Wind Energy Program Overview Fiscal Years 1995 and 1996

U.S. Department of Energy

Wind Energy Program Overview
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The Benefits of Wind Energy

New wind technologies will provide clean, affordable electricity for the 21st century and enhance U.S. competitiveness in international wind markets.

From bustling cities in the nation's heartland to tiny villages in northern Alaska, Americans are discovering the many benefits of wind energy. Thanks to modern technology, electrical power producers can harness the wind to generate electricity at costs only slightly higher than fossil-fuel generation. And, because new technologies will continue to bring these costs down, earth's winds promise an abundant harvest of electricity in the 21st century.

The value of wind energy to the nation goes far beyond cost, however. Transforming wind energy into electricity protects the environment. Wind generation produces no emissions and no hazardous wastes. It reduces the nation's use of fossil fuels, thereby reducing air pollution, smog, acid rain, and global warming.

Every billion kilowatt-hours (kWh) of electricity produced by wind instead of fossil fuels averts the release of nearly 6 million pounds of air pollutants and a billion pounds of carbon dioxide. For instance, Denver and its suburbs, which together have more than 2 million residents, could keep twice this much pollution out of the air by buying a third of the electricity used each year from wind power plants instead of coal-fired power plants.

Wind generation diversifies the nation's energy supply, enhancing our national security. Unlike fossil fuels, which are limited in supply and may be imported from the Middle East, wind is a domestic and renewable energy resource.

The U.S. Department of Energy's (DOE's) Wind Energy Program has worked hard to develop technologies to make electricity from wind as affordable as electricity from oil, coal, or natural gas. In 1980, electricity from wind cost \$0.35/kWh. Today, wind systems in areas with good wind resources can produce electricity for less than \$0.05/kWh—a decrease of 85% in just 15 years.

Fossil-fuel generation costs have also fallen, however. As a result, the federal wind program must meet new technological challenges to make wind generation economically competitive. The program is working with industry to bring wind energy's costs down to \$0.025/kWh by the turn of the century at excellent wind sites with annual average wind speeds of at least 7.0 meters per second (m/s) (15.5 miles per hour [mph]).

For nearly 20 years, DOE has supported the wind industry in developing technologies to capture energy from winds throughout the nation—from the mountains of California and the windswept Great Plains to the ridges and valleys of New England. The installation of new wind power plants in California, Iowa, Michigan, Minnesota, Texas, and Vermont since 1993 testifies to the maturity of this technology. (During the 1980s, most of the nation's wind capacity was installed in California's Altamont and San Gorgonio passes and the Tehachapi area.)

The construction of wind power plants in the United States slowed significantly during the past two years because of the anticipated deregulation of the utility industry. But, even as wind markets stagnated at home, they exploded in Europe and Asia.

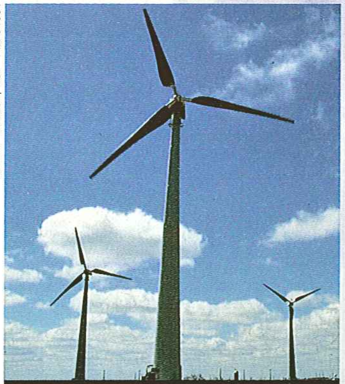
To keep abreast of these developments, DOE's Wind Energy Program worked with electric utilities, independent power developers, and the wind industry in 1995 and 1996 to structure its research program to support U.S. competitiveness in changing world wind energy markets. Research projects were designed to (1) help in understanding the basic scientific and engineering principles needed to develop advanced technologies, (2) help U.S. companies develop next-generation technologies, (3) introduce utilities and other wind energy users to the latest turbines, (4) better understand and evaluate the wind resource, and (5) better grasp the political, institutional, and cultural barriers to marketing wind technologies at home and abroad.

This overview provides an introduction to DOE's Wind Energy Program. It shows how the program is supporting the development of innovative technologies to compete in multibillion-dollar international wind markets and in the deregulated utility markets developing in the United States. It presents ongoing research programs conducted by the National Renewable Energy Laboratory (NREL) and Sandia National Laboratories (Sandia). It describes the sophisticated research and testing facilities at the National Wind Technology Center (NWTC). The overview also discusses new projects initiated in fiscal years 1995 and 1996 and highlights future initiatives.

WARREN GRETZ, NREL PIX 03848

Government research on wind energy technologies helps enhance national security, protect the environment, and strengthen competitiveness.

JERRY MILLER, NSP PIX 04681



New wind technologies capture energy throughout the nation, including this power plant located near Lake Benton in southwestern Minnesota.

WPP94, PIX 03615

Unlike conventional generation, this wind power plant in Culberson County, Texas, uses no fuel and produces no air pollution, acid rain, or carbon dioxide.

Wind Resource Potential Is Huge

The global wind resource is huge. Major planetary winds, such as the trade winds and the jet stream, are created by the uneven heating of the earth's surface and modified by the planet's rotation. Locally, winds are created by temperature differences between mountains and valleys or coastal areas and inland regions. Winds are also created by pressure differences between large air masses and by the storms generated at the boundaries between these air masses, called fronts. Wind speeds range from gentle breezes to destructive winds traveling at speeds of more than 150 mph. Taken together, planetary winds could produce at least five times more electricity than is currently used on the planet.

Even relatively moderate winds of 13 mph contain significant amounts of energy. Wind turbines can capture this energy to generate electricity or to run mechanical devices such as water pumps. Theoretically, the U.S. wind resource is large enough to provide all of the electricity the nation requires, about 2.8 trillion kWh of wind power annually. More than 90% of this wind resource is found in a wide band through the nation's midsection, stretching from Montana, North Dakota, and Minnesota south through Texas.

The intermittent nature of the wind resource makes it necessary for utilities and village power systems to limit their use of wind, however. Hybrid village power systems using some wind turbines may be able to integrate as much as 50% wind generation, but these systems are designed for remote areas without access to a utility grid. Grid-connected systems can include as much as 20% wind generation. If every utility added this much, the nation would produce 560 billion kWh of wind power each year. At this level, wind generation would significantly reduce the environmental impacts of electricity generation by fossil fuels.

Wind Energy in the United States

Despite wind energy's many benefits, new capacity additions in the United States have been slower than projected. The slowdown in construction of new wind power plants is a result of restructuring in the U.S. electric power industry to provide lower cost electricity and customer choice. There is significant uncertainty about how this process will affect the electric power industry in the long run. As a result, utilities and other power producers are reluctant to invest in new generation at this time.

The United States added 53.6 megawatts (MW) of new wind capacity in 1995 and 16.2 MW in 1996. At the end of 1996, wind capacity in the United States totaled approximately 1.8 gigawatts (GW) and produced approximately 3.2 billion kWh of electricity—enough to meet the residential needs of more than 1 million people.

WIND ENERGY TECHNOLOGY STATUS*

Technology Characteristic	Before 1975	Current	2000
Cost/kWh	\$0.50–\$1.00	\$0.035–\$0.05	\$0.025–\$0.04
Operating Life	1–5 Years	30 Years	30 Years
Capacity Factor (Average)	10%	25%	35%
Availability	60%–70%	98%	98%+
Turbine Size	<20 kW	300 kW–700 kW	500 kW–1.5 MW

*For a wind site with an annual average wind speed of 7.0 meters per second (15.5 miles per hour). Wind speeds were measured at a height of 30 meters (100 feet). The low-end cost of energy assumes municipal utility financing.

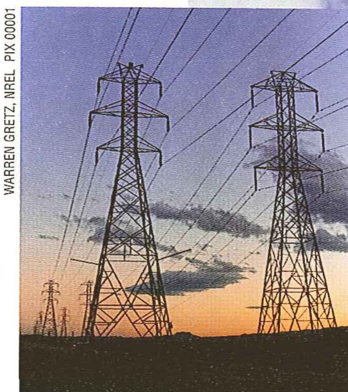
DOE, Private Sector Work Together to Promote Competitiveness

The DOE Wind Energy Program is committed to bringing wind generation's potential into reality. The program sponsors a major effort to develop more efficient, robust, and less costly wind turbines. Only with advanced wind systems can the U.S. wind industry hope to gain a competitive edge in domestic and international wind energy markets. Research is the key to rapidly developing these sophisticated new technologies.

The federal government sponsors research at the NWTC, NREL, and Sandia. It investigates innovative methods for understanding the wind resource. Federal wind research is carried on in collaboration with the nation's universities. (Industry has limited resources to carry on this type of fundamental research. However, industry collaborates with the federal government in setting research priorities.)

The government transfers the knowledge it gains from research to the private sector through partnerships with the wind industry, utilities, and independent power producers. The American Wind Energy Association helps disseminate new information via conferences and educational publications.

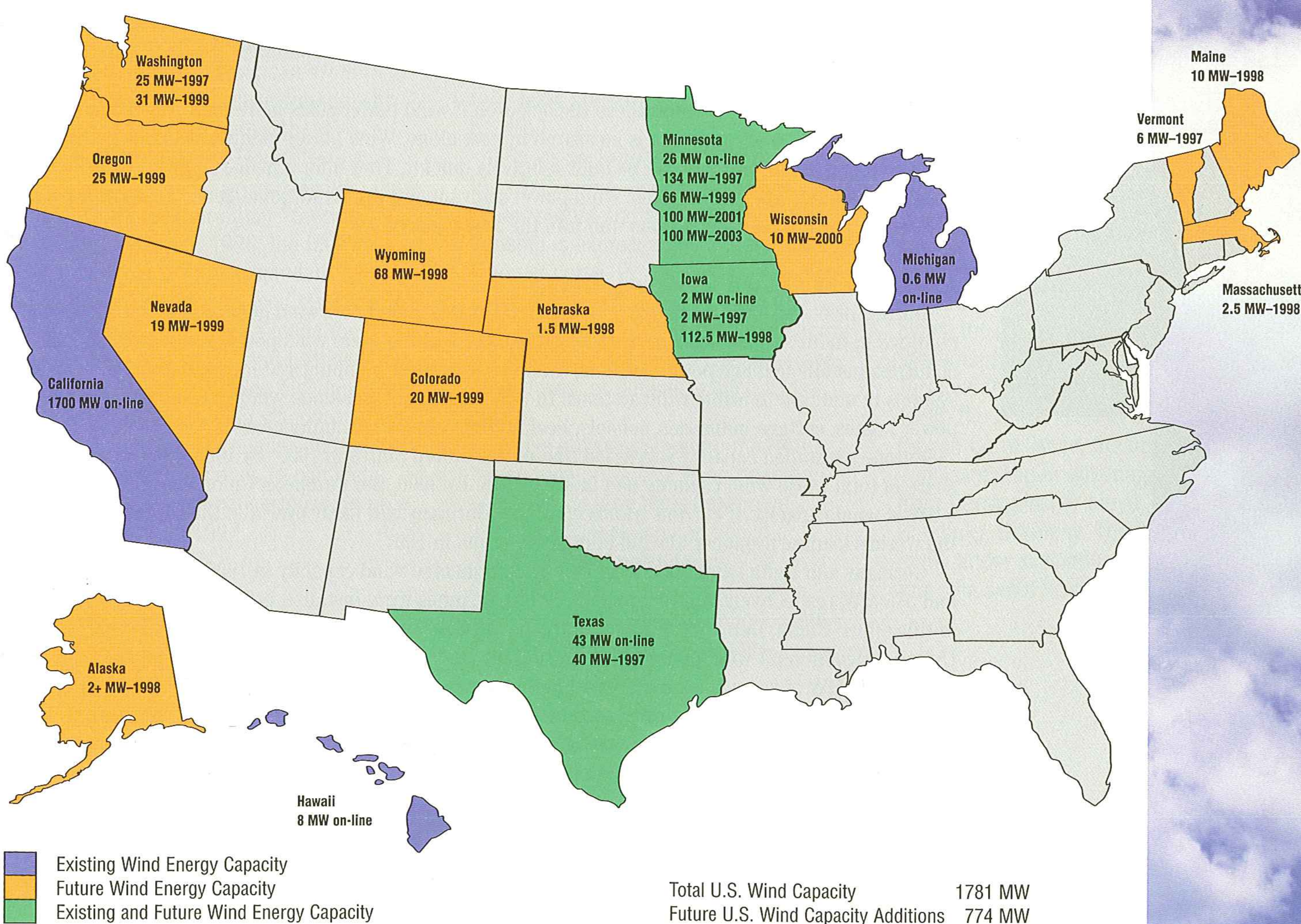
The private sector assumes responsibility for developing and marketing commercial products. Working together, the public and private sectors both contribute to technological innovation and competitiveness.



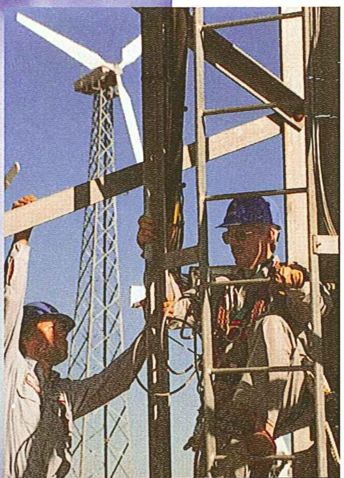
WARREN GRETZ, NREL PIX 00001

Uncertainty surrounding the current restructuring of the electric power industry is discouraging utilities and other power producers from investing in new technologies.

U.S. Wind Energy Capacity by State—Existing and Future



Total U.S. Wind Capacity	1781 MW
Future U.S. Wind Capacity Additions	774 MW



KRTSTIN TROMLY, NREL PIX 04692

Utility Wind Interest Group members got hands-on experience with wind turbines in California's Tehachapi area during fiscal year 1995. The group works to expedite the integration of wind energy into utility systems.

RON ROESLER, AWT, INC. PIX 04690

The six AWT-26 wind turbines shown above generate electricity for residents of Ramagiri in the Indian state of Andhra Pradesh. India, which installed 375 MW of new wind capacity in 1995, is an important market for U.S. technology.

The National Wind Coordinating Committee (NWCC) plays a key role in facilitating the interaction of the public and private sectors. This consensus-based organization has worked since 1994 to further the development of wind energy and increase U.S. competitiveness in wind markets at home and abroad. NWCC members include wind power producers, utilities, regulators, environmental and trade organizations, and DOE.

In 1995 and 1996, the NWCC began preparing guidelines for siting wind power plants and monitoring the impact of wind power plants on migratory birds and birds of prey. It completed background papers on key issues in wind technology development and deployment, including wind turbine performance, wind energy costs, siting issues, and the environmental impacts of wind power generation. The committee's goal in preparing the papers was to ensure that accurate information on wind energy was available to utilities, regulators, and others involved in utility restructuring. The committee also began work on defining wind's role in U.S. power generation during the next decade.

The Utility Wind Interest Group, Incorporated (UWIG), which represents utility interests, is an important NWCC participant. Launched with support from DOE and the Electric Power Research Institute, the group works to expedite the integration of wind power into utility systems. UWIG provides utilities with information on wind power, a forum for discussion of utility-specific issues, and technical support for wind energy planning and implementation. UWIG also furnishes a utility perspective on wind power to federal regulatory agencies and legislators.

During 1995 and 1996, UWIG incorporated and grew to 23 members. It published its ninth informational brochure, *The European Wind Experience*, and launched a new newsletter, *Wind Watch*. *Wind Watch* highlights wind industry news, utility wind projects, upcoming meetings, and technical workshops.

Multibillion-Dollar International Wind Energy Markets Developing

Since 1990, wind power generating capacity has grown by about 20% per year, reaching a total installed capacity of nearly 6.2 GW by the end of 1996. Although wind power currently accounts for less than 1% of the world's electricity, it is expected to become an increasingly important energy resource during the next decade in Europe, Asia, and South America. The International Energy Agency estimates that wind capacity will increase to 12 GW by 2001.

Growth is likely to continue in these regions even if wind power costs more than traditional generation. Wind has value beyond what is measured by cost alone. Wind power plants have no fuel costs, no environmental emissions, and can be built relatively quickly. They offer a hedge against price fluctuations or disruptions in fuel supplies. Wind power's advantages over traditional generation are expected to stimulate new capacity additions well into the 21st century.

Wind Markets Expand in Europe, Asia

During 1995 and 1996, more than two dozen countries added new wind generation. Most new wind facilities in industrialized nations were grid-connected, utility-scale wind power plants. Developing countries installed village power systems, wind-electric water pumping systems, and stand-alone wind systems in addition to utility wind systems. In remote areas, stand-alone wind systems are used to power homes, cottage industries, schools, health clinics, and community centers.

Europe's installed capacity surpassed that of the United States in 1995. By 1996, the United States' share of total world wind capacity had fallen to 25%. By 2000, the European Union expects to have 4 GW of wind capacity. If current trends continue, Germany will likely overtake the United States as the world's leading producer of wind energy sometime in 1997.

Germany and India led the world in new grid-connected wind capacity in 1995, installing 505 MW and 375 MW, respectively. Approximately 100 U.S. turbines were installed in India during 1995 as part of this effort. China, Denmark, Finland, Italy, Japan, the Netherlands, Spain, Sweden, Ukraine, and the United Kingdom built wind power plants during the past two years. China announced plans to add nearly 1000 MW of new wind capacity within four years.

The U.S. wind industry is working to gain a strong position in multibillion-dollar wind markets in Europe and Asia. Advanced U.S. technologies and certification testing are the key to gaining market share for utility wind systems. DOE assists industry with certification testing (see sidebar on page 5) and the development of next-generation technologies.

Certification Testing a Must for U.S. Competitiveness

The National Wind Technology Center (NWTC) launched a $1.9 million certification testing program for U.S.-made turbines in 1996. The program was created in response to urgent requests from the wind industry, which was concerned that certification requirements were, in effect, a trade barrier to marketing U.S. technology. Wind turbine certification is required in Europe and has recently been mandated in India. Other countries are expected to follow suit.

Certification is a two-stage process: first, an approved laboratory such as the NWTC conducts certification testing; then, a turbine manufacturer forwards the test results to an authorized agent such as Germany's Germanischer Lloyd, which guarantees, or certifies, that the turbine conforms to set standards.

The U.S. Department of Energy, National Renewable Energy Laboratory (NREL), Sandia National Laboratories (Sandia), and the American Wind Energy Association have worked with the International Energy Agency's (IEA's) International Electrotechnical Commission (IEC) on establishing these standards for more than 15 years. During 1995 and 1996, the IEC finalized a power performance standard for large turbines, drafted a revised standard for safety, and developed a guide for the structural testing of wind turbine blades. The commission also launched new efforts to develop standards for certification, power quality, and loads measurement. It hopes to complete work on international certification procedures by late 1997.

NREL works to ensure that its certification testing conforms closely to international standards and recommended practices. In 1996, NREL agreed to manage a "round-robin" turbine testing program for IEA. Laboratories in Canada, Denmark, Greece, Italy, and the NWTC will conduct similar tests on one wind turbine to see how well test results match. In 1995 and 1996, NREL and Sandia participated in expert meetings sponsored by the IEA. Meeting topics included lightning protection, the interaction of the wind and wind turbines, long-term wear and tear on turbine structures, and the measurement of wind turbulence. In 1995 and 1996, NREL also participated in an IEA aerodynamics research project.

NREL completed preparation for three types of certification tests in early 1996: power performance, noise emissions, and blade structural tests. The first two tests are required. Though not required for certification, blade structural tests are strongly recommended by NREL.

Power performance tests measure the relationship between a turbine's power output and wind speed. The relationship is expressed by a graph called a power curve. Power curves are often used to estimate annual energy production from a wind turbine. Annual energy production is needed to calculate revenues, taxes, or subsidies such as tax credits.

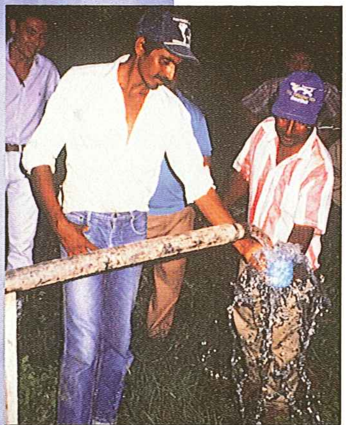
Noise emissions testing measures the sounds produced by an operating wind turbine. The tests determine whether changes in wind speed or direction affect noise levels. The tests are particularly important in Europe, where wind turbines are often located close to homes and businesses.

Blade structural tests help determine the strength of turbine blades and their attachments to the hub. They also show how long blades will last before they wear out and need replacement.

WARREN GRETZ, NREL PIX 02131

A researcher conducts a noise emissions test on an AWT-26 turbine at the National Wind Technology Center. Noise emissions, power performance, and blade structural tests comprise the National Renewable Energy Laboratory's certification testing program.

During 1996, NREL conducted certification testing on two U.S. wind turbines, the Z-40, manufactured by Zond Systems, Inc., and the Advanced Wind Turbines Incorporated AWT-27. In May 1996, the Z-40 received a Statement of Design Compliance, the first and most important step in obtaining certification, from Germanischer Lloyd, based in Hamburg, Germany. The AWT-27 is currently under evaluation for certification from the same firm.



LARRY FLOWERS, NREL PIX 04689

Ranchers in Oaxaca, Mexico, celebrate the installation of a new wind-electric water-pumping system, which will provide a dependable supply of water for crops and cattle.

Wind, the Technology of Choice for Village Power Systems

Thanks to DOE's support, the U.S. wind industry is currently well positioned to meet the increasing demand for electricity in remote areas of the globe. Growth in demand for electricity in the developing world is huge and comes at a time when most nations recognize the need to control energy-related environmental impacts. Where wind resources are good, wind energy systems are an excellent choice.

A single wind turbine can pump water for drinking or irrigation, or provide power for water treatment, communications, ice making, refrigeration, grain grinding, or lighting. Larger, hybrid wind power systems, which link wind turbines with other renewable power sources, batteries, and backup diesel generators, can meet the needs of an entire village.

DOE's Wind Energy Program helps to bring wind systems to areas where they are most needed. The program offers technical assistance in wind resource assessment; technology development; and wind project planning, implementation, and evaluation. DOE leverages its technical assistance budget by working closely with other international organizations on new wind projects. The organizations include the World Bank and other financial institutions; the United Nations; the U.S. Export Council for Renewable Energy; the Committee on Renewable Energy Commerce and Trade; the National Rural Electric Cooperative Association/South America; Winrock International, a private development organization; and other government agencies, including the Departments of Agriculture, Commerce, Defense, and State, the U.S. Environmental Protection Agency, and the U.S. Agency for International Development.

During 1995 and 1996, NREL and Sandia worked with these groups to plan and/or deploy small wind energy systems in Alaska, Argentina, Brazil, Chile, China, the Dominican Republic, Guatemala, India, Indonesia, Mexico, the Philippines, Russia, and South Africa.

International Wind Resource Assessments Create Market Opportunities

NREL offers technical assistance in evaluating wind resources to countries where there are market opportunities for U.S. industry. During 1995 and 1996, NREL staff prepared wind resource maps of Mexico; Nan'ao Island, a small island off the southeast coast of China; and the islands of Sumba and West Timor in southeastern Indonesia.

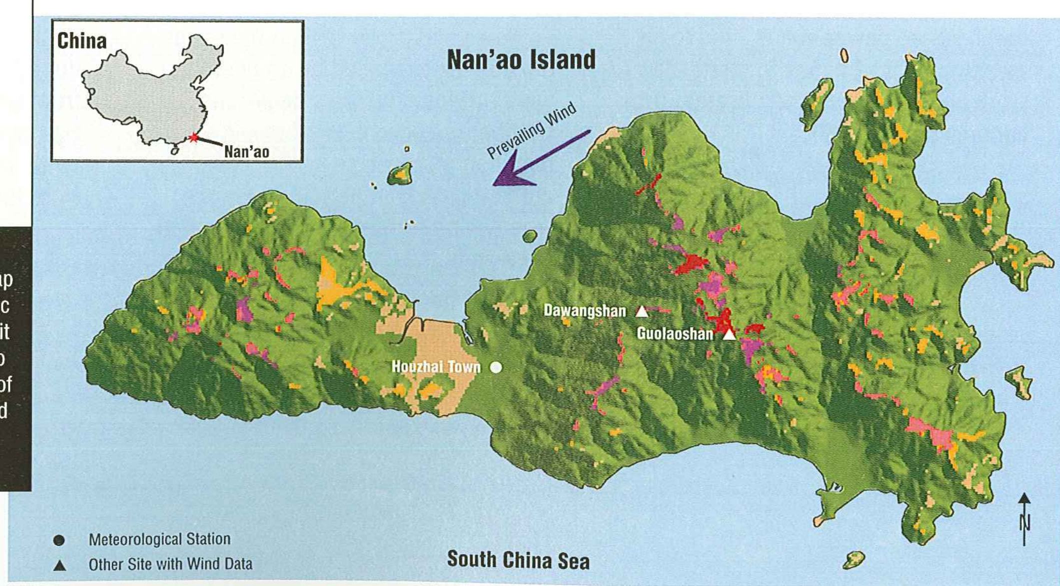
Mexico expects to use its resource map to site grid-connected wind power plants and remote, village power systems. China plans to build a 50-MW wind power plant on Nan'ao with the support of the World Bank, which requested NREL's assistance in making the wind resource map. Indonesia has a huge potential market for village power systems; its 13,000 islands are home to more than 100 million people without access to electricity.

Researchers created the Nan'ao and Sumba maps using Geographic Information Systems and new techniques developed at NREL. Previously, wind resource maps were painstakingly drawn by hand and showed less detail. NREL researchers have begun gathering data for new wind resource maps of Argentina, Baja California, Chile, southeast China, the Dominican Republic, India, Inner Mongolia, the Philippines, Taiwan, and Thailand.

Wind Energy Classification

Wind Power W/m²	Wind Speed m/s
300–400	5.8–6.8
400–500	6.8–7.5
500–600	7.5–8.1
600–700	8.1–8.7
>700	>8.7

National Renewable Energy Laboratory researchers created this wind resource map of China's Nan'ao Island with a Geographic Information Systems technique. To make it easier to site a wind power plant, the map uses color coding to indicate the amount of wind energy available in specific areas and superimposes this information over the island's terrain features.



Wind Turbine Research

Wind turbine research is propelling U.S. technology into the 21st century.

Competitive, high-performance wind turbines will dominate tomorrow's wind energy markets. DOE wants to ensure strong U.S. participation in these markets. Consequently, DOE designed a 10-year Wind Turbine Development Program in 1992 to help industry lower the cost of wind-generated electricity to $0.05/kWh by 1995 and 20% less by 2002. New technologies, the development of sites with excellent wind resources, and improved financing strategies will be key factors in achieving these cost goals.

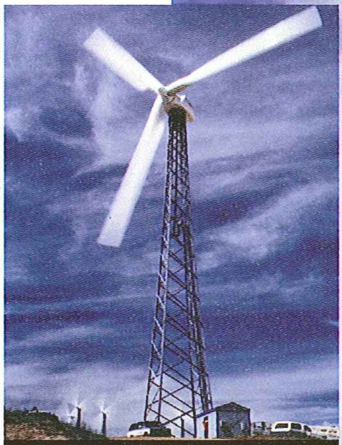
The first stage of the program, which is a cost-shared effort with industry, was the development of new turbines for commercial sales in 1995 and 1996. The turbines were developed by enhancing existing technology to improve performance and lower costs. The program's next stage, which began in 1994, was to develop a whole new generation of wind turbines by the turn of the century. Next-generation turbines will incorporate innovative components and subsystems. The next-generation turbine development project is a two-pronged effort to develop not only advanced turbines, but also the cutting-edge technology needed to create them. The turbine development program also includes technology transfer efforts and special projects to develop small wind turbines and village power systems.

The first turbines developed under this program are now commercially available. They include the Zond Corporation Z-40 turbine, the Advanced Wind Turbines Incorporated AWT-26/27 turbines, and the Atlantic Orient Corporation AOC 15/50 turbine. Flowind Corporation's 17 EHD vertical-axis wind turbine and New World Power Technology Company's North Wind 250 turbine are undergoing refinements. The AOC 15/50 was designed for village power systems. The others will be used in grid-connected wind power plants.

The turbines were developed to bridge the gap between conventional technologies and the next generation of utility-grade wind turbines. Energy costs for these machines are among the lowest in the industry. When coupled with the production tax credit of $0.016, wind energy generation costs are highly competitive with conventional sources.

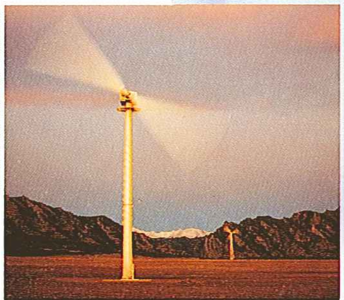
The new turbines underwent testing and refinement during 1995 and 1996. The goal of this intensive evaluation was to find ways to improve turbine performance, increase reliability, decrease costs, and encourage utilities and independent power producers to consider wind generation. Accomplishments are summarized below.

- Zond completed blade design refinements for its 550-kW Z-40 wind turbine. The turbine was deployed in Central and South West Services' 6.6-MW wind power plant in west Texas in 1995 and in Green Mountain Power Corporation's 6.0-MW facility in southern Vermont in late 1996.
- Advanced Wind Turbines completed testing of the AWT-27 turbine's extended rotor, refined its hub design, improved manufacturing processes for the blades, and developed a 43-m (140-ft) lattice tower. FloWind, which markets the turbines, installed turbines in India during 1995 and has contracts to deploy more turbines in India and China.
- FloWind also developed new blades for the 17 EHD. The 17 EHD is the only vertical-axis wind turbine under development in the United States. Its three blades spin on an axis perpendicular to the ground. The 17 EHD's low-cost blades are manufactured using an automated pultrusion technique, in which fiber-resin blades are pulled through a die. Its long, thin blades incorporate new airfoils to increase energy capture. FloWind redesigned the struts that hold the blades in place, giving them an airfoil shape. The company also developed new software for the turbine controller.
- Atlantic Orient's AOC 15/50 (shown on page 14) is currently undergoing extensive reliability testing at multiple sites in the United States. The turbine has been selected for "round-robin" testing at the National Wind Technology Center and at laboratories in Canada and Europe. Up to six 50-kW wind turbines will be installed in Kotzebue, Alaska, under the Sustainable Technology Energy Partnerships Program.
- Engineers completed 1000 hours of testing on the North Wind 250 proof-of-concept turbine.



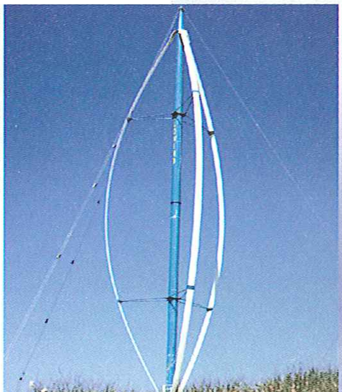
LLOYD HERZIGER, ZOND CORPORATION PIX 01502

The Zond Corporation Z-40



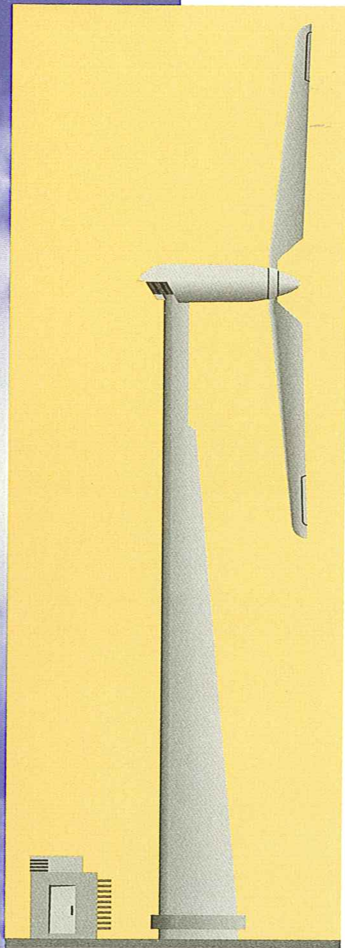
WARREN GRETZ, NREL PIX 01497

The Advanced Wind Turbines Incorporated AWT-26



BOB THRESHER, NREL PIX 04688

The FloWind Corporation 17 EHD



An artist's concept of a next-generation turbine.

DOE, Industry Developing a New Generation of Wind Turbines

In 1994, DOE and NREL launched a $50 million project to develop a new generation of wind turbines for the next century's marketplace. The turbines should significantly expand markets for U.S. technology by bringing wind energy costs down to $0.025 at excellent wind sites.

During 1995 and 1996, eight teams created concepts for an innovative utility wind turbine capable of meeting DOE's ambitious cost goals. After the studies were completed, NREL selected two participants for the next stage of the cost-shared project: Zond Corporation of Tehachapi, California, and The Wind Turbine Company of Bellevue, Washington. The firms will each design, fabricate, and test a new utility-grade turbine incorporating cutting-edge technology. Both will provide approximately 30% of project costs.

Zond plans to develop the Z-56, an upwind, variable-speed turbine rated at 1 MW. In variable-speed machines, the turbine rotor slows down or speeds up in response to changes in wind velocity. This feature typically increases energy capture and reduces wear and tear on turbine components. The three-bladed turbine will generate electricity in wind speeds ranging from 3 m/s (7 mph) to 29 m/s (65 mph).

The current concept for the Z-56 features a smart controller, NREL-designed airfoils, variable-pitch blades, and an innovative variable-speed generator.

The Wind Turbine Company is designing the WTC 1000, a two-speed, variable-pitch turbine rated at 1 MW. The two-bladed, downwind turbine will sit atop a 100-m (328 ft) tower. The tall, thin tubular tower will come equipped with an internal service elevator to transport maintenance workers up to the turbine nacelle.

The lightweight turbine will incorporate a drivetrain with multiple generators, blades made with a resin-transfer-molding process, and an innovative teetering rotor. Teetered rotors are designed to rock back and forth in response to wind gusts, thereby dissipating loads. Loads are the forces in the wind that cause wear and tear on turbine structures. The WTC 1000's rotor blades will be hinged at the root, allowing them to bend slightly downwind in high winds to shed loads.

The turbine will operate at two constant speeds. It will capture energy from wind speeds ranging from 3.5 m/s (8 mph) to 30 m/s (67 mph).

Cutting-Edge Technology Supports Turbine Development

The development of innovative components and subsystems is a key component of DOE's next-generation turbine development program. This facet of the program encourages industry to explore cutting-edge technology and depart from traditional designs. NREL and Sandia currently oversee more than a dozen different cost-shared activities to develop new generators, rotors, blades, airfoils, and controls.

New Generator Designs Will Be More Efficient

Most turbines use induction generators that generate electricity when the turbine's high-speed shaft turns faster than 1800 revolutions per minute (rpm). Because most turbine rotors spin at less than 60 rpm, wind systems must use costly transmission and gearing to increase the speed of the generator shaft. Many conventional turbines use this technology, however, because induction generators and gearboxes are available off the shelf.

NREL is sponsoring the development of three advanced generators that show promise of being more efficient and less costly than the traditional design. Two generators are described here. A third has been built and installed in the National Wind Technology Center's Variable-Speed Test Bed, which is described in the next section.

Electronic Power Conditioning, Inc. (EPC), of Corvallis, Oregon, is developing an innovative power subsystem consisting of a doubly fed, variable-speed generator and a power-electronic converter. EPC's patented power-electronic converter is required to convert the variable-frequency electricity produced by the generator into 60-cycle electricity compatible with the utility grid. The unique generator design allows the use of a converter less than half the size normally required for a similarly sized turbine, significantly lowering costs.

During 1995 and 1996, EPC built a 325-kW generator, then tested and refined it in the laboratory. In the spring of 1996, the company began field-testing the generator and power-electronics converter in collaboration with Zond. The devices were installed on Zond's 750-kW Z-46 prototype wind turbine in California's Tehachapi area.

Field testing will continue in 1997 to determine whether the new power subsystem will allow the turbine to operate at maximum efficiency over a wide range of wind speeds. In addition, the power subsystem should improve the turbine's power quality; allow for smoother, more controlled turbine start-ups and shutdowns; and permit quieter turbine operation, particularly at low wind speeds. In some cases, significant reductions in design loads are also achievable.

New World Power Technology Company will complete the development of a 100-kW low-speed generator for a variable-speed wind turbine. The new generator eliminates the requirement for a gearbox. It will be the largest permanent magnet, direct-drive wind turbine device in the United States. The complete system consists of the generator, a controller, and a power inverter, which changes the variable-frequency electricity from the generator into 60-cycle alternating current. When the generator system is built, it will be tested on a North Wind 100 turbine.

DALLAS MARCKX, EPC PIX 04687

Electronic Power Conditioning, Inc., developed an innovative power subsystem consisting of a doubly fed, variable-speed generator and a power-electronic converter. The unique design allows for the converter to be less than half the size normally required, significantly lowering costs.

Advanced Rotors Will Improve Energy Capture

Rotor design determines how efficiently a turbine captures the energy in the wind. Rotors are also one of the largest and heaviest turbine subsystems. For these reasons, innovative rotor designs can have a significant impact on energy cost. NREL has been investigating new airfoils, blades, and rotors since the 1980s. The laboratory sponsors several advanced rotor design projects and a related effort to design and test new airfoils for wind turbines.

PS Enterprises, Inc. (PSE), of Glastonbury, Connecticut, is developing a highly flexible, lightweight, multibladed advanced rotor. The rotor was designed for a downwind, free-yaw turbine. Free yaw means that the wind pushes the turbine into the proper orientation for operation, similar to how the wind orients a weather vane. The rotor uses five slender, flexible blades that incorporate spoiler flaps on the trailing (downwind) edge. Spoiler flaps deploy up or down to control rotor speed. The rotor's pultruded blades cost about half as much as conventional fiberglass-reinforced plastic blades. They were manufactured by Creative Pultrusions, Inc., of Alum Bank, Pennsylvania.

In October 1996, PSE installed its unique five-bladed rotor on an 80-kW turbine in the Cabazon Wind Park near Palm Springs, California. Researchers will spend a full year studying the rotor's performance and structural stability in the park's turbulent winds. In a parallel development effort, the California Energy Commission is supporting PSE in developing a 750-kW prototype turbine using the innovative rotor design developed under the NREL subcontract.

PAUL MIGLIORE, NREL PIX 04686

PS Enterprises installed an innovative five-bladed rotor on a 80-kW turbine in fall 1996 near Palm Springs, California. The rotor was developed under a National Renewable Energy Laboratory subcontract.

The University of Texas at El Paso (UTEP) is investigating innovative designs for teetered rotors under a subcontract with NREL. In one three-bladed configuration, there is a hinge on each blade at the hub. This allows each blade to flex in response to the wind.

In another two-bladed design, the rotor consists of a single, continuous piece with the two blades held together by a shaft through the middle. The rotor flexes in response to wind gusts in much the same way a teeter-totter works.

In a related project, UTEP researchers are looking at a rotor design in which the blades pitch as well as flex back and forth in response to the wind. This configuration allows for more rotor control, but the rotor must be very flexible for it to work well. UTEP researchers are also studying the effects of using variable-speed operation with teetered rotors.

Since 1984, NREL researchers have developed seven families of thick and thin airfoils designed for wind turbine blades. In conjunction with its airfoil design and testing effort, NREL has prepared a catalog of test data on all major airfoils used in the wind industry.

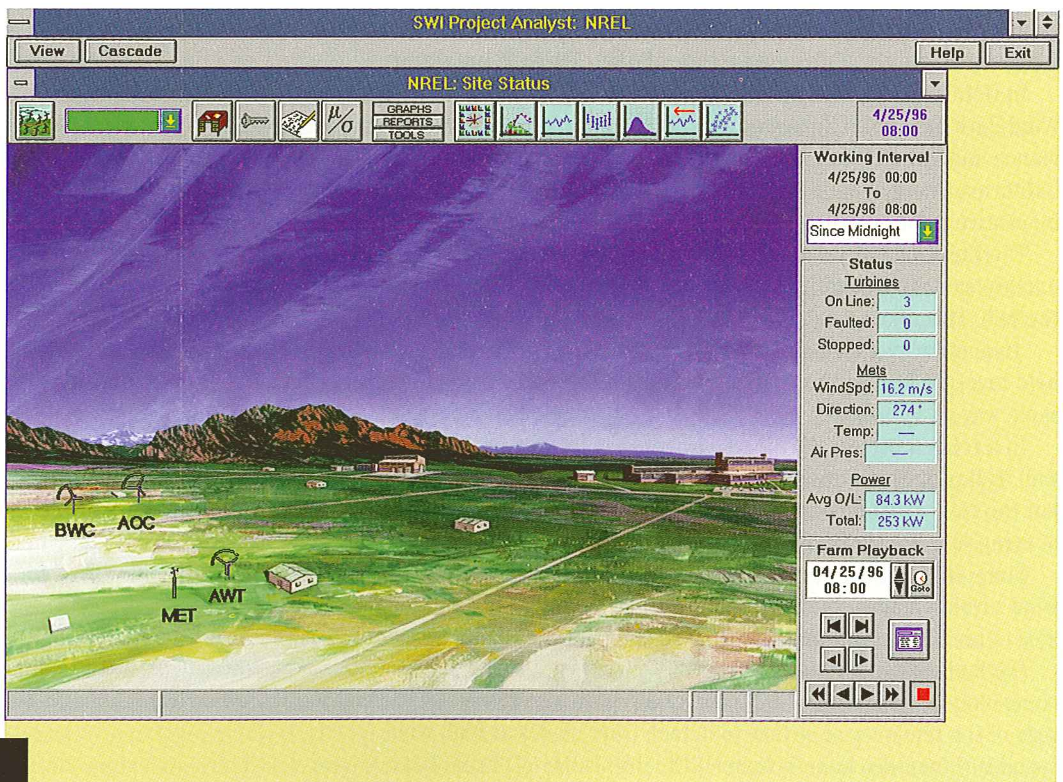
NREL-designed airfoils can increase energy capture by 20% to 30% on constant-speed, stall-controlled turbine rotors. Stall-controlled rotors regulate power output in high winds by taking advantage of the tendency of airflow to detach from blades at high wind speeds. Variable-pitch and variable-speed turbines also benefit from NREL airfoils. Many of the nation's newest turbines, including the Z-40, AWT-27, and AOC 15/50, use NREL-designed airfoils.

Innovative Control Systems Will Improve Power Plant Operation

In the past, turbine controls were often implemented to solve a particular problem: to slow or stop the rotor, to prevent power spikes during wind gusts, to avoid potentially damaging vibrations during operation, to mitigate damaging loads from turbulent winds, and so on. As wind turbines grow more and more complex, it is becoming clear that plant operators will benefit from sophisticated turbine control systems.

New and improved control systems for wind power plant operation translate to better turbine reliability, lower operation and maintenance costs, and increased annual energy production. Second Wind Inc. of Somerville, Massachusetts, has developed a sophisticated wind plant control system. The Advanced Distributed Monitoring System can monitor each turbine's power output and current wind conditions, allowing plant operators to adjust the turbine for optimal performance. A supervisory computer allows power plant operators to see the entire plant at one time by displaying a map of the turbines, meteorological towers, and substations. The system can monitor the condition of wind turbines during power plant operation. Plant operators can use the information to assess the amount of wear a turbine is experiencing and adjust turbine operation, if desired.

Second Wind began testing a prototype control system in the laboratory in the fall of 1996. The company expects to begin field-testing the system in 1997.



SECOND WIND INC.

Second Wind Inc.'s computerized wind turbine control system can monitor the operation of wind turbines during wind power plant operation, allowing plant operators to adjust turbine operation to reduce wear and tear.

Sandia's Blade Manufacturing Project Targets New Fabrication Methods

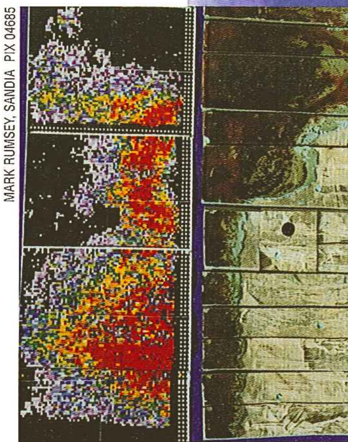
DOE's Blade Manufacturing Project was established at Sandia in 1995 to help U.S. turbine manufacturers produce cost-effective hardware to compete in global energy markets. As part of the project, Sandia issued a request for quotes to develop new methods for manufacturing utility-scale wind turbine blades that improve quality and reliability while lowering costs by 25% or more. The development of better blade manufacturing methods should significantly lower total wind system costs. Sandia awarded a contract to the winning bidder and will solicit for additional companies to participate.

In 1996, Sandia undertook blade manufacturing research. The laboratory used a commercial manufacturing design tool to study the manufacturing process that produced blades for FloWind's new 17 EHD turbine. The analysis helped them to improve the EHD's blade design.

In a related effort, Sandia researchers used nondestructive tests to identify manufacturing flaws in a joint substructure in an industry blade undergoing structural testing at NREL. Researchers then used similar techniques to look for manufacturing defects in new wind turbine blades. The laboratory evaluated several nondestructive testing methods to see whether they could be used for quality control checks on new wood-epoxy composite blades for the AWT-26/27 turbines.

The blade manufacturer, Advanced Blade Manufacturing of Pinconning, Michigan, gave Sandia wood composite samples with known defects for testing. An ultrasonic test identified defects in three of the samples and determined that the fourth sample was free from defects. Sandia researchers then used the method to run successful quality control checks on new blades.

MARK RUMSEY, SANDIA PIX 04685



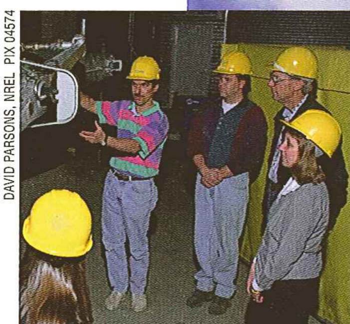
The photo above shows how ultrasonic testing results (left) can pinpoint defects in a bonded joint of a turbine blade root (right). Red areas indicate a strong bond, while black areas indicate a defect. During 1996, Sandia National Laboratories developed the technique for inspecting newly manufactured turbine blades.

DOE to Sponsor Small Wind System Development

For the first time since the early 1980s, DOE is providing assistance for the development of small wind systems of 5 to 40 kW in size. The Small Wind Turbine Project is designed to help the wind industry develop highly reliable, cost-effective small systems that have low maintenance needs, are easy to transport and install, and meet current safety and environmental standards.

The new small wind systems will be designed to fill niches in both domestic and international markets. Participants in the project will define the market they wish to address, then design, build, and test a prototype wind system to compete in that market. The National Wind Technology Center will provide testing and evaluation of the turbines once they are built. NREL is currently negotiating four cost-shared subcontracts.

DAVID PARSONS, NREL PIX 04574



During the Windpower '96 Conference, participants toured the National Wind Technology Center.

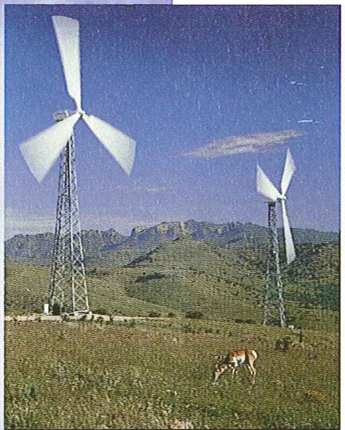
Transferring New Technology to Utilities and the Private Sector

Since 1990, DOE has worked with utilities and the wind industry to build a bridge between research and development programs and the commercial use of utility wind turbines. As part of this effort, DOE sponsors activities to help the private sector gain experience with emerging technologies. For instance, electric utilities in 15 states are in the process of acquiring hands-on experience with wind resource assessment and wind power generation. DOE and the national laboratories also disseminate information about wind energy to engineers, business professionals, and the public.

Wind Information Dissemination Aids Technology Transfer

Disseminating information about the latest wind energy technologies is an important aspect of technology transfer. DOE supported a variety of activities during 1995 and 1996, including

- The American Wind Energy Association's (AWEA's) annual Windpower Conference and workshops
- The Wind Energy Applications & Training Symposia, which is designed to teach foreign engineers about wind energy and is held in conjunction with AWEA's annual Windpower Conference
- Technical courses
- Technical papers, conference papers, brochures, pamphlets, book chapters, and books, including *The Wind Energy Information Guide*
- Participation in the American Society of Mechanical Engineers annual Wind Energy Symposium
- Visiting professionals programs at the National Wind Technology Center and Sandia for graduate students, foreign engineers, and others
- The creation of web sites for DOE's Wind Energy Program (http://www.eren.doe.gov/wind), the National Wind Technology Center (http://nwtc.nrel.gov), Sandia's wind program, (http://www.sandia.gov/Renewable_Energy/wind_energy/homepage.html), and the International Energy Agency's *IEA Wind Newsletter* (http://www.eren.doe.gov/ieawind).



LLOYD HERZIGER, ZOND CORPORATION PIX 04694

Central and South West Services' new 6.6-MW wind power plant came on-line in September 1995 in west Texas near Fort Davis.

BOB THRESHER, NREL PIX 04679

Workers have just placed this Zond Z-40 wind turbine nacelle and rotor on the tubular tower during construction of Green Mountain Power's new 6-MW wind power plant near Searsburg, Vermont. Construction was completed in late 1996.

Utility Wind Turbine Verification Program Demonstrates Value of Wind Energy

In 1992, DOE and the Electric Power Research Institute (EPRI) initiated a joint Utility Wind Turbine Verification Program to evaluate the performance of new wind turbines and to demonstrate the value of wind energy to utilities. The program was designed to reduce the risks to a utility from using advanced wind technologies. DOE and EPRI believe that experience operating a small wind power plant will allow utilities to make informed decisions about adding new wind generation.

During 1995 and 1996, Central and South West Services, Inc., of Dallas, Texas, and Vermont's Green Mountain Power Corporation built new wind power plants as part of the program. Central and South West's 6.6-MW facility is located in southwest Texas near Fort Davis. It came on-line in September 1995. The plant consists of twelve 550-kW Z-40 wind turbines developed by Zond Corporation under the auspices of DOE's Wind Turbine Development Program. The plant is operated by West Texas Utilities, a Central and South West operating company.

The power plant is undergoing a three-year testing and evaluation period. Utility personnel are monitoring turbine performance, power production, power quality, wind conditions, and noise. They are studying the impact of the plant on birds and other wildlife. They are also keeping track of how nearby residents respond to the new facility.

Green Mountain Power began construction of its new 6-MW wind facility near Searsburg, Vermont, in May 1996. The facility is situated in a sparsely populated, forested area on privately owned land. It consists of eleven 550-kW Z-40 turbines, which are expected to generate about 14 million kWh of electricity a year in normal wind conditions. The installation of the new wind power plant was completed in late 1996. Green Mountain Power will also conduct a three-year testing and evaluation program.

The Z-40 turbines used in Vermont were designed to ensure reliable cold-weather operation. They include specially coated black blades, which absorb solar energy to reduce icing; cold-temperature steel for the towers; heaters for the control systems, gearbox oil, and hydraulic fluids; a turbine cover (known as a nacelle) large enough to protect maintenance workers from the weather; and tubular towers that provide access to the turbine from the inside.

In August 1996, EPRI and DOE issued a new solicitation under the Utility Wind Turbine Verification Program. The solicitation was targeted at both small and large utilities and independent power producers interested in building smaller wind generation facilities connected directly to a distribution line. Such facilities can be less expensive than building a new power plant or extending transmission lines. For example, a few turbines at the end of a transmission line can help regulate voltage and frequency on the line. The addition of small, distributed power generation facilities at the end of electrical distribution lines may be a promising development option for wind systems in the future.

Participants in a distributed generation project will be responsible for siting, designing, building, and evaluating a wind power plant ranging in size from 500 kW to 5 MW. Each project is expected to include at least two turbines with a minimum rating of 250 kW. A utility must either own and operate the new wind facility or contract with an independent power producer to buy power from it. DOE and EPRI plan to make five distributed wind project awards in 1997.

In a related research effort during 1995 and 1996, Tennessee State University researchers investigated problems associated with interconnecting dispersed wind power generation and storage systems with the grid. Researchers are developing solutions to ensure smooth, two-way power flow in such circumstances.

Wind Energy Deployment Project Helps Utilities Understand Wind Technologies

DOE designed a Wind Energy Deployment Project to help utilities reduce the risk of introducing a new and unfamiliar technology. Under the cost-sharing initiative, DOE will contribute funds toward the cost of deploying two new wind power facilities, one in Iowa, and the other in Minnesota.

Waverly Light and Power plans to install two Zond Z-46 turbines in northwestern Iowa in 1997. The turbines will give the small public utility experience operating and maintaining wind turbines as well as integrating wind power with conventional power generation.

Zond plans to develop an 11.5-MW wind power plant in late 1997 near Lake Benton, Minnesota, in cooperation with Northern States Power Company. The project will be an addition to a 100-MW wind power plant Zond is building for the utility in the same area.

In a related effort, DOE funded several wind projects under the Indian Energy Resource Development Program. A 100-kW Vestas V-17 turbine was installed near Blackfeet Community College in Browning, Montana, in May 1996. Zond supplied the turbine, which is connected to a local grid operated by Glacier Electric Company.

Two North Dakota tribes began using wind turbines to help power reservation facilities in late summer of 1996. A 108-kW Micon turbine provides about one-quarter of the electricity for the Spirit Lake Nation's casino. An identical turbine provides power for a water treatment plant that serves the Turtle Mountain Chippewa reservation and neighboring communities.

DOE Provides Technical Assistance for Wind Resource Assessments

Because winds vary considerably, it is necessary to conduct wind resource assessments to determine if a specific location is suitable for wind power development. Wind resource assessments consist of systematic measurements of wind speed and direction for a year or more. DOE provides technical assistance in conducting and analyzing these measurements.

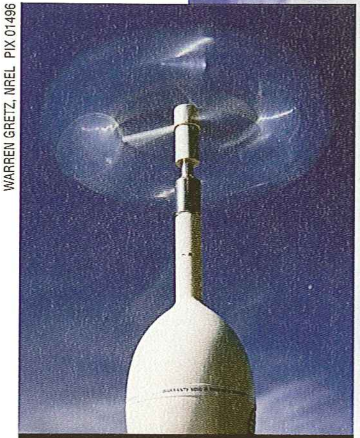
During 1995 and 1996, the cost-shared Utility Wind Resource Assessment Program, managed by the Utility Wind Interest Group, began. The program provides assistance to utilities in conducting detailed wind resource measurements in locations under consideration for siting a wind power plant. To ensure that uniform data are collected by the utilities, participants conduct their measurements according to procedures outlined in the *Wind Resource Assessment Handbook: Fundamentals for Conducting a Successful Monitoring Program*, prepared for NREL by AWS Scientific, Inc., of Albany, New York.

In July 1995, the Utility Wind Interest Group and NREL selected six organizations to participate in the program: Public Service Company of Colorado; the Nebraska Power Association, a group that includes most of that state's utilities; Kansas Electric Utilities Research Program, which represents seven Kansas utilities; Southwestern Public Service Company; Montana Power Company; and Tucson Electric Power Company. By the end of 1996, wind measurement equipment had been installed in 34 different sites in seven states. Each site will gather wind data for two years.

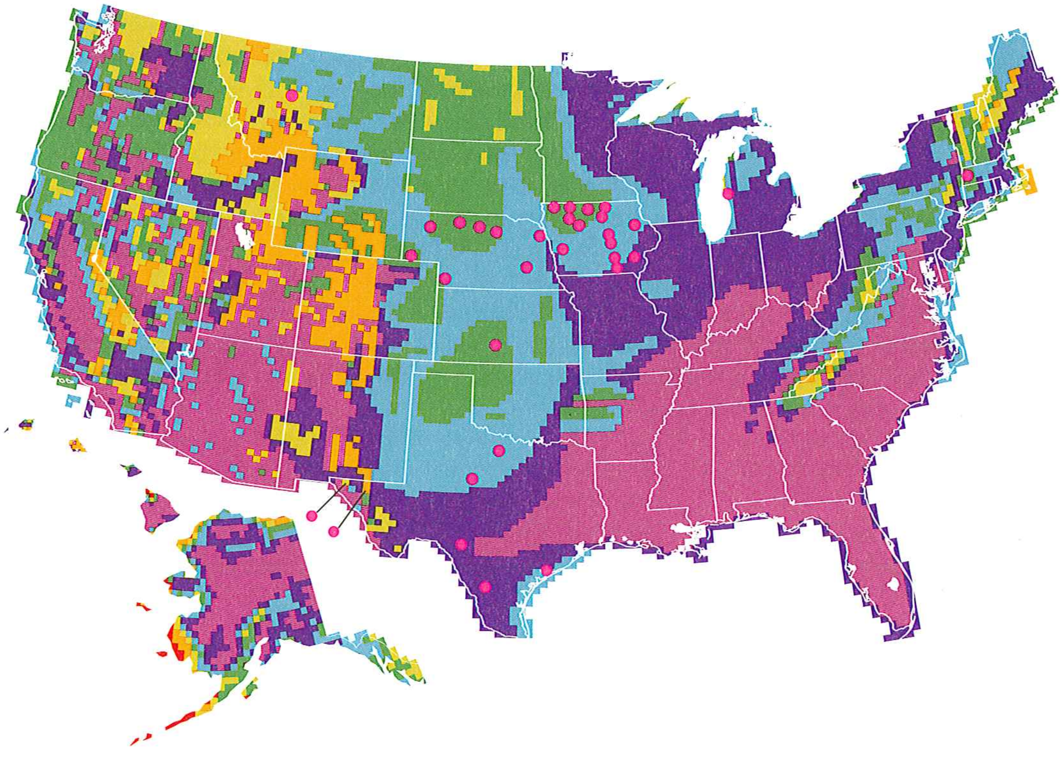
In 1995, NREL initiated a cost-shared Cooperative Network for Renewable Resource Measurements program to gather information from existing solar and wind measurement stations in the United States and to establish new sites. In July 1996, NREL awarded subcontracts to AWS Scientific and West Texas A&M to set up new measurement stations. AWS Scientific will establish five new sites across the country. West Texas A&M will set up seven measurement stations in Texas. Data gathered through the program will be made available to the public through NREL's Renewable Resource Data Center, located on the World Wide Web at http://rredc.nrel.gov.

Wind resource assessments will also be conducted under the auspices of the Sustainable Technology Energy Partnerships Program. Under this initiative, NREL will work with state energy offices, industry, academia, and utilities in Colorado, Iowa, Minnesota, Nebraska, New Mexico, Oregon, and Wisconsin to measure wind resources.

WARREN GRETZ, NREL PIX 01496



The cup anemometer shown here provides accurate measurements of wind speed, a crucial part of any wind resource assessment. The U.S. Department of Energy and the National Renewable Energy Laboratory are sponsoring wind resource assessments at more than 50 locations in the United States.



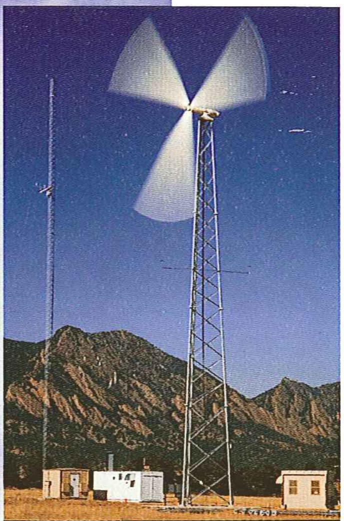
Wind Energy Classification

Power Class	Wind Power* W/m²	Speed m/s
1	<200	<5.6
2	200-300	5.6-6.4
3	300-400	6.4-7.0
4	400-500	7.0-7.5
5	500-600	7.5-8.0
6	600-800	8.0-8.8
7	>800	>8.8

● Wind resource assessment sites

* At 50 m (164 ft)

These maps show the annual wind energy resource in the United States. The resource is expressed in terms of wind power classes, a measure of how much energy is contained in the wind. Wind power classes of 3 or higher can be economically developed using next-generation technologies.



The National Renewable Energy Laboratory is operating this AOC 15/50 wind turbine as part of a 50-kW hybrid power system at the National Wind Technology Center's Hybrid Power Test Bed.

New World Village Power Company's village power system consists of a diesel generator, batteries, controls, and a rotary converter that changes direct current into alternating current or vice versa.

Hybrid Power Research Targets Innovations in Remote Wind Systems

In rural areas across the globe, hybrid power systems can provide enough electricity for a whole village to enjoy lighting, refrigeration, and other amenities the developed world takes for granted. Hybrid power systems combine multiple power sources such as wind turbines, photovoltaic (PV) arrays, battery storage systems, and backup diesel generators. The generators run the system when wind and solar resources aren't available. During their service lifetime, hybrid power systems cost less, are more reliable, and have fewer environmental impacts than stand-alone diesel generators. The market for hybrid power systems is expected to expand as demand for electricity in the developing world rises.

New Field-Testing Laboratory Bolsters Hybrid Power Research

The National Wind Technology Center built a new Hybrid Power Test Bed during 1995 and 1996. The test bed was designed to assist the U.S. wind industry in developing and testing hybrid power generation systems. Using simulated village power requirements, researchers can evaluate the interaction of system components under realistic conditions. Design engineers can work through actual problems the system might encounter in the field. The research test bed also provides the opportunity to develop and test new technologies, including improved energy storage devices and smart control systems.

In 1995, NREL began testing a 50-kW village power system manufactured by New World Village Power Company at the Hybrid Power Test Bed. The system consists of a diesel generator, batteries, controls, and a rotary converter, which changes alternating current into direct current, or vice versa, depending on whether the batteries are being charged or used for power. An AOC 15/50 wind turbine was connected to the village power system.

The test was designed to increase understanding of the interaction of wind turbine generation with weak grids typical of small villages. Researchers discovered that integrating a wind turbine into a small, weak grid is challenging. Most problems were solved by improving the software used by the system controller and making minor changes to the converter and battery-charging system.

Ice Makers Must Be Specially Designed to Operate with Wind Power

Ice making is an important application for a remote power system. During 1995 and 1996, NREL researchers used a new 75-kW dynamometer at the Hybrid Power Test Bed to evaluate whether a single wind turbine could run a commercial ice maker. (A dynamometer is a device that mimics the output of a rotating turbine.) Tests showed that the commercial ice maker will need to be redesigned to run directly off power from a variable-speed wind turbine.

Wind-Powered Battery Charging Lowers Cost of Electricity in Remote Areas

In developing countries, the only way many people can afford electricity for lighting, television, and radio is to own or lease a battery. The battery needs to be recharged about once a week.

Unfortunately, many households are far from the grid. A typical example is a small boy and his father who used to walk about 10 miles every week to the town of Temuco, Chile, to charge the family's battery. NREL helped install a small, off-grid wind battery-charging station near the family's home in the fall of 1996. The new station is not only closer, it's much less expensive to use.

During 1995 and 1996, NREL researchers developed the wind-powered battery-charging system, which consists of a turbine, controllers, and a battery rack for charging 12-volt batteries. During the development process, researchers discovered that small wind turbines often capture much less wind energy for battery charging than expected.

After studying the problem, they concluded that a peak power tracker could double the power available from the turbine for battery charging. A peak power tracker consists of an electronic power converter and a controller. Researchers designed a new tracker and are testing it in a battery charging application. Researchers will conduct field tests in 1997.

NREL, University of Massachusetts Complete Development of Hybrid2 Software

In 1996, NREL and the University of Massachusetts completed development and testing of Hybrid2, a computer simulation that predicts the technical and economic performance of hybrid power systems. The software models a range of system configurations, including multiple wind turbines, multiple diesel generators, a PV array, battery storage, various power-conversion devices, and different types of village power requirements. NREL submitted Hybrid2 to DOE's Energy Science and Technology Software Center, a central software repository.

Cooperative Projects Advance Hybrid Power Systems

NREL, Sandia, and DOE increase the benefits of their hybrid power system research by working with other federal and state agencies to test and refine new technologies. Cooperative projects help get new technologies to market faster.

DOE, Agriculture Department Conduct Hybrid Power Studies

In 1994, DOE and the U.S. Department of Agriculture (USDA) initiated a five-year project to investigate hybrid power systems that rely entirely on renewable resources such as wind, solar, and biofuels made from vegetable oils or animal fat. The project site is the USDA's Southern Plains Area Conservation and Production Research Laboratory in Bushland, Texas.

During 1995 and 1996, researchers at the site built a new hybrid power system from three diesel generator sets, two wind turbines, and a water pump. They also evaluated the wind resource at the site and purchased 8000 gallons of biofuel. Researchers will use the hybrid power system to study computer controls and power quality.

Public-Private Partnerships Support New Wind-Diesel Systems for Rural Alaska

Alaska has about 250 small villages with no link to central power grids. Utility residential rates in these villages range from $0.30/kWh to $0.60/kWh for electricity from diesel generators, which pose a significant threat to Alaska's fragile environment. Environmental hazards include emissions, diesel fuel spills during transport, and leaky fuel storage tanks.

The Alaska Department of Community and Regional Affairs—Division of Energy, Kotzebue Electric Association, the U.S. Environmental Protection Agency, and NREL are working together to develop a wind-diesel hybrid power system for Wales, a village in northwest Alaska. NREL expects the new system to reduce diesel fuel consumption by 40%. Because excess wind energy will be used for district heating, the system will also save heating oil.

During 1995 and 1996, NREL engineers assisted in developing a hybrid power system that includes 150 kW of wind generating capacity, a system controller, components to regulate frequency and voltage on transmission lines, and battery storage. The system will be integrated with existing diesel generators. In 1997, NREL engineers will test software for the system controller prior to shipping the complete hybrid power system to Wales.

Another wind energy project will be installed in Kotzebue, a large village in northwestern Alaska. Kotzebue Electric Association plans to integrate a new 300-kW wind power plant with an existing 11.18-MW diesel power plant. The project, which is part of NREL's Sustainable Technology Energy Partnerships Program, will consist of six AOC 15/50 wind turbines. As soon as the local utility is comfortable operating its new wind power plant, it plans to build another, larger wind power plant in Kotzebue.

Navy to Install Wind Generation System on San Clemente Island

NREL began working with the U.S. Navy in 1994 to design and build a wind generation system on San Clemente Island, located off the coast of southern California. The wind system will power a Navy training facility on the island and reduce diesel fuel requirements for the existing power generation system.

After a competitive solicitation, NREL selected FORAS Energy, Inc., of North Palm Springs, California, to install two 225-kW Micon turbines on the island in 1997. Once they come on-line, the turbines are expected to supply about 50% of the island's power.

The San Clemente project is funded by the U.S. Department of Defense's Strategic Environment Research and Development Program through a "work-for-others" agreement with DOE.

DAVID CORBUS, NREL PIX 04682

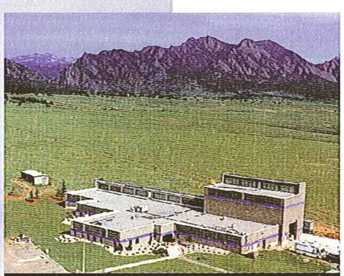
Thanks to a new wind-powered battery-charging station near Temuco, Chile, this boy and his father no longer have to walk 10 miles every week to charge the battery that provides electricity for their household. National Renewable Energy Laboratory staff helped install the new wind facility in fall 1996.

LARRY FLOWERS, NREL PIX 04684

Kotzebue, Alaska, plans to integrate a new 300-kW wind power plant with an existing diesel power plant as part of the National Renewable Energy Laboratory's Sustainable Technology Energy Partnerships Program. The town plans to build a new, larger wind power plant within two years.

The National Wind Technology Center

The center is home to the nation's most sophisticated wind energy research and testing facilities.



WARREN GRETZ, NREL PIX 00337

The National Wind Technology Center is located at the foot of the Rocky Mountains near Golden, Colorado.

The National Wind Technology Center is a world-class energy research, development, and demonstration center located near Golden, Colorado. The NWTC is home to wind energy researchers, offices, laboratories, and a brand new Industrial User Facility. It has a Hybrid Power Test Bed (described on page 14), four commercial turbines, 10 additional turbine test pads suitable for machines sized up to 1 MW, two research turbines, instruments for measuring wind conditions, a Variable-Speed Test Bed, and modern structural testing facilities.

Turbines at the site include a 10-kW Bergey Excel, developed by Bergey Windpower Company, Inc., of Norman, Oklahoma; a 275-kW Advanced Wind Turbines AWT-26; and an 50-kW Atlantic Orient Corporation AOC 15/50. The latter two turbines were developed as part of DOE's Wind Turbine Development Program (see page 7). In 1996, the NWTC purchased a Cannon Wind Eagle 300 turbine, manufactured by Cannon Wind Eagle Corporation of Tehachapi, California. The turbine will be installed at the site in 1997.

NREL monitors these turbines to acquire an in-depth understanding of their performance and operation. NREL also uses the turbines to develop improved techniques for certification testing and as research tools for validating computer design and analysis codes.

The NWTC uses two specially modified 20-kW Grumman Windstream 33 turbines for advanced research and development projects. One turbine is extensively instrumented to provide research data on wind inflow, the interaction of wind with turbine structures, and power production. A second turbine, part of the NWTC's Variable-Speed Test Bed, is being tested with an experimental, variable-speed generator.

The turbines feed power into a 13.2-kW/480-volt power distribution system. Engineers control the turbines and monitor their performance by means of a Supervisory Control and Data Acquisition System, which was installed and refined during 1995 and 1996. The system is a two-way communication network that runs between the wind turbines and a central operations center, located in the Industrial User Facility.

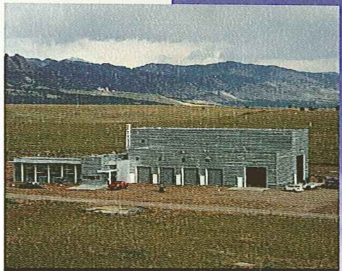
During 1995 and 1996, NREL installed a new Site Meteorological System at the NWTC to enhance wind measurement capabilities. The system consists of two 80-m (262-ft), fully instrumented towers on the eastern and western boundaries of the 113-hectare (280-acre) site. The instruments gather information on the local wind resource, including daily and seasonal wind patterns and turbulence characteristics.

The wind resource at the NWTC provides a variety of conditions for testing new technology. During fall and winter, westerly winds propelled by the jet stream race across the Continental Divide and down canyons along the Front Range, reaching speeds of as much as 54 m/s (120 mph). Such high winds test the durability of wind machines. During later winter and spring, smoother, more consistent winds become the norm as the jet stream shifts northward. The more gentle westerly winds allow researchers to study turbine performance under conditions typical of the Great Plains, where the bulk of the U.S. resource is located.

Industrial User Facility Opens

The NWTC's new Industrial User Facility opened for business in September 1996. The facility was designed for government/industry collaboration in technology innovation. The facility has office space for industry engineers working with NREL's technical staff, experimental laboratories, computer facilities, machine and wood shops, a complete electronics laboratory, and a large blade-testing bay for evaluating turbine blades up to 33 m (100 ft) long. The building is partitioned into three user bays, which allows industrial research teams to work in separate, secure areas large enough to assemble complete turbine subsystems. This feature allows industry to protect proprietary information.

NREL assigned a special testing team to support the new facility. One of the team's first assignments was to instrument and install the new Wind Eagle 300 turbine. The lightweight, highly flexible downwind turbine is one of the most unique machines made by the American wind industry. The turbine has a 29.3-m (96-ft) diameter rotor and sits atop a 50-m (164-ft) tower. NREL will study the prototype turbine because it presents a major challenge to existing computer models.



WARREN GRETZ, NREL PIX 00640

The National Wind Technology Center's new Industrial User Facility has office space for industry engineers, experimental laboratories, computer facilities, machine and wood shops, and a large blade-testing bay. The building is designed to allow industrial research teams to work in separate, secure areas to protect proprietary information.

Structural Testing Major Benefit to Wind Industry

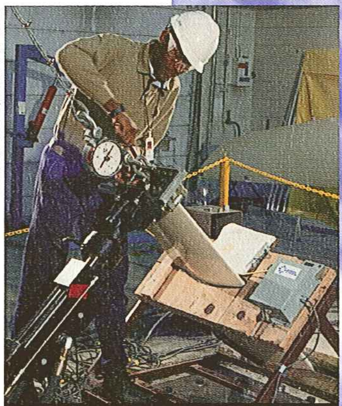
Structural testing facilities at the NWTC include the finest equipment available for evaluating the strength, durability, and service lifetimes of wind turbine components and systems. During 1995 and 1996, NREL performed structural testing on 17 turbine blades. In most instances, NREL engineers designed the tests in collaboration with blade manufacturers to meet international testing standards.

NREL used static-strength tests to evaluate the forces, or loads, that damage and break wind turbine blades. The tests are a good indication of whether wind turbine blades can survive an extreme event such as a hurricane-force wind gust.

NREL used fatigue tests to evaluate the effects of continuous wear and tear on turbine components. Wear and tear occurs because wind turbines are routinely exposed to atmospheric turbulence, wind shear, insects, dust, temperature extremes, high winds, rain, snow, and sleet. Designers try to take these factors into account when designing a durable turbine, and fatigue testing is used to determine if they have succeeded. Fatigue testing is the basis for estimating the service lifetime of wind turbine systems and components.

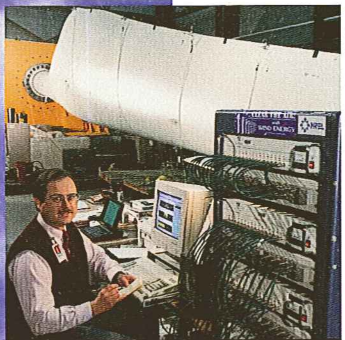
Structural tests at NREL during 1995 and 1996 were instrumental in helping several turbine manufacturers improve their blade designs and manufacturing processes. (See sidebar on page 18.) During 1996, NREL developed a new data acquisition system, known as the Blade Structural Testing Real-time Acquisition Interface Network, or BSTRAIN, to monitor structural testing and process data.

During 1995 and 1996, Sandia conducted fatigue tests on blades from FloWind Corporation's new 17 EHD turbine as part of the laboratory's Structural Health Monitoring Program. In the process, researchers developed a new method for fatigue testing that takes less time and less equipment. Known as Resonant Fatigue Testing, the new technique shakes the turbine structure at one of its natural resonant frequencies. Under such conditions, high stress areas quickly wear out. FloWind used the blade fatigue test results to redesign its turbine blade and to improve its blade-manufacturing process. In a related effort, Sandia evaluated turbine cable dampers and determined that they were working well.



WARREN GRETZ, NREL PIX 04696

A National Renewable Energy Laboratory researcher conducts a blade-tip test on an industry blade to determine its strength and durability. Structural testing facilities at the National Wind Technology Center use the finest equipment available for evaluating turbine components and systems.



WARREN GRETZ, NREL PIX 02133

The National Renewable Energy Laboratory purchased new modal testing equipment and software during 1995 and 1996 to help researchers more easily identify a turbine's natural vibration frequencies. Designers must avoid operating the turbine at these frequencies or the machine will suffer serious damage.

Researchers at Sandia and NREL continue to develop nondestructive tests to evaluate the condition of turbine blades. Nondestructive tests include acoustic emissions, ultrasonics, thermography, and vibration analysis. Acoustics emissions tests use microphones mounted on a blade to listen for pinging sounds that occur in weak areas where there are microscopic fractures. During 1995 and 1996, Sandia tested about half a dozen blades with this technique and was able to identify manufacturing defects that led to failures in static-strength tests. Ultrasonic testing is used to examine a small area in detail, including damaged areas identified by acoustic emissions testing. The technique allows researchers to look underneath the blade surface to see defects. Thermography identifies high stress areas that occur during fatigue testing. Materials in high stress areas may generate hot spots that can be detected with an infrared camera. Sandia conducted three successful thermography tests on blades during 1995 and 1996.

During 1995 and 1996, NREL acquired new modal testing equipment and software that cut testing time in half and produced more reliable results. Modal tests are used to identify the natural vibration frequencies of turbine components such as blades or towers. Designers need this information to ensure that a turbine will not excite at a natural frequency during operation. A structure so excited for any length of time can shake itself apart. Researchers are using the new equipment to analyze a specially instrumented research turbine at the NWTC. In the fall of 1996, they took the new equipment to California and tested turbines in the field.

A Wind Energy Success Story

Test engineers at the National Wind Technology Center (NWTC) have something to be proud of. They helped Zond Corporation design a better blade for the Z-40 wind turbine.

In early 1994, Zond built the first prototype of its new turbine. Zond made two extra blades for testing at the NWTC. The blades included ailerons, structures similar to the flaps on an airplane wing, that help slow the turbine rotor when deployed. The company wanted structural testing to help identify ways to make the blade lighter and better suited for mass production.

Initial tests helped Zond identify areas to target in the blade redesign process. Zond was able to create a more sophisticated blade design model that allowed it to solve problems with the original blade. The company redesigned the blade's root attachment, strengthened the blades near the ailerons, and selected stronger materials for the blade. Once the new production blade was finished, Zond sent it back to the NWTC for complete structural testing.

The results of the new round of testing were spectacular. The new blade survived the most rigorous ultimate static strength test without breaking. In the fatigue test, the blade surpassed its design expectations. Even so, Zond still wanted to do better. The blade was still too heavy, and consequently too expensive.

For the past two years, Zond has worked with NWTC engineers to develop a lower cost, lighter weight blade without compromising the strength and performance of production blade design. A new blade that is 15% lighter is currently under test in Colorado.

DAVID PARSONS, NREL PIX 04364

Using data from structural tests conducted at the National Wind Technology Center, Zond Corporation engineers improved the Z-40 blade. Above, the blade is fatigue tested.

Variable-Speed Test Bed Equipped with Advanced Generator

The NWTC's Variable-Speed Test Bed is currently testing a variable-speed, direct-drive generator on a Grumman Windstream 33 wind turbine. The generator was developed by the University of Colorado (CU) and built by Unique Mobility, Inc., of Golden, Colorado.

The 20-kW experimental generator spins at the same rate as the turbine rotor. It is directly connected to the rotor shaft and requires no transmission or gearing. The variable-speed generator allows the turbine rotor to slow down or speed up in response to changes in wind speed. This feature increases energy capture and reduces wear and tear on turbine components. If the generator performs as expected, it could lead to a lower cost turbine, reduced maintenance costs, and higher energy production.

NREL researchers tested the new generator on a 75-kW dynamometer during 1995. The generator worked well. Researchers then installed the generator in the test bed and outfitted it with instruments to measure the efficiency of energy capture, performance, and loads. The turbine became fully operational in 1996 and passed tests in low wind speeds with flying colors. NREL has ordered new blades to test the system in high winds.

During 1995 and 1996, CU researchers designed a power electronics unit to convert the variable-frequency, alternating current produced by the generator into a constant-frequency, 60-cycle alternating current compatible with the utility grid. Once the power-electronics assembly is ready, NREL will complete full system testing on the Variable-Speed Test Bed. Part of this testing will include an evaluation of new turbine control software designed to maximize energy production and minimize wear on turbine components.

New Capabilities on Tap for the National Wind Technology Center

NREL plans to add two new facilities to the NWTC in the near future, a 1.5-MW dynamometer and an Advanced Research Turbine (ART). Researchers will use the dynamometer to conduct performance, fatigue, and loads tests on generators or gearboxes before they are installed in a wind turbine system. The new dynamometer can test components for wind turbines rated up to 1.5 MW.

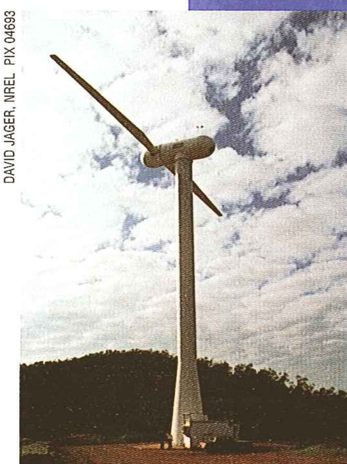
The ART will consist of a 600-kW Westinghouse wind turbine (the WWG-0600) modified to meet specific experimental objectives. Under an NREL subcontract, New World Grid Power Company dismantled the turbine in Hawaii, where it had been operating since the mid-1980s. The company refurbished the turbine and shipped it to the NWTC in the winter of 1996. Researchers expect the turbine to be operational in 1997.

NREL will use the ART to improve the fundamental understanding of wind turbine technology. A deeper understanding of turbines and wind/wind turbine interactions will help designers create more efficient, reliable, and cost-effective machines. The first project will be to test a new rotor using blades with ailerons.

WARREN GRETZ, NREL PIX 04119

National Renewable Energy Laboratory researchers are testing an innovative variable-speed, direct-drive generator on a research turbine at the National Wind Technology Center. The turbine is part of the National Wind Technology Center's Variable-Speed Test Bed.

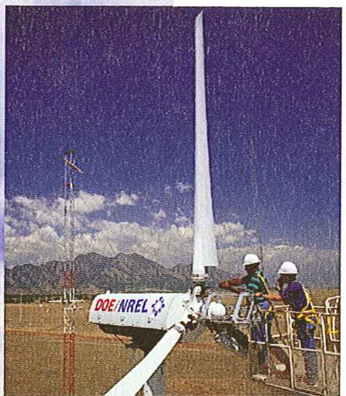
DAVID JAGER, NREL PIX 04693



This 600-kW Westinghouse turbine, shown above on Oahu, Hawaii, was moved to the National Wind Technology Center, modified for cutting-edge turbine research, and renamed the Advanced Research Turbine.

Wind Energy Applied Research

The U.S. Department of Energy's applied research program supports the development of competitive wind technologies for global energy markets.



WARREN GRETZ, NREL PIX 00342

The U.S. Department of Energy supports applied research on wind/wind turbine interactions, design code validation, wind turbine fatigue, integration of wind turbines into the utility grid, and the impact of wind turbines on birds and other wildlife.

Wind energy research seeks to better understand and control the interactions between wind and wind turbines and to provide the wind industry with improved design tools for advanced technologies. The development of sophisticated computer models and their integration into the design of new turbine components and systems is necessary for cost-effective innovation. The development and refinement of new computer codes, in turn, depends upon gaining a fundamental understanding of how wind turbines work. The solution to these problems will lead to advanced technologies capable of competing with low-cost fossil-fuel generation.

As a result of input from the wind industry, utilities, regulatory officials, and environmental advocates, DOE sponsors research to find better methods for estimating the strength and longevity of turbine structures, analyze the impact of integrating wind generation into the utility grid, and investigate the impact of wind power plants on birds and other wildlife.

As soon as research findings become available, the national laboratories transfer information to industry through workshops, conferences, and publications. The following research highlights provide an overview of the achievements of DOE's applied research endeavors during 1995 and 1996.

Building and Operating a Wind Turbine on the Computer

Long before a turbine is ever built, designers use sophisticated computer systems to model the entire wind energy system. A computer design strategy allows them to explore different designs before building expensive hardware. Once a prototype is built and ready for testing, computer models help engineers diagnose problems and solve them. The test results also help software engineers refine the computer models to more closely reflect reality. The synergistic relationship between modeling and testing lies at the heart of modern technological innovation.

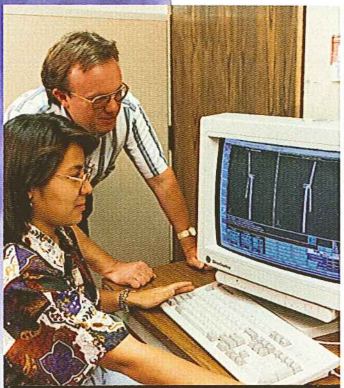
The ADAMS-WT software (see sidebar on page 22) is a sophisticated model of wind turbine system operation. Other, less complex codes model one aspect of turbine operation such as inflow (wind characteristics), aerodynamics (the interaction of the wind with the turbine), structures (turbine behavior during operation), fatigue (wear and tear over time), or turbine controls.

Sandia, NREL, and their subcontractors have developed a number of major design codes since 1980. Those currently in use or under development are listed in the table on the facing page.

Information about obtaining design codes is available from NREL on the World Wide Web at http://nwtc.nrel.gov/html_docs/codes.html.

WIND TURBINE DESIGN CODES

Modeling Area	Code	Description	Complexity	Run Time
Inflow	SNLWIND-3D	Simulates wind flowing into a turbine rotor	Detailed	Moderate
Aerodynamics	AERODYN	Predicts blade aerodynamic loads	Moderate	Moderate
	PROPPC	Predicts power output for a specified rotor	Simple	Short
	WT-PREP	Prepares input data set for PROPPC	Simple	Short
	PROP93	Graphics-based version of PROPPC	Simple	Short
	PROPGA	Optimizes blade shape for maximum performance	Detailed	Moderate
	PROPID	Designs turbine blades for specific power output	Moderate	Moderate
	SEAC	Predicts rotor performance, annual energy output	Moderate	Moderate
	SLICEIT	Predicts rotor performance, blade loads for VAWTs	Simple	Short
	VDART3	Predicts VAWT rotor performance, blade loads	Moderate	Long
	WT_Perf	Predicts rotor performance	Simple	Short
Structures	YAWDYN	Predicts blade loads, yaw response to turbulence	Simple	Short
	UMDAC	Predicts drivetrain loads caused by turbulence	Simple	Short
	FAST	Predicts loads for intermediate wind turbine model	Moderate	Moderate
	TRES4	Calculates VAWT natural modes and response to turbulence	Moderate	Long
	3DBEAM	Maximizes blade strength and minimizes weight	Simple	Short
Fatigue	LIFE2	Analyzes fatigue of turbine components	Detailed	Short
	FAROW	Calculates fatigue reliability of components	Moderate	Short
Controls	ASYM	Simulates a wind turbine controller	Simple	Moderate
Total System	ADAMS-WT	Simulates total wind system operation	Detailed	Long



WARREN GRETZ, NREL PIX 00359

Researchers at the National Renewable Energy Laboratory and Sandia National Laboratories are developing sophisticated computer models to help designers create tomorrow's advanced technologies.

During 1995 and 1996, researchers at NREL, Sandia, Oregon State University, and the University of Utah made progress developing and validating structural design and fatigue codes. Researchers at the University of Utah demonstrated that the YAWDYN code realistically portrayed turbine yaw motion under some test conditions. The YAWDYN code models simple blade motion and yaw in two- and three-bladed rotors. Researchers are using the comparisons between turbine behavior and code predictions to refine the code.

Researchers at the University of Utah developed new software that links codes such as YAWDYN and ADAMS with the LIFE2 code. The LIFE2 code was developed by Sandia to help turbine designers estimate the fatigue life, or durability, of turbine components. The software linkage makes it relatively easy for designers to determine which turbine components are most likely to experience wear and tear in turbulent wind conditions. This information then allows designers to improve the design of particular components, increasing the durability of the whole system.

NREL continued to refine the FAST code, originally developed at Oregon State University. The FAST code is an intermediate-level structural-design code that models a complete turbine, including the effects of yaw motion, two- and three-bladed rotors, two-bladed teetering hubs, and tower motions. Designers can use the FAST code to model machine start-up, shutdown, variable-speed operation, and constant-rotor-speed operation.

FAST includes most of the important features of wind machines. It runs much faster than ADAMS on the computer and can simulate turbine operation for periods of 10 minutes to several hours. (In contrast, ADAMS-WT typically simulates turbine operation for a half minute or less.) Not surprisingly, FAST is becoming the design tool of choice for preliminary or intermediate design. During the past two years, researchers modified the FAST code to perform long simulations of turbine operation under turbulent wind conditions and added simple controls for variable-speed operation, blade pitch, and ailerons.

The World's Most Sophisticated Computer Model of a Wind Turbine

The ADAMS software and the ADAMS-WT preprocessor comprise one of the most comprehensive computer models of a wind turbine system ever created. ADAMS and ADAMS-WT allow turbine designers to design a new turbine from scratch, evaluate individual components and subsystems, and operate the entire system on the computer.

Mechanical Dynamics, Incorporated, of Ann Arbor, Michigan, made the ADAMS software to model mechanical systems in the aerospace, robotics, automotive, and wind industries. NREL researchers developed the ADAMS-WT preprocessor to produce a comprehensive, realistic simulation of the interactions between the wind and the operating wind turbine. ADAMS-WT allows designers to automatically create a tower, blades, rotor, and nacelle without having to spend hours defining every single detail of the structure.

Researchers at NREL and the University of Utah created subroutines for ADAMS-WT to model wind characteristics and the interaction of the wind with the turbine on the computer. The subroutines allow designers to simulate turbine operation and analyze problems that occur during prototype testing and final design.

During 1995 and 1996, NREL researchers programmed ADAMS-WT to model new turbine configurations, developed examples to show new users how to design a turbine, and improved software documentation. University of Utah researchers began modeling wind turbine control systems with ADAMS.

During the next two years, NREL plans to validate ADAMS-WT by using it to model the operation of the Cannon Wind Eagle 300 turbine. Researchers plan to refine the software to make it accurately reflect test data from the turbine.

NREL continued development of blade design codes during 1995 and 1996. Given a blade's shape, geometry, and airfoil performance characteristics, the PROPPC code will calculate the rotor's power curve, which is a graph of power generated versus wind speed. A graphics-based version of PROPPC called PROP93 has been developed by the Alternative Energy Institute at West Texas A&M University.

NREL researchers used PROPPC to analyze the impact of dirty blades (roughness) on blade performance. The study showed that certain blade designs are far more vulnerable to the effects of roughness than others.

The new WT-PREP code prepares a data set of airfoil characteristics for the PROPPC code. An electronic data table for NREL-designed airfoils is also available for use with PROPPC.

NREL's new 3DBEAM code helps fiberglass blade designers maximize performance and minimize weight. The simple code helps them choose blade materials, identify the correct geometry, and determine the correct order for layering different fiberglass strips to make the blade.

The University of Illinois at Urbana-Champaign began developing a design code that works like natural selection in biological systems. Called PROPGA, the code generates hundreds of new blade designs in response to specified performance characteristics, then optimizes those likely to give the best performance. The selected blade designs undergo incremental changes (mutations) for several generations and converge on the best possible design. NREL researchers expect the new code to be commercially available in 1998.

Researchers at Stanford University developed a statistical method for estimating the occurrence of rare, but unusually destructive, loads. Sandia used the new software to refine the LIFE2 and FAROW codes. The new software allows LIFE2 to better estimate fatigue life and FAROW to better evaluate safety considerations in turbine design.

During 1995 and 1996, Sandia published a new FAROW users manual and improved the code's ability to describe turbine loads. Sandia developed the FAROW code to help designers create more reliable turbines by identifying the critical uncertainties in fatigue performance.

During 1995 and 1996, researchers at Iowa State University and Wichita State University used a technique called Computational Fluid Dynamics to model airflow around turbines in a wind park and around blade substructures. The technique tries to solve the fundamental equations of motion that describe airflow. Researchers want to see whether it could be used as an additional tool for wind turbine development and analysis.


WALT MUSIAL, NREL PIX 00572

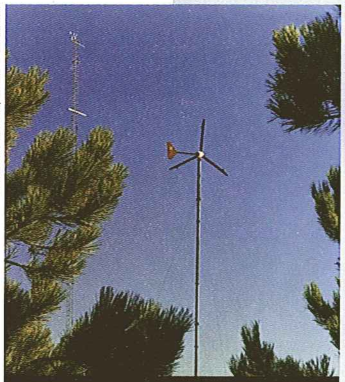
Insect buildup along the leading edge of a wind turbine blade results in roughness, which can impact aerodynamic performance. National Renewable Energy Laboratory researchers found that certain blade designs are more sensitive to the effects of roughness than others.

Understanding Wind/Wind Turbine Interactions

Wind turbulence can damage operating wind turbines. NREL researchers are studying whether loads responsible for the damage are associated with particular wind characteristics. In previous years, they developed a statistical method for evaluating wind characteristics and incorporated it into a turbulence simulation code called SNLWIND-3D. The model, which was originally developed at Sandia, can be used with the ADAMS, FAST, and YAWDYN codes to simulate turbine operation under turbulent wind conditions and assess machine responses.

In 1995, researchers compared predictions from computer simulations of the reaction of a 10-kW wind turbine to wind turbulence with measured data. They were able to identify two specific aspects of wind turbulence that allowed them to predict the severity of loads on the turbine.

NREL researchers used measurements from a multirow California wind farm to create a 24-hour wind turbulence simulation using SNLWIND-3D. The simulation modeled the impact of the turbulence on two different turbines, one in the front row and the other deep inside the facility where it would be subjected to wind patterns created by other turbines. When researchers ran the new simulation with ADAMS, FAST, and YAWDYN, the models showed similar patterns for damaging loads. SNLWIND-3D appeared to closely mirror real wind turbulence.


WARREN GRETZ, NREL PIX 02144

In 1995, National Renewable Energy Laboratory researchers compared the reactions of the 10-kW Bergey Excel wind turbine to wind turbulence with predictions made by computer simulations. The experiment helped them identify turbulence characteristics associated with damaging turbine loads.

WARREN GRETZ, NREL PIX 02148

The National Renewable Energy Laboratory uses the specially instrumented turbine shown here to conduct a multiyear Unsteady Aerodynamics Experiment. During 1995 and 1996, the laboratory used the turbine to study how blade twist affects a rotor's aerodynamic performance.

NREL Studies Effects of Wind Speed, Turbulence on Rotor Operation

Since 1989, NREL has studied the interaction of stall-controlled turbine rotors with the wind. Stall is the loss of the aerodynamic force, called "lift," that drives a wind turbine. Understanding how wind speed and turbulence affect rotor operation is necessary for industry to create more durable and low-cost turbines.

During 1995 and 1996, NREL began a new phase of the Unsteady Aerodynamics Experiment. Researchers are studying the influence of blade twist on a blade's aerodynamic performance. They are using experimental data to improve computer codes and models, which don't simulate the complicated airflow over twisted blades very well. In a spinning rotor with twisted blades, air flows out along the blade from the hub as well as across the blade. Both flows interact to create complex patterns that are affected by wind speed, turbulence, airfoil shape, and even atmospheric stability.

NREL continues to analyze data from the experiment in cooperation with the University of Colorado. NREL exchanges this information with researchers from Europe as part of an international research project to understand the physics of wind/wind turbine interactions.

NREL, Industry Evaluating Advanced Aerodynamic Controls

Since 1993, NREL has worked with industry to evaluate advanced aerodynamic control devices. The devices regulate power production in high winds and can prevent the rotor from overspeeding. Overspeeding can cause serious turbine damage. Aerodynamic control devices also help optimize energy capture, control loads, and control rotor speed.

Several devices were evaluated by NREL during 1995 and 1996, including spoiler flaps and two different ailerons. Spoiler flaps are mounted on the trailing edge of a turbine blade and rotate down or up to control rotor speed. The device was developed under an NREL subcontract.

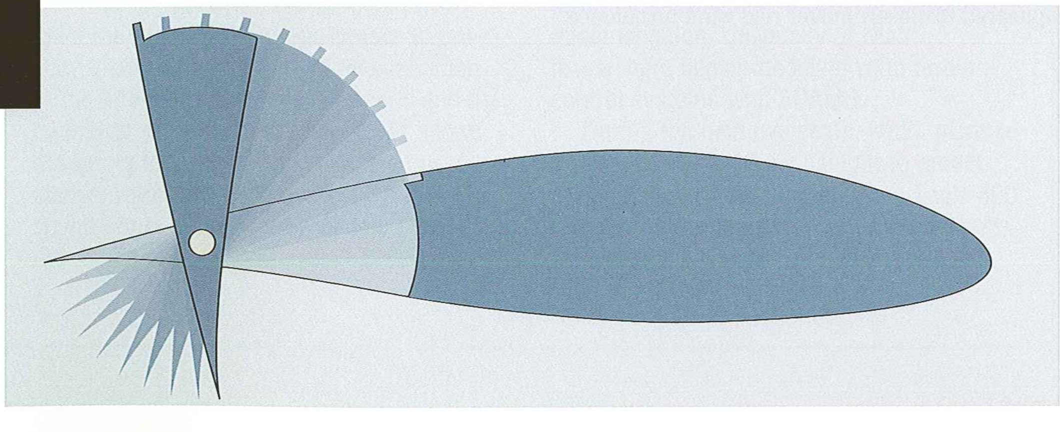
Ailerons are also mounted on a blade's trailing edge. Some ailerons fit snugly against the blade and rotate up, like those on an airplane wing. Others can rotate up or down, leaving a space between the aileron and the blade when they are deployed.

Aerodynamic devices were tested on industry wind turbines, including New World Power Technology Company's North Wind 250, the Westinghouse WWG-0600, the Zond Z-40, and the Advanced Wind Turbines AWT-26. NREL also conducted eight weeks of field testing of all three devices on a research turbine at the NWTC. Wichita State University fabricated the blades for the tests. Ohio State University had previously conducted wind tunnel tests of the same devices. The atmospheric tests confirmed the wind tunnel tests, which showed that all three devices could regulate peak power and control rotor speed.

Sandia Investigating Adaptive Blades

Researchers at Sandia have begun investigating adaptive structures that change shape in response to the wind. A blade's ability to change shape as the wind changes could increase energy capture by as much as 35% and reduce loads. With constant-speed machines, this could be accomplished by using materials that passively pitch the blades toward stall as wind speed increases. In 1997, researchers will investigate adaptive blade designs for variable-speed turbines.

When mounted on a turbine blade, the spoiler flap (shown here) can regulate power production in high winds and prevent a rotor from overspeeding. The device performed well in both wind tunnel and field tests during 1995 and 1996.



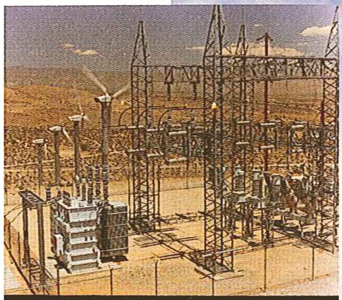
Researchers Study Longevity of Turbine Structures

Sandia and NREL have supported fatigue tests of blade materials and substructures at Montana State University since 1989. The goal of the tests was to develop a database to help turbine manufacturers select the best materials and substructures for their blade designs. The university released the database for the first time through Sandia in the fall of 1995. The DOE/Montana State Wind Turbine Blade Composite Material Fatigue Database contains test results on many fabric types commonly used in turbine blades. The university plans to offer a short course for industry in 1997 on how to use the new data set.

The university's substructure tests are part of an effort to develop better manufacturing techniques. Researchers are investigating how specific design details, such as materials, glues, resins; the proximity of other structures; and the assembly process, contribute to manufacturing flaws. They are also studying joints, bonded joints, and internal fiber patterns to determine the best materials for these substructures. Montana State's goal is to develop fatigue design guidelines for industry.

Montana State is also working on a project to see how well material tests predict actual fatigue life in a turbine blade. Researchers plan to build and test a new blade under real-life conditions until it breaks. They plan to compare the broken blade's characteristics with materials test results.

In related research, Sandia has spent several years studying fiberglass-to-metal bonded joints found in turbine blade roots. The strength of these joints is related to the way loads are distributed through them. In 1996, researchers showed that the service life of these joints can be increased by controlling the shape of the metal, fiberglass, and adhesive that form the joint.



WARREN GRETZ, NREL PIX 01501

The National Renewable Energy Laboratory and the U.S. Department of Energy work with utilities to better understand the integration of wind systems into utility generation.

NREL Helps Utilities Understand Wind Generation

Utilities worked closely with DOE in 1995 and 1996 to better understand the integration of wind systems into utility generation. Wind represents a unique challenge to utilities because they must integrate an intermittent wind resource into a system that supplies power on demand. Wind integration studies look for technical solutions to maintaining good power quality, keeping system operations running smoothly, and controlling costs when utilities use wind power generation.

There are three key developments needed to encourage utilities to use more wind generation. They include (1) new technology to bring wind's costs in line with competing technologies with very low fuel costs, (2) creative power-engineering solutions for integrating wind generation into utility systems, and (3) better wind forecasting techniques.

Cost Modeling Shows Whether Wind Generation Makes Sense for Utilities

NREL has adapted two utility computer models to help utilities decide whether wind generation makes sense for them. One model, called "ELFIN," was developed by the Environmental Defense Fund. The second model is a sophisticated utility resource and operations planning model, known as P+, developed by the P Plus Corporation. During 1995 and 1996, NREL created a subroutine to work with both models called the Wind Power Simulator. The simulator uses wind resource data to calculate annual power output from different-sized wind power plants at different sites under variable wind conditions.

Utilities can use ELFIN or P+ to create a high- or low-growth scenario and see how to meet the growth with conventional generation. They can then repeat the simulation by adding a wind power plant and see how costs change. During 1995 and 1996, NREL researchers found that both models produced good results in this type of simulation. However, the P+ model was able to provide more detailed information about the operating costs of wind generation and how those costs varied with time of year.

EPRI PIX 1448

U.S. utilities rely on coal for electricity generation at power plants such as the one shown above. The National Renewable Energy Laboratory works with utilities across the nation to evaluate how wind energy generation could reduce their use of fossil fuels.

NREL Provides Technical Assistance to Utilities

NREL worked with Public Service Company of Colorado and Tri-State Generation & Transmission Association, Inc., to help determine whether wind generation would make sense for them. Tri-State is an electricity cooperative serving Colorado, Nebraska, and Wyoming. Both utilities used computer models to determine that wind's capacity value varies significantly from year to year because of variations in the wind resource. The study also showed that wind's capacity value varies from site to site, underscoring the need for resource assessment at every potential wind site.

Next year, Minnesota's Department of Public Service will work with NREL on evaluating the benefit to a utility of having wind power plants in different geographic locations. The study will compare wind resource patterns with demand profiles supplied by Northern States Power Company.

Accurate Wind Forecasting Could Save Utilities Millions of Dollars

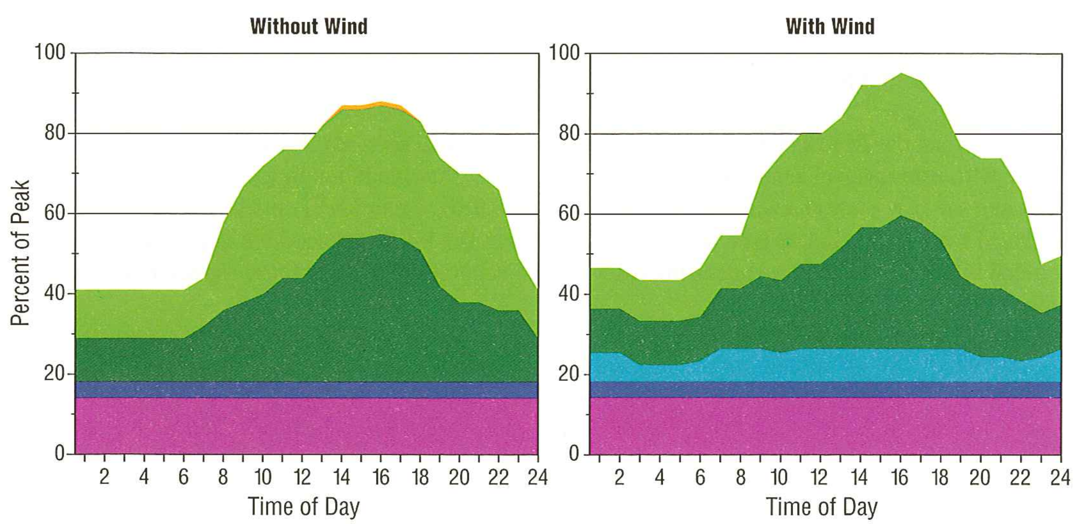
During 1995 and 1996, NREL researchers used the ELFIN model to study the value of accurate wind forecasts to utilities using wind power generation. The model simulated the impact of having more or less wind than expected on two large utilities with 1000-MW wind power plants. It found that accurate wind forecasts could save the utilities tens of millions of dollars a year by allowing them to plan ahead for wind generation. Wind's cost benefits fell, however, as the wind forecasts grew less accurate. As a result of the study, NREL launched a research project to develop better wind forecasting techniques.

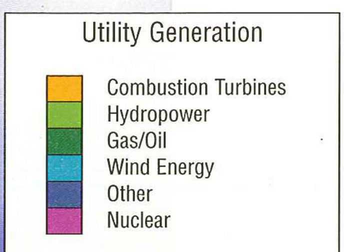
Fuel Diversity Can Help Utilities Reduce Impact of Deregulation

With utility restructuring, utilities will no longer be able to count on guaranteed markets for their electricity. One way to manage risks in such circumstances is to invest in diverse energy resources such as wind. Wind power plants are less risky than conventional fossil-fuel plants because small facilities can be built rapidly as the need arises, they avoid fuel price fluctuations, and they emit no air, land, or water pollutants, which may be more heavily regulated in the future.

During 1995 and 1996, an NREL subcontractor used computer simulations to compare the costs and risks of building a 400-MW, gas-fired, combined-cycle power plant and a 1600-MW wind power plant. Because of the intermittent nature of the wind resource, both plants would be expected to provide about the same power when utility demand peaks. The study concluded that wind would provide a significant benefit to utilities in tomorrow's unregulated markets and that the value of wind includes environmental benefits, fuel diversity, and job creation.

P+ Utility Simulations





P+, a utility resource and operations planning model, shows that this utility's use of fossil fuels (gas/oil and combustion turbines in graph on right) could be reduced with the addition of wind energy (far right).

Investigating Bird Behavior Near Wind Power Plants

NREL initiated studies of bird behavior near wind power plants in response to concerns expressed by plant operators and environmental groups. The groups worried that turbines operating in California's Altamont Pass posed a threat to golden eagles and other birds of prey. NREL and its subcontractors are investigating the impact of wind power plants on birds, developing siting methods that avoid such problems in the future, and looking for ways of reducing or eliminating wind generation's impacts on birds.

During 1995 and 1996, the Predatory Bird Research Group at the University of California at Santa Cruz conducted detailed studies of golden eagles in and around the Altamont Pass. They discovered that while few eagles live in the wind resource area, many birds enter the area to feed on squirrels and gophers. They also found that most eagles die from causes other than wind turbines. Of the more than 100 deaths documented since 1994, only 19 occurred in the wind resource area. Of these, seven were caused by the turbines.

In 1995, Montana State University began a preconstruction survey of bird populations near the Norris Hill Wind Resource area. The site lies just north of Ennis Lake, which attracts flocks of migratory birds during spring and fall. Researchers used radar and personal observations to assess the number of birds in the area and their migratory paths. Birds sighted at the lake included shore birds, trumpeter swans, pelicans, geese, ducks, eagles, hawks, and falcons. From preliminary observations, researchers concluded it would be advisable to site a wind power plant away from the lake.

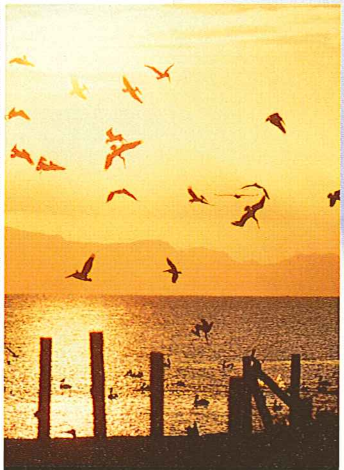
During 1996, DOE and NREL awarded three new subcontracts to study birds and wind power development. Minnesota will conduct a statewide inventory of birds that could be affected by wind development. The California Energy Commission will study the risk to birds posed by existing and future wind power plants. And, Vermont's Department of Public Service will determine the impact of wind power plants on the breeding and night migration of songbirds and the daytime migration of hawks.

NREL issued a new solicitation in 1996 to find ways to reduce the interaction of birds with wind turbines. Bidders will study the impact of treating turbines in a wind power plant to reduce the risk of killing birds. Treatments could include painted blades, new tower designs, perch guards, warning devices, or decoys.

BRIAN LATTA, UC SANTA CRUZ PIX 04680

A researcher from the Predatory Bird Research Group at the University of California at Santa Cruz releases a golden eagle after attaching a radio tag. The group is studying golden eagles in and near the Altamont Pass wind resource area to determine the impact of wind turbines on bird populations.

M. ALLEN JENKINS, U.S. FISH AND WILDLIFE SERVICE PIX 04698



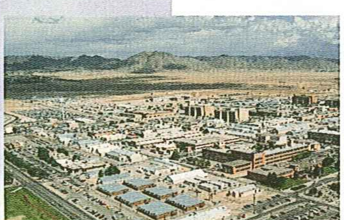
After conducting a preconstruction survey of birds near Montana's Norris Hill Wind Resource Area, researchers from Montana State University concluded that a wind power plant should not be built directly north of Ennis Lake as planned. The large lake attracts shore birds, trumpeter swans, pelicans (shown here), geese, ducks, eagles, hawks, and falcons.

The Program Structure

U.S. Department of Energy laboratories spearhead the Wind Energy Program.

The National Renewable Energy Laboratory's National Wind Technology Center near Golden, Colorado.

WARREN GRETZ, NREL PIX 00337



Sandia National Laboratories in Albuquerque, New Mexico.

SANDIA NATIONAL LABORATORIES PIX 04678

DOE's Office of Photovoltaic and Wind Technologies manages the Wind Energy Program. The office is responsible for ensuring that program activities are consistent with national energy policy, priorities, and directives. DOE's field offices and national laboratories implement program activities. The Wind Energy Program was appropriated $49 million in fiscal year 1995 and $32.5 million in fiscal year 1996.

The National Renewable Energy Laboratory, located in Golden, Colorado, is the world's largest scientific institution dedicated to developing renewable energy technologies. As DOE's lead laboratory in wind technology development, NREL operates the National Wind Technology Center. NREL manages wind turbine research and development, and utility, industry, international, and applied research programs. NREL conducts research in structures and fatigue testing, wind characterization, aerodynamics, advanced components and systems, wind resource assessment, and wind forecasting.

Sandia National Laboratories, located in Albuquerque, New Mexico, has been involved in renewable energy technologies, including wind, for more than 20 years. Sandia's wind program encompasses applied research, turbine development, and industry programs. As part of its turbine development efforts, Sandia is leading an advanced manufacturing initiative to reduce turbine costs through innovative component manufacturing. Applied research activities emphasize the development, validation, and transfer to industry of analytical and experimental tools in the areas of aerodynamics, structural dynamics, fatigue, reliability, materials, and controls.

A Look Toward Tomorrow

Certification testing at the National Wind Technology Center will help the U.S. wind industry establish a stronger position in international wind markets.

The DOE Wind Energy Program supports the nation's economic goals by pursuing the following objectives: (1) increase the productivity and competitiveness of U.S. technology, (2) aggressively pursue the development of a new generation of utility-grade wind turbines, and (3) foster applied research that will lead to lower cost and more reliable wind technologies. Here's what to expect in the coming years in wind technology development and its impact on wind energy markets.

- Certification testing will help the wind industry establish a stronger position in international wind markets.
- A whole new generation of utility wind turbines will provide electricity for $0.025/kWh by 2000.
- The wind turbine development project for small machines will produce new, more competitive technology for village power and stand-alone applications.
- DOE will support the development of larger wind energy systems at the National Wind Technology Center with the Advanced Research Turbine and the 1.5-MW dynamometer.
- Research engineers will develop efficient, direct-drive generators to enhance variable-speed generation and advanced, integrated wind turbine control systems.
- Meteorologists will develop better methods for wind forecasting.
- Hybrid power systems will become more widely used for remote power applications at home and abroad.
- Consumers will have the option to choose electricity providers who offer some power from wind and other renewables.
- The phased development of small wind power plants will spread throughout the United States.

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