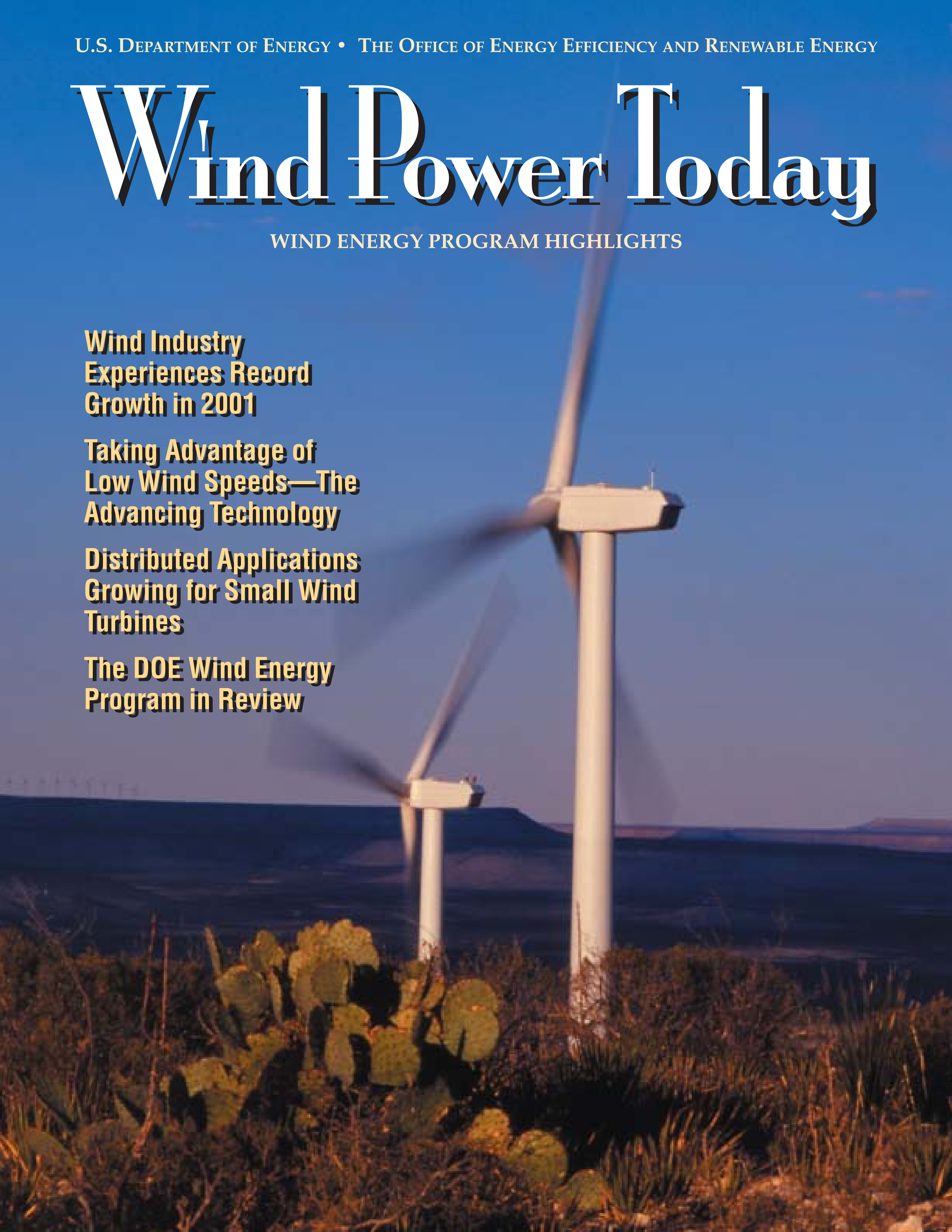
U.S. Department of Energy • The Office of Energy Efficiency and Renewable Energy

Wind Power Today

WIND ENERGY PROGRAM HIGHLIGHTS



Wind Industry Experiences Record Growth in 2001

Taking Advantage of Low Wind Speeds—The Advancing Technology

Distributed Applications Growing for Small Wind Turbines

The DOE Wind Energy Program in Review

2001: THE YEAR IN REVIEW

Cover photo: ***Clear Sky Wind Power Facility, Pecos County, Texas.***

About "Wind Power Today"

Energy shortages pose a threat to the security of our nation and our quality of life. To address this threat, the U.S. Department of Energy (DOE) has developed a comprehensive approach to meet our nation's energy needs. According to the National Energy Policy (NEP), America has an abundance of diverse energy resources and strong technological leadership for developing and efficiently using these resources. Wind energy is one of these valuable resources. Through research and development, DOE's Wind Energy Program helps the U.S. electric industry develop wind resources to their maximum potential. The following program overview highlights the accomplishments of DOE's 2001 Wind Energy Program.

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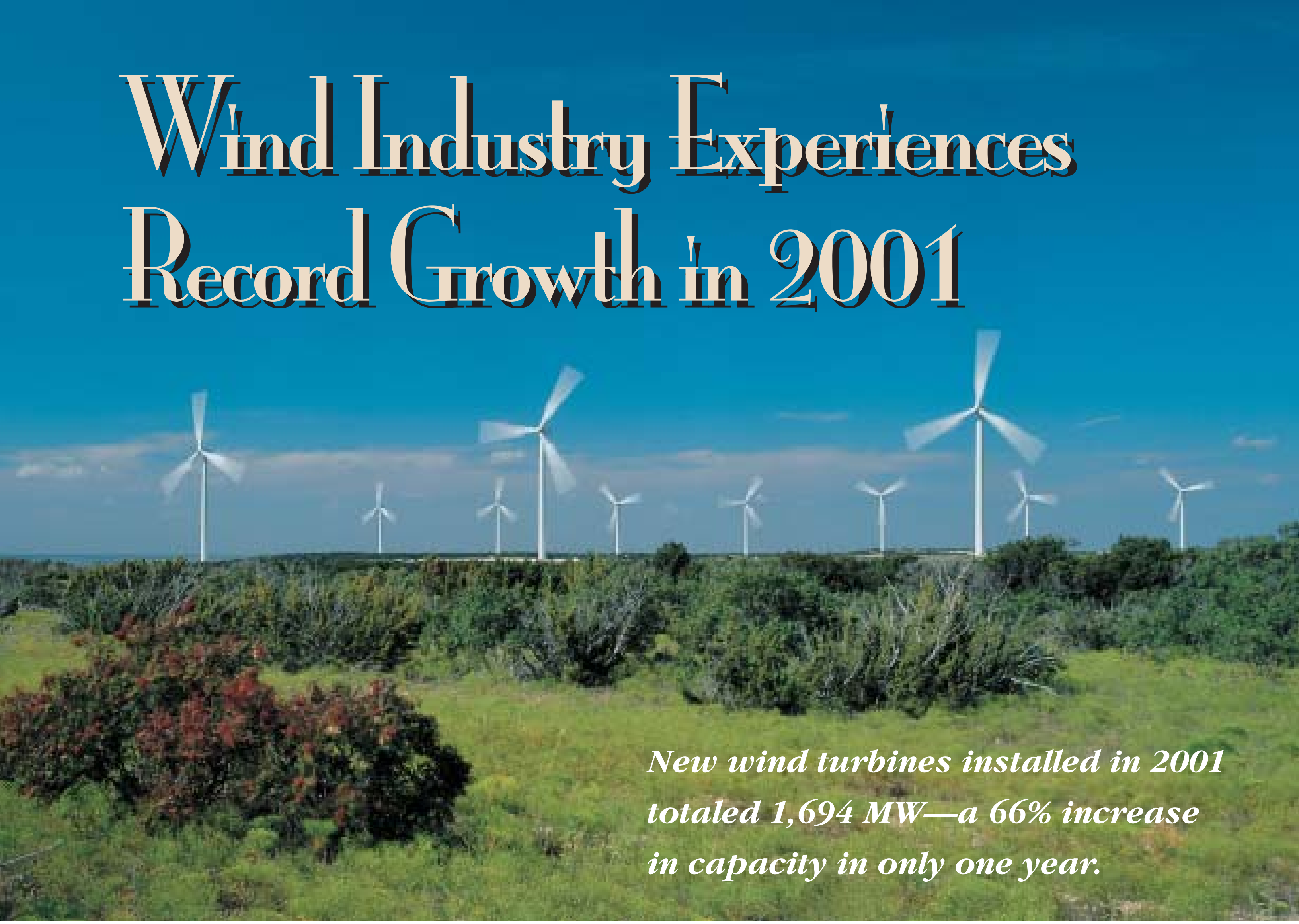


New wind turbines installed in 2001 totaled 1,694 MW—a 66% increase in capacity in only one year.

The new 150-MW Trent Mesa Wind Project, developed by AEP Energy Services near Abilene, Texas, consists of 100 Enron 1.5-MW turbines that DOE's Wind Energy Program helped to develop.

WIND ENERGY OFFERS THE REAL PROMISE OF DIVERSIFYING OUR NATION'S ENERGY sources using a clean, purely domestic renewable resource while protecting our nation's energy security. The industry supporting this valuable resource is experiencing record growth—in the past two years alone, the amount of electricity produced by wind energy has almost doubled. By the close of 2001, the United States contained nearly 20% of the wind generating capacity in the world—about 4,260 megawatts (MW). Four states added more than 100 MW capacity each, and 12 states added more than 20 MW each. The state of Texas increased its wind generating capacity by 915 MW, the largest increase in the country.

Most of this wind generating capacity comes from large projects in which hundreds of turbines generate electricity at one site. The latest of these projects employs the new generation of turbines, rated at 1 MW or greater. These projects mark the beginning of the growing contribution of wind generation. Even though many projects are now on the drawing board, the more than 1 million MW of wind power potential available at sites across the country has barely been tapped.

Markets for small- and intermediate-sized wind turbines are also growing rapidly. As energy prices increased in 2001, rural homeowners and small businesses in areas with weak or overloaded distribution and transmission systems found wind to be an economically competitive energy source. Sales of

Wind Fact: **Each 3,000 MW of installed wind capacity reduces CO_2 emissions by 10 million metric tons and NO_x emissions by 25,000 tons per year.**

machines rated at 10 kW (kilowatts) or less reached record levels—an estimated 12,000 turbines were sold during 2001 at a value of about $18 million. Small machines are increasingly attractive power sources because they are reliable and provide their owners with security of electricity supply and price.

This phenomenal growth in wind generating capacity is due to the declining cost of wind energy, the increasing demand for clean diverse sources of energy, and combined state and federal financial and other incentives designed to stimulate the market.

NATIONAL ENERGY POLICY

The *National Energy Policy*, a report written by the Vice President's National Energy Policy Development Group in May 2001, addressed the issue of the nation's energy security. Wind energy can help meet several of the key objectives listed in this report—increase our nation's energy supply through increased domestic production, move toward clean affordable energy sources, and ensure our energy security by strengthening the electricity grid and infrastructure that support the production and delivery of energy.

In working toward these objectives, the key performance metrics guiding DOE's Wind Energy Program are reducing the cost of energy from wind turbines and increasing the total contribution of wind energy to the generation mix.

In 2001, the electricity generated by wind energy represented about 0.3% of the national electricity supply, but its importance is growing, especially in rural areas with good wind resources and incentives for development. The Wind Energy Program is working with the American Wind Energy Association (AWEA) to meet the industry's goal for wind energy to contribute 6% of the nation's electricity by 2020 with 100,000 megawatts (MW) of installed capacity.

In 2001, the average cost of electricity from wind was $0.04/kilowatt hour (kWh) in high wind speed areas and $0.06/kWh in lower wind speed sites. Although costs have decreased dramatically from the $0.80/kWh (in 2002 dollars) of the 1980s, researchers believe that further improvements in the technology could reduce costs an additional 30% to 50%. DOE's R&D program goal is to improve wind turbine technology so that the cost of energy falls to $0.03/kWh in 2004 for high-wind-speed areas and $0.03/kWh in lower-wind-speed areas by 2010. These cost goals are technically feasible with continued research and will support AWEA's goal of generating 6% of the nation's electricity.

Wind turbines rated at less than 100 kW are well suited to rural commercial use. The G.M. Allen & Sons blueberry farm near Orland, Maine, uses this AOC 15/50 wind turbine to provide part of its electricity needs. Any excess electricity it generates is fed into Central Maine Power's utility grid and is used to offset the business' electricity consumption through net billing.

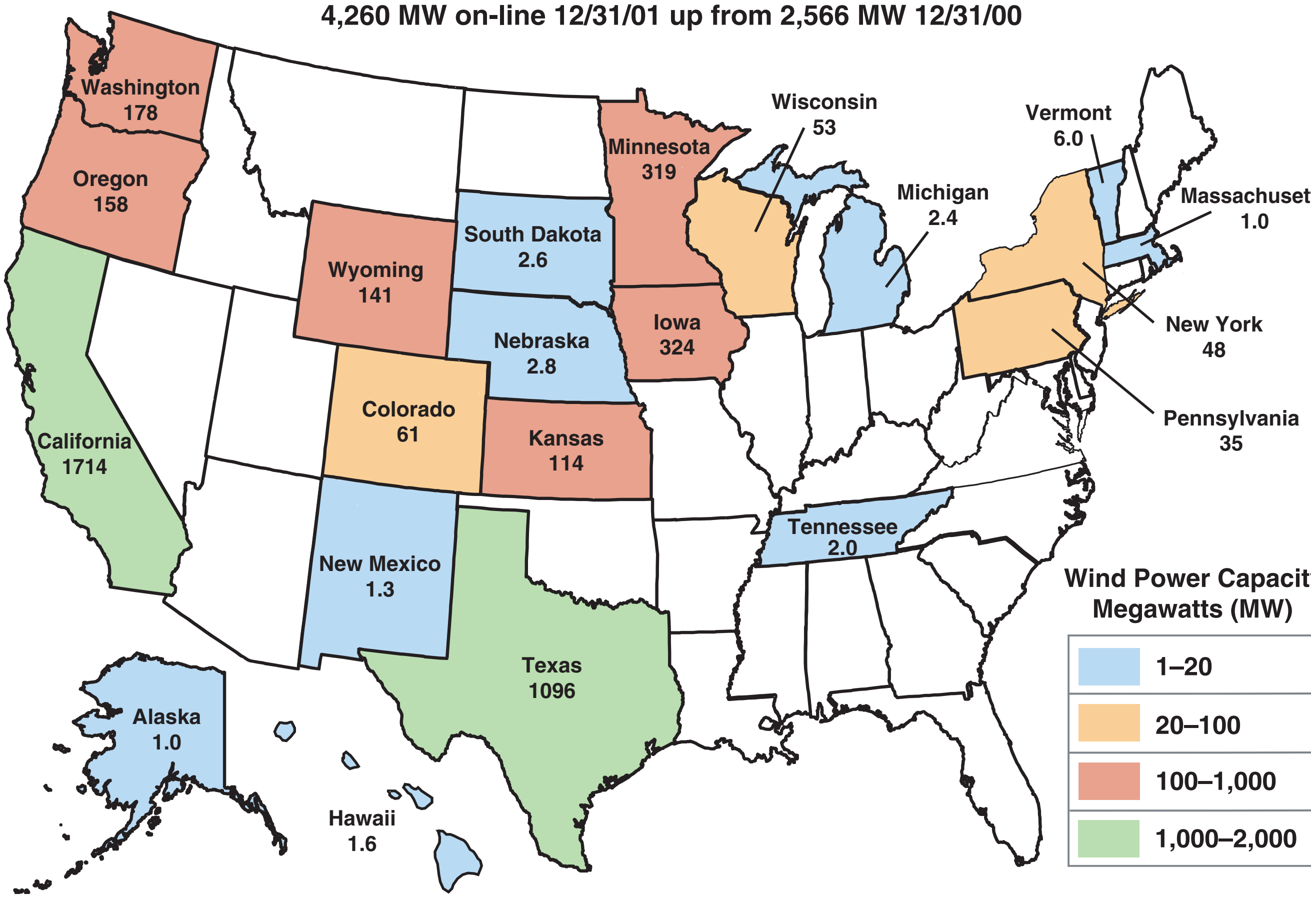
This phenomenal growth in wind generating capacity is due to the declining cost of wind energy, the increasing demand for clean diverse sources of energy, and combined state and federal financial and other incentives designed to stimulate the market.

WIND POWERING AMERICA

To bridge the gap between research for technology development and widespread deployment of commercial hardware, WPA was launched in 1999. The United States has a huge, untapped wind energy potential, and because the best wind resources are in our rural areas, wind energy development can contribute to the nation's energy supply and rural economic development. In 2001, wind projects on private land generated annual payments to landowners of between $2,700/MW and $4,000/MW

United States—2001 Year End Wind Power Capacity (MW)

4,260 MW on-line 12/31/01 up from 2,566 MW 12/31/00



Map of US with total capacity and increase in capacity indicated.
Source: DOE/NREL

Wind Fact: Total wind capacity potential in Germany is 100 GW. Total wind capacity potential in North Dakota is 250 GW.

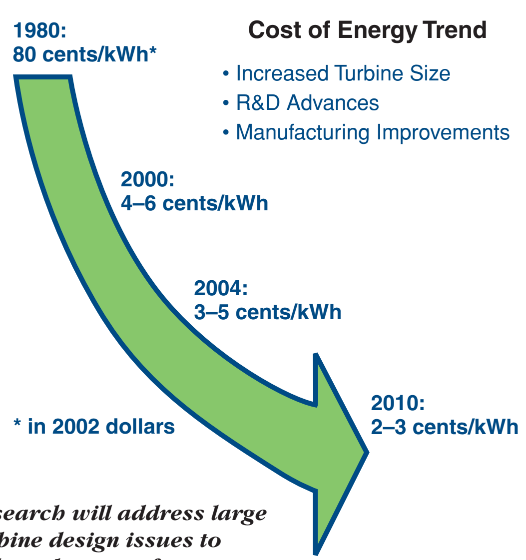
Texas Leads Nation's Wind Energy Growth

Texas is outstripping the other states in installed wind capacity for several reasons. First, Texas has one of the best wind resource potentials in the United States and plenty of open land that can support agricultural activities while allowing massive wind farm development. Second, the Texas legislature enacted a Renewables Portfolio Standard (RPS) requiring 2,000 MW of renewable energy systems to be installed by power suppliers by 2009. Electric power suppliers must include renewable energy sources in their generation mix or face penalties. In Texas, wind energy is the most cost-effective option for a large addition to renewable energy capacity, so many suppliers are choosing to install wind projects.

The mission of DOE's Wind Energy Program is to assist the United States to attain the substantial economic, environmental, and energy security benefits of expanding the domestic and worldwide use of wind energy and of fostering a world-class, domestic wind energy industry.

of installed capacity. In addition, local and state taxes and other payments by developers provide revenue for public infrastructure development in rural communities. Wind projects also create local jobs, first during the construction phase and later during the operation of the wind plant, when employees are needed to operate and perform maintenance on the wind turbines.

To reap these long-term benefits, WPA activities have the twin objectives of increasing the installed capacity of wind generation and promoting rural economic development. Strong and emerging commercial markets are continuing without help from WPA. Therefore, the WPA teams of experts address underdeveloped markets (states with fewer than 20 MW of installed wind capacity), using the infrastructure and resources of state, regional, and national organizations for outreach and to encourage pilot projects. Information and experience are the key commodities these groups make available to aid individual landowners, community leaders, utility managers, regulators, policy officials, developers, suppliers, and others in the wind energy decision-making process. WPA brings knowledgeable people to state and regional wind power meetings and also makes exhibits, technical reports, and analysis software available to back them up.



Research will address large turbine design issues to reduce the cost of energy.

State Cooperation

One of the first goals of WPA activities at the state level is to encourage formulation of state wind working groups containing representatives from landowners, utilities, regulators, local officials, industry, power marketers, environmentalists, public interest groups, and private sector elements. Then the WPA team helps the wind working groups organize state wind workshops. Such workshops often result in a state wind strategy that includes activities such as landowner meetings, creation of better wind resource maps, anemometer loan programs, possible pilot projects, and policy development.

Wind Fact: Today a 50-MW wind power facility can be completed and operational in 18 months.

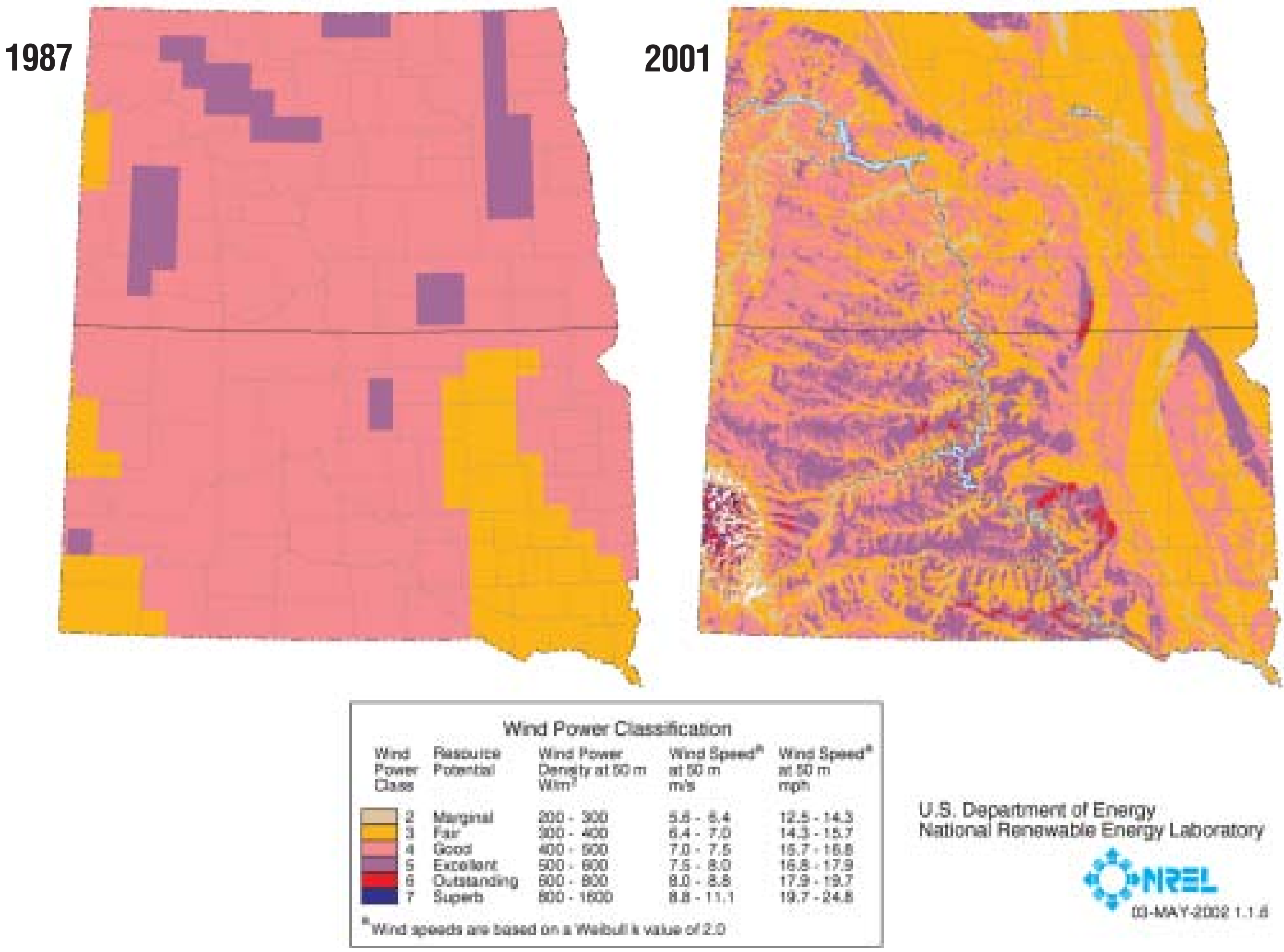
In 2001, WPA encouraged outreach activities in Alaska, Arizona, Idaho, Illinois, Montana, Nevada, New Mexico, New York, North Dakota, Oklahoma, South Dakota, Utah, and New England. WPA provided technical experts, exhibits, and printed information to inform meeting participants about the benefits of wind energy development and the experiences of wind energy developers in other areas of the United States. Information tailored for each state, such as wind resource maps and consumer guides for purchasing small wind systems, also supported the outreach effort.

American Indian Cooperation

Wind energy presents a special opportunity for rural economic development for American Indians. Several tribes have used federal renewable energy grant programs for small demonstration wind and solar projects. Some of these projects have already generated valuable wind data and operating experience that can support further wind development. A few tribes, including the Blackfeet, Rosebud, Mandan, Hidatsa, Arikara, and the Turtle Mountain Chippewa, are in various stages of developing utility-scale projects.

In 2001, WPA provided information from tribal pilot projects and other sources to U.S. tribes through regional wind power workshops held in the Great Lakes, northern Great Plains, Pacific Northwest, Northeast, Southwest, California, and Alaska. They also provided information and sent exhibits to national meetings and tribal gatherings, including the annual conference of the National Congress of American Indians and the Denver March Powwow, a celebratory gathering of the American Indian tribes.

In addition to sharing the personal experiences of those who have been involved in wind development



The new high resolution maps, as exemplified here by the North and South Dakota maps, indicate considerably better wind resources than shown in the U.S. wind atlas of 1987. In 2001, new maps were prepared for Illinois, Montana, Idaho, Washington, and Oregon. The higher wind resource areas could support thousands of megawatts of installed capacity.

Wind Fact: Great Plains landowners receive more than $2,000 annually for each 750-kW wind turbine. Each turbine occupies less than 1/3 acre.

projects, WPA and the Western Area Power Administration help tribes assess the wind resource on their lands. In 2001, 16 tribes in eight states participated in an anemometer loan program and received technical assistance on siting, installation, and analysis of the data. WPA also provided wind resource maps showing the locations of Indian reservation lands that allow tribal members to see the wind resource available.

Power Partnerships

Public power partnerships are cooperative activities with the nation's regional power-producing organizations, such as the National Rural Electric Cooperative, Power Marketing Administrations (Bonneville Power Administration, Western Area Power Administration), and the American Public Power Association. These cooperative activities provide members with technical information about wind energy. For example, WPA developed a spreadsheet tool that enables a utility to analyze the economics of wind for its own situation. In another project, WPA developed an updated wind resource map of Bonneville Power Administration's territory to help identify the best areas for development.

The WPA team is also working with program researchers to develop a wind power plant analysis model, which can be used by utilities to help them predict the impacts of large wind power plants on their grids. Because of the need to transmit electricity from high-wind areas to dense population centers, other studies are exploring the constraints of the transmission system. Increasing the understanding of these issues is the first step toward overcoming barriers to the increased use of our wind energy resources.

With the extension of the federal electricity production tax credits and the continuing efforts of people at the federal, regional, tribal, state, and local levels, 2002 should see continued strong growth in wind-generating capacity. ◆

Taking Advantage of Low Wind Speeds—The Advancing Technology

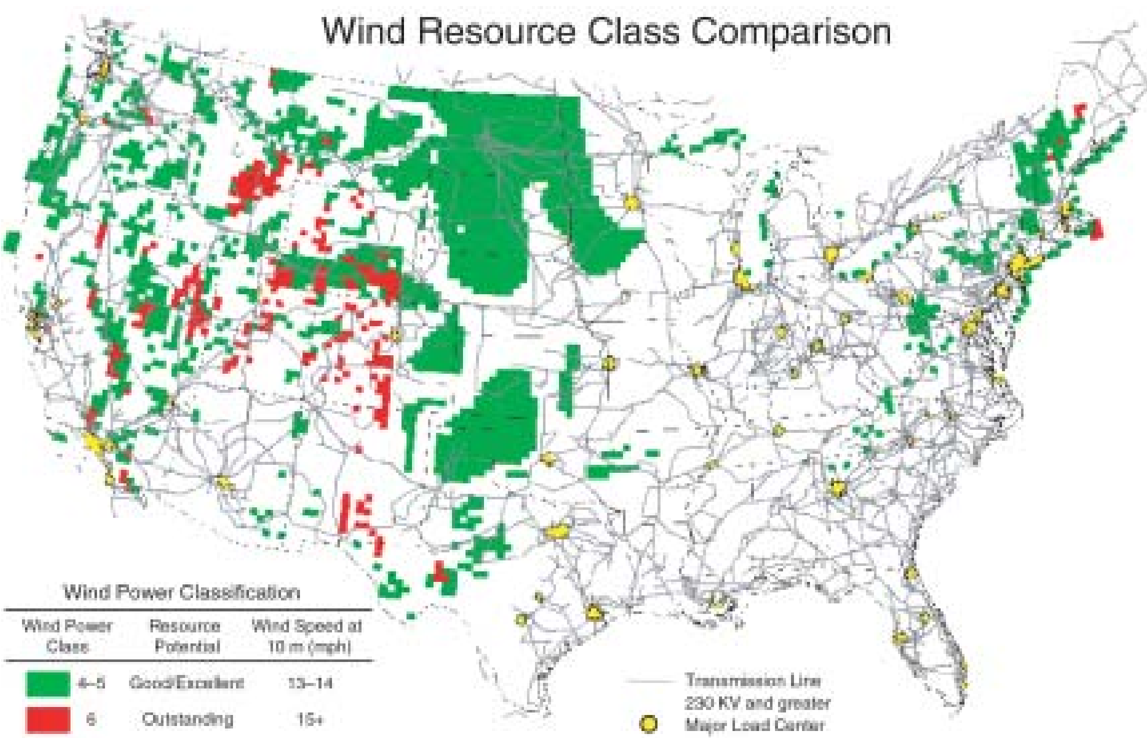
Research in wind energy technologies continues to lower the cost of electricity and make wind generation cost effective in more areas.

THE UNITED STATES HAS A HUGE WIND RESOURCE POTENTIAL. THE EXPLOSIVE growth in wind energy development in 2001 demonstrates that in areas with good resources, wind can be a cost-effective power generation source. In addition, wind energy provides an inexhaustable resource, stimulates rural economic development, and generates no harmful emissions. Also, the power plants take relatively little time to construct. However, in order for wind energy to contribute significantly to our electrical generation, we need to take full advantage of our nation's wind resources. This means that the technology must be cost effective in lower wind speed areas as well as the high wind speed areas.

Currently, utility-scale wind turbines can produce cost-effective electricity in a fairly narrow range of wind velocities, such as those found in many areas of the Great Plains (one of the major areas of U.S. wind energy production). However, many large power grids and population centers are located in areas with lower wind speeds than those found in the Great Plains region; therefore, researchers are working to develop turbines that operate more economically at lower wind speeds and can be integrated into many U.S. utility grids.

Most large wind turbines today are designed for optimal performance in class 6 wind resource areas where the average annual wind speed is 15 miles per hour (mph) at a height of 33 feet (6.7 meters per second [m/s] at a height of 10 m). If turbines could operate economically in class 4 wind regions, where the average annual wind speed is 13 mph at a height of 33 ft (wind speeds of 5.8 m/s at a height of 10 m), the average distance between the resource and the 50 largest load centers in the United States would be about 100 miles (160 km). The current average distance between class 6 resource areas and the 50 largest load centers is nearly 500 miles (800 km). If class 4 wind resource areas could be used effectively for bulk power generation, transmission costs for wind energy could be greatly reduced, and total land area available for wind project development would increase 20 times.

To take advantage of lower wind speeds, researchers must develop taller towers, lighter-weight materials, larger rotors, and increase conversion efficiencies of airfoils and improve control strategies while reducing component costs. Much of the groundwork necessary to develop low wind speed technologies has been underway in the Wind



If class 4 wind resource areas could be used effectively for bulk power generation, transmission costs for wind energy could be greatly reduced and total land area available for wind project development would increase 20 times.

Energy Program's cost-shared next generation turbine development projects and in the design and testing of innovative components for wind turbines under WindPACT (Wind Partnerships for Advanced Component Technologies). To further focus the effort, a new solicitation for industry participants was issued in October 2001. The specific objective of the low wind speed technology project is to develop large wind turbines capable of producing electricity for $0.03/kWh at class 4 sites by 2010. This solicitation is the first phase of a three-phase effort. In this first phase, three types of projects will be conducted.

1. Concept and scaling studies to examine new concepts and configurations to help achieve the cost-of-energy objective;
2. Component development subcontracts to assist industry in designing, fabricating, and testing advanced innovative components for new and existing turbines;
3. Systems development subcontracts to help industry partners create new full-scale turbine prototypes that achieve the cost-of-energy objective.

Phase II of this effort, planned for 2004, will initiate additional component and systems development subcontracts as new ideas come to maturity and new players enter the field. Phase III, planned for 2006, will continue to support component improvements for incorporation into the new family of low wind speed technologies.

DEVELOPING AND TESTING BETTER TURBINES

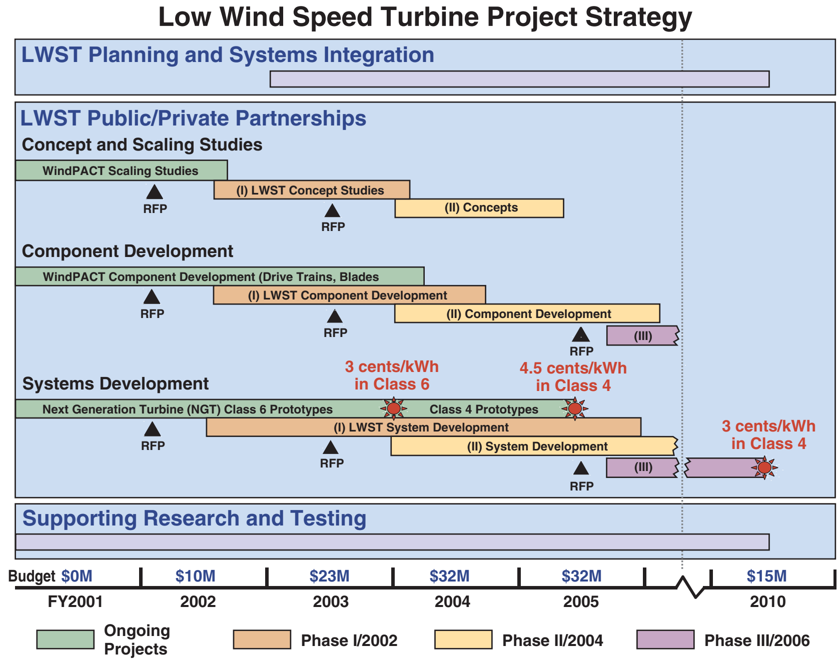
Ranging in size from 5 kW to 1,500 kW (1.5 MW), wind turbines suited for environments ranging from tropical to arctic are being developed in partnerships between the DOE Wind Program and U.S. industry. Specialists in the Wind Energy Program at the National Renewable Energy Laboratory's (NREL's) National Wind Technology Center (NWTC) and Sandia National Laboratory (Sandia) work with industry members to apply new technology, design tools, and state-of-the-art testing facilities to develop advanced next generation wind turbines. In 2001, cost-shared contracts awarded through competitive solicitations have moved several turbine designs forward toward commercial applications.

NEXT GENERATION TURBINES

In 2001, industry participants in cost-shared contracts included the Wind Turbine Company; Enron Wind Corporation (EWC), which was acquired by GE Power Systems in May 2002; and Northern Power Systems. The next generation turbines developed by these industry members will help advance the goal of more cost-effective wind energy.

The Wind Turbine Company began testing the second of three versions of its next generation turbine. The first turbine was a 250-kW proof-of-concept turbine installed at the NWTC in 2000. This 250-kW machine ran in unattended mode through the end of 2001 while the Wind Turbine Company and a subcontractor conducted acoustic tests to better understand potential noise.

After working with researchers at the NWTC to test the proof-of-concept machine, the company installed a scaled-up, 500-kW engineering and manufacturing development model at the Fairmont Reservoir of the Los Angeles Department of Water and Power. This larger turbine was initially erected with 23-m blades. Later, the company plans to upgrade to



DOE's three-phase strategy and timeline for the development of low wind speed technologies.

Applied Research for Low Wind Speed Technology

The applied research activities of the Wind Energy Program support development of low wind speed technology in several important ways. Work to understand the physical properties of wind inflow helps designers prevent damage to turbines operating on taller towers. Validating wind resources helps match technology to specific sites. Improving and validating design codes contributes to designs that compensate for fatigue, use lighter weight materials, and produce little noise. Developing improved components, such as control systems, will avoid inefficient operation or damage to new technology. These research activities and others provide the experience necessary to speed the progress of low wind speed technology from prototype to commercial application.

larger, custom-designed blades to achieve the full potential of the 750-kW rated drive train.

The Wind Turbine Company's turbines are innovative machines with downwind rotors, hinged blades that flex, and soft towers that bend slightly to reduce loads on other components. When loads are reduced, components can be made from lighter materials that are less expensive.

EWC produced hundreds of its 1.5-MW turbine at its manufacturing facility in Tehachapi, California. These turbines were installed in large U.S. wind projects and are descendants of a proof-of-concept turbine developed in cooperation with the Wind Energy Program. The EWC 1.5-MW turbine with a 70.5 m rotor includes advanced airfoils, independent blade pitch controls, a water-cooled generator, and a soft tower, all designed and tested under this project. In rigorous field tests, the turbine generated the expected amount of power with minimal stress on components.

The EWC team also conducted technology trade-off studies that led to development plans for the next version under its development contract—the engineering and manufacturing development turbine. The recommended configuration includes a high-energy capture, 77-m rotor concept with advanced control technology that shows potential for a 22% reduction in the cost of energy at low wind speed sites (6.5 m/s at hub height).

The Northern Power Systems North Wind 100 turbine was designed to provide a durable alternative to the diesel generators commonly used in remote research stations and villages of the polar regions. The special features of this turbine include a direct-drive design that requires no gearbox or lubricating oil, tilt-up assembly that does not require a crane and enclosed areas for climbing the tower and maintaining the turbine. The North Wind 100 is the only small-to-moderate size turbine available that has the ability to operate in extremely cold environments. In 2001, engineers began testing the second prototype of this award-winning design at the NWTC. The turbine was operated in attended mode for several weeks while engineers collected a preliminary set of load data over a range of wind speeds that could be verified against design predictions. Then the turbine was switched to unattended operation, which means that the turbine ran with no major faults and its safety systems were tested and verified. Engineers from Northern Power and the NWTC will perform certification testing of the turbine in 2002.

After working with researchers at the NWTC to test a proof-of-concept machine, the Wind Turbine Company installed a scaled-up, 500-kW engineering and manufacturing development model at the Fairmont Reservoir of the Los Angeles Department of Water and Power.

The EWC 1.5 MW turbines installed in large U.S. wind projects today are descendants of the proof-of-concept turbine developed in cooperation with the Wind Energy Program.

ADVANCED COMPONENTS

Advanced components, including blades, drive trains, and towers, will be crucial to the design of low wind speed turbines. To help industry design and test components to reduce the cost of energy, WindPACT was launched in 1999. In 2001, researchers completed component-scaling and design trade-off studies. When work begins on new low wind speed technology development projects, the public domain results from the 2001 studies will be available to benefit turbine designers.

Blades

Innovative blade design and manufacture can decrease the cost of energy by increasing wind turbine performance and reducing component costs.

Designed for operation in extremely cold climates, the NorthWind 100 turbine underwent initial testing in 2001 for power performance, power quality, and noise levels at the National Wind Technology Center south of Boulder, Colorado.

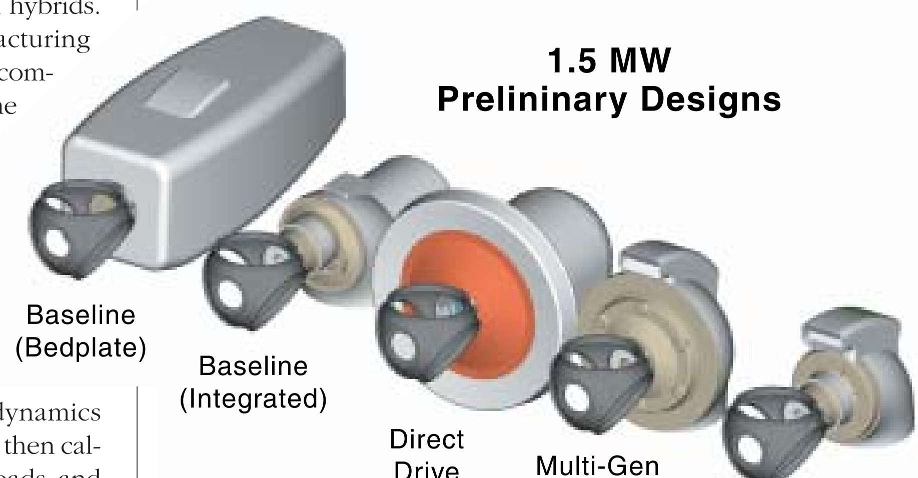
In 2001, a WindPACT blades study concluded that to make rotor diameters larger than 80 m (260 ft), designers will need to use lighter weight composite materials such as carbon or glass-carbon hybrids. They will also need to employ manufacturing processes that improve fiber alignment, compaction, and void reduction to maximize the performance of these materials. Finally, they will need to design rotor structures that reduce the loads imparted to the turbine. Future plans include fabrication and testing of the new blade designs.

Rotors

To address these issues, in another WindPACT study, more than 20 rotor configurations were analyzed using dynamics models. The cost of each configuration was then calculated on the basis of the structural loads and dynamics impacts on principal components of the wind turbine. The study concluded that rotor control systems are critical to reducing loads and the cost of energy in future wind turbine designs. The design team recommended five rotor configurations for more detailed modeling and costing in the remaining phases of this subcontract. The results of these studies will be available to industry in a report to be completed early in 2002.

Drive Trains

The drive train components, which can include generators, gearboxes, shafts, and bearings, transfer the slow-rotating mechanical energy from the rotor and convert it to electrical energy. In 2001, to help reduce the cost of these key components of all wind turbines, two contractors, Global Energy Concepts and Northern Power Systems, considered the cost and efficiency impacts of new approaches to drive shaft supports, gearboxes, gearing configurations, gear loading, gearbox bearings, gearbox supports, generators, generator bearings, and generator supports. After reviewing six approaches, each contractor selected three promising drive train designs for closer analysis. In 2002, each contractor will select one design for fabrication and testing.



Drawing comparison of drive train concepts. Source: Global Energy Concepts.

Towers

Because wind speed increases with height above the ground, wind turbines on taller towers experience higher wind speeds and generate more electricity than do turbines on shorter towers. For the low wind speed turbine designs being evaluated, towers between 60 and 90 m (200 and 300 feet) are being discussed. A WindPACT study of tower logistics published in 2001 concluded that traditional towers taller than 65 m (213 ft) present serious logistics

Blade Manufacturing Research

Sandia manufacturing specialists are working with contractors and NWTC test engineers to explore innovative manufacturing techniques that could reduce the cost of energy from very large wind turbines. Transporting blades that are longer than 40 m from a factory to a wind site could involve special equipment and procedures that are expensive. To avoid extraordinary transportation costs, Sandia and blade manufacturer TPI Composites tested the idea of moving the blade factory to the wind site. They moved the fabrication equipment outside the factory and made several subscale blades to demonstrate the feasibility of remote blade-building. Those blades will be tested at the NWTC in 2002.

problems during installation. They require large, very expensive cranes, both during the construction phase, and also during certain repair procedures, when it may be necessary to lower heavy turbine components to the ground. The requirement for such cranes and the expense involved can increase the cost of energy from these turbines. The study found several viable alternative methods of erecting very tall towers, ranging from self-erecting concrete towers to telescoping tubes or jack-up devices. This work will form the foundation for further study by designers of low wind speed technologies in the years ahead.

Wind Fact: Wind velocity increases with altitude. Hence, wind turbine output increases with height.

COMPONENT TESTING

In addition to helping industry design advanced components to reduce the cost of energy, WindPACT helps industry test components. In 2001, both the blade testing facility and the 2.5-MW dynamometer at the NWTC tested the largest components they can accommodate. These components came from today's 1.5-MW turbines.

Blade Testing

The NWTC blade test facility helps manufacturers evaluate the anticipated lifetime performance of their designs and identify weaknesses before moving to commercial deployment. Blade tests that can be performed at the NWTC include fatigue testing, ultimate static strength testing, photoelastic stress visualization, thermographic stress visualization, and acoustic emissions.

In 2001, after completing certification tests, the 34-m (about 100 feet) EWC blade was subjected to a more strenuous fatigue test that included simultaneous flap and edge (side-to-side) bending motions for more than one million cycles to simulate the equivalence of 20 to 30 years of operation in the field. This is the largest blade ever tested at the NWTC facility. In 2002, the NWTC will test EWC's 37-m blades.

Dynamometer Testing

NWTC's dynamometer facility conducts tests that cannot be duplicated in the field, such as applying a constant, steady load to wind turbine drive trains. In 2001, the 2.5-MW dynamometer was used for several different tests of the EWC-750 drive train developed under the next generation turbine development project. Tests begun in 2000 evaluated the effect of lubricants on gearbox parameters such as temperature and wear. In other tests, high loads

The specialized facilities at the NWTC can support manufacturers of the smallest and largest wind turbines.

similar to those applied during braking were applied, and engineers monitored stress and wear on key components. Finally, the endurance test, the equivalence of 35 years of operation in the field, was completed at the close of 2001. After driving the turbine at 1.4 times its rated torque and applying a lifetime's worth of braking cycles, test engineers returned the machine to EWC. EWC engineers expect to gain valuable information that they can use to extend the design life of the weakest components by analyzing the worn, but still functional, machine. By the close of 2001, a similar regimen was being planned for the drive train of the 1.5-MW turbine.

These test results have shown the importance of gear contact and temperature on the durability of components. As a result, NREL's standard practices for validation tests of gearbox prototypes for wind turbine applications will now include contact tests of gear teeth and monitoring of the temperature of key components during full operation in hot weather.

Dynamometer tests at the NWTC also support manufacturers of small wind turbines. In 2001, the 50-kW turbine being developed by Bergey Windpower Company underwent extensive tests of its innovative alternator design that includes neodymium magnets that greatly reduce the size and weight of the alternator. To refine the alternator

The controls advanced research turbine (CART) at the NWTC will begin testing advanced wind turbine control strategies designed to reduce loads. The CART test bed offers variable-speed power electronics, independent blade pitch control, and an integrated high-rate data acquisition and control system. Testing of advanced load-mitigating control strategies will begin in 2002.

The ability to offer a certified product at home and abroad will help ensure the commercial success of U.S. wind turbine suppliers. To support efforts by U.S. manufacturers to get their wind turbines certified, NREL's NWTC is accredited to conduct acoustic, blade, power performance, power quality, and loads testing. In 2001, the American Association for Laboratory Accreditation (AALA) renewed the NWTC's accreditation for certification testing until December 31, 2002, after conducting a careful audit of procedures and record-keeping. In addition to previous accreditation, NREL was accredited to perform flicker measurements as part of power quality testing. Wind turbines can generate electricity with voltage fluctuations that cause electric lamps to "flicker". Not all voltage fluctuations will produce a noticeable change in the illumination from a lamp. However, when the magnitude and shape of the voltage fluctuations is just right, the flicker can be a serious nuisance to people. The International Electrotechnical Commission (IEC) has developed a group of standards that systematically account for flicker measurement, quantification, and limiting issues. The new "flicker-meter" has significantly streamlined the whole power quality test procedure.

design, the company took advantage of the dynamometer test bed at the NWTC. The dynamometer tests helped identify electrical filter components that could reduce voltage stresses on the alternator windings and reduce acoustic noise.

REGIONAL FIELD VERIFICATION

Another DOE Wind Energy Program effort that bridges the gap from cost-shared technology development to commercial sales is the Regional Field Verification (RFV) project, a project that evolved from the earlier, very successful, Turbine Verification Program (TVP). As was the case with TVP, the new RFV will aid manufacturers in verifying the performance and reliability of advanced prototype turbines. Additionally, RFV will help expand opportunities for wind energy in new regions of the United States by tailoring cost-shared projects to meet unique regional requirements.

WIND FARM MONITORING

There is still much to learn about how large wind power plants behave under varying wind conditions and how they interact with the electric utility grid. To provide concrete information to turbine designers, plant operators, and utility distribution planners, the Wind Energy Program collects long-term power data from large commercial wind farms. Wind power data collected in 2001 provided important information about short-term fluctuations. These data will also be used in case studies of electrical grid operating and planning issues like those being conducted by the Utility Wind Interest Group (UWIG). UWIG is a nonprofit corporation working to accelerate the integration of wind power for utility applications. UWIG's Operating Impact Study will examine impacts of wind plants on two case study systems: Northern States Power/Mid-Continent Area Power Pool and Bonneville Power Administration in the Northwest. UWIG members (55 utilities) are providing funds for the study, and DOE/NREL is providing access to project data from wind farm monitoring, as well as providing members for review panels.

UNDERSTANDING THE RESOURCE

Wind speed increases with height above the ground. This means that even in locations with low wind speeds (class 4), turbines placed on towers taller than the traditional height of 33 ft (10 m) can be cost effective. However, researchers know very little about the detailed characteristics of wind at higher levels above the ground. In 2001, NWTC wind resource scientists took measurements from a tower with a height of nearly 400 feet (120 m) that was located south of Lamar, Colorado. Their measurements show that significant nocturnal wind shears exist between the 50- and 120-m levels. In 2002, a state-of-the-art Doppler acoustic wind profiler (Sodar) will be used at the 120-m tower to increase our understanding of this phenomenon and its effect on wind turbine operation.

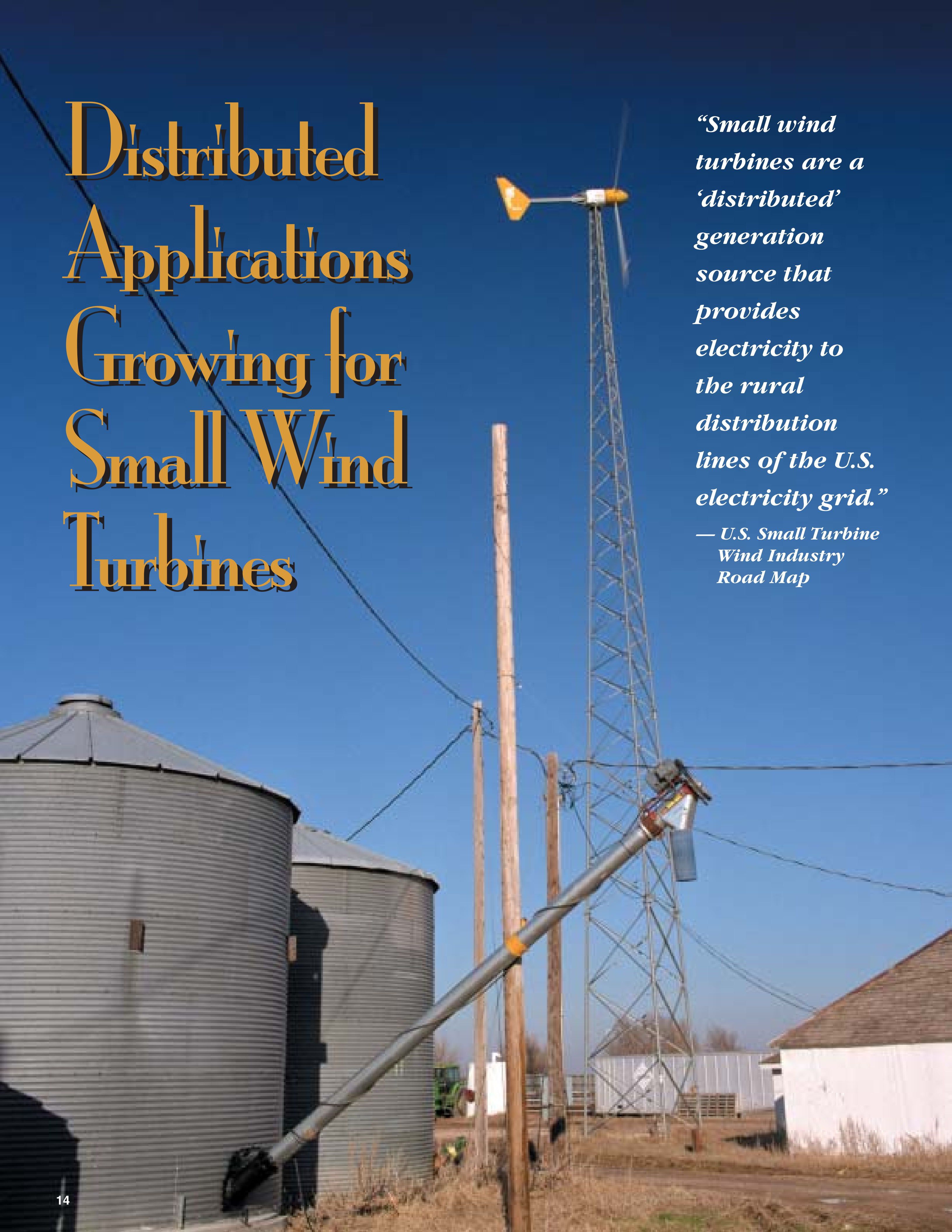
Wind Fact: **The power available in the wind is proportional to the cube of its speed, which means that doubling the wind speed increases the available power by a factor of eight.**

To move the nation toward AWEA's goal of generating 6% of our electricity from wind turbines by 2020, these and other projects supported by the Wind Energy Program are advancing wind turbine technology to take advantage of low wind speeds. ◆

Distributed Applications Growing for Small Wind Turbines

"Small wind turbines are a 'distributed' generation source that provides electricity to the rural distribution lines of the U.S. electricity grid."

— U.S. Small Turbine Wind Industry Road Map



WIND TURBINES CAN BE DISTRIBUTED ALONG A UTILITY LINE, GENERATING electricity where it will be used. These distributed turbines can increase electrical supply to an area while delaying or avoiding the need to increase the capacity of the transmission line. Most turbines used in distributed applications are small (under 100 kW), versatile tools that can generate electricity to meet a wide range of energy needs in rural areas. Small wind turbines in these distributed applications can also be combined with other generation systems, such as solar electric panels, diesel generators, and micro-gas turbines to create reliable hybrid systems to supply electricity for homes, businesses, a ranch, or a small village.

In 2001, most people who bought small wind turbines bought them to help offset their electricity bills from the utility company. Consumers have discovered that electricity generated by small wind turbines in places with a good wind resource can cost less over the lifetime of the system than the current retail utility rate. This is especially true for states that have small-wind financial incentives, like rebates and price buy-downs. To broaden the economic impact and increase the contribution to our electrical supply of small wind technology, the DOE Wind Program is committed to making the cost of energy from these wind systems competitive in distributed applications with lower wind speeds as well.

Wind Fact: In 2001, sales of the U.S. small wind turbine industry amounted to about 13,400 turbines valued at around $20 million.

Advancing the technology is one way to make small wind technology more cost-effective. Researchers believe that by developing and incorporating advanced technology in new small wind turbines, by 2007 the cost of energy can be reduced to $0.10–0.15/kWh in class 3 wind areas (12 mph measured at a height of 10 meters). To achieve this goal, the Wind Energy Program is making the financial and technical resources of the national laboratories available to U.S. companies developing commercial products. Companies can take advantage of the supporting R&D underway at the national laboratories, explore new concepts, develop advanced components, integrate advances into wind system designs, and improve designs or develop new product lines that take advantage of the latest technology.

ADVANCING THE TECHNOLOGY

In 2001, important technical support led to refinements in components that will improve system performance and decrease the cost of energy from small wind turbines. Part of the challenge of improving wind turbine technology is that when one element of the system is changed, it affects other parts of the system. For example, the new airfoil developed under subcontract for the Bergey XL.50 (a 50-kW machine) is efficient, quiet, and cheaper to manufacture. However, this airfoil also responds more quickly than previous designs to changes in wind speed and direction. This quick response resulted in the need for a redesign of the passive controls that have been used with Bergey's other small turbine models.

To advance the design of passive controls for all small wind turbines, NREL researchers are analyzing furling techniques—a simple, inexpensive type of control. On a furling turbine, in high winds, the tail stays fixed into the wind and the rotor moves around the tail into a furled or folded position. This reduces the wind that the rotor is exposed to, reducing the rotational speed thus protecting the variable speed turbine from damage that might be caused by higher winds. Data from furling tests conducted by NREL in the NASA Ames wind tunnel in 2000 promise to advance the way turbine designers integrate this control strategy (unique to small wind turbines), which can keep costs low.

Wind Fact: Small wind turbine technology can play an important role in our energy security, strategic technology, and long-term economic growth.

DEVELOPING SMALL WIND TURBINE TECHNOLOGY

To help U.S. industry develop cost-effective, highly reliable small wind turbine systems for rural America, the DOE Wind Energy Program began a series of procurements in 1997. In 2001, three subcontracts were in place with Bergey Windpower, Southwest Windpower, and WindLite Corporation. These subcontracts will result in innovative small wind turbine prototypes that have undergone extensive tests of components and complete systems.

As part of the small wind turbine development project, in 2001 Bergey Windpower developed a new wind turbine design to take advantage of a manufacturing technology called "pultrusion." Here the blades for the new turbine are passing strength and deflection tests that exceeded all design loads and conditions.

For example, in 2001 the 50-kW turbine being developed by Bergey Windpower Company underwent extensive tests of its advanced components. The Bergey XL.50 is designed for grid-connected applications in North America and incorporates innovative design features, including neodymium magnets that greatly reduce the size and weight of the alternator. The finished design could be used in distributed applications for reducing peak power demands on the utility (peak shaving) or serving as an uninterruptible power supply for village power or for a wind-diesel hybrid system. In 2002, a prototype turbine incorporating these new technologies will undergo tests at the NWTC.

VERIFYING SMALL WIND TURBINE PERFORMANCE

To provide U.S. manufacturers the opportunity to verify the performance and reliability of their small wind turbines, the Wind Energy Program supports the installation and evaluation of turbines that serve distributed power needs under diverse ownership and operating scenarios in various regions of the United States. In 2001, the field verification project included seven sites. Turbines at all seven sites were tested according to standards of the International

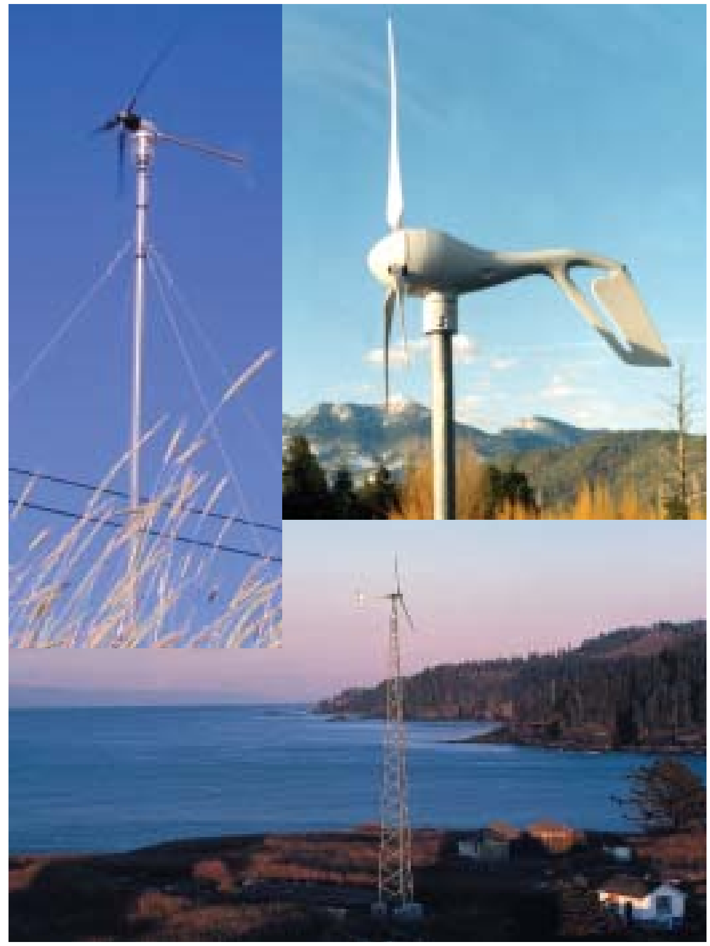
DOE's Wind Energy Program is working with Bergey Windpower in a cost-shared effort to develop an advanced turbine to supply the growing market for grid-connected applications in the United States. The company completed the detailed design and progressed toward component qualification testing. This model XL.50 pre-prototype, installed in 2000, progressed through three test configurations by the end of 2001 in its progress toward a prototype configuration for certification testing.

Electrotechnical Commission. These tests included noise, system safety and function, power performance, and duration. The duration tests, conducted at the NWTC, require the turbine to run a minimum of 1500 to a maximum of 3000 hours without major problems. The quarterly reports of the Field Verification Project are available for consumers and stakeholders.

To develop technology-supporting applications of small wind turbines in hybrid generating systems, the Wind Energy Program established two hybrid test facilities; one at the NWTC and one at the U.S. Department of Conservation and Production Research Laboratory in Bushland, Texas. The facility in Bushland has an independent generating capacity equivalent to that of a small village with a corresponding level of uncontrolled loads. Several configurations using multiple diesel generators and multiple wind turbines, with and without battery storage are possible. This system can determine the long-term operational characteristics of such hybrid systems.

The hybrid-power test bed at the NWTC supports industry in developing and validating innovative wind hybrid systems that incorporate wind energy, solar cells, fuel cells, and diesel or gas generators into power systems that can serve areas with small, isolated communities. The test bed can simulate loads and connect or disconnect storage and various generators as needed. NWTC's hybrid test facility was designed with an emphasis on versatility and flexibility, providing both real and simulated wind and photovoltaic (PV) energy sources.

DOE/NREL has also analyzed the operation of a wind-diesel system owned by the Alaska Native Tanadgusix (TDX) Corporation. The system provides electricity to a warehouse and an airport on St. Paul Island. Another wind-diesel project at Wales, Alaska, uses a special rotary powered converter designed and tested by NREL.



"Our vision is to make small wind turbine technology a significant contributor to America's energy supply portfolio by providing consumers with an affordable renewable energy option for their homes and businesses; and to make wind energy a significant contributor toward improving the quality of life and economic opportunities of people in developing nations worldwide through electrification."
— Vision Statement,
U.S. Small Turbine Wind Industry Road Map

INDUSTRY PLANNING FOR TECHNOLOGY ADVANCES

The American Wind Energy Association (AWEA) recognizes the importance of collaborative planning and R&D partnerships to the future vitality of small wind turbine technology. AWEA is a national trade association that represents wind power plant developers, wind turbine manufacturers, utilities, consultants, insurers, financiers, researchers, and others involved in the wind industry. In addition, AWEA represents hundreds of wind energy advocates from around the nation. The AWEA WINDPOWER 2001 Conference, held in June 2001, provided a forum for discussion of technology, market, and policy issues for wind energy development.

In 2000, AWEA's Small Wind Turbine Committee began to develop an industry road map. In cooperation with members of the Wind Energy Program and other stakeholders, the committee identified technical, market, and policy barriers to wider use of small wind turbine technology. The committee also developed specific goals and actions to improve the technology, reduce the costs of hardware and installation, stimulate the market, and influence government policy at federal, state, and local levels. In October 2001, the committee met at the NWTC to finalize the road map's contents. After a thorough review process, the committee approved the road map, which will be published in 2002. The final document will provide a framework to develop strategic plans for and investments in this promising technology. ◆

The DOE Wind Energy Program in Review

THE MISSION OF THE DOE WIND Energy Program is to help the United States maximize the substantial economic, environmental, and energy security benefits of expanding the domestic and worldwide use of wind energy and of fostering a thriving domestic wind energy industry. Directed by the Office of Wind and Hydropower Technologies under the Assistant Secretary for Energy Efficiency and Renewable Energy, the program advances its mission by taking advantage of the unique skills and facilities at two of DOE's principal research laboratories: the National Renewable Energy Laboratory (NREL) and Sandia National Laboratories (Sandia).

NREL's National Wind Technology Center (NWTC) near Boulder, Colorado, has been designated as the lead research facility for the wind program. The NWTC staff and facilities provide a broad range of capabilities in aerodynamics, structural testing, field testing, structural code development, controls theory and control systems, systems analysis, power system analysis, and subcontract management.

The Sandia staff and facilities, based in Albuquerque, New Mexico, provide extensive capabilities in advanced manufacturing, component reliability, aerodynamics, structural analysis, material fatigue, and control systems. Both Sandia and NREL conduct in-house and contracted research, as well as development and testing for DOE and for U.S. industry. Projects and tasks are often accomplished in collaboration with university and industry researchers.

To ensure the success of the Wind Energy Program, program managers conduct strategic mission review meetings throughout the year that allow critical review of program activities. The annual peer review meeting, held in August 2001, was an intensive technical event with topical sessions structured around major program research efforts. Session speakers made formal presentations that were subjected to questions by a peer review panel. The peer review panel, comprised of internal as well as external technical experts, then prepared a report of its findings that is used for strategic R&D planning, fine tuning the following year's budget, and to provide specific feedback on individual research projects.

HOW OUR RESEARCH PROGRAM WORKS

Research conducted by the Wind Energy Program falls under one of three categories: (1) applied research, (2) turbine research, and (3) cooperative research.

APPLIED RESEARCH

The major aim of applied research is to develop advanced low wind speed turbines capable of further reducing the cost of wind energy. Understanding all the natural and mechanical factors at work in wind energy generation is crucial to developing more efficient turbines that can produce electricity at lower cost. These factors include inflow and wind characteristics; aerodynamics; structures and dynamics; materials, manufacturing, and fatigue; systems and components; and distributed applications.

Inflow and Wind Characteristics

A better understanding of our nation's wind resources is crucial to development of advanced low wind speed turbines. To gain that understanding, DOE's Wind Energy Program is conducting research on inflow and wind characteristics. The research has two major components—quantifying the physical properties of the inflow and validating the wind resources.

Quantifying the physical properties of the inflow—Advanced low wind speed turbines must operate on very tall towers to take advantage of the increased wind speeds at higher altitudes. Very little is known about the turbulent wind patterns at these heights. Interactions between turbulent wind patterns and a wind turbine can cause damage to the rotor that will ultimately limit the turbine's energy capture and operational lifetime. Of particular interest on the Great Plains, where many wind farms will be located, are the high-level wind flows called nocturnal jets that dip close to the ground at night, creating violent turbulence. Wind resource assessment experts at NREL measure the higher altitude wind patterns and develop computer models that simulate a turbine's interaction with turbulent wind patterns to develop ways to prevent damage.

Validating the wind resources—DOE researchers are also working in cooperation with the National Oceanic and Atmospheric Administration (NOAA) and others to validate the nation's wind resources and develop methods of short-term (one to four hours) wind forecasting. Wind resource validation is important for both wind resource assessment and the integration of wind farms into an energy grid. Development of short-term forecasting tools will help energy producers proceed with new wind farm projects and avoid the penalties they must pay if they do not meet their hourly generation targets. In addition, validating new high-resolution wind resource maps will give people interested in developing wind energy projects greater confidence as to the level of the wind resource for a particular site.

Aerodynamics

Because low wind speed turbines will be lighter weight and have larger rotors than previous models, they may be more vulnerable to materials fatigue. To improve current design codes so that they compensate for fatigue, researchers at NREL and Sandia combine field and wind tunnel test data to predict aerodynamic loads on turbines under varied inflow conditions. Researchers are also working to develop a special airfoil that produces little noise for use on low wind speed turbines sited near large populations.

Structures and Dynamics

By creating and evaluating advanced prototypes of low wind speed turbines, substantial cost savings in design and development will be achieved. Researchers in the DOE Wind Energy Program are developing techniques to predict the performance of new turbine designs in order to evaluate and modify the designs before they are built.

Materials, Manufacturing, and Fatigue

Stronger, lighter-weight materials and improved rotor blade designs are needed to reduce the cost of low wind speed turbines. Researchers at Sandia develop tools to better predict how materials and component parts of these turbines react to high loads, especially from infrequent high wind gusts. The performance of composite materials, especially resin systems and carbon and carbon/glass hybrids, is a special focus of this research. Nondestructive testing techniques of materials are being developed at Sandia, which maintains a test site for wind turbine components at the U.S. Department of Agriculture's Agricultural Research Service in Bushland, Texas. Sandia's researchers also investigate ways to reduce the cost of the manufacture of low wind speed turbines, especially rotor blades.

Systems and Components

The Wind Energy Program includes research and development into control systems that sense varying aerodynamic forces and adaptively control the loads caused by these forces in order to avoid inefficient operation or damage to turbines. The new control systems are tested at the NWTC on a 600-kW controls advanced research turbine (CART), on which blade motion, pitch positioning, and rotor speed can be independently controlled.

At Sandia, work is underway to develop aeroelastic tailoring control systems, in which blades are designed with bend-twist coupling that promotes pitch-to-feather motion to reduce material fatigue.

Distributed Applications

Small wind turbines can be combined with solar electric systems, diesel generators, and micro gas turbines to form reliable hybrid systems capable of powering ranches or small villages. These hybrid systems have great potential in the developing world market as well as in rural areas of the United States. Small wind turbines can also be connected to the utility grid by consumers to help offset their utility bills. DOE, NREL, and Sandia are collaborating with the wind industry and utilities to develop and test small turbines for specific applications. Several test facilities for small turbines are used by industry and university partners, as well as researchers at the national laboratories.

TURBINE RESEARCH

The goal of the Wind Energy Program's turbine research is to assist U.S. industry in developing competitive high performance wind turbine technology for global energy markets. DOE works closely with the companies to research, design, build, test, and refine advanced large and small wind turbine designs. These public-private partnerships are developing breakthrough technologies that will significantly reduce the cost of wind-generated electricity and, ultimately, expand our domestic renewable energy supply. Industry partners are selected through competitive solicitations and share in the costs of the project.

Development Subcontracts for Turbine Research

Through Sandia and NREL, the DOE Wind Energy Program provides funds and project management to competitively selected industry projects developing high-risk, advanced wind technology. Researchers working under these contracts explore the effects of increased turbine size on performance and cost. A new generation of large wind turbines is being designed and tested by EWC and the Wind Turbine Company. A special turbine for operation in cold, remote locations, such as Alaska and Antarctica, is being developed in conjunction with the National Science Foundation, NASA, and Northern Power Systems. The Wind Energy Program is also working with Bergey Windpower Company, Southwest Windpower, and Windlite Corporation to design, build, and test more cost-effective, reliable small turbines for specialized markets.

Support of Turbine Research and Testing

The Wind Program offers design review and analysis, field-testing, structural testing, dynamometer testing, and staff support to the projects described above, as well as to a wider range of subcontractors. The capability to offer these services is continually maintained and upgraded.

Design reviews and analyses at NREL and Sandia evaluate the adequacy and safety of engineering designs explored in each subcontract, and a wide range of tools are offered to help companies solve problems and meet project deadlines. The program collaborates with Underwriters Laboratories (UL) on design review and testing for UL certification of wind turbines and wind turbine components for large and small machines.

Field-testing of whole turbine systems gives insight into performance under actual conditions. In 2001, NREL was accredited to perform field tests of power performance, noise, loads, and power quality in turbines, and it is helping to develop international standards for field-testing.

Structural tests on rotor blades include fatigue testing, ultimate static strength testing, photoelastic stress visualization, thermographic stress visualization, and acoustic emissions.

Dynamometer tests of turbine drive trains, drive-train components such as gearboxes, and power systems are conducted at the NWTC. The NWTC's megawatt-scale dynamometer is used to conduct tests that cannot be duplicated in the field, such as applying a constant, steady load.

COOPERATIVE RESEARCH

The Wind Energy Program's Cooperative Research projects are designed to develop new markets, with emphasis on rural development, integrating wind with other energy sources, penetrating low-wind regions, and promoting national and regional policies that encourage use of wind energy. Cooperative Research promotes strong partnerships with a variety of stakeholders, including industry, utilities, government (federal, state, and local), regulatory bodies, power marketers, environmentalists, public interest groups, and private sector elements.

Market Acceptance

The Wind Energy Program publicizes the achievements and potential of wind energy by issuing technical reports and brochures, sponsoring conferences and workshops, funding competitively selected outreach activities, and working with stakeholder organizations such as the National Wind Coordinating Committee, the Utility Wind Interest Group, and the American Wind Energy Association. The Wind Energy Program staff helps organizations like the National Association of Regulatory Utility Commissioners and the National Association of State Energy Officials to formulate and propose rules and guidelines that are friendly to wind energy. It also encourages federal agencies to make commitments to the use of wind energy.

Wind Integration

The electric generation industry is in an intense period of restructuring and technological change. The integration of renewable energy, including wind energy, into its supply mix is one of many issues the industry is grappling with before it can move fully into a newer, more competitive market structure. The DOE Wind Energy program is assisting the industry with a number of projects aimed at increasing understanding of integration issues and increasing confidence in the reliability of new wind turbine products.

Results from ceritifications tests conducted on wind turbine blades at the NWTC are used by Underwriters Laboratories as the basis for certifying machines designed by U.S. manufacturers.

Certification and Standards

International certification standards ensure that wind turbine designs are sound, safe, and executed with good engineering practice. The sales of U.S. wind turbines abroad depend heavily on their ability to meet international wind energy standards. In 2000, NREL completed a certification quality system that supports design evaluation and certification approval through a partnership between Underwriters Laboratory (UL) and the certification team at the NWTC. Standards developed under the International Electrotechnical Commission (IEC) are used as the basis for this certification program. ◆

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Wind Energy Program Web Sites:

U.S. Department of Energy:
  http://www.eren.doe.gov/wind
National Renewable Energy Laboratory:
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Sandia National Laboratories:
  http://www.sandia.gov/Renewable–Energy/wind–energy/homepage.html
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