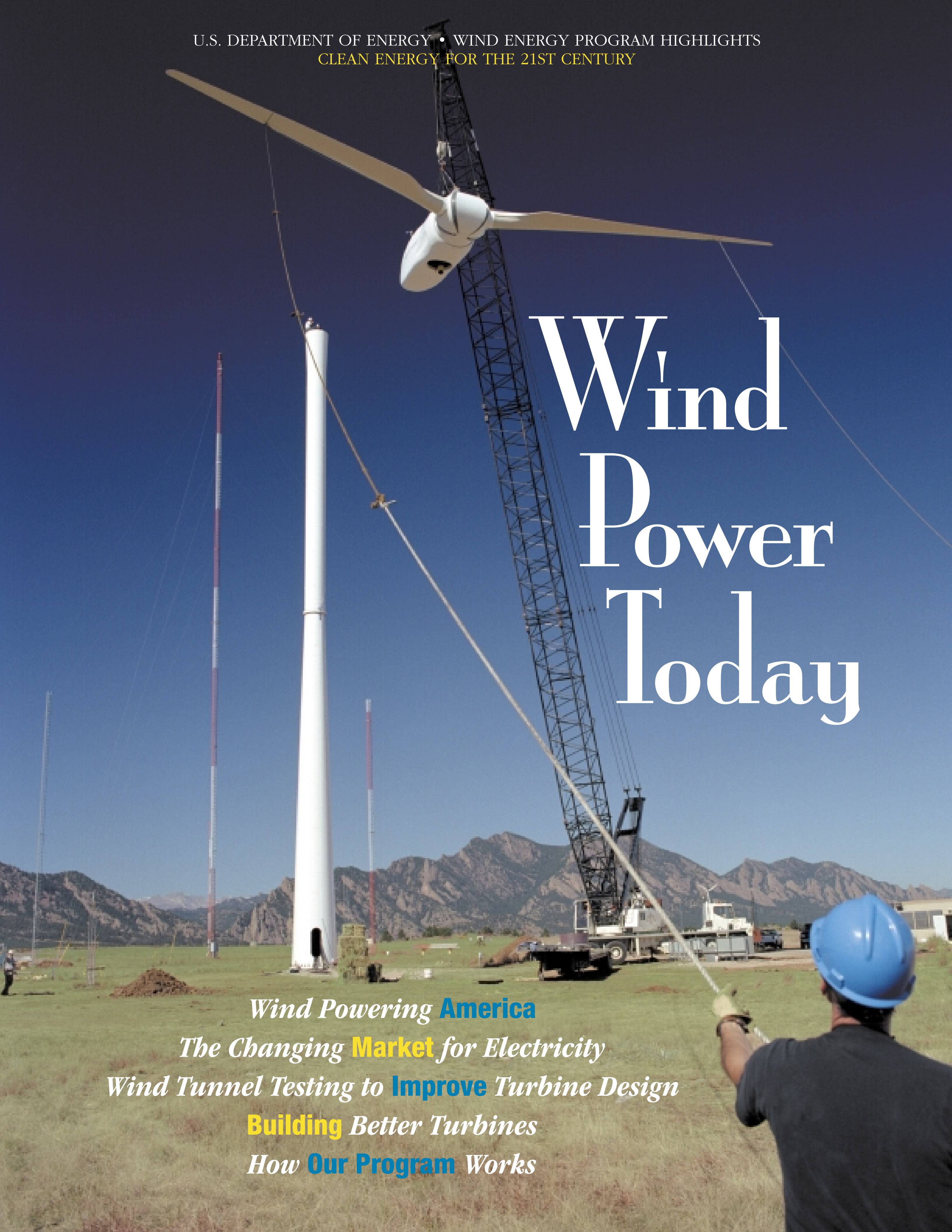
U.S. DEPARTMENT OF ENERGY • WIND ENERGY PROGRAM HIGHLIGHTS

CLEAN ENERGY FOR THE 21ST CENTURY

Wind Power Today



Wind Powering **America**

The Changing **Market** *for Electricity*

Wind Tunnel Testing to **Improve** *Turbine Design*

Building *Better Turbines*

How **Our Program** *Works*

1999: THE YEAR IN REVIEW

April

Worldwide wind-generating capacity reaches 1 GW (10,000 MW). More than 25% of this capacity is in the United States.

June

U.S. Energy Secretary Bill Richardson announces the Wind Powering America initiative to meet 5% of our electricity needs with wind power by 2020.

The Wind Power '99 Conference of the American Wind Energy Association is held in Burlington, Vermont.

The Federal production tax credit of $0.015/kWh for wind-generated electricity expires on June 30.

President Clinton announces the Greening of the Government through Efficient Energy Management, Executive Order 13123, challenging Federal agencies to expand renewable energy use.

July

The National Wind Technology Center (NWTC) adds a 600-kW variable speed turbine to its Advanced Research Turbine test bed.

August

The world's only 2.5-MW Dynamometer Test Bed for wind turbines completes readiness verification at the NWTC.

September

Enron Wind Corporation dedicates the world's largest wind power-generating plant near Storm Lake, Iowa. The 193-MW Storm Lake wind farm joined Lake Benton I and II to bring the combined generating capacity of the Buffalo Ridge area in Minnesota and the northwestern Iowa region to more than 400 MW of electricity.

November

Senator Byron Dorgan of North Dakota and the U.S. Department of Energy convene the Wind Energy and Rural Development Conference in Grand Forks, North Dakota, with attendees from 16 states.

The Wind Turbine Company installed its 250-kW, hinged-blade, proof-of-concept, next-generation turbine at the NWTC.

December

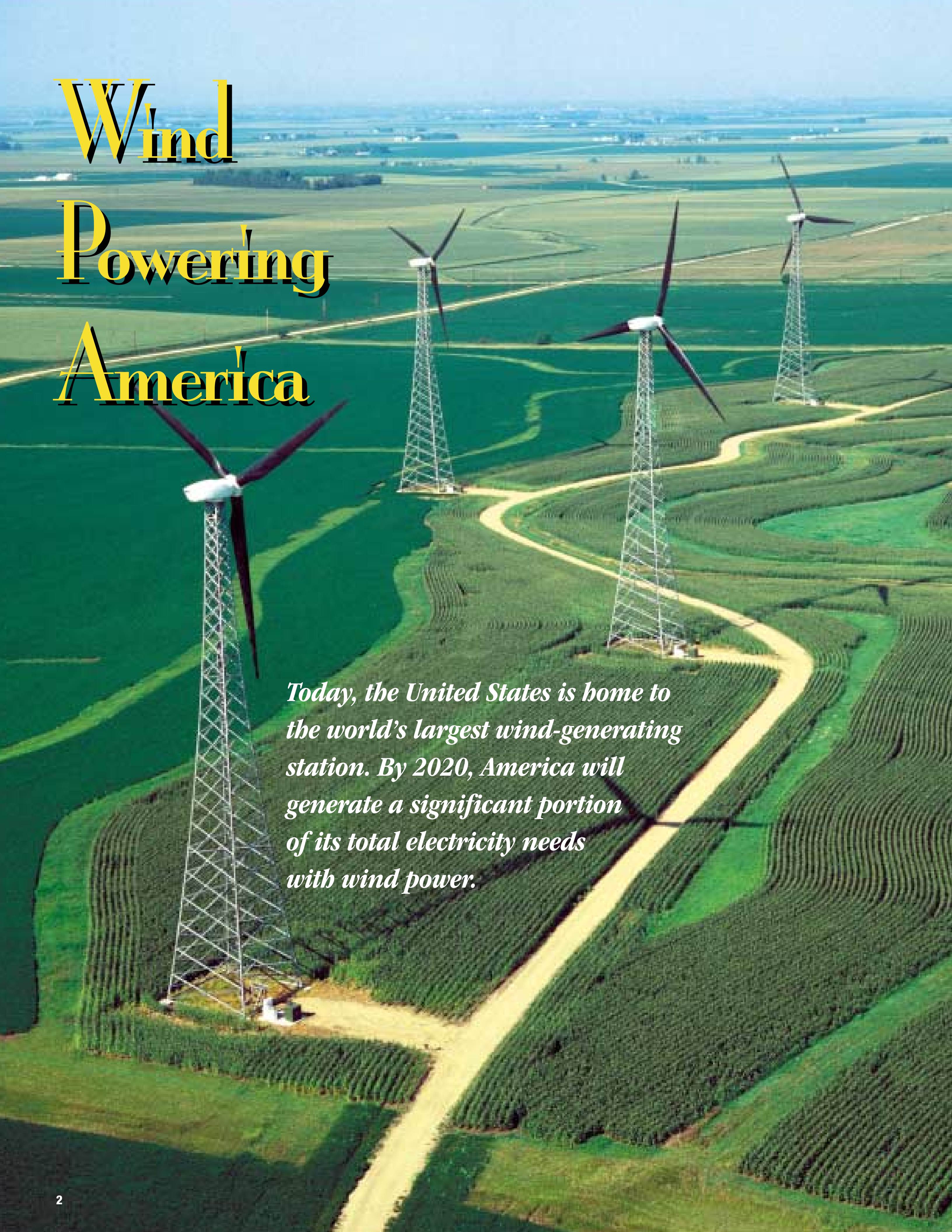
Production tax credits for wind-generated electricity are extended to December 31, 2001.

A 10-meter-diameter wind turbine was installed in the NASA Ames Research Center wind tunnel. The heavily instrumented research turbine will allow researchers in the world's largest wind tunnel to study unsteady aerodynamic-stall processes.

About "Wind Power Today"

BY THE END OF 1999 THE U.S. TOTAL INSTALLED WIND CAPACITY HAD REACHED A landmark 2500 megawatts (MW). The U.S. domestic markets for wind power have broadened beyond California over the past few years, with new multi-megawatt wind farms installed in Texas, Minnesota, Iowa, Wisconsin, Wyoming, Colorado, and Oregon. A number of states are also seeing smaller wind farms and distribution-connected clusters being developed. These installations are successful as a result of a combination of Federal tax incentives, state-level mandates, customer preference (green pricing), and occasionally, the desire of utilities to gain experience with wind technology. In mid-1999, the U.S. government made a dramatic commitment to: (1) use wind power to supply at least 5% of the nation's electricity need by the year 2020: (2) double the number of states that have more than 20 MW of wind capacity to 16 by 2005; (3) and increase the Federal government's use of wind-generated electricity to 5% by 2010. These goals are combined under a new initiative called "Wind Powering America" will be a major focus for the U.S. Department of Energy Wind Program in fiscal year 2000 and in years to come.

Contents



Wind Powering America

Today, the United States is home to the world's largest wind-generating station. By 2020, America will generate a significant portion of its total electricity needs with wind power.

ON EARTH DAY 1999, BEFORE AN ENTHUSIASTIC AUDIENCE assembled at United Nations headquarters in New York, U.S. Secretary of Energy Bill Richardson announced that worldwide capacity for electrical power generation from the wind had exceeded 10,000 megawatts (MW). These wind turbines generate enough electricity for two cities the size of Madrid, Spain, according to the International Energy Agency Committee for Cooperative Research and Development of Wind Power Systems. About 25% of this worldwide generation capacity (nearly 2500 MW) is installed in the United States, with more than 700 MW installed here in 1999 alone. Even so, this 2500 MW represents only about 0.1% of our total electricity consumption. In contrast, Denmark generates about 10% of its electricity from the wind. Aggressive government incentive and development programs are doubling national wind-generating capacity every few years in countries such as Denmark, Germany, and Spain.

Confident of wind power's potential to significantly contribute to America's energy needs, in June 1999, Secretary Richardson announced Wind Powering America, a bold new initiative to be led by the U.S. Department of Energy, in collaboration with non-Federal partners. "Wind Powering America will double U.S. wind capacity by 2005, and double it again by 2010 to create enough energy to fulfill the annual energy needs of three million households," Richardson said. "By 2020 a combination of continued research and policy initiatives should make wind energy a major commercial power generation technology. Wind energy will supply 5 percent of the nation's electricity needs and establish new sources of income for American farmers, rural landowners, and Native Americans." Today, the United States is home to the world's largest wind-generating station. By 2020, America will generate a significant portion of its total electricity needs with wind power.

Secretary of Energy, Bill Richardson, announces the Wind Powering America Initiative at the American Wind Energy Association conference in June 1999.

At left: The world's largest wind farm, the193-MW Storm Lake project in northwestern Iowa, went on line in September 1999.

Wind Powering America will double U.S. wind capacity by 2005, and double it again by 2010 to create enough energy to fulfill the annual energy needs of three million households
— Secretary of Energy Bill Richardson

INITIATIVE BENEFITS

- Adding $60 billion in capital investment in rural America during the next 20 years
- Reaching $8 billion in annual investment by 2020
- Providing $1.2 billion in new income for American farmers, Native Americans, and rural landowners during the next 20 years
- Displacing 35 million metric tons of carbon equivalent per year by 2020
- Creating 80,000 permanent jobs by 2020.

Increasing the nations's wind energy capacity will provide both environmental and economic benefits. The benefits of wind energy development were underscored in November at the Wind Energy and Rural Development Conference in Grand Forks, North Dakota. At this meeting, Assistant Secretary for Energy Efficiency and Renewable Energy, Dan Reicher, and U.S. Senator Byron Dorgan of North

Dakota stressed that Wind Powering America could enhance both regional and environmental quality and sustainable economic development. In fact, one of the highlights of the meeting was a tour of a wind turbine blade manufacturing facility operated by the LM Glas Fiber Company. This kind of manufacturing facility that employs local people can add to the economic diversity of a region sorely in need of jobs.

"This historic event paved the way for an objective, technically-based discussion of the short-term and long-term economic opportunities wind power can offer rural America," says Dr. Gerald Groenewold, director of the Energy and Environmental Researcher Center of North Dakota—a co-sponsor of the event. "We had people from 16 different states bringing success stories, and we had farmers, researchers, and agency people talking about how to build on this foundation. I came away thinking that this is a good new product for rural America."

ECONOMIC BENEFITS

The blade manufacturing plant in Grand Forks, North Dakota, is just one example of the economic potential of wind energy development. Analysts project that the Wind Powering America initiative will result in $60 billion in capital investment in rural America and $1.2 billion in new income for farmers, Native Americans, and rural landowners during the next 20 years. And the expansion of wind generating capacity will create 80,000 permanent jobs by 2020.

Sixty-nine turbines at Foote Creek Rim near Arlington, Wyoming, have 41 MW of generating capacity.

Wind power offers special benefits to rural landowners. Studies conducted for DOE at the National Renewable Energy Laboratory (NREL) indicate that a 1000-acre farm could easily accommodate as many as 10 turbines. Such a farm could generate $2,000 in land royalties per turbine; an additional income of $10K to $20K per year. And although some wind years are better than others, there are no fallow years, and no water, fertilizer, weeding, or harvesting is required of the landowner. These wind revenues would be in addition to crop revenues. Iowa farmer Delbert Watson sums it up, "We grow corn on the ground and power in the air—all on the same piece of property."

In rural America, tribal lands contain some of the best wind resource areas of the country and developing this resource can help meet goals of economic sustainability.

Two tribes in North Dakota have been gaining experience with wind turbines and saving on electricity charges since 1997. The Spirit Lake Nation at Ft. Totten owns and operates a 100-kilowatt (kW) turbine connected to the Spirit Lake Casino. About 150 miles away in Belcourt, the Turtle Mountain Chippewa operate an identical machine connected to the tribe's municipal water treatment plant. Purchased with funds from DOE under the "Title 26" program to encourage tribes to explore alternative energy, the turbines are giving the tribes the experience necessary for larger developments in the future. The tribes help each other out with troubleshooting and maintenance but there have been few problems. Each tribe saves between $500 and $1,000 per month on their utility bills.

In South Dakota, a 750-kW turbine on the Rosebud Sioux reservation will soon supply power to the Rosebud Casino and Convention Center. "Casinos are a really good load for a wind turbine owned by the tribe," says Jay Haley, an engineer with EAPC Architect and Engineers who works for several tribes in North Dakota on technical aspects of wind development. "We size the wind turbine based on that constant demand and know that every kilowatt generated will be used." By using all the wind-generated electricity themselves, the tribe saves paying the retail price for its electricity—around seven or eight cents per kilowatt-hour.

Generating electricity for "export" to cities can also be good business for rural America. In Wyoming, at Foote Creek Rim near Arlington, 69 turbines totaling 41 MW of generating capacity export power to urban areas in Washington and Oregon.

The case for large wind power generating stations

Most of the 2500 MW of capacity in the United States today is installed in wind power plants that are managed much like other utility power plants. The electricity these "wind farms" generate is directed to a substation and the voltage is stepped up to move through large transmission lines. The bulk of new generation expected under Wind Powering America will be located in large wind farms of 100 MW or more.

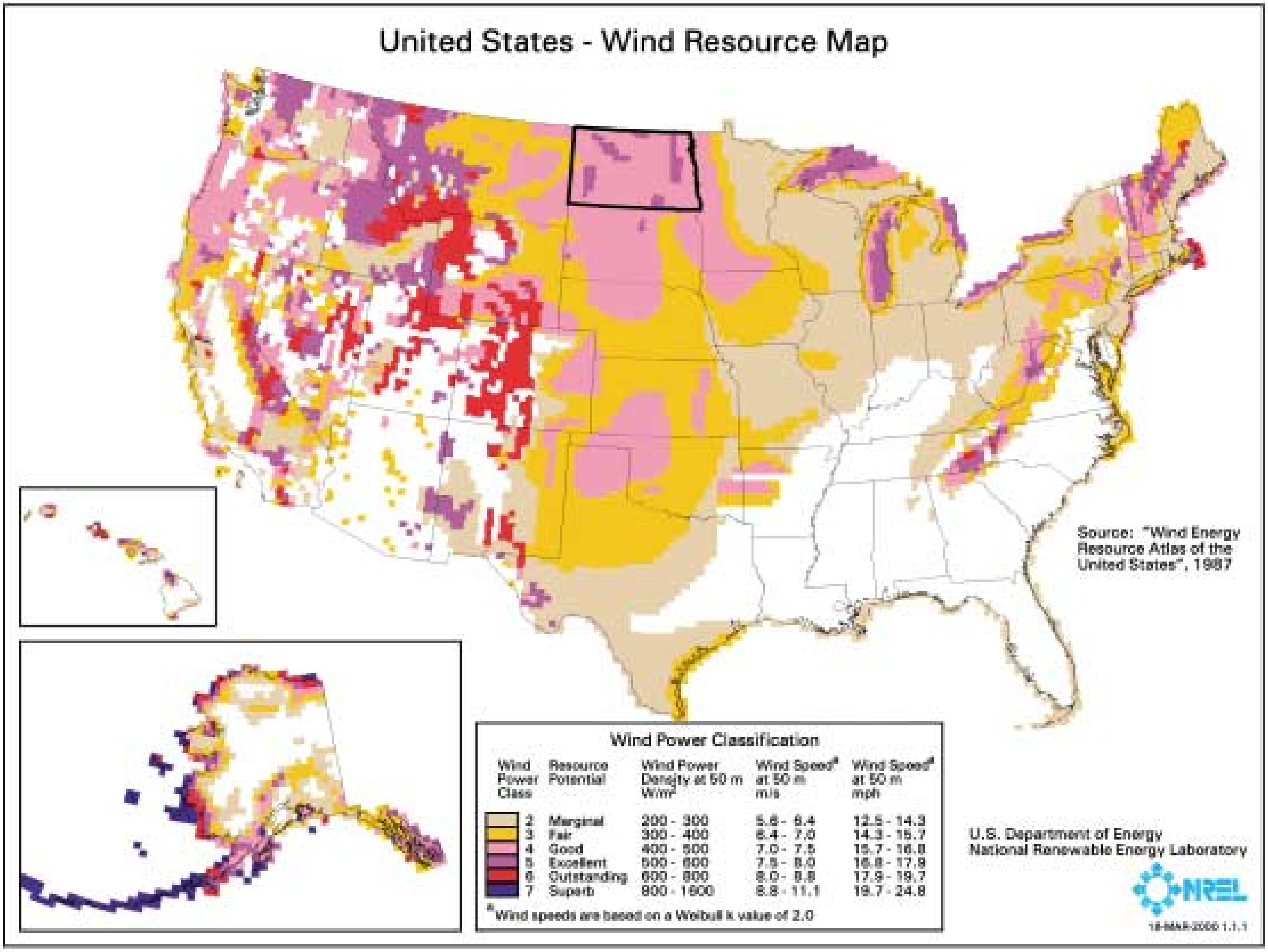
The world's largest wind farm—193 MW— went on line in September 1999 near Storm Lake in northwestern Iowa. (This project is the largest single project in the world with its turbines spread over the countryside in small clusters like typical European installations.) This wind energy project was developed and constructed, and is owned and operated by Enron Wind Corporation. The Storm Lake project, with 257 turbines, rated at 750 kW each, has brought permanent, well-paying jobs to people in the area.

In addition to adding economic diversity and jobs to this farming area, there has been an inflow of money to the landowners. Mary Plagman, who owns land and lives within the Storm Lake development, said that the developer, Enron, pays very well to have turbines on her land. They pay each year for the right of way, they pay for crop damage if there is any, and they maintain the gravel roads around the turbines. The annual payment amount includes a bonus if energy production exceeds company projections for the year. The electricity is purchased from Enron by two investor-owned utilities—MidAmerican and IES Utilities (a subsidiary of Alliant Energy). To be competitive, the project also takes advantage of the Federal production tax credit, which currently has a value of approximately $0.017/kWh during the project's initial 10 year operating period. The tax credit, taken by Enron, reduces the cost of the wind-generated electricity it sells to the utilities.

By the end of 1999, Iowa alone had almost 250 MW of wind-generating capacity. These turbines represented $300 million of new investment and provide over $500,000 in land-use royalties to hundreds of rural landowners each year. This latest project in Iowa is a direct result of a law enacted by the state legislature requiring the state's investor-owned utilities to invest in wind energy.

Large developments such as Storm Lake benefit from the foundation built by the DOE Wind Program. For example, the Zond Systems, Inc., 750-kW turbines used at Storm Lake are based on the Zond Z-40 550-kW turbine developed with support from the Wind Program. In addition, facilities at NREL's National Wind Technology Center are being used by Zond to test improvements to the 750-kW turbine designed to lower the cost and improve performance.

Wind farms such as Storm Lake (top) in northwestern Iowa, and Lake Benton in Minnesota provide economic diversity, jobs, and additional income to landowners in these rural communities.



The U.S. wind resource map shows national wind resources based on a combination of wind speed data and wind speeds estimated using the latest models.

The Foote Creek project earns a $140,000-per-year royalty payment for landowners in Wyoming. More wind turbines are planned to expand generation capacity.

Federal facilities in urban areas can help create the demand for clean power that leads directly to development and economic benefits for rural America. The U.S. Environmental Protection Agency's demand for clean power at its Seattle office building could lead the Blackfeet tribe in northwest Montana, to develop a 15-MW wind farm. In 1999, tribal officials were talking with Bonneville Power Administration about shipping power to Seattle.

DEVELOPING WIND RESOURCE MAPS

Strong, frequent winds are ideal for generating electricity. Wind speeds measured throughout the year at monitoring stations and estimated wind speeds based on the latest models are used to develop maps indicating the best wind resource areas. Annual average wind speed is used to calculate the amount of energy in the wind per square meter of area blowing through a wind turbine's rotor. This is expressed as watts per square meter. From this calculation of energy in the wind, geographic areas as small as one square mile are assigned a wind power class from 1 to 7. State officials and developers use this information to find the best areas for wind development. Sites in wind power class 4 or better are candidates for wind farm development. Regions that are categorized as Class 3 may have terrain features that locally accelerate the wind, providing limited wind farm development opportunities. Small wind turbines have a range of applications in Class 3 and higher wind areas. Class 2 sites or better may offer possibilities for adding small wind generators where a backup generating system is needed for reliability, or the cost of utility service is unusually high.

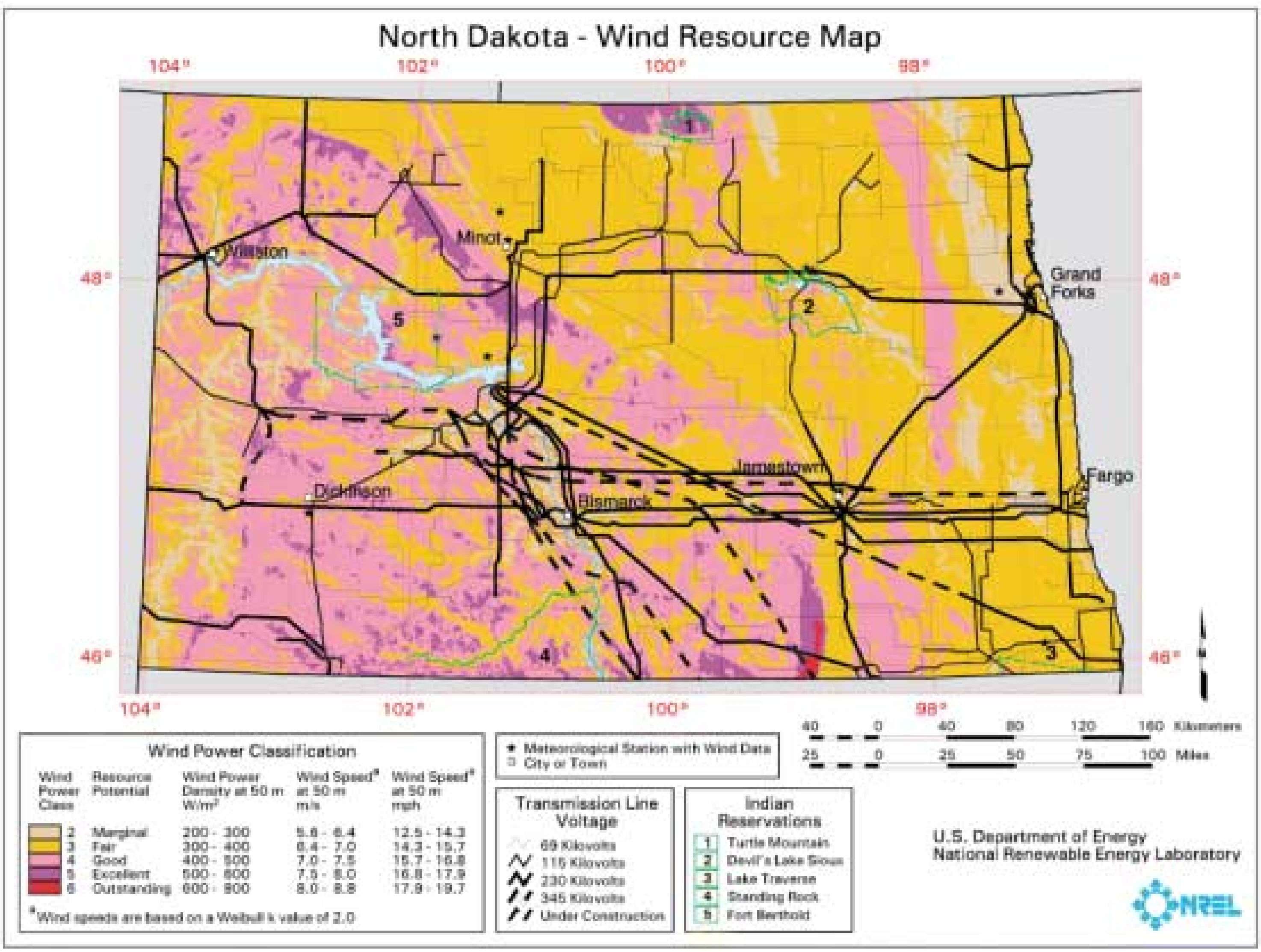
ENVIRONMENTAL BENEFITS

At the Wind Powering America goal of meeting 5% of the nation's electricity needs with wind by 2020, wind power generation will reduce carbon equivalent by 35 million metric tons per year in the United States. According to advertisements from the Public Service Company of Colorado, each penny spent on electricity from their Windsource^{sm} Green Power program saves a pound of CO_2. In addition, using wind power can help the Western Governors Association and Western Regional Air Partnership reach their goal of reducing haze in the West. They hope to increase the use of nonhydro power renewable energy in the region to 10% by 2005 and 20% by 2015. Wind power will be a major contributor to these goals in 10 states—Arizona, Colorado, Idaho, Montana, New Mexico, North Dakota, Oregon, Utah, Washington, and Wyoming.

AMERICA HAS A HUGE WIND RESOURCE

Confirming what many Midwestern farmers have always known, the *Wind Energy Resource Atlas of United States*, published in 1981 by the Department of Energy, documented a huge energy potential in the U.S. wind resource. This pioneering work revealed that we could generate more electricity from the wind than our total current electrical consumption. Updates and revisions to the wind database and the tools used to construct it continue to help industry, utilities, and governmental bodies plan for wind energy development.

The latest wind resource maps being developed by the DOE Wind Program have a greater level of detail and allow users to overlay the resource maps with features of interest. For example, the North Dakota map shows several large Native American reservations and the proximity of transmission lines.



The North Dakota wind resource map shows several large Native American Reservations and the proximity of transmission lines.

Wind turbines at the Navy facility on San Clemente Island, California, displace fuel use and emissions from the existing diesel system.

The U.S. map shows the inherent wind resources of the country based on a combination of measured wind speed data taken over decades and estimated wind speeds based on the latest models for areas with little or no data.

EXPANDING MARKETS

Under Wind Powering America, Federal facilities offer an expanding early market for cost-effective applications of wind systems. Executive Order 13123, Greening the Government Through Energy Efficiency Management, encourages each Federal agency to strive to expand its renewable energy use. They can use more clean energy both by installing renewable energy systems and by buying electricity produced by renewable energy systems. Although agencies generally select the lowest market prices for goods and services, they have the flexibility to pay a higher price for certain products, such as green electricity. In addition, the executive order allows them to use their savings accrued through energy savings performance contracts (ESPC) to pay the higher green price of electricity generated from renewable sources such as wind.

Using the foundation laid by the six DOE regional offices, agencies can draw on a network of organizers and a portfolio of strategies for using green power. For example, the Seattle Regional Office has about 20 ESP contractors available for Federal agencies to use. These companies, at the invitation of a Federal agency, can examine a facility and survey what energy saving technologies can be applied. Then, under a contract, the companies install the energy-saving devices and split the resultant financial savings with the agency. It is these savings to the agency that can be used to buy green power.

In addition, Federal departments and agencies can own wind generation if they choose. Various agencies have installed wind turbines, and the DOE Wind Program has supported the installation of three 225-kW wind turbines at a Navy facility on San Clemente Island, California. The turbines on San Clemente are reducing the cost of shipping and storing fuel and reducing emissions from the existing diesel power generation system. The U.S. Department of Agriculture (USDA) Agricultural Research Service at Bushland, Texas, has long been a pioneer in research on agricultural uses of wind turbines. The USDA's National Rural Development Partnership is working with Federal, state, local, and tribal governments as well as the private sector to improve rural American communities. In this program, USDA makes insured loans and loan guarantees to nonprofit and cooperative associations to finance the construction of new facilities such as wind-generating plants. The Administration for Native Americans, located in the Department of Health and Human Services, runs a grant program that could be used to facilitate wind energy use on tribal lands.

The DOE regional offices and the Federal Energy Management Program work with state energy offices and local government to put together workable strategies for expanding the use of renewable energy, including wind generation.

BRINGING IT ALL TOGETHER

The success of the Wind Powering America initiative will rely on the continued and expanded

The case for large turbines connected to distribution lines

Many wind development options will need to be pursued in order to meet the Wind Powering America goal of providing 5% of the nation's electricity from wind by 2020. One of these options is to connect smaller groups of wind turbines or single turbines directly to the utility distribution line. One advantage of this "distributed generation" is that the electricity is used near where it is consumed. And in some cases construction of higher capacity transmission lines can be postponed or avoided.

On a breezy day in October 1998, the city of Springview, Nebraska, celebrated its first annual Wind Turbine Day and dedicated the first utility wind power project in Nebraska. Referred to by the locals as the "twin turbines," the project consists of two Zond Systems, Inc., 750-kW turbines with 164-foot (50-meter) rotors. The machines sit atop lattice-style towers that are 213 feet (65 meters) high. They are expected to generate enough electricity annually to serve 700 to 800 residential customers.

Unlike the large wind farms that have their own substations and feed power into high-voltage transmission lines, these turbines are connected at the beginning of a long, 12.5-kilovolt (kV) distribution line. When the turbines generate more power than the customers along the line need, the excess power is stepped up to transmission line voltages to be sent out to other utilities across the state.

This distributed power project is similar to installations in Europe where land is scarce. In the United States, this cluster approach to wind turbine development could be applicable in more populated areas. Analysts also believe that connecting generators of any kind on distribution lines will make economic sense in the new market for electricity (see "The Changing Market for Electricity).

Using a local resource to generate electricity goes well with the farm and ranch ethic of rural Nebraska. Nebraska's electricity comes primarily from out-of-state, coal-fired power plants supplemented by some small hydropower plants, gas-peaking units, and one nuclear power plant. Looking for alternatives, Nebraska Public Power District engineers participated in the DOE Utility Wind Resource Assessment Program that helps utilities evaluate sites for wind-generating developments.

Another DOE project that contributed to this development is the Turbine Verification Program. In 1996, DOE and the Electric Power Research Institute (EPRI) put together this program to help utilities in good wind resource areas gain experience owning and operating wind turbines connected to the distribution line. Since its inception, the Turbine Verification Program has contributed through cost sharing and technical assistance to the installation of projects in six states. These projects generated 112.2 million kilowatt-hours (kWh) in 1999.

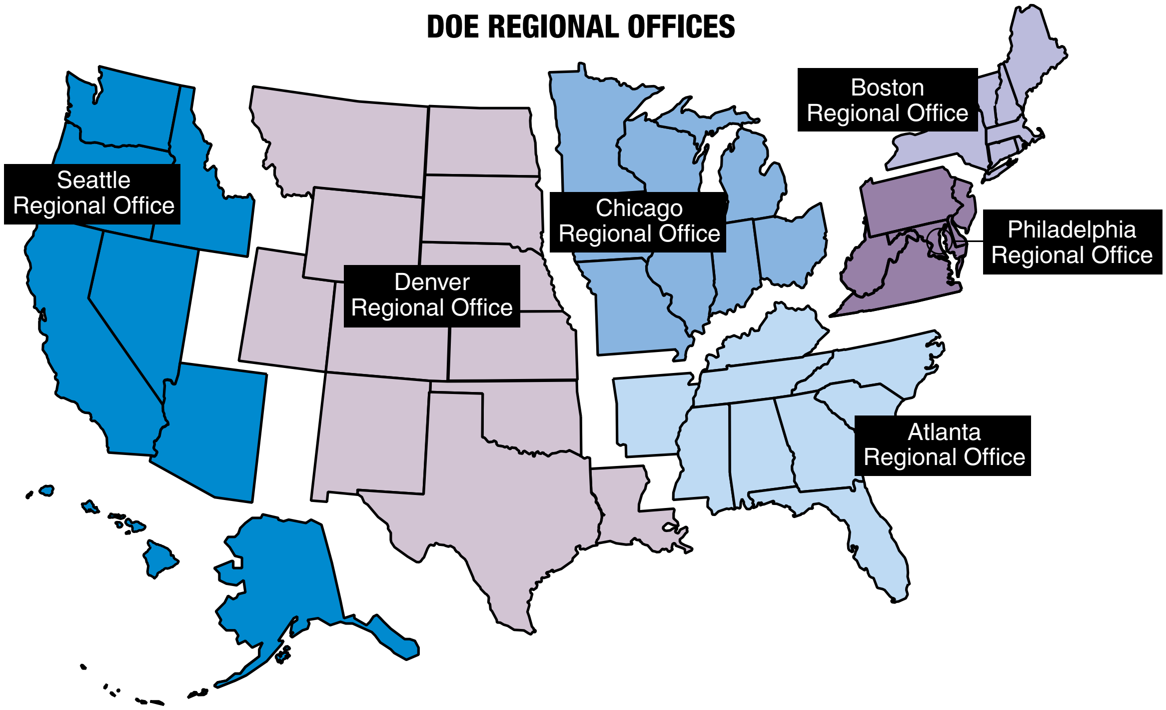
The twin turbines near Springview, Nebraska, generate enough electricity annually to serve 700 to 800 residential customers.

"From participating in the wind resource assessment program, we knew we had a good wind resource," explains Frank Thompson, project coordinator for the Nebraska Public Power District.

Knowing they had a good wind resource, Nebraska Public Power District put together a team of project owners and operators to participate in the program. By sharing the cost of the project, the Turbine Verification Program offered the Nebraska utilities a way to gain hands-on experience with new wind technologies with a lower capital outlay for the project. The program also provided technical support from the National Wind Technology Center managed by NREL for DOE.

This technical support proved important because most conventional electric distribution systems are designed for power flow only in one direction, from the utility source (distribution substation) to the load (customer). NREL helped address issues surrounding safety, liability, power quality, system protection, and the variable output of wind turbines compared with other forms of generation. The Springview turbines are connected at a point 1.5 miles from a utility substation. The turbines are operating as expected, and in 1999 they produced more than 4.3 million kWh of electricity. The power quality monitoring equipment has detected no problems to date.

DOE REGIONAL OFFICES



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cooperation of many stakeholder groups across the country, including private companies, industrial partners in the DOE wind research program, utilities, utility regulatory bodies, state energy offices, local governments, Federal agencies, and collaborative groups representing combinations of these stakeholders. With Wind Powering America, these groups are more important than ever in establishing wind energy as a sustainable contributor to the nation's energy portfolio.

The American Wind Energy Association (AWEA) is a national trade association that represents wind power plant developers, wind turbine manufacturers, utilities, consultants, insurers, financiers, researchers, and others involved in the wind industry. In addition, AWEA represents hundreds of wind energy advocates from around the nation.

The National Wind Coordinating Committee (NWCC), formed in 1994, identifies issues that affect the use of wind power, establishes dialogue among key stakeholders, and catalyzes appropriate activities to support the development of an environmentally, economically, and politically sustainable commercial market for wind power. The NWCC strives to obtain a consensus from its members, which include representatives from electric utilities and support organizations, state legislatures, state utility commissions, consumer advocacy offices, wind equipment suppliers and developers, green power marketers, environmental organizations, and state and Federal agencies. An important activity has been the Avian Subcommittee that worked to produce the guidance document *Studying Wind Energy/Bird Interactions* in 1999. Another important activity is the transmission working group that addresses issues associated with wind energy and the nation's electric transmission systems. A number of issues must be addressed to ensure that new wind energy installations have the access they need to transmit clean power to customers in many areas of the United States.

The Utility Wind Interest Group (UWIG) is a non-profit corporation whose mission is to accelerate the appropriate integration of wind power for utility applications through the coordinated efforts and actions of its members, in collaboration with public- and private-sector stakeholders. Membership is open to utilities and other entities that have an interest in wind generation. UWIG experts in utility analysis participate on NWCC committees and contribute to standards development through the Institute of Electrical and Electronics Engineers to resolve issues of wind energy development and utility interactions.

PARTNERSHIPS WILL MAKE THE DIFFERENCE

Wind Powering America will be a partnership of organizations from both the private and public sectors representing suppliers, customers, environmental concerns, and regulatory bodies. Keeping in mind that much more can be done, one way to accomplish this tremendous increase in wind-generating capacity is to apply lessons learned from wind applications across the country.

A significant aspect of the Wind Powering America initiative will be the way in which it is aided

The case for small turbines connected to distribution lines

Since the 1920s, small wind-electric systems have been supplying homes with electricity and keeping batteries charged for times when the winds were calm. Today, small wind turbines can be connected to the utility distribution line, thus eliminating the need for batteries. These distributed wind generators of 400 W to 100 kW will play a small, but important part in Wind Powering America.

During a power outage, the control system on this small turbine disconnects the home from the power grid and supplies the home with power from the batteries and the wind turbine.

Although his electricity rates from Oklahoma Electric Cooperative are reasonable, Clark Taylor was intrigued by the offer to participate in the Coop's Distributed Generation Project using wind turbine generators. Taylor lives on five acres in central Oklahoma, where ice storms and tornados take their toll on the long power lines between his home and the nearest substation. It is not uncommon for his home to be without power for days at a time.

Under this project, Taylor and five other rural homeowners put up wind systems that connect to the utility grid. When the wind turbine produces more than the family uses, the electric meter runs backwards, selling electricity to the utility for exactly what Taylor pays for it. Except for summer, when he runs his air conditioner, Taylor gets electric bills with zero charges or even credits on his account that he can apply to future consumption. This type of connection to the utility is called net metering. Several states now allow this sort of arrangement for small generators connected to distribution lines.

In addition to reducing his energy bills, Taylor's system has a battery bank that stores electricity to provide power to his home, even if the coop's power goes out.

The safe operation of this control system was a major concern of the utility. When people go out to repair the line, they need to know that no electricity is coming into the line from the user. Thanks to the research and development sponsored by NREL, much of the safety control is built right into today's small wind turbines. Experts at NREL demonstrate this to utilities that have little or no experience with the hardware. In addition, NREL experts help develop safety and design standards for connection of small generators to distribution lines.

The case for wind hybrid power systems

Combining wind turbines with existing generators that use diesel or gas can increase the capacity of a small electric grid and reap significant fuel savings for users. Adding wind hybrid systems to electric grids will play a part in Wind Powering America.

"We feel that wind is probably the only near-term technology that has some potential for reducing the cost of power in rural Alaska," says Brad Reeve, general manager of Kotzebue Electric Association (KEA), a nonprofit, consumer-owned cooperative. Drawing upon its experience with the first three wind turbines installed in 1997 under a combination of Federal and state programs, KEA added another seven turbines in 1999. The ten 66-kW turbines have worked out so well with the diesel generators in Kotzebue that plans are underway to install two turbines in the smaller town of Wales.

The KEA turbines in Kotzebue operate as part of a hybrid wind/diesel system allowing the diesels to consume less fuel when the winds are good. These Alaskan winds are saving more than $100,000 a year in diesel fuel, according to KEA. But saving the cost of diesel fuel is only part of the equation that favors wind energy in Alaska. In the north, storing diesel fuel is a very costly proposition. A 20% to 30% reduction in diesel fuel usage, especially in a small village like Wales (population 177), can reduce the need to add expensive storage tanks. Displacing diesel also reduces pollution of air, soil, and water.

Construction is underway to install two 66-kW turbines to supply power to this small arctic community in Wales, Alaska.

The KEA wind project in Wales will have some different technical issues because the wind turbines, during periods of high winds, will supply the majority of the electrical energy of the village. This "high-penetration" scenario demands a sophisticated control system to coordinate the diesel generators and the wind generators to efficiently meet the electrical load for the village. Such a system was developed and tested for the Wales project in 1999 at the Hybrid Power Test Bed (HPTB) at DOE's NWTC in Colorado.

The HPTB can simulate various types of electrical loads that hybrid systems may be designed to supply. It also simulates the transient conditions that occur when the wind turbine connects and disconnects from the generating system or when large loads on the system come on or go off. Many hybrid systems incorporate battery storage and this too is part of the test bed's capability. The test bed can also test control algorithms designed to optimize use of backup generators. Thus, industry can test innovative concepts in hybrid systems at the Hybrid Power Test Bed and then move on to field testing and eventually to commercialization.

by improved wind energy technologies that have been developed under the DOE Wind Program during the past two decades. This groundwork, laid by joint public and private research and development investments, will help wind energy to increase its contribution to the nation's energy portfolio.

Wind Powering America will meet its goals through the application of wind turbine technology tailored to the energy needs in many parts of the nation. From multi-megawatt turbines grouped together in utility wind farms to grid-connected generators reducing a rural homeowner's utility bill, wind power will become an invaluable element in our nation's electric generation mix. ◆

The Changing Market for

The deregulation and restructuring of the electric utility industry presents opportunities as well as challenges for the wider use of wind-generating plants.

To reduce consumption of fossil fuels and production of greenhouse gases, some state legislatures are requiring incorporation of wind and other renewables into the electric generation mix.

THE DEMAND FOR ELECTRICITY FROM WIND GENERATORS IS GROWING AND THE Wind Powering America initiative will push it even higher. In this changing market for electricity, a variety of pricing, regulatory, and policy schemes is paving the way for more wind turbines. In addition, technical research and development activities of the U.S. Department of Energy and the wind industry are breaking down both real and perceived barriers to increased use of wind energy by clarifying the value and reliability of electricity from wind turbine generators.

In Colorado, Public Service Company of Colorado announced completion in August 1999 of the 22-MW wind project that supplies power for its Windsource^{sm} green-pricing program. At that time, more than 12,000 residential customers and about 250 businesses had already subscribed for the wind power the plant will produce. These customers agreed to pay a premium of 2.5¢/kWh for the wind energy, which they bought in 100-kWh monthly blocks.

RESTRUCTURING THE UTILITY INDUSTRY

Wholesale power generation is becoming more competitive through restructuring of the utility industry. Utility regulation is changing at the state level to either allow or require competition among companies providing electricity. This increasing competition among suppliers is giving consumers choices about the electricity they buy. They can choose a company they trust, they can shop for price, or, increasingly, they can choose a clean generation source like wind energy. Consumers' power to choose clean energy sources can have profound implications for wider use of wind energy.

Of all the clean generation sources (solar, wind, and biomass) wind is by far the most cost competitive. The cost of electricity generated from the wind has been reduced by DOE's 20 years of R&D activities with industry from 40¢/kWh in 1980 to about 4¢–6¢/kWh in 1999 (assuming constant dollars, a 30-year project life, and 15 miles per hour average annual wind speed measured at 10 meters above the ground). This cost is competitive now with fossil fuels in some areas. However, more R&D projects are underway to lower the cost to 2.0¢–2.5¢/kWh to meet the Wind Powering America goals for 2020.

While work toward the cost goals proceeds, pricing and regulatory schemes from green pricing to tax incentives are being developed to increase the contribution of clean energy sources, such as wind, to the generation mix. Researchers and analysts in DOE's Wind Program contribute to the success of these activities by providing technical details about the technology and analyzing policy impacts.

GREEN PRICING

In survey after survey, utility customers say they prefer cleaner energy sources, and they have shown that they are willing to pay more for them. Utilities are responding by offering optional pricing schemes that give customers a way to support utility investment in renewable energy technologies. With this "green pricing," customers choose to pay a small premium on their electric bill to help cover the extra cost of renewable energy. Many utilities are offering green pricing to attract customers and to expand business lines and expertise in advance of electric market competition in their state. By the end of 1999, more than 50 utilities had green-pricing options in the works to serve people in 11 states—Colorado, Idaho, Kansas, Michigan, Minnesota, Nebraska, New Mexico, Oregon, Texas, Washington, and Wisconsin.

Marketing clean power through green pricing has already pointed to a number of important market needs. There is a need to verify "green" or "clean" power claims of marketers. Certification of green power marketers and guidelines for advertising are being discussed at the Federal and state levels. To promote dissemination of accurate information on green power markets and related activities, NREL created a Web site in 1999 called the Green Power Network. It contains links to other sites and information on clean power providers, utility green-pricing programs, and other utility programs that affect clean power markets. (www.eren.doe.gov/greenpower/)

PORTFOLIO STANDARDS

Hoping to reduce consumption of fossil fuels and production of greenhouse gases and other contaminants, some state legislatures are requiring incorporation of wind and other renewables into the electric generation mix. One approach to encouraging utilities to diversify their generation mix uses a "renewables portfolio standard" to define the minimum share of total electricity generated that must come from renewable energy generating stations, such as those using wind turbines.

By the close of 1999, six states had adopted such standards. The most ambitious example is Texas, where electricity providers must add 2000 MW of renewables-based generation by 2009. Having one of the best wind resource potentials among the states, Texas will use more wind energy than other renewable sources, adding to the 200 MW of wind capacity present in 1999.

In another example of a state guiding the generation mix, the Minnesota state legislature required Northern States Power to install 425 MW of wind capacity by 2002 and another 400 MW by 2013 in return for permission to continue storing waste fuel at its nuclear power plants. This requirement led to the development of the Enron Wind Corporation's Lake Benton I and II wind projects in southwestern Minnesota, which have a total of over 200 MW of generating capacity. Those projects, which were built to meet the wind power requirements mandated by the Minnesota state legislature, sell electricity to Northern States Power under a long-term power purchase agreement between the utility and Lake Benton Power Partners, LLC, a subsidiary of Enron Wind Corporation.

Many more states are considering a renewable portfolio standard and specialists in the DOE Wind Program are providing analysis support and expert testimony to state legislatures and public utility commissions about the technical and economic aspects of wind energy development.

SYSTEM BENEFIT CHARGES

When restructuring eliminates a utility's ability to include its research program in the rate it charges for electricity, renewable energy projects could lose important participants in the utility industry. One approach to keeping energy research and development projects going at the state level is to replace the income used by regulated utilities for special programs and research with funds from a systems benefit charge. This 2% to 3% surcharge on customers' bills goes into a fund for the public benefit. Depending on the legislative guidance, this money could be used to subsidize renewable energy projects or to conduct research programs.

For example, California established a $540 million renewables trust fund to be supplied by a surcharge on ratepayers of investor-owned utilities between 1998 and 2002. In 1999, the California Energy Commission allocated $162 million to 55 new renewables-based development projects including wind. Personnel from the DOE Wind Program responded to requests for technical information from the participants in the design and implementation of this complex program.

In Texas, electricity providers must add 2000 MW of renewables-based generation by 2009.

INFORMATION ON INCENTIVES

Investment in renewable energy projects is encouraged by many states and by the Federal production tax credit that was extended in 1999 to December 31, 2001. The production tax credit provides an incentive to wind farm operators of 1.7¢ for every kilowatt-hour of electricity produced for a period of 10 years. Incentives to wind energy development as well as the latest legislation or policy initiatives are followed by the DOE Wind Program and by organizations DOE helps support. The Green Power Network (www.eren.doe.gov/greenpower) contains the latest information on restructuring, green pricing, portfolio standards, and more on a state-by-state and utility-by-utility basis. The American Wind Energy Association (www.awea.org), National Wind Coordinating Council (www.nationalwind. org), and the Utility Wind Interest Group (www. uwig.org) also maintain informative Web sites.

REDUCING BARRIERS

When states contemplate a future where renewable power systems constitute a significant portion of the electric capacity in the state, they realize that

FORECASTING CAN INCREASE THE VALUE OF WIND POWER

The increasingly competitive electricity market demands that, to receive the best price, sellers commit to deliver certain amounts of power at specific times. The challenge for owners and operators of wind plants, which produce varying amounts of electricity depending on wind speed and direction, is to bid on and deliver real-time and next-day wind energy and ancillary services.

Forecasting wind speed and direction as many as 48 hours in advance could greatly increase the value of electricity from wind farms by allowing operators to predict hourly production and bid for firm delivery to buyers. Wind energy forecasting could also help power buyers and sellers, generation dispatchers, power pool operators, and green power marketers to optimize daily generation operations and transactions. The greater the percentage of wind generation in the mix, the more valuable the forecasts of wind farm output will be.

"We see wind forecasting as one of the most promising approaches for leveraging the economics of wind power into a range that is directly competitive with electricity generated with natural gas," says Michelle Pantoya, manager of the California Energy Commission's wind research and development program.

Work to forecast hourly power generation from wind farms began in the European Union (EU) in the early 1990s. In 1999, DOE and EPRI published the results of a study they funded to test the performance of the best of these wind power forecasting models. Using observed wind speed data at the 25-MW Buffalo Ridge Wind Power Plant in Minnesota, the study compared the generation forecast by the EU model to actual generation data from the wind farm. Although the performance of the model was lower than expected, this study provides the foundation for transferring and modifying the EU wind forecasting models for use at U.S. wind farms.

Building on this foundation, the DOE Wind Program will work with experts in other countries to refine wind-forecasting techniques. Through its participation in the International Energy Agency Implementing Agreement for Cooperation in the Research and Development of Wind Turbine Systems, DOE hosted a meeting of international experts in April 2000 at NREL to design an international cooperative research task on this topic.

much of that renewable generating capacity will be comprised of wind systems. However, many utilities are concerned about increased reliance on wind energy because they have no experience with a power technology they are unable to turn on and off at will. Utilities are concerned about using more wind generation because many have no experience with generators that they can not turn on and off at will. In addition, with restructuring of the utility industry, the same company will no longer own all the pieces of the electric generation and distribution system. The control and balancing of loads and generators will be divided among several parties, making it less clear which party will compensate for intermittent generation sources. All these issues can raise real or perceived barriers to wider use of wind generation.

DETERMINING VALUE

One possible barrier to integrating wind generation into the energy portfolio is how the value of electricity is affected by the way wind farms interact with the rest of the generation mix. Issues around this interaction result from the variable output of wind farms—individually or in groups along a line when the wind changes. The DOE Wind Program works with industry, utilities, and groups such as the NWCC and UWIG to provide data and analyses that can help resolve these issues.

One issue of value involves paying for services that help preserve the stability of the network. These "ancillary services" include things such as voltage and reactive power support; regulation; load following; spinning and operating reserve; and quick-start capability. If wind farms behave in such a way as to require these ancillary services, the wind farm owners may be required to pay for them. The value and frequency of this type of ancillary service is generally uncertain because little information has been collected on the exact behavior of an operating wind farm, and the cost of these services has never been priced independently.

To address the issue of ancillary services, NREL completed a study early in 1999 on the importance of wind farm monitoring at transmission grid interconnection points. The result was a proposal to fund the monitoring of electrical output on a second-by-second basis at many large wind stations in cooperation with owners and operators. Those contracts will begin in 2000 and should provide valuable information on the potential effects of power output fluctuation on the value of wind power. Meanwhile, recognizing the need for this information, Enron Wind Corporation and NREL researchers worked together to set up a monitoring system at the Lake Benton II station in 1999.

Once this data is collected for different hardware and different wind resources, analysts will plug it into utility system models to evaluate the costs of ancillary services. If these costs are fairly small, then a barrier to wind farm development is removed. If there are significant costs, then steps can be taken to mitigate these costs through wind turbine and wind farm control systems, turbine hardware design modifications, or through forecasting.

Similarly, these analyses will determine the added value of ancillary services, such as reactive power, that wind farms can potentially provide. In fact, UWIG, NREL, and memebers of the NWCC are currently assessing the benefits that wind plants may bring to the system. Wind farms using Zond turbines have power electronics-based variable-speed technology that can control harmonics and provide reactive power to strengthen the distribution systems of smaller utilities. If owners of distributed wind generation are paid for the benefits that accrue to the distribution and transmission system, then wind farms will be more economically attractive to developers.

Another issue of value is the variability of output from wind power plants of different sizes. Theoretically, the bigger the wind farm the lower the relative extremes of fluctuation in output as changes in wind speed move across the development. How much advantage large farms have over small ones is a question that will be answered with data from the DOE-funded cooperative wind farm monitoring studies.

Yet another important question about the value of wind-generated electricity is its location with respect to population centers where electricity is used. If the power is consumed near where it is generated, then its value should be higher because it does not need the transmission system to carry the electricity to the user. In addition, if the wind installations are distributed throughout the utility system rather than in a single large wind development, the reliability should be higher due to geographic diversity. All of the turbines' power will not fluctuate up and down together; the outputs will fluctuate according to the instantaneous wind speed at each location.

Selecting the highest value development sites is of prime importance to utilities and developers. In Iowa, for example, where the legislature is considering a portfolio standard for renewables, utilities must decide how much capacity should be placed in each of several possible locations to maximize the value of the electricity generated. A subcontractor to NREL, working with the Iowa Wind Energy Institute, has developed advanced methods to evaluate the value of wind within established utility model frameworks. Using these models and capacity estimation based on the wind resource, the analyst determined the optimum mix and the level of uncertainty. This kind of information could be used by the utilities seeking wind-generating sources of electricity and by wind plant developers proposing power plants to utility buyers.

TRANSMISSION AND DISTRIBUTION

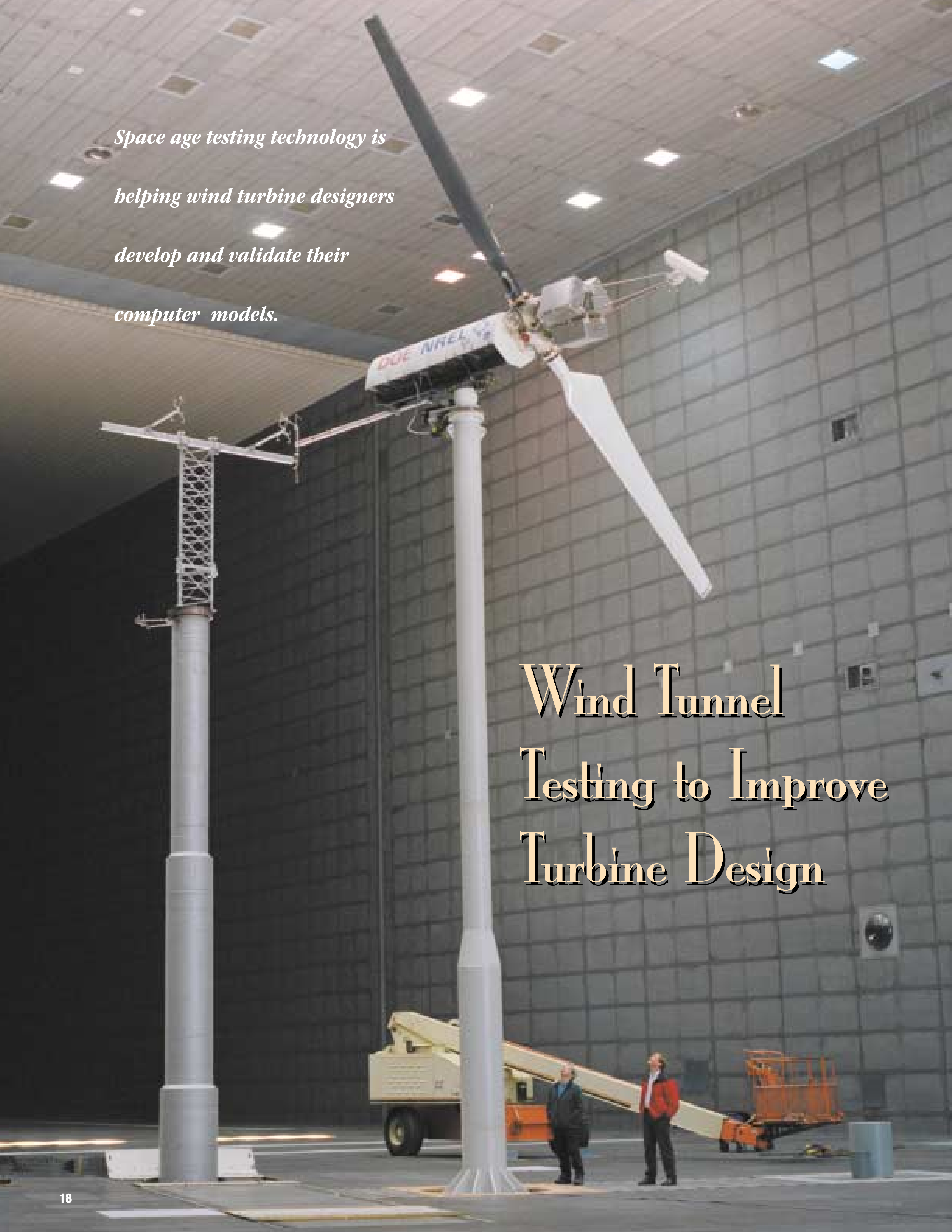
Another issue is just how much wind-generated electricity can be harvested and transmitted through power lines from the best resource areas. NREL and Western Area Power Administration worked together in 1999 to answer this question for North and South Dakota. Asking the simplest questions about maximum capacity, analysts ran the utility transmission model for various scenarios of wind contribution, based on actual resource location with respect to the transmission lines. The report is being finalized and will be used by developers, utilities, policy makers, and those planning transmission systems.

One issue facing wind-generated electricity today is whether it can be harvested and transmitted through power lines from the best resource areas.

The quality of power generated by wind turbines is another concern of utilities. In 1999, DOE's NWTC (operated by NREL) was accredited to conduct power quality tests for wind turbines according to International Standards Organization standards. Now a wind turbine manufacturer can have its turbine tested by NWTC staff and certified by the Underwriters Laboratories, Incorporated, to international standards. This international testing standard addresses utility concerns about power quality.

CHANGE CAN BE GOOD

Although the changing market for electricity in the United States presents challenges for developing wind-generating stations and integrating their output with conventional sources of electricity, in the long run, wind energy will benefit from a more competitive market for electricity. Electricity generated in wind farms is a highly cost-competitive renewable energy option. As customers increasingly choose renewable and clean electricity in the open market, the goals of Wind Powering America will be achieved. ◆



Space age testing technology is helping wind turbine designers develop and validate their computer models.

Wind Tunnel Testing to Improve Turbine Design

THE SUCCESSFUL START OF WIND TUNNEL STUDIES AT THE NATIONAL Aeronautics and Space Administration (NASA) Ames Research Center, near Mountainview, California, this year is a significant step toward improving turbine design. Understanding the behavior of wind turbine aerodynamics is critical to the design of new lower-cost, longer-lived, lighter-weight, more flexible wind turbines. This is why engineers at the National Renewable Energy Laboratory have worked with NASA to get the wind tunnel tests underway.

Wind turbine design draws on three key types of models. Models of the wind inflow tell the aerodynamic models what the wind looks like on a second-by-second basis. Aerodynamic models take this wind inflow information and predict loads on the turning rotor. These time-variant loads are fed to the structural-dynamics models, which predict the stress and strain on all the individual parts of the turbine. Designing durable turbines depends on the interaction of all three models to get the correct turbine structural response.

The structural dynamics models used today correctly predict the structural behavior of wind turbines if they are given the correct loads. The key is to provide the right inputs from the inflow and aerodynamic models. Atmospheric and wind tunnel testing are critical to developing the best inflow and aerodynamic models possible.

AERODYNAMICS TESTING

The aerodynamics models available today are based on simplified assumptions that are extremely difficult to test under natural atmospheric conditions. In the atmosphere, the wind flow is never smooth enough to allow engineers to separate out the unsteady inflow from the dynamic response of the turbine itself. In other words, the turbine response to the wind is often masked by random gusts and turbulence.

The absence of gusts and turbulence in the large wind tunnel at NASA will allow NREL's engineers to fully understand the aerodynamic response of rotating turbine blades under a steady wind inflow. Once the steady response is correctly modeled, it can be used to sort out the effects of the turbulent inflow in atmospheric tests.

At left: Using the 80 by 120 foot (24 by 37 meter) wind tunnel at the NASA Ames Research Center, NREL researchers have a unique opportunity to observe actual turbine behavior in a controlled, operating environment.

Most wind tunnels are much too small to conduct full-size, three-dimensional testing of complete wind turbines. Aerodynamic tests are normally constrained to turbine components such as blades or two-dimensional blade sections. Engineers then assemble the component results and project the response of the entire blade, rotor, and turbine.

In contrast, the tests at NASA will reproduce the actual response of the entire wind turbine under normal operating conditions. In addition, researchers will also be able to test off-nominal conditions such as yawed inflow, simulating rapid changes in wind direction.

MEASURING THE WIND

Work is also underway to improve the models of wind inflow that feed the aerodynamic models. The Long-Term Inflow and Structural Testing (LIST) Program is a joint, basic science program conducted by NREL and Sandia National Laboratories to understand inflow structure and turbulence and how these characteristics affect wind turbine loads. It explores atmospheric events—especially rare ones—the turbine may experience that can heavily influence the turbine's operational life. Automated instruments will measure both inflow and turbine response, including wind speed, wind direction, and blade loads 30 times a second for more than a year.

Observations from one of the highly instrumented turbines at the U.S. Department of Agriculture's research station in Bushland, Texas, will provide an important database to quantify inflow effects. At Bushland, the wind properties are characterized by lower turbulence levels consistent with locations in the Great Plains. Sandia instrumented a 100-kW, 52-foot (16-meter) diameter turbine and a meteorological inflow array to collect both turbine and inflow data. Researchers will use the Bushland turbine and associated wind-monitoring equipment to gather load and wind information continuously for approximately one year.

The Bushland work on mid-sized turbines is complemented with experimental results from a larger turbine at NREL's National Wind Technology Center. Wind at the NWTC is more energetic and turbulent because of the mountainous terrain upstream of the test site. Researchers are particularly interested in wind loads created by large wind gusts and extremely turbulent flows passing through their 600-kW test turbine. In the extreme, such inflow events can reduce the life of a turbine blade by 50%.

Documenting these events is part of the ultimate goal of developing accurate models to predict turbulent inflow phenomena. Eventually, accurate inflow and aerodynamic models will help researchers to design new turbines with enhanced capabilities that will withstand extremely harsh environments and operate for a sustained 30-year period.

Developing advanced design and analysis tools is much more than an academic exercise. Enhanced modeling capability holds the dual promise of speeding the development process for new turbine architectures while saving money. In the usual development process, as many as two or three prototypes may be necessary before achieving a commercially viable machine design. Associated costs for such a development can easily range between $20 and $30 million for a single large-scale machine.

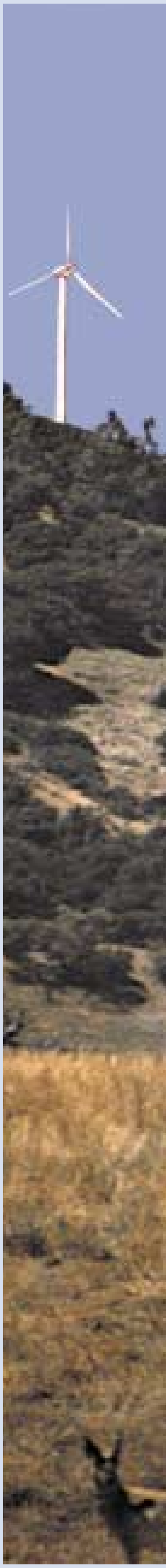
The future promises enhanced modeling tools that accurately predicte turbine performance by simulation, thus eliminating the need for interim prototype development and field testing. The total development costs would easily be reduced by a factor of 2–3 over the current development approach. Thus, the applied research being conducted at NASA, NWTC, and Sandia should speed technology development by reducing prototype requirements, reducing overall development costs, and delivering significantly improved wind turbine designs. ◆

Avian Interactions

Other research directed at moving wind technology forward is designed to increase our understanding of how birds use and interact with wind farms. This spectrum of research is aimed at addressing two key regulatory issues for wind power development—the effect of wind turbines on individual birds that are protected by legislation such as the Migratory Bird Treaty Act or the Endangered Species Act, and the effect of turbines on bird populations of specific species.

The DOE Wind Program's Avian Research Program began in 1992 in response to increasing concern about potential impacts of wind turbines on birds. Early wind turbine installations in the Altamont Pass area of California raised concern when golden eagle carcasses were found near turbines. This concern was viewed as a potential obstacle to future wind turbine developments. Preliminary results from recent studies at other wind turbine installations show that wind turbines can be installed without causing any biologically significant impacts on bird species. Much of the current research continues to strive to identify steps to reduce or eliminate any hazards wind turbines may pose to birds.

Based on the studies that have been done to date, significant levels of bird fatalities have been identified at only one major commercial wind energy development in the United States.
— Studying Wind Energy/Bird Interactions: A Guidance Document, National Wind Coordinating Committee



UTILIZATION STUDIES

One step to assessing the risk wind turbines pose to birds is to conduct utilization surveys. The survey records what species use a wind resource area (WRA), what part of the site they use, when they use it, and how much they use the area. A problem with previous bird utilization studies has been the lack of comparability among studies.

The publication in 1999 of a research guidance document by the National Wind Coordinating Committee, *Studying Wind Energy/Bird Interactions: A Guidance Document*, is an important step toward assuring comparable research results. The NWCC is a collaborative endeavor formed in 1994 to identify and work to resolve issues that affect the commercial use of wind power. The NWCC Guidance Document was developed over several years by the NWCC Avian Subcommittee and has been accepted by NWCC's diverse membership, which includes representatives from electric utilities, state utility commissions, state legislatures, consumer advocates, wind equipment suppliers and developers, green power marketers, environmental organizations, and state and Federal agencies. Although there can be no "cookbook" approach to research, the document provides basic concepts and tools for studying the interactions of birds with wind turbines. The document also points out that "Based on the studies that have been done to date, significant levels of bird

Any potential impact of wind turbines on birds is an important placement criterion for proposed facilities.

fatalities have been identified at only one major commercial wind energy development in the United States." This statement refers to the Altamont Pass WRA, the site of NREL's largest avian utilization and behavioral research project.

BEHAVIORAL STUDIES

In addition to utilization studies that tell us how many birds of which species use a WRA, behavioral studies help researchers understand why birds collide with wind turbines. Studies of bird behavior around wind turbines may help researchers recommend ways to reduce the likelihood of bird collisions.

Current collaborative research is focusing on a number of parameters that may affect how wind farms impact birds. These parameters include topography; weather; habitat fragmentation; urban encroachment; habitat loss; species abundance, distribution, and behavior; and turbine type and location. Once the interactions are understood, any one of these parameters might be taken into consideration to improve the impact on birds in the area. The most common use of behavioral data from observations at a WRA is to change the wind farm layout. This could require keeping turbines out of frequently observed avian flight paths or increasing tower height to give birds more flight space below turbines.

In another approach, behavioral researchers are trying to better understand how a bird sees a wind turbine. A field study in the Foote Creek Rim Wind Resource Area in Arlington, Wyoming, is capitalizing on an opportunity to test the long-theorized idea that birds may see better in the ultraviolet (UV) spectrum. The 69 original turbines at this site were painted with UV-reflective paint. Subsequent turbines added to this site were not painted with UV-reflective paint. A study now under way is comparing bird behavior, utilization, and fatalities around both sets of turbines.

Research on bird behavior is ongoing in the laboratory as well. A pilot study began in 1999 at the University of Maryland to better understand how birds receive information from their environment. Researchers hope to learn whether painting blades with a certain type of pattern would help birds see the moving blades more clearly. One theory about why birds do not see wind turbine blades is that they experience "motion smear" when looking at moving blades, especially the tips. Motion smear occurs as the image of an object moves across the retina with increasing speed, becoming blurred. By painting blades with different patterns, researchers are trying to determine whether the additional stimuli—the contrast from the patterns—can minimize the motion-smear effect.

Once the interactions between birds and turbines are understood in sufficient detail, it is possible that wind turbines and wind farms could be designed to minimize impact on birds. Examples of turbine design adjustments range from painting a more visible pattern on the blades to adjusting revolutions per minute (rpm), tower height, and even tower type. In some instances, during the planning and siting phase of wind farm development, relocating the turbines may require only a slight change. Such micrositing could result from detailed understanding of bird behavior in the region. Although siting to reduce avian interactions may impact the economic bottom line of a project, this may be less costly than having to deal with avian issues if they arise after the turbines are installed.

Building Better

Turbine development and testing programs are helping transfer applied research findings from the laboratory to industry engineers that design, build, and operate wind turbines.

IN 1999, TWO NEW TEST CAPABILITIES AND ADDITIONS TO THE ARSENAL OF accredited test procedures increased the capacity to serve the wind industry at DOE's National Wind Technology Center, which is operated by the National Renewable Energy Laboratory near Boulder, Colorado. The Dynamometer Test Stand is a unique facility for testing full-scale wind turbine drivetrains. The Advanced Research Turbine Test Bed provides a platform for testing wind turbine control strategies. Together with comprehensive design review and accredited test procedures for turbine certification, these additions to industrial support and research activities at the NWTC will continue progress toward developing lower-cost, highly reliable wind turbines.

DYNAMOMETER TEST STAND

In August 1999, NREL engineers throttled up the new 2.5-MW Dynamometer Test Stand for wind turbines. Located in a cavernous 7500-square-foot building at NREL's NWTC near Boulder, Colorado, the Dynamometer Test Stand is a unique tool to improve performance and reliability of wind turbines and, ultimately, to reduce the cost of the electricity they generate. The dynamometer's ability to test full-scale wind turbine drivetrains will help engineers from NREL and industry understand the lifetime impact of various wind conditions, with the goal of improving hardware designs.

NREL's new Dynamometer Test Stand is the only one of its kind. Before building the impressive test stand, NREL test engineers hoped to rent facilities to conduct dynamometer tests on large wind turbines. But they could not find a dynamometer with the features they needed, even outside of the wind industry. The uniqueness of NREL's facility has attracted international attention. National laboratories in other countries are inquiring about the test bed's capabilities, because, worldwide, there are many wind turbine design issues that could be investigated with this new tool.

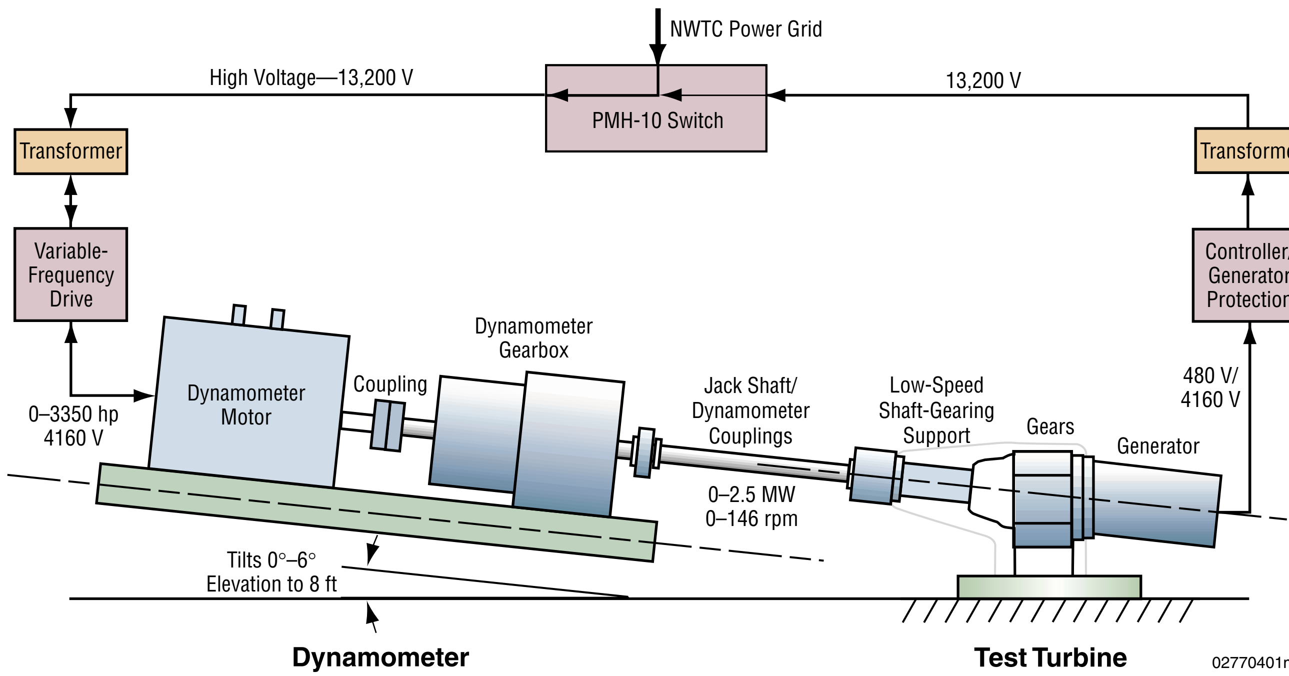
By October 1999, the U.S. wind industry began taking advantage of this versatile addition to the Wind Program's testing facilities at the NWTC. Since 1990, the industry has used the NWTC blade test facility where loads are applied to full-size wind turbine blades. After subjecting blades to a series of these tests, engineers develop a sense of how long the blades will last in the field. Industry now has an appreciation of the benefits of blade testing and considers it a required step in the turbine development process. Now, with the addition of the Dynamometer Test Stand, engineers can perform both blade and drivetrain tests to get results for full-scale wind turbine systems and components.

At left: NREL's new 2.5-MW Dynamometer Test Stand will help engineers understand the lifetime impact of wind conditions to improve hardware designs.

In the Dynamometer Test Stand, engineers can test all wind turbine components except the blades and tower. They place the wind turbine—minus the rotor and tower—in the Dynamometer Test Stand, adjusting the huge steel support platforms for the size of the turbine and the angle of the rotor shaft. Then they connect the dynamometer to the hub shaft and apply the equivalent of the wind hub loads directly to the drivetrain shaft. This simulated wind force is then used for testing the operation of the turbine

The Dynamometer Test Stand includes a powerful 3350-horsepower electric motor coupled to a 2.5-MW, three-stage epicyclic gearbox with an output of variable speeds from 0 to 146 rpm and the ability to run at torque levels of as many as 9.6 million inch-pounds, depending on the need. Engineers at NREL are working to develop closed-loop torque control that will allow simulation of real wind conditions, including random wind gusts being applied to the shaft. The turbine should respond to those turbulent gusts the way it would typically respond in the field, thus providing valuable measurements of stress on components.

The test bed is designed to accommodate the gearbox dimensions and shaft position of any wind turbine system from 100 kW to 2 MW in size. A 50-ton electric crane operates on a bridge 30 feet (9 meters) above the test table to move the large test drivetrains into position. Tests can also be conducted in conjunction with hydraulic actuators or electric cranes to apply transverse or ancillary bending loads to a rotating shaft or coupling.



The test stand is designed to accommodate the gearbox dimensions and shaft position of any wind turbine system from 100 kW to 2 MW in size.

NREL's new dynamometer will help designers working to increase the field lifetime of wind turbines. An important aspect of field lifetime is the gradual wear on components resulting from loads experienced during years of operation. Wind turbine engineers design to decrease the loads on components or to make the components more resistant to wear. Drivetrains contain many components that work together as a system, and each of these parts is the subject of design and manufacturing improvements to reduce wear.

These design improvements can be tested on the dynamometer. For example, a Zond 750-kW turbine, the first to be connected to the dynamometer, underwent tests to evaluate the net improvement on performance and reliability of several individual changes to components. One of the changes involves using different materials and manufacturing techniques for gearbox elements. Engineers run a test with the old component on a fully instrumented drivetrain. Then they substitute a new component to see if there is an improvement based on fixed parameters. They can change the gear sets within the gearbox and measure the time that it takes for the gears to start developing wear. They can also look at a new brake design and see if it lowers the loads on the drivetrain during stops.

In addition to gearboxes and brakes, the dynamometer can test all the other components of the drivetrain—the control system, the generator, the power transmission system, the fault-logic controls, and more.

While improving the lifetime of wind turbines, designers are also increasing the size of turbines to reduce the cost of electricity. The need to test these larger turbines provided part of the impetus for building the 2.5-MW Dynamometer Test Stand.

The new large test stand can perform endurance testing for megawatt-scale turbines to demonstrate the fatigue life of a particular gearbox. Such endurance tests require high, steady-state power levels that vary from 1.3 to 1.8 times the rated capacity of the test turbine. The new facility can test machines rated up to about 1.8 MW. Megawatt-scale machines can undergo endurance tests that require several months of continuous, unattended operation. The test stand's sophisticated supervisory control and data acquisition system monitors the critical test parameters and can shut down the test if abnormal conditions are detected.

The first lifetime endurance test will be conducted in 2000 on a Zond 750-kW turbine. The test drivetrain will be Zond's best design that incorporates any changes suggested by earlier component testing on the dynamometer. According to Brian McNiff, a consultant working with Zond, "We plan to put the equivalent of 30 years on the machine in three months by running it at 1 MW and by applying a lifetime's worth of braking cycles during the period." The heavily instrumented machine will provide

A 50-ton electric crane moves the large test drive-trains into position on NREL's new 2.5-MW Dynamometer Test Stand.

We plan to put the equivalent of 30 years on the machine in three months by running it at 1 MW and by applying a lifetime's worth of braking cycles during the period.
— Brian McNiff, engineering consultant to Zond

valuable information about what wears out first over the lifetime of the machine.

In addition to testing turbines from industrial partners, the Wind Program's new Dynamometer Test Stand will support the development of prototype advanced wind turbines. These turbines will lower the cost of wind energy to levels that are competitive with electricity generated by coal, nuclear, oil, and gas. The prototypes will be lighter than today's turbines, making use of optimum design techniques. Testing prototypes from NREL's Advanced Turbine Research Program on the Dynamometer Test Stand will confirm the benefits of new approaches and identify problems requiring redesign well before machines are deployed for field testing.

ADVANCED RESEARCH TURBINE

In July 1999, a second turbine dedicated strictly to research was erected at the NWTC's Advanced Research Turbine (ART) test bed. The test bed's two 600-kW turbines operate at the high wind speeds and under the extreme-duty load cycles required for research testing. Although the turbines look identical from a distance, their operation differs to meet specific research goals.

The first turbine, ART #1, installed in 1997, performs advanced tests on innovative components for the wind turbine industry and for specific research projects. ART#1, developed with DOE assistance, is a structurally overdesigned, 600-kW Westinghouse turbine with a 42-m-diameter, two-bladed, upwind, teetered-rotor and full-span, hydraulically activated, pitch-controlled blades. Tests in 1998 characterized its power performance and identified loads on key system components. In 1999, ART #1 joined the LIST program, in which the turbine's performance will be analyzed to help researchers understand inflow and the resulting structural loads on the turbine's system.

The second turbine, ART #2, installed in 1999, is based on the same 600-kW Westinghouse design but is optimized to test wind turbine control systems. Two key features make this turbine ideal for testing control systems. First, the blade pitch is activated by electromechanical actuators or motors. These motors pitch the blades about 10 times faster than the hydraulic system on ART #1. This makes the turbine extremely responsive to control system signals—a feature deemed necessary to the next generation of wind turbine designs. The second feature that makes ART #2 a good test bed for wind turbine controls is its full-range, variable-speed drive. To achieve variable-speed operation, an induction generator is connected to a sophisticated power electronics package. This setup allows the rotor and generator to run at variable speed, optimized aerodynamically with the wind speed while the power electronic components convert the output to the steady 60-Hz power that the utility demands.

The new turbine will undergo checkout and design of control software until the next wind season—November 2000. Checkout is extensive because there are more than 50 specialized instruments on this test bed and each must be carefully calibrated and controlled. In addition to all the control circuits normally used to test a commercial wind turbine, ART #2 has about 20 extra instruments to provide data about the structural and power output impacts of various control strategies. For example, the blades and the tower have strain gauges to measure both flap and edge bending in response to turbine operation. Instruments also measure rpm and torque of both the low-speed and high-speed drives. Accelerometers on the turbine measure movement of the overall structure such as nodding and shaking. And there are instruments that measure frequency, voltage, power, and many other characteristics of electrical output from the generator and the power electronics package that makes variable-speed operation possible.

The information provided by all of the test instruments is recorded by a special high-bandwidth integrated control and data acquisition system developed under previous DOE research projects. This data acquisition system records information at such a high speed that researchers can detect short-duration events that could have a large impact on structures or output. In addition, the system allows correlation of events between the tower and the turbine—important information for variable-speed operation. Correlation of measurements at an upwind meteorological tower with turbine performance will also be possible.

NWTC's new test bed will produce information in two important ways to improve control strategies. First, existing control systems can be tested on ART #2, and their impact on structures and output can be evaluated. Second, research engineers at NREL can try out new control strategies and move incrementally toward optimum methods of control. The end result should be turbines that produce more electricity with less strain on components. This means more productive machines with longer lifetimes and lower-cost electricity.

CERTIFICATION TESTING

In 1999, the Wind Program added three new tests to its certification testing service at NREL's NWTC. Certification is a procedure whereby an independent party gives written assurance that a product, process, or service conforms to specified requirements or standards. In the case of wind turbines in the United States, the Underwriters Laboratories, Incorporated (UL), certifies that machines operate in accordance with international standards issued by the International Electrotechnical Commission (IEC). To measure conformance to IEC standards, test procedures must be written that meet the standards. Engineers at the NWTC wrote detailed test procedures for three recently approved standards—power quality, structural loads, and blade structural loads. These test procedures were accepted in 1999 by the American Association of Laboratory Accreditors. Now tests for these standards and for power performance and noise—approved in 1998—performed at the NWTC are accepted by certifying parties throughout the world.

In addition to reviewing certification test results, certifying bodies perform a design audit of a wind turbine to determine conformance to accepted design practices. Because there is no agency in the United States with the technical skills to do a design audit, NREL has developed a complete design evaluation quality system. The quality system describes how the design evaluation is performed. Each company requesting an audit receives a document that describes the design evaluation process step by step. The documentation includes checklists for the designer to see exactly what the evaluator is looking for.

With standardized design review and accredited certification testing, the NWTC can provide all the documentation necessary for a machine to receive certification. These certification tests for international standards can be performed on any size machine.

UL will work with NREL to take advantage of the large-scale test facilities at the National Wind Technology Center in Golden, Colorado. These facilities are the most advanced in the United States for wind turbine system testing. ◆

Researchers from Sandia National Laboratories instrument three 52-foot-diameter turbines mounted on 72-foot towers to gather load and wind inflow information.

Left to right: The National Wind Technology Center, near Boulder, Colorado. Dynamometer Test Stand at the NWTC. Next-generation research turbine at the NWTC.

The NWTC's 290-acre site north of Golden, Colorado, is the focal point for wind turbine research and development in the United States.

THE FEDERAL WIND ENERGY PROGRAM

Generating electricity with wind energy diversifies the nation's energy supply, takes advantage of a domestic resource, and helps the nation meet its commitments to curb emissions of greenhouse gases. In accordance with our national energy policy, DOE's Office of Energy Efficiency and Renewable Energy manages the Federal wind energy program.

The mission of the DOE Wind Program is to enable U.S. industry to complete the research, testing, and field verification needed to fully develop the world's most cost-effective and reliable advanced wind technologies. The Program accomplishes this mission by directing basic science, research, and development efforts at two of DOE's principal laboratories—the National Renewable Energy Laboratory and Sandia National Laboratories.

Equally important is work with industry, utilities, environmentalists, and other stakeholder groups. Groups such as the American Wind Energy

Association, the National Wind Coordinating Committee, and the Utility Wind Interest Group receive financial and technical support from the program. Government researchers work side-by-side with wind turbine manufacturers, university researchers, wind power plant developers, wind plant operators, and utilities to advance the technology and improve the understanding of wind energy systems.

The centerpiece of the Wind Energy Program is the National Wind Technology Center (NWTC), located near Boulder, Colorado, and managed by NREL. The NWTC is a world-class research facility that supports the research, development, and testing needs of industry. The NWTC houses laboratories, offices, and field-test facilities for the three major research areas in the Wind Energy Program: (1) Applied Research, (2) Turbine Research, and (3) Cooperative Research and Testing. Expertise to thoroughly explore all of the issues involved in developing advanced wind technology is provided by both NREL and Sandia.

APPLIED RESEARCH

The Applied Research Program seeks to understand the basic scientific and engineering principles that govern wind technology and underlie the aerodynamics and mechanical performance of wind turbines. The program also seeks to improve cost and reliability of different wind turbines, by conducting applied research in aerodynamics; structures and fatigue; advanced components and systems; as well as wind characteristics. A combination of in-house research, subcontracted and cost-shared research with private industry, and a strong program to involve scientists and engineers from university research groups, contributes to the advancement of wind turbine technology.

- **Aerodynamics and Structural Dynamics.** To lower costs and lengthen lifetimes of wind generators, lighter, more flexible turbines are being developed. Critical to the development of such new designs is improved understanding of the behavior of wind turbine aerodynamics. The goal of the aerodynamics program is to couple aerodynamics loads and performance codes with field-test and wind tunnel

Left to right: Modal testing provides researchers with information about the wind turbine's physical properties as part of the Long-Term Inflow and Structural Testing National Laboratories, Albuquerque, New Mexico

data to improve current design codes. Field-test data are collected at the NWTC, including the aerodynamic and structural parameters of a highly instrumented experimental wind turbine. In addition, full-scale wind tunnel testing conducted during fiscal year (FY) 2000 at the NASA Ames Research Center will provide data to benchmark future aerodynamic-code development. Dynamic codes for predicting structural response are under development.

• **Systems and Components.** Improving components and subsystems is vital to increasing performance and reliability and lowering costs. The Advanced Research Turbine Test Bed tests innovative approaches to component design. The highly instrumented ART turbines also support testing of large-scale turbine components such as generators, rotors, data acquisition systems, and controls.

The ART Test Bed will be used in FY 2000 for the Long-Term Inflow and Structural Testing Program, which aims to understand inflow and resulting loads in the turbine system. A major goal of the LIST Program is to identify and document atmospheric events—especially rare ones—that can heavily influence fatigue lifetime of turbines.

The new variable-speed ART turbine with high-speed blade pitch control mechanisms, installed in 1999, will allow testing of wind turbine control systems on a full-sized turbine.

• **Materials, Manufacturing, and Fatigue.** Lowering the cost of electricity generated by wind energy requires some combination of improving the amount of energy captured, reducing capital costs, and reducing maintenance. One way to reduce capital and maintenance costs is to improve blade strength and reliability during the manufacturing process. Researchers exploring materials, manufacturing, and fatigue seek to improve manufacturing processes, build and test components, and introduce innovative processes in turbine and blade design.

• **Wind Hybrid Systems.** Power systems using wind turbines linked to diesel generators, battery storage, photovoltaics, and other energy sources are becoming an increasingly effective method for providing electricity in areas with small, isolated population centers. The Hybrid Power Test Bed at the NWTC supports industry development and validation of such innovative wind hybrid systems, components, and concepts. The HPTB can simulate loads and connect or disconnect storage and generation

(List) Program at Sandia. The LIST Program at Sandia National Laboratories strives to understand inflow and resulting loads in the turbine system. Sandia

sources on command. When combined with field testing and demonstration, HPTB research provides industry with the opportunity to commercialize new hybrid technologies.

- **Avian Research.** The potential impacts of wind turbines on birds is a concern at both new and existing wind power sites. The wind program conducts research to identify ways to reduce or avoid bird deaths caused by wind energy development. In cooperation with industry, environmental groups, governmental bodies, and universities, the program studies the impact of current wind plants; develops approaches to siting wind plants, and disseminates information on research to reduce or eliminate the impact on birds of wind energy development.
- **Wind Resource Analysis.** Analysis of wind resource data and the models used to assess the wind resource are used to generate wind resource maps of use to the industry and government planners. In addition, modeling tools to forecast the energy output of wind turbine projects are under development in conjunction with U.S. and international experts.

TURBINE RESEARCH

DOE's Wind Energy Program sponsors a multi-faceted Turbine Research program to assist U.S. industry in developing competitive, high-performance, reliable wind turbine technology for global energy markets. The program funds competitively selected industry partners in their development of advanced technologies.

Currently, research projects include a Near-Term Research and Testing contract with Zond Energy Systems, Next-Generation Turbine Development contracts with the Wind Turbine Company and Zond Energy Systems; Small Wind Turbine Projects with Bergey Windpower Company, WindLite Corporation, and World Power Technology; and a cold weather turbine development contract with Northern Power Systems.

The Wind Turbine Verification Program, a joint effort with the Electric Power Research Institute, evaluates early commercial wind turbines in distributed power applications.

The Small Wind Turbine Field Verification Program provides U.S. manufacturers the opportunity to verify the performance and reliability of their machines at the NWTC and in a variety of actual applications.

The NWTC's Industrial User Facility incorporates structural testing and other capabilities with the goal of encouraging government and industry collaboration in technology innovation. Major activities include blade testing, turbine testing, laboratory testing, on-site certification testing, mobile certification testing, and modal testing for field applications. In addition, comprehensive design reviews are available to industry.

Additional activities include wind farm monitoring to characterize electrical output, utility analyses, and support for developing information such as with the National Wind Coordinating Council, the Utility Wind Interest Group, and the American Wind Energy Association.

COOPERATIVE RESEARCH AND TESTING

Through Cooperative Research and Testing activities, the program works with the wind industry, end users (such as utilities and governments), and international agencies and laboratories to further the use of wind energy. Testing is one of the most valuable services the Wind Program offers to U.S. industry. Most wind turbine companies have neither the resources nor the expertise to conduct these tests in-house.

Wind turbine blade testing includes three types of tests—ultimate static strength, fatigue, and nondestructive. These tests help industry identify and correct problems before going into full-scale production.

Modal testing is performed by NWTC engineers to provide useful information about the structural-dynamic characteristics of a wind turbine system. Companies use this information to avoid designs that are susceptible to fatigue-related failure and excessive vibrations.

Dynamometer testing is conducted on turbine drivetrains as large as 1.8 MW both to identify weak points in design and to measure the lifetime of systems.

The DOE Wind Program continues to play a major role in developing international standards and working to ensure their application in certification test and accreditation programs. At the request of U.S. industry, NREL has become an accredited test laboratory able to supply test reports to any certification body around the world. NREL, working with Underwriters' Laboratory, developed a U.S. certification program.

The American Association of Laboratory Accreditors has approved NREL as a testing laboratory for measuring noise, power performance, turbine loads, and blade loads. NREL also continues to develop and document quality assurance procedures for both testing and certification.

Other activities to help U.S. industry compete abroad include cooperation with member countries of the International Energy Agency. A Round-Robin Testing activity to be completed in calendar year 2000 will help calibrate testing equipment at laboratories in different countries. Cooperation supporting international databases of rotor aerodynamics and wind characteristics will help researchers and designers alike.

The DOE Wind Program began active support of the Wind Powering America initiative in 1999 when it was announced by of the Secretary of Energy. Drawing from all the activities described above, researchers from NREL, Sandia, and affiliated institutions are providing information and analysis to design, direct, and deploy Wind Powering America activities.

Wind energy is currently the fastest growing energy technology in the world. The DOE Wind Energy Program continues to collaborate with industry and international partners to ensure that wind energy will continue to provide clean, low-cost, reliable power to meet both the need for electrical power today and the projected electrical demands of tomorrow. ◆

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