# Wind Power Today

## 2010

- BUILDING A CLEAN ENERGY ECONOMY
- ADVANCING WIND TURBINE TECHNOLOGY
- SUPPORTING SYSTEMS INTERCONNECTION
- GROWING A LARGER MARKET

# BUILDING A CLEAN ENERGY ECONOMY


Built in 2009, the 63-megawatt Dry Lake Wind Power Project is Arizona's first utility-scale wind power project.

## Building a Green Economy

In 2009, more wind generation capacity was installed in the United States than in any previous year despite difficult economic conditions. The rapid expansion of the wind industry underscores the potential for wind energy to supply 20% of the nation's electricity by the year 2030 as envisioned in the 2008 Department of Energy (DOE) report *20% Wind Energy by 2030: Increasing Wind Energy's Contribution to U.S. Electricity Supply.* Funding provided by DOE, the American Recovery and Reinvestment Act of 2009 (Recovery Act), and state and local initiatives have all contributed to the wind industry's growth and are moving the nation toward achieving its energy goals.

Wind energy is poised to make a major contribution to the President's goal of doubling our nation's electricity generation capacity from clean, renewable sources by 2012. The DOE Office of Energy Efficiency and Renewable Energy invests in clean energy technologies that strengthen the economy, protect the environment, and reduce dependence on foreign oil. Within that office, the Wind and Water Power Program manages the public's investment in wind power technology to improve the performance, lower the cost, and accelerate the deployment of wind power.

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## Another Record Year for Wind

In 2009, the U.S. wind industry installed 10,010 megawatts (MW) of generating capacity, breaking U.S. installation records for the third year in a row. Wind power represented 39% of all U.S. electric generation capacity additions for the year. According to the American Wind Energy Association, the wind capacity added in 2009 generates enough electricity to power the equivalent of 2.4 million homes—the generation capacity of three large nuclear power plants. The entire wind turbine fleet in place at year's end—more than 35,000 MW—was enough to power the equivalent of nearly ten million homes. This wind power capacity will avoid an estimated 62 million tons of carbon dioxide ($CO_2$) emissions annually, equivalent to taking 10.5 million cars off the road, and will conserve about 20 billion gallons of water each year that would otherwise be withdrawn for steam or cooling in conventional power plants.

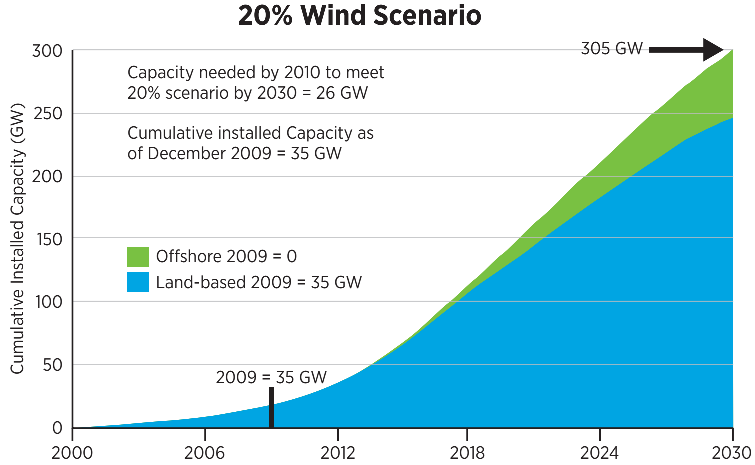
The renewable energy industry creates thousands of long-term, high-technology careers in wind turbine component manufacturing, construction and installation, maintenance and operations, legal and marketing services, transportation and logistical services and more. In 2009, the wind sector invested $17 billion in the U.S. economy and employed 85,000 workers. A modern wind turbine has more than 8,000 component parts. To supply this market, 39 manufacturing facilities were brought online, announced, or expanded in 2009, bringing the total number of wind turbine component manufacturing facilities now operating in the United States to more than 200.

Over half of the wind power generating capacity added in 2009 was installed in Texas, Indiana, and Iowa. Texas is home to the Roscoe Wind Plant, the world's largest wind generation plant. After a construction period of just over two years, Roscoe has 627 wind turbines with an installed capacity of 780 MW that can generate electricity for more than 230,000 homes. Thirty-six states now have commercial wind energy systems installed. Arizona inaugurated its first large-scale wind plant, the 64-MW Dry Lake Wind Power Project, in 2009.

The market for small wind turbines (rated capacity of less than 100 kilowatts) grew by 15% in 2009, adding 20 MW of generating capacity to the nation. Seven small wind turbine manufacturing facilities were opened, announced or expanded in 2009.

## A National Strategy

The DOE Wind Program leads the federal government's efforts to expand domestic wind energy capacity. According to the *20% Wind Energy by 2030* report, supplying 20% of our nation's electrical demand with wind energy by 2030 is technically feasible and would reduce greenhouse gas emissions, create jobs, stimulate economic activity, and reduce water use. Generating 20% of the nation's electricity from wind would require increasing the nation's wind generating capacity from today's 35 gigawatts (GW) to 300 GW of capacity over the next twenty years.




This 20% wind scenario graph shows how the total capacity installed by the end of 2009 compares to the capacity needed by 2010 to meet 20% wind by 2030 (1 GW=1,000 MW).

The report found that achieving 20% wind energy by 2030 would provide significant economic and environmental benefits, including:

- Roughly 500,000 jobs in the United States with an annual average of more than 150,000 workers directly employed by the wind industry;
- More than 100,000 jobs in associated industries (e.g., steel workers, electrical manufacturing, accountants, and lawyers);
- More than 200,000 jobs through economic expansion based on local spending;
- An increase in annual property tax revenues to more than $1.5 billion by 2030;
- An increase in annual payments to rural landowners of more than $600 million in 2030;
- Avoidance of approximately 825 million metric tons of $CO_2$ emissions in the electric sector;
- A reduction in water consumption by 4 trillion gallons in the electric sector.

The report also identified major challenges along the path to a 20% wind scenario. The nation's institutions need to:

- Invest in the nation's transmission system so that the electricity generated by wind power can be delivered to urban centers that need the increased supply;
- Develop larger electric load balancing areas, in tandem with better regional planning, so that regions can depend on a diversity of generation sources including wind power;

- Grow the manufacturing supply chain to remedy the current shortage in wind turbines and components and provide jobs;
- Continue to reduce the capital cost and improve the performance of wind turbines through technology advancement and improved domestic manufacturing capabilities;
- Address potential concerns about local siting, wildlife, and environmental issues within the context of wind-generated electricity.

To meet these challenges, the Wind Program works to improve the cost, performance, and reliability of land-based and offshore wind technologies. The program also addresses barriers to wind energy's rapid market expansion such as electrical transmission and integration, manufacturing, project siting, and public and market acceptance. This work is conducted through cost-share agreements with industry and agencies such as DOE's Office of Electricity Delivery and Energy Reliability, transmission and distribution industry groups, the Federal Aviation Administration, the Department of Defense, and the Department of the Interior's Minerals Management Service. Cooperative research and development is performed with the International Energy Agency, academia, and DOE's national laboratories. The Wind Program focuses specialized technical expertise, comprehensive design and analysis tools, and unique testing facilities on addressing technology challenges (improving wind technology and facilitating grid interconnection) and market barriers (permitting, siting, radar, and environmental impacts).

A key question in this era of increasing demand for clean energy supplies is "How much electricity can wind energy contribute?" A new wind resource assessment recently released by DOE finds that the contiguous 48 states have the potential to generate up to 37 million gigawatt-hours (GWh) of electricity from wind annually. By comparison, total U.S. electricity generation from all sources was roughly 4 million GWh in 2009. Although U.S. wind energy capacity has increased from about 2.5 GW in 2000 to 35 GW by the end of 2009, it still only provides about 2% of our nation's electrical energy. The Wind Program helps industry tap this vast renewable resource to provide a greater portion of our nation's electricity needs.

*DOE's Wind Program focuses specialized technical expertise, comprehensive design and analysis tools, and unique testing facilities on addressing wind technology challenges and market barriers.*

## Recovery Act Helps Wind

Investments in wind energy from the American Reinvestment and Recovery Act (Recovery Act) began to bear fruit in 2009 and will have significant impacts through 2012 and beyond. The Act provides a three-year extension of the production tax credit and offers alternatives to tax credits for renewable energy systems. The production tax credit provides a 2.1¢/kilowatt-hour credit for every kilowatt-hour produced by new qualified wind power facilities during the first 10 years of operation, provided the facilities are placed in service before the tax credit's expiration date, now extended through 2012.

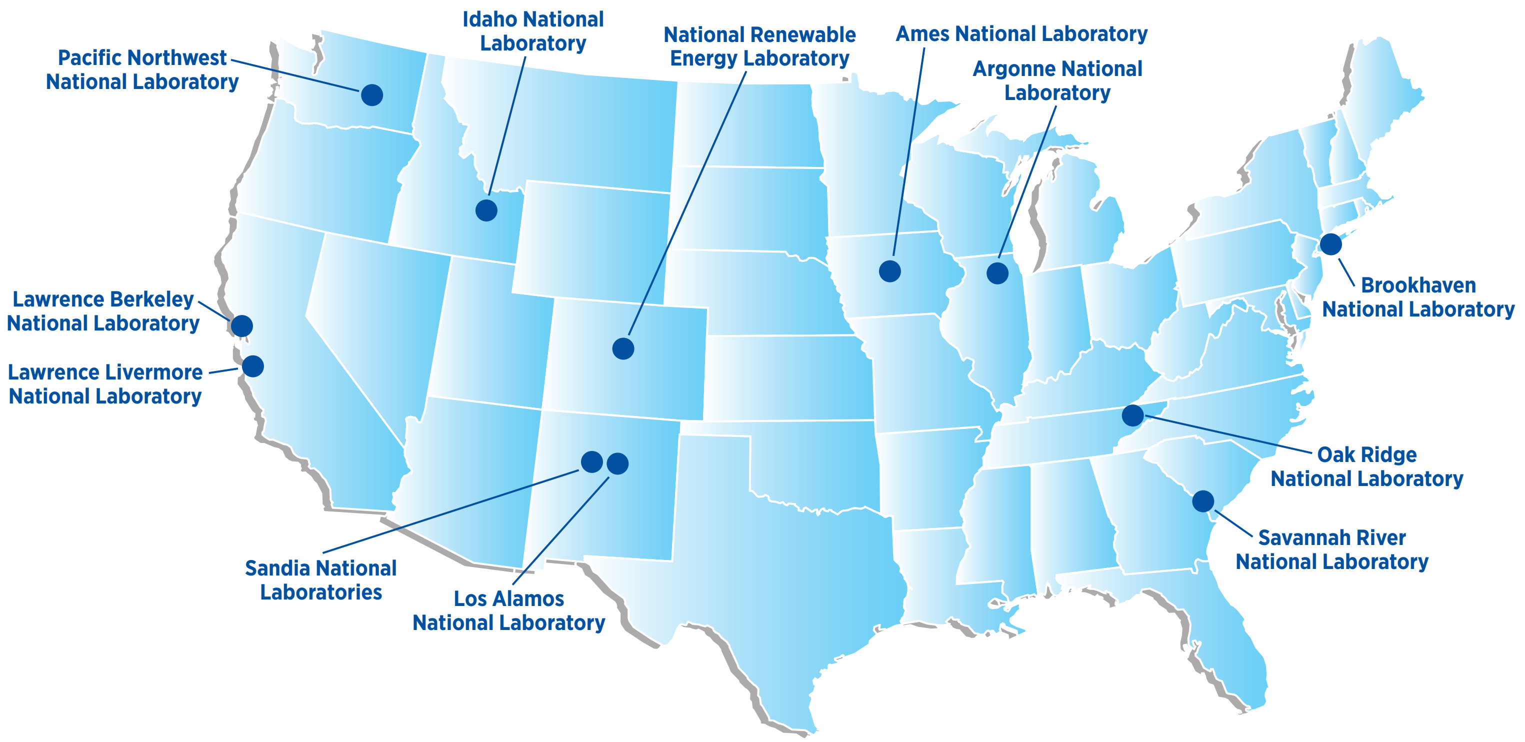
The Recovery Act also allows wind energy facility owners to choose a 30% business energy investment credit rather than the production tax credit through 2012. Alternately, owners of qualified facilities could choose to receive a grant equal to 30% of the tax basis (that is, the reportable business investment). The grants will be paid directly from the U.S. Treasury. Businesses and homeowners can also claim the full 30% tax credit for qualified small wind systems (under 100 KW) with no dollar cap (previously $4,000) on the credit.

For wind turbine manufacturers, the Recovery Act provides a tax credit for qualified investments in new, expanded, or re-equipped domestic facilities engaged in the manufacture of renewable energy equipment. Credits, which will be worth 30% of the investment, are made available for projects through a competitive bidding process. Applicants will receive tax credits based on the expected commercial viability of their project, expected job creation, reduction of air pollutants and greenhouse gas emissions, technological innovation, and ability to implement the project quickly.

### Wind Program Recovery Act Projects

- Clemson University will receive up to $45 million for a wind turbine drivetrain test facility.
- Twenty-seven new wind energy projects will receive up to $14 million for wind technology research and development, streamlining manufacturing processes, and easing systems interconnection.
- Massachusetts will receive $25 million in funding for a large wind turbine blade test center.
- Three university-led consortia will receive approximately $24 million for land-based and offshore wind research, development, and education.
- The National Renewable Energy Laboratory will receive $10 million to upgrade the drivetrain test facility and for infrastructure improvements to the National Wind Technology Center.

## DOE Laboratories Conducting Wind Energy Research




Recovery Act funds also support wind energy through DOE research and development, loan guarantees for renewable energy projects, development of efficient electrical transmission, and the Advanced Research Projects Agency – Energy (ARPA-E).

### DOE's Wind Energy R&D Capabilities

DOE draws on the capabilities and technical expertise found in its 12 national laboratories to meet the many complex challenges facing the wind industry today. The Wind Program uses cooperative research and development agreements that allow collaborative activities, closely supported by laboratory-based research and testing, to help private organizations improve wind technology.

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

The National Renewable Energy Laboratory (NREL) in Golden, Colorado, provides industry with the technical support it needs to develop advanced wind energy systems. NREL's research capabilities include design review and analysis; software development, modeling, and analysis; systems and controls analysis; turbine reliability and performance enhancement; certification and standards; utility integration assessment; wind resource assessment and mapping; technology market and economic assessment; workforce development; and outreach and education. As the only facility in the United States accredited through the American Association of Laboratory Accreditation to perform several critical tests, NREL's National Wind Technology Center provides the high quality testing required by wind turbine certification agencies, financial institutions, and other organizations throughout the world. Accredited tests that meet the International Electrotechnical Commission standards include wind turbine noise, power performance, power quality, and several structural safety, function, and duration tests.

Sandia National Laboratories

Sandia National Laboratories headquartered in Albuquerque, New Mexico, specializes in all aspects of wind turbine blade design and system reliability. Activities focus on reducing the cost of wind-generated electricity and improving the reliability of systems operating nationwide. Sandia's research addresses materials, manufacturing, aerodynamics, aeroacoustics, structural analysis, resource characterization, and integration studies. By partnering with universities and industry, Sandia has advanced knowledge in the areas of materials, structurally efficient airfoil designs, active-flow aerodynamic control, and sensors.

Pacific Northwest
NATIONAL LABORATORY

Pacific Northwest National Laboratory in Richland, Washington, is evaluating the effectiveness of integration strategies such as virtual balancing areas, sharing of regulation resources, operating reserves, area control error, and control room use of forecasting to address wind and load variability on the utility grid in the Pacific Northwest. Researchers are also evaluating sensitivities of wildlife species to wind energy development.

The Lawrence Livermore National Laboratory in Livermore, California, has a robust and growing program in wind power to help address the challenges in developing clean and renewable energy. Currently, a staff of nearly 20 scientists and engineers, drawn from programs in atmospheric science, engineering, and computation, are directly involved in wind power. The Laboratory includes a 7000-acre rural facility in the Altamont foothills that is being used for meteorological data acquisition and wind resource characterization.

Oak Ridge National Laboratory in Oak Ridge, Tennessee, is developing an archive of wind resource data that will provide information for wind energy research, planning, operations, and site assessment. Researchers are also examining the issues involved in importing large quantities of wind energy to the southeastern United States to satisfy possible renewable portfolio standards, and are investigating innovative control strategies for damping oscillatory modes.

Argonne National Laboratory in Argonne, Illinois, is developing improved methodologies for wind power forecasting and is working to increase the deployment of advanced wind forecasting techniques that will optimize overall grid reliability and systems operations. Work is also underway to assess and mitigate environmental impacts of wind power plants, and to enhance the reliability, performance, and efficiency of wind turbine drivetrains through advanced lubrication technologies.

The Idaho National Laboratory in Idaho Falls, Idaho, has more than 10 years of experience in wind-radar interaction research and development. Research staff work with wind developers and radar site managers to mitigate wind-radar system interactions that may ultimately affect the development of wind plants. Wind-radar interaction research efforts include conducting site-specific assessments to develop guidelines; improving radar software; improving hardware; developing filtering algorithms, gap filling, and fused radar systems; improving small plane detection; providing better modeling techniques; and developing computer modeling systems to predict performance before construction. Through the Center for Advanced Energy Studies, researchers test new wind energy systems, such as the Blackhawk vertical-axis turbine. Idaho National Laboratory also supports Wind Powering America activities and works on the integration of wind energy into power systems for remote areas such as mining operations.

Lawrence Berkeley National Laboratory in Berkeley, California, works with DOE, state, and federal policy makers, electricity suppliers, renewable energy firms, and others to evaluate state and federal renewable energy policies. Researchers provide expert assistance in policy design; analyze the markets for, and economics of, renewable energy sources; and examine the benefits and costs of increased market penetration of renewable energy technologies with a focus on wind and solar power. Researchers at Berkeley Lab also spearhead production of the Wind Program's annual *Wind Technologies Market Report*.

The Ames Laboratory in Ames, Iowa, focuses on forecasting wind energy resources, particularly for the high resource wind area in the Midwest. Ames Lab researchers are also studying interactions between wind turbines and agricultural crops. Ames is also a leader in rare-earth materials and alloys and other magnetic materials that are used for wind-turbine generator components, and it is developing a variety of robust supply chain and materials-substitution strategies to ensure the viability of the turbine manufacturing industry.

Los Alamos National Laboratory in Los Alamos, New Mexico, is conducting power flow analyses of the Western Interconnect, of scenarios associated with providing 20% of the nation's electricity with wind by 2030, and of scenarios to reach state renewable electricity standards.

Savannah River National Laboratory in Aiken, South Carolina, conducts studies on wind energy related technologies for coastal and marine environments. These studies include testing SODAR (Sonic Detection and Ranging) technology for wind resource assessment in coastal and offshore wind energy development along the Eastern Seaboard and testing of large wind turbine drivetrains at the Clemson University Drivetrain Test Facility. Savannah River is also studying radar impacts from wind turbines in environments with high refractivity resulting from high moisture content in the atmosphere, as is present in coastal and marine environments.

Brookhaven National Laboratory in Upton, New York, evaluates the dynamic response of large wind turbine systems and assesses alternative foundation materials, including concrete with high fly ash content, and fiber-reinforced concrete.

# ADVANCING LARGE WIND TURBINE TECHNOLOGY

The *20% Wind Energy by 2030* report included a landmark assessment of wind technology that is guiding research and development to reduce the cost of energy from wind technology, improve its performance, and increase its reliability. The DOE Wind Program sponsors targeted research and development projects through competitively selected public/private partnerships and cooperative research agreements. In their collaborations with industry, DOE's national laboratories provide critical expertise to enhance the success of these efforts to improve wind technology.

Laboratory-based research and testing activities develop technologies with the potential to reduce the cost and improve the performance and reliability of small, mid-sized, and utility-scale wind systems. The Wind Program coordinates and supports three key types of activities to improve turbine technology: conceptual design studies; component development and testing; and full scale turbine development and testing. Components and complete machines can be tested at DOE's National Renewable Energy Laboratory and Sandia National Laboratories, and at program-funded testing centers in Massachusetts and South Carolina.

### Small Business Support

DOE awards funds to small businesses for renewable energy research and development projects through its Small Business Innovation Research and Small Business Technology Transfer programs. Current innovative research projects include:

- Non-contact, laser-based techniques for in-line inspection of welds, which will lead to faster, lower-cost tower assembly (Intelligent Optical Systems, Inc., Torrance, California);
- A novel sensing system to detect defects in wind turbine blades, preventing costly turbine shutdowns due to predictable blade failures (Intelligent Fiber Optic, Santa Clara, California);
- A portable instrument that uses vibrothermography, a nondestructive evaluation technique, to look for defects during the manufacture of composite components of wind turbines and throughout the lifetimes of wind turbine systems (Resodyn Corporation, Butte, Montana).

## Full-Scale Turbine Development and Testing

Since the beginning of the modern wind energy industry, the DOE Wind Program has worked with companies to develop and test full-scale wind turbines. In the 1970s, the Wind Program designed, built, and tested the 100-kW Mod series of wind turbines, the largest wind turbines of their day. That effort paved the way for today's multimegawatt wind turbines. More recently, Wind Program researchers worked with General Electric (GE)

The 2.3-megawatt Siemens wind turbine installed at the National Renewable Energy Laboratory is the centerpiece of a government-industry research partnership between Siemens and the laboratory to study the turbine's performance and aerodynamics.


Blue skies and calm conditions contributed to a smooth installation of the DOE 1.5 megawatt wind turbine at the National Wind Technology Center.

Energy and its predecessors to design and test components such as blades, generators, and control systems that led to GE's 1.5-MW commercial wind turbine, now operating worldwide. The Wind Program also worked with Clipper Windpower to develop its 2.5-MW Liberty series turbine, introduced in 2006.

In addition to helping industry design and develop full-scale prototypes, the Wind Program provides industry with technical support to test its new machines. Testing for structures, designs, and performance allows for system optimization as well as for incremental improvements in individual components. Laboratory and field tests can be used to improve the control algorithms and simulation codes from which the turbines are designed and to validate the design models. Turbine tests conducted at the National Wind Technology Center evaluate turbine loads, power performance, power quality, and acoustic emissions in accordance with standards developed by the International Electrotechnical Commission and the American Association of Laboratory Accreditation.

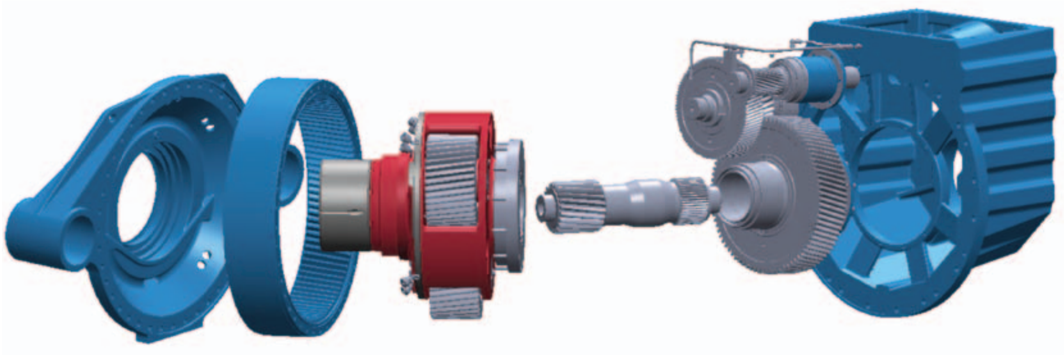
DOE has purchased a 1.5-MW turbine from GE and installed it at the National Wind Technology Center for long-term research and testing. This turbine, called the DOE 1.5, will be instrumented to collect detailed data that will help researchers assess the aerodynamics of its design, the effects of turbulence on its load and performance, and the influence of the combination of these factors on its performance. The turbine will feed electricity into the local grid, and as a landmark for towns in the area, the turbine will be used for education and outreach.

One late-stage prototype undergoing testing at the National Wind Technology Center under a cooperative research and development agreement is a Siemens 2.3-MW turbine featuring a novel blade design. This turbine will be heavily instrumented to produce a constant stream of data on aerodynamics, power characteristics, vibrations, system fatigue, acoustics, and other key measurements. Under the agreement, Siemens will provide the turbine, engineering support, and maintenance, while the National Renewable Energy Laboratory will provide the site, installation services, and expertise in field aerodynamics testing, structure and reliability testing, and meteorological analysis. These tests will provide knowledge to optimize turbine structures, mitigate loads, increase power production, test safety systems, develop and validate controls, improve system and component reliability, and better understand wind turbine aerodynamics.

To meet industry's growing demands for utility-scale prototype testing, DOE has begun efforts to expand its testing capabilities at existing centers and at several new research and test facilities around the country. Over the next two years, DOE will invest up to $70 million in Recovery Act funds to develop facilities capable of testing next-generation wind turbine blades and drivetrains.

The Wind Program is also investing $24 million in Recovery Act funds in university-led wind energy research consortia that include partners from private industry and state and local governments. These consortia, led by the University of Maine, the University of Minnesota, and Illinois Institute of Technology, will conduct research and development to improve the performance and reliability of land-based and offshore wind technology, and will also use the DOE funds to enhance their wind technology curricula and provide students with educational opportunities in wind energy technology. The University of Maine will design, develop and deploy prototype floating platforms for offshore wind turbines, and will also investigate deployment logistics and the use of composite materials in these platforms. The University of Minnesota will install a utility-scale, land-based wind turbine to investigate aerodynamics and acoustics, novel systems for mechanical power transmission and electric power generation, wind farm siting, and interactions between wind turbines and radar. The utility-scale land-based test turbine installed at Chicago's Illinois Institute of Technology will be used for research and development to develop control algorithms for increasing the reliability of wind turbine components, and to develop operation and planning tools for accommodating large amounts of wind into electric power utility systems.

## Component Development and Testing



Main components of a wind turbine gearbox.

Wind turbines are complex systems comprising many components, each with potential for improvements that could contribute to reductions in overall system cost. The Wind Program works with industry to develop and test key wind turbine components, including gearboxes, control systems, and blades, as well as non-turbine components such as foundations.

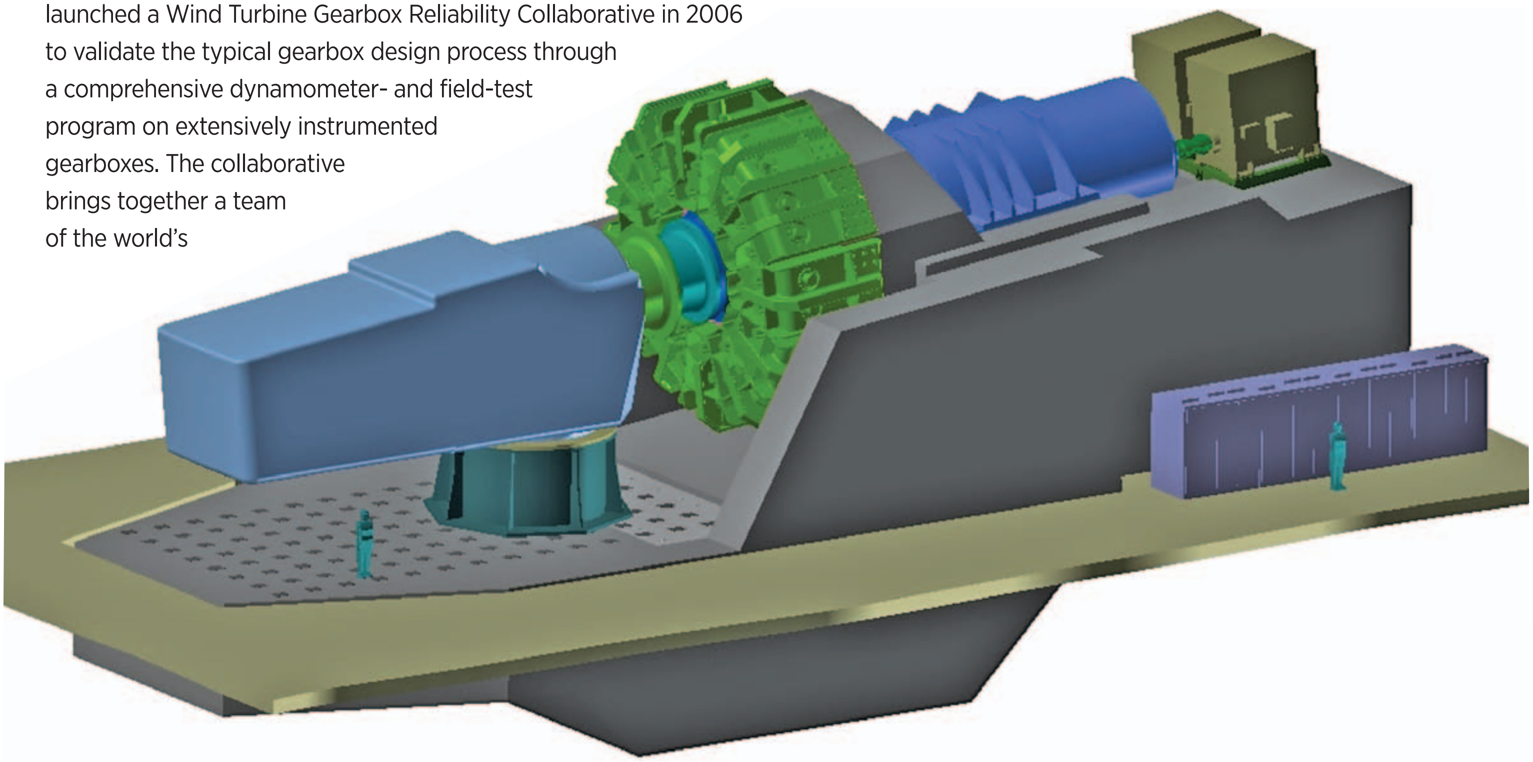
### Drivetrain Development and Testing

The drivetrain—generator, gearbox, and power converter—represents roughly 25% of the capital cost of a modern wind turbine. The drivetrain's weight and size also affect the cost of the foundation and tower; larger, heavier components are more expensive to install.

Gearbox reliability is a major issue for the wind energy industry. Gearbox failures require expensive and time-consuming replacement, significantly increasing the cost of wind plant operation while reducing the plant's power output and revenue. In an effort to help industry increase gearbox reliability and design gearboxes that can survive the demanding requirements of the wind turbine operating environment, the Wind Program launched a Wind Turbine Gearbox Reliability Collaborative in 2006 to validate the typical gearbox design process through a comprehensive dynamometer- and field-test program on extensively instrumented gearboxes. The collaborative brings together a team of the world's leading turbine manufacturers, consultants, and experts, from more than 30 companies and organizations.

In 2009, the collaborative's first 750-kW gearbox was instrumented and tested at the National Wind Technology Center dynamometer. The dynamometer measured the power output of the gearbox to help researchers determine its baseline characteristics. The gearbox was then installed at the Xcel Energy Ponnequin wind plant for field testing. Data acquired from field tests have already provided valuable information about possible causes of early gearbox failures. Evaluation of the data from this gearbox will be shared among participants in the collaborative and used to improve gearbox design codes. Interim and final results will be published for the benefit of the entire industry.

In 2009, new wind turbines had an average capacity of 1.7 MW. A 1.5-MW machine (the most commonly installed wind turbine



A new wind turbine drivetrain test facility to be built in Charleston, South Carolina, will be capable of testing drivetrains with capacity ratings from 5 to 15 megawatts – similar in size to the 15-megawatt drivetrain in this concept drawing for a drivetrain test facility. Illustration provided courtesy of RENK LABECO Test Systems Corporation.

Wind turbine component manufacturing facilities, like the blade manufacturing facility above, provides thousands of jobs nationwide.

today) is almost as tall as the Statue of Liberty, has a rotor (blades and hub assembly) large enough to sweep a football field, and can produce enough electricity to power approximately 500 homes. Several manufacturers are working on designs for 3-MW to 5-MW turbines, which will generate enough electricity to power more than 1,300 homes. A 3.6-MW machine has a rotor diameter large enough to park 24 cars end-to-end, and a 5-MW machine is as tall as the Space Needle in Seattle, Washington.

To meet the need to test the larger drivetrains for these turbines, the Wind Program is investing $45 million in Recovery Act funds for a larger dynamometer test facility to be built by Clemson University at the Charleston Naval Complex in South Carolina. This new facility will be capable of testing 5-MW to 15-MW drivetrains for land-based and offshore wind turbines and will feature power analysis equipment capable of performing highly accelerated endurance testing. The program is also investing $10 million in Recovery Act funds to upgrade the test facility at the National Wind Technology Center so that it will be capable of testing 5-MW drivetrains.

Argonne National Laboratory researchers are exploring a novel approach to enhance reliability, performance, and efficiency of gearboxes, bearings, shafts, and other drivetrain components of advanced wind turbine systems. They are developing breakthrough ultra-fast chemical conversion and nano-colloidal boron-based lubrication technologies that can substantially reduce friction, increase load-bearing capacity, and increase resistance to wear, scuffing, and fatigue-related failures of gears and bearings.

## Blade Development and Testing

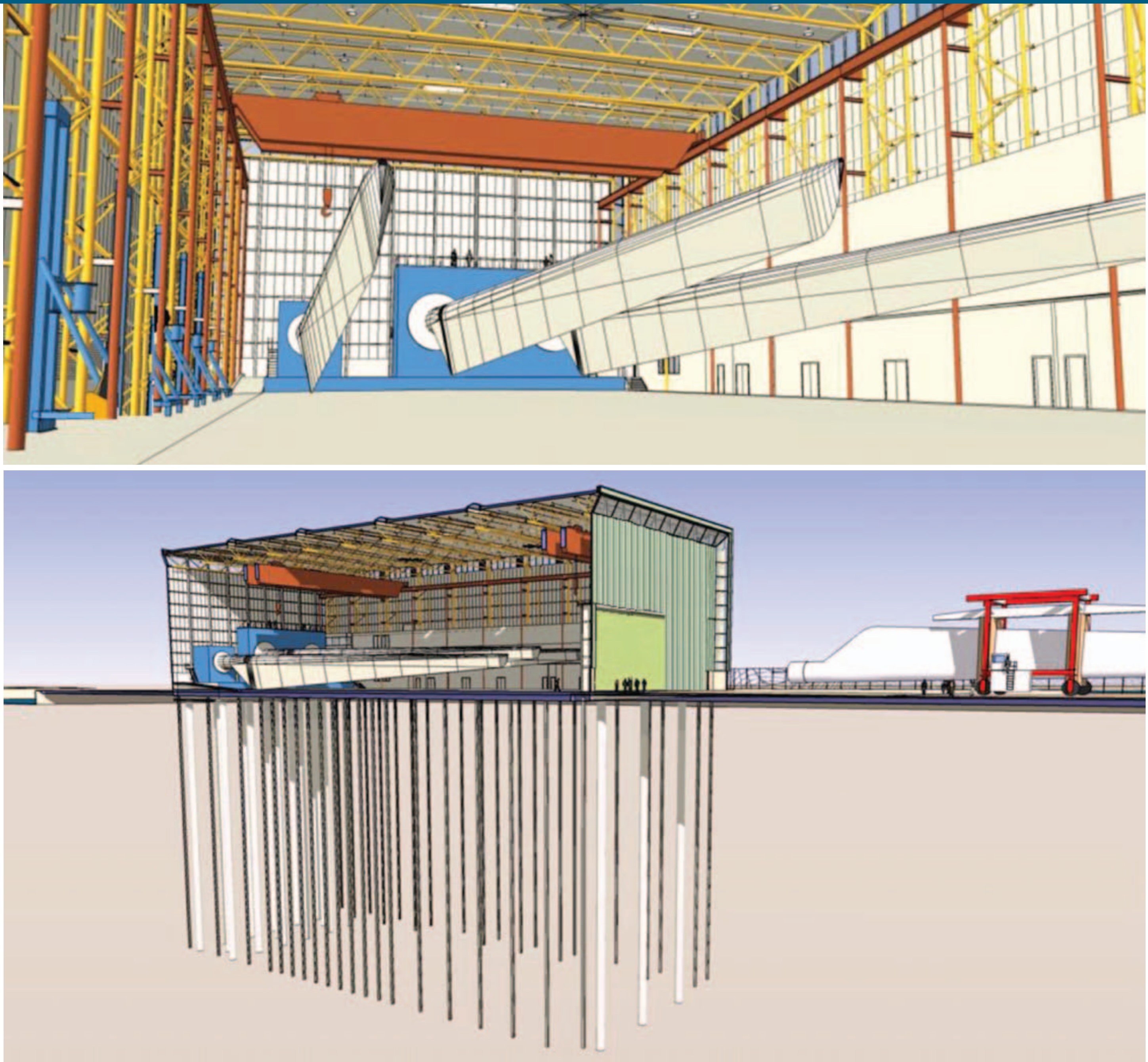
The wind turbine rotor, consisting of the blades and the hub, drives the design of the rest of the wind turbine. The rotor is the component that captures the wind's energy, and the airfoil shape, mechanical properties, and weight of the blades determine the loads transmitted to the other components in the turbine. The Wind Program works to develop and test advanced blade technologies that can increase energy capture and decrease weight and transferred loads, thereby reducing capital costs.

### *Blade Development*

As conventionally designed and manufactured blades increase in size, their weight tends to increase proportionately faster than the additional energy they capture from the wind. New technology innovation may be able to address these physical constraints. Researchers at Sandia National Laboratories help bring about those innovations by evaluating new materials, advanced control techniques, airfoil designs, improved manufacturing processes, and enhanced design tools that will contribute to the development of next generation rotors. A key goal for the Wind Program's work with Sandia is to improve scientific knowledge and engineering tools used to develop advanced rotors at the lowest possible cost.

Next generation rotors will require a multidisciplinary approach to provide the most efficient, lightweight, robust designs. As an example, Sandia continues to evaluate advanced materials such as carbon fiber and to develop optimal carbon/glass hybrid designs that will reduce the weight of the blade while increasing

This 45-meter wind turbine blade being transported to a construction site demonstrates the size of the blades installed on the multimegawatt turbines commonly installed at wind plants today.



Interior and exterior concept drawings for a new blade test facility being built in Boston, Massachusetts. The new facility will be capable of testing wind turbine blades up to 90 meters in length. For the facility to withstand the force required to conduct some of the tests on 90-meter blades, the structure is anchored by 58 piles and 18 caissons set to a depth of approximately 160 feet (bottom illustration).

its strength and flexibility. By using advanced materials and optimized blade sensors to enhance reliability and load control, researchers hope to extend the lives of blades and other turbine components, thus reducing repair and replacement costs. The program also conducts research into processes for manufacturing blades and is identifying automated processes that can help manufacturers ensure consistent product quality and improve labor productivity. Additional rotor research topics include:

- More efficient blade structures, such as thick airfoils with designs that fully integrate structure and aerodynamics, along with slenderized blade geometries;
- Adaptive structures, such as passive bend-twist coupling and active-aero devices;
- Design details to minimize stress concentrations in certain regions;
- Non-destructive evaluation and inspection technologies;
- Acoustic performance analysis and testing.

***Blade Testing***

Blade tests help manufacturers evaluate the anticipated lifetime performance and identify weaknesses of their designs before moving to commercial deployment. Tests are also required to meet wind turbine design standards, reduce the technical and financial risk of deploying mass-produced wind turbine models, and reduce the cost of wind energy.

DOE's National Wind Technology Center currently operates the only facility in North America capable of performing full-scale testing of wind turbine blades up to 50 meters long. Blade testing techniques developed at the National Wind Technology Center are now used by the industry worldwide to ensure quality and performance of new designs.

To keep up with industry's need to test the larger blades under development, in 2009 DOE broke ground for the construction of a new blade test facility in Massachusetts. The facility will be the only U.S. test center capable of testing wind turbine blades up to 90 meters long. Supported by funding from the Recovery Act and the State of Massachusetts, the test facility is expected to begin operation in 2011. This capability will spur the development of next-generation wind turbine technology, both land-based and offshore, in the United States while creating 250 immediate construction jobs.

Technical staff from DOE's National Renewable Energy Laboratory and Sandia National Laboratories are cooperating to complete structural laboratory testing of the Sandia Sensor Blade. This S-Blade is a 9-m blade that incorporates health monitoring systems, such as accelerometers and strain gauges that could potentially improve blade performance and alert operators to excessive loads being applied to the blade. Sandia staff will complete a field test using the S-Blade, while the National Renewable Energy Laboratory will conduct full-scale structural tests.

DOE's Los Alamos National Laboratory is developing and will field test an instrument capable of making detailed inflow, blade, and outflow velocity field measurements in full-scale wind turbines. This experiment will lay the foundation for collecting data that will improve understanding of blade loading and load control in a variety of wind conditions. Los Alamos is also working to design and implement efficient, adaptable, and responsive structural health monitoring and state-awareness systems, relatively new concepts in wind energy applications.

## Controls Systems

Although larger blades can capture more energy and be more cost-effective, the increased structural loads they impose throughout the system can lead to system failures and increased maintenance costs. To reduce these loads, the Wind Program has been working to develop innovative control systems, with industry and academic partners such as Catch the Wind, Inc., Garrad Hassan and Partners, Ltd., Risø National Laboratory in Denmark, the Colorado School of Mines, and the University of Colorado.

Since 2001, two turbines at the National Wind Technology Center have been used to test control schemes that could reduce loads and increase energy capture. The Controls Advanced Research Turbines are highly instrumented 600-kW machines, and their array of wind speed sensors can be modified to meet the needs of test engineers. The objectives of the work conducted on the research turbines is to develop advanced feed-back and feed-forward controls that can be implemented on commercial turbines through industry collaborations. These controls will mitigate loads, improve turbine performance, and ultimately reduce the cost of energy thus contributing  to the long-term vision described in the 20% Wind Energy by 2030 report.

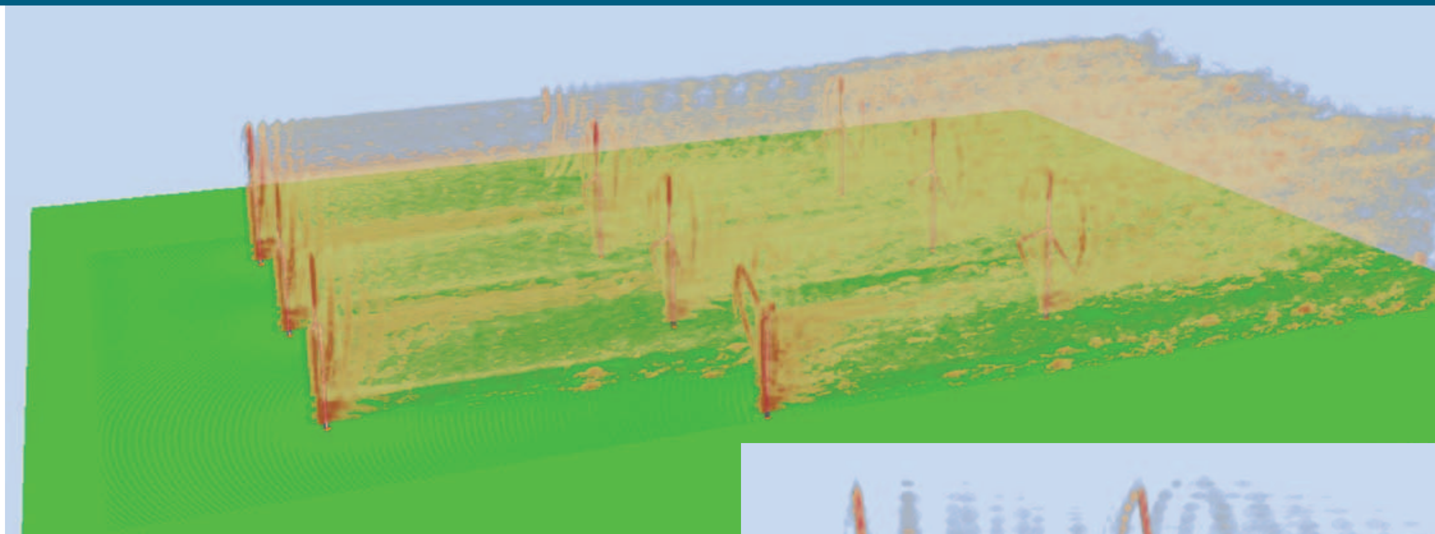
## Foundations

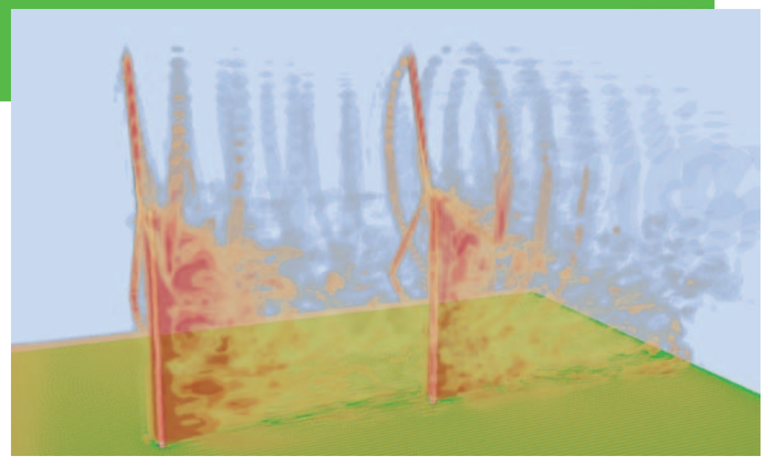
To help reduce the costs of foundations and electrical power infrastructure for utility-scale wind turbines, the Wind Program has partnered with RES Americas through a cooperative research agreement. For this project, foundations for the two multimegawatt turbines installed at the National Wind Technology Center in 2009 were custom-designed and heavily instrumented to provide data on loads. The program and RES Americas are also using the turbines to optimize thermal performance of underground electrical cables by installing cabling in various types of soil conditions and measuring heat dissipation.

## Design Tools and Concept Studies

Computer modeling and turbine simulations are important elements of DOE's contributions to the industry's development of better turbines. Designing large wind plants (100 MW or more) for specific site conditions will reduce the cost of energy and improve performance. Site-specific design involves methods to tailor turbine designs to the characteristics of a specific site, including energy yield, load conditions, and turbine inflows. For example, site-specific design considers how to modify blade designs, including aerodynamic geometry, controls, and structural details, in order to optimize energy capture and durability at sites with gusty, strong winds.

The Wind Program has developed wind turbine simulation codes to support the industry's design of next-generation turbine blades and other components. These codes reduce development costs by allowing designers to build virtual models of blades and full systems to predict the design performance in different environments before prototypes are constructed and tested. These publicly available computer codes, such as FAST and AeroDyn, are widely used by universities, government agencies, and the wind energy industry. In 2005, the internationally recognized certification body Germanischer Lloyd (GL) of Hamburg, Germany, accepted two of the program's wind turbine design codes, FAST





The Windblade modeling software developed by Los Alamos National Laboratory simulates wind turbine wake flows, providing information critical for planning wind turbine arrays.

and ADAMS, for calculating land-based wind turbine loads for design and certification.

Los Alamos National Laboratory is developing a physics-based modeling software application called Windblade to simulate the interactions between rotating turbine blades and the complex atmospheric conditions to which they are exposed, including wind shears. The results of these simulations are critical for designing wind turbines, predicting wind turbine performance, siting wind farms, planning wind turbine arrays, and assessing the environmental effects of wind turbine arrays. Windblade is available for licensing to industry.

## Offshore Wind Technology

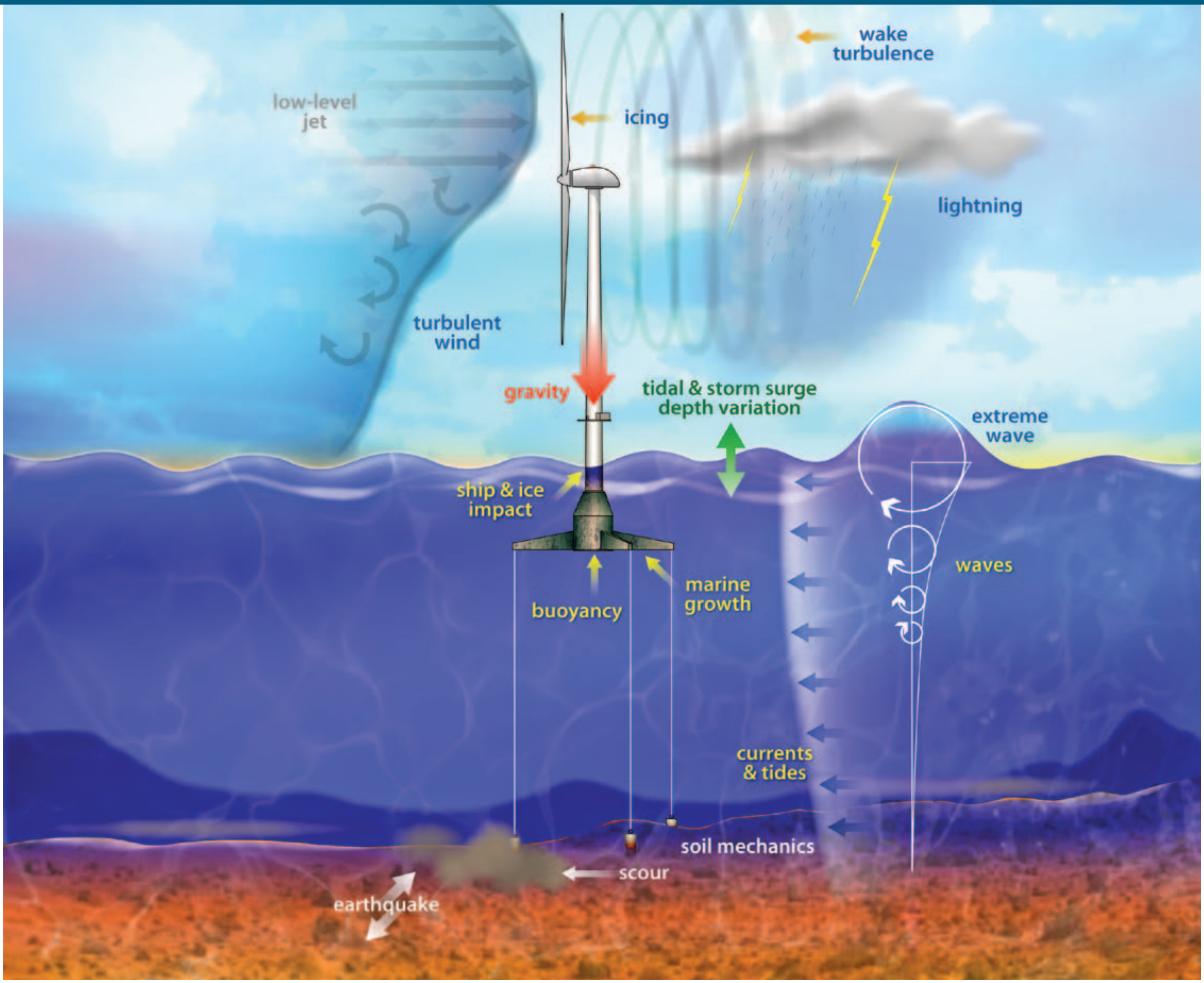
The Wind Program supports the development of offshore wind technology by developing design tools and simulation codes to predict turbine performance, loads, and stability in the offshore environment.

Working with the International Energy Agency (IEA), DOE's National Renewable Energy Laboratory researchers will verify the primary design codes used to predict wind and waves for both land-based and offshore wind turbines and identify the best features of floating platform concepts for offshore wind turbines. In 2009, the National Renewable Energy Laboratory presented the results of its effort to develop a deepwater floating spar for use in the floating platform phase of the IEA wind Task 23 research project. A prototype of this floating platform was installed in 2009 off the coast of Norway. In addition to modeling a spar, researchers modeled a floating offshore tension-leg platform and compared the results to studies of other floating platform concepts, including the spar and a barge.

The National Renewable Energy Laboratory works with MMI Engineering to understand foundation types, including monopiles, gravity bases, tripods, and jackets, to improve understanding of when certain foundation types are appropriate. Parameters such as water depth and soil type are being studied for each type of substructure.

To ensure the safe installation and operation of wind plants in U.S. waters, the Wind Program is comparing the European certification standards for offshore wind turbines to the standards developed by the American Petroleum Institute for offshore drilling platforms, to see if they can deliver comparable levels of structural safety.

In 2010, the Wind Program will begin working with the University of Maine on a project, supported in part by the Recovery Act, to design and deploy two 10-kW prototypes and one 100-kW prototype offshore wind turbine mounted on floating platforms. The purpose of the prototype experiments is to validate floating wind turbine design tools. The prototype designs will be optimized for floating platforms by identifying and incorporating durable, lightweight, hybrid composite materials. The effort will also determine the requirements and logistics for manufacturing and deploying offshore platforms. Two turbines will be located at the University of Maine's Deepwater Offshore Wind Test Site in state waters and one turbine will be operated by the University of New Hampshire at an offshore test site in the Isle of Shoals.




To design floating platforms for offshore wind turbines, researchers study the characteristics of the marine environments, including extreme waves, storm surges, turbulent wind, currents and tides, and marine growth.

In 2010, the Wind Program will also begin work to further characterize the offshore wind resource and identify special design requirements for offshore wind turbines, which may be vastly different than the design requirements for land-based wind turbines.

## International Cooperation

The United States participates in international studies to learn from the experiences of other nations working to integrate wind energy into electrical grids. Collaborative research with international partners helps the DOE Wind Program further its mission. Through the program's work with the International Energy Agency (IEA) Wind agreement, U.S. researchers have participated in meetings and areas of research called Tasks. In Task 11, Base Technology Infromation Exchange, researchers attended topical expert meetings on radar, radio links, and wind turbines; remote wind speed sensing techniques using SODAR and LIDAR; and sound propagation models and validation. Active participation in Task 19, Wind Energy in Cold Climates, informs strategy for wind development in the northern states. The Wind Program supported U.S. researchers who acted as operating agents for Task 23, Offshore Wind Technology and Deployment; Task 24, Integration of Wind and Hydropower Systems; and Task 26, Cost of Wind Energy. Work conducted for Task 25, Operation of Power Systems with Large Amounts of Wind Power, resulted in the publication of key reports in 2009 that address issues of grid connection that are relevant in all countries. Under Task 27, Labeling Small Wind Turbines, researchers are helping to develop a labeling protocol for small wind turbines. The United States also hosted a meeting for Task 28, Social Acceptance of Wind Energy Projects, and is cooperating in Task 29, aerodynamic research based on data from wind tunnel tests conducted at NASA.

# SMALL AND MID-SIZED TURBINE DEVELOPMENT

Small and mid-sized wind turbines provide clean, renewable, on-site power for residential, small commercial, farm, and community applications. Small wind turbines, with a capacity rating of less than 100 kilowatts, are typically used to supplement the power supply for residential and farm applications. Mid-sized turbines, with a capacity rating of more than 100 kilowatts but less than 1,000 kilowatts (1 megawatt), are typically used for small commercial and community applications. Adding small and mid-sized turbines to the electric power supply can help optimize grid capacity in places where utility-scale wind plants are not feasible. When these systems feed excess power into the utility grid, they can help relieve pressure on the grid while contributing to our nation's energy security.

## Technology Development and Testing

For more than a decade, DOE has partnered with industry to support the development of innovative concepts, components, and prototypes for residential, farm, and small industrial wind energy applications. From drawing board to market, the Wind Program and the National Renewable Energy Laboratory assisted with the development and certification of the award-winning Southwest Windpower 1.8-kW Skystream wind turbine, which has gone on to become a commercial success.

Idaho National Laboratory's Center for Advanced Energy Studies is working on a project with Blackhawk Project, LLC to develop a new vertical-axis wind turbine. Former helicopter researchers are testing and monitoring the Blackhawk tilt-rotor vertical-axis machine installed at the Center. The vertically-oriented airfoils attach to a patent-pending tilt rotor in the center of the turbine. The slanted rotor allows the turbine to self-start, unlike some other vertical-axis designs. This system could represent a significant evolution in vertical-axis wind energy technology.

### Independent Testing

In 2007, the Wind Program launched an Independent Small Wind Test Project to both improve the quality of small wind turbines and provide consumers with unbiased information. Test data from this project will support turbine certification and be published on the National Renewable Energy Laboratory's wind technology Web site. As of January 2010, four commercially available turbines have been tested to standards adopted by the International Electrotechnical Commission, as well as the American

Photo on left:Blackhawk tilt-rotor vertical-axis wind turbine installed at Idaho National Laboratory's Center for Advanced Energy Studies.

The four commercially available wind turbines tested under the Program's small wind test project in 2009 from left to right, Entegrity EW50, Mariah Windspire, Abundant Renewable Energy 442, and Gaia-Wind.

A 100-kW turbine developed by Northern Power Systems undergoing tests at the National Wind Technology Center.

Wind Energy Association draft standards for small wind turbine systems. The tests included power performance, power quality, acoustics, safety, and function. To meet the growing demands for small turbine testing, the Wind Program has launched an effort to establish regional test centers, and four new centers in Kansas, New York, Texas, and Utah will become operational in 2010.

## Standards and Labeling

Certification of small wind turbines will increase consumer confidence that turbines will operate as advertised. Manufacturers benefit from certification because consumers are more likely to purchase a certified turbine. The availability of certified small wind turbines will also help ensure that public incentive programs for small wind support quality equipment. The Small Wind Certification Council is a nonprofit organization formed with support from the DOE Wind Program, the American Wind Energy Association, state energy offices, and turbine manufacturers to certify small wind turbine systems. The council is developing guidance for manufacturers to submit appropriate test data and have their turbines certified. Certification will begin in 2010. The United States is also participating in an international effort coordinated by the IEA Wind Task 27 to develop and implement a labeling system for small wind turbines.

## Midsized Turbines

Since the early 1990s, the market has grown for both utility-scale turbines larger than 1 MW and for small turbines under 100 kW. Only a few turbine models in the mid-size range, from 100 kW to 1 MW, are available for purchase in the United States. A DOE-sponsored market assessment in late 2008 identified a market potential of 220 GW for midsize turbines. These turbines could be used for industrial operations, larger farms, public facilities, and community wind. To help fill this technology gap, the Wind Program launched a Midsize Turbine Development Project in 2009 to encourage U.S. manufacturers and wind turbine designers to create prototype turbines between 100 kW and 1,000 kW (1 MW).

# SUPPORTING GRID INTERCONNECTION

Wind power is a unique source of electricity. The natural variability of the wind resource can present challenges for integrating wind into routine electric power system operations. Operating costs associated with wind power variability and uncertainty have been examined for an increasing number of power systems. The levels of wind penetration of interest have grown toward 20% and higher due to improved comparative economics and favorable state and regional policies. DOE's *20% Wind Energy by 2030* report has further focused attention on integrating larger amounts of wind power by providing a thorough assessment of challenges and solutions for wind to provide 20% of the nation's electricity. Attaining a better operational understanding of electricity sector integration issues will also help remove barriers to increased grid interconnection of other renewable energy sources.

As increasing amounts of wind generation capacity are installed and connected to the grid, grid operators need to become more familiar with ways to reliably integrate wind energy into routine system operations. In response to this need, DOE's Wind Program has tapped the resources of its national laboratories to form a Renewable Systems Interconnection research team, which includes researchers from Ames National Laboratory, Argonne National Laboratory, Idaho National Laboratory, Lawrence Livermore National Laboratory, Los Alamos National Laboratory, the National Renewable Energy Laboratory, Oak Ridge National Laboratory, Pacific Northwest National Laboratory, and Sandia National Laboratories. Team members work with industry partners, university researchers, independent system operators, regional transmission organizations, the Federal Energy Regulatory Commission, and DOE's Office of Electricity Delivery and Energy Reliability. The team's charter is to increase understanding of the true impacts of wind energy on the U.S. electrical infrastructure

All new electricity generation, including wind energy, would require expansion of U.S. transmission by 2030.

and to ensure that grid reform measures include provisions for variable generation resources such as wind energy.

The Wind Program's Renewable Systems Interconnection team has participated in several high-penetration utility wind integration studies that demonstrate the ability of significant wind energy generation to be integrated into electric grid systems in a cost-effective manner. Scenarios evaluated included penetrations of up to 25% of electrical energy from wind in Minnesota, 33% of electrical energy from renewable sources in California, and 20% of generating capacity from wind power plants in Colorado. At these moderately high wind energy penetration levels, the studies found that wind power's variability and uncertainty imposed reasonably low ancillary costs, less than $5 per megawatt-hour (MWh).

## Regional System Integration Studies

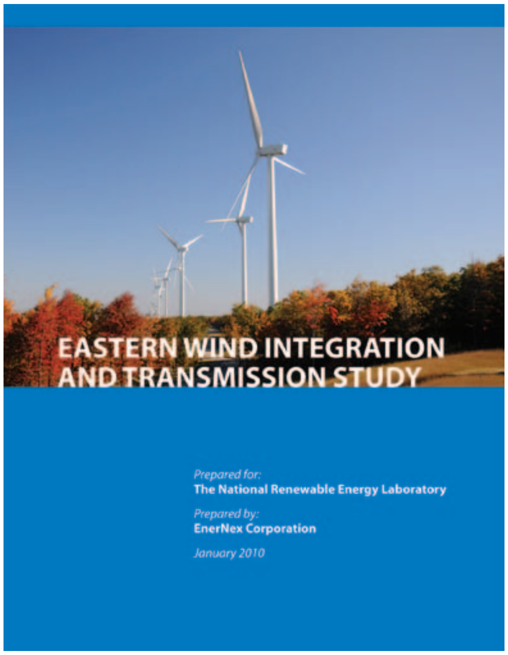
According to the *20% Wind Energy by 2030* report, generating 20% of the nation's electrical energy from wind requires a major national commitment and the answers to two key questions: (1) Can the electrical grid accommodate very high amounts of wind energy without jeopardizing security or degrading reliability? (2) Given the constraints of the nation's current transmission infrastructure, how could significantly larger amounts of wind energy be developed? To answer these questions, the Wind Program has commissioned studies to model and analyze high penetrations of wind generation (between 20% and 30%) on a large scale in the synchronous electricity grids that cover the lower 48 states.

Studies of the Eastern and Western Interconnections undertaken by the Wind Program's Renewable Systems Interconnection team used realistic wind energy data covering three historic years of weather and electrical loads to model electric system production. Operational modeling was performed on an hourly time step; each study also analyzed sub-hourly wind and load data to provide insight into the intra-hour impacts and variability characteristics of wind energy. Additionally, each study evaluated alternative wind energy build-out scenarios to help demonstrate the impacts of developing local wind with lower capacity factors against more remote wind resources that require construction of longer transmission lines.

The *Eastern Wind Interconnection Study*, published in 2010, found that supplying 20% of the electric energy requirements for the U.S. portion of the Eastern Interconnection would call for approximately 225,000 MW of wind generation capacity, almost a tenfold increase above today's levels. The study team also developed a "business-as-usual" scenario, resulting in wind energy meeting about 6% of the total projected load requirements for the U.S. portion of the Eastern Interconnection by 2024. The study concluded that new transmission is required to accommodate wind generation even for the 6% penetration scenario in the Eastern Interconnection. This means that planning for new transmission should begin now, as building transmission capacity takes longer than building wind power plants. Researchers also found that high penetrations (20% to 30%) of wind generation are technically feasible; however, unless transmission is enhanced, substantial curtailment (shutting down) of wind generation would be required. The full report and supporting materials are available on the Web site of the National Renewable Energy Laboratory.

The *Western Wind and Solar Integration Study*, also published in 2010, examined the operational impact of up to 35% wind and solar energy penetration levels on the WestConnect grid in Arizona, Colorado, Nevada, New Mexico, and Wyoming. The study concluded that 35% wind and solar energy penetration in WestConnect is feasible, provided that there is sub-hourly scheduling and substantial cooperation between utility balancing areas. The full report and supporting materials are available on the Web site of the National Renewable Energy Laboratory.

The Eastern and Western integration studies developed datasets to help energy professionals perform wind integration studies, compare potential wind sites over land areas and time periods, and estimate power production from hypothetical wind plants. The *Eastern Wind Integration and Transmission Study* developed a dataset of three years of modeled time-series wind speed and power output that can be used to evaluate the power system impacts and transmission capacity associated with increasing wind penetration to 20% and 30% on most of the Eastern Interconnect. The *Western Wind and Solar Integration Study* produced a comprehensive dataset to help model the potential for building wind plants in the Western United States. The datasets will make it possible to assess the impacts on operation due to wind variability and uncertainty and will help develop ways to mitigate these potential impacts of wind power on utility grids.

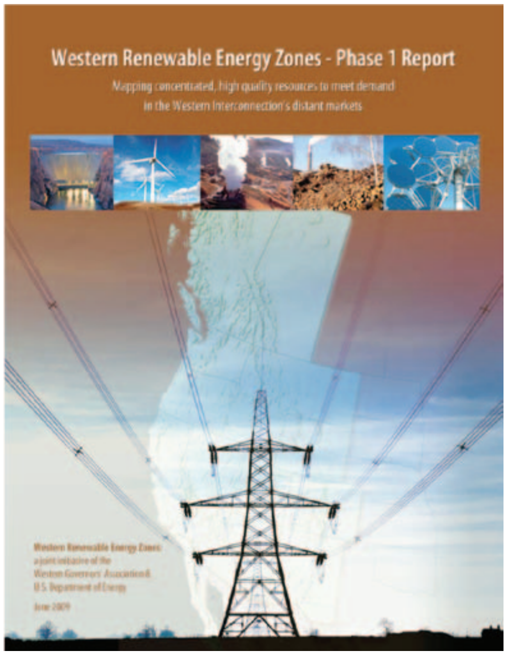



Another study conducted in 2009 by DOE's Lawrence Berkeley National Laboratory reviewed 40 transmission planning studies from 2001 to 2008 and compared them to two scenarios of 20% wind electricity penetration in the United States. This report, *The Cost of Transmission for Wind Energy: A Review of Transmission Planning Studies*, found that unit transmission costs did not appear to increase significantly with higher levels of wind capacity additions.

Members of the Renewable Systems Interconnection team also work with state and regional power distributors, state governors, and public utility commissioners. DOE's National Renewable Energy Laboratory collaborated with the Western Electricity Coordination Council to develop and validate dynamic wind turbine models for use by utility planners, consultants, and researchers in the Western region. To better understand the impacts of large amounts of wind power in the Western Area Power Administration's service area, the team collaborated with consumer-owned electric power cooperatives and members of the Nebraska Power Association. The Nebraska Statewide Wind Integration study, published in 2010, is available on the Web site of the National Renewable Energy Laboratory.

The Renewable Systems Interconnection team works with the Western Governors' Association to find ways to connect electricity consumers to the region's abundant renewable energy resources. The Western Governors' Association supports efforts to develop 30,000 MW of clean energy in the region by 2015. To identify the best route to 30,000 MW of clean energy, DOE and the Association will spend $2.3 million over three years to address Western regional power supply issues in 11 Western states, two Canadian provinces, and areas in Mexico composing the grid. This partnership is important for transmission planning, and eventually, for regional cost allocation and cost recovery.

Another 2009 Lawrence Berkeley National Laboratory study found that wind energy would play a major role in meeting the West's demand for clean energy in all cost and tax scenarios under the Western Renewable Energy Zone Initiative. Researchers ran sensitivity analyses to see how several variables affect economic decisions to expand transmission lines. The report also found that the production and investment tax credits played a crucial role in reducing the cost of meeting the region's demand for clean energy. The ability to trade renewable energy credits freely within the region was found to reduce the cost of clean energy. The study concluded that transmission costs would be a minor component of overall electric sector costs in all scenarios. The overall Western Renewable Energy Zone effort focuses on taking advantage of the western states' collaboration to acquire renewable energy. By covering multiple states, a strong possibility exists that a more economic renewable energy supply plan can be developed and that fewer miles of transmission line will be required compared to individual state plans.




## Power Markets

In the mid-1990s, organizations called transmission system operators were formed to ensure that wholesale power markets in their regions operated efficiently, treated all market participants fairly, gave all transmission customers open access to the regional electric transmission system, and supported the reliability of the bulk power system. Today, two-thirds of the population of the United States and more than one-half of the population of Canada obtain their electricity from transmission systems and organized wholesale electricity markets run by these transmission system operators.

Wind energy integration studies must consider regional markets that span large geographic areas and how the power grid might be optimized to promote efficiency through resource sharing. Markets are designed so that an area with surplus electricity can benefit by sharing that energy with another region in the open market. These markets allow participants and operators to see the "big picture" of maximizing efficiency when dispatching electricity. DOE's Pacific Northwest National Laboratory and the National Renewable Energy Laboratory are building and comparing models of partitioned power markets for renewable energy and power storage. The laboratories are using a regionally-disaggregated optimization model of electric power and renewable energy in the United States and running parallel sets of technology and policy scenarios to provide insights on renewable energy in power markets.

## Interconnection Impacts

The natural variability of wind resources can challenge grid system operators and planners with regard to managing regulation, load following, scheduling, line voltage, and reserves. Wind penetration experience in the United States and around the world has yielded new grid operation methods that ensure reliable and economic service is maintained. The Wind Program works to expand and disseminate this information to provide grid operators with a better understanding of the impacts of wind on the utility grid.

Wind Program efforts in 2010 will be closely coordinated with clean energy grid investments provided under the Recovery Act. These efforts include:

- Analyzing and modeling operations to better understand the dynamic interaction between wind plants and the rest of the utility electric system;
- Characterizing renewable plant performance and forecasting at levels of detail required for electric system planning and operations;
- Providing renewable interconnection planning support to assist transmission planners with long-term integrated resource planning;
- Establishing a centralized source of technical information on wind energy interconnection.

In one effort to mitigate the effects of wind variability, Pacific Northwest National Laboratory is developing operational methods that evaluate the effectiveness of integration strategies such as virtual balancing areas, regulation resource sharing, operating reserves, area control error, and control room use of forecasting to address wind and load variability on the utility grid.

Pacific Northwest National Laboratory is also working to enhance a model for evaluating the impacts of wind generation development scenarios on power systems operation. This model will enable the power system to operate more reliably with higher levels of variable renewable energy generation. The newly named Renewable Integration Model is designed to evaluate the impacts of variable renewable generation on the bulk electric power system in the presence of complex complementary systems such as hydrological systems, mesoscale wind systems, solar photovoltaic systems, energy storage systems, and demand management. This evaluation is accomplished by integrating these complex systems into a single simulation environment at one minute intervals, making it possible to combine power system tools such as unit commitment, economic dispatch, and reserves with meteorological tools such as mesoscale wind models. The model will also allow engineers to better evaluate the effects of high penetration levels of variable output renewable generation on operations at high temporal resolution.

## Characterizing Wind Plant Performance

Predicting the amount of energy that will be generated by one or more wind power plants in an area requires a detailed understanding of the wind plant's characteristics combined with good forecasts of the wind resource. The Wind Program works with industry to provide utilities and grid planners with better models of wind plants for use in interconnection studies. Using non-proprietary models allows wide distribution of these tools to speed the interconnection process and to better represent wind turbines' capabilities to contribute to overall power system reliability. The program also collects data about the power supplied from commercial wind plants. These data allow analysis of how to determine wind plant power curves, improve wind forecasts, and evaluate turbine wake effects on power production.

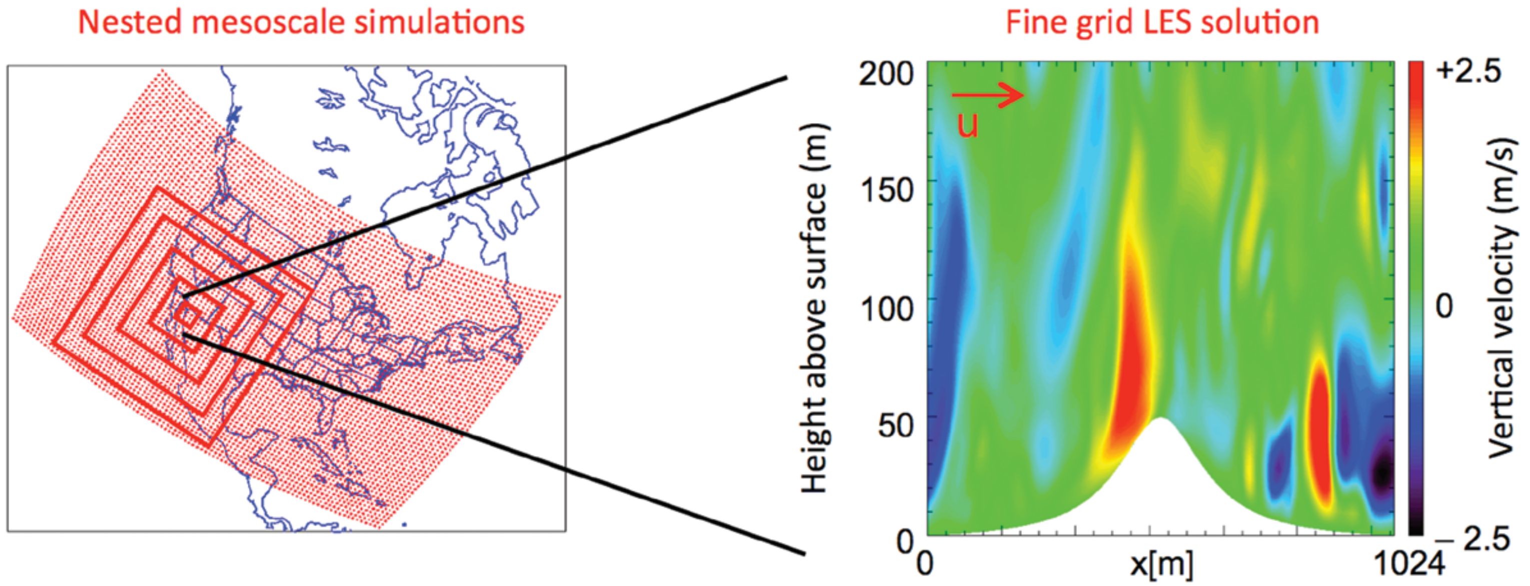
DOE's Lawrence Livermore National Laboratory has several ongoing efforts to improve and extend the state of the art in numerical simulation of wind power at all scales, from wide area resource assessment to wind power plant site characterization. These efforts capture various terrain and turbine simulations that evaluate loads, wakes and rotor performance for individual turbines. Much of the work on wind simulation is done with the open-source wind research and forecasting code, which is used as a test vehicle for innovation. Current research and forecasting efforts include improving modeling methods to assess complex terrain. A new project called cgWIND focuses on the individual turbine scale and combines compact, high-order schemes with overset grids and large-eddy simulation turbulence models. This approach will allow for accurate simulation of turbine wakes without significant numerical dissipation, critically important for understanding how wake effects interact within a turbine array.

## Wind Forecasting

Wind forecasting allows system operators to anticipate the electrical output of wind plants and adjust the electrical output of other generating plants accordingly. Improved short-term forecasts of wind production let operators make better decisions about the day-ahead electricity market, generation unit commitment, and real-time operations for the hour ahead. Advanced forecasting systems can also help warn the system operator if extreme wind events are expected. The seamless integration of wind plant output forecasts, power market operations, and utility control room operations is crucial for accommodating large amounts of wind power while maintaining reliable operation of the grid.

Uncertain forecasts can have complicated financial consequences. For example, wind power plant operators may be penalized when their plants produce less energy than estimated and may receive no payment for power generated above an estimate. More accurate wind predictions hours or even days ahead of time would significantly increase the efficiency of wind plant operations.

Numerical weather prediction models, applied to large or mesoscale areas, are used to develop detailed wind datasets




In this example of cgWIND modeling, the fine-grid Large Eddy Simulation (LES) solution is a model of the wind profile and turbulence found in the area shown on the nested mesoscale simulation. The bell-shaped curve on the LES solution represents a hill. The color contours represent vertical wind velocity and show how the wind changes as it passes over the hill. On the lee side (right) of the hill, the wind creates several small eddies close to the ground.

for estimating wind power plant output. Supercomputers allow for numerical simulations that integrate observational data to re-create years of wind speed data. A wind speed time-series data set is extracted and converted to show wind power output. For the DOE-funded *Eastern Wind Integration and Transmission Study*, the research team projected wind power output for hundreds of wind plants and used these data sets to model the different scenarios described in the study. Wind forecast data modeling is an increasingly common tool used by utilities and system operators to schedule generation units. The National Renewable Energy Laboratory has developed a Web site to provide energy professionals nationwide with wind profiles for the different transmission operating regions.

Lawrence Livermore National Laboratory is conducting a study to analyze existing wind data for improved scheduling and forecasting. The analysis of existing data will improve the understanding of ramp events and their correlation to seasonal and diurnal patterns. By analyzing observations at discrete locations, researchers can correlate actual ramp event occurrences to wind power forecasts. Lawrence Livermore National Laboratory, working with Siemens Energy, is also using its high-resolution atmospheric modeling capabilities to improve wind energy forecasts. In this project, laboratory researchers are developing algorithms that combine mesoscale modeling, ensemble-based forecasting techniques, improved representations of atmospheric turbulence effects, and complex databases of topography and sea-surface temperature to improve wind power forecasts. Broader goals in this effort also include the modeling of turbine wakes and evaluating the effects of climate change on wind resources over time.

Scientists at DOE's Pacific Northwest National Laboratory are working in collaboration with atmospheric scientists to develop new data products for use in the wind energy industry. These new data products will allow rigorous evaluation of low-level wind forecasts and systemic testing of long-period mesoscale models of various turbulence parameterizations. The objective is to provide relevant data sets for atmospheric model validation and improvement, and to assess the potential of using non-traditional sources of meteorological data. Researchers will obtain wind profile and turbulence observations from both traditional and non-traditional sources collected continuously over multiple seasons at multiple locations. Traditional sources include direct measurements of winds via radar profilers, SODAR (Sound Detection and Ranging), and/or tower instrumentation, while non-traditional sources include wind data retrievals derived from the existing network of NEXRAD weather radars.

DOE's Argonne National Laboratory completed the *Wind Power Forecasting: State-of-the-Art 2009* report, which includes an in-depth description of physical and statistical forecasting approaches, an overview of available forecasting models and typical application areas, and a discussion of the strengths and limitations of current tools. On the basis of the report's findings, the Argonne team is developing and testing new concepts and methods for improved wind power forecasting with a focus on statistical forecasting methodologies. The report is available on the laboratory's Web site.

Researchers at Argonne National Laboratory are also addressing how operators of wind power plants and power systems can use advanced wind forecasting technologies to improve their operations in timeframes ranging from several days ahead to real-time operations. The team is developing improved methodologies and algorithms to efficiently incorporate the output of advanced wind energy forecasts into decision support models for wind power plant and power system operation, from day-ahead scheduling and generation unit commitment to real-time dispatch.

DOE's Ames National Laboratory and MidAmerican Energy Corporation are analyzing wind speed data from approximately 380 turbines in Iowa, using a combination of statistical and physical simulation models, to better understand atmospheric flow at different times of day and seasonally across multiple plants. Access to large numbers of turbines from multiple wind plants in similar terrain enables researchers to validate their simulations. The improved ability to forecast wind conditions and power generated by wind plants 6 to 48 hours in advance will enable the electric utility industry to decrease the impacts of variability in wind power production, both at the distributed level (individual wind power plants) and at the bulk power generation level (the aggregate of simultaneous output from multiple wind power plants).

# GROWING A LARGER MARKET

Staff from the Wind Program's Wind Powering America initiative have provided technical assistance to the Alaska Energy Authority, helping to support wind energy development in Alaska. Alaska has recently installed three 1.5-megawatt turbines on Kodiak Island, six 100-kilowatt machines in Unalakleet (pictured above), and one 900-kilowatt turbine in Delta Junction.

To reap the benefits of increased use of wind energy—reduced greenhouse gas emissions, economic stimulus, and increased energy security—the DOE Wind Program conducts research and coordinates activities to overcome the barriers to deployment.

Increasing the amount of energy that wind contributes to the nation's electricity supply requires more than just improving wind technology or building transmission lines. It requires addressing potential barriers posed by market challenges, siting issues, public acceptance, and workforce capabilities. By providing a clear understanding of the benefits and challenges of wind energy development, the Wind Program helps pave the way for the responsible deployment of wind energy. The program works with states and other stakeholders through its Wind Powering America outreach and stakeholder engagement initiative and in forums such as the National Wind Coordinating Collaborative to provide objective information on wind energy policy, siting, environmental effects, and the economic benefits of wind development.

## Outreach and Stakeholder Engagement

DOE's Wind Powering America initiative provides technical support, guidance, and information for national, regional, state, and local efforts to explore and develop wind energy resources, both on land and offshore. Activities are conducted in partnership with public officials, utility generators, equipment manufacturers, project financiers and developers, regulators, industry and public-sector consumers, other federal and state agencies, and public stakeholder groups.

### State Activities

For wind energy development to progress in a state, officials and community leaders must first have reliable information about the benefits and challenges of wind energy for their area. The Wind Program has invested in analyses that estimate those effects, and Wind Powering America activities deliver that objective information to key decision makers at state and regional levels.

## Sample JEDI Output

JEDI Model Version W1.09.03e

| Wind Farm — Project Data Summary based on model default values | |
|---|---|
| Project Location | COLORADO |
| Year of Construction | 2009 |
| Total Project Size — Nameplate Capacity (MW) | 100 |
| Number of Projects (included in total) | 1 |
| Turbine Size (KW) | 1500 |
| Number of Turbines | 67 |
| Installed Project Cost ($/KW) | $2,043 |
| Annual Direct O&M Cost ($/KW) | $20.00 |
| Money Value (Dollar Year) | 2008 |
| Installed Project Cost | $204,315,234 |
| Local Spending | $36,581,782 |
| Total Annual Operational Expenses | $33,598,101 |
| Direct Operating and Maintenance Costs | $2,000,000 |
| Local Spending | $697,527 |
| Other Annual Costs | $31,598,101 |
| Local Spending | $869,090 |
| Debt and Equity Payments | $0 |
| Property Taxes | $567,590 |
| Land Lease | $301,500 |

| Local Economic Impacts — Summary Results | | | |
|---|---|---|---|
| **During construction period** | **Jobs** | **Earnings*** (in millions) | **Output**** (in millions) |
| Project Development and Onsite Labor Impacts | 67 | $4.24 | $4.91 |
| Construction and Interconnection Labor | 60 | $3.78 | |
| Construction Related Services | 7 | $0.45 | |
| Turbine and Supply Chain Impacts | 306 | $11.99 | $41.47 |
| Induced Impacts | 122 | $4.30 | $14.63 |
| Total Impacts | 495 | $20.52 | $61.02 |
| | | | |
| During operating years (annual) | | | |
| Onsite Labor Impacts | 6 | $0.41 | $0.41 |
| Local Revenue and Supply Chain Impacts | 8 | $0.31 | $1.68 |
| Induced Impacts | 7 | $0.23 | $0.79 |
| Total Impacts | 21 | $0.95 | $2.89 |

* Earnings include wages and salaries for each category

** Output refers to all dollars flowing into the local economy from project-related activity Researched by Stephen Hendrickson

To provide information about the economic and environmental impacts of wind technology deployment in each state, Wind Powering America team members use state-specific analyses from the Jobs and Economic Development Impacts (JEDI) wind model. The data provided by the analyses allow each state to weigh the economic impacts of wind energy development. Based on an extensive survey of reported impacts, a new version of the JEDI wind model (Version W1.09.03e) was released in 2009. Overall project costs and cost distributions reflect recent changes in capital costs, productivity improvements, and changing industry practices. The JEDI model was used to calculate the economic development impacts of the first 1,000 MW of wind deployment for 16 states.

Wind Powering America team members also work with community members to form Wind Working Groups. Group members include state energy officials, landowners and agricultural-sector representatives, county commissioners and rural development specialists, utilities and regulators, colleges and universities, advocacy groups, and other state and local groups. Thirty-three state Wind Working Groups were active at the close of 2009. Through the efforts of these groups, stakeholders gain access to detailed information on available wind technology, projected economic impacts (such as on the supply chain, labor requirements, and tax revenue), detailed wind resource maps, demonstrated policy options, information about state permitting regulations and incentives, results of wind energy integration studies, status and impacts of wind forecasting, and potential environmental and social impacts.

Since many benefits and challenges associated with wind energy are not limited by state borders, Wind Powering America has also established Regional Wind Energy Institutes. At these institutes, members of state wind outreach teams that are actively engaged in wind power development can learn from the experiences and best practices of others in their region, as well as from DOE wind energy specialists.

### Community and Tribal Wind

Community wind projects embody a business model of community involvement. They offer economic benefits—including land lease payments, construction and operations jobs, and increased local tax base—that flow to the community. In these projects, the community has some control over management of the project, including voting rights regarding matters of great importance to the community. Community members often have a direct financial stake in the project, assuming a share of both the risks and rewards of investment. Community wind projects vary from 100 kW to 20 MW or more. Project participants include rural landowners, publicly- and

The Greensburg Wind Plant in Kansas, comprising ten 1.25-megawatt wind turbines, supplies enough energy to power every house, business, and municipal building in Greensburg.

customer-owned utilities, school districts, colleges, and Native American tribes. Windustry, a nonprofit organization that receives DOE funding to organize community wind regional conferences, estimates that of the 35,000 MW of installed wind capacity in the United States today, more than 1,000 MW are community wind projects. Community wind projects also provide an opportunity to optimize the nation's electric transmission grid, as a transmission line may be able to accommodate a smaller community project but not a utility-scale wind farm.

In 2009, DOE selected five projects to receive more than $20.5 million from the Recovery Act to support community-based renewable energy projects. One of these projects will support the development of a 30-MW wind project in Northeastern Colorado, with the ultimate goal of expanding the facility to 650 MW. This project will share revenues with local landowners and other project participants, create local jobs, generate property tax revenue, provide clean, renewable energy, and help other communities by sharing information about its ownership model.

DOE's Savannah River National Laboratory is working with the Center for Hydrogen Research in Aiken, South Carolina, and Santee Cooper Public Utility to install small vertical axis wind turbines as pilot tests for industry and community-based wind projects. These projects will overcome barriers associated with unfamiliarity of new technologies and provide experience in operating and integrating the renewable energy resource. The Center for Hydrogen project is part of a hybrid wind/solar project that uses renewable energy to power a regenerative fuel cell for backup power applications.

Native American tribes represent a major potential market for community wind projects. The United States is home to 2.4 million Native Americans living on 96 million acres of tribal lands. Wind Program researchers have estimated that these tribal lands could provide 14% of the nation's annual electricity demand while providing revenue to the reservations. Through Wind Powering America outreach and stakeholder engagement activities, DOE experts work with tribal entities including the National Congress of American Indians, the National Tribal Environmental Council, NativeEnergy, the Indigenous Environmental Network, Honor the Earth, the International Treaty Council, and the Northern Cheyenne.

## Workforce Development

According to the American Wind Energy Association, one wind technician is needed to service each additional 10 MW of wind generation installed in the United States. If the wind industry continues to grow to supply 20% of the nation's electricity by 2030, it will require at least a doubling of the current workforce in the fields of project development, engineering, environmental assessment, and wind power plant operations. To meet this need, the development of an education infrastructure from primary through graduate school is critical. By the end of 2009, more than 200 educational programs offered certificate, degree, or coursework related to wind energy. Of these programs, 45% were offered by universities and colleges and 43% by community colleges or technical schools. With the release of 13 competitive workforce development grants in 2009, the funding of university-led research consortia to develop wind energy curricula, and through activities with DOE's national laboratories, the Wind Program is working to increase the number of wind energy-related educational programs nationwide.

DOE's Idaho National Laboratory and Idaho State University have teamed to develop two new energy degree programs that specifically train students in mechanical engineering technology and wind power generation fields. The Energy Systems Mechanical

Construction workers in Milford, Utah, lower the first section of a tower for a multimegawatt wind turbine.

Engineering Technology and Energy Systems Wind Energy Technician Programs became available in 2009.

Working in close collaboration with DOE and the American Wind Energy Association, the National Renewable Energy Laboratory is drafting a roadmap for the development of a wind educational infrastructure.

### Wind for Schools

Wind Powering America's Wind for Schools project educates students about the application of wind energy, engages school teachers and students in discussions about wind energy, and introduces wind energy options to communities to stimulate discussion about the benefits, challenges, and deployment options. The Wind for Schools project supports educational programs at universities and K-12 schools that enable students to learn about wind energy through hands-on experiences with wind technology. By targeting students, the activities address one of the major challenges for the wind energy industry identified in the 20% Wind Energy report: the need for a skilled workforce to support the expanded development and application of wind technologies. In 2009, DOE's Wind for Schools project supported Wind Applications Centers at universities in six states, installed 20 turbines at K-12 schools, and held teacher training workshops in Colorado, Idaho, Kansas, Nebraska and Montana.

Early in 2010, five additional states were selected through a competitive solicitation to participate in the Wind for Schools project. The universities leading these efforts include Appalachian State University (North Carolina), James Madison University (Virginia), Northern Arizona University, Penn State University (Pennsylvania), and the University of Alaska, Fairbanks.

## Wind Energy at Federal Facilities

The U.S. Government is the largest energy user in the world. The Energy Policy Act of 2005 requires that each federal agency provide for at least 5% of its electric energy needs from renewable

Pocatello Community Charter School in Idaho installed a wind turbine in September 2009 as part of Wind Powering America's Wind for Schools project.

sources by 2010 and at least 7.5% by 2013. To provide information on the role of wind energy in achieving these standards, DOE's National Renewable Energy Laboratory hosted the Federal Wind Energy Applications Technology Symposium in 2009, which was attended by 13 federal agencies as well as industry representatives. Wind Program scientists and engineers presented on a wide range of topics for energy managers, engineers, planners, and property managers.

In cooperation with the Idaho Department of Water Resources Energy Division, DOE's Idaho National Laboratory provides technical support for wind energy deployment at federal facilities. This support includes the installation of anemometers on federal sites to record the wind resource, analysis of wind data, and the presentation of workshops for the public. Support of this nature is vital to the development of wind energy projects at federal agencies including the Department of Defense. Idaho National Laboratory has been actively working with DOE's Sandia National Laboratories to implement multi-megawatt wind projects at two DOE facilities.

## Siting

Choosing the best place to build a wind energy facility, also known as a wind farm, involves a complex decision-making process that requires data from a variety of sources. The United States has excellent wind resources, but most people do not live in areas where the wind resource is greatest. Identifying the best combination of good wind resources, few environmental and social impacts, and favorable regulatory and market environments, is a challenge for the growing wind industry. To facilitate the responsible siting of wind farms, the DOE Wind Program conducts research and coordinates activities to provide information to decision makers.

### Potential Environmental Effects

While wind farms have substantial environmental benefits, they also pose risks to wildlife and habitats, as do other construction activities. Not knowing the potential for harm to wildlife can delay or prevent wind farm development. The Wind Program works with groups like the National Wind Coordinating Collaborative, the Grassland Shrub Steppe Species Collaborative, Bat Conservation International, the Bats and Wind Energy Cooperative, and the U.S. Fish and Wildlife Service to find ways to quantify and reduce the negative effects of wind projects on wildlife. These efforts require rigorous studies of specific species and habitats. In 2009, the Wind Program funded 12 new projects to study wind-wildlife interactions.

Prairie species inhabiting prime wind areas are of particular interest. In 2009, the Grassland Shrub Steppe Species Collaborative, with technical support from DOE's National Renewable Energy Laboratory, completed its first full year of study on the Lesser Prairie Chicken before and after construction of a wind farm. Also in 2009, DOE's Pacific Northwest National Laboratory completed a literature review and summary of existing knowledge on how sage grouse populations may respond to wind energy development. Given increased attention to the Sage Grouse, the National Wind Coordinating Collaborative added a new subgroup to study this species in 2010.

DOE's Argonne National Laboratory is developing a landscape-based modeling framework that considers the cumulative impacts of prospective wind energy development on populations of critically important wildlife species. The framework focuses on the Greater Sage Grouse to demonstrate the viability of the modeling framework and its applicability to evaluating the cumulative effects of wind energy development. This analysis will assist DOE, wind energy developers, and permitting authorities in planning for wind development in critically important wildlife areas.

A 600–killowatt wind turbine installed near Boston, Massachusetts.

In 2009, the National Renewable Energy Laboratory worked with Bat Conservation International to test mitigation strategies that were suggested in a 2008 study to reduce bat fatalities from wind turbines. This project will develop and field test a commercial-scale acoustic deterrent and test the effectiveness of operational curtailment in reducing bat fatalities.

To evaluate sites for wind turbines and mitigate environmental effects of new wind facilities, Wind Program researchers worked with geographic information system experts at DOE’s Lawrence Livermore National Laboratory. Using observational data compiled by the California Energy Commission and the National Renewable Energy Laboratory, the researchers linked the avian behavioral data from a six-year study to maps of the terrain that birds fly over. The team’s work suggests that installing turbines away from the high-usage flyways would reduce the risk to birds. This analysis capability is now part of a Web-based Renewable Energy Portal sponsored by the California Energy Commission.

The Department of Energy is a member of the U.S. Fish and Wildlife Service’s Wind Turbine Guidelines Federal Advisory Committee, which also includes members from federal and state agencies, conservation groups, Native American tribal governments, wind energy developers, and utilities. This group provides advice and recommendations to avoid and minimize the impacts of land-based wind farms on wildlife and habitats. DOE’s Oak Ridge National Laboratory is evaluating an ecological risk assessment framework, similar to the one recommended by the Federal Advisory Committee.

The Wind Program is also investigating whether artificial intelligence can be used to detect the presence of birds in data from Next-Generation Radar (NEXRAD) stations. NEXRAD is a network of 158 high-resolution Doppler weather radars operated by the National Weather Service. The National Renewable Energy Laboratory, the U.S. Geological Survey, and Montana State University have joined forces to develop algorithms to differentiate biological (bird) echoes in the NEXRAD data to help identify migratory flyways.

There is a range of risks associated with the development and siting of wind and other renewable energy technologies. The current approach for addressing potential effects consists of responding to issues as they emerge. Recognizing the need for a more integrated approach as the scale of wind deployment expands, in 2010 the National Renewable Energy Laboratory published a report outlining a proposed integrated risk framework approach to decision making. This research outlines how developing and applying an integrated risk assessment framework that systematically assesses and compares the broad continuum of energy related risks and benefits will help decision makers to make good siting decisions in a timely manner under conditions of significant uncertainty.

Following from this work, Pacific Northwest National Laboratory is developing a risk-informed decision framework to evaluate information on environmental impacts from the installation and operation of offshore wind farms. This framework will help to accelerate the design and permitting of offshore wind farms by addressing regulatory and stakeholder concerns, identifying important environmental issues, evaluating appropriate measurement and monitoring systems to assess potential impacts, exploring mitigation options where impacts are likely, and providing a comprehensive framework to encourage discussion and collaboration among stakeholders.

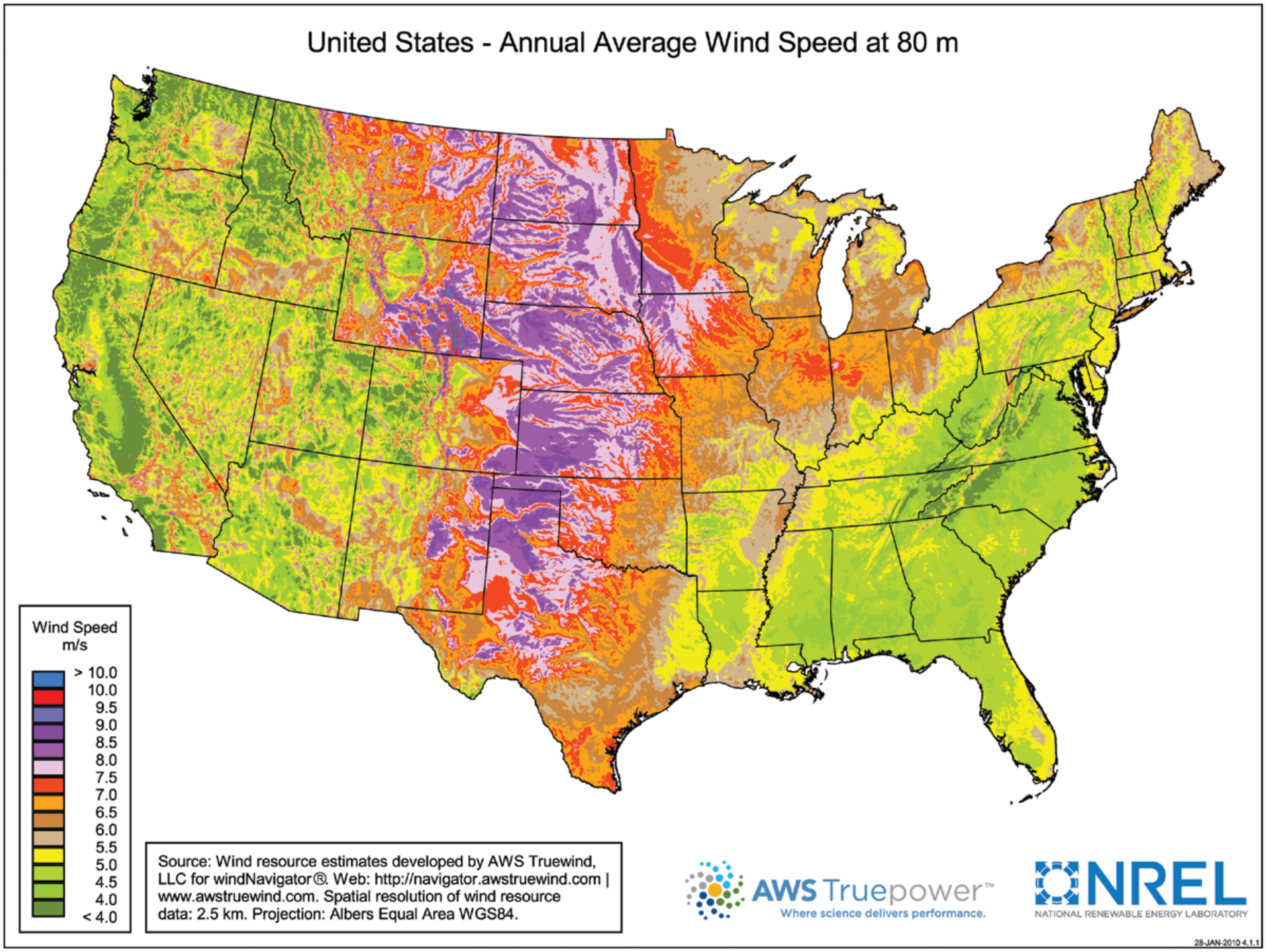
### Potential Social Effects

In 2009, DOE’s Lawrence Berkeley National Laboratories released a technical analysis of wind energy facility impacts on the property values of nearby residences. The investigation found that the prices of homes surrounding wind facilities are not consistently, measurably, or significantly affected by either the view of wind facilities or the distance of the home from those facilities. While other studies have found negative property value impacts near landfills, high voltage transmission lines, and other types of electric generation facilities, the Berkeley Lab analysis did not detect any evidence of widespread property value impacts from existing wind energy facilities in the United States.

Researchers at DOE's Argonne National Laboratory are working to develop a geographic information system screening tool to identify lands at high risk of visual impacts from wind energy development. This information system will help developers and land managers choose project sites less likely to face community opposition related to aesthetic issues. The researchers will also develop visual impact mitigation measures for a potential wind site based on the site's topography, vegetation, and other site-specific environmental conditions.

### Resource Assessment

The Wind Program has been producing high-resolution wind resource maps for decades. Based on advanced meteorological models, and validated with real data at 50 meters above the ground, the latest versions of these maps can be enhanced with overlays that describe important features such as power lines, park boundaries, and roads. These resource maps help developers and policy makers determine which areas are best suited for wind energy development. The Wind Program has upgraded these maps to indicate the wind resource at 80 to 100 meters above the ground to provide information for developers using larger turbines on taller towers. Using highly accurate Global Positioning System mapping tools, data from satellites, weather balloons, and meteorological towers, and much-improved numerical computer models, the Wind Program is working with U.S. companies to produce higher resolution maps of resources at higher heights above ground for the United States and other countries. Improved horizontal resolution of these maps (1 kilometer or better) allows for more accurate siting of wind turbines, and has led to the recognition of higher wind speed areas where no such winds were thought to exist.

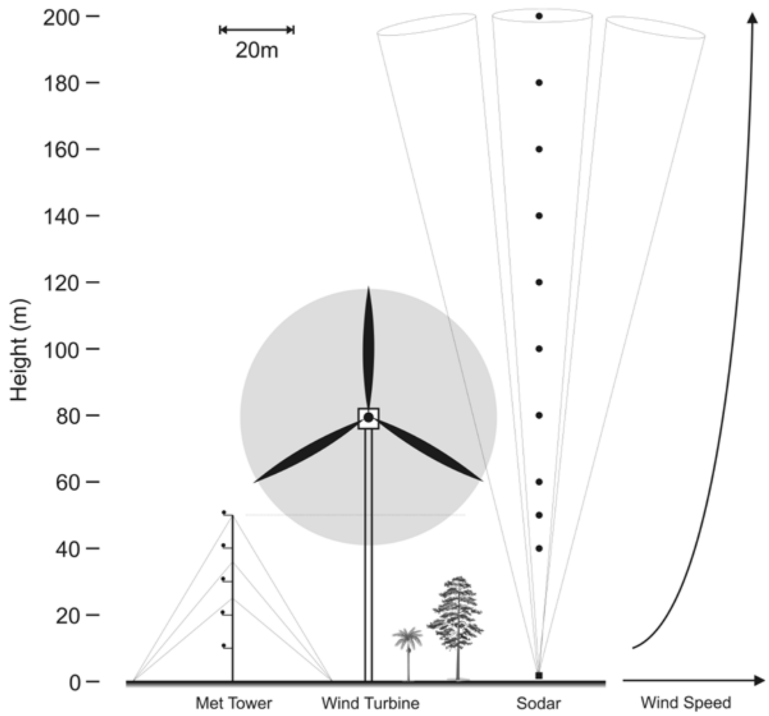



NREL worked with AWS Truepower for more than a decade to update U.S. wind resources maps. The new maps include wind data at 80 m.

A new assessment released by the National Renewable Energy Laboratory in 2010 shows that U.S. wind resources are even larger than previously estimated. The potential capacity of the land-based wind resource is more than 10,000 GW. For comparison, current installed wind capacity is 35 GW, and meeting 20% of the nation's electrical demand with wind in 2030 would require 300 GW. The larger wind potential at 80 to 100 meters is due to improved wind turbines that operate on taller towers to capture faster winds at higher elevations.

The National Renewable Energy Laboratory has worked with AWS Truepower for almost a decade to update wind resource maps for each state. Four new state wind maps were posted to the Web site in 2009: Georgia, New York, South Carolina, and Wisconsin.

DOE's Savannah River National Laboratory is working with utility provider Santee Cooper, Clemson University's South Carolina Institute for Energy Studies, Coastal Carolina University, and others to assess both land-based and offshore wind resources in South Carolina. The team is evaluating the use of Sound Detection and Ranging (SODAR) systems, which use sound waves to measure atmospheric turbulence and wind profile, to assess the wind resources in coastal and offshore environments at higher altitudes than traditional meteorological towers. Initially, SODAR is being tested at a marsh on the South Carolina coast to determine its suitability for marine environments, but it will later be tested offshore on a U.S. Coast Guard platform. This research has the potential to produce a new methodology for assessing offshore winds using a mobile platform.



Comparison of SODAR's assessment altitude with meteorological tower and swept area of a typical offshore wind turbine.

## Radar

Wind-radar interactions drew the attention of researchers and developers in 2006 when the U.S. Department of Defense discovered that wind turbine structures and rotors can reflect radar signals and thus interfere with accurate readings. Concerns over interference caused the U.S. Department of Homeland Security, the Federal Aviation Administration, and the Department of Defense to contest many proposed wind turbines in the line of sight of radar installations, stalling development of several thousand megawatts of wind energy.

According to a report sponsored by the Department of Homeland Security in 2008, there is no fundamental physical constraint that prohibits the accurate detection of aircraft and weather patterns around wind farms. However, the old age of the nation's long-range radar infrastructure significantly increases the challenge of distinguishing wind farm radar signatures from the signatures of airplanes or weather. The report also stated that there is great potential for mitigation measures that include modifications to wind farms (such as methods to reduce radar cross section and telemetry from wind farms to radar) and modifications to radar (such as improvements in processing, radar design modifications, radar replacements, and the use of gap fillers in radar coverage).

Developing strategies to mitigate wind-radar interference is difficult because the amount of interference depends on turbine height, rotor sweep area, blade rotation speed, and the landscape surrounding a wind energy project. Researchers at DOE's Idaho National Laboratory and Sandia National Laboratories are working with federal radar agencies to determine the extent of wind-radar interactions and to develop measures to mitigate the possible effects of wind turbines on civilian and military radar systems.

Coastal and offshore locations have a greater propensity for atmospheric attenuation caused by marine boundary layer moisture gradients and thermal inversions, so standard assumptions made to determine the radar line-of-sight and identify wind farm locations are not appropriate for sites near the nation's shores. Meteorologists at DOE's Savannah River National Laboratory are studying methods to better define the atmospheric conditions in coastal and marine environments and develop tools to improve wind farm siting from a radar impact perspective and to mitigate future impacts from offshore wind farms on radar.

# ENSURING LONG-TERM INDUSTRY GROWTH

DOE's Wind Program has worked with industry and other partners for more than 30 years to advance both large and small wind energy technologies. For large wind technologies, industry partnerships have successfully improved the performance of wind turbines while dramatically reducing costs. Advances in small wind technology have produced quieter, more reliable systems that are easier to install and cost less to operate. Many technologies developed with the support of the program have moved into the marketplace to become commercial successes. In addition to helping industry advance wind technologies, the Wind Program has worked to increase public and utility acceptance of wind energy by developing methodologies to reliably integrate wind energy into our nation's infrastructure and provide accurate up-to-date information.

Although wind technology and the wind industry have come a long way, generating 20% of the nation's electricity from wind energy by 2030 will require comprehensive research and development to address a broad spectrum of challenges. Wind turbines need to become more reliable, capture more energy, and cost less to produce and operate so that wind energy can compete with traditional fuel sources in the marketplace. The nation's transmission infrastructure needs to be expanded and upgraded so that clean energy from wind and other renewable sources can be efficiently transported to areas with a high demand for electricity. Manufacturing facilities need to increase and improve their production processes to keep pace with demand, and a skilled workforce is needed to fill the jobs generated by this growth. Finally, continued outreach and stakeholder engagement efforts are needed to break down barriers created by misconceptions and a lack of understanding of wind energy.

Research has shown that achieving 20% wind energy by 2030 is technically feasible, and with more than 30 years of wind energy research and development experience, the DOE Wind Program is well positioned to continue contributing to the advancement of clean, affordable, reliable, domestic wind power.

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## Wind Energy Web Sites

U.S. DEPARTMENT OF ENERGY WIND AND WATER POWER PROGRAM
www.windandwater.energy.gov

WIND POWERING AMERICA
www.windpoweringamerica.gov

NATIONAL RENEWABLE ENERGY LABORATORY
www.nrel.gov/wind

SANDIA NATIONAL LABORATORIES
www.sandia.gov/wind

PACIFIC NORTHWEST NATIONAL LABORATORY
www.pnl.gov

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www.lbl.gov

AMES LABORATORY
www.ameslab.gov

LOS ALAMOS NATIONAL LABORATORY
www.lanl.gov

SAVANNAH RIVER NATIONAL LABORATORY
http://srnl.doe.gov

BROOKHAVEN NATIONAL LABORATORY
www.bnl.gov

AMERICAN WIND ENERGY ASSOCIATION
www.awea.org

DATABASE OF STATE INCENTIVES FOR RENEWABLES & EFFICIENCY
www.dsireusa.org

INTERNATIONAL ENERGY AGENCY – WIND AGREEMENT
www.ieawind.org

NATIONAL WIND COORDINATING COLLABORATIVE
www.nationalwind.org

UTILITY WIND INTEGRATION GROUP
www.uwig.org

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