, you should check for and replace any worn leading edge tape on the blades, if appropriate. After 10 years, the blades or bearings may need to be replaced, but with proper installation and maintenance, the machine should last up to 20 years or longer.

If you do not have the expertise to maintain the machine, your installer may provide a service and maintenance program.

How Much Energy Will My System Generate?

Most U.S. manufacturers rate their turbines by the amount of power they can safely produce at a particular wind speed, usually chosen between 24 mph (10.5 m/s) and 36 mph (16 m/s). The following formula illustrates factors that are important to the performance of a wind turbine. Notice that the wind speed, V, has an exponent of 3 applied to it. This means that even a small increase in wind speed results in a large increase in power. That is why a taller tower will increase the productivity of any wind turbine by giving it access to higher wind speeds as shown in the Wind Speeds Increase with Height graph. The formula for calculating the power from a wind turbine is:

$$\text{Power} = k\, C_p\, 1/2\, \rho\, A\, V^3$$

Where:

P = Power output, kilowatts

C_p = Maximum power coefficient, ranging from 0.25 to 0.45, dimension less (theoretical maximum = 0.59)

ρ = Air density, lb/ft^3

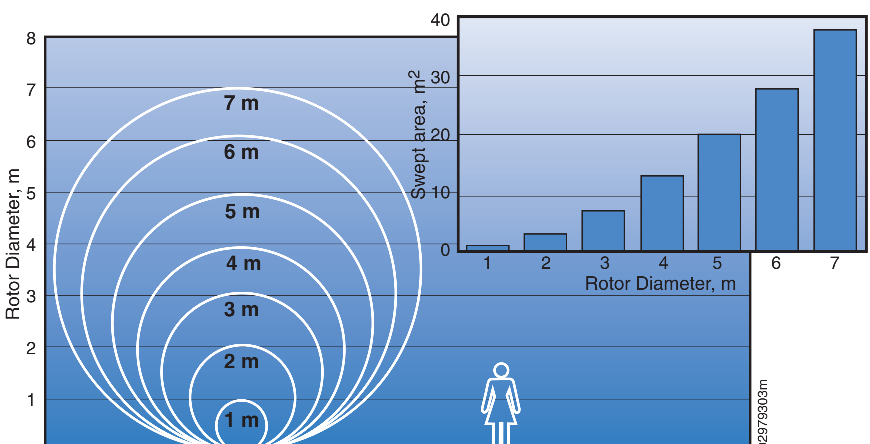
A = Rotor swept area, ft^2 or $\pi D^2/4$ (D is the rotor diameter in ft, $\pi = 3.1416$)

V = Wind speed, mph

k = 0.000133 A constant to yield power in kilowatts. (Multiplying the above kilowatt answer by 1.340 converts it to horsepower [i.e., 1 kW = 1.340 horsepower]).

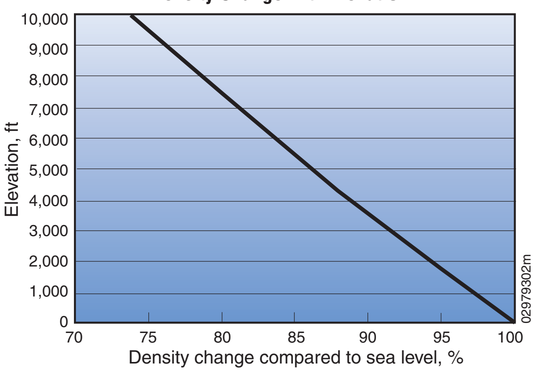
The rotor swept area, A, is important because the rotor is the part of the turbine that captures the wind energy.

Relative Size of Small Wind Turbines

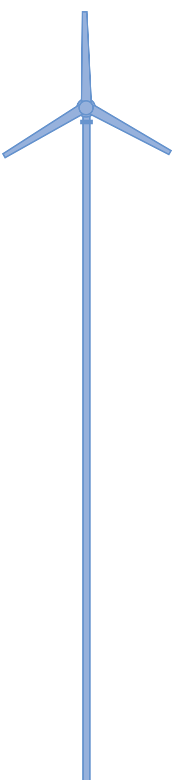


Source: Paul Gipe, *Wind Energy Basics*

Air Density Change with Elevation



So, the larger the rotor, the more energy it can capture. The air density, ρ, changes slightly with air temperature and with elevation. The ratings for wind turbines are based on standard conditions of 59° F (15° C) at sea level. A density correction should be made for higher elevations as shown in the Air Density Change with Elevation graph. A correction for temperature is typically not needed for predicting the long-term performance of a wind turbine.



Although the calculation of wind power illustrates important features about wind turbines, the best measure of wind turbine performance is annual energy output. The difference between power and energy is that power (kilowatts [kW]) is the rate at which electricity is consumed, while energy (kilowatt-hours [kWh]) is the quantity consumed. An estimate of the annual energy output from your wind turbine, kWh/year, is the best way to determine whether a particular wind turbine and tower will produce enough electricity to meet your needs.

A wind turbine manufacturer can help you estimate the energy production you can expect. They will use a calculation based on the particular wind turbine power curve, the average annual wind speed at your site, the height of the tower that you plan to use, and the frequency distribution of the wind–an estimate of the number of hours that the wind will blow at each speed during an average year. They should also adjust this calculation for the elevation of your site. Contact a wind turbine manufacturer or dealer for assistance with this calculation.

To get a preliminary estimate of the performance of a particular wind turbine, use the formula below.

$$AEO = 0.01328\ D^2\ V^3$$

Where:

AEO = Annual energy output, kWh/year

D = Rotor diameter, feet

V = Annual average wind speed, mph

The Wind Energy Payback Period Workbook found at www.nrel.gov/wind/docs/spread_sheet_Final.xls is a spreadsheet tool that can help you analyze the economics of a small wind electric system and decide whether wind energy will work for you. The spreadsheet can be opened using Microsoft Excel 95 software. It asks you to provide information about how you're going to finance the system, the characteristics of your site, and the properties of the system you're considering. It then provides you with a simple payback estimation in years. If it takes too long to regain your capital investment—the number of years comes too close or is greater than the life of the system—wind energy will not be practical for you.

Is There Enough Wind on My Site?

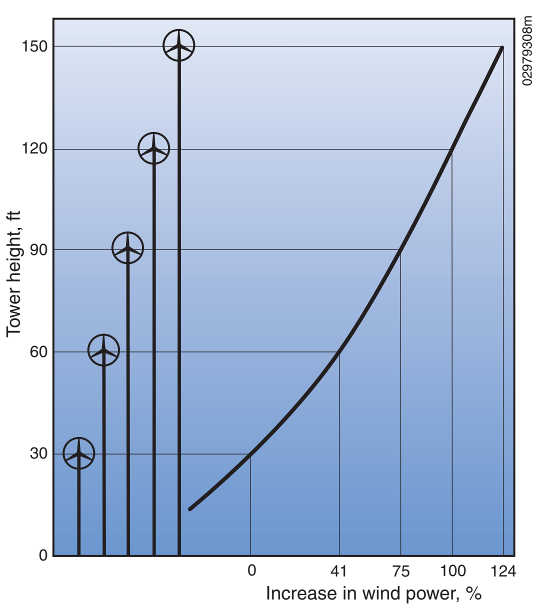
Does the wind blow hard and consistently enough at my site to make a small wind turbine system economically worthwhile? That is a key question and not always easily answered. The wind resource can vary significantly over an area of just a few miles because of local terrain influences on the wind flow. Yet, there are steps you can take that will go a long way towards answering the above question.

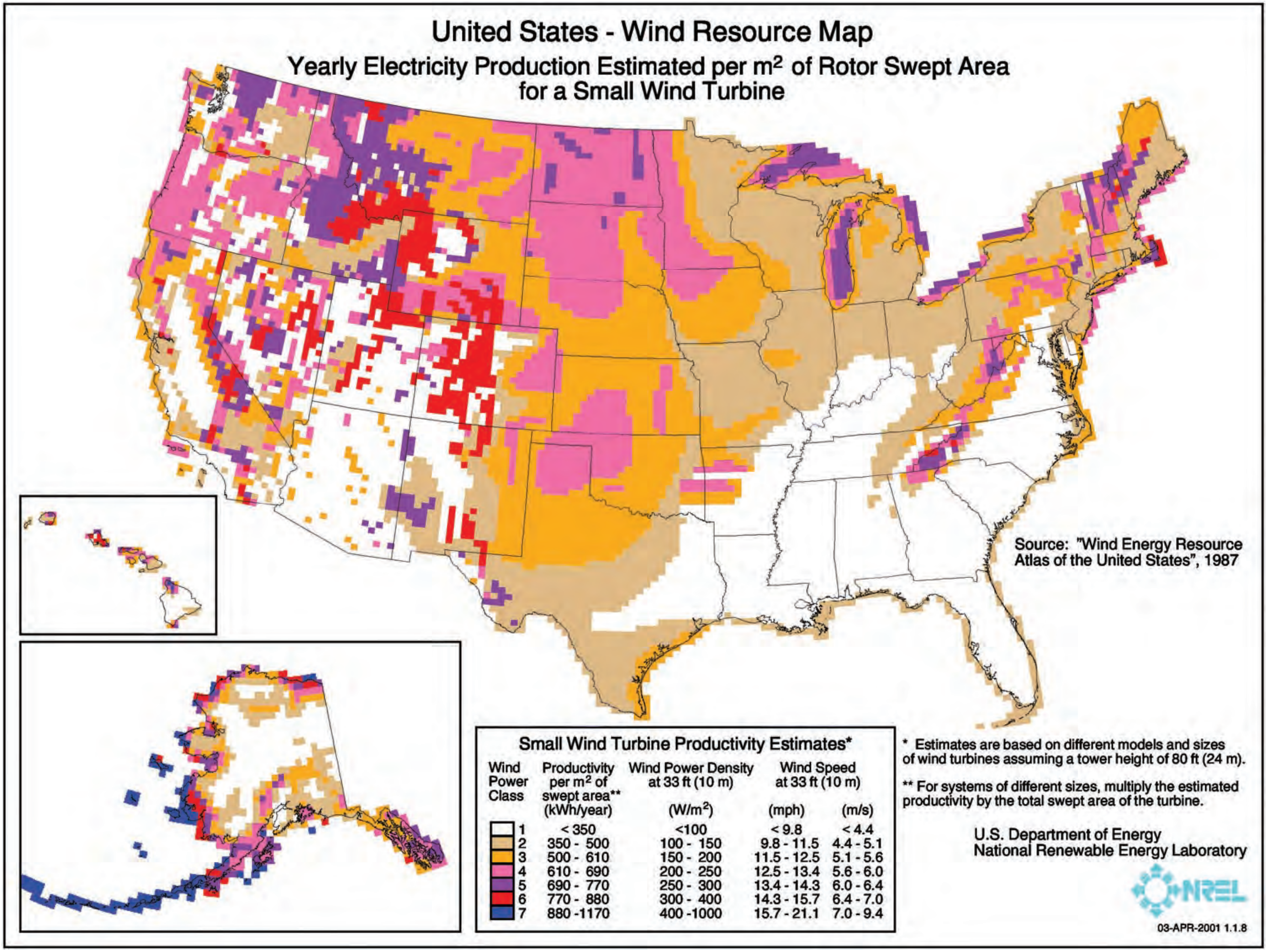
As a first step, wind resource maps like the one on pages 12 and 13 can be used to estimate the wind resource in your region. The highest average wind speeds in the United States are generally found along seacoasts, on ridgelines, and on the Great Plains; however, many areas have wind resources strong enough to power a small wind turbine economically. The wind resource estimates on this map generally apply to terrain features that are well exposed to the wind, such as plains, hilltops, and ridge crests. Local terrain features may cause the wind resource at a specific site to differ considerably from these estimates. More detailed wind resource information, including the *Wind Energy Resource Atlas of United States*, published by the U.S. Department of Energy (DOE), can be found at the National Wind Technology Center Web site at www.nrel.gov/wind/ and the DOE Wind Powering America Web site at www.windpoweringamerica.gov.

Another way to indirectly quantify the wind resource is to obtain average wind speed information from a nearby airport. However, caution should be used because local terrain influences and other factors may cause the wind speed recorded at an airport to be different from your particular location. Airport wind data are generally measured at heights about 20–33 ft (6–10 m) above ground. Average wind speeds increase with height and may be 15%–25% greater at a typical wind turbine hub-height of 80 ft (24 m) than those measured at airport anemometer heights. The National Climatic Data Center collects data from airports in the United States and makes wind data summaries available for purchase. Summaries of wind data from almost 1000 U.S. airports are also included in the *Wind Energy Resource Atlas of the United States* (see For More Information).

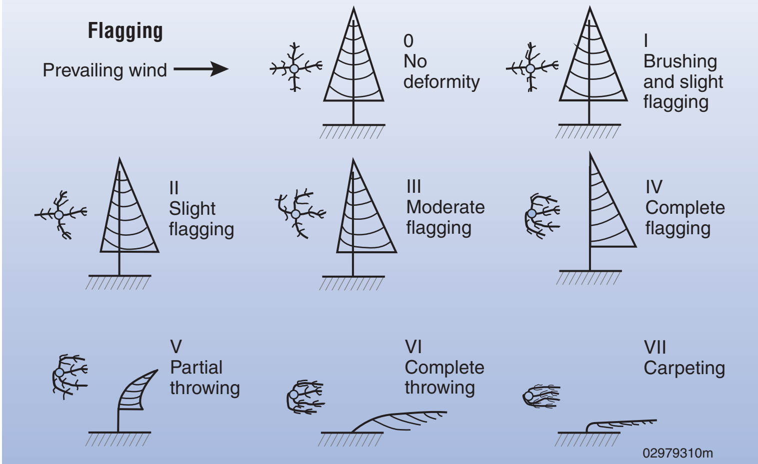
Another useful indirect measurement of the wind resource is the observation of an area's vegetation. Trees, especially conifers or evergreens, can be permanently deformed by strong winds. This deformity, known as "flagging," has been used to estimate the average wind speed for an area. For more information on the use of flagging, you may want to obtain

Wind Speeds Increase with Height




United States - Wind Resource Map
Yearly Electricity Production Estimated per m2 of Rotor Swept Area
for a Small Wind Turbine
Source: "Wind Energy Resource Atlas of the United States", 1987
Small Wind Turbine Productivity Estimates*
Wind Power Class
Productivity per m2 of swept area** (kWh/year)
Wind Power Density at 33 ft (10 m) (W/m2)
Wind Speed at 33 ft (10 m)
(mph)
(m/s)
1 < 350 <100 < 9.8 < 4.4
2 350 - 500 100 - 150 9.8 - 11.5 4.4 - 5.1
3 500 - 610 150 - 200 11.5 - 12.5 5.1 - 5.6
4 610 - 690 200 - 250 12.5 - 13.4 5.6 - 6.0
5 690 - 770 250 - 300 13.4 - 14.3 6.0 - 6.4
6 770 - 880 300 - 400 14.3 - 15.7 6.4 - 7.0
7 880 -1170 400 -1000 15.7 - 21.1 7.0 - 9.4
* Estimates are based on different models and sizes of wind turbines assuming a tower height of 80 ft (24 m).
** For systems of different sizes, multiply the estimated productivity by the total swept area of the turbine.
U.S. Department of Energy
National Renewable Energy Laboratory
NREL
03-APR-2001 1.1.8

Flagging, the effect of strong winds on area vegetation, can help determine area wind speeds.



Griggs-Putnam Index of Deformity

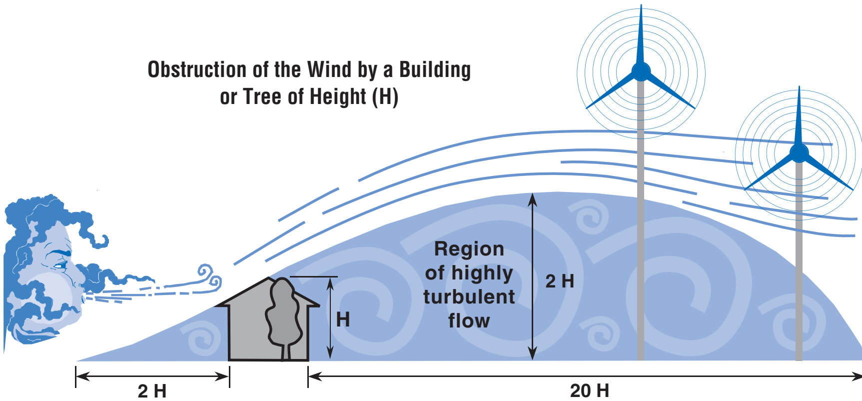
Index	I	II	III	IV	V	VI	VII
Wind mph	7-9	9-11	11-13	13-16	15-18	16-21	22+
Speed m/s	3-4	4-5	5-6	6-7	7-8	8-9	10

A Siting Handbook for Small Wind Energy Conversion Systems (see For More Information).

Direct monitoring by a wind resource measurement system at a site provides the clearest picture of the available resource. A good overall guide on this subject is the *Wind Resource Assessment Handbook* (see For More Information). Wind measurement systems are available for costs as low as $600 to $1200. This expense may or may not be hard to justify depending on the exact nature of the proposed small wind turbine system. The measurement equipment must be set high enough to avoid turbulence created by trees, buildings, and other obstructions. The most useful readings are those taken at hub-height, the elevation at the top of the tower where the wind turbine is going to be installed. If there is a small wind turbine system in your area, you may be able to obtain information on the annual output of the system and also wind speed data if available.

How Do I Choose the Best Site for My Wind Turbine?

You can have varied wind resources within the same property. In addition to measuring or finding out about the annual wind speeds, you need to know about the prevailing directions of the wind at your site. If you live in complex terrain, take care in selecting the installation site. If you site your wind turbine on the top of or on the windy side of a hill, for example, you will have more access to prevailing winds than in a gully or on the leeward (sheltered) side of a hill on the same property. In addition to geologic formations, you need to consider existing obstacles such as trees, houses, and sheds, and you need to plan for future obstructions such as new buildings or trees that have not reached their full height. Your turbine needs to be sited upwind of buildings and trees, and it needs to be 30 feet above anything within 300 feet. You also need enough room to raise and lower the tower for maintenance,



The farther you place your wind turbine from obstacles such as buildings or trees, the less turbulence you will encounter.

and if your tower is guyed, you must allow room for the guy wires.

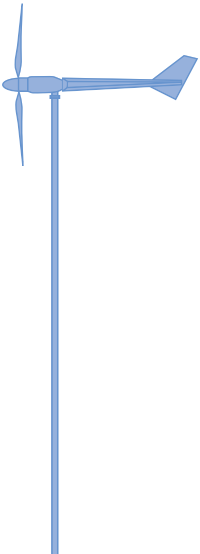
Whether the system is stand-alone or grid-connected, you will also need to take the length of the wire run between the turbine and the load (house, batteries, water pumps, etc.) into consideration. A substantial amount of electricity can be lost as a result of the wire resistance—the longer the wire run, the more electricity is lost. Using more or larger wire will also increase your installation cost. Your wire run losses are greater when you have direct current (DC) instead of alternating current (AC). So, if you have a long wire run, it is advisable to invert DC to AC.

Can I Connect My System to the Utility Grid?

Small wind energy systems can be connected to the electricity distribution system and are called grid-connected systems. A grid-connected wind turbine can reduce your consumption of utility-supplied electricity for lighting, appliances, and electric heat. If the turbine cannot deliver the amount of energy you need, the utility makes up the difference. When the wind system produces more electricity than the household requires, the excess is sent or sold to the utility.

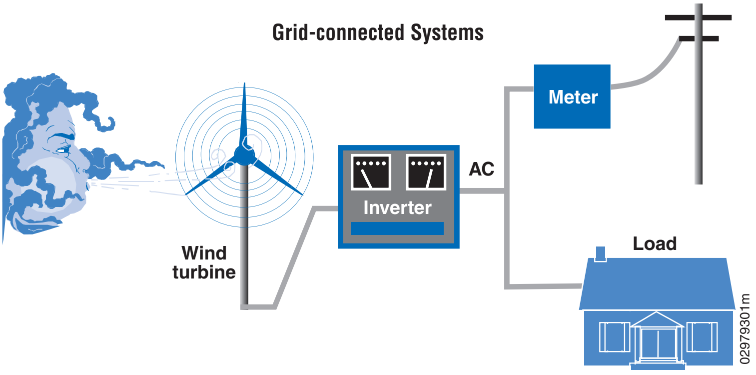
Grid-connected systems can be practical if the following conditions exist:

- You live in an area with average annual wind speed of at least 10 mph (4.5 m/s)
- Utility-supplied electricity is expensive in your area (about 10 to 15 cents per kilowatt-hour)
- The utility's requirements for connecting your system to its grid are not prohibitively expensive
- There are good incentives for the sale of excess electricity or for the purchase of wind turbines.



Federal regulations (specifically, the Public Utility Regulatory Policies Act of 1978, or PURPA) require utilities to connect with and purchase power from small wind energy systems. However, you should contact your utility before connecting to their distribution lines to address any power quality and safety concerns. Your utility can provide you with a list of requirements for connecting your system to the grid. The American Wind Energy Association is another good source for information on utility interconnection requirements. The

A grid-connected wind turbine can reduce your consumption of utility-supplied electricity.



following information about utility grid connection requirements was taken from AWEA's Web site. For more detailed information, visit www.awea.org/ or contact AWEA (see For More Information).

Net Metering

The concept of net metering programs is to allow the electric meters of customers with generating facilities to turn backwards when their generators are producing more energy than the customers' demand. Net metering allows customers to use their generation to offset their consumption over the entire billing period, not just instantaneously. This offset would enable customers with generating facilities to receive retail prices for more of the electricity they generate.

Net metering varies by state and by utility company, depending on whether net metering was legislated or directed by the Public Utility Commission. Net metering programs all specify a way to handle the net excess generation (NEG) in terms of payment for electricity and/or length of time allowed for NEG credit. If the net metering requirements define NEG on a monthly basis, the consumer can only get credit for their excess that month. But if the net metering rules allow for annual NEG, the NEG credit can be carried for up to a year.

Most of North America gets more wind in the winter than in the summer. For people using wind energy to displace a large load in the summer like air-conditioning or irrigation water pumping, having an annual NEG credit allows them to produce NEG in the winter and be credited in the summer.

Safety Requirements

Whether or not your wind turbine is connected to the utility grid, the installation and operation of the wind turbine is probably subject to the electrical codes that your local government (city or county), or in some instances your state government, has in place. The government's principal concern is with the safety of the facility, so these code requirements emphasize proper wiring and installation and the use of components that have been certified for fire and electrical safety by approved testing laboratories, such as Underwriters Laboratories. Most local electrical codes requirements are based on the National Electrical Code (NEC), which is published by the National Fire Protection Association. As of 1999, the latest version of the NEC did not have any sections specific to the installation of wind energy facilities' consequently wind energy installations are governed by the generic provisions of the NEC.

If your wind turbine is connected to the local utility grid so that any of the power produced by your wind turbine is delivered to the grid, then your utility also has legitimate concerns about safety and power quality that need to be addressed. The utility's principal concern is that your wind turbine automatically stops delivering any electricity to its power lines during a power outage. Otherwise line workers and the public, thinking that the line is "dead," might not take normal precautions and might be hurt or even killed by the power from your turbine. Another concern among utilities is whether the power from your facility synchronizes properly with the utility grid and it matches the utility's own power in terms of voltage, frequency, and power quality.

A few years ago, some state governments started developing new standardized interconnection requirements for small renewable energy generating facilities (including wind turbines). In most cases, the new requirements are based on consensus-based standards and testing procedures developed by independent third-party authorities, such as the Institute of Electrical and Electronic Engineers and Underwriters Laboratories.

Interconnection Requirements

Most utilities and other electricity providers require you to enter into a formal agreement with them before you interconnect your wind turbine with the utility grid. In states that have retail competition for electricity service (e.g., your utility operates the local wires, but you have a choice of electricity provider) you may have to sign a separate agreement with each company. Usually these agreements are written by the utility or the electricity provider. In the case of private (investor-owned) utilities, the terms and conditions in these agreements must be reviewed and approved by state regulatory authorities.

Insurance

Some utilities require small wind turbine owners to maintain liability insurance in amounts of $1 million or more. Utilities consider these requirements necessary to protect them from liability for facilities they do not own and have no control over. Others consider the insurance requirements excessive and unduly burdensome, making wind energy uneconomic. In the 21 years since utilities have been required to allow small wind systems to interconnect with the grid, there has never been a liability claim, let alone a monetary award, relating to electrical safety.

In seven states (California, Georgia, Maryland, Nevada, Oklahoma, Oregon, and Washington), laws or regulatory authorities prohibit

This grid-connected, 10-kW Bergey wind turbine offsets electrical power consumption for a small business in Norman, Oklahoma.

Bergey Windpower/PIX07166

utilities from imposing any insurance requirements on small wind systems that qualify for "net metering." In at least two other states (Idaho, Virginia), regulatory authorities have allowed utilities to impose insurance requirements but have reduced the required coverage amounts to levels consistent with conventional residential or commercial insurance policies (e.g., $100,000 to $300,000). If your insurance amounts seem excessive, you can ask for a reconsideration from regulatory authorities (in the case of private investor-owned utilities) or the utility's governing board (in the case of publicly owned utilities).

Indemnification

An indemnity is an agreement between two parties in which one agrees to secure the other against loss or damage arising from some act or some assumed responsibility. In the context of customer-owned generating facilities, utilities often want customers to indemnify them for any potential liability arising from the operation of the customer's generating facility. Although the basic principle is sound—utilities should not be held responsible for property damage or personal injury attributable to someone else—indemnity provisions should not favor the utility but should be fair to both parties. Look for language that says, "each party shall indemnify the other . . ." rather than "the customer shall indemnify the utility . . ."

Customer Charges

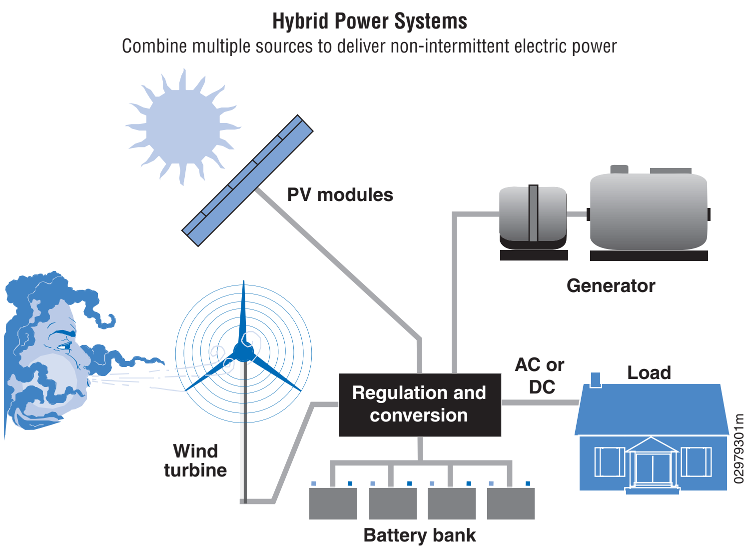
Customer charges can take a variety of forms, including interconnection charges, metering charges, and standby charges. You should not hesitate to question any charges that seem inappropriate to you. Federal law (Public Utility Regulatory Policies Act of 1978, or PURPA, Section 210) prohibits utilities from assessing discriminatory charges to customers who have their own generation facilities.

Warren Gretz, NREL/PIX09634

Connecting to the Utility Grid: A Success Story

This 10-kW Bergey wind turbine, installed on a farm in Southwestern Kansas in 1983, produces an average 1700–1800 kilowatt-hours per month, reducing the user's monthly utility bills by approximately 50%. The turbine cost about $20,000 when it was installed. Since then, the cost for operation and maintenance has been about $50 per year. The only unscheduled maintenance activity over the years was repair to the turbine required as a result of a lightning strike. Insurance covered all but $500 of the $9000 cost of damages. The basic system parts include:

Bergey XL.10 wind turbine
100-foot free-standing lattice tower
Inverter



A hybrid system that combines a wind system with a solar and/or diesel generator can provide reliable off-grid power around the clock.

Can I Go "Off-Grid"?

Hybrid Systems

Hybrid wind energy systems can provide reliable off-grid power for homes, farms, or even entire communities (a co-housing project, for example) that are far from the nearest utility lines. According to many renewable energy experts, a "hybrid" system that combines wind and photovoltaic (PV) technologies offers several advantages over either single system. In much of the United States, wind speeds are low in the summer when the sun shines brightest and longest. The wind is strong in the winter when less sunlight is available. Because the peak operating times for wind and PV occur at different times of the day and year, hybrid systems are more likely to produce power when you need it. (For more information on solar electric or PV systems, contact the Energy Efficiency and Renewable Energy Information Portal—see For More Information.)

For the times when neither the wind turbine nor the PV modules are producing, most hybrid systems provide power through batteries and/or an engine-generator powered by conventional fuels such as diesel. If the batteries run low, the engine-generator can provide power and recharge the batteries. Adding an engine-generator makes the system more complex, but modern electronic controllers can operate these systems automatically. An engine-generator can also reduce the size of the other components needed for the system. Keep in mind that the storage capacity must be large enough to supply electrical needs during non-charging periods. Battery banks are typically sized to supply the electric load for one to three days.

An off-grid hybrid system may be practical for you if:

- You live in an area with average annual wind speed of at least 9 mph (4.0 m/s)
- A grid connection is not available or can only be made through an

expensive extension. The cost of running a power line to a remote site to connect with the utility grid can be prohibitive, ranging from $15,000 to more than $50,000 per mile, depending on terrain.

- You would like to gain energy independence from the utility
- You would like to generate clean power.

Living Off-Grid: A Success Story

This home, built near Ward, Colorado (at an elevation of 9000 feet), has been off-grid since it was built in 1972. When the house was built, the nearest utility was over a mile away, and it would have cost between $60K–$70K (based on 1985 rates) to connect to the utility lines. The owners decided to install a hybrid electric system powered by wind, solar, and a generator for a cost of about $19,700. The parts of the system include:

Jim Green, NREL/PIX02796

Bergey 1.5-kW wind turbine, 10-ft (3-m) diameter rotor, 70-ft. (21-m) tower

Solarex PV panels, 480 watts

24 DC battery bank, 375 ampere-hours

Trace sine wave inverter, 120 AC, 1 phase, 4 kW

Onan propane-fueled generator, 6.5 kW rated (3 kW derated for altitude)

Electric appliances in the home include television, stereo, two computers, toaster, blender, vacuum cleaner, and hair dryer. The largest electric loads are created by a well pump and washing machine. The generator runs about 20% of the time, particularly when the washing machine is in use. Propane serves the other major loads in the home: range, refrigerator, hot water, and space heat. Solar collectors on the roof provide pre-heating for the hot water.

Glossary of Terms

Airfoil—The shape of the blade cross-section, which for most modern horizontal axis wind turbines is designed to enhance the lift and improve turbine performance.

Ampere-hour—A unit for the quantity of electricity obtained by integrating current flow in amperes over the time in hours for its flow; used as a measure of battery capacity.

Anemometer—A device to measure the wind speed.

Average wind speed—The mean wind speed over a specified period of time.

Blades—The aerodynamic surface that catches the wind.

Brake—Various systems used to stop the rotor from turning.

Converter—See Inverter.

Cut-in wind speed—The wind speed at which a wind turbine begins to generate electricity.

Cut-out wind speed—The wind speed at which a wind turbine ceases to generate electricity.

Density—Mass per unit of volume.

Downwind—On the opposite side from the direction from which the wind blows.

Furling—A passive protection for the turbine in which the rotor folds either up or around the tail vane.

Grid—The utility distribution system. The network that connects electricity generators to electricity users.

HAWT—Horizontal axis wind turbine.

Inverter—A device that converts direct current (DC) to alternating current (AC).

kW—Kilowatt, a measure of power for electrical current (1000 watts).

kWh—Kilowatt-hour, a measure of energy equal to the use of one kilowatt in one hour.

MW—Megawatt, a measure of power (1,000,000 watts).

Nacelle—The body of a propeller-type wind turbine, containing the gearbox, generator, blade hub, and other parts.

O&M costs—Operation and maintenance costs.

Power coefficient—The ratio of the power extracted by a wind turbine to the power available in the wind stream.

Power curve—A chart showing a wind turbine's power output across a range of wind speeds.

PUC—Public Utility Commission, a state agency which regulates utilities. In some areas known as Public Service Commission (PSC).

PURPA—Public Utility Regulatory Policies Act (1978), 16 U.S.C. § 2601.18 CFR §292 that refers to small generator utility connection rules.

Rated output capacity—The output power of a wind machine operating at the rated wind speed.

Rated wind speed—The lowest wind speed at which the rated output power of a wind turbine is produced.

Rotor—The rotating part of a wind turbine, including either the blades and blade assembly or the rotating portion of a generator.

Rotor diameter—The diameter of the circle swept by the rotor.

Rotor speed—The revolutions per minute of the wind turbine rotor.

Start-up wind speed—The wind speed at which a wind turbine rotor will begin to spin. See also Cut-in wind speed.

Swept area—The area swept by the turbine rotor, A = π R^2, where R is the radius of the rotor.

Tip speed ratio—The speed at the tip of the rotor blade as it moves through the air divided by the wind velocity. This is typically a design requirement for the turbine.

Turbulence—The changes in wind speed and direction, frequently caused by obstacles.

Upwind—On the same side as the direction from which the wind is blowing—windward.

VAWT—Vertical axis wind turbine.

Wind farm—A group of wind turbines, often owned and maintained by one company. Also known as a wind power plant.

Yaw—The movement of the tower top turbine that allows the turbine to stay into the wind.

For More Information

Books

A Siting Handbook for Small Wind Energy Conversion Systems
H. Wegley, J. Ramsdell, M. Orgill and R. Drake
Report No. PNL-2521 Rev.1, 1980
National Technical Information Service
5285 Port Royal Rd.
Springfield, VA 22151
(800) 553-6847
www.ntis.gov

Energy Savers Tips on Saving Energy and Money at Home — A consumer's guide for saving energy and reducing utility bills. www.eere.energy.gov/consumerinfo/energy_savers

Wind Energy Basics
Paul Gipe
ISBN 1-890132-07-01
A comprehensive guide to modern small wind technology.
American Wind Energy Association
(202) 383-2500
www.awea.org
or
Chelsea Green Publishing Company
www.chelseagreen.com

Wind Energy Resource Atlas of the United States
D. Elliott et al.
American Wind Energy Association
(202) 383-2500
www.awea.org
rredc.nrel.gov/wind/pubs/atlas

Wind Power for Home, Farm, and Business: Renewable Energy for the New Millenium
Paul Gipe
ISBN-1-931498-14-8
Completely revised and expanded edition of Wind Power for Home and Business
Chelsea Green Publishing Company
www.chelseagreen.com

Wind Power Workshop
Hugh Piggott
Provides an overview on how to design a home-built wind turbine.
The Center for Alternative Technology
Machynlleth, Powys
SY20 9AZ, UK
Phone: 06154-702400
E-mail: help@catinfo.demon.co.uk
www.foe.co.uk/CAT

Government Agencies

U.S. Department of Energy's Energy Efficiency and Renewable Energy Information Portal
www.eere.energy.gov

National Climatic Data Center
Federal Building, 151 Patton Avenue
Asheville, North Carolina, 28801-5001
Phone: (828) 271-4800
www.ncdc.noaa.gov

U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Road
Springfield, Virginia 22161
(800) 553-6847
www.ntis.gov

Non-Government Organizations

American Wind Energy Association
1101 14th St., NW
12th Floor
Washington, D.C. 20005
Phone: (202) 383-2500
www.awea.org

Solar Energy International
Short courses on renewable energy and sustainable development
Phone: (970) 963-8855
www.solarenergy.org

Periodicals

Apples and Oranges
Mick Sagrillo
A comprehensive comparison of available small wind turbines available on the Home Power Magazine Web site: www.homepower.com

Home Power Magazine
The definitive bimonthly magazine for the homemade power enthusiast.
Phone: (800)707-6586
www.homepower.com

Videos

An Introduction to Residential Wind Systems with Mick Sagrillo
A 63-minute video answering questions most often asked by homeowners as they consider purchasing and installing wind power systems
American Wind Energy Association
Phone: (202) 383-2500
www.awea.org

Web Sites

Small Wind Systems
Includes answers to frequently asked questions and information on U.S. manufacturers.
www.awea.org/smallwind.html

Database of State Incentives for Renewable Energy
www.dsireusa.org

Green Power Network Net Metering
Net metering programs are now available in more than 35 states.
www.eere.energy.gov/greenpower/markets

Small Wind "Talk" on the Web
AWEA's Home Energy Systems electronic mailing list is a forum for the discussion of small-scale energy systems that include wind. To subscribe, send a subscription request to awea-wind-home-subscribe@egroups.com.

Wind Energy for Homeowners
This Web page covers items you should consider before investing in a small wind energy system and provides basic information about the systems.
www.nrel.gov/clean_energy/home_wind.html

Wind Resource Assessment Handbook
www.nrel.gov/docs/legosti/fy97/22223.pdf

2002 Farm Bill — Wind Energy Development Provisions

Renewable Energy Systems and Energy Efficiency Improvements

Incentive Type: Low-interest loans, loan guarantees, and grants

Eligible Technologies: Renewable energy systems (energy derived from wind, solar, biomass, geothermal, and hydrogen derived from biomass or water using a renewable energy source) and energy efficiency improvements.

Applicable Sectors: Agriculture, rural small commercial

Amount: Varies. The grant may not exceed 25% of the cost of a project, and a combined grant and loan or guarantee may not exceed 50% of the cost of a project.

Terms: 2003 – 2007

Date Enacted: 2002

Authority: Farm Bill, Title IX, Section 9006

Summary: This law allows direct financial assistance to farmers, ranchers, and rural small businesses for the purchase of wind power and other renewable energy systems and for energy efficiency improvements. This program is authorized for funding for up to $23,000,000 per year in 2003-2007, totaling up to $115 million. In determining the amount of a grant or loan, USDA shall consider the type of renewable energy system, the quantity of energy likely to be generated, the expected environmental benefits, the extent to which the system is replicable, and the amount of energy savings from energy efficiency improvements and the likely payback period.

USDA Rural Development State Office contacts can be found at www.rurdev.usda.gov/rbs/farmbill/contacts.htm

USDA Farm Bill Web site: www.rurdev.usda.gov/rbs/farmbill/resourc.htm

Green Tag Purchase Program

Mainstay Energy is a private company offering customers who install, or have installed, renewable energy systems the opportunity to sell the green tags (also known as renewable energy credits, or RECs) associated with the energy generated by these systems. These green tags will be brought to market as Green-e* http://www.green-e.org or state certified products. Participating customers receive regular, recurring payments through the Mainstay Energy Rewards Program.

The amount of the payments depends on the size of the wind installation, the production of electricity by that system, and the length of the contract period. Mainstay offers 3-, 5-, and 10-year purchase contracts. The longer contract periods provide greater incentive payments on a $/kWh basis. Typical payments for wind, which are made quarterly, range from 0.2¢/kWh to 1.5¢/kWh.

There is a $100 certification fee to get started with Mainstay Rewards. However, the fee may be paid with future green tag sales, and is generally waived for participants who opt for 10-year contracts.

The requirements are:

1. The system must be grid-connected;
2. Net-metering by the utility does not restrict the system owner from selling the green tags;
3. The system owner must have title to the green tags or renewable energy credits. They cannot have been sold or transferred to any other entity;
4. The system must be a new renewable, which, in most states, means powered up on or after 1/1/1999. See the Mainstay Energy web site for exceptions;
5. For any systems over 10 kW, the system generation must be metered separately. For systems under 10 kW, separate metering is not necessary. Payments are made based on estimated production.

Contact:
Mainstay Rewards Program
Mainstay Energy
161 E. Chicago Ave.
Suite 41B
Chicago, IL 60611-2624
Phone: (877) 473-3682
Fax: (312) 896-1515
E-Mail: info@mainstayenergy.com
Web site: http://mainstayenergy.com

Notes

U.S. Department of Energy Regional Offices
www.eere.energy.gov/regions/

States in Region

Southeast Regional Office
75 Spring Street, S.W., Suite 200
Atlanta, GA 30303
(404) 562-0555
www.eere.energy.gov/regions/southeast

Alabama, Arkansas, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, Tennessee, Puerto Rico, U.S. Virgin Islands

Northeast Regional Office
JFK Federal Building, Suite 675
Boston, MA 02203
(617) 565-9700
www.eere.energy.gov/regions/northeast

Connecticut, Maine, Massachusetts, New Hampshire, New York, Rhode Island, Vermont

Midwest Regional Office
One South Wacker Drive, Suite 2380
Chicago, IL 60606-4616
(312) 353-6749
www.eere.energy.gov/regions/midwest

Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, Ohio, Wisconsin

Central Regional Office
1617 Cole Blvd.
Golden, CO 80401
(303) 275-4826
www.eere.energy.gov/regions/central

Colorado, Kansas, Louisiana, Montana, Nebraska, New Mexico, North Dakota, Oklahoma, South Dakota, Texas, Utah, Wyoming

Mid-Atlantic Regional Office
1880 John F. Kennedy Boulevard, Suite 501
Philadelphia, PA 19103
(215) 656-6950
www.eere.energy.gov/regions/mid-atlantic

Delaware, Washington DC, Maryland, New Jersey, Pennsylvania, Virginia, West Virginia

Western Regional Office
800 Fifth Ave., Suite 3950
Seattle, WA 98104-3122
(206) 553-1132
www.eere.energy.gov/regions/western

Alaska, Arizona, California, Hawaii, Idaho, Nevada, Oregon, Washington, American Samoa, Guam, Palau, North Marianas

Wind Powering America
www.windpoweringamerica.gov

A Strong Energy Portfolio for a Strong America

Energy efficiency and clean, renewable energy will mean a stronger economy, a cleaner environment, and greater energy independence for America. Working with a wide array of state, community, industry, and university partners, the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy invests in a diverse portfolio of energy technologies.

Produced for the U.S. Department of Energy by the
National Renewable Energy Laboratory,
a DOE national laboratory

DOE/GO-102005-2095 • March 2005

For more information contact:
EERE Information Center
1-877-EERE-INF (1-877-337-3463)
www.eere.energy.gov

Printed with a renewable-source ink on paper containing at least 50% wastepaper, including 20% postconsumer waste.