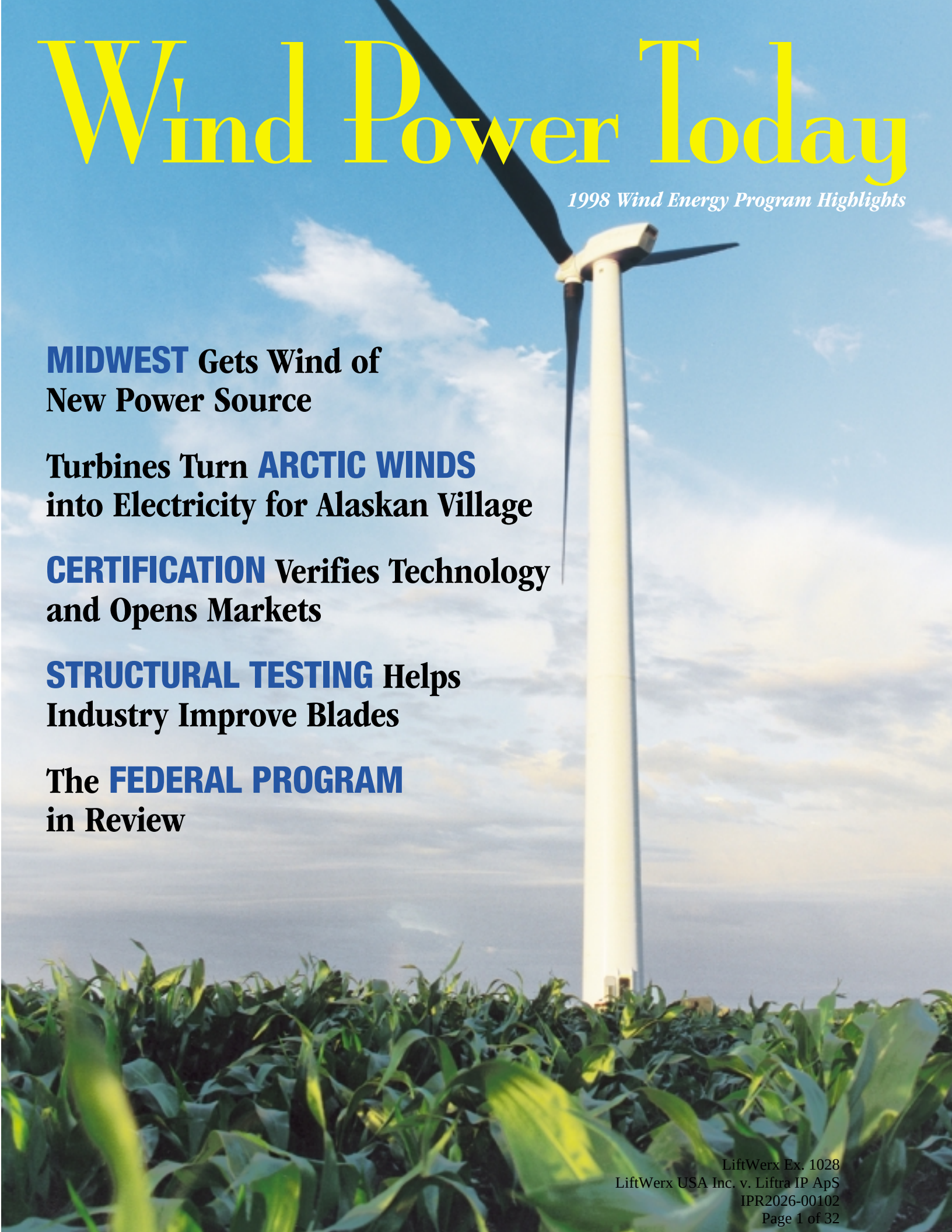
Wind Power Today

1998 Wind Energy Program Highlights



MIDWEST Gets Wind of New Power Source

Turbines Turn **ARCTIC WINDS** into Electricity for Alaskan Village

CERTIFICATION Verifies Technology and Opens Markets

STRUCTURAL TESTING Helps Industry Improve Blades

The **FEDERAL PROGRAM** in Review

LiftWerx Ex. 1028
LiftWerx USA Inc. v. Liftra IP ApS
IPR2026-00102
Page 1 of 32

1998: THE YEAR IN REVIEW

January

The 18th Wind Energy Symposium, sponsored by the
American Society for Mechanical Engineers, is held in Reno, Nevada.

April

California consumers are offered their choice of electricity suppliers.
Six residential energy service providers offer "green" products using renewable energy.
At least two of these products include commitments to construct new wind projects in the state.

The Windpower '98 Conference is held in Bakersfield, California.
Participants tour the Zond Energy Systems, Inc., turbine manufacturing facility in nearby Tehachapi.

June

The National Renewable Energy Laboratory completes testing of a highly flexible wind turbine.
The test results are used to validate structural dynamics codes.
Researchers believe highly flexible turbines may help bring down wind energy costs.

August

National Wind Technology Center engineers complete full-scale testing
of a production Zond Z-48 wind turbine blade in the Industrial User Facility.
This is the first time a two-axis load test is performed on a blade in the United States.

September

Enron Wind Corporation announces completion of the
107-megawatt Lake Benton I Project, the world's largest single wind power generation facility,
located near Lake Benton, Minnesota.

October

Iowa Distributed Wind Generation Project,
consisting of three Zond Z-750 kW Series turbines, begins commercial operation.

Dedication is held for the first utility wind turbines in Nebraska at Springview.
Local residents celebrate Wind Turbine Day.

December

National Wind Technology Center receives accreditation from the
American Association of Laboratory Accreditors for wind turbine power
performance and acoustic emissions (noise) tests.
Laboratory accreditation will support international acceptance of the tests.

About "Wind Power Today"

THE WORD THAT BEST DESCRIBES WIND POWER TODAY IS GROWTH. After several sluggish years, wind energy projects are popping up throughout the country. Construction crews are busy getting wind turbines in the ground before June 30, 1999, when the eligibility period for a federal tax credit on electricity produced by wind turbines will end, unless legislation is passed to extend it. Most of the new wind turbines are being installed in the Midwest and Great Plains states, where the winds are strong and steady and agricultural land can be shared by wind turbines. In Alaska, utilities are interested in a small but growing project in Kotzebue, Alaska, where turbines are cranking out power from Arctic winds.

Worldwide, wind power continued to be the fastest-growing energy source in the world in 1998. To compete abroad, U.S. wind turbine manufacturers are pursuing wind turbine certification, now required in five European countries. Testing services are provided by the U.S. Department of Energy Wind Energy Program in support of certification, and Underwriters Laboratories Inc. serves as the U.S. certification agent.

The Federal Wind Energy Program continues to support wind turbine manufacturers in their efforts to reduce costs. The goal of the program is to reduce the cost of energy from wind to $0.025 per kilowatt-hour (in good wind areas). The goal will be achieved through the combination of applied research, turbine research, and cooperative research and testing.

Contents

2
Midwest Gets Wind of New Power Source

12
Alaska Storm Tests Turbines

16
Certification Program Opens Markets to U.S. Turbines

24
A Closer Look at Structural Testing

26
The Federal Wind Energy Program in Review

LiftWerx Ex. 1028
LiftWerx USA Inc. v. Liftra IP ApS
IPR2026-00102
Page 3 of 32

Midwest Gets Wind of New Power Source

Wind power plants are cropping up across the Midwest, fueling local economies and generating local support and interest in clean energy.

WIND TURBINES ON TOP OF BUFFALO RIDGE, MINNESOTA, APPEAR ON THE horizon, shooting up from the rolling farmland with sleek white towers and aerodynamically shaped black blades. This unusual new crop is sprouting up across the Midwest, turning the wind into a bankable asset for farmers and rural communities.

LiftWerx Ex. 1028
LiftWerx USA Inc. v. Liftra IP ApS
IPR2026-00102
Page 4 of 32

In 1998, the Midwest led the nation in wind energy capacity additions. The Lake Benton I Project atop Buffalo Ridge accounted for 73% of the 147 megawatts (MW) of wind energy capacity added in the United States. Several smaller wind installations went up in the Midwest as well. For 1999, the American Wind Energy Association estimates that nearly 300 MW of wind capacity, or about half of projected U.S. additions, will be added in three Midwestern states: Minnesota, Iowa, and Wisconsin. North Dakota and South Dakota have huge, untapped wind resources.

Farmers and local residents have long known about the near-continuous winds in some regions of the Midwest. Wind energy advocates have been lobbying for years for more wind turbines in the region. So why are there now so many wind energy projects built, under construction, or planned in the Midwest?

The dramatic increase in wind energy development in the Midwest appears to be the result of many factors. In some states, utilities are required to use wind energy. In addition to the Midwest's vast wind resource and work by wind energy advocates, the dramatic reduction in wind energy costs resulting from technology improvements has contributed to increased wind energy use. In 1980, wind-generated electricity cost about $0.35 per kilowatt-hour (kWh). Today, advanced wind turbines can generate electricity for $0.05/kWh or less in areas with good wind resources. The federal Production Tax Credit (for investor-owned utilities) and the Renewable Energy Production Incentive (for municipal utilities and electric cooperatives) contribute $0.017/kWh for wind-generated electricity, although the future of the tax credit is uncertain. Funding for utilities to get experience owning and operating wind turbines, through the U.S. Department of Energy (DOE)/Electric Power Research Institute (EPRI) Turbine Verification Program, has been the key to some utilities' decision to give wind energy a try.

In addition to technical and financial considerations, many utilities are responding to customer preferences for renewable energy: their customers like the idea of clean energy from a local resource. And some utilities hope that, by taking voluntary action to add renewable energy to their systems,

When completed, the 193-megawatt wind power project near Alta, Iowa, will be the single largest wind project in the world. The Zond Z-750 kW Series wind turbines, developed by Zond Energy Systems, Inc., will output enough power for 71,000 average Midwestern homes. Two large utilities will purchase the power to meet a state mandate.

LiftWerx Ex. 1028
LiftWerx USA Inc. v. Liftra IP ApS
IPR2026-00102
Page 5 of 32

they may reduce the likelihood that state or federal restructuring legislation will demand it. Wind energy plants also promise economic benefits to the rural economies where they are built.

The Lake Benton I Project comprises 143 wind turbines, each with a rotor (the part that spins) diameter of 157.4 feet (48 meters), as wide as a DC-10's wingspan. The towers are 168 feet (51.2 meters) high. Each 1369-square-foot (127.2-square-meter) turbine foundation covers as much ground as a single-family home. One 750-kilowatt wind turbine can supply the annual residential electrical needs of 280 average U.S. homes. The project as a whole has a capacity of 107 MW and can meet the annual electrical needs of more than 40,000 homes.

UTILITIES TOLD TO ADD WIND ENERGY

Like many of the large wind energy projects in the region, the Lake Benton I Project was state mandated. In 1994, the Minnesota legislature agreed to let Northern States Power (NSP) store nuclear waste at its Prairie Island nuclear plant but required the utility to add 425 MW of wind energy to its resource portfolio by 2002. NSP elected to purchase wind-generated electricity from project developers rather than owning and operating its own wind turbines. To help meet the 425 MW requirement, NSP signed an agreement with a subsidiary of Enron Wind Corporation to purchase power from the Lake Benton project, which Enron owns and operates. Enron's manufacturing company, Zond Energy Systems, Inc., provided the Zond Z-750 kW Series wind turbines. All but 132 MW of the 425 MW mandated in the Prairie Island agreement are under development.

In the Prairie Island legislation, the legislature directed the public utilities commission (PUC) to require another 400 MW of wind if the PUC determined it would be in the public interest. After public hearings were held around the state, in which consumers spoke out in favor of wind energy, the PUC decided in January 1999 to require NSP to add 400 MW of wind energy by 2012.

Residents of Lake Benton were skeptical when the first wind turbine project on Buffalo Ridge was built. (NSP agreed to purchase electricity from a 25-MW wind plant built by KENETECH Windpower to help meet the 425 MW requirement.) In an article in the Star Tribune, Lake Benton Mayor Marlin Thompson said, "Some people were of a mind that all this would not fit into the community. But it's been just the opposite." The town completed a $2.5 million dollar street and infrastructure project, including streetlight banners depicting wind turbines and colored concrete poured in the main intersection in the shape of wind turbine blades. The town calls itself the Windpower Capital of the Midwest and is planning to build a wind energy learning center to attract students and tour groups.

The three Zond Z-750 kW Series turbines at Algona, Iowa, are generating interest from local residents. Iowa utilities purchased the turbines with support from the U.S. Department of Energy and the Electric Power Research Institute.

NSP will purchase power from four other projects under construction on Buffalo Ridge. A second project developed by Enron and using Zond turbines will be 103.5 MW, nearly as large as the Lake Benton project.

Zond is developing a project in northwestern Iowa, near Alta and Storm Lake, a 193-MW wind power plant that, when completed, will beat out Lake Benton to become the largest single wind power project in the world. (Several geographical areas of California, such as Altamont Pass, are covered with turbines, but those turbines are part of smaller, separately owned projects.)

The Iowa project is a result of an Iowa state law requiring the state's investor-owned utilities to invest in wind energy. Enron will develop, construct, own, and operate the project and MidAmerican will purchase 112.5 MW of wind. IES Utilities, a subsidiary of Alliant, will purchase 80.3 MW.

The Zond Z-750 kW Series Wind Turbine

The Zond Z-750 kW Series wind turbines are descended from the Zond Z-40 wind turbine, developed with support from the U.S. Department of Energy (DOE) under the DOE Turbine Research Program. The Z-750 kW Series turbines are designed in accordance with the International Electrotechnical Commission 61400-1 standard for large wind turbines. Zond expects to receive a Design Evaluation Conformity Statement for the Z-750 kW Series.

Zond has a subcontract with the National Renewable Energy Laboratory (NREL) to lower the cost and improve performance and reliability of the Z-750 kW Series. A 20% cost of energy reduction is expected.

Zond's variable-speed Z-750 kW Series wind turbines are three-bladed, upwind, active yaw, pitch-regulated machines. The 750-kilowatt turbines come in three rotor diameters: 151, 157, and 164 feet (46, 48, and 50 meters). Larger rotors are used in lower wind speed areas. Airfoils (cross-sectional blade shapes) developed by NREL are used on the Z-750 kW Series turbines.

The Zond turbine blade under test at the National Wind Technology Center.

The advanced airfoil shape increases aerodynamic efficiency of the rotor and reduces the blades' sensitivity to roughness (caused by dirt and insect buildup), which improves energy capture and reduces the frequency of washings. The blades are made from fiber-reinforced plastic with epoxy resin for shape stability. Blades are available in white or black, which reduces icing in colder climates. NREL performed blade tests on the Z-750 kW Series wind turbines. Each blade has a variable-pitch control system. Blade pitch angles are controlled by a hydraulic actuator system.

The Z-750 kW Series turbine uses a six-pole, doubly fed, wound-rotor induction generator rated at 750 kilowatts along with a converter system that reduces the need for power conditioning by 75% over standard variable-speed systems. This configuration reduces the size, complexity, and cost of the power converter. The integrated drivetrain combines the main shaft and gearbox into one single unit, adding strength and minimizing the number of parts. The yaw system is electrically operated and directed by the controller. Two yaw drives share the operating load. Turbines are mounted on tubular or lattice steel towers with hub heights of 180, 197, or 213 feet (55, 60, or 65 meters).

Zond's integrated controller provides reliable and comprehensive control of wind turbine operations including pitch and speed regulation, aerodynamic and mechanical brake application, yaw control, hydraulic system control, fault monitoring, user communication, and an interface with the supervisory control and data acquisition (SCADA) system. The Zond SCADA system is designed to assist in the management, operation, and maintenance of each wind power facility.

The Zond Z-750 kW Series wind turbine.

LiftWerx Ex. 1028
LiftWerx USA Inc. v. Liftra IP ApS
IPR2026-00102
Page 7 of 32

Alliant is also purchasing power from a 42-MW project being developed by Florida Light and Power near Clear Lake, Iowa.

The Public Service Commission of Wisconsin requires Wisconsin public utilities to carry out activities to promote renewable energy development within the state. About 20 MW are under construction in Wisconsin.

Project developers are pushing to complete these wind energy projects by June 30, 1999, when the eligibility period for federal production tax credits ends. The tax credits of $0.017/kWh (adjusted annually for inflation) are available to investor-owned utilities for 10 years. DOE and members of Congress have proposed legislation extending the credits but the future of the tax credit is uncertain.

Although these projects are the result of state requirements, many other smaller projects are cropping up in the region, the result of forward-looking utilities that want to gain experience with wind energy.

TURBINE VERIFICATION PROGRAM

The U.S. Department of Energy/Electric Power Research Institute Turbine Verification Program (TVP) helps utilities gain experience with owning and operating wind turbines. The program also supports the validation of turbines developed under the DOE Turbine Research Program. Participating utilities share performance information and experiences at TVP workshops and in reports.

Two TVP wind projects were installed in Texas and Vermont in 1997. Also that year, DOE and EPRI selected utility projects to evaluate distributed wind generation using small wind turbine clusters connected directly to the electric distribution system. Projects in Algona, Iowa, and Springview, Nebraska, came on-line last year.

One of two Zond Z-750 kW Series turbines in Springview, Nebraska, the first utility-sized wind turbines in the state.

Distributed wind generation projects are connected directly to a distribution line. Most existing U.S. wind power plants use large numbers of turbines at a single site with a substation and transmission line interconnection. The advantage of distributed generation is that utilities can use existing distribution lines, which are located everywhere there are customers. Distribution lines are more likely to be located near good wind sites than transmission lines. The distribution lines must be three-phase, not single-phase, and the wind turbines need to be within several miles of a substation so that the voltage of the distribution lines is not adversely affected. Another advantage of distributed generation is that it allows utilities to locate generation nearer to load centers instead of expanding centralized generation.

IOWA UTILITIES JOIN TOGETHER TO LEARN ABOUT WIND ENERGY

Municipal utilities in Iowa were already talking about a jointly owned wind power plant when the TVP request for proposals went out in 1996. Seven municipal utilities joined together to submit a proposal and were selected to participate in TVP. Municipal utilities and cooperatives in Iowa are not required to use wind-generated electricity, as the investor-owned utilities are, but state or federal legislation may change that in the future. The utilities figured "sooner or later we're going to have to get into wind. Maybe the way to get into it is through this program, where we can get into it for less money and learn something about wind energy in the process," says Dave Martin, strategic projects coordinator for Cedar Falls Utilities, the lead utility. Customer support for renewables also encouraged the utilities to participate. The project cost $2.8 million, $1.3 million of which was funded by TVP. The participating utilities shared the remaining $1.5 million cost, which allowed each utility to minimize its risk.

The Iowa Distributed Wind Generation Project is located in the service territory of Algona Municipal Utilities, which maintains the turbines. The other utilities include Ellsworth, Esterville, Fonda, Montezuma, and Westfield, Iowa.

Three Zond Z-750 kW Series turbines with 164-foot (50-meter) rotors sit atop 164-foot (50-meter) tubular towers. The Algona project uses the first commercial Z-750 kW Series turbines with the 164-foot (50-meter) rotor. The annual average wind speed at the site is 15.9 miles per hour (7.1 meters per second). Annual power generation

LiftWerx Ex. 1028
LiftWerx USA Inc. v. Liftra IP ApS
IPR2026-00102
Page 8 of 32

is estimated to be 1.9 million kilowatt-hours per year per turbine. The plant generated its first kilowatt-hours in September 1998.

One of the project's technical challenges is that the turbines are located six miles from the nearest substation. Usually wind turbines need to be no more than three or four miles from the nearest substation to avoid causing power quality problems for nearby residents served by the distribution lines. The design of the Zond turbines' electrical system enables them to work well at the Algona site without causing power quality or voltage problems.

Besides learning about operating distributed wind generation, one of the biggest benefits from the project has been the strong customer support. The turbines are visible from miles around, and many visitors drive out to the site to watch the huge turbines operate.

"There are more visitors out there. It's probably the most positive thing that (Algona Municipal Utilities) has ever done, as far as customer interest in it. It's just a good symbol. People like the fact that the utility has gone this extra step and spent this extra money to do something that is perceived as good for the environment," says Tom Wind, a consultant to the Algona project.

The utilities involved in the project are sharing information about the project both through regularly scheduled TVP meetings and with other Iowa municipal utilities. Municipal utilities and cooperatives in the region attended an open house and project dedication in June 1999.

FIRST UTILITY WIND TURBINES IN NEBRASKA

Soon after the Algona project was built, the first utility-scale wind turbines were installed in Nebraska with support from TVP. The host utility and project manager of the Nebraska project is Nebraska Public Power District. The project site is in Springview, Nebraska, in the service territory of KBR Rural Public Power District. KBR maintains the facility and receives the power output. Other project owners include Lincoln Electric System, the Cities of Grand Island and Auburn, and the Municipal Energy Agency of Nebraska. The project consists of two Zond Z-750 kW Series turbines with 164-foot (50-meter) rotors that sit atop 213-foot (65-meter) lattice towers. The average wind speed at the project site is 16.7 miles per hour (7.5 meters per second) and annual power generation is estimated at 2.1 million kWh per year per turbine. The turbines were installed in September 1998. The project cost about $2.2 million dollars and TVP paid for half of the cost.

A dedication was held in October 1998 and Springview celebrated the first annual Wind Turbine Day, including a wind story contest and street dance. The locals refer to the project as the twin turbines.

Because the Algona project was a few months ahead of the Springview project, utilities involved with both projects have shared information.

"We've been meeting together…and sharing stories and helping each other. There aren't that many utilities that own utility-size wind turbines, and especially little utilities owning big turbines. We're definitely on the upward slope of the learning curve and it helps to share experiences with other people," says Wind.

The Springview turbines are located one and a half miles from the substation, which has power quality monitoring equipment installed. There have been no problems with power quality.

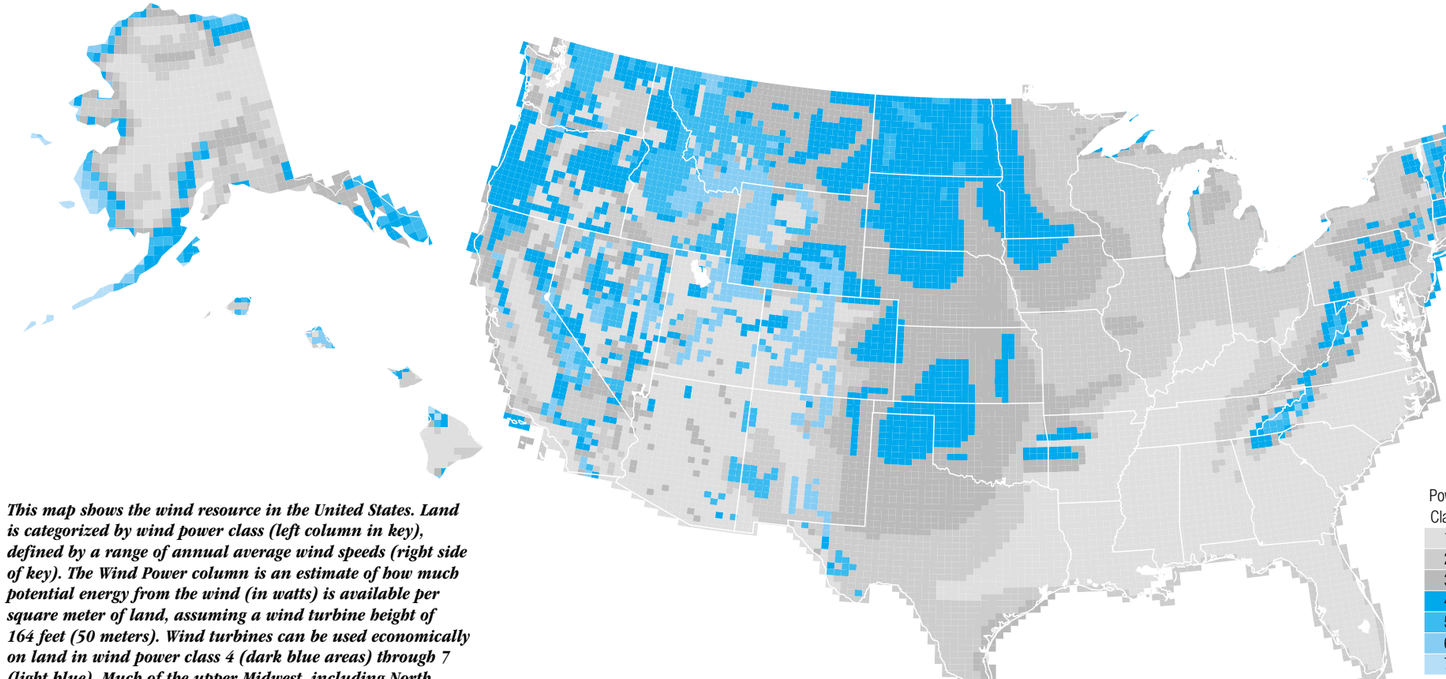
An early problem involved noise on area phone lines. Help from consultants and the addition of special equipment fixed the problem.

Other than the temporary phone-line problem, customers have been supportive. "We serve predominantly an agricultural base of customers, so we do have a lot of farmers and ranchers and a lot of these people are familiar with the old windmills. I think…they see wind as being a resource that we can use within our state, without having to go outside the state for the source of energy," explains Nebraska Public Power District Project Manager Mike Hasenkamp. The state's generation is fueled primarily by out-of-state coal, although the state is served by some small hydropower plants, gas peaking units, and a nuclear power plant. Using a local resource, the wind, fits into the farm and ranch mentality of self-reliance and independence.

WHERE DO THE MIDWEST WINDS COME FROM?

The Midwest's strong, frequent winds are the result of weather systems that originate as far away as the lee of the Canadian Rockies and the Gulf of Mexico. Upper-level winds (the jet stream) bring high-pressure systems bearing cold, dry Canadian air southward from Alberta to the Dakotas, southern Minnesota, and northern Iowa. Low-pressure systems, also influenced by upper-level winds, bring warm, humid air north from the Gulf. When the high- and low-pressure systems meet in the Great Plains, storms and wind are generated by the differences in moisture and air pressure. The flat terrain offers no obstructions to stop the wind and storms and the jet stream steers them east toward the Great Lakes. This "storm track" is the strongest in the region and storms move through continually. The surface winds are the strongest in the winter and spring, less strong in fall, and weakest in summer.

Two other storm tracks bring wind through the Midwest: one from Colorado to New England, and one from Texas to the mid-Atlantic region. These storm tracks are a bit weaker because the high-pressure systems are not as strong as those from Canada.



The United States Wind Resource

WIND ENERGY CLASSIFICATION

Power Class	Wind Power* watts/meter^2	Annual Average Wind Speed meters/second	miles/hour
1	<200	<5.6	<12.5
2	200–300	5.6–6.4	12.5–14.3
3	300–400	6.4–7.0	14.3–15.7
4	400–500	7.0–7.5	15.7–16.8
5	500–600	7.5–8.0	16.8–17.9
6	600–800	8.0–8.8	17.9–19.7
7	>800	>8.8	>19.7

*At 164 ft (50 m)

This map shows the wind resource in the United States. Land is categorized by wind power class (left column in key), defined by a range of annual average wind speeds (right side of key). The Wind Power column is an estimate of how much potential energy from the wind (in watts) is available per square meter of land, assuming a wind turbine height of 164 feet (50 meters). Wind turbines can be used economically on land in wind power class 4 (dark blue areas) through 7 (light blue). Much of the upper Midwest, including North Dakota, South Dakota, Minnesota, Nebraska, and Iowa, has an excellent wind resource, with strong and frequent winds, which are ideal for generating electricity.

LiftWerx Ex. 1028
LiftWerx USA Inc. v. Liftra IP ApS
IPR2026-00102
Page 9 of 32

A group of Wisconsin utilities purchased two wind turbines optimized for operation in low wind speeds. The annual average wind speed at the site is 13.7 miles per hour (6.1 meters per second).

ASSOCIATE TURBINE VERIFICATION PROJECTS

Several utilities' wind projects have been involved in the Turbine Verification Program as "associate" projects. These utilities do not receive funding for wind turbine purchase, installation, or operation, but they do receive a supervisory control and data acquisition system produced by Second Wind Inc. to gather operating data to share with other TVP participants. Second Wind developed the system under the DOE Turbine Research Program. Associate TVP projects include the Kotzebue wind project in Kotzebue, Alaska, the TU Electric project in Big Spring, Texas, and the Low Wind Speed Turbine Project in Glenmore, Wisconsin, near Green Bay.

In order to better understand the operation of wind turbines in lower wind resource areas, a group of Wisconsin utilities purchased two utility-scale wind turbines in January 1998. The average annual wind speed at the project site is 13.7 miles per hour (6.1 meters per second). The turbines are optimized for low wind speeds. The two Tacke 600-kW turbines are two-speed, stall-regulated machines with 151-foot (46-meter) rotors and 164-foot (50-meter) hub height. Annual power generation is estimated to be 1.63 million kilowatt-hours per turbine per year.

ECONOMIC BENEFITS TO FARMERS

One thing shared by the Midwestern wind projects is the economic benefit for rural areas. Typically, the project owner (either a developer or utility) will lease land from farmers for the wind turbines. The wind turbines take up only a small percentage of the land and farming activities continue with minimal disruption.

Landowners are usually given two choices for payment options: a lump-sum payment or a percentage of annual gross revenues. The decision by the Minnesota PUC to require NSP to add another 400 MW of wind has renewed project developers' interest in signing easements with landowners in good wind areas. Lisa Daniels of the Sustainable Resources Center (SRC) is holding workshops for community leaders and landowners in good wind resource areas to help them learn about wind energy easement agreements for their land. The SRC has published a report about legal issues landowners should consider before signing easement agreements with project developers.

A goal of the SRC is for wind energy to bring long-term, sustainable economic development to the farmers and landowners in the Midwest. That may mean that communities develop their own wind turbine projects for local benefit.

LiftWerx Ex. 1028
LiftWerx USA Inc. v. Liftra IP ApS
IPR2026-00102
Page 10 of 32

Wind turbines operate in harmony with farming and ranching.

Local economies can also benefit from increased tax revenues, although some states including Iowa, Minnesota, and Wisconsin have laws on the books waiving taxes for wind energy equipment sales or property taxes or both.

In Minnesota, property taxes from the NSP wind energy projects benefit state and local government. The Lake Benton I Project brought 150 construction jobs to the area. Zond will have more than 30 local employees to maintain the turbines in the Lake Benton area. Visitors are coming to the area to see the turbines and learn about them.

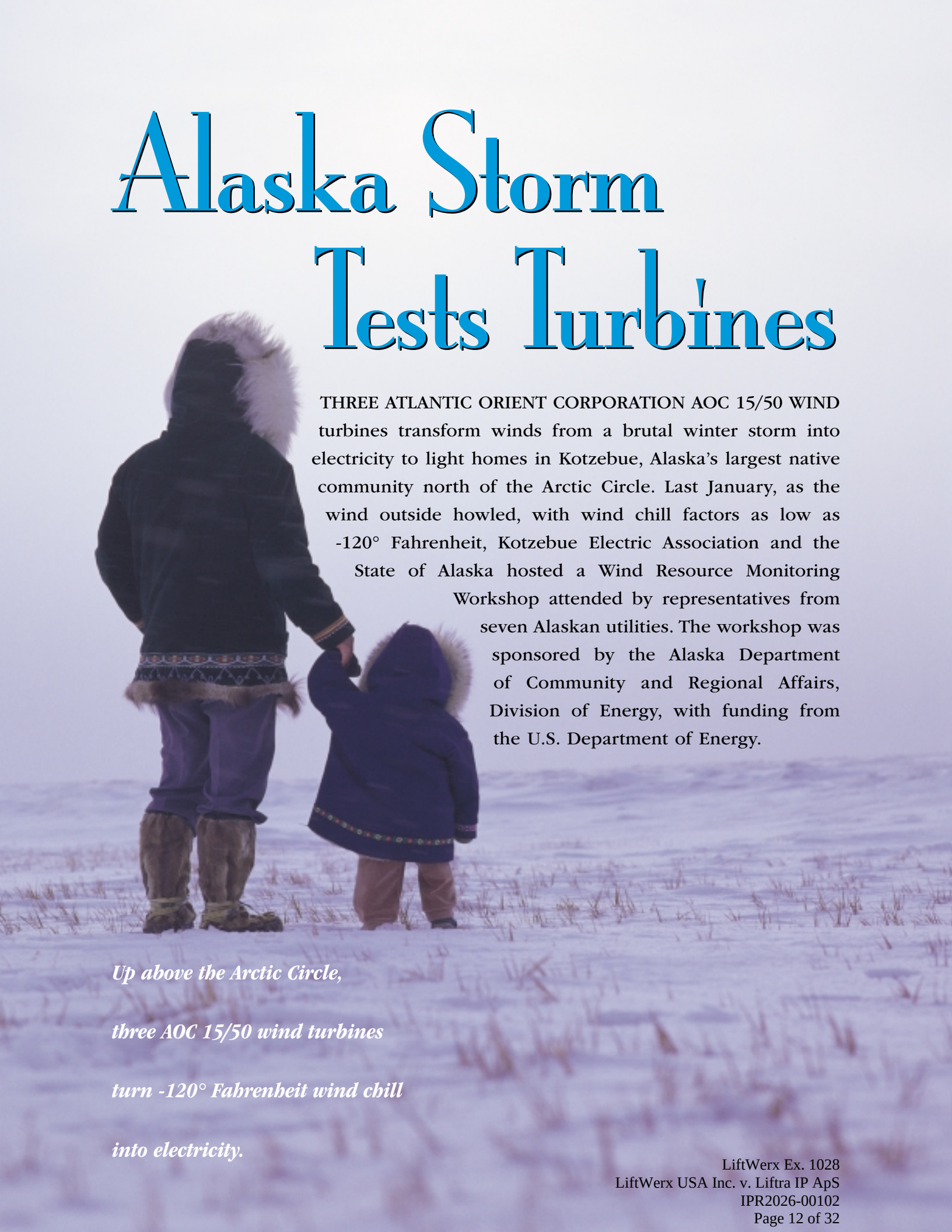
TURNING MIDWESTERN WIND INTO OPPORTUNITY

The boom in Midwestern wind energy projects is sure to continue until June 30, 1999, when the federal production tax credit eligibility period comes to an end. Projects must be completed by then to receive the $0.017/kWh tax credit for 10 years.

Even without the credit, wind energy development will continue in states where the legislature or public utility commission requires utilities to use wind energy. Utility-restructuring legislation at the state and federal levels may require all utilities to include a percentage of renewable energy in their generation portfolios. Even if utilities are not required to use renewable energy, they may choose to because some customers will pay more for clean, "green" power, such as wind energy.

Meanwhile, utilities in the Midwest are gaining experience with wind energy and sharing their experiences. Utilities in Iowa and Nebraska are learning about how wind turbines work in distributed applications. Wisconsin utilities are finding out how well their turbines work in low wind speed areas. And local communities are finding that they can turn the wind into opportunities for economic development. ◆

Alaska Storm Tests Turbines



THREE ATLANTIC ORIENT CORPORATION AOC 15/50 WIND turbines transform winds from a brutal winter storm into electricity to light homes in Kotzebue, Alaska's largest native community north of the Arctic Circle. Last January, as the wind outside howled, with wind chill factors as low as -120° Fahrenheit, Kotzebue Electric Association and the State of Alaska hosted a Wind Resource Monitoring Workshop attended by representatives from seven Alaskan utilities. The workshop was sponsored by the Alaska Department of Community and Regional Affairs, Division of Energy, with funding from the U.S. Department of Energy.

Up above the Arctic Circle, three AOC 15/50 wind turbines turn -120° Fahrenheit wind chill into electricity.

Brad Reeve, general manager of Kotzebue Electric Association (KEA), explains, "When the wind's like that, it's almost like it slaps you in the face. It really wakes you up." Because the air gets denser the colder it is, the 50-mile-per-hour (22.4 meter-per-second) winds packed extra force, causing the turbines to output as much as 20% more power than normal. The utility workshop participants saw the wind turbines operate under extreme conditions and took home monitoring equipment to measure the winds in their communities. Wind resource monitoring is the first step in determining if using wind to create electricity makes sense at a particular location.

Back in 1992, Reeve realized that Kotzebue was a good site for evaluating wind technology in an Arctic environment and he began looking for a good cold-weather wind turbine for a research project. Reeve was concerned about the high cost of diesel generation in Kotzebue and other rural Alaska communities and he wanted to find out if wind energy could provide reliable electricity and lower costs. Reeve selected the AOC 15/50 turbine, developed with funding from the U.S. Department of Energy (DOE) Turbine Research Program. Money for the three turbines came from the State of Alaska and KEA.

When three 66-kilowatt AOC 15/50 turbines were installed in 1997, Reeve began learning a lot about wind turbine operation in the Arctic. "After we debugged them, they have been operating extremely well," says Reeve. Since the 1998 pre-winter inspection, the turbines' availability factor has been above 97%. (The availability factor is the percentage of time the turbines are capable of operating in a given time period.) Kotzebue's high wind season, late fall and winter, coincides with high electricity use in the town.

KEA participates in the DOE/Electric Power Research Institute Turbine Verification Program (TVP) as an associate member. TVP is designed to help utilities gain experience operating turbines and integrating them into their systems. KEA received system control and data acquisition equipment through TVP to gather operational data from the turbines. KEA shares its experiences with other TVP participating utilities and interested parties at TVP workshops held each year.

WIND PROMISES TO REDUCE COSTS

The three AOC wind turbines are producing electricity for about the same cost as KEA's diesel units. Reeve is happy with the performance of this project and feels that costs will continue to decrease as technical improvements are made. KEA has worked extensively with the turbine manufacturer on this project. Future projects in Alaska could benefit from the lessons learned by KEA and Atlantic Orient Corporation. Reeve believes improved foundation designs developed by KEA will reduce costs for new turbines installed in 1999. Special foundations must be used to protect the tundra and underlying permafrost. Another technical issue to be solved is slow start-up. The controller signals the turbine when winds are strong enough to generate electricity, spinning the blades until the generator comes on-line and puts out electricity. Faster generator start-up would mean more electricity from the turbines and a lower cost of energy.

Seven new AOC 15/50 wind turbines are joining three wind turbines installed in 1997 near Kotzebue, Alaska. Kotzebue Electric Association and other Alaskan utilities are learning about how the wind turbines perform in the cold, harsh Alaskan climate.

Dennis Meiners, with Alaska's Department of Community and Regional Affairs (DCRA), believes there are many opportunities to lower the cost of wind energy in rural Alaska. He says the keys to widespread use of wind energy in rural Alaska are lower costs, proven turbine reliability, and a support infrastructure. Also important is building trust in wind energy technology. A state program installed 140 turbines in the 1980s, but many of the turbines failed.

Meiners, who saw the turbines operate during the January storm, says, "I personally believe, after watching these turbines operate in some of those extreme weather conditions, that the wind is a viable energy source and it only makes sense that it will gradually play an increasingly important role in the energy needs of rural Alaska."

LiftWerx Ex. 1028
LiftWerx USA Inc. v. Liftra IP ApS
IPR2026-00102
Page 13 of 32

Wales residents hope a wind/diesel system will help them considerably reduce their diesel use. Electricity in Wales costs $0.41 per kilowatt-hour because of the high cost of transporting diesel fuel to the remote village.

PROJECT REDUCES DIESEL USE

Seven more AOC 15/50 turbines are going up in Kotzebue in the spring of 1999, funded by DOE. These turbines will help KEA, a nonprofit consumer-owned cooperative, to reduce diesel fuel use by 90,000 to 100,000 gallons (340,687 to 378,541 liters) a year. KEA's goal is to reduce its diesel fuel use by 300,000 gallons (1,135,624 liters) a year using wind energy. Reeve also wants to share what he is learning about wind energy technology with other utilities in Alaskan villages.

Diesel generators are the main source of electricity in rural Alaska. The diesel fuel that powers the generators in Kotzebue comes from North Slope oil fields. The oil is piped to a refinery near Fairbanks, then transported by train to Anchorage, where it is shipped out by barge more than 1300 miles (2092 kilometers) to Kotzebue. Many villages, like Kotzebue, are accessible by sea only in the summer months. Therefore, large diesel storage tanks are required.

Villages that need to put in new tanks, either because of load growth or to replace aging tanks, find that costs are significantly higher now because of stricter environmental regulations. In some areas, diesel storage capacity costs as much as $8.00 per gallon (3.8 liters) to install. Many storage tanks are 20 years old and need to be replaced. Meiners hopes to quantify the costs of adding expensive new diesel storage tanks versus using wind energy to reduce diesel use and avoid building new tanks.

Kotzebue's diesel costs are relatively low because it buys large quantities of diesel. Reeve feels wind energy could be of great benefit to villages with higher fuel costs. "We feel that wind is probably the only near-term technology that has some potential for reducing the cost of power in rural Alaska. [It] could significantly help some of these communities that have very high costs because of difficulty transporting fuel."

DCRA and KEA are leading a project in Wales, a village on the Cape Prince of Wales, at the western tip of the Seward Peninsula, with a population of 177. Electricity costs $0.41 per kilowatt-hour (kWh) in Wales. This project is designed to reduce diesel use by 40% to 50% and replace it with wind energy. Two AOC 15/50 wind turbines will be installed in summer 1999, along with special batteries and a computerized controller developed for the Wales project by the National Renewable Energy Laboratory.

During the fall, local workers installed the piling foundations and assembled the lattice towers. Because there are no cranes in Wales, the Wales turbines will be erected using a "gin pole," a simple method for raising the turbine and tower. One of the seven new Kotzebue turbines will be erected with a gin pole, with the Wales crew present for training. Funding for the Wales project comes from DOE, the U.S. Environmental Protection Agency, and Alaskan organizations. Says Reeve, "They have a very good wind regime there. We believe this could be setting the stage for really showing what wind can do. And there are potentially 70 other coastal communities in Alaska that could benefit from having wind [energy] as a resource."

CONSUMERS LOSING ASSISTANCE

Wales, Kotzebue, and 173 other rural villages will be hard hit if the state's Power Cost Equalization (PCE) Program is discontinued. State assistance reduces the cost of electricity for Kotzebue residents from $0.20/kWh to about $0.12/kWh. The PCE Program has been subsidizing rural electricity since the mid-1980s, supporting diesel power generation in 175 villages. If the state legislature fails to provide additional funding in 1999, residents might have to pay much higher electricity bills. A task force is looking into ways to restructure the program that could reduce benefits to many communities, including Kotzebue. KEA has been warning its customers to begin planning for higher electricity rates. KEA estimates the average KEA residential-customer bill could increase by more than $40.00 a month. If the PCE Program goes away or is greatly reduced, wind energy will become an even more attractive option for rural Alaska.

TURBINES GENERATE LOCAL JOBS

Not only can wind energy lower electric rates, it also provides local jobs. "I'm really glad we have such skilled and hard-working people here in

LiftWerx Ex. 1028
LiftWerx USA Inc. v. Liftra IP ApS
IPR2026-00102
Page 14 of 32

Workers attach one of seven new AOC 15/50 wind turbines to its foundation, specially designed to protect the tundra and underlying permafrost.

Kotzebue. Having people on the project who are used to our conditions has really helped keep it moving through harsh weather this winter," says Reeve. The Kotzebue project provided jobs for people that would not have had employment otherwise. This economic development aspect of the project has been well received by local Kotzebue residents. The community also takes pride in making wind energy technology work in Kotzebue's harsh climate.

Philip Stalker, an experienced carpenter who worked with the Kotzebue crew last winter preparing for the new turbines, says "there are very few jobs in construction like this," in Kotzebue.

Reeve wants to develop a technical training program for wind turbine technicians. He expects that the Kotzebue technicians, with their training and experience installing, operating, and maintaining the turbines, will be able to use their skills throughout Alaska, in other states, and even in other countries. Their knowledge will be particularly useful in cold climates.

Many Kotzebue residents rely on "on-call" employment, for example, as firefighters. They are used to working when needed and could help install and operate turbines anywhere in the world.

KOTZEBUE IS BECOMING TECHNICAL CENTER FOR WIND ENERGY

The Alaska Technical Center in Kotzebue provides technical and vocational training. KEA is working with the Alaska Technical Center to develop a wind energy resource center, where people can come and see the turbines and learn about the technology. Future plans include the installation of a North Wind 100, developed by Northern Power Systems Company, with DOE support, for cold, harsh climates. Kotzebue will help Northern Power validate the operation of the North Wind 100 before it is installed in the Antarctic. Other turbines will be installed in Kotzebue in 2000.

FUTURE OF WIND ENERGY IN ALASKA

As seven utilities measure their winds in 1999, crews in Kotzebue and Wales will debug the new turbines and learn how to operate the turbines in conjunction with the diesel generators. The seven new turbines in Kotzebue will increase wind energy penetration in the electrical system to about 30% at times.

The State of Alaska and DOE are also looking to put in a wind/diesel system in an Alaskan community that will later be augmented by a reversible fuel-cell system. The fuel cell, which operates like a constantly charging battery and emits only water, would produce electricity when winds are low and the wind turbines aren't operating. The state and DOE will analyze the economics of the demonstration project to see if it makes sense for other communities.

Before wind energy spreads to other Alaskan villages, more data on the costs and performance of the wind turbines in Kotzebue and Wales are needed. A support structure for turbine maintenance and service must be developed. And packaging of projects could reduce costs. "There's a lot of work to do. But we think probably in three to five years we're going to have many of the answers," says Meiners. ◆

LiftWerx Ex. 1028
LiftWerx USA Inc. v. Liftra IP ApS
IPR2026-00102
Page 15 of 32

The U.S. Certification Program will strengthen customer confidence in U.S. wind turbines and remove a competitive barrier to sales for U.S. turbine manufacturers.

Certification Program Opens Markets to U.S. Turbines

IN THE 1980s, EUROPEAN WIND TURBINE MANUFACTURERS STARTED CERTIFYING THEIR wind turbines to demonstrate the safety and design integrity of the machines. Turbine buyers like the assurance that the certified turbines they buy are designed according to accepted industry standards. Today, every major European wind turbine company has certified turbines. Certification is now required in five European countries and India. In many other countries, including the United States, local building authorities, project financiers, and insurance companies are asking for certification to protect their investment before projects can move forward.

With the help of the U.S. Department of Energy (DOE) and Underwriters Laboratories Inc. (UL), the U.S. wind turbine industry is now focusing on certification to keep its technology competitive.

WHAT IS CERTIFICATION?

Certification is a procedure by which an independent party gives written assurance that a product, process, or service conforms to specified requirements. In the case of wind turbines, the third-party certification body uses international standards to determine the requirements that must be met.

There are several certificates available for wind energy technology but the one most commonly sought by turbine makers is the "Wind Turbine Type Certificate." The purpose of type certification is to confirm that wind turbines of a particular type (distinguished by size, form, and use) are designed, documented, and manufactured in conformity with valid design assumptions, specific standards, and other technical requirements.

While certification bodies have differing rules for type certification, they generally have the same goal: to review the design documentation and assure that the turbine was designed with engineering discipline, in accordance with recognized international standards.

CERTIFICATES AVAILABLE FOR WIND ENERGY TECHNOLOGY

- Design Conformity Statement
- Component Certificate
- Type Testing Conformity Statement
- Type Characteristics Conformity Statement
- Wind Turbine Type Certificate
  - *—Design Conformity Required*
  - *—Type Testing Required*
  - *—Manufacturing Evaluation Required*
  - *—Type Characteristics Optional*
- Wind Turbine Site Certificate

LiftWerx Ex. 1028
LiftWerx USA Inc. v. Liftra IP ApS
IPR2026-00102
Page 16 of 32

The Zond Energy Systems Z-40, shown here, received type certification in June 1997 from Germanischer Lloyd, a German certification agent. U.S. manufacturers can now get their turbines certified in the United States.

INTERNATIONAL ELECTROTECHNICAL COMMISSION WIND ENERGY STANDARDS

Title	Defines	Document
Safety Requirements for Large Wind Turbines	Design requirements	IEC 61400-1, 2d ed.*
Small Wind Turbine Systems	Design requirements for small wind turbines	IEC 61400-2*
Acoustic Emission Measurement Techniques	Acoustic measurement methods	IEC 61400-11*
Performance Measurement Techniques	Performance measurement methods	IEC 61400-12*
Structural Loads Measurement	Operational loads measurement methods	IEC 61400-13
Power Quality Measurements	Power quality measurement methods	IEC 61400-21
Wind Turbine Certification	Certification requirements	IEC 61400-22
Blade Structural Testing	Blade structural testing methods	IEC 61400-23

*Published standard

AN INTERNATIONALLY ACCEPTED STANDARD

The European Commission is encouraging the harmonization of the different certification requirements in order to facilitate trade within the European Community. The International Electrotechnical Commission (IEC) Technical Committee 88 (TC-88), Wind Turbine Generator Systems, has developed standards that will be the basis for harmonization. The certification standard is the International Electrotechnical Commission IEC 61400-22, a document in the final stages of becoming an official international standard. This document outlines the processes and approvals required for certification and refers to other IEC standards for technical requirements.

National Wind Technology Center (NWTC) technical experts participate in the TC-88 working groups that develop wind energy standards. NWTC personnel have had a major impact on the standards development process, ensuring that standards do not impede international industry development and trade opportunities, while ensuring that environmental, safety, and health interests of industry employees, utility personnel, and the general public are maintained.

The American Wind Energy Association (AWEA), the wind industry trade group, has worked since 1978 on national standards. Recognizing the importance of international standards, AWEA is participating in IEC standards development. The IEC standards will support the marketing of U.S. turbines in Europe and other foreign markets.

Three bodies are required for certification: the wind turbine manufacturer, an accredited or recognized testing agent, and the certification body. Three European certification bodies have awarded nearly all of the wind energy technology certificates to date. Germanischer Lloyd, a German firm with a background in safety and quality for shipbuilding, certifies wind energy technology as well as offshore structures and other industrial units, and is recognized as the leading wind turbine certification body.

U.S. CERTIFICATION PROGRAM A REALITY

Until recently, U.S. wind turbine companies, with no accredited domestic testing or certification body, were clearly at a disadvantage. Several years ago, AWEA asked the U.S. Department of Energy to support the development of a U.S. certification program and provide testing at the National Renewable Energy Laboratory (NREL). NREL began by offering power performance and acoustics (noise) testing in 1996 at its National Wind Technology Center. Current tests offered also include loads testing, blade testing, power quality testing, and dynamic characterization testing.

IEC 61400-22 requires the testing body to be either a nationally accredited lab or at least comply with the International Standards Organization/IEC Guide 25 requirements for calibration and testing laboratories. In 1998, NREL was accredited to perform power performance and acoustics tests by the American Association for Laboratory Accreditation. NREL will be accredited for loads measurements and power quality testing in 1999.

Although U.S. turbine companies can choose to work with European certification agents, there are language, cost, and geographical barriers to overcome. At the request of the U.S. industry, DOE, and

LiftWerx Ex. 1028
LiftWerx USA Inc. v. Liftra IP ApS
IPR2026-00102
Page 18 of 32

NREL, Underwriters Laboratories Inc. is serving as a U.S.-based certification agent. "Customers asked if we could do wind turbines. It's a natural extension of one of our major testing and certification activities, which is electrical testing," says Tom Wollan, engineering manager at Underwriters Laboratories.

Founded in 1894, Underwriters Laboratories is the undisputed leader in U.S. product safety and certification. The independent, not-for-profit organization applies more than 14 billion of the familiar UL Marks to products worldwide each year. More than 17,000 product types produced by more than 40,000 manufacturers are evaluated by UL. UL has an excellent reputation in the United States for electrical products and systems and is working to achieve a similar international reputation for wind turbine certification.

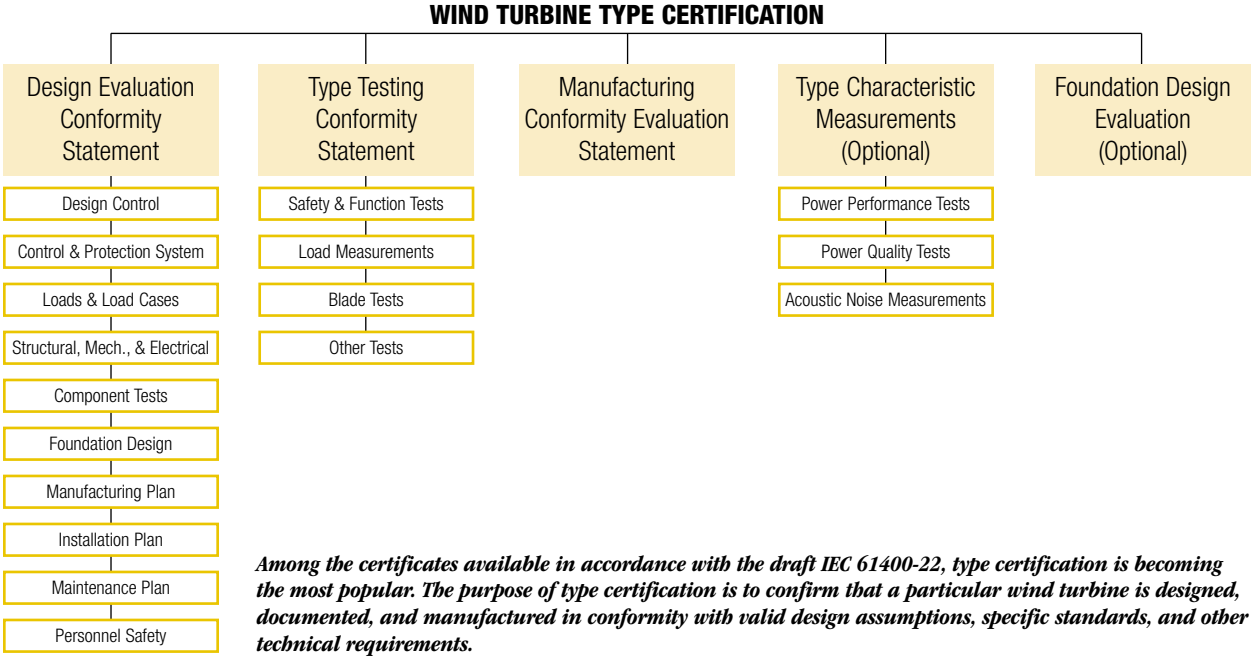
FIRST TURBINE MANUFACTURER SEEKS CERTIFICATE FROM UNDERWRITERS LABORATORIES INC.

Southwest Windpower, a maker of small turbines, is the first U.S. wind turbine manufacturer to seek certification from UL (see sidebar, page 21). UL has also been in contact with other wind turbine manufacturers interested in certification.

Zond Energy Systems has been a leader among the U.S. industry in seeking certification. The Zond Z-40 wind turbine received type certification in 1997. Because there was no U.S. certification body for wind energy technology at the time, Zond worked with Germanischer Lloyd in Germany. NREL performed power performance and loads tests on the Z-40 leading to certification.

A National Renewable Energy Laboratory engineer installs an anemometer near a Zond Z-48 turbine at the Lake Benton I Project in Minnesota. The anemometer was installed as part of power performance testing of the Z-48 turbine, which will lead to type certification of the Z-750 kW Series.

WIND TURBINE TYPE CERTIFICATION



Among the certificates available in accordance with the draft IEC 61400-22, type certification is becoming the most popular. The purpose of type certification is to confirm that a particular wind turbine is designed, documented, and manufactured in conformity with valid design assumptions, specific standards, and other technical requirements.

Technicians at the National Wind Technology Center perform calibrations for loads testing as part of international "round-robin" turbine tests. The goal is to improve testing methods so that different wind energy testing labs obtain similar results when performing the same tests.

Southwest Windpower Seeks the UL Mark

Southwest Windpower is the first small turbine company in the United States to seek certification. David Calley, president of Southwest Windpower, is passionate about the need for certification of small wind turbines but believes that the International Electrotechnical Commission (IEC) draft requirements for small wind turbines are not nearly strong enough.

Southwest Windpower is working with the National Renewable Energy Laboratory (NREL) and Underwriters Laboratories Inc. (UL) to get the Air 403 battery-charging turbine certified. The Air 403 weighs only 13 pounds and has a rotor diameter of 46 inches (1.15 meters). Its rated output is 400 watts at 28 miles per hour (12.5 meters per second). It can be easily installed and requires no maintenance. Primary uses are to charge batteries for remote homes, ocean-going ships, and industrial applications.

An Air 403 turbine is under test at NREL and Calley hopes to have the turbine certified by UL in 1999. Southwest Windpower is the first U.S. firm to seek certification from UL. "In the case of UL it has instant recognition [in the United States] which is about half of our market, so if you were going to pick one certification agency they would probably be the most recognized."

Calley plans to do testing and analysis "well in excess of the [IEC] standard." The draft IEC 61400-22 standard states in Annex E that, for small turbines, a duration test may replace the safety and function tests, blade tests, and load measurements required for larger turbines. Under the duration test, the turbine must operate for a minimum of 2500 hours without major repair and with an availability of at least 90%. The turbine must undergo at least 250 hours operation in average wind speeds at or above 22 miles per hour (10 meters per second) and 25 hours in average winds at or above 33 miles per hour (15 meters per second).

Southwest Windpower is pursuing certification of the Air 403 model not to meet customer or market demands, "rarely has anyone asked us for certification," Calley says, but because lack of customer confidence in small wind energy technology means that his firm and his competitors have barely scratched the surface of the available market for small wind turbines. Sales of the Air line of turbines have been excellent since it was introduced in 1994. The company has sold more than 25,000 Air turbines in the United States and 150 countries. But Calley believes that the size of the market for small wind turbines should be on a par with photovoltaics, with about $750 million per year in sales, and utility-scale turbines, about $1.5 billion per year. He says the small wind turbine market is now about $15 to $20 million a year.

The cost of certification for a small company like Southwest Windpower is high but Calley feels it is worth it. "[Certification] is very, very, very important to us. We are spending a huge amount of money [on certification]." Calley estimates that the entire cost to certify the Air 403, including internal engineering costs, travel, fees paid to UL, and so on, will amount to about $150,000 to $200,000. Without the testing support provided by NREL, certification would be out of the question for the firm.

While the Air 403 is under test, Calley will work to strengthen the small turbine requirements. "We're going to try our absolute best to affect that standard into being a more rugged standard."

Even after the Air 403 is certified, Southwest Windpower will continue to improve it and its other turbines. "We're trying to make small wind make a difference and it won't happen unless we can make [small turbines] better."

Southwest Windpower employees Rusty Knowler, mechanical engineer (left), and Tim Sasseen, director of research and development, with the Southwest Windpower Air 403 battery-charging wind turbine at the National Wind Technology Center. The turbine will operate under test for 2500 hours as part of wind turbine type certification.

LiftWerx Ex. 1028
LiftWerx USA Inc. v. Liftra IP ApS
IPR2026-00102
Page 21 of 32

Acoustic noise measurements are not required for type certification but many local authorities require them. The National Renewable Energy Laboratory received accreditation in 1998 to perform acoustics tests on turbines.

Zond is currently pursuing type certification of its Z-750 kW Series of turbines and expects to receive a Design Evaluation Conformity Statement from Germanischer Lloyd. NREL has performed acoustics, dynamic characteristics, power quality, power performance, and blade tests. NREL will also perform power peformance, acoustics, and loads testing on the Z-750 VE turbine (part of the Z-750 kW Series) when it's installed in Tehachapi, California. Zond has not decided if it will seek type certification from UL as well as Germanischer Lloyd but is optimistic about the U.S. certification body.

"It will definitely be beneficial to the wind industry to have a certification agency in the United States for the U.S. industry that will have reciprocity among it and other certifying agencies in Europe," says Amir Mikhail, vice president of engineering at Zond Energy Systems.

GLOBAL ACCEPTANCE KEY

Reciprocity and global acceptance of certificates issued by UL and other certification bodies is crucial. The participation of UL as the U.S. certification agent will boost global acceptance of U.S. certifications. UL already works globally, serving clients in 88 countries. UL has subsidiaries in 18 countries and field representatives all over the world. With established relationships and agreements with certifiers in other countries, UL expects that foreign certifiers will accept its wind certificates.

The approval of the IEC 61400-22 wind turbine certification standard by the 60 IEC member countries will be an important step towards global reciprocity for wind turbine certificates. IEC 61400-22, however, is at least a year away from becoming an international standard. As well, members of the European Community have their own process for standards-making. CENELEC, the European Committee for Electrotechnical Standardization, is working toward developing a uniform set of standards that will apply to all EC countries. CENELEC will probably base its standard for wind turbine certification on IEC 61400-22.

IEC 61400-22 will ensure that wind energy technology is tested and certified to a common set of criteria. However, countries have found that there can be discrepancies between tests conducted in different locations using different test equipment. A "round-robin" test of anemometers showed that even simple wind speed measurements can be significantly affected by different anemometer calibration procedures. In 1996, the members of the International Energy Agency Implementing Agreement for Cooperation in the Research and

LiftWerx Ex. 1028
LiftWerx USA Inc. v. Liftra IP ApS
IPR2026-00102
Page 22 of 32

Development of Wind Turbine Systems (known as IEA R&D Wind) began a wind turbine "round-robin" test program. Three identical turbines, the Atlantic Orient Corporation AOC 15/50 model, are being tested at the National Wind Technology Center, and at test sites in Canada and Europe. Engineers at the NWTC and Risø, the Danish lab, have completed power performance tests and compared results. NWTC engineers have finished acoustics tests and loads tests are under way. Risø has completed loads tests and sent the turbine to Greece for testing. When testing is complete, participants will analyze and resolve sources of discrepancies and make recommendations to the IEA R&D member countries to improve testing methods and procedures.

INTEGRATING CERTIFICATION INTO DESIGN

DOE started the Turbine Research Program in 1990 to help U.S. industry to improve its turbines with advanced technology. Wind turbine companies are selected to participate in the program by competitive solicitation. The projects are cost-shared; NREL and the company each provide funding. NREL also provides technical support and design reviews. The program has a well-established design review process with regular design reviews and test readiness reviews as prototype turbines evolve from conceptual to final design stages. In many ways, this program parallels certification requirements. With minor modifications, the Turbine Research Program has aligned its requirements to match the IEC certification requirements. Companies that participate in this program can now expect to finish the program with all the documentation and reviews needed to satisfy the IEC certification requirements as written.

Currently, NREL has two subcontracts with turbine companies to build large turbines and three subcontracts for small turbine development. Each subcontract has a task called certification planning, in which the company will meet with NREL and the certification body early in the project to lay the foundation for certification. NREL requires documentation of all important design steps. NREL engineers will review the companies' documentation and inform companies if deficiencies exist that may hinder certification. In this way, companies can avoid having to rerun engineering calculations, tests, or even redesign major components to get certification. At the end of the projects, the five new turbines DOE is supporting will not only meet DOE cost and performance goals, they will also be ready for certification and able to compete in the United States and abroad.

FUTURE OF CERTIFICATION

What will be the future of wind turbine certification? Zond's Amir Mikhail believes that as the wind industry matures, there will be a reduced emphasis on certification. Says Mikhail, "[Certification] adds into the cost and complexity of product development. However, it has the beneficial effect that it produces an independent review of the design process."

David Calley, president of Southwest Windpower, hopes to see a stronger certification standard for small wind turbines that will help the small wind industry gain credibility and enlarge its market.

Underwriters Labs expects to see its business grow globally in certification of U.S. and internationally made turbines. Depending on the demand for its services, UL may well add wind turbine testing capabilities down the road.

Whatever the future of certification, the benefits are summed up by Sandy Butterfield, leader of the NREL Certification Test Team and a wind industry veteran, who says, "All mature industries include certification of some kind. This is a sign that the wind industry is more than an emerging technology. It will assure quality products." ◆

LiftWerx Ex. 1028
LiftWerx USA Inc. v. Liftra IP ApS
IPR2026-00102
Page 23 of 32

A Closer Look at Structural Testing

Researchers use world-class testing facilities to improve wind turbine blades.

SINCE 1990, NATIONAL RENEWABLE ENERGY Laboratory engineers have been breaking wind turbine blades and wind turbine companies have been thanking them for it. Blade testing can help wind turbine companies verify and improve new blade designs, analyze blade structural properties, and improve manufacturing processes.

Wind turbine customers are reassured knowing that the blades on the wind turbines they purchase have been tested to sustain simulated extreme conditions and 30-year operating lifetimes. Prototype turbines tested in the field can't come close to this type of validation.

WORLD-CLASS FACILITIES

At the National Wind Technology Center (NWTC), three bays are available for testing blades. More than 75 blades have been tested at the center. Two of the bays have stands rated at 1 million foot-pounds. A high-capacity test stand was recently added to the third bay to accommodate testing blades for turbines rated 1 megawatt and greater. The test stand is rated at 4 million-foot pounds. Its tilting face plate will enable more displacement (bending) of large blades under test. The test stand was designed by NWTC engineers.

A 100-kip load frame was added to test blade subcomponents such as glue joints, root connections, and other design details. These parts of the blade are often where failure occurs.

THREE TYPES OF TESTS OFFERED

National Renewable Energy Laboratory (NREL) and Sandia National Laboratories engineers use the NWTC blade test facilities to perform three types of structural tests: ultimate static strength testing, fatigue testing, and nondestructive evaluation.

A National Wind Technology Center test engineer observes a fatigue test of a Zond Z-48 blade under two-axis loading to simulate thrust and torque. Blade tests conducted on the Zond Z-750 kW Series will lead to wind turbine type certification.

• **Ultimate Static-Strength Testing.** Ultimate static-strength testing helps turbine designers predict a blade's ability to withstand extreme loads such as those caused by hurricane-force winds. Researchers apply loads to the blade, displacing the blade until it breaks or withstands maximum loading. This allows designers to compare the blade's actual strength with design specifications and to determine if the blade failed or broke where the designers expected it would.

• **Fatigue Testing.** Fatigue testing simulates continuous operating loads. Engineers are able to put a blade through a 30-year operating lifetime in a few months. Weaknesses in structural details such as joints, ply drops, and geometric transitions are difficult to model and may not show up until the blade is fatigue tested.

The recent addition of two-axis loading to fatigue-testing equipment allows engineers to simulate both thrust (incoming wind forces on the blades) and torque and gravity forces in the plane of the rotor.

• **Nondestructive Testing.** Nondestructive tests—acoustic emissions, ultrasonic, and photoelastic strain tests—do not damage blades. Acoustic emissions tests identify possible failure locations likely to show up during static-strength or fatigue testing. Researchers attach high-tech microphones to the blade and increase loading, recording pinging sounds as glass fibers break in areas experiencing high strain.

Ultrasonic tests examine high-strain areas identified during acoustics, static, or fatigue tests. A signal sent into the blade travels through smooth, undamaged laminate, but bounces off any air gaps, pinpointing flaws beneath the blade's surface.

During photoelastic strain testing, researchers identify strain patterns on turbine blades by coating them with a strain-sensitive material. When viewed under polarized light, colorful strain patterns are clearly visible. The strain patterns can be used to infer stress patterns and blade loads.

INTERNATIONAL ACCEPTANCE KEY

NREL is working to make sure its blade test results are accepted internationally. In order for blade-testing results to be fully accepted, other countries must have confidence in the test results. International acceptance is important because blade testing may be required for certification in the future. (See page 16 for more on certification.) The goal of the European-initiated Standards, Measurements, and Testing Program is to improve instrumentation and measurement methods for blade testing so that different testing labs produce similar results for the same blade type. NREL and four European test labs are each testing blades of the same type. To ensure the uniformity of the blades, the manufacturer performed initial tests on the blades. Each lab is performing static and fatigue tests using the lab's usual test procedures and equipment. Finally, results from each lab will be reported and compared. This effort will increase international acceptance of blade test results from NREL and the other participating labs. ◆

LiftWerx Ex. 1028
LiftWerx USA Inc. v. Liftra IP ApS
IPR2026-00102
Page 24 of 32

The Federal Wind Energy Program in Review

Establishing the United States as the world leader in the understanding, development, and use of advanced wind turbine technology to generate electricity.

Left to right: The National Wind Technology Center near Golden, Colorado, the U.S. Department of Energy headquarters in Washington, D.C., and Sandia National Laboratories in Albuquerque, New Mexico.

PROGRAM MISSION AND STRATEGY

The mission of the U.S. Department of Energy (DOE) Wind Energy Program is to enable the U.S. wind industry to complete the research, testing, and field verification needed to fully develop advanced wind technologies that will lead the world in cost-effectiveness and reliability. The wind program accomplishes this mission through two national laboratories: the National Renewable Energy Laboratory (NREL), Golden, Colorado, and Sandia National Laboratories, Albuquerque, New Mexico. Engineers and analysts at the labs work closely with industry, utilities, universities, and other stakeholders through organizations such as the American Wind Energy Association, the National Wind Coordinating Committee, and the Utility Wind Interest Group.

To establish the United States as a world leader in wind turbine technology, the Wind Energy Program will meet the following objectives:

By 2002—Develop advanced wind turbine technologies capable of reducing the cost of energy from wind to $0.025 per kilowatt-hour (kWh) in 15-mile-per-hour (6.7-meters-per-second) winds

By 2005—Establish the U.S. wind industry as an international technology leader, capturing 25% of world markets

By 2010—Achieve 10,000 megawatts of installed wind-powered generating capacity in the United States.

The heart of the program lies at a National Renewable Energy Laboratory research facility, the National Wind Technology Center (NWTC). NREL and Sandia researchers collaboratively use the excellent research and testing facilities at the NWTC to expand the engineering knowledge that is required for the development of advanced wind technology. The NWTC supports the research, development, and testing needs of the wind turbine industry. The three major research areas carried out at the NWTC are 1) applied research, 2) turbine research, and 3) cooperative research and testing.

APPLIED RESEARCH

The Applied Research Program addresses fundamental engineering principles and technology issues that must be understood in order to design advanced turbines that can compete in the energy markets of the future.

• **Aerodynamics and Structural Dynamics.** To lower costs and lengthen turbine lifetimes, lighter, more flexible turbines may be the answer. Understanding the behavior of wind turbine aerodynamics is critical to the development of such new designs. The goal of the aerodynamics program is to couple aerodynamics loads and performance codes with field test and wind tunnel data to understand complex wind/wind turbine interactions and improve current design codes. Engineers record field test data, including the aerodynamic and structural parameters of a highly instrumented experimental wind turbine operated in various configurations, called the Unsteady Aerodynamics Experiment. Full-scale wind-tunnel testing of the same turbine will provide data to benchmark future aerodynamic-code development.

LiftWerx Ex. 1028
LiftWerx USA Inc. v. Liftra IP ApS
IPR2026-00102
Page 25 of 32

Large-scale components will be tested on the Advanced Research Test Bed at the National Wind Technology Center. The trend for utility-scale wind generation is larger turbines with lower costs per kilowatt capacity.

• **Systems and Components.** Most current wind turbine designs use proven technology. Research into new designs for components and subsystems such as generators, rotors, data acquisition systems, and controls is crucial to advancing the technology. Improving the components and subsystems is vital to increasing performance and reliability and lowering costs. Most wind turbine developers are unable to devote the resources to design and test such new concepts. The NWTC has an Advanced Research Turbine (ART) Test Bed to support testing of large-scale components developed for use on large turbines. The first turbine of three is installed and will provide baseline data. The second turbine will be installed in late 1999. It will incorporate a variable-speed generation system to allow testing of variable-speed operation, and the necessary power electronics, on a full-scale turbine. A third turbine configuration will be based on test data from the first two turbines. Options include upwind or downwind operation, a tilting hub, an advanced blade set, a direct-drive generator, a three-bladed rotor, and a highly flexible configuration.

The ART will also be used for the Long-Term Inflow and Structural Testing (LIST) Program. LIST is a joint NREL-Sandia project to understand inflow and resulting loads in the turbine system, and which atmospheric events—especially rare ones—the turbine will experience over its lifetime that can heavily influence fatigue lifetime.

• **Materials, Manufacturing, and Fatigue.** The aim of this task is to reduce turbine capital and maintenance costs by reducing the cost of turbine blades while also improving reliability. Improvements in manufacturing processes not yet implemented by the wind industry are researched, components are built and tested, and innovative manufacturing processes are brought to bear on whole-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 populations and no access to reliable, low-cost power. The program supports research to advance the development and deployment of such "hybrid" systems.

For example, NREL engineers developed a control system that will use wind energy to replace diesel generation. The controller is under test at the NWTC Hybrid Power Test Bed, which simulates loads and connects or disconnects storage and generation sources. The system will be sent above the Arctic Circle to Wales, Alaska, for operation and evaluation. It is expected to offer large cost savings over the current all-diesel system.

• **Avian Research.** The potential impacts on birds from wind turbines 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 throughout the country. In cooperation with industry, environmental groups, governmental bodies, and universities, the program 1) studies the impacts of current wind plants on avian species, 2) develops approaches to siting wind plants to avoid future problems, 3) investigates methods for reducing or eliminating avian impacts from wind energy development, and 4) disseminates information on research.

TURBINE RESEARCH

DOE began the Turbine Research Program in 1990 to help the U.S. wind industry incorporate advanced technology into its wind turbine designs. Under this program, the labs select industry partners through competitive solicitations, then work with the companies to develop, test, and refine new designs. DOE provides funding and the industry partners share in the costs of the project. Initially, the program focused on large, utility-scale turbines, but now small and midsize turbines are also being developed for niche applications.

• **Large, Utility-Scale Turbines.** To stimulate the U.S. industry to explore new concepts and apply cutting-edge technology to the development of prototype, utility-scale wind turbine systems, DOE launched the Next-Generation Product Development effort. The goal is to produce wind-generated electricity for $0.025 per kWh or less at 15 mile-per-hour (6.7 meter-per-second) sites.

The Next-Generation effort is broken down into two parts: the Innovative Subsystems Project and the Turbine Development Project. Innovative Subsystems is devoted to supporting industry in the development and testing of new components and subsystems. Turbine Development is a cost-shared effort to build new, highly innovative wind turbines that might use the new components and subsystems and other technology advancements. Two companies are participating in the Turbine Development Project: Zond Energy Systems and The Wind Turbine Company.

Zond Energy Systems, Inc. Zond is developing a machine that will probably be 1.8 megawatts or larger. Its architecture hasn't been determined, but it might use a direct-drive generator alone or in combination with a conventional gearbox. Significant departures from conventional rotor design are anticipated, including purpose-designed airfoils and low-solidity, flexible blades with individual pitch control. Taller, low-stiffness towers

LiftWerx Ex. 1028
LiftWerx USA Inc. v. Liftra IP ApS
IPR2026-00102
Page 27 of 32

Zond Energy Systems' Z-40 wind turbine, shown here at the Green Mountain Power Corporation wind plant near Searsburg, Vermont, was developed under the Turbine Research Program.

are expected, as are advanced control strategies to optimize energy capture and reduce loads. The NREL/Zond subcontract funding totals $20,844,761.

The Wind Turbine Company. The Wind Turbine Company is designing the WTC 1000, a lightweight, two-bladed, downwind machine. The megawatt-scale turbine may include blades with individual pitch control, a variable-coning (flapping) rotor, highly integrated structure and drivetrain, load-mitigating control strategies, simplified fluid systems, and an extremely tall (328 feet [100 meter]) guyed tower. The WTC is targeted for wind power plant applications, primarily for Midwestern states. The total amount of cost-shared funding is $22,136,146.

• **Small Wind Turbines.** Small wind turbines are typically used for off-utility-grid applications or by homeowners who wish to reduce their use of utility electricity. Wind energy can be a good option in areas too remote for grid extension or where grid extension or other off-grid generation is too costly.

In 19 states, owners of wind-generated electricity who are connected to the grid can sell their excess power to the utility at "retail" rates, the same rate they pay for electricity. This practice, called net metering, makes wind energy economically attractive for small power producers.

Three companies are now developing small turbines with DOE support. The projects comprise four stages: 1) preliminary prototype system design, 2) detailed design and qualification tests of key components, 3) fabrication and field tests of the first turbine, and 4) design refinements and qualification tests of the commercial prototype. These tests, including IEC 1400-12 power performance, IEC 1400-11 acoustic emissions, and loads tests, will be performed at the NWTC and will lead to certification.

The goal of the Small Wind Turbine Project is to develop tested systems up to 40 kilowatts (kW) in size that achieve a cost/performance ratio of $0.60 per annual kWh or less at sites with annual average wind speeds of 12.1 miles per hour (5.4 meters per second) and to significantly reduce the cost of energy. The cost/performance ratio is the initial capital cost of the turbine divided by its annual energy capture. Cost of energy is based on life-cycle cost.

WindLite Corporation. Formed in 1996, WindLite Corporation is developing an 8-kW, variable-speed, direct-drive machine with a rotor diameter of 23 feet (7 meters). The turbine uses a wound-rotor generator and a new controller that significantly increases its battery-charging efficiency compared to permanent-magnet generators. The projected cost/performance ratio for the WLC 7.5 is $0.46/kWh and $1,430,901 in funding is cost-shared.

World Power Technology. World Power has been making small turbines since 1978. Its product line includes six models ranging in size from 500 to 4500 watts. The Windfarmer, a 7-kW battery-charging wind turbine, is a three-bladed, upwind, variable-speed machine using a direct-drive, permanent-magnet generator. Fiberglass blades will be used on a rotor about 16 feet (5 meters) in diameter. The machines will use a unique, patented angle-furling governor for protection in high winds. World Power is also developing a novel, counter-weighted, tilt-down tower of 98 feet (30 meters) in height. The projected cost/performance ratio for the Windfarmer is $0.59/kWh and $1,248,838 in funding is cost-shared.

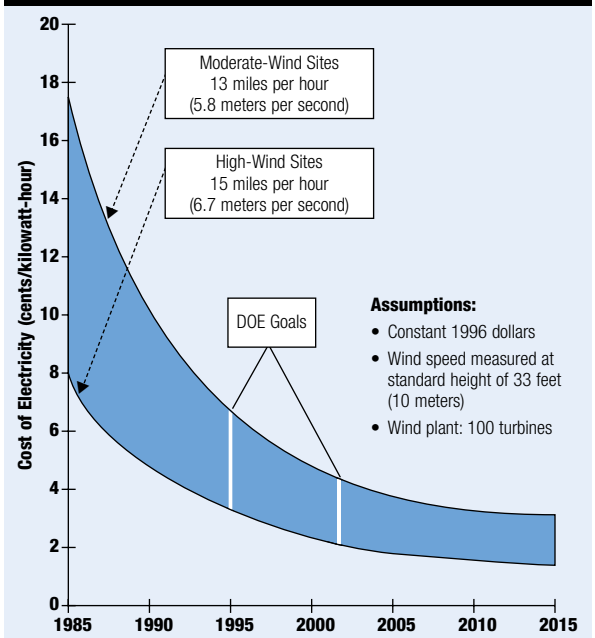
Bergey Windpower Company. Bergey Windpower Company has sold more than 1600 turbines since 1980. The 40-kW BWC Excel 40 is targeted for village power battery charging. The turbine is an

LiftWerx Ex. 1028
LiftWerx USA Inc. v. Liftra IP ApS
IPR2026-00102
Page 28 of 32

upwind, variable-speed machine with a direct-drive permanent-magnet alternator. The three-bladed rotor uses pultruded fiberglass blades. To match the wind regime, three rotor diameters are available: 41, 46, and 52.5 feet (12.5, 14, and 16 meters). The guyed lattice towers will be 118, 180, or 269 feet (36, 55, or 82 meters) tall. Bergey's goal is to build a turbine with minimal maintenance requirements. The projected cost/performance ratio for the BWC Excel 40 is $0.38/kWh. Cost-shared funding is $1,211,486.

• **Intermediate-Sized Wind Turbines.** Two intermediate-sized turbines are being developed with DOE support for specific niche applications.

COST OF WIND ENERGY



The goal of the Turbine Research Program is to help industry lower the cost of electricity from wind energy.

Atlantic Orient Corporation. The AOC 15/50 turbine is a three-bladed, downwind machine with a 49-foot (15-meter) rotor; it's rated 50 kW at wind speeds of 27 miles per hour (12 meters per second). AOC has deployed 32 machines, some in remote, harsh enviroments where its ease of transport and installation is a plus. The turbine is used to power small towns or villages around the world. Several turbines are running at research facilities in the United States and abroad. NREL subcontracts fund the development and testing of the AOC 15/50 to the amount of $1,793,594.

Northern Power Systems Company. The North Wind 100 is a 100-kW, three-bladed, upwind, variable-speed turbine. It uses a direct-drive generator developed under the Next-Generation Innovative Subsystems Project. In developing the North Wind 100 for harsh and remote enviroments, Northern Power drew on its experience deploying another turbine model on the South Pole, where low maintenance and high reliability are required. A proof-of-concept turbine was installed at the Vermont test site in 1998. A prototype will be tested in 2000 at the NWTC. DOE is joined by the National Aeronautics and Space Administration (NASA) and the National Science Foundation (NSF) in sponsoring development. The project is receiving $1,587,951 in funding from DOE. NASA and NSF plan to do follow-on development for use of the turbine in Alaska and Antarctica.

COOPERATIVE RESEARCH AND TESTING

As its name implies, Cooperative Research and Testing activities involve working with the wind industry, end users here and abroad such as utilities and governments, and international agencies and labs to further the use of wind energy.

• **Wind Industry Support.** Testing is one of the most valuable services the wind program offers to the wind industry. Most wind turbine companies have neither the resources nor the expertise to conduct these tests in-house, which are key to refining and proving product designs.

Structural Testing. Since 1990, the structural test facility at the NWTC has offered wind turbine blade testing services to industry. These tests help industry identify and correct any problems in prototype blades before going into full-scale production. To date, more than 75 blades have been tested. Three major types of testing are currently offered: ultimate static strength, fatigue, and non-destructive. For more on structural testing, please see the story on page 24.

Modal Testing. Modal testing provides useful information about the structural dynamic characteristics of a wind turbine system. Wind turbine companies use this information to avoid designs that are susceptible to fatigue-related failures and excessive vibrations. This type of testing is complex and requires special equipment and expertise. In support of industry, NWTC engineers perform modal tests of components in the lab and test entire turbine systems in the field.

Dynamometer Testing. A new 2.5-megawatt (MW) Dynamometer and Spin Test Facility is scheduled for completion in 1999. Wind turbine drivetrains as large as 1.5 MW, drivetrain components, and power systems developed by the U.S. wind industry will be tested on the dynamometer.

Certification and Standards. In the international marketplace and here at home, wind turbine certification is required more and more by wind

LiftWerx Ex. 1028
LiftWerx USA Inc. v. Liftra IP ApS
IPR2026-00102
Page 29 of 32

These turbines on San Clemente Island, California, will reduce the Navy's use of diesel fuel. National Renewable Energy Laboratory engineers helped the Department of Defense bring wind energy to the military base.

upwind, variable-speed machine with a direct-drive permanent-magnet alternator. The three-bladed rotor uses pultruded fiberglass blades. To match the wind regime, three rotor diameters are available: 41, 46, and 52.5 feet (12.5, 14, and 16 meters). The guyed lattice towers will be 118, 180, or 269 feet (36, 55, or 82 meters) tall. Bergey's goal is to build a turbine with minimal maintenance requirements. The projected cost/performance ratio for the BWC Excel 40 is $0.38/kWh. Cost-shared funding is $1,211,486.

• **Intermediate-Sized Wind Turbines.** Two intermediate-sized turbines are being developed with DOE support for specific niche applications.

Atlantic Orient Corporation. The AOC 15/50 turbine is a three-bladed, downwind machine with a 49-foot (15-meter) rotor; it's rated 50 kW at wind speeds of 27 miles per hour (12 meters per second). AOC has deployed 32 machines, some in remote, harsh enviroments where its ease of transport and installation is a plus. The turbine is used to power small towns or villages around the world. Several turbines are running at research facilities in the United States and abroad. NREL subcontracts fund the development and testing of the AOC 15/50 to the amount of $1,793,594.

Northern Power Systems Company. The North Wind 100 is a 100-kW, three-bladed, upwind, variable-speed turbine. It uses a direct-drive generator developed under the Next-Generation Innovative Subsystems Project. In developing the North Wind 100 for harsh and remote enviroments, Northern Power drew on its experience deploying another turbine model on the South Pole, where low maintenance and high reliability are required. A proof-of-concept turbine was installed at the Vermont test site in 1998. A prototype will be tested in 2000 at the NWTC. DOE is joined by the National Aeronautics and Space Administration (NASA) and the National Science Federation (NSF) in sponsoring development. The project is receiving $1,587,951 in funding from DOE. NASA and NSF plan to do follow-on development for use of the turbine in Alaska and Antarctica.

COOPERATIVE RESEARCH AND TESTING

As its name implies, Cooperative Research and Testing activities involve working with the wind industry, end users here and abroad such as utilities and governments, and international agencies and labs to further the use of wind energy.

• **Wind Industry Support.** Testing is one of the most valuable services the wind program offers to the wind industry. Most wind turbine companies have neither the resources nor the expertise to conduct these tests in-house, which are key to refining and proving product designs.

Structural Testing. Since 1990, the structural test facility at the NWTC has offered wind turbine blade testing services to industry. These tests help industry identify and correct any problems in prototype blades before going into full-scale production. To date, more than 75 blades have been tested. Three major types of testing are currently offered: ultimate static strength, fatigue, and non-destructive. For more on structural testing, please

LiftWerx Ex. 1028
LiftWerx USA Inc. v. Liftra IP ApS
IPR2026-00102
Page 30 of 32

KEY CONTACTS

U.S. Department of Energy
Peter Goldman
Wind Energy Program
1000 Independence Avenue, SW
Washington, DC 20585

National Renewable Energy Laboratory
Robert Thresher
Director
National Wind Technology Center
1617 Cole Boulevard
Golden, CO 80401
(303) 384-6922

Susan Hock
Wind Energy Technology Program Manager
National Wind Technology Center
1617 Cole Boulevard
Golden, CO 80401
(303) 384-6950

Sandia National Laboratories
Henry Dodd
Wind Energy Technology Program Manager
P.O. Box 5800
Albuquerque, NM 87185-0708
(505) 844-5253

NOTICE: This report was prepared as an account of work sponsored by an agency of the United States government. Neither the United States government nor any agency thereof, nor any of their employees, makes any warranty, expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States government or any agency thereof.

Printed in the United States of America

Available to DOE and DOE contractors from:
Office of Scientific and Technical Information (OSTI)
P.O. Box 62
Oak Ridge, TN 37831

Prices available by calling (423) 576-8401

Available from:
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161
(703) 605-6000 or (800) 553-6847
or
DOE Information Bridge
http://www.doe.gov/bridge/home.html

Information pertaining to the pricing codes can be found in the current issue of the following publications which are generally available in most libraries: Government Reports Announcements and Index (GRA and I); Scientific and Technical Abstract Reports (STAR); and publication NTIS-PR-360 available from NTIS at the above address.

PHOTO CREDITS: Cover, PIX 06325 Warren Gretz/NREL; pgs. 2 and 3, PIX 07317 Warren Gretz/NREL; pg. 4, Zond Energy Systems; pg. 5, Algona Municipal Utilities; pg. 6, top, PIX 05979 Scott Hughes, NREL; pg. 6, bottom, PIX 06325 Warren Gretz/NREL; pg. 7, Nebraska Public Power District; pg. 10, Wisconsin Public Service; pg. 11, PIX 06331 Warren Gretz/NREL; pg. 12, © 1999 Chris Arend/AlaskaStock.com; pg. 13, Kotzebue Electric Association; pg. 14, PIX 05626 Steve Drouilhet/NREL; pg. 15, Kotzebue Electric Association; pg. 17, PIX 06802 David Parsons/NREL; pg. 19, Ryan Jacobsen/NREL; pg. 20, PIX 07313 Warren Gretz/NREL; pg. 21, David Corbus/NREL; pg. 22, PIX 02131 Warren Gretz/NREL; pgs. 24 and 25, PIX 06513 David Parsons/NREL; pgs. 26 and 27, left to right, PIX 00337 Warren Gretz/NREL, PIX 04125 U.S. Department of Energy, PIX 04678 Sandia National Laboratories; pg. 28, PIX 05770 Warren Gretz/NREL; pg. 30, PIX 06772 David Parsons/NREL; p. 32, PIX 07378 Warren Gretz/NREL.

WIND ENERGY PROGRAM WEB SITES:
U.S. Department of Energy: http://www.eren.doe.gov/wind
National Renewable Energy Laboratory: http://www.nrel.gov/wind
Sandia National Laboratories:
http://www.sandia.gov/Renewable_Energy/wind_energy/homepage.html

Produced for the
U.S. Department of Energy

1000 Independence Avenue, SW
Washington, DC 20585

by the
National Renewable Energy Laboratory,
a DOE national laboratory

DOE/GO-10099-820
June 1999

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