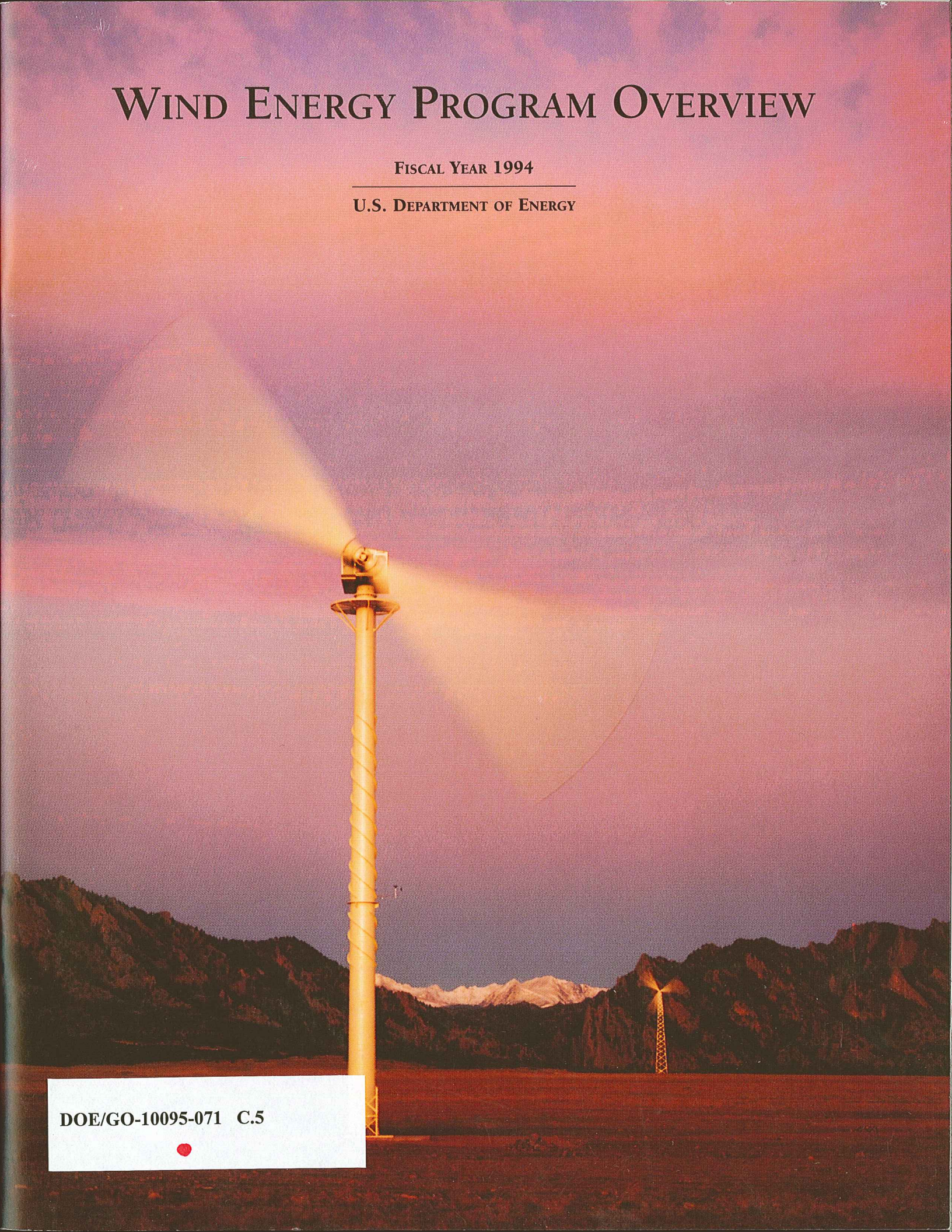
Wind Energy Program Overview

Fiscal Year 1994

U.S. Department of Energy



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Wind Energy Program Overview
Fiscal Year 1994

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THE DEPLOYMENT OF WIND POWER

THE INTRODUCTION OF NEW WIND ENERGY SYSTEMS IS RAPIDLY EXPANDING AT HOME AND ABROAD.

Wind power generation has begun to compete with conventional generation in energy markets in the United States and around the world. Energy costs of $0.05/kilowatt-hour (kWh) or less, wind's environmental benefits, the introduction of reliable new technology, and a better understanding of the huge U.S. wind resource have set the stage for a major commercial thrust for both utility and small wind systems. The emergence of new public/private partnerships is accelerating the deployment process for both domestic and international applications.

The wind industry is moving toward a new, more mature phase of development. Two firms, KENETECH Windpower, of Livermore, California, and New World Power Corporation, of Lime Rock, Connecticut, now offer publicly traded common stock through the NASDAQ stock exchange. Renewed public and private investment in wind energy reflects the nation's growing confidence in wind technology.

During fiscal year (FY) 1994,[1] approximately 100 megawatts (MW) of new wind generation came on-line in California, Minnesota, and Iowa. New installations brought the nation's total to 1630 MW.

U.S. utilities are gaining experience with wind power generation projects.

Nearly 700 MW of additional wind generation is expected to be on-line in the United States by the end of 1996. A $0.015/kWh federal wind production tax credit, which took effect January 1, 1994, is helping to promote these new deployment initiatives, particularly in regions where wind is only marginally cost competitive.

Utilities and wind developers have also announced plans for more than 4200 MW of new wind generation in 15 states by 2006. New wind projects are slated for Alaska, California, Hawaii, Iowa, Maine, Massachusetts, Minnesota, Montana, New York, Oregon, Texas, Vermont, Washington, Wisconsin, and Wyoming.

State legislatures in Minnesota and Iowa are encouraging the development of renewable energy such as wind with new laws. In response to a 1993 report issued by the Union of Concerned Scientists entitled *Powering the Midwest: Renewable Electricity for the Economy and the Environment*, these states accelerated their efforts to encourage energy self-sufficiency through the use of indigenous renewable resources. For example, an Iowa statute now requires that investor-owned utilities spend 2% of their funds for power from alternative energy resources. In addition, the Minnesota legislature has mandated that Northern States Power Company (NSP) acquire 425 MW of wind generation by 2002.

NSP is a large Midwestern utility headquartered in Minneapolis. The utility provided land and a substation for the 25-MW Buffalo Ridge Wind Power Plant, the first domestic power plant built outside California that uses new wind technology. NSP purchases power from the facility, which came on-line in May 1994 near Lake Benton in southwestern Minnesota. KENETECH Windpower built and operates the wind power plant. NSP issued a request for proposals for an additional 100 MW of wind generation in the Lake Benton area in October 1994.

[1] Fiscal year 1994 ran from October 1, 1993, through September 30, 1994.

In Texas, state officials, utilities, wind developers, and utility regulators made plans during FY 1994 to develop the state's wind resource. This large resource, which is concentrated in west Texas and the Texas Panhandle, could provide more than 100,000 MW of wind generation if fully exploited. Central and South West Services, Inc., a Texas utility holding company, is building the state's first new wind power plant in southwest Texas. The 6-MW plant, scheduled for completion in 1995, will use wind turbines developed under a U.S. Department of Energy (DOE) subcontract by Zond Systems, Inc., of Tehachapi, California.

The Lower Colorado River Authority, a state agency that supplies electricity wholesale to utilities and electric cooperatives, signed a joint-development contract with KENETECH Windpower in FY 1994 for a 250-MW wind power plant to be located 6 miles south of Guadalupe Mountains National Park in southwest Texas. The first phase of the project will be a 50-MW power-purchase agreement, with electricity costs to the authority set at less than $0.05/kWh.

Late in FY 1994, New World Power Corporation announced a 15-year power-purchase agreement with Texas Utilities (TU) Electric Company for a 40-MW wind power plant. The plant will be built in west Texas, near Big Springs, and is expected to produce electricity for about $0.04/kWh. The utility, which is the state's largest with a system capacity of more than 20,000 MW, is considering adding 340 MW of wind generation by 2004.

TECHNOLOGY STATUS*	BEFORE 1975	CURRENT	AFTER 2000
Cost/kWh	$0.50–$1.00	$0.05–$0.07	<$0.04
Operating Life	1–5 Years	20 Years	30 Years
Capacity Factor (Average)	10%	20%–25%	30%
Availability	60%–70%	95%	95%+
Size Range	<20 kW	200–500 kW	300–1000 kW

*For a wind site with an annual average wind speed of 6.9 meters per second (15.4 miles per hour). Wind speeds were measured at a height of 30 meters (100 feet).

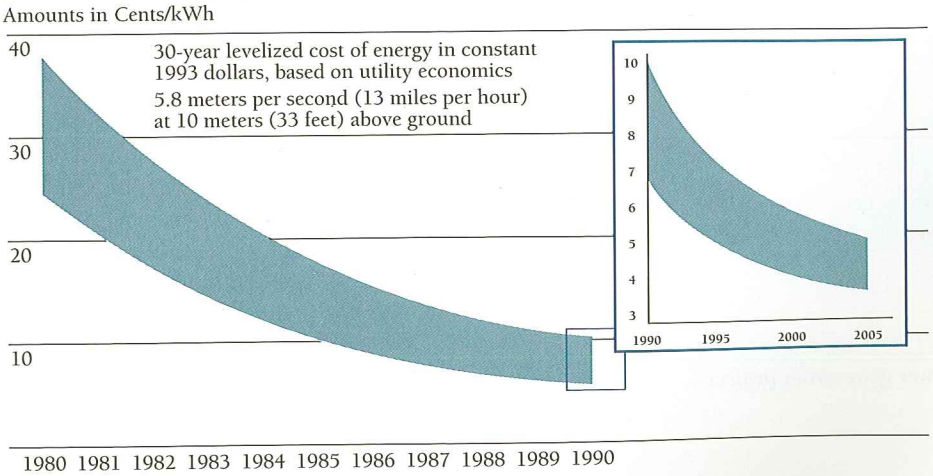
The decisions by TU Electric Company and the Lower Colorado River Authority to include wind in their generation mix resulted from integrated resource planning, a long-term strategy that helps utilities address future needs for electricity. The strategy involves considering many alternatives, including supply-side options such as renewable resources and demand-side options such as conservation, in long-range planning. The process encourages utilities to understand current renewable technologies and evaluate wind resources in their service territories. Consequently, it has become an important mechanism for introducing renewables into the nation's utility systems. For example, an official at the Texas Public Utility Commission has estimated that integrated resource planning will result in a minimum of 600 to 800 MW of wind generation in Texas within 10 years.

In the Pacific Northwest, wind projects totaling up to 300 MW are under way. In Columbia Hills, Washington, KENETECH Windpower is developing a 50-MW wind power plant for Portland General Electric, Puget Sound Power & Light Company, and PacifiCorp. The utilities have optioned another 50 MW for future development at the site. Portland General Electric is also negotiating with KENETECH Windpower for a new 100-MW wind project in Umatilla County, Oregon.

In FY 1994, FloWind Corporation, of San Rafael, California, signed a letter of agreement with a Seattle-based consortium of eight utilities, the Conservation and Renewable Energy System (CARES), and the Bonneville Power Administration (BPA) to develop a 25-MW wind power plant in Columbia Hills. FloWind plans to use 91 AWT-26 wind turbines, developed by Advanced Wind Turbines Incorporated, of Seattle, Washington, as part of DOE's Wind Turbine Development Program.

BPA is also sponsoring a similar project in Wyoming. In FY 1994, BPA agreed to purchase 25 MW of wind generation from a 70.5-MW power plant under development in Wyoming's Carbon County for four utilities: PacifiCorp; Tri-State Generation & Transmission Association, Inc.; Public Service Company of Colorado; and the Eugene Water & Electric Board.

THE COST OF ELECTRICITY FROM WIND TURBINES
Amounts in Cents/kWh



New technology has lowered wind energy costs to $0.05/kWh.

The three projects in Washington and Wyoming are undergoing environmental reviews and permitting. Construction is expected to begin during FY 1995.

In FY 1994, the Sacramento Municipal Utility District (SMUD) completed the first 5-MW phase of a planned 50-MW wind power plant. The SMUD project is the first U.S. wind power plant owned and operated by a utility.

DAVID PARSONS, NREL

With the completion of the 5-MW facility shown here, the Sacramento Municipal Utility District became the first utility to own and operate a wind power plant.

International Markets, Defense Applications Expanding for Wind

Utility-scale wind generation in the United States is one of the largest potential markets for wind energy systems. In addition, other industrialized nations, developing nations, and remote military installations also represent sizable markets for the wind industry. At the beginning of FY 1994, for example, the European Union had a total of 1000 MW of wind generation installed, with plans to increase that amount to more than 4000 MW by 2000 and 20,000 MW by 2010.

U.S. companies made sales in Europe and Canada during FY 1994. An 18.9-MW wind power plant using American technology came on-line in Canada. Three additional wind projects totaling 160 MW were under development in Spain, the Netherlands, and Canada. In a joint venture with KENETECH Windpower, a Ukrainian firm completed and installed five 100-kW wind turbines for a 500-MW wind power plant to be built on the Crimean peninsula in southern Ukraine.

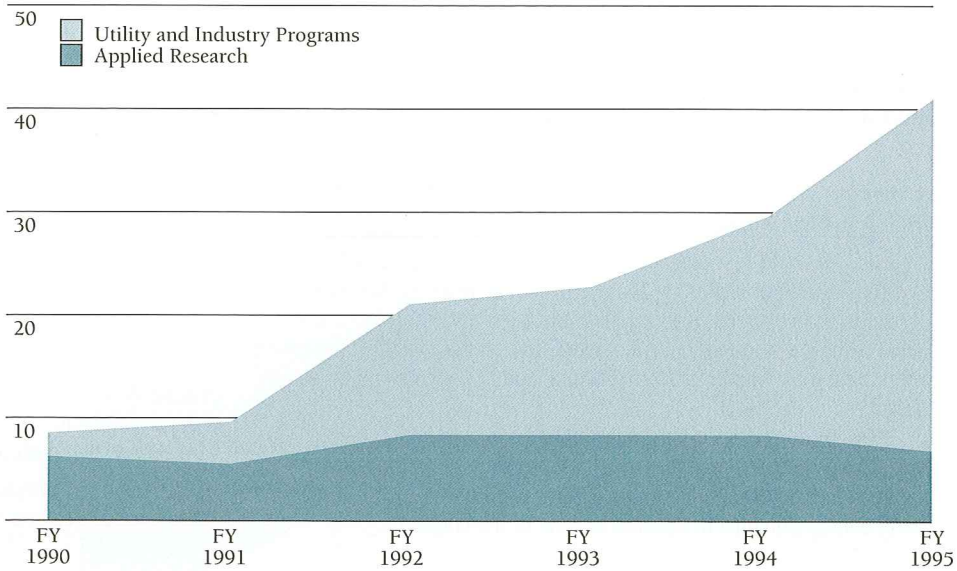
New agreements, including joint ventures, were reached with three U.S. firms to develop wind power plants in Chile, China, Costa Rica, India, Mexico, and New Zealand. In addition, U.S. firms made progress in developing new markets for small wind energy systems suitable for village power and stand-alone applications. These efforts are highlighted in the International Programs section.

Efforts to introduce the military to the benefits of wind energy also gathered momentum in FY 1994. In March 1994, Executive Order 12902 was issued requiring the Department of Defense (DOD) to increase its use of renewable energy. DOD is the largest consumer of energy within the federal government, which is the largest single user of energy in the nation.

The executive order meshes with efforts already under way at the National Renewable Energy Laboratory (NREL) to develop wind projects for military applications. DOD's Strategic Environmental Research and Development Program is funding NREL's efforts through a "work-for-others" agreement with DOE. The program was initiated in FY 1991 in response to a Congressional mandate to address environmental matters of concern. This arrangement not only allows DOE to support DOD in meeting its environmental obligations, but it also helps the U.S. wind industry develop a new market. Small wind turbines could potentially replace thousands of diesel generators at U.S. military installations that have good wind resources.

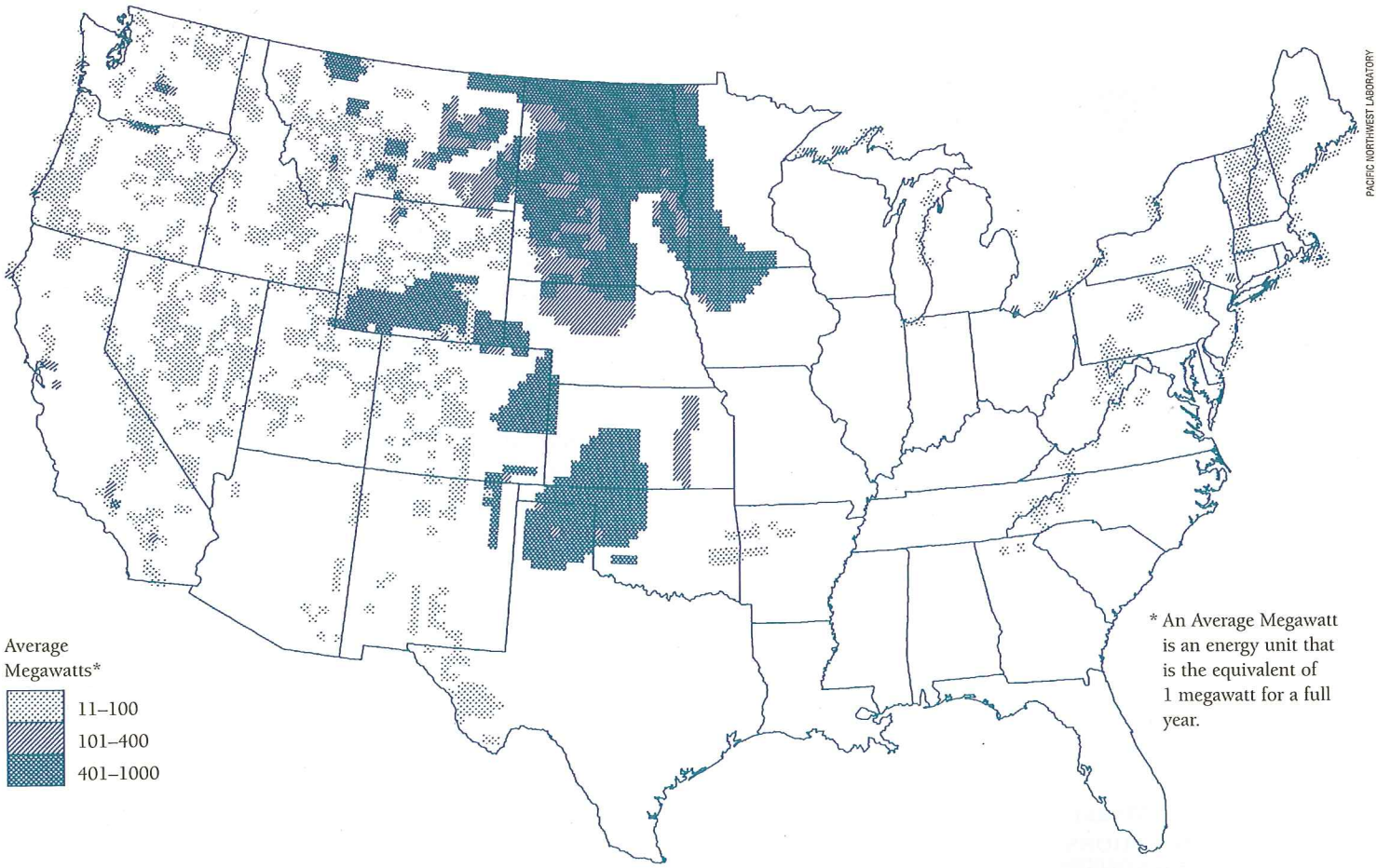
NREL is currently working with the U.S. Navy to design and build a 1- to 1.5-MW wind generation system at a site yet to be determined. During FY 1994, NREL began monitoring wind resources on San Clemente and San Nicolas Islands, located off the coast of California between San Diego and Los Angeles. NREL expects the Navy's new wind facility to be on-line by late 1996.

Budget Perspective
Amounts in Million $



Investment in new wind technology is a national priority.

During FY 1994, DOE also made plans for a project to develop small, advanced wind turbines as part of DOE's Wind Turbine Development Program. Turbine designers will determine the best size for the new machines based on an analysis of specific applications. However, most of the new turbines are expected to be rated between 20 and 40 kilowatts (kW). They will be designed to meet such criteria as high reliability, field maintainability, and salt-corrosion resistance. Although they will be developed primarily for village power and other civilian applications, the machines can also be designed to meet military power requirements. NREL plans to issue a solicitation in FY 1995 to develop the small turbine systems.



The Great Plains contain substantial wind resources suitable for wind power development. The map above shows the amount of wind-generated electricity that could be economically produced each year from resources of Class 4 and above. Class 4 is one of seven wind power classes used to express the energy contained in wind.

The U.S. Wind Resource

The U.S. wind resource is large enough to produce more than 4.4 trillion kWh of electricity each year, or half again as much electricity as the entire nation used in 1990. More than 90% of the usable wind resource is found in a wide band through the nation's midsection, stretching from Montana, North Dakota, and Minnesota south through Texas.

DOE, through Pacific Northwest Laboratory and NREL, has developed wind resource assessment and evaluation tools to help utilities, independent power producers, and other wind developers estimate the wind energy potential of specific regions of the country.

These resource evaluation products are available through the American Wind Energy Association (AWEA) and include the following titles:

- *The Wind Energy Resource Atlas,* which contains detailed color maps of the wind resource in the United States
- *State Resource Information Sheets,* which describe how much windy land each state contains and how much electricity could be produced by developing the state's wind resource
- *Shaded-Relief Elevation Maps for Wind Prospectors,* which enhance terrain features and help identify promising locations for prospective wind plants.

The National Wind Coordinating Committee

The wind industry, utilities, state officials, environmental groups, and DOE are working together to ensure the responsible use of wind power in the United States.

DOE believes there are important strategic benefits in using public/private partnerships to develop and deploy renewable energy technologies such as wind. Consequently, the wind industry, utility organizations, and DOE worked together during FY 1994 to establish a national group to address the goals of furthering the development of renewable energy and increasing U.S. competitiveness. Initial stakeholders, including the American Wind Energy Association (AWEA), the Electric Power Research Institute (EPRI), the Edison Electric Institute, the American Public Power Association, and DOE, held strategy discussions regarding wind development coordination with utilities, environmental groups, and others during the first 6 months of the fiscal year.

These efforts culminated in the formation of the National Wind Coordinating Committee in April 1994. Members include utilities, environmental groups, utility consumer advocates, utility regulators, government officials, and the wind industry. By working to ensure the responsible use of wind power in the United States, the committee envisions the creation of a self-sustaining commercial market for wind power.

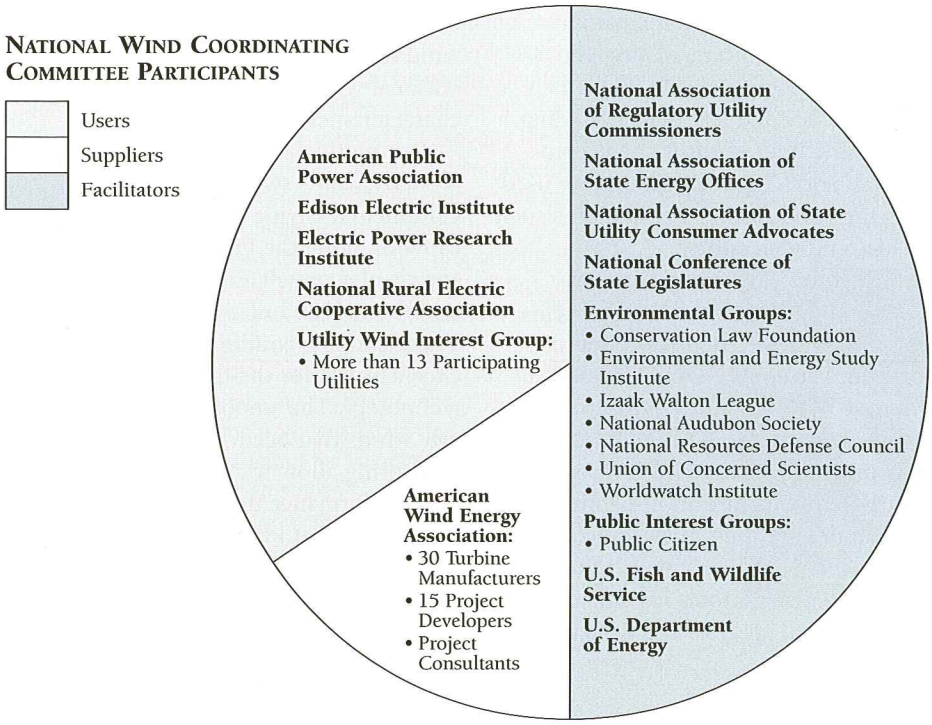
To bring its vision into reality, the committee will outline an orderly path for wind power development by identifying issues that impact the use of wind power, establishing dialogue among key stakeholders, and catalyzing appropriate activities. In the near term, it will explore regulatory and environmental barriers to renewable energy, address transmission access and pricing, and provide technical assistance to utilities conducting wind resource assessments.

The Utility Wind Interest Group

The Utility Wind Interest Group (UWIG) is a nonprofit corporation whose members work to expedite the appropriate integration of wind power into utility systems. The group works closely with the National Wind Coordinating Committee, providing a utility perspective to national energy policy discussions. UWIG also serves as a vehicle for implementing certain government/utility cost-sharing programs. During FY 1994, UWIG member utilities were active in forming the National Wind Coordinating Committee and in defining the committee's vision and strategies.

UWIG also provides utilities with information on wind power, a forum for discussion of utility-specific issues regarding the integration of wind power, and technical support for wind energy planning and implementation. During FY 1994, the group published two new informational brochures in a series on wind energy aimed at utility management: *Utilities Move Wind Technology Across America* and *Another Asset in the Utility Resource Portfolio.*

National Wind Coordinating Committee Participants

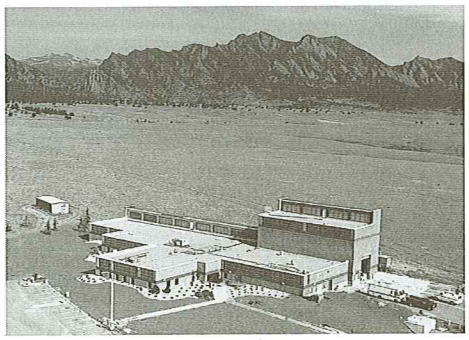


The National Wind Technology Center

In FY 1994, DOE opened a world-class energy research, development, and demonstration center near Golden, Colorado.

WARREN GRETZ, NREL

U.S. Secretary of Energy Hazel R. O'Leary highlighted wind energy's potential for enhancing global competitiveness at the dedication of the National Wind Technology Center.



WARREN GRETZ, NREL

The National Wind Technology Center near Golden, Colorado.

U.S. Secretary of Energy Hazel R. O'Leary dedicated DOE's new National Wind Technology Center in October 1994. The world-class wind energy research and testing center, located on 113 hectares (280 acres) near Golden, Colorado, is home to NREL's Wind Technology Division, laboratories, offices, and state-of-the-art testing facilities. The center is expected to become a technology magnet for wind and other high-tech industries.

Secretary O'Leary highlighted wind energy's competitive costs and its potential for fostering partnerships between the private sector and government, for creating new private-sector jobs, and for enhancing global competitiveness.

"I'm so proud of what's being developed here," she said. "There's a stark contrast between the old way of looking back and the new and appropriate way of not only looking forward, but also taking action in furtherance of a better future for this nation."

The dedication was the culmination of efforts launched in October 1992 to refurbish and expand facilities at the site, which has been used for wind research since 1976. Current facilities include a structural test facility, 16 turbine test pads suitable for machines sized up to 1 MW, a specially instrumented wind turbine used to study the interactions of the wind with turbine blades, and a 2137-square-meter (m^2) (23,000-square-foot [ft^2]) office and laboratory building. The building houses NREL's wind program staff and a high-bay laboratory used for testing wind turbine components such as blades and generators.

Three commercial wind turbines have been installed at the site. Two of these, the Atlantic Orient Corporation (Norwich, Vermont) AOC 15/50 and the Advanced Wind Turbines AWT-26, were developed as part of DOE's Wind Turbine Development Program. NREL installed the turbines to acquire an in-depth understanding of their operation and performance. NREL also plans to use the turbines as research tools for enhancing computer-aided analysis and design codes. The site also contains a 10-kW turbine developed by Bergey Windpower Company, Inc., of Norman, Oklahoma. The turbine will undergo testing with an advanced power-electronic controller.

During the next several years, NREL plans to install as many as 16 experimental turbines at the center and use them to study wind power plant operation and performance. The turbines will feed power into the site's existing 13.2-kilovolt/480-volt power distribution system. NREL will install a Supervisory Control and Data Acquisition System (SCADA) at the site early in FY 1995. A SCADA is a two-way communication network that runs between the wind turbines and a central operations center, allowing test engineers to turn the turbines on or off and monitor their performance.

During the next 2 years, the wind technology center will undergo additional changes to make it the most advanced wind energy research facility in the world. A new, more sophisticated *Site Meteorological System,* scheduled to become operational early in FY 1995, will augment current wind measurement facilities. NREL will install 80-meter (m) (262-ft) meteorological towers on the eastern and western boundaries of the site. Instruments on the two towers will gather information on the local wind resource, including daily and seasonal wind patterns and turbulence characteristics.

During the fall and winter, strong westerly winds sweep over the Continental Divide and down the canyons along the Front Range, reaching speeds of as much as 54 meters per second (m/s) (120 miles per hour [mph]). These extreme conditions provide an excellent test for the durability of new technology. The smooth and stable easterly winds that occur in the late winter and spring allow researchers to study turbine performance under conditions typical of the Great Plains, where the bulk of the U.S. wind resource is located.

A 929-m² (10,000-ft²) *Industrial User Facility* is scheduled for completion at the site in 1996. The facility is designed to encourage government/industry collaboration in technology innovation. It will provide office space for industry engineers desiring to use the center's facilities and work with NREL researchers to evaluate new wind turbine components and systems. It will also house laboratories, computer facilities, and a large blade-testing bay for studying the structural performance and fatigue durability of blades more than 20 m (66 ft) long. The facility will be partitioned into three user bays to enable industrial research teams to evaluate new components and turbines in separate, secure areas. The latter feature allows industry to protect intellectual property.

The construction of a new *Hybrid Power Test Facility* is planned at the site in FY 1995. The facility will allow researchers to evaluate power generation systems that combine wind turbines, photovoltaic (PV) arrays, backup generators, and storage systems. The goal of this testing program is to improve the performance, cost-effectiveness, and reliability of commercial hybrid power systems. Hybrid power systems are rapidly becoming the technology of choice for delivering electricity to remote areas without access to an electrical grid. NREL's hybrid power system research will strengthen DOE's international technical assistance program.

NREL also plans to build an *Advanced Research Turbine* facility at the center. The facility will consist of one or more experimental turbines designed to test rotor and generator systems under a variety of wind conditions. NREL will conduct basic research testing designed 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.

Educational Programs

DOE invests in the future of wind energy research and development (R&D) by providing a variety of educational programs for students in elementary through graduate school. The most comprehensive of these is the University Participation Program for Wind Energy Research. NREL established the program as a way to involve colleges and universities in wind technology research, increase the fundamental scientific understanding of wind energy conversion processes, and train future scientists and engineers.

During FY 1994, the program supported more than a dozen graduate students at seven U.S. universities in graduate research projects, which included analyzing wind turbine blade materials, developing computer models of wind turbine systems, and looking for ways to reduce wind turbine interactions with birds. Participants included Boise State University, Montana State University, Stanford University, Tennessee State University, the University of Illinois at Urbana-Champaign, the University of Texas at El Paso, and the University of Utah. Universities with high minority student enrollments also received funding for the development of graduate courses and seminars in wind energy and support for undergraduate research.

In FY 1995, DOE plans to initiate a new program for Historically Black Colleges and Universities. The program will provide funding for as many as eight graduate engineering students. The students will spend one summer working at the National Wind Technology Center.

NREL and Sandia National Laboratories employ student interns who work with wind researchers each summer. During FY 1994, Sandia hosted students from Iowa State University and the University of Texas at El Paso as part of the laboratory's Outstanding Student Summer Program. Eleven students from the University of Utah, the University of Colorado at Boulder, the University of Texas at El Paso, the Colorado School of Mines, and Colorado State University worked with NREL researchers on a variety of projects at the National Wind Technology Center.

In related efforts, NREL funds the work of graduate students at the University of Colorado at Boulder through research subcontracts with the university. As part of their thesis work, aerospace engineering students are analyzing data collected as part of NREL's unsteady aerodynamics experiment, and electrical engineering students are investigating an advanced low-speed generator. NREL and Sandia also support students at Iowa State University, Ohio State University, Oregon State University, Montana State University, and the University of Massachusetts through research subcontracts.

Wind program engineers participate in Sandia's educational outreach activities, teaching students about math and science, including the fundamentals of wind energy. They have participated in the Sandia/Albuquerque Public Schools Science Advisor program since its inception in 1990 and serve as science fair judges at the local and state level. The wind energy program staff at Sandia also assists in the preparation of wind energy displays for special events such as Earth Day and makes presentations on request. NREL staff members also make presentations on wind energy to Denver-area grade schools and local organizations.

SANDIA NATIONAL LABORATORIES

Sandia researcher teaches an Albuquerque fifth grader about the fundamentals of wind energy.

Utility Programs

DOE IS WORKING WITH UTILITIES TO INTRODUCE ADVANCED WIND TURBINE TECHNOLOGY TO THE UTILITY PLANNERS AND ENGINEERS WHO WILL INTEGRATE TOMORROW'S HIGH-TECH WIND POWER PLANTS INTO THE UTILITY GRID.

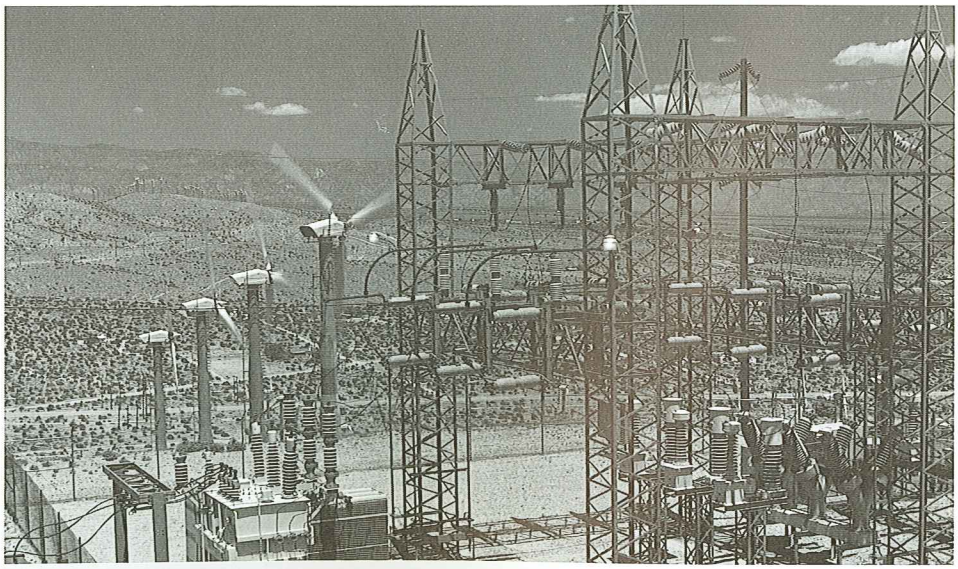
The U.S. utility industry is exploring wind as a new generation source. Dozens of electric utilities in 15 states are in the process of acquiring hands-on experience with wind power generation. This unprecedented involvement with wind energy is a necessary precursor to the widespread integration of wind into the U.S. utility grid. Since 1990, DOE has worked with utilities and the wind industry to build a bridge between research and development (R&D) programs and the commercial use of utility-scale wind turbines.

During FY 1994, utility plans for new wind projects more than doubled as a result of increased interest in renewable energy systems on the part of utility regulators and utilities. To further encourage utilities to evaluate wind energy systems, DOE launched two multimillion-dollar deployment assistance programs.

DOE announced plans in 1994 for a new Wind Turbine Deployment Project designed to help the United States meet national economic and environmental objectives. DOE expects the initiative to result in commercial partnerships among U.S. utilities, independent power producers, and wind turbine manufacturers that will enhance the U.S. competitive position in domestic and international energy markets.

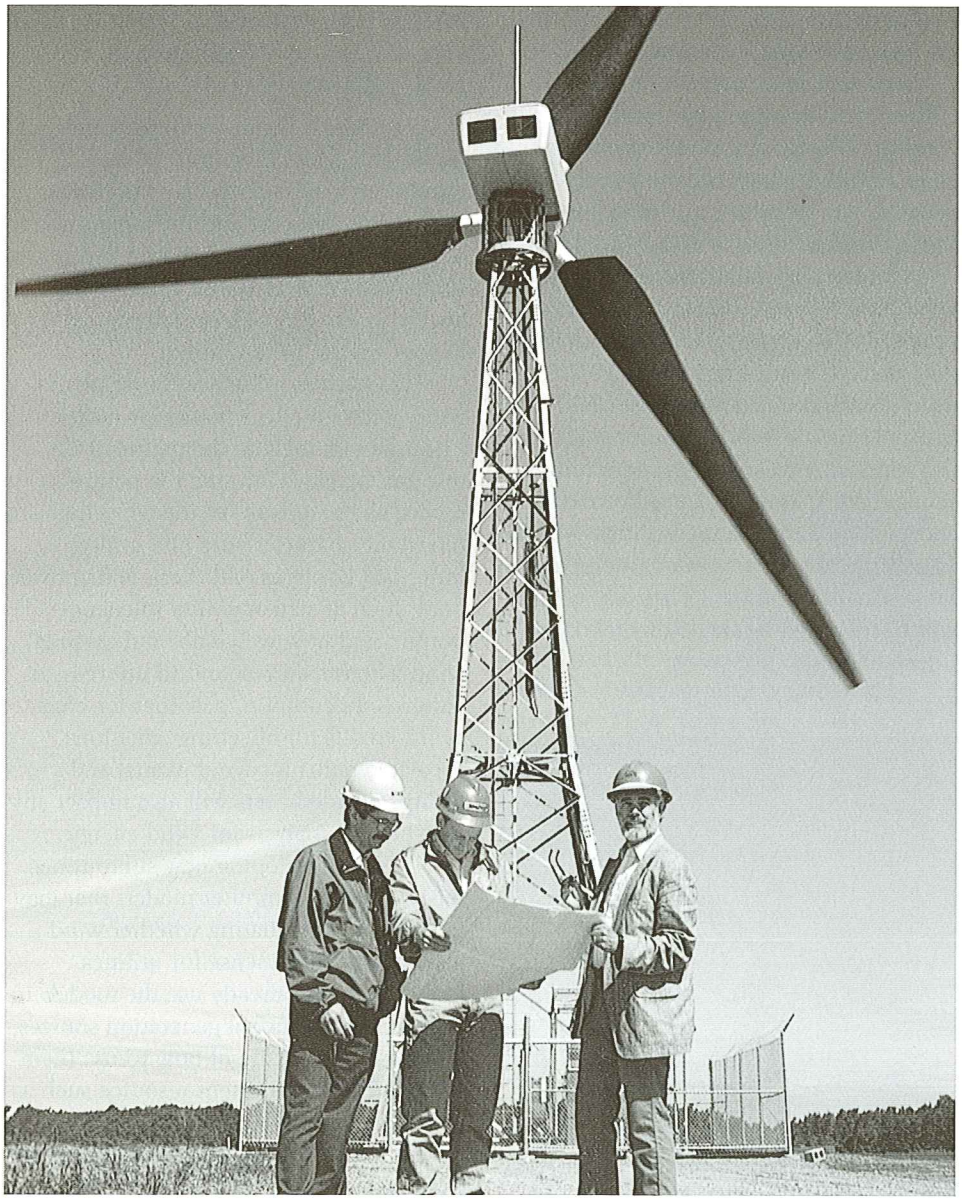
Under the cost-sharing initiative, DOE will contribute as much as 20% of the total cost for constructing a new 25-MW wind power plant, distributed wind system, or wind-diesel hybrid system. (Utilities with a peak capacity of less than 100 MW will be allowed to propose smaller power plants under this initiative.) DOE expects the enterprise to facilitate the introduction of new wind generation and help utilities reduce the perceived risk of introducing a new and unfamiliar technology. DOE plans to collaborate in the development of as much as 500 MW of new wind generation in the United States and its territories by 2000. NREL will issue a solicitation early in FY 1995 for developing the first power plants under this initiative.

In a related endeavor to further wind energy deployment, NREL launched the Sustainable Technology Energy Partnerships program in FY 1994. Under this initiative, NREL will work with state energy offices throughout the nation to create partnerships with private industry, academia, and utilities for conducting pilot projects including wind technology deployment, resource assessment, and bird population studies.



WARREN GRETZ, NREL

The U.S. utility industry is the largest potential market for wind energy technology in the world.



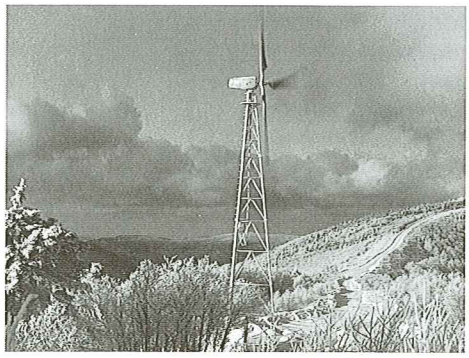
RENATE GADDIS, NIAGARA MOHAWK POWER CORPORATION

Niagara Mohawk Power Corporation tested this new turbine, then decided to build a 6-MW wind power plant as part of the Utility Wind Turbine Performance Verification Program.

The Utility Wind Turbine Performance Verification Program is another major component of DOE's efforts to demonstrate the value of wind energy to utilities. The 5-year program is a joint effort between DOE and EPRI designed to reduce the risk of bringing advanced wind turbine technology into a utility setting for testing and evaluation.

Participating utilities will build and operate a wind power plant of at least 6 MW that uses the latest technology. They will select the wind power plant site, solicit bids from U.S. vendors, and purchase the turbines. They will also be responsible for power plant design, construction, start-up, and 3 years of testing, evaluation, and documentation. Such experience will allow utilities to make informed decisions when considering wind energy for replacing an outdated power plant or adding new capacity.

Vermont's Green Mountain Power Corporation and Central and South West Services, Inc., were awarded $3.5 million and $2 million, respectively, during FY 1993 to participate in the program. During that year, both utilities began the process of siting their facilities and applying for necessary permits.



GREEN MOUNTAIN POWER CORPORATION

Green Mountain Power Corporation is obtaining permits for a new 6-MW wind power plant in Vermont. The utility used the turbine shown here to evaluate its wind resource.

During FY 1994, Central and South West Services selected a power-plant site in southwest Texas near Fort Davis and initiated a study to monitor birds passing through the project area. Central and South West Services also selected an advanced wind turbine for the power plant, the Z-40. The Z-40, developed under the auspices of DOE's Wind Turbine Development Program, is a 500-kW machine manufactured by Zond Systems, Inc. Central and South West will use 12 of the new machines in the demonstration power plant, scheduled to come on-line during FY 1995.

Green Mountain Power continued its efforts to secure permits from the U.S. Forest Service for a ridge-top site east of Bennington, Vermont, during FY 1994. Green Mountain Power plans to conduct interviews with potential turbine vendors in FY 1995.

In late 1994, DOE and EPRI awarded Niagara Mohawk Power Corporation $1.5 million to participate in the Turbine Verification Program. Niagara Mohawk plans to build a 6-MW wind power plant by 1996 at a location not yet specified in New York. Niagara Mohawk, which has announced plans to become the lead utility for wind in New York State, will receive an additional $1.5 million for the wind project from the New York State Energy Research and Development Authority.

During FY 1994, DOE also supported the National Wind Coordinating Committee in initiating a cost-shared Utility Wind Resource Assessment Program. The program will provide assistance to utilities in conducting their detailed wind resource measurements in their service territories or in other locations under consideration for siting a wind power plant. To help launch the program, a meteorologist supported by the Edison Electric Institute and NREL developed specifications for standard instruments and procedures for evaluating wind resources. The wind monitoring standards will ensure that uniform data is collected by participating utilities. About 10 utilities are expected to participate in the resource assessment program, which will be managed by the Utility Wind Interest Group.

JERRY MILLER, NSP

Northern States Power Company purchases electricity from this 25-MW wind power plant near Lake Benton in southwestern Minnesota.

NREL INVESTIGATES THE VALUE OF WIND POWER TO UTILITIES

As utilities consider adding significant wind generation, they must address a number of key issues such as transmission access and cost and the integration of an intermittent resource into the generation mix. Ultimately, the value of wind energy to a utility will be determined by factors unique to that utility.

Many factors influence the value of wind generation to a particular utility. These factors include the nature of the resource at a specific site; the performance characteristics of the wind turbines; the characteristics of a utility's other power plants and those of its power pool, such as size or ability to change output; and how well daily and seasonal wind patterns correspond to utility load patterns. In addition, penalties for emissions, credits for offsetting emissions, capacity credits for wind plants, and a utility's avoided costs will also impact any cost-benefit analysis for wind energy.

NREL is developing new subroutines for two utility computer models that may be helpful in evaluating whether wind generation makes sense for utilities. Utility planners already use the models to evaluate conventional generation sources, but are as yet unsure of how to use them to model an intermittent resource such as wind. One model, called "ELFIN," was developed by the Environmental Defense Fund. California utilities are required to use it to analyze the impact of new power plants on rate decisions. The second model is a sophisticated utility resource and operations planning model, known as P+, developed by the P Plus Corporation. During FY 1994, NREL researchers studied both models and determined that both are useful in modeling wind energy in a utility system.

Wind Turbine Development

The development of technologically advanced, high-efficiency wind turbines is a top priority of the federal Wind Energy Program and the U.S. wind industry.

DOE sponsors a multifaceted Wind Turbine Development Program to help the U.S. wind industry develop competitive, high-performance technology for global energy markets. Market opportunities are multiplying as policymakers, utility regulators, and the private sector affirm wind energy's potential for delivering affordable electricity *and* protecting the environment. DOE has designed its turbine development efforts to help the U.S. wind industry capture a significant share of new wind markets in the face of increasing international competition.

The Wind Turbine Development Program is a cost-shared effort with industry. Its goal is to lower the cost of wind-generated electricity to be competitive with fossil-fuel generation in most regions of the nation. The first turbines developed under the program, which began in 1992, are now commercially available. They have energy costs of $0.05/kWh or less at sites with moderate annual average wind speeds of 5.8 m/s (13 mph) at a height of 10 m (33 ft). These costs, in conjunction with today's $0.015/kWh wind energy production tax credit, have made wind energy competitive with conventional electric technologies in some areas.

By 2000, a new generation of wind turbines developed under this program is expected to bring wind energy costs to less than $0.04/kWh at moderate wind sites. Competitive costs, plus the experience utilities are currently gaining with the technology, will put wind in a solid competitive position with respect to fossil fuels by the end of the decade.

Many activities comprise DOE's far-reaching Wind Turbine Development Program. The multiphased, cost-shared program is supporting the U.S. wind industry's development of today's emerging wind turbines and a new generation of utility wind turbines expected to be introduced between 1998 and 2000.

FY 1994 saw important progress as the wind industry continued the design, field-testing, and refinement of six new near-term turbines. Five of the six machines produced as part of the near-term development efforts are highlighted later in this section. A sixth turbine, the AOC 15/50, is profiled in the International Programs section.

FY 1994 also ushered in next-generation turbine development. The two-pronged effort includes (1) the development of innovative turbine subsystems and (2) the development and testing of advanced full-system turbine prototypes. The development of next-generation prototypes began with a concept development activity that will lead to as many as three multimillion-dollar subcontracts to develop next-generation wind turbines.

The national laboratories provide technical support to industry's turbine development efforts with technical design reviews, analysis and support, and structural and field-testing services. Taken together, Wind Turbine Development Program activities are helping the U.S. wind industry make rapid progress toward the goals of economically exploiting windy areas of the nation and creating competitive technologies for international markets.

NEAR-TERM UTILITY TURBINES UNDERGO DEVELOPMENT, TESTING

The 500-kW *Z-40* is one of the new turbines being developed in collaboration with NREL. In FY 1994, Zond Systems, Inc., completed two prototypes of its three-bladed, upwind, rigid-hub machine. Both designs capitalized on Zond's extensive experience operating a 260-MW wind power plant.

One prototype uses aileron controls, which are similar to flaps on an airplane, to slow the rotor and modulate power output. The turbine is mounted on a free-standing lattice tower. A second prototype, which sits atop a tubular tower, is equipped with a full-span pitch-control system that modulates power output by changing the angle of the blades with respect to the wind. Both prototypes incorporate NREL-designed airfoils and an integrated gearbox design that minimizes the number of turbine parts and reduces installation and maintenance costs.

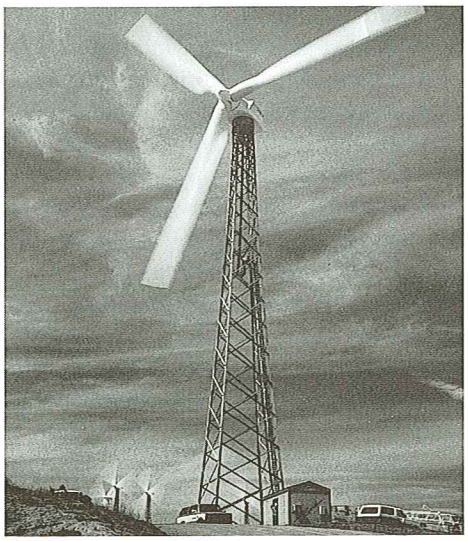
During FY 1994, Zond began field-testing its new prototype turbines. NREL also began testing the turbine's new blades at the National Wind Technology Center. The Z-40 turbine, which became commercially available in 1994, was selected by Central and South West Services for the utility's 6-MW power plant, scheduled for installation in 1995 in west Texas.

As part of a new NREL subcontract, New World Grid Power Company, formerly known as Field Service and Maintenance Company, will develop the *500XST* (eXperimental Synchronous Turbine). The company, located in North Palm Springs, California, is a subsidiary of New World Power Corporation. New World will use its experience operating a variety of European wind turbines to develop the new 500-kW, three-bladed, upwind machine. Its basic features include full-span pitch control, a free-standing tubular tower, and active yaw-control. An active yaw-control system uses a motor to turn the turbine into or out of the wind. The turbine will also include an innovative drivetrain and a generator that provides improved output power quality. It includes an on-board crane for ease of maintenance.

FloWind Corporation is the only U.S. firm developing an enhanced Darrius (eggbeater-shaped) vertical-axis wind turbine. FloWind's *EHD* (Extended Height/Diameter ratio) turbine will have three blades that spin about an axis perpendicular to the ground.

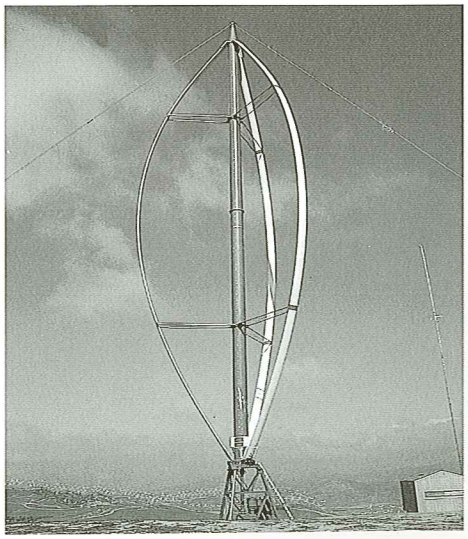
The enhanced EHD series will be based on FloWind's new 17-m-diameter (56-ft-diameter) EHD turbine, which was built, tested, and refined during FY 1994 under several agreements with Sandia. The 17 EHD's rotor is a taller, thinner, and more efficient version of the 19-m-diameter (62-ft-diameter) rotor used today on more than 200 FloWind turbines in California.

The 17 EHD's low-cost blades are manufactured using an automated pultrusion technique, in which fiber-resin blades are pulled through a die. The blades incorporate airfoils specially designed to keep air flowing smoothly over them and to increase energy capture. FloWind estimates that the new rotor will double the annual energy output of the older turbine design.



LLOYD HERZIGER, ZOND SYSTEMS, INC.

Zond Systems, Inc., built the 500-kW Z-40 prototype wind turbine as part of the Wind Turbine Development Program.



BRAD MILLIKEN PHOTOGRAPHY

FloWind Corporation will enhance the 17 EHD vertical-axis wind turbine, shown here, under a new subcontract with the National Renewable Energy Laboratory.

WARREN GRETZ, NREL

The AWT-26 turbine prototype underwent reliability testing in FY 1994 to satisfy requirements for a 25-MW wind power plant under development in Washington State.

The EHD will be a constant-speed machine rated from 300 to 500 kW, depending on the size of the high-performance rotor. As part of the development project, FloWind plans to evaluate a variety of height-to-diameter ratios for 17- to 21-m (56- to 69-ft) rotors to find the configuration that yields the best performance for the lowest cost.

NEW WORLD POWER TECHNOLOGY COMPANY

New World Power Technology Company designed an innovative turbine rotor as part of the U.S. Department of Energy's Wind Turbine Development Program.

Two 275-kW *AWT-26* turbine prototypes, developed by Advanced Wind Turbines, underwent more than 4000 hours of reliability testing and produced more than 600,000 kWh of electricity during FY 1994. The tests will be used to satisfy reliability testing requirements for a 25-MW wind power plant under development in Washington State by FloWind, which markets the turbine. In advance of the testing, one prototype was modified to include improvements planned for the commercial turbine, including a 43-m (140-ft) guyed tubular tower. The National Wind Technology Center installed an AWT-26 wind turbine during FY 1994. The turbine, along with other new turbines, will undergo extensive operational testing at the center.

The AWT-26 is a downwind, two-bladed machine employing an innovative teetered rotor. The rotor rocks back and forth in response to wind gusts, thereby dissipating stress and strain on turbine components. The rotor uses efficient wood-epoxy blades incorporating NREL-designed airfoils, which increase energy capture, particularly when blades are soiled with insects or dirt. Aerodynamic tip brakes, located at the end of the blades, can be deployed to slow the rotor during times when the machine is disconnected from the grid.

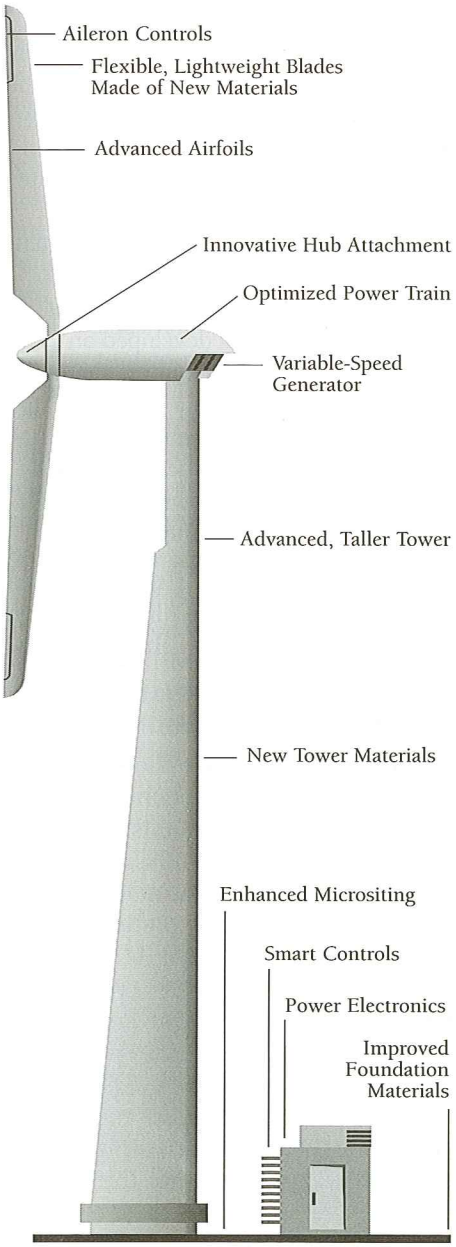
New World Power Technology Company, of Moretown, Vermont, initiated a proof-of-concept testing for the *Northwind 250* turbine in FY 1994. The company, a wholly-owned subsidiary of New World Power Corporation, installed the turbine in California's San Gorgonio Pass for field-testing. It plans to use test results to confirm its innovative rotor design before constructing a prototype turbine.

The two-bladed, upwind Northwind 250 features an integrated drivetrain, aileron controls, and a "flow-through" teetering rotor that is fabricated as a single unit. The rotor has large, filament-wound blades and incorporates teeter dampers and a teeter brake. The ailerons on each blade regulate the turbine's power output and protect against rotor overspeeding.

Cutting-Edge Technology Supports Turbine Development

Inspiring the wind industry to explore cutting-edge technology is a key objective of the next-generation turbine development effort. Innovative components and subsystems will be vital to developing next-generation utility wind turbines that can produce electricity for less than $0.04/kWh. To encourage industry to depart from traditional designs, DOE split the next-generation turbine development phase into two projects, one of which is the Innovative Subsystems Project.

In FY 1994, NREL awarded five 2-year subcontracts under the project, which requires a minimum of 30% cost-sharing from participants. With the addition of the new projects, DOE, NREL, and Sandia now conduct or oversee more than a dozen different activities to develop new airfoils, innovative generators, advanced rotors, structurally tailored turbine blades, smart turbine controls, and advanced aerodynamic controls.



An artist's concept of a next-generation utility wind turbine is shown here.

NREL-DESIGNED AIRFOILS INCREASE ENERGY CAPTURE

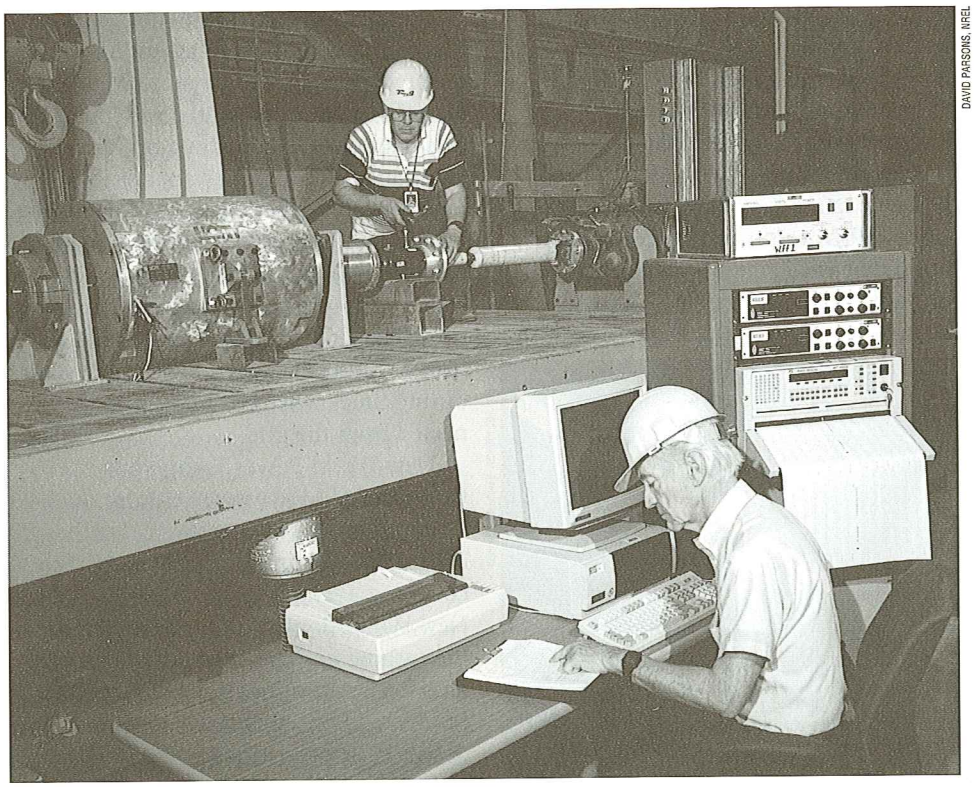
Since 1984, NREL researchers have developed seven families of thick and thin airfoils specifically designed for wind turbine blades. Using the NREL-designed airfoils on stall-controlled turbine rotors can increase energy capture by 20% to 30%. Stall-controlled rotors regulate power output in high winds by taking advantage of the tendency of air flow to detach from turbine blades at high rotational speeds.

During FY 1994, NREL designed a new airfoil family for large wind turbines using pitch-controlled blades and variable speed. Rotor speed on variable-speed turbines changes in response to changes in wind speed to allow the rotor to operate at maximum efficiency. NREL expects the new airfoil family to improve annual energy capture by 8% to 10%.

In a related effort, a University of Illinois researcher has developed an advanced, less time-consuming method for designing new turbine blades. Using this method, designers can specify desired performance characteristics, then use a new computer code known as PROP-ID to design and optimize the blade. The new method is expected to allow a designer to complete an entirely new blade design in about 40 hours.

NREL, INDUSTRY EXPLORING NEW GENERATOR DESIGNS

The majority of turbines operating today use induction generators. Induction generators are electric motors that generate electricity when the turbine's high-speed shaft turns the motor at a rate higher than 1800 revolutions per minute (rpm). Because a turbine rotor typically spins at less than 60 rpm, most turbines use costly transmission and gearing to increase the rotational speed of the generator shaft. NREL is now sponsoring the development of three advanced generators that show promise of being more efficient and less costly than the traditional generator design.



DAVID PARSONS, NREL

The National Renewable Energy Laboratory will test innovative generator designs with this generator-power electronics test stand.

During FY 1994, Unique Mobility, Inc., of Golden, Colorado, built a direct-drive, variable-speed, permanent-magnet generator and delivered it to NREL for testing and evaluation. The 20-kW experimental generator, designed by University of Colorado (CU) researchers under a University Participation Program subcontract, spins at the same rate as a turbine rotor. When installed in a wind turbine, it can be connected directly to the rotor shaft, completely eliminating the need for transmission and gearing. The generator's variable-speed feature allows the turbine rotor to slow down or speed up in response to changes in wind velocity. This increases energy capture and reduces wear and tear on turbine components.

CU researchers have also completed a power electronics unit to convert the variable-frequency, alternating current produced by the generator into constant-frequency, 60-cycle alternating current compatible with the utility grid. NREL plans to complete laboratory tests of the generator and power-electronics assembly during FY 1995. Next, researchers plan to install the direct-drive generator on a research turbine at the National Wind Technology Center. The advanced generator system will allow researchers to evaluate new turbine control software designed to maximize energy production while minimizing wear on turbine components.

Electronic Power Conditioning, Inc. (EPC), of Corvallis, Oregon, was awarded an Innovative Subsystems Project subcontract from NREL in FY 1994 to develop an innovative variable-speed generator and power-electronics subsystem. The subsystem design consists of EPC's patented power-electronic converter and a doubly fed generator. In a doubly fed generator, electricity is generated by both the rotor and the stator, which is the stationary part of the generator. Only the power from the rotor needs to be converted to 60-cycle electricity prior to introduction to the utility grid, however. This means that the power-electronic converter handles less than half of the power of a conventional generator operating at variable speed.

Under its subcontract, EPC will build a 325-kW generator unit, test and refine it in the laboratory, and then field-test it on an AWT-26 advanced wind turbine. Variable-speed generators typically allow a wind turbine to operate at maximum efficiency over a wide range of wind speeds, thus lowering energy costs by about 15%. In addition, they improve power quality; allow for smoother, more controlled turbine start-ups and shutdowns; and permit quieter turbine operation, particularly at low wind speeds. However, there is a design trade-off: the power electronics and the advanced generator tend to be more expensive than conventional components such as induction generators and gearboxes, which are available off the shelf.

CERTEK Corporation, of Bedford, Massachusetts, will develop a 100-kW, low-speed, direct-drive, permanent-magnet generator for a variable-speed wind turbine under a new Innovative Subsystems Project subcontract. When completed, it will be the largest permanent-magnet, direct-drive wind turbine generator developed in the United States. The complete subsystem under development consists of the generator, a controller, and a power inverter, which converts the variable-frequency electricity produced by the generator into 60-cycle alternating current. The subsystem will be tested on a Northwind 100 turbine at San Gorgonio Pass in California.

NREL, Industry Developing Advanced Aerodynamic Brakes, Rotors

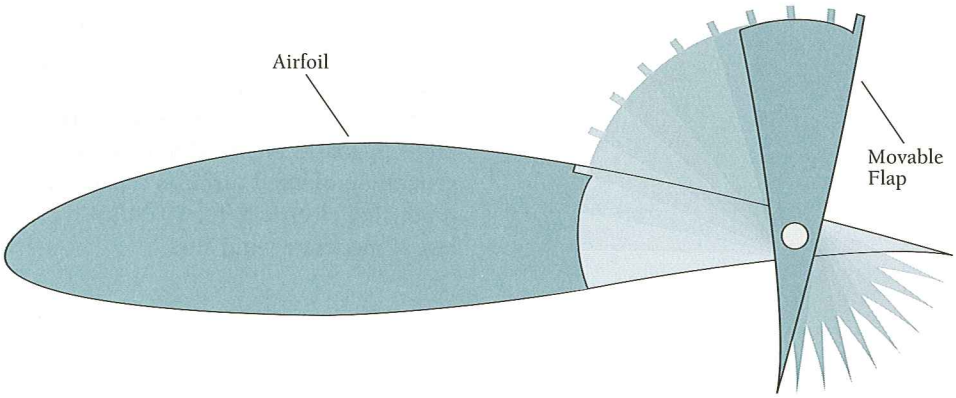
Since 1993, NREL has been investigating aerodynamic devices that regulate power production in high winds and also provide protection against rotor overspeeding. A new device known as a "spoiler flap," which was developed by a Colorado State University graduate student, showed promise based on wind tunnel tests conducted during FY 1994.

Mounted on the trailing (downwind) edge of a turbine blade, the spoiler flap can rotate up or down to control rotor speed. Wind tunnel tests indicated that it would perform well in wind speeds up to 50 m/s (112 mph) and that it could stop a rotor spinning as much as 20% faster than its normal operating speed. NREL has shared these wind tunnel test results with the wind industry and is assisting two design teams in evaluating the potential benefits of incorporating the flap into advanced blade designs.

Advanced Wind Turbines began an Innovative Subsystems Project in FY 1994 to design, build, and test an advanced rotor for the AWT-26 wind turbine. The extended rotor will have a larger swept area and incorporate spoiler flaps into the blades to control rotor speed, regulate power, and increase energy capture. Blades will also feature vortex generators, small protrusions that help keep air flow attached to the turbine blades. The rotor is expected to increase annual energy production by as much as 15% without increasing turbine cost.

PS Enterprises, Inc., of Glastonbury, Connecticut, was awarded an Innovative Subsystems subcontract by NREL in late FY 1994 to develop a highly flexible, lightweight, multibladed advanced rotor. Designed for a downwind, free-yaw turbine, the rotor will use four or five pultruded blades, which cost about 40% less than conventional fiberglass-reinforced plastic blades. The company is evaluating whether to incorporate spoiler flaps into the blades.

The project will result in a half-size rotor suitable for testing and validation purposes. In a parallel development effort, the California Energy Commission is supporting PS Enterprises in developing a utility-scale, 750-kW prototype turbine that will use the rotor design developed under the NREL subcontract.



The spoiler flap in this drawing shows promise for regulating power production in high winds and protecting against rotor overspeeding.

INNOVATIVE CONTROL SYSTEMS WILL MANAGE WIND POWER PLANTS

Better control systems for wind power plant operation translate to improved turbine reliability, lower operation and maintenance costs, and increased annual energy production. In FY 1994, Sandia researchers made progress in their efforts to create an advanced, expert control system. Such a system would be able to detect wind gusts and adjust individual turbines throughout a power plant to maximize energy capture and minimize damage to the turbines.

Sandia researchers have used "fuzzy logic" to design a smart controller. Fuzzy logic is a kind of artificial intelligence that allows the controller to consider multiple factors, such as wind speed, changes in wind speed and direction, and time of day in making control decisions. With it, researchers can design an expert system that makes decisions more like human beings do. In preliminary tests, a control system using fuzzy logic resulted in fewer turbine start-ups and shutdowns, resulting in less wear and tear on the turbine.

Second Wind Inc. of Somerville, Massachusetts, began an Innovative Subsystems Project in FY 1994 to develop a new wind turbine control system. The system employs hardware and software engineered to monitor the condition of wind turbines operating in a power plant. It uses this information to assess the amount of wear a turbine is experiencing and adjusts turbine operation accordingly. The goal is not only to keep each turbine operating safely, but also to maximize the service lifetime of each machine. The control system can also monitor each turbine's power output and adjust the turbines for optimal performance. Once a prototype has been tested in the laboratory, Second Wind plans to field-test the system.

DOE LAUNCHES NEXT-GENERATION TURBINE DEVELOPMENT PROJECT

During FY 1994, NREL initiated a Next-Generation Turbine Development Project with a solicitation for stage one: the development of concepts for an innovative utility wind turbine capable of significantly lowering the cost of wind-generated electricity. The studies are the precursor to a full-scale turbine development effort. NREL is negotiating subcontracts with nine organizations. Those selected include both individual wind firms and partnerships between companies.

On completion of the studies, NREL will select as many as three participants for the project's second stage—the design, fabrication, and testing of prototype, next-generation, utility wind turbines. Between 1995 and 2000, DOE plans to provide an estimated $30 million for the cost-shared Turbine Development Project. Stage two participants will contribute from 30% to 50% of project costs. The project's goal is the development of a new generation of wind turbines capable of producing electricity for $0.04/kWh or less at moderate wind sites.

DOE ESTABLISHES BLADE MANUFACTURING PROJECT AT SANDIA

In response to a national mandate to improve U.S. competitiveness by developing advanced manufacturing technology, DOE established a Blade Manufacturing Project in FY 1994 at Sandia. Sandia was selected for the project to take advantage of expertise at Sandia's DOE Center for Advanced Manufacturing. The center develops advanced tools and processes to support manufacturing improvements in all U.S. industries.

The project's ultimate goal is to help U.S. turbine manufacturers produce cost-effective hardware to compete in global energy markets. DOE believes this can be accomplished with technical improvements in design tools, advanced materials, systems integration, robotics, cost/performance analyses, and quality control.

The project is designed to encourage the wind industry to find ways to improve the manufacture of turbine blades. In addition to supporting wind industry manufacturing efforts, Sandia will conduct R&D on improved manufacturing tools and nondestructive testing for process quality control.

Industry Programs

Government/industry partnerships are expediting the development and deployment of advanced wind energy systems to compete in global energy markets.

The federal government is working closely with the U.S. wind industry to make wind a competitive, energy-producing technology in global markets. Together, this partnership is meeting the challenge of demonstrating wind energy's technical, economic, and environmental benefits to utilities, state regulators, policy makers, and the public. In FY 1994, DOE worked with AWEA in developing new wind energy markets, transferring new technology to industry, developing standards for wind systems, and planning for certification testing of U.S. technology.

DOE, NREL, and Sandia have worked with the wind industry for more than 15 years to develop industry consensus standards for wind turbine generating systems. This work, carried out under the sponsorship of the International Energy Agency in conjunction with the International Electrotechnical Commission (IEC),[2] is vital to U.S. competitive interests. Matching U.S. industry standards to international standards is critical to ensure that U.S. turbines can compete in projected multibillion-dollar global wind energy markets.

In FY 1994, the IEC approved design safety standards for wind turbine systems and immediately established a new working group to redo and improve the document. Nevertheless, the initial acceptance of the standard is significant: utilities around the world should now be able to buy wind energy systems that meet uniform standards for wind turbine design, installation, performance, and safety. NREL is already incorporating the new standards into its design specifications for the development of new technology. The IEC is also working to develop standards for power performance testing, acoustic noise, and blade testing.

NREL to Initiate U.S. Certification Testing Program

In Europe, wind turbine certification is a two-stage process: first, an approved laboratory conducts certification testing; then the turbine manufacturer forwards the test reports to an authorized agent such as Germany's Germanischer Lloyd, which certifies, or guarantees, that the product conforms to established standards. NREL, in response to a 1993 request from AWEA, is now developing a certification testing program at the National Wind Technology Center. NREL's goal is to develop a U.S. testing program that would be accepted in Europe.

During FY 1994, NREL researchers conducted a fact-finding tour of certification testing programs and agents in northern Europe. To meet European certification requirements, testing programs are required for wind turbine power performance and noise. Testing is also recommended for loads. In FY 1995, NREL plans to initiate a certification testing program that will include performance, noise, and loads. NREL will prepare test reports the U.S. wind industry can use in applying for certification from European agents, as there is no U.S. certification agent at this time.

[2] The International Electrotechnical Commission is the recognized authority for electrical equipment standards.

In related efforts during FY 1994, NREL hosted the International Meeting of Test Stations in September. The meeting provided a forum for discussing certification testing issues.

NREL and DOE also participated in the International Energy Agency's Annex XI, which sponsors international experts meetings. During FY 1994, experts meetings were held on aerodynamics, structural reliability and fatigue, and turbulence-induced turbine loads. NREL served as the operating agent for 11 countries that participated in Annex XIII, which monitored large-scale wind developments throughout the world. NREL also participated in Annex XIV, in which several nations are collaborating on studies of aerodynamic stall.

In other government/industry activities, DOE supported AWEA's annual wind power conference held in Minneapolis, Minnesota, in May 1994. DOE also supported the development of new educational media and publications, including *Evaluating The Economics of Residential Wind Systems*; *Understanding Your Wind Resource*; *Wind Energy Regulators Handbook*; *Wind Energy in the U.S., A State-by-State Survey*; and a *Wind Energy Slide Presentation*.

American Wind Energy Association

The American Wind Energy Association and the U.S. Department of Energy work together to develop international standards for the design, installation, performance, and safety of wind turbines.

DOE Testing Programs Help Industry Evaluate New Technology

Design engineers must take many factors into account when designing a new wind turbine. One challenge is designing components rugged enough to withstand 30 years of exposure to wind, atmospheric turbulence, insects, dust, temperature extremes, rain, snow, and sleet. Another challenge is creating a turbine that can withstand a single extreme event such as a tornado, lightning strike, or hurricane-force wind gust. DOE's testing program helps industry analyze how well their designers have succeeded in meeting these challenges.

Modal testing allows researchers to identify the natural vibration frequencies of turbine components such as blades and towers. Designers need this information to ensure that a turbine will not become excited at its natural frequencies during operation. A structure that is excited for any length of time at its natural frequency can literally shake itself apart.

NREL researchers have now performed full-systems modal tests on both of the AWT-26 prototype turbines in Tehachapi, California. Modal tests can be used to identify potential operational problems in a new turbine, to understand how wind turbulence excitation can damage turbines, and to validate computer models of a wind turbine system. One such model, called ADAMS-WT, had suggested that an interaction of the AWT-26's rotor, nacelle (enclosed part of the turbine), and tower might create an unwanted vibration in the turbine. Modal testing confirmed this prediction and helped guide a redesign that successfully avoided the unwanted interaction on the second prototype.

Following these successful tests, Advanced Wind Turbines entered into a cooperative research and development agreement (CRADA) with Sandia to analyze field-test data gathered during natural turbulent wind excitation of an AWT-26 prototype. The analysis will elucidate the machine's dynamic behavior and allow engineers to fine-tune the commercial turbine design to ensure durability, reliability, and cost-effectiveness. The CRADA is designed to optimize a state-of-the-art commercial turbine likely to increase U.S. competitiveness in wind energy markets.

During FY 1994, NREL conducted a modal test on a 20-m (66-ft) blade with ailerons developed by Zond for its Z-40 utility wind turbine. Test results were used to validate and refine the ADAMS-WT model and a Finite Element Model developed at Zond. The ADAMS-WT model predicted the blade's response to turbine operation; the Zond model predicted stresses and strains likely to occur in the blade and identified five probable vibration modes.

The modal test confirmed the three most important vibration modes predicted by the Zond model. In addition, the test results confirmed that the Zond turbine would not encounter any unexpected resonance conditions.

WARREN GRETZ, NREL

Researchers at the National Wind Technology Center conduct modal tests to identify natural vibration frequencies of turbine components and systems.

Structural Testing Improves Turbine Component Reliability

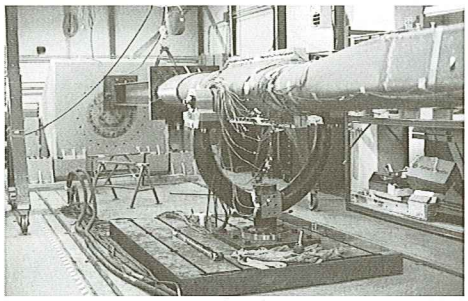
NREL has operated a structural test facility, now part of the National Wind Technology Center, since 1990. The facility is equipped for evaluating the strength, durability, and service lifetime of turbine components and systems. NREL plans to enhance its testing capabilities with new fatigue-testing equipment that can better simulate loads caused by the wind and measure the stresses that cause damage.

During FY 1994, NREL and KENETECH Windpower completed fatigue tests on two 33M-VS wind turbine blades manufactured by different companies. NREL conducted the tests as part of a 5-year CRADA with KENETECH Windpower. Both blades met the fatigue life requirements established by the company. The new tests verified earlier tests that showed the 33M-VS blade to be exceptionally strong. It required the equivalent of more than 60 years of normal operation to damage the blade, whose design life is 30 years.

NREL completed static and fatigue tests on the new rotor for New World's Northwind 250 turbine in FY 1994. Tests on the rotor's composite center joint led to design improvements in the strength of the center section. A subsequent fatigue test on the entire hub led to further improvements and validated the company's fatigue analysis model.

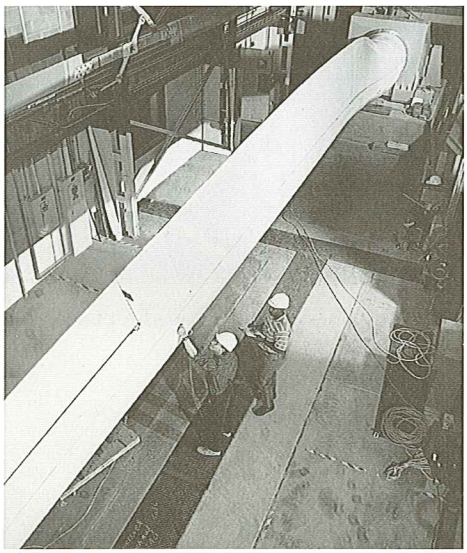
Initial structural testing of Zond's Z-40 wind turbine blade in FY 1994 rapidly led to blade design improvements. NREL will test the redesigned blade in FY 1995. In the meantime, NREL has begun fatigue tests of the blade's aileron by simulating its deployment and operation. The test will evaluate aileron function and long-term reliability.

Sandia participated in the Zond and KENETECH Windpower blade tests to evaluate nondestructive blade tests currently under development. Nondestructive testing uses acoustic and optical techniques to inspect turbine blades for manufacturing flaws or areas of fatigue damage. The tests at NREL confirmed that the techniques show promise for assessing quality control during manufacturing and for evaluating the condition of aging turbine blades in the field. As a result, Sandia and KENETECH Windpower initiated a new CRADA in November 1994 to develop nondestructive testing methods to improve quality assurance techniques for wind turbine blade manufacturing.



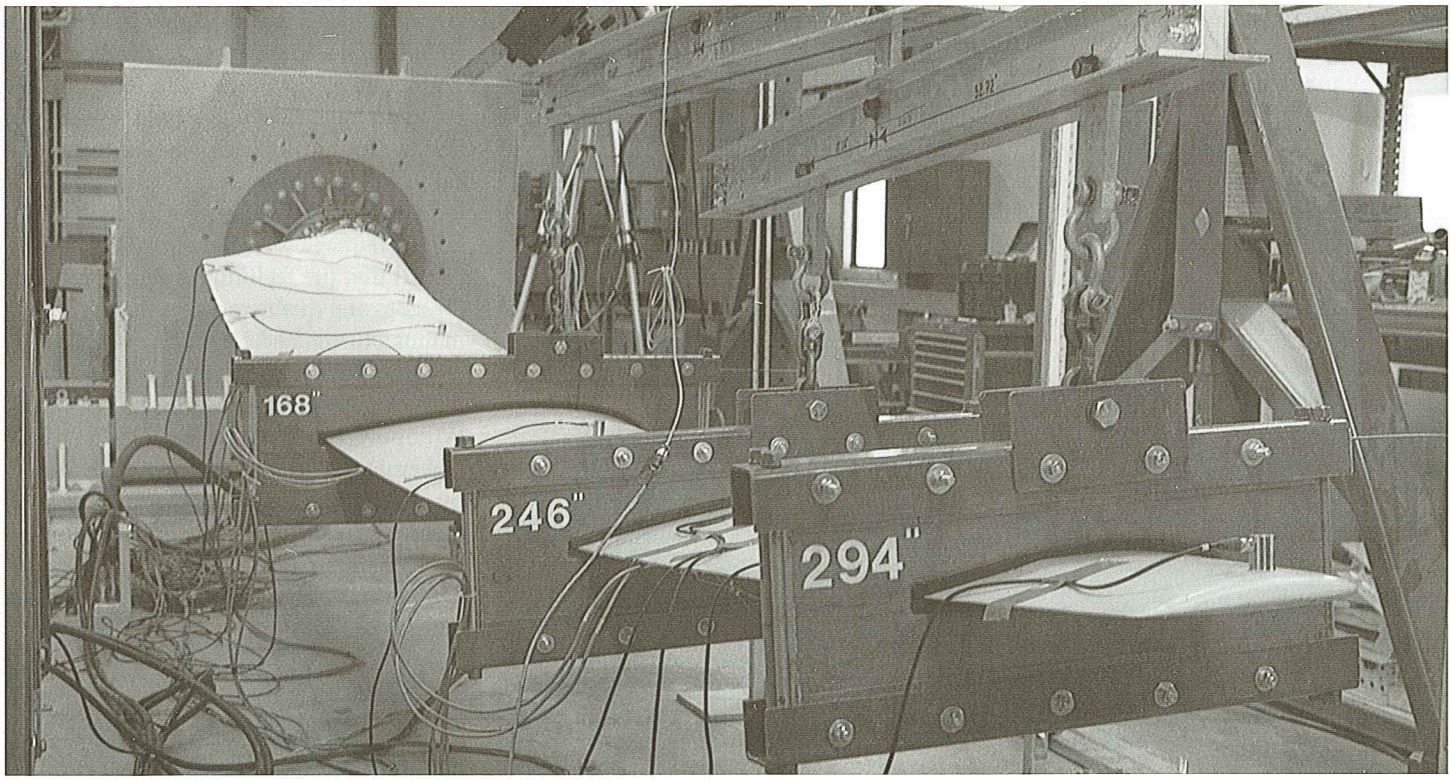
WARREN GRETZ, NREL

The National Renewable Energy Laboratory conducted a fatigue test on the Northwind 250 turbine's flow-through rotor during FY 1994.



WARREN GRETZ, NREL

The National Renewable Energy Laboratory conducted modal and structural tests on a Zond Z-40 blade during FY 1994.



WARREN GRETZ, NREL

Sandia is developing nondestructive blade tests, such as this acoustic test conducted at the National Wind Technology Center, to assess quality control during manufacturing and to evaluate the condition of aging turbine blades in the field.

The nondestructive testing program at Sandia is linked to both the Federal Aviation Administration's Aging Aircraft Program and Sandia's Structural Health Monitoring Program. The latter uses vibration sensors and other nondestructive tests to evaluate the condition of wind turbines, aircraft, offshore drilling rigs, bridges, and other structures.

In related efforts, NREL and Sandia continued to support ongoing tests of blade materials and substructures at Montana State University. Blade material coupon tests, which are done on small material samples supplied by the U.S. wind industry, are part of an effort to develop improved composite materials for turbine blades. The substructure tests are part of an effort to develop better manufacturing techniques that avoid flaws in substructures. Researchers can now tell whether flaws in blade substructures are caused by the design itself, the composite material, or the assembly process. Montana State will use this information to help the wind industry to design more durable blade substructures.

COOPERATIVE PROJECTS WITH INDUSTRY REAP MANY BENEFITS

In FY 1992, DOE initiated cost-shared Government/Industry Wind Technology Application Projects (WTAP), which focused on improving wind power plants, encouraging regional diversity for wind power in the United States, and defining new wind energy applications. Thanks to these projects, FloWind has a new rotor design for the company's vertical-axis wind turbine and Zond Systems has a computer model, which the company applied to wind flows over the complex terrain found in the Tehachapi region. In addition, Zond evaluated NREL-designed airfoils, now part of the company's Z-40 turbine blades, as part of its WTAP subcontract. Under the program, blade designs were completed for the Advanced Wind Turbines AWT-26 and the Atlantic Orient Corporation AOC 15/50 advanced wind turbines.

Two other WTAP projects made progress during FY 1994. Macani Uwila Power Corporation of Oahu, Hawaii, completed detailed hardware designs for aileron controls for the company's 600-kW Westinghouse wind turbines. The project had been delayed by Macani Uwila's 1993 purchase of the turbines from Hawaiian Electric Renewable Systems, Inc., the original subcontractor.

Bergey Windpower selected Second Wind Inc. as a new partner in a project to develop more powerful, reliable inverters for small wind turbines. Inverters change direct current into the alternating current required to run household devices. Bergey is designing a basic inverter, a second inverter that incorporates short-term battery storage, and a third tailored to wind-diesel systems.

Turbine Measurement System Monitoring New Technology

NREL has purchased five Advanced Data Acquisition Systems (ADAS) to monitor field operation of advanced wind turbines developed by NREL subcontractors. The ADAS, developed by Zond Systems under an NREL subcontract, is unique because of its low cost and ability to download data from the rotating hub of a wind turbine directly to a personal computer through a radio link. The system is being used in prototype testing of the AWT-26, 17 EHD, and AOC 15/50 turbines. Two more tests are scheduled in support of other industry projects.

In a related effort, Sandia began developing new software to facilitate information sharing regarding wind turbine measurements. Sandia's graphics-based, data acquisition software is being designed to examine data from the ADAS, other measurement systems, and laboratory instruments at NREL and Sandia. In the past, each organization developed its own data analysis software, then tried to figure out how to make different methods work together—a difficult and time-consuming process. Developing standard software will decrease the time and cost of designing software to process and compare data from a variety of sources.

LLOYD HERZIGER, ZOND SYSTEMS, INC.

The National Renewable Energy Laboratory is using Zond's Advanced Data Acquisition System, shown here, in turbine prototype testing.

International Programs

DOE SUPPORTS THE U.S. WIND INDUSTRY IN DEVELOPING INTERNATIONAL MARKETS FOR WIND ENERGY AND VILLAGE POWER SYSTEMS.

Market opportunities for wind energy systems exist in both industrial nations and developing countries. These opportunities include sales of wind power plants, village power systems, wind-electric water pumping systems, wind power support for telecommunications, and stand-alone wind systems for homes, cottage industries, health clinics, and community centers. Taken together, prospective wind energy markets could translate into several billion dollars in sales for the U.S. wind industry by 2000.

The U.S. wind industry is already marketing utility wind turbines and complete wind power plants outside the United States. Since 1990, U.S. firms have installed turbines in Canada, The Netherlands, Mexico, South America, Spain, Ukraine, and the United Kingdom. Power plants using U.S. technology are planned for Canada, Chile, Mexico, and the United Kingdom. DOE supports such projects with its Wind Turbine Development Program and with technical assistance on a case-by-case basis to foreign utilities, private industry, and government agencies interested in developing grid-connected wind energy systems as well as off-grid village power and isolated systems.

DOE supports industry's efforts to develop cooperative international wind projects. The Wind Energy Program offers foreign policy makers, engineers, and private-sector representatives assistance with wind resource assessment; technology development; wind project planning, implementation, and evaluation; education; and training.

DOE also provides technical assistance to international organizations that encourage the deployment of renewable energy systems around the world. These organizations include the World Bank and other financial institutions, the United Nations, the U.S. Export Council for Renewable Energy (ECRE), the Committee on Renewable Energy Commerce and Trade (CORECT), and agencies of the U.S. government, including the Departments of State, Defense, and Commerce, and the U.S. Agency for International Development (USAID).

Developing World's Demand for Electricity Expanding

The growth in demand for electricity in the developing world far outstrips that of the industrial world. Within 15 years, total energy consumption in the developing world will surpass that of the United States, Western Europe, Australia, Iceland, Japan, New Zealand, and Turkey combined. This growth comes at a time when most nations recognize the need to control energy-related environmental impacts. DOE's international programs emphasize wind energy's competitive costs and environmental benefits in helping to meet the developing world's needs for electricity.

A single, stand-alone wind power system is often sufficient to raise the standard of living for many of the world's poorest rural inhabitants. One wind turbine with battery storage can support such community services as water pumping for drinking or irrigation, water treatment, communications, ice making, refrigeration, grain grinding, a school, or a community center.

Larger, hybrid power systems can meet the needs of an entire village. Such systems incorporate one or more wind turbines, other renewable generation sources such as PV arrays, and battery storage or backup generators fueled with diesel or vegetable oils. Backup generators run the system when the intermittent wind and solar resources are not available. During their service lifetime, hybrid power systems cost less and are more reliable than stand-alone diesel generators. They also have far less impact on the environment.

DOE Provides Technical Assistance in Developing New Markets

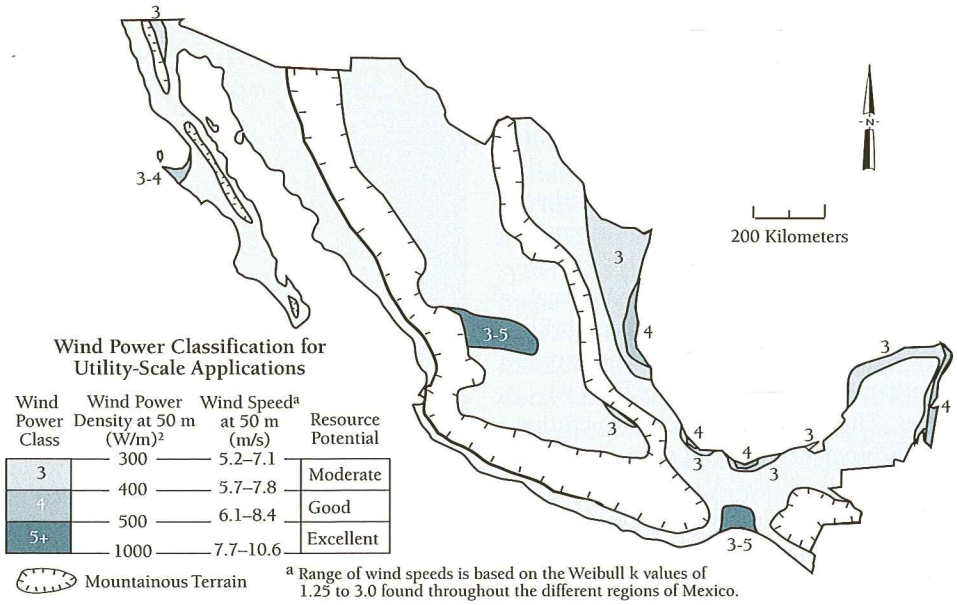
DOE provides technical assistance to the U.S. wind industry in its efforts to develop export markets in Mexico, Indonesia, Latin America, the newly independent states of the former Soviet Union, India, Pakistan, China, and the Philippines. Wind resource assessments, conducted in cooperation with USAID and AWEA, were a major focus of this effort.

In FY 1994, Pacific Northwest Laboratory (PNL) published two wind resource maps of Mexico, one highlighting areas suitable for utility-scale wind development and another showing areas with potential for rural wind applications. Mexico is now applying to the World Bank for approximately $350 million to expand its efforts to develop renewable, rural energy systems.

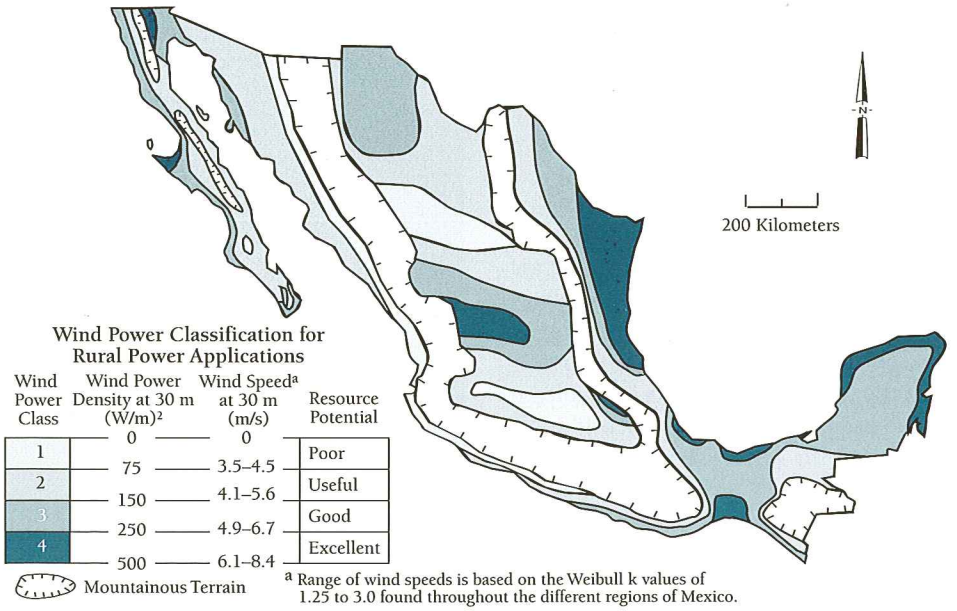
PNL prepared preliminary wind maps of Indonesia's southeastern islands in support of the USAID Windpower for Island and Nongovernmental Development Project. DOE meteorologists will continue to assist the rural development project with site evaluations and detailed resource assessments. DOE is also supporting a 50-village electrification project in Indonesia's eastern islands with testing and evaluation of a new hybrid power system at the National Wind Technology Center.

During FY 1994, PNL prepared a preliminary wind resource map of Poland in support of that country's plan to develop utility wind projects. The Polish wind assessments provide a model for future wind development in other newly independent states of the former Soviet Union such as Ukraine.

Mexico—Preliminary Wind Resource Map for Utility-Scale Applications



Mexico—Preliminary Wind Resource Map for Rural Power Applications



Pacific Northwest Laboratory developed these maps of Mexico's wind resources. The top map shows areas suitable for utility power plant development. The bottom map indicates where hybrid power or stand-alone wind systems could be used to bring electricity to remote, rural areas.

A 1994 study conducted by DOE and Ukrainian officials showed that wind could play a significant role in providing power to replace nuclear generation at Chernobyl. The Group of Seven leading industrialized nations recommended closing the Chernobyl plant as early as 1995.

In other activities, NREL supported the National Rural Electric Cooperative Association's evaluation of wind and wind-hybrid systems for Central America. DOE has also begun exploring wind energy development in the Philippines, India, Pakistan, and China by initiating trade missions and educational workshops.

TECHNOLOGY DEVELOPMENT TARGETS VILLAGE POWER SYSTEMS

DOE continued its multifaceted program to improve technology for hybrid village power systems during FY 1994. A new 50-kW commercial wind turbine, the AOC 15/50, underwent testing at the Atlantic Wind Test Site on Prince Edward Island in eastern Canada. The turbine was integrated into a wind-diesel hybrid system constructed for a simulated village at the site. The turbine, like the hybrid power system, has withstood the extreme weather conditions typical of high latitudes. The Canadian test confirmed that the turbine's new control system operates as expected.

The AOC 15/50 was developed by Atlantic Orient Corporation as part of DOE's Wind Turbine Development Program. The three-bladed, downwind turbine features passive yaw control, NREL-designed airfoils, tip and dynamic brakes, and an integrated drivetrain. The dynamic brakes use the generator to slow or stop the turbine rotor. The new turbine has also been selected for a new hybrid power system in Morocco.

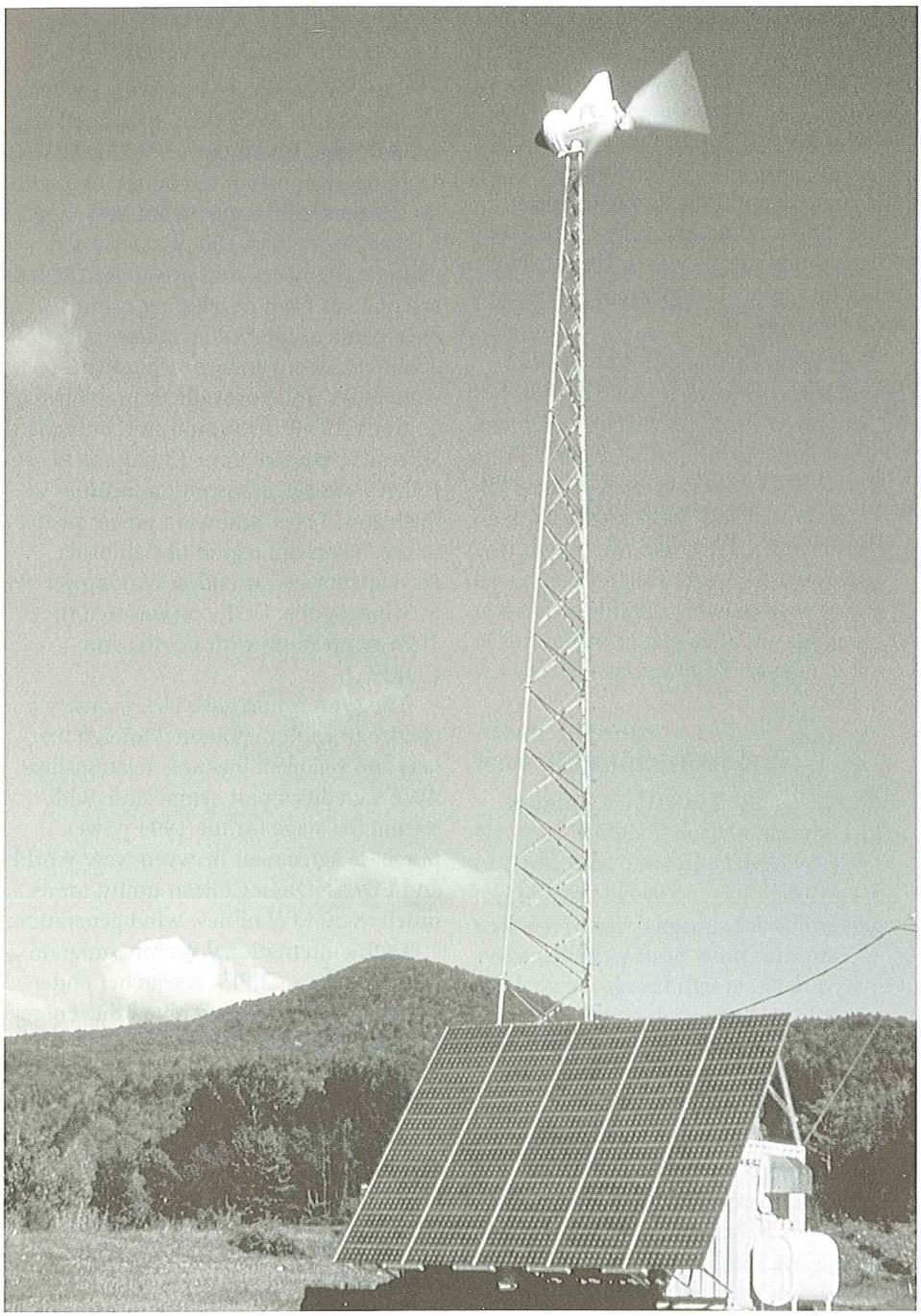
In June 1994, New World Power Corporation disconnected its manufacturing facility in Waitsfield, Vermont, from the local electric utility to demonstrate the firm's new 50-kW village power system. NREL and Sandia, in cooperation with the Alaska Science and Technology Foundation, supported New World in developing the system. It incorporates a wind turbine, a PV array, a diesel engine, a battery bank, a power-conditioning unit, and system controllers. New World plans to install similar plants in Wales, Alaska, Mexico, and Central and South America.

As technology development for new village power systems accelerates in response to emerging international markets, DOE offers technical support for industry's development efforts. Researchers at NREL and the University of Massachusetts are developing improved analytic tools to evaluate the new hybrid technologies. In FY 1994, the university validated its HYBRID-1 computer model using laboratory apparatus that simulated a wind-diesel system. Researchers also began work on HYBRID-2, an enhanced model that is faster, more flexible, and user friendly. HYBRID-2 can model a range of configurations that include system controllers and as many as 20 wind turbines. It can also run a life-cycle cost analysis of any system under evaluation.

DOE has initiated two long-term efforts to help industry evaluate operating hybrid power systems. In FY 1994, DOE and the U.S. Department of Agriculture (USDA) initiated a 5-year project to investigate hybrid power systems that rely entirely on renewable resources such as wind, solar, and biofuels made from vegetable oils. Researchers plan to use data from the project to validate computer models of innovative hybrid systems. The project will take place at the USDA's Southern Plains Area Conservation and Production Research Laboratory in Bushland, Texas. Researchers will coordinate their efforts with related work at the National Wind Technology Center's Hybrid Power Test Facility.

ATLANTIC ORIENT CORPORATION

The AOC 15/50 wind turbine underwent testing in FY 1994 as part of a hybrid power system on Prince Edward Island in eastern Canada.



NEW WORLD POWER CORPORATION

New World Power Corporation's new 50-kW village power system runs the firm's manufacturing facility in Waitsfield, Vermont.

Pilot Projects Progress in Mexico, South America

DOE is supporting pilot projects using wind energy in Argentina, Brazil, Chile, and Mexico. In Argentina, NREL is providing resource assessments and other technical assistance to a large rural school electrification project. The project's goal is to provide electricity from wind and PV systems to approximately 600 schools in Buenos Aires province.

NREL is collaborating with a large Brazilian utility research organization, the Centro de Pesquisas de Energia Elétrica (CEPEL), on rural electrification projects planned for remote areas of northern Brazil. As part of the project, NREL will conduct wind resource assessments and install pilot hybrid village power systems and wind-electric water-pumping operations. During FY 1994, DOE and NREL participated in a technical seminar on wind systems, a meeting in Bella Horizonte, and a renewables conference sponsored by the World Bank and the United Nations in Rio de Janeiro. At the Bella Horizonte meeting, Brazil affirmed its commitment to developing renewable energy systems.

During FY 1994, NREL initiated a cooperative project with Chile's Ministry of Energy to provide technical assistance to the first phase of a 6-year rural electrification program using renewable energy. NREL will help with resource assessments, pilot project implementation, and training.

Sandia continued to monitor the performance of a hybrid power system located in the Mexican village of Xcalak on the southeastern tip of the Yucatán peninsula during FY 1994. The project includes six Bergey 10-kW wind turbines, a PV array, an inverter, a battery bank, a manual controller, and a backup diesel generator. The system has experienced tremendous load growth since it was installed in 1992.

CONFERENCES, WORKSHOPS TARGET SUSTAINABLE ENERGY DEVELOPMENT

The Renewable Energy in the Americas conference in Puerto Rico brought representatives from 38 North, South, and Central American nations together in June 1994 to discuss energy-related opportunities in Latin America and the Caribbean. The Energy Minister of Chile and the Deputy Energy Minister of Argentina were among approximately 550 attendees. The event was sponsored by ECRE, CORECT, DOE, and other organizations. The U.S. wind industry helped plan and organize the conference.

ECRE estimated that more than 150 new projects (equivalent to more than $1 billion in sales of renewable energy and energy efficiency systems) resulted from the conference. The event also successfully met goals of fostering collaborative partnerships to accelerate market development, initiating policies favorable to the development of renewable energy, and highlighting the role of sustainable energy systems in meeting global commitments to reduce greenhouse gas emissions.

The conference generated great enthusiasm for renewable energy—enthusiasm participants brought to the Summit of the Americas held in December 1994 in Miami, Florida. The summit grew out of the United Nations Conference on Environment and Development held in Rio de Janeiro, Brazil, in June 1994. One of the summit's goals was to lay the foundation for regional cooperation in sustainable energy use.

In related efforts, Sandia's Design Assistance Center, NREL, USAID, and AWEA conducted workshops on such topics as wind-electric water pumping, large and small wind energy systems, and wind resource assessments in the Caribbean and Latin America.

INTERNATIONAL VISITORS PROGRAMS HELP DEVELOP NEW MARKETS

Since 1987, AWEA has sponsored an annual Wind Energy Applications and Training Symposium in conjunction with the association's annual wind power conference. More than 100 planners, policy makers, engineers, and private-sector representatives from developing countries have come to the United States to learn about U.S. wind energy technologies, companies, and government programs.

In FY 1994, the symposium brought 24 representatives from 15 nations to USDA's wind demonstration facilities in Bushland, Texas, and wind power plants in the Tehachapi region of California. Participants also attended Windpower '94 in Minneapolis. DOE cosponsored the 1994 symposium with USAID and CORECT.

The symposium gave U.S. industry a chance to explore potential foreign markets and establish business relationships. AWEA credits a past symposium with setting the stage for the 1994 power-purchase agreement between New World and EDELNOR, a Chilean utility, for as much as 50 MW of new wind generation.

DOE's international visitors program also brought a CEPEL researcher and a member of Guatemala's renewable energy coordinating team to NREL during FY 1994. And during the summer of 1994, Sandia hosted a professor from Puerto Rico University.

Wind Energy Applied Research Highlights for FY 1994

DOE's applied research program supports the development of competitive wind technologies for applications at home and abroad.

Wind energy research has two goals: (1) to provide U.S. industry with improved design tools for advanced technologies, and (2) to better understand the interactions between wind and wind turbines. The development of sophisticated computer codes and their integration into the design, testing, and evaluation of turbine components and systems is a primary objective of DOE's applied research effort.

DOE works closely with the wind industry, utilities, regulatory officials, and environmental advocates in setting its applied research priorities. 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 in FY 1994.

Avian Studies Now Research Priority

In July 1994, DOE, EPRI, AWEA, the National Audubon Society, and the Union of Concerned Scientists cosponsored a meeting in Lakewood, Colorado, to set a national research agenda for addressing avian mortality from wind turbines. Participants agreed that research was needed to better define the problem and to develop standard methods for conducting population and other studies in the field. Standard procedures would allow researchers in different locations to compare their data as they seek answers to such questions as: Why do birds come near wind turbines? What, if any, are the effects of wind development on bird populations? What can be done to mitigate the problem?

In the future, the National Wind Coordinating Committee plans to keep DOE apprised of emerging priorities in this important research area. In the meantime, DOE has already initiated population studies of golden eagles in and around California's Altamont wind power plant. The Altamont plant is the only U.S. wind power facility that appears to be associated with increased avian mortality. The studies will investigate the causes of bird collisions with wind turbines. Once the causes are understood, researchers will study ways to mitigate such problems or avoid them altogether.

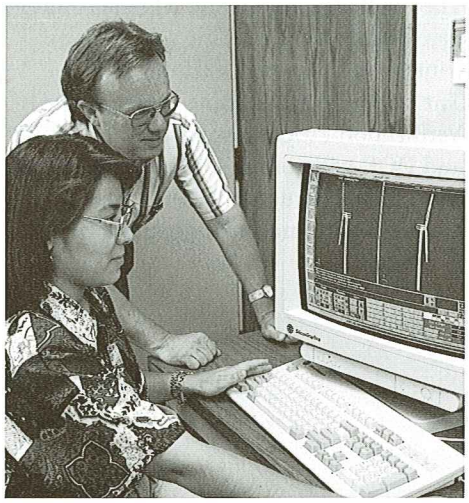
The University of California at Santa Cruz is conducting the study under an NREL subcontract. Preliminary results indicate that while few eagles live in Altamont's wind resource area, birds nearby enter the area to feed on its high population of squirrels and gophers. The study also showed that California's golden eagle population is much larger than official estimates.

In the future, researchers plan to study how the wind power plant encourages larger-than-normal populations of prey. They will also investigate whether birds' perching on wind turbine towers contributes to their increased mortality. The Utility Wind Turbine Performance Verification Program sponsored by EPRI and DOE will continue to mandate pre- and post-construction environmental studies, including avian population assessments.

DESIGN TOOLS ADVANCING WIND TECHNOLOGY DEVELOPMENT

A computer-based design strategy allows designers to explore different designs before building expensive hardware. Once hardware is ready for testing, computer models allow engineers to rapidly diagnose any potential problems and rapidly solve them. Modeling each stage of the turbine development process involves different levels of sophistication and complexity.

The ADAMS-WT software is an example of a sophisticated, comprehensive model capable of modeling most aspects of wind turbine system operation. Other, simpler codes model one aspect of turbine operation such as inflow (the characteristics of the wind), aerodynamics (the interaction of the wind with the turbine), structures (turbine behavior during operation), fatigue (wear and tear over time), or turbine controls. Major design codes developed by Sandia and NREL since 1980 are listed in the table on page 29.



WARREN GRETZ, NREL

The development of sophisticated computer codes is a primary objective of the U.S. Department of Energy's applied research effort.

DOE sponsored multiple efforts to develop better turbine design tools and train industry in their use during FY 1994. For example, NREL sponsored a training course for new ADAMS-WT users in April 1994 at the Ann Arbor, Michigan, offices of Mechanical Dynamics, Incorporated. Mechanical Dynamics developed the original ADAMS software, which NREL modified to produce a realistic simulation of wind turbine design and operation.

During FY 1994, NREL researchers used the ADAMS-WT code to help NREL subcontractors refine their prototype turbine designs to keep them free from unwanted vibrations. They also refined the software to make it easier for new users to operate. For example, designers can now build a basic tower or blade with the click of a key.

Researchers at Oregon State University, the University of Utah, and Sandia made progress developing design codes during 1994. Oregon State researchers completed 3 years of development work on a new structural code to predict loads and turbine responses in a simplified wind system. Known as FAST, the code can predict loads throughout the turbine caused by turbulent winds. Several versions of the code are available for different turbine configurations. For example, FAST2 models a two-bladed, teetering rotor, and FAST3 models a three-bladed rotor. NREL researchers are currently validating and refining the codes.

University of Utah researchers refined unsteady aerodynamics subroutines that enable ADAMS-WT to model both dynamic stall and inflow to the turbine blades. In addition to making the aerodynamics package more user friendly, they prepared user manuals.

Sandia completed a new version of the Fatigue and Reliability of Wind Turbines (FAROW) code. Sandia is developing FAROW to allow turbine designers to enhance reliability by identifying the sources of poor fatigue performance. The new version makes the code more flexible and expands the range of problems it can address. Sandia will publish a new FAROW users manual early in FY 1995.

In related efforts, researchers at Stanford University continued efforts to analyze fatigue reliability for typical wind turbine components. Their objective is to refine FAROW and other fatigue codes by developing a statistical method for estimating the likelihood of highly damaging loads. So far, they have developed a mathematical model that fits well with observed data and does a reasonably good job of estimating the occurrence of rare, but unusually destructive, loads. The project's long-term goal is to create standards for turbine design and testing based on better fatigue damage estimates.

Other researchers at Stanford are developing software to facilitate wind industry composite-blade design using finite-element analysis. By looking at a composite-blade structure as a matrix of tiny pieces, finite-element analysis can track how forces introduced into one area will interact with surrounding elements to transfer loads throughout the blade. The method allows designers to discern areas of high stress and change a design if warranted. Until now, finite-element analysis on composite turbine blades has been too complicated, costly, and time consuming to make it worthwhile to use. The new software will simplify the process and allow designers to use it routinely on personal computers to optimize wind turbine blades.

Wind Turbine Design Codes

	Code	Description	Complexity	Run Time
Inflow	SNLWIND-3D	Simulates wind flowing into a turbine rotor	Detailed	Moderate
Aerodynamics	PROP	Predicts power output for a specified rotor	Simple	Short
	PROP-3D	Incorporates stall model into PROP	Simple	Short
	PROPID	Designs turbine blades for specific power output	Moderate	Moderate
	AERODYN	Predicts blade loads	Moderate	Moderate
	SEAC	Predicts rotor performance, annual energy output	Moderate	Moderate
	SLICEIT	Predicts rotor performance, blade loads	Simple	Short
	VDART3	Predicts rotor performance, blade loads (more complex)	Moderate	Long
	F3D	Calculates airfoil performance characteristics	Detailed	Long
Structures	YAWDYN	Predicts blade loads, yaw response to turbulence	Simple	Short
	UMDAC	Predicts drivetrain loads caused by turbulence	Simple	Short
	FLAP	Calculates loads on a single blade	Moderate	Short
	FAST	Predicts loads for simplified wind turbine model	Moderate	Moderate
	FEVD	Calculates natural vibration frequencies of VAWT	Moderate	Short
	FFEVD	Calculates VAWT structural response	Moderate	Short
	TRES4	Calculates VAWT structural response to turbulence	Moderate	Long
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
	ACES	Simulates smart turbine controllers	Moderate	Moderate
Total System	ADAMS-WT	Simulates total wind system operation of HAWT	Detailed	Long
	VAWT-SDS	Simulates total wind system operation of VAWT	Detailed	Long

Uniform Design Criteria Will Enhance Turbine Service Life

To aid designers of advanced wind turbines, NREL researchers are investigating fatigue loading on many different turbines in different operating environments. Their goal is to use an in-depth understanding of the physics of wind/wind turbine interactions to establish uniform engineering design criteria for advanced U.S. wind technology. Uniform design criteria will help ensure a safe, 20- to 30-year service life for advanced turbine designs.

As part of this effort, researchers compared fatigue loads experienced within a multirow wind power plant in the western United States with those experienced by individual turbines operating in northern Europe. They found the operating environment inside the U.S. wind power plant to be much more severe than that encountered by the European turbines. The difference was due to turbulence created within the U.S. wind park and the more complex terrain found there. The study also indicated that it is possible to define design load criteria with acceptable levels of certainty.

NREL researchers are currently developing a method for characterizing fatigue loads on a wide variety of turbine designs. Their goal is to test the hypothesis that measurements of specific parameters of wind turbulence can provide enough information to characterize the actual loads measured in a wide range of operating environments. In testing the hypothesis, they plan to collect data from similar turbines operating in diverse environments and from different turbines operating in the same environment.

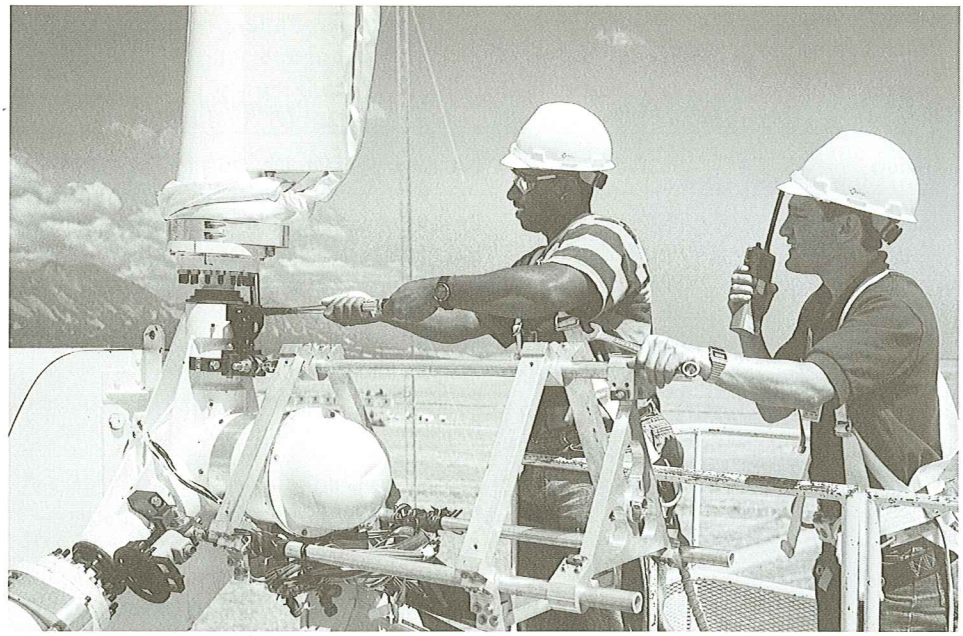
AERODYNAMICS RESEARCH FOCUSES ON ROTOR OPERATION

Since 1989, NREL has studied the interaction of stall-controlled rotors with the wind. Turbulent winds affect both turbine performance and loads in complex ways. Understanding these interactions is necessary for industry to create more durable, low-cost turbine designs. In FY 1994, NREL researchers completed the second phase of the unsteady aerodynamics experiment at the National Wind Technology Center and began designing new blades to investigate the influence of blade twist on unsteady stall behavior.

NREL is currently analyzing data from the experiment's first two phases in cooperation with the University of Colorado. NREL is exchanging this information with researchers from Europe as part of a 3-year international research project to elucidate the physics of wind/wind turbine interactions.

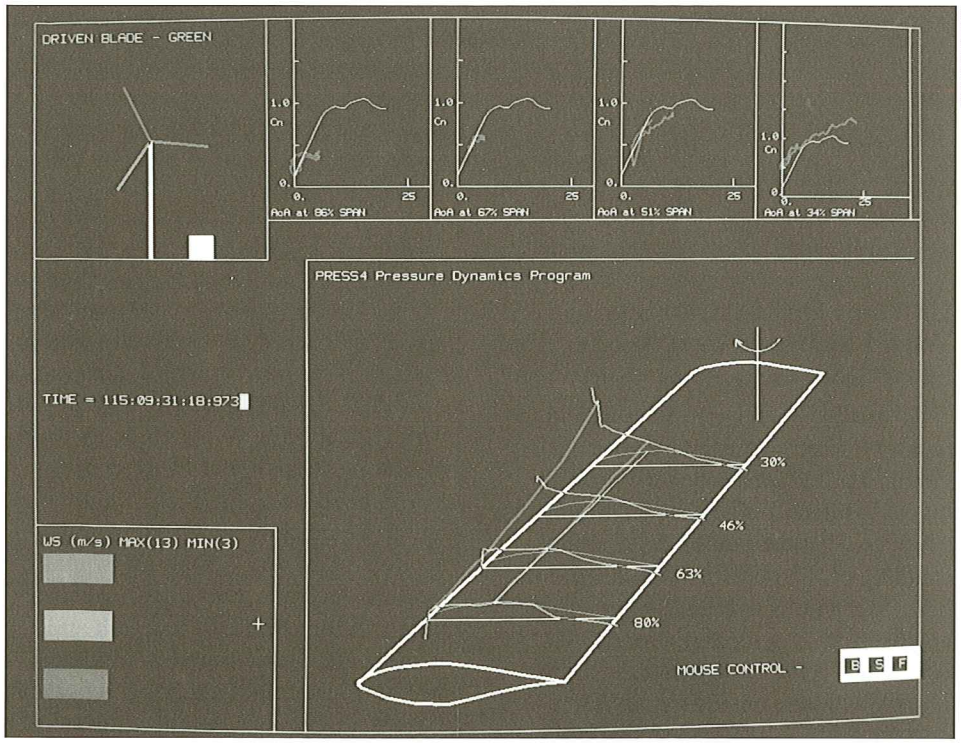
Researchers at the University of Colorado are developing a new model that can predict a turbine blade's aerodynamic response during dynamic stall if inflow conditions are known. Because the statistical model is based on the specific geometry of the blade and turbine, it can be used with any blade on any turbine. The new model should make it easier to accurately predict the fatigue life of stall-controlled rotors.

In other aerodynamics research, Ohio State University completed wind-tunnel tests on five different airfoils as part of an NREL project to develop a catalog of wind turbine airfoils. The catalog will eventually contain test data (gathered under standardized conditions) on all major airfoils used in the wind industry.



WARREN GRETZ, NREL

The National Renewable Energy Laboratory's research in unsteady aerodynamics is leading to a better understanding of wind/wind turbine interactions.



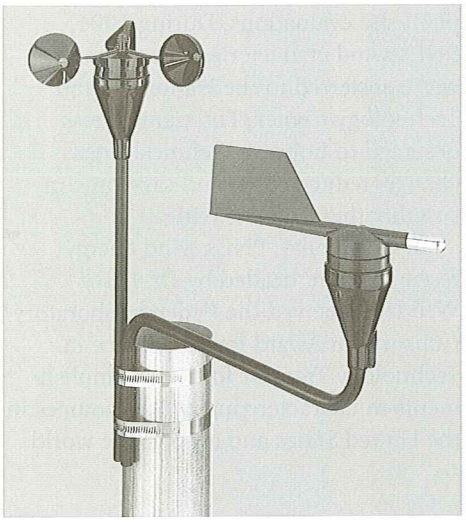
WARREN GRETZ, NREL

The National Renewable Energy Laboratory is sharing test data from the unsteady aerodynamics experiment with European researchers as part of an effort sponsored by the International Energy Agency.

PNL Wind Studies Assist Utilities, Wind Industry

Since 1990, PNL has collaborated with the wind industry and utilities to better understand wind turbulence and its effect on power production and turbine fatigue damage. Previous studies had shown that two types of turbulence affect rotating turbines: engulfing gusts and fluctuating shear. Engulfing gusts are turbulent eddies in the wind that are large enough to completely envelop the rotor. Fluctuating shear is caused by eddies smaller than the rotor.

In FY 1994, PNL began investigating the impact of both kinds of turbulence on blades and compared its findings with data from NREL's unsteady aerodynamics experiment, with encouraging results. PNL plans to use this type of analysis to develop an inexpensive procedure to evaluate potential wind sites.



NRG SYSTEMS, INC.

Pacific Northwest Laboratory (PNL) developed a special filtering technique to enhance wind-speed and direction data gathered from the cup anemometer and direction vane. PNL developed the technique to allow industry to use less expensive instruments for wind resource assessments.

In related efforts, PNL initiated a new phase of the Turbulence Characterization Project, selecting utility participants from Minnesota, Nebraska, Texas, and Wisconsin. PNL installed measurement systems at sites in these states in 1994. The goal of the new study is to better understand wind turbulence and its effect on power production in the energy-rich areas of the Midwest and the Great Plains.

In FY 1994, PNL continued efforts to develop special techniques to enhance data gathered by the inexpensive, durable sensors widely used by the wind industry for resource measurements. PNL has developed a special filtering technique to enhance the quality of data gathered by a cup anemometer and a simple direction vane. A cup anemometer measures wind speed and a vane measures wind direction. With the new technique, both wind direction and wind speed measurements (at frequencies of less than 10 cycles per second) compare favorably with measurements from a sonic anemometer. The sonic anemometer is a sophisticated, expensive device researchers use to precisely measure the turbulence in the wind.

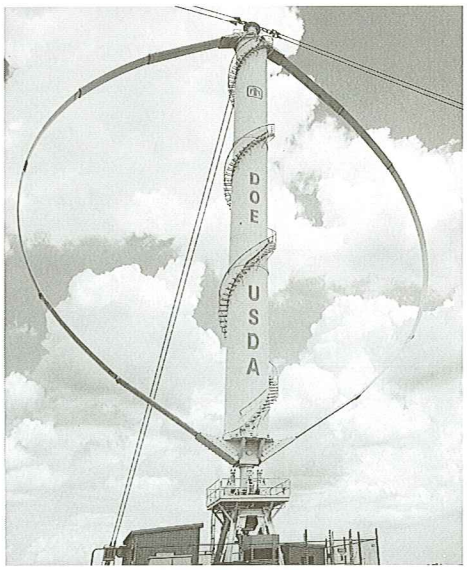
NREL Turbulence Study Augmenting ADAMS-WT Model

NREL has developed a statistical method to evaluate wind characteristics associated with severe damage to wind turbines. Researchers have incorporated it into a turbulence simulation code called SNLWIND-3D, originally developed at Sandia. Used as input to the ADAMS-WT model, SNLWIND-3D allows designers to observe the impact of atmospheric turbulence on wind turbine components and modify their designs to be more durable.

The method is based on research studies at San Gorgonio Pass, California, that showed turbine damage to be correlated with turbulence, which varied with the time of day. Turbulent conditions that develop during the daylight hours when the atmosphere is unstable were different from those likely to occur in the early morning hours when the atmosphere becomes very stable. The most damaging conditions occurred during the transition from unstable daytime conditions to stable ones at night. Researchers discovered that more severe turbulence was produced inside the power plant. The presence of the turbines and their wakes enhances the severity of the turbulence caused by local wind flow patterns.

Sandia Tests Variable-Speed Operation on Research Turbine

During FY 1994, Sandia tested variable-speed operation on the 34-m (111-ft) vertical-axis wind turbine test bed in Bushland, Texas. The major challenge was developing control software that would avoid exciting the turbine at one of its natural vibration frequencies that occur between 28 and 38 rpm. Sandia developed a special control procedure to enable the turbine to rapidly move through certain rotational speeds to avoid damaging the machine. The test showed that the turbine could be operated near peak efficiency over a range of wind speeds by varying the turbine rotational speed.



SANDIA NATIONAL LABORATORIES

Sandia tested variable-speed operation of its 34-m vertical-axis wind turbine test bed during FY 1994 in Bushland, Texas.

The Program Structure

DOE laboratories spearhead the National Wind Energy Program.

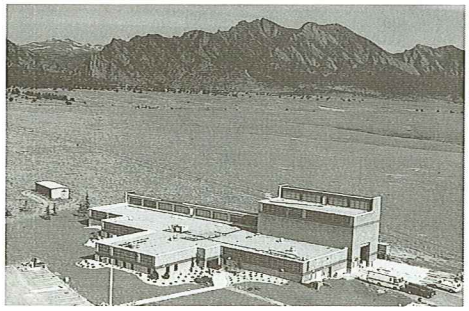
The Wind/Hydro/Ocean Division of DOE's Office of Energy Efficiency and Renewable Energy manages the National Wind Energy Program. The division is responsible for ensuring that program activities are consistent with national energy policy, priorities, and directives. DOE's field offices and national laboratories implement program activities, including subcontracts with utilities, industry, and academia. The agreements with utilities and industry are designed to foster the development of new wind energy technologies and accelerate their commercialization. University subcontracts help build the wind energy technology base. The FY 1994 Wind Energy Program budget was $30.3 million.

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 DOE's cooperative government/industry programs, including wind turbine development, utility programs, and industry programs. NREL also manages international and applied research programs, conducting research in structures and fatigue testing, wind characterization, aerodynamics, advanced components and systems, and wind resource assessments.

Sandia National Laboratories, located in Albuquerque, New Mexico, and Livermore, California, has been involved in renewable energy technologies, including wind, for more than 20 years. Sandia's wind program focuses on both industry/utility issues and applied research. As part of the industry-driven Wind Turbine Development Program, 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.

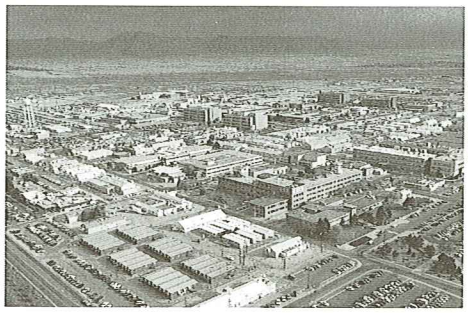
Until the summer of 1994, *Pacific Northwest Laboratory*, located in Richland, Washington, conducted research on wind turbulence, atmospheric physics relating to wind turbines, tools for wind resource assessments, and power plant site evaluations. During 1994, PNL's wind characterization program was transferred to the National Wind Technology Center. The transfer was designed to improve technical interchange, reduce costs, and save time in coordinating R&D activities.

In April 1994, PNL's wind energy research team, headed by Dr. Larry Wendell, received the Federal Laboratory Consortium Award for Excellence in Technology Transfer for its accomplishments in characterizing wind resources in the United States and around the world.



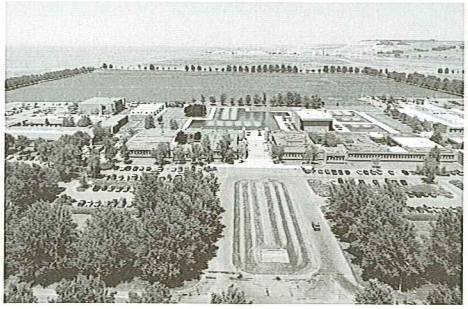
WARREN GRETZ, NREL

The National Wind Technology Center, operated by the National Renewable Energy Laboratory, near Golden, Colorado.



SANDIA NATIONAL LABORATORIES

Sandia National Laboratories in Albuquerque, New Mexico.



PACIFIC NORTHWEST LABORATORY

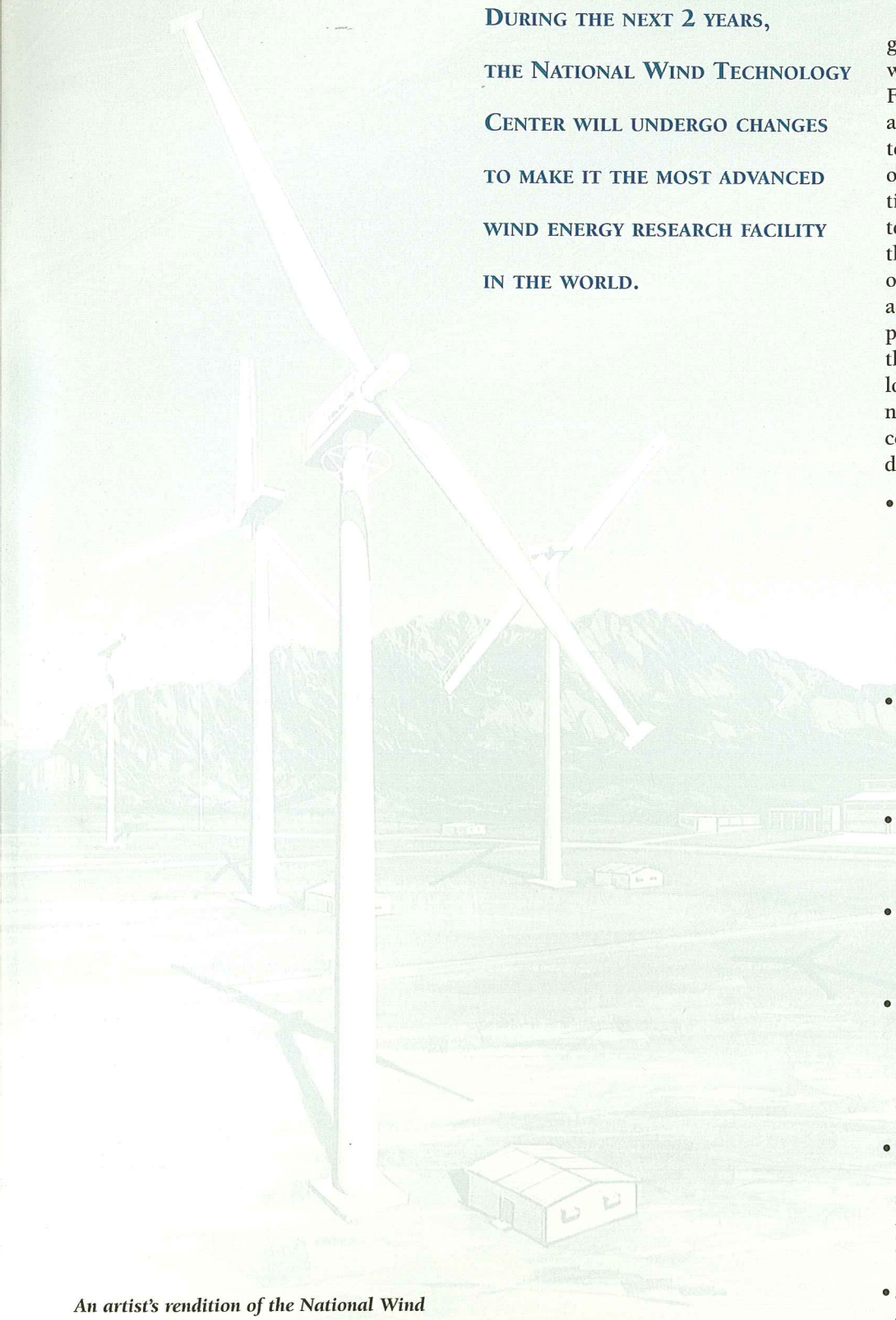
Pacific Northwest Laboratory in Richland, Washington.

A Look Toward Tomorrow

During the next 2 years, the National Wind Technology Center will undergo changes to make it the most advanced wind energy research facility in the world.

In support of the nation's economic goals, the DOE Wind Energy Program will pursue the following objectives in FY 1995: (1) undertake collaborative activities with utilities and industry to ensure the responsible deployment of wind power, (2) increase the productivity and competitiveness of U.S. technology, (3) aggressively pursue the development of a new generation of utility wind turbines, (4) initiate an advanced wind turbine development project for small machines, and (5) further 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.

- DOE will further the adoption of wind technologies by supporting the National Wind Coordinating Committee initiatives in utility wind resource assessments, wind power plant deployment, and avian research studies.
- DOE will begin construction of the Industrial User and Hybrid Power Test Facilities at the National Wind Technology Center.
- NREL will select subcontractors to develop next-generation turbine prototypes.
- NREL will initiate wind characterization studies at Midwest and Great Plains sites.
- Sandia will work with industry to promote innovations in blade manufacturing, tool design, nondestructive testing, and advanced manufacturing processes.
- DOE, NREL, and Sandia will support the development of sustainable wind energy systems for utility-scale, village power, and stand-alone applications throughout the world.
- Sandia and NREL researchers will continue to provide industry with improved design and analysis tools for developing advanced technology.



An artist's rendition of the National Wind Technology Center shows how the center will appear with the addition of new industry turbines and the completion of new facilities for industry users, hybrid power testing, and advanced research turbine testing.

RAY DAVID, NREL

National Renewable Energy Laboratory
02LIB068159

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