
# 2015 Key Wind Program and National Laboratory Accomplishments

U.S. DEPARTMENT OF
ENERGY

# Powering the Energy Revolution through Wind Evolution

The U.S. Department of Energy (DOE) Wind Program is committed to helping the nation secure cost-competitive sources of renewable energy through the development and deployment of innovative wind power technologies. By investing in improvements to wind plant design, technology development, and operation as well as developing tools to identify the highest quality wind resources, the Wind Program serves as a leader in making wind energy technologies more competitive with traditional sources of energy and a larger part of our nation's renewable energy portfolio. Greater use of the country's abundant wind resources for electric power generation will help reduce emissions of greenhouse gases and other air pollutants, diversify the energy supply, provide cost-competitive electricity to key regions across the country, and reduce water usage for power generation. In addition, wind energy deployment will help stimulate the revitalization of key sectors of the economy by investing in infrastructure and creating long-term jobs.

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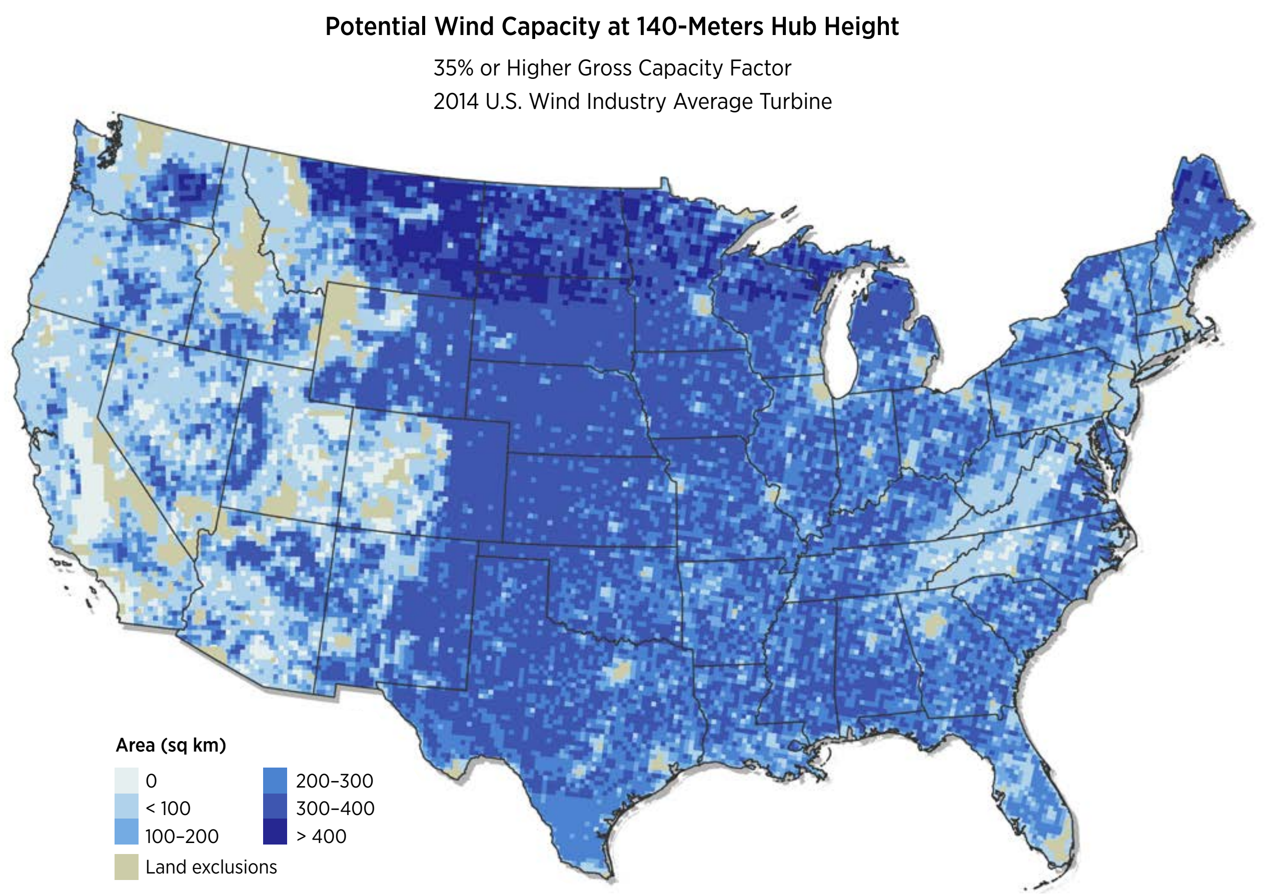
***Wind Vision Report Highlights Long-Term Benefits of Investing in America's Wind Energy Industry***

In 2015, DOE published a new Wind Vision report that analyzes the potential for wind power to provide 20% of the nation's electricity demand by 2030 and 35% by 2050. *Wind Vision: A New Era for Wind Power in the United States* is the culmination of a 2-year collaborative effort by more than 250 experts from industry, government, and academia. It is one of the many examples of how DOE's Wind Program provides a nucleus for the research community, bringing together its many diverse stakeholders to achieve a common goal—powering the nation's energy revolution through wind evolution.




***Unlocking Wind Power Across America***

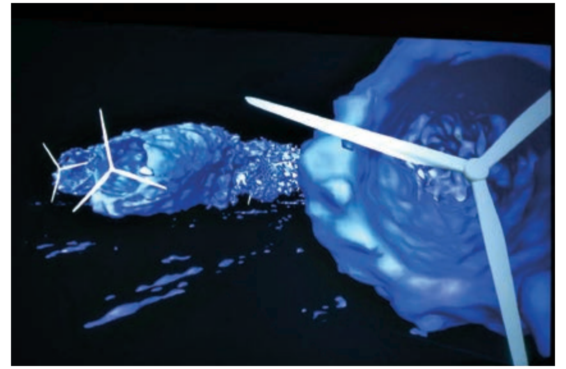
In support of the President's all-of-the above energy strategy, in May 2015, DOE released *Enabling Wind Power Nationwide*, a report showing how the United States can unlock the vast potential for wind energy deployment in all 50 states—made possible through the next-generation of larger wind turbines.

The new report highlights the potential for technical advancements to unlock wind resources in regions with limited wind deployment today, such as the Southeast. These new regions represent an additional 700,000 square miles—or about one-fifth of the United States—bringing the total area of technical wind potential to 1.8 million square miles.

Technological advancements, such as taller wind turbine towers of 110 and 140 meters and larger rotors—currently under development by DOE and its private sector partners—can more efficiently capture the stronger and more consistent wind resources typically found at greater heights above ground level, compared with the average 80-meter wind turbine towers installed in 39 states today.

*Atmosphere to Electrons—Transforming Today's Wind Plant*

To develop the next-generation technologies that would make wind energy economically viable in low-wind-speed sites, researchers must first comprehend the turbulent nature of the environment in which these larger machines operate. Under its Atmosphere to Electrons (A2e) initiative, DOE works with its national laboratories, industry, and academia to gain a better understanding of the Earth's atmospheric boundary layer (ABL) and how it impacts wind plant performance. The ABL is the turbulent region of air—extending from the Earth's surface up to a few kilometers—that drives the wind plant. Not only does the turbulence in the ABL affect the performance of turbines within a wind plant, but also, the larger rotors of the upstream turbines in the plant create wakes that impact the performance of the downstream turbines. In 2015, DOE released a new model that will help designers and developers optimize the performance of wind turbines and wind plants. The Simulator fOr Wind Farm Applications (SOWFA) simulates everything from the regional weather patterns that influence the ABL to the wakes within the plant and how all of these environmental factors affect individual turbine performance.

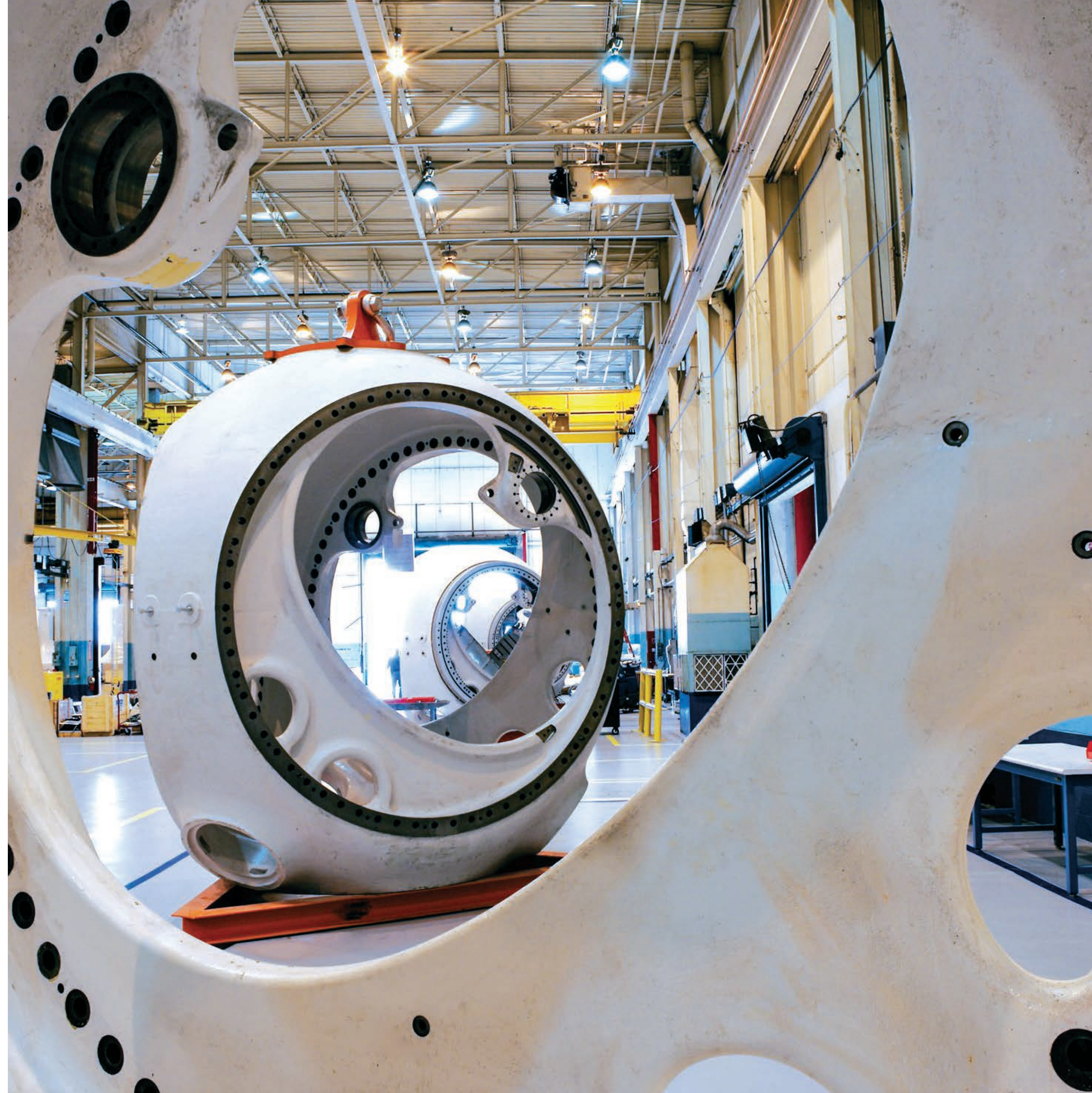


*New National Laboratory Pilot Opens Doors to Small Businesses*

Small businesses have a big impact on America's economy, adding more than 1 million employees last year. They are central to developing the new clean energy technologies that are needed to cut carbon pollution and improve the environment. Yet, small business entrepreneurs often lack the resources necessary to move their innovative ideas from the laboratory bench to the marketplace.

In 2015, DOE announced that five of its national laboratories will lead in implementing a new Small Business Vouchers Pilot, a public-private partnership that will connect clean energy innovators across the country with top-notch scientists, engineers, and world-class facilities. The laboratories leading this $20 million project include Oak Ridge National Laboratory (ORNL), the National Renewable Energy Laboratory (NREL), Lawrence Berkeley National Laboratory (LBNL), Sandia National Laboratories (SNL), and Pacific Northwest National Laboratory (PNNL).

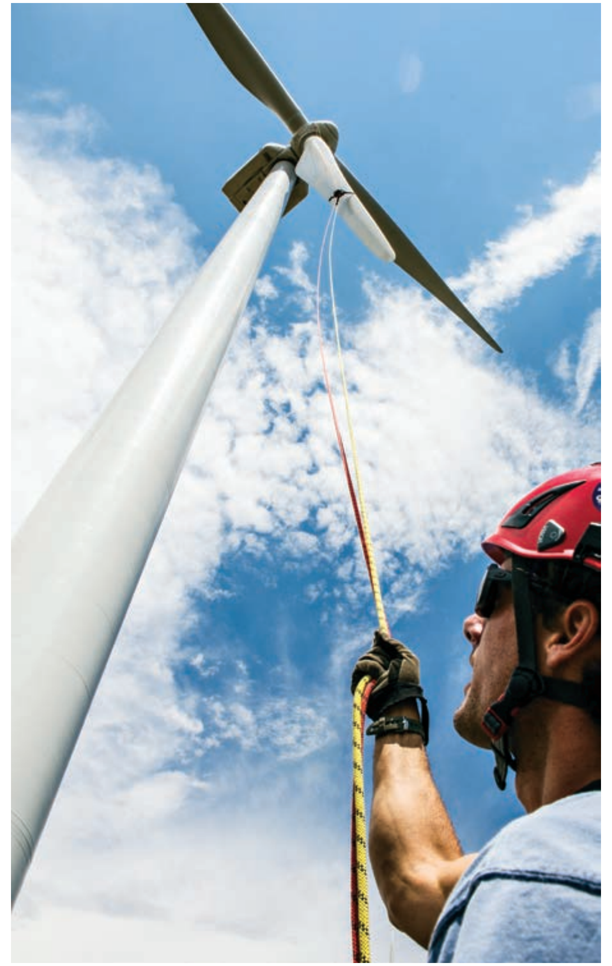
With this federal funding, more than 100 small businesses will receive vouchers so they can access considerable lab expertise and tools that will help them test, validate, and introduce new products, expand their businesses, and grow the clean energy sector.



*Wind Program Executive Summit to Accelerate Technology Transfer*

The goal of DOE's research and development (R&D) efforts is to accelerate the transfer of advanced technologies to industry, ultimately reducing the levelized cost of energy (LCOE). Industry typically invests heavily in shorter-term, component-level R&D but has fewer resources dedicated to longer-term, next-generation technology development. To bridge this gap, DOE prioritizes high-risk, high-reward R&D and invests in government-sponsored projects to drive innovations.

As part of its effort to plan the funding for its future short- and long-term R&D efforts, the Wind Program hosted an Executive Summit in November 2015 that brought together members of the wind industry community and DOE's national laboratories to focus on investments and technology transfer as they apply to wind energy technology research, development, deployment, and demonstration.



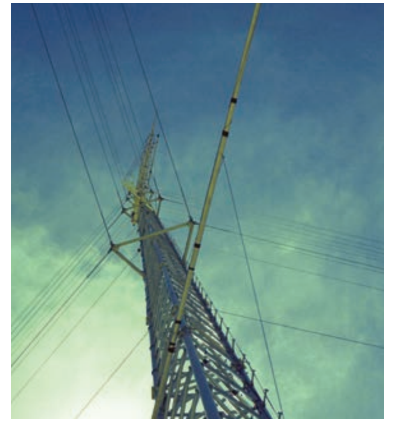


# Research and Development

Greater use of the nation's abundant wind resources for electric power generation will help the nation reduce emissions of greenhouse gases and other air pollutants, diversify its energy supply, provide cost-competitive electricity to key regions across the country, and reduce water usage for power generation. The Wind Program's research and development activities are leading the nation's efforts to accelerate the deployment of wind power technologies through improved performance, lower costs, and reduced market barriers.

## Market Analysis

The Wind Program's market analysis activities help increase the use of wind energy in the marketplace by providing strategic data to decision makers and stakeholders interested in rapidly changing electricity markets. Data include market penetration; industry trends; cost, price, and performance trends; policy and market drivers; and future outlooks.



*2014 Market Report Highlights Technology Advancement and Industry Growth*

According to the *2014 Wind Technologies Market Report* produced by LBNL, since the late 1990s, the average nameplate capacity of wind turbines installed in the United States has increased by 172% to 1.9 megawatts (MW) in 2014. Also, the average turbine hub height has increased by 48% to 83 m, and the average rotor diameter has increased by 108% to 99 m. This scaling has enabled wind energy developers to build projects more economically at sites with lower wind speeds.

Performed by: LBNL
Principal Investigators: Ryan Wiser, RHWiser@lbl.gov and Mark Bolinger, MABolinger@lbl.gov

## Resource Characterization

A crucial factor in the development, siting, and operation of a wind plant is the ability to assess and characterize available wind resources. To achieve this, the Wind Program supports efforts to accurately define, measure, and forecast the nation's land-based and offshore wind resources.



*Exploring New Ways to Collect Atmospheric Data*

To optimize the design and performance of wind farms, it is necessary to understand the atmospheric turbulence of the environment in which they operate. Modern high-performance computing provides the ability to simulate the atmosphere in unprecedented detail, and advances in measurement technologies—particularly scanning Doppler remote sensing systems—promise the possibility of validating these simulations and gaining new physical insights using observation of atmospheric fields. However, it is unclear how well current measurement systems can actually map atmospheric fields at the relevant time and spatial scales to provide the data required for wind plant flow characterization.

In 2015, the DOE Wind Program assembled a team of researchers from the National Oceanic and Atmospheric Administration's Earth Systems Research Laboratory, NREL, PNNL, Texas Tech University, University of Colorado Boulder, University of Texas at Dallas, and University of Maryland Baltimore County to conduct the eXperimental Planetary boundary layer Instrument Assessment (XPIA). The team explored new ways of collecting data on atmospheric turbulence and winds at a higher time resolution than is currently considered by the wind energy industry. They also validated microwave radiometer measurements of temperature profiles against established standards. Comparing measurements from scanning lidars and radars to each other and to those on the Boulder Atmospheric Observatory 300-m meteorological (met) tower, the team assessed new sophisticated approaches for measuring winds and turbulence and quantified measurement uncertainty. The data are archived at the A2e Data Archive Portal, and will be available for other teams to use for instrument verification as well as for validation of atmospheric models.

Performed by: NREL and PNNL
Principal Investigator: Andrew Clifton, Andrew.Clifton@nrel.gov

## Technology Development

To ensure future industry growth, wind technology must continue to evolve, building on earlier successes to further improve reliability, increase capacity factors, and reduce costs. The Wind Program works with its national laboratories and industry partners to increase the performance and reliability of next-generation wind technologies while lowering the cost of wind energy.

### *New Drivetrain to Significantly Reduce Cost of Wind Energy*

A team led by NREL built and commissioned a new medium-speed drivetrain that is expected to increase reliability, improve efficiency, and significantly reduce the cost of wind energy. The new drivetrain weighs significantly less than current designs to facilitate easier installation on taller towers and requires fewer of the expensive, hard-to-come-by rare earth magnets. The 750-kilowatt drivetrain design can be scaled up to generate power in 2- and 3-MW machines for land-based wind farms as well as 5- to 10-MW machines for offshore wind applications. After successful completion of performance testing at DOE's National Wind Technology Center (NWTC) in 2016, the technology will be transferred to industry for global deployment.

Performed by: NREL
Principal Investigator: Jon Keller, Jonathan.Keller@nrel.gov



### *Using a $1 Billion X-Ray Machine to Help Wind Manufacturers Solve Premature Equipment Failures*

Wind plant operation and maintenance costs consume up to one-third of the plant's total revenue, and are increasing 5% to 10% per year. A major portion of these costs are related to premature failures typically found in wind turbine drivetrains. Researchers at DOE's Argonne National Laboratory (ANL) have characterized the leading cause of drivetrain component failures using the Advanced Photon Source, a user facility at DOE's Office of Science and the brightest synchrotron X-ray source in the western hemisphere. ANL scientists and wind equipment manufacturing experts use this $1-billion facility to shine the Advanced Photo Source's light beam at failed turbine components to look deep inside the material to locate microscopic cracks within the steel bearings, thereby furthering our understanding of these premature failures.

Performed by: ANL
Principal Investigator: Aaron Greco, agreco@anl.gov

### *Understanding the Physics Impacting Wind Plant Performance*

As part of the A2e initiative, NREL and SNL developed a 3-year collaborative research plan to develop and field test wind turbine controls. New control systems, such as the advanced feed-forward control system that incorporates lidar and is currently under development at NREL, will help researchers improve simulations and increase the understanding of the physics impacting wind plant performance. The plan developed by the two laboratories identified collaborative field testing of wind plant controls at SNL's Scaled Wind Farm Technology (SWiFT) Facility, which studies wind-plant-scale performance. NREL is helping to develop and implement the field tests and SNL is setting up the field tests, helping with implementation, and collecting data.

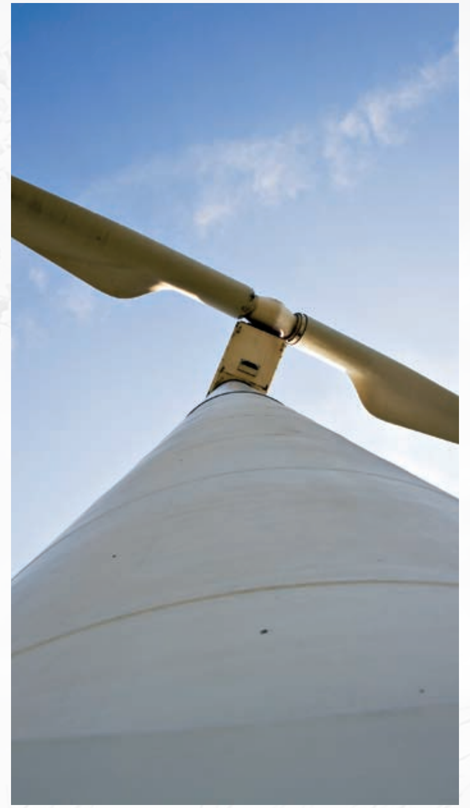
Performed by: NREL and SNL
Principal Investigators: Paul Veers, Paul.Veers@nrel.gov and David Minster, dgminst@sandia.gov

### *Optimizing Wind Plant Performance with Siting*

Even though airflow around wind turbines is invisible to the naked eye, wind energy researchers know that wakes shed from upstream wind turbines in a wind plant can significantly reduce the power production and increase loads on downstream turbines, driving up the cost of energy. Therefore, to develop effective solutions, they must first understand wake flow (or turbulence) structures and the forces involved.

The researchers at SNL have developed the Sandia Wake-Imaging-System (SWIS) that enables them to map the invisible turbulent wakes formed by wind turbines and show developers how to site their turbines, increase power production, and reduce costs.

The system uses cameras, a portable aerosol-particle generator on a lift, and a laser-light sheet carefully configured between two wind turbines at the DOE-SNL SWiFT facility in Lubbock, Texas, to produce a motion picture of wind turbine wake formation and development. Because the accuracy of the measurements depends heavily on the system setup configuration, the research team also developed a simulation tool that models SWIS physics to effectively plan for and optimize testing configurations of different flow structures of interest.



Performed by: SNL

Principal Investigator: Brian Naughton, bnaught@sandia.gov

***National Rotor Testbed Meets Research Needs for Years to Come***

The National Rotor Testbed developed by SNL will do for the wind industry what the Bell XS-1 (experimental supersonic) aircraft did for the aeronautics industry—help produce a machine designed for ultimate performance. The X-1 series of experimental aircraft produced the first manned aircraft to break the speed of sound in level flight. The flight data collected by the X-1 tests proved invaluable to further U.S. fighter jet design throughout the latter half of the 20th century.

The high-quality experimental data collected by the new National Rotor Testbed at the SWiFT facility will meet the needs of the wind energy industry for years to come. The facility is ideally suited for the atmosphere/aerodynamic experiments needed to achieve ultimate wind plant performance and cost reductions. SWiFT contains a carefully spaced array of three highly instrumented, research-scale wind turbines along with numerous met towers and cutting-edge flow measurements to record mesoscale weather around the turbine array, inflow directly into each turbine, and wake flow from each turbine.

The new, sophisticated subscale rotor designed for the testbed is well-suited to support turbine-turbine interaction research at SWiFT and will also represent full-sized turbines. This physical relevance is especially important for the coupled experimental and modeling-simulation campaign launched by the A2e initiative because it ensures that the credibility of numerical models is demonstrated within physical regimes that are directly relevant to full-scale industry applications.

The National Rotor Testbed will be an important public resource for wind energy research. Public rotor models and field hardware designs are crucial to the success of the wind industry because they allow for the effective collaboration between researchers from national labs, industry, and academia. These types of public resources especially enable cost-effective research activities for small- and medium-sized businesses in the United States because they remove many of the barriers to entry into wind turbine rotor research.

Performed by: SNL
Principal Investigator: Jonathan White, jonwhit@sandia.gov

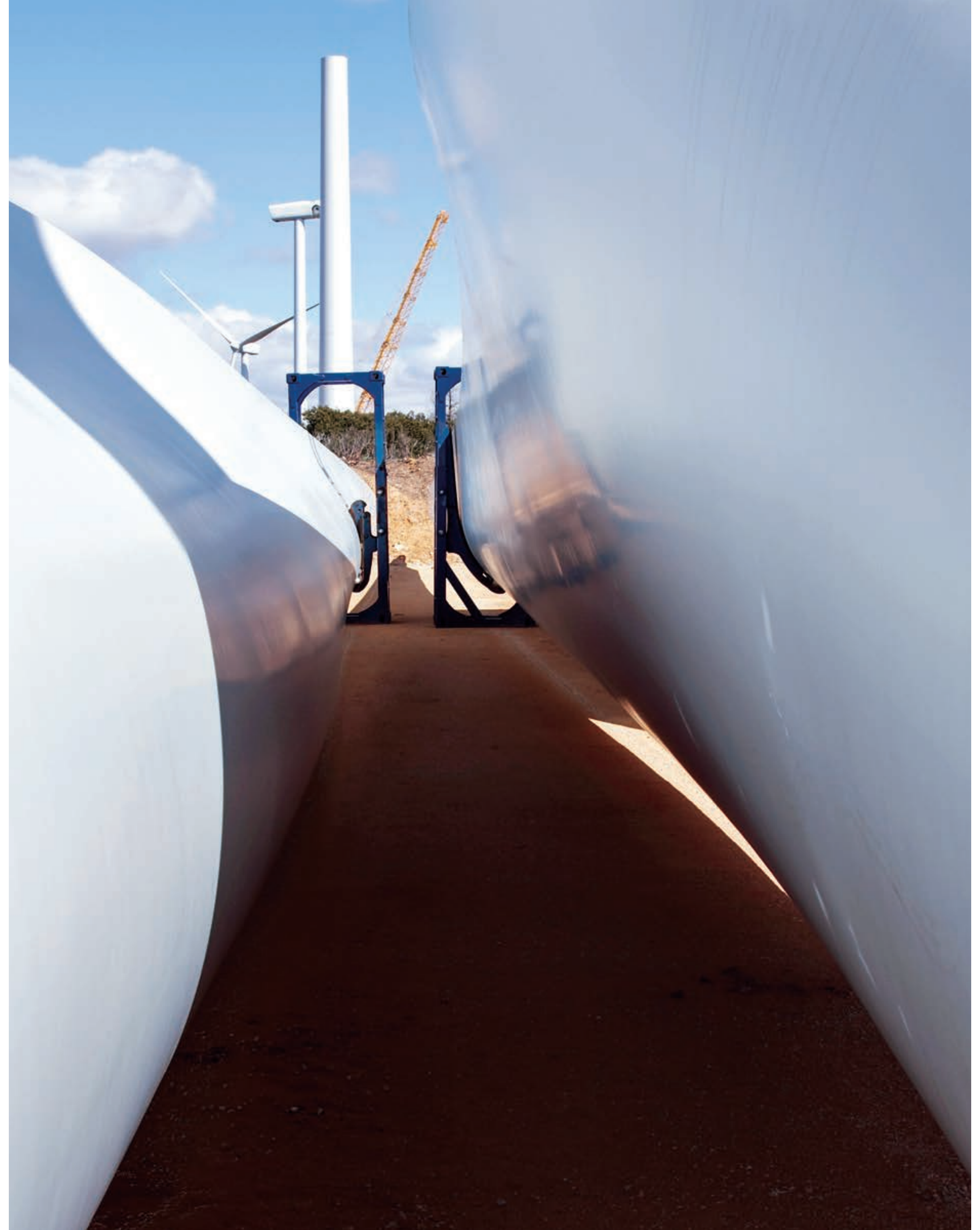
### *Blade Instrumentation Validates Industry Design and Research Model*

NREL collaborated with Siemens to instrument, install, and test state-of-the-art Siemens B53 passive load alleviation blades on the Siemens 2.3-MW wind turbine at the NWTC near Boulder, Colorado. Passive load alleviation means that the curved flexible shape of the blades enables them to deflect large loads caused by gusts of wind. The 53-m blades were heavily instrumented with hundreds of surface pressure taps, five-hole pressure probes, and fiber-optic strands that ran from the tip of the blade to its root to measure how this highly flexible blade reacts to the rapidly varying aerodynamic phenomena that occurs in the turbulent atmosphere in which the turbine operates.

The extensive instrumentation provided extremely accurate data that NREL used to validate its latest version of FAST (FAST8)—an open-source wind turbine and wake modeling software used by the wind energy community in research and design. FAST8 includes BeamDyn, a high-order finite-element blade model based on geometrically exact nonlinear beam theory that is capable of modeling anisotropic composite materials, highly nonlinear deflections, bend-twist coupling, and nonstraight blades. FAST8's AeroDyn aerodynamics module was also overhauled to support the analysis of advanced aero-elastically tailored blades. The new FAST addresses the greatest weakness of prior versions with its new capabilities for modeling highly flexible and nonstraight blades. With these model upgrades and validation, wind energy researchers can employ FAST8 as a verification benchmark for their in-house models and design innovative rotors that improve energy capture and reduce the cost of wind energy.

Performed by: NREL
Principal Investigator: Scott Scheck, Scott.Schreck@nrel.gov






### *Wind Turbine Controls Improve Performance, Reduce Loads, and Increase Energy Capture*

Researchers at the NWTC developed a feed-forward controller that is able to regulate turbines and wind plants by "looking ahead" at incoming wind conditions and eliminating the delayed control response time that currently exists when the controller senses a wind gust and the mechanical adjustment to the rotor torque responds.

Until recently, wind turbine controls that reduce the impacts of wind gusts and turbulence were always reactive—responding to the wind rather than anticipating it. Now, NWTC researchers and their industry partners have shown that wind speed can be measured ahead of the turbine, thereby improving performance, reducing structural loads, and increasing energy capture.

In 2015, the lidar for feed-forward control system testing was installed and tested for more than 300 hours on the 3-MW Alstom wind turbine at the NWTC. The lidar signals were successfully integrated into the turbine controller in preparation for feed-forward controller implementation and field tests to be conducted early in 2016. The lidar was characterized by comparing its wind-speed measurements to upwind anemometer data, increasing researcher confidence that the system will perform as predicted.

Performed by: NREL
Principal Investigator: Alan Wright, Alan.Wright@nrel.gov

## Offshore Wind

Offshore wind resources are abundant, stronger, and blow more consistently than land-based wind resources. Data on the technical resource potential suggest that more than 4,000 GW of capacity could be accessed in state and federal waters along the coasts of the United States and the Great Lakes.

***Market Report Highlights Potential for Offshore Wind Development***

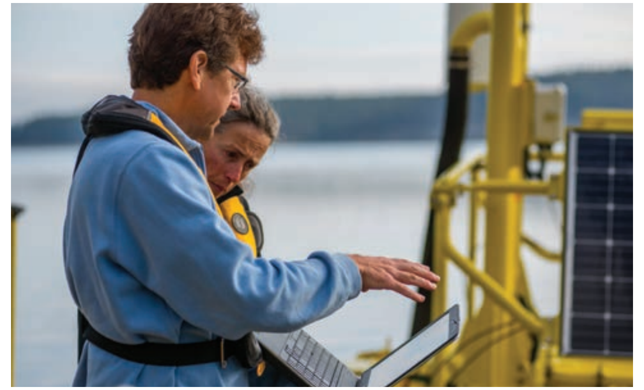
According to the *2014–2015 Offshore Wind Technologies Market Report* published by NREL in 2015, there are 21 U.S. offshore wind projects in the development pipeline, representing 15,650 MW of offshore wind. Thirteen of these projects, representing 5,939 MW, have achieved site control or a more advanced phase of development. Approximately 3,305 MW of U.S. projects have announced a commercial operation date by 2020, which is consistent with the timing of the deployment scenario defined for offshore wind in DOE's *Wind Vision*.

Deepwater Wind began offshore construction on what will be the nation's first offshore wind project. The 30-MW Block Island Wind Farm promises to significantly lower electricity prices for the residents of Block Island, provide substantial clean energy to the mainland townships of the southern region of Rhode Island, and generate up to 300 jobs during construction.

Performed by: NREL

Principal Investigator: Walt Musial, Walter.Musial@nrel.gov

### *Lidar Buoys Accelerate Offshore Wind Development*



Although offshore wind development holds great promise as a source of clean, renewable electricity, determining the consistency and yield of a site can be a long and expensive process between securing the required permits, building a test tower, and gathering the necessary years' worth of data. In the hostile marine environment, gathering such data can be prohibitively expensive in many locations. To accelerate the development of offshore wind, DOE commissioned PNNL to procure and deploy two research buoys designed to more accurately predict the power-producing potential of a site.

The bright yellow buoys—each worth $1.3 million—were completed at the end of 2014 and include advanced scientific instruments designed to measure wind speed at multiple heights, air and sea surface temperature, barometric pressure, relative humidity, wave height and period, and water conductivity. Subsurface ocean currents are also measured using Doppler sensors.

All of these measurements will help scientists and developers better understand air-sea interactions and their impact on how much wind energy a turbine can capture at particular offshore sites. The data will also help validate the wind predictions derived from computer models, which have thus far relied on extremely limited real-world information.

One buoy has been deployed off Virginia Beach, Virginia, since December 2014. Its first round of data is being analyzed and is already yielding valuable insights. The second buoy will be deployed off New Jersey after a short detour through Washington, DC, for public viewing.

Performed by: PNNL

Principal Investigator: William Shaw, will.shaw@pnnl.gov



### *Researchers Analyze Potential for First Offshore Floating Wind Farm*

Farther from shore and at greater depths, floating offshore wind turbine technology can access wind resources that are often higher and more available than in shallower water, and where fixed-bottom structures are more economically challenged. Statoil, an international energy company, took advantage of these unique resources and conditions when it deployed the first spar-based system, known as the Hywind Demo, in 2009. In 2015, the company partnered with NREL to analyze the Hywind technology as it applies to U.S. waters.

NREL used its software program FAST7 to build a model of Statoil's 6-MW turbine design to investigate four design load cases based on international standards and allow Statoil to compare the resulting data against their own findings. Researchers also studied wake modeling of multiple turbines in an array by using the FAST7 model and NREL's high-fidelity wind farm simulation tool, SOWFA. The simulations were performed using two high-performance computing systems: Peregrine at NREL and Hexagon at the University of Bergen.

In addition, researchers conducted a national economic analysis using a new geo-spatio-economic methodology developed by NREL that assesses how resource variability in different water depths can influence the LCOE for different offshore wind technologies. Ultimately, the information gained from this work provided Statoil with the data needed to inform their decision making and determine where the best offshore sites are located for implementing future commercial-scale installations in the United States.

Performed by: NREL

Principal Investigator: Senu Sirnivas, Senu.Sirnivas@nrel.gov

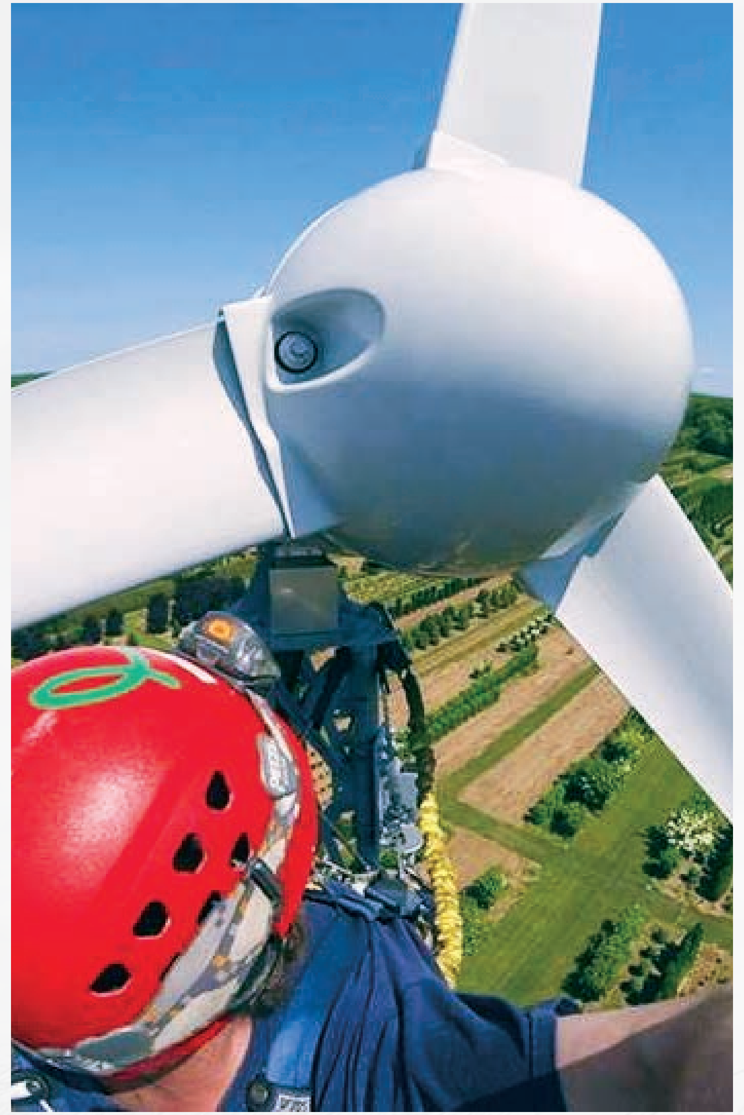
***Sediment Stability Tools Minimize Risks of Offshore Wind Development***

Coastal environments are harsh. Ocean waves and currents create continuous stresses to submerged structures and the surrounding seabed that can lead to harmful scour and damage critical infrastructure. Despite these ongoing and relentless conditions, offshore wind structures and seabed infrastructure must perform with minimal maintenance. A major part of the offshore wind industry's success depends on efficient and accurate analysis and design to overcome these challenges.

To meet this industry-wide need, SNL has developed tools to accurately assess seabed stability to help minimize risks to offshore wind infrastructure, and help reduce financing, installation, and maintenance costs throughout the structure's lifecycle. SNL's tool creates spatial maps of sediment stability that provide the offshore wind industry with the ability to quantitatively evaluate site characteristics for planning and siting of arrays as well as future monitoring of seafloor infrastructure.

Performed by: SNL
Principal Investigator: Jesse.Roberts, jdrober@sandia.gov





## Distributed Wind

The Wind Program's distributed wind research and development activities address the performance and reliability challenges associated with small wind turbines and turbines in distributed applications. Distributed wind applications are defined by a wind plant's location relative to end-use and power distribution infrastructure rather than turbine size.

***Small Wind Exports Generate More Than Just Power***

According to the *2014 Distributed Wind Market Report*—prepared by researchers at PNNL and in conjunction with DOE's Wind and Water Power Technologies Office in 2015—nearly 74,000 distributed wind turbines are now in operation within the United States, totaling 906 MW of power. Approximately 1,700 units, a $170-million investment, were added in 2014 with installations of large-scale turbines (greater than 1 MW) growing almost threefold.

Although the use of distributed wind power in the United States is noteworthy in and of itself, the report found international demand for the technology has given rise to a strong export market for U.S. manufacturers. Distributed wind exports accounted for nearly 80% of 2014 U.S. manufacturers' sales. In particular, international demand for small wind units (up through 100 kilowatts) generated $60 million in revenue. The growth of distributed wind exports supports domestic manufacturing and supply chain jobs.

Performed by: PNNL
Principal Investigator: Alice Orrell, alice.orrell@pnnl.gov

### *Competitiveness Improvement Project Results in Dramatic Cost Reduction*

Funding provided by DOE's Competitiveness Improvement Project and technical support from NREL were key to enabling Pika Energy of Westbrook, Maine, to develop and test its innovative manufacturing process that reduced the end-user cost of its wind turbine by more than $3,000.

The purpose of the Competitiveness Improvement Project is to help U.S. manufacturers that produce distributed wind systems to lower the cost of energy from their turbines and increase their share of the market. By focusing on component and manufacturing process improvements and turbine testing, the cost-shared awards help small and midsize wind turbine companies improve their system designs and earn certification that shows they have met performance and safety requirements—thereby increasing their competitive edge.

Performed by: NREL
Karin Sinclair, Karin.Sinclair@nrel.gov



### *Innovative Distributed Wind Model Shows Potential for Market Growth*

NREL developed an innovative distributed wind market diffusion model—dWIND—that provides manufacturers, investors, and incentive providers with critical, third-party, unbiased data on the size of the potential market and the cost of energy (COE) they need to offer to achieve the desired market growth. It also includes quantitative data that DOE and wind industry stakeholders can use to set targets for cost and performance goals. The dWIND model analyzes customer purchase dynamics, based on economics and acceptance of new technology. It combines high-resolution wind resource data; utility customer data for residential, commercial, and industrial customers; current and future wind generator cost and performance data; and diffusion models describing new technologies entering the marketplace.

Designed with many options, dWIND is a powerful tool for studying the impact of changes in assumptions for the future installed cost, turbine performance, operation and maintenance costs, COE, available incentives, and deployment barriers.

Through the use of this tool, DOE and the distributed wind industry will, for the first time, have a high-fidelity methodology to assess distributed wind market potential. dWIND also offers expanded capabilities to understand how different technology, market, and policy approaches can impact the distributed wind industry.

Performed by: NREL
Principal Investigator: Robert Preus, Robert.Preus@nrel.gov

## Facilities and Testing

The DOE Wind Program supports R&D activities at nine national laboratories and two user facilities. The facilities work together, sharing data, information, and resources to advance the development and deployment of wind energy technologies.

### *Nation's Most Advanced Wind Research Facilities Join Forces to Increase Drivetrain Reliability*

Two of the nation's most advanced wind research and test facilities joined forces in 2015 to help the wind energy industry improve the performance of wind turbine drivetrains and comprehend how the turbines can integrate effectively with the electrical grid. NREL and Clemson University are partnering to share resources and capabilities in the operation and development of testing facilities and exchange staff for training, research, and development purposes.

NREL operates 2.5-MW and 5-MW dynamometers and a 7-MW controllable grid interface (CGI). The CGI provides system engineers with a better understanding of how wind turbines, photovoltaic inverters, and energy storage systems interact with the grid and react to grid disturbances. NREL completed the connection of its 7-MW CGI to the utility-scale wind turbines and energy storage pads at the NWTC in 2015 and established a high-rate data connection to the Energy System Integration Facility (ESIF) at NREL's main campus. By including a virtual link with the ESIF's super-computing capabilities, researchers and industry partners can visualize complex systems in a virtual environment and observe advanced, real-time testing schemes that combine the flexibility of the CGI with ESIF's grid simulator and smart-grid capabilities. NREL is also working to expand the capacity of the grid connection at the NWTC from 10 MW to 20 MW to allow for additional generation capacity to be installed.

Clemson University operates the South Carolina Electric and Gas Energy Innovation Center with 7.5-MW and 15-MW dynamometers and a 15-MW grid simulator. Clemson's Electrical Grid Research Innovation and Development Center housed at the Energy Innovation Center supports education, research, and economic development to speed new electrical technologies to market and can simulate the electrical grid of any country in the world.

Performed by: NREL
Principal Investigator: Mark McDade, Mark.McDade@nrel.gov

### *Meteorological Tower Data Used by Researchers Worldwide*

Reliable, long-term, public meteorological data has been proven to be a high-priority need of the wind industry. To that end, DOE installed two 135-m-tall met towers with research-grade instrumentation at the NWTC. After some initial preprocessing and data validation, data from a wide array of sensors are directly published onto a publicly available website. These data are being used by wind energy developers and researchers worldwide to improve the design of wind plants and develop the next generation of wind turbines. In the future, these data will enable correlation of atmospheric conditions with turbine loads and performance, and planned grid integration work with the utility-scale wind turbines at the NWTC.

Performed by: NREL
Principal Investigator: Andrew Clifton, Andrew.Clifton@nrel.gov

*New Data Acquisition System Provides Superior Product, Saves Time and Money*

NREL developed a stable, verified version of an EtherCAT data acquisition system that provides DOE and the wind energy research community with a flexible, highly accurate and reliable data collection tool. The new system is used by researchers at both the NWTC in Boulder, Colorado, and the Wind Technology Test Center in Boston, Massachusetts, to view, collect, and process large quantities of blade test data. The system is also used at the NWTC for collecting data on dynamometer tests, wind turbine field tests, and met towers and includes optimized features for those applications.

The EtherCAT data acquisition system:

- Is built around robust National Instruments hardware that enables researchers to construct a distributed network of sensors to be measured at up to a 1,000-Hertz data rate
- Ensures that all channels are recorded at the same time for each line in the data file even when located on separate parts of large test articles
- Enables a combination of signals with measurements from other independent systems while maintaining data synchronicity
- Enables signals from met towers and turbine controller operation states to be integrated simultaneously with measurements of the structural loads on the turbine
- Allows for the frequent change of test articles and measurement hardware with easy setup and configuration
- Saves time and money and increases the potential impact of research and certification tests to advance the wind turbine industry.

Performed by: NREL

Principal Investigator: Nathan Post, Nathan.Post@nrel.gov

# Market Acceleration and Deployment

The DOE Wind Program's Market Acceleration and Deployment activities are focused on disseminating applicable information from the Program's research efforts to those who need it, educating tomorrow's workforce, and cultivating networks of regional partners to help support the effective transfer of information enabling well-informed decisions about the appropriate deployment of wind energy.

## Workforce Development and Education

Continued growth in the U.S. wind industry requires trained and qualified workers to manufacture, construct, operate, and maintain wind turbines. Additionally, the nation will continue to need skilled scientists and engineers who can develop the next generation of wind power technologies..

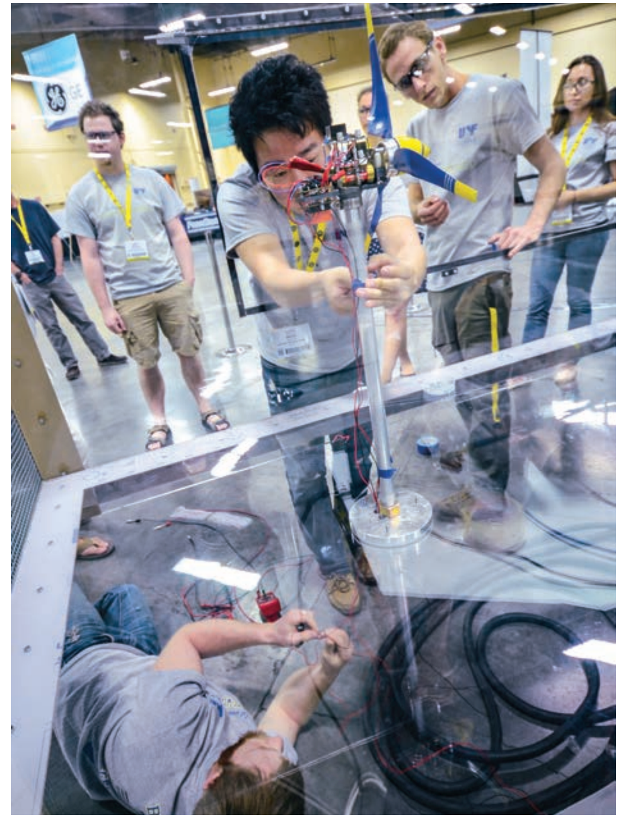
***Boise State Comes Out on Top at the Collegiate Wind Competition 2015***

Hosted at NREL, the U.S. Department of Energy Collegiate Wind Competition 2015 inspired seven teams of students to stretch their imaginations and use innovative thinking to solve complex wind energy problems. This year's competition took the inaugural Collegiate Wind Competition 2014 to the next level by requiring teams to upgrade their 2014 prototype wind turbines for testing in the NWTC's wind tunnel and present a complementary design report. Teams were also tasked with a surprise challenge that required using a set of criteria to determine the optimal location for a wind turbine with the goals of optimizing COE, performance, and other relevant deployment metrics.

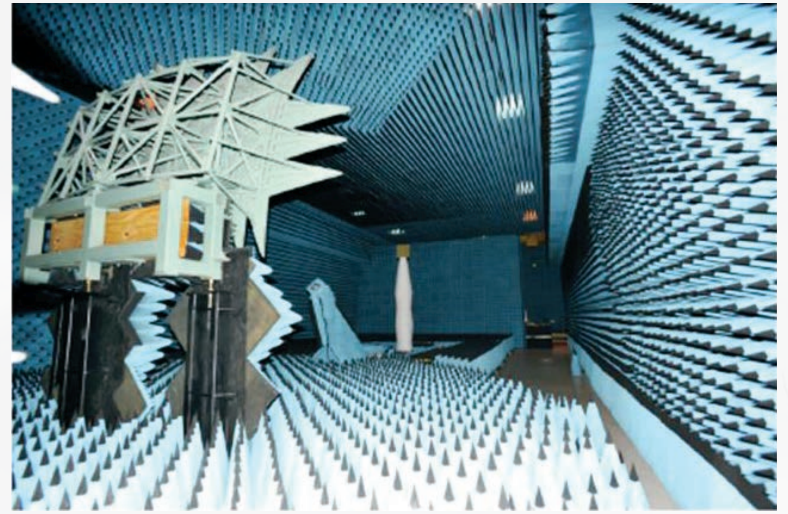
Collegiate Wind Competition 2015 winners included Boise State University with first place, followed by Cal Maritime (second place) and Pennsylvania State (third place). Pennsylvania State also won the surprise challenge. Regardless of standing, all participants gained hands-on experience and real-world knowledge to help them better prepare for a future in the wind energy industry.

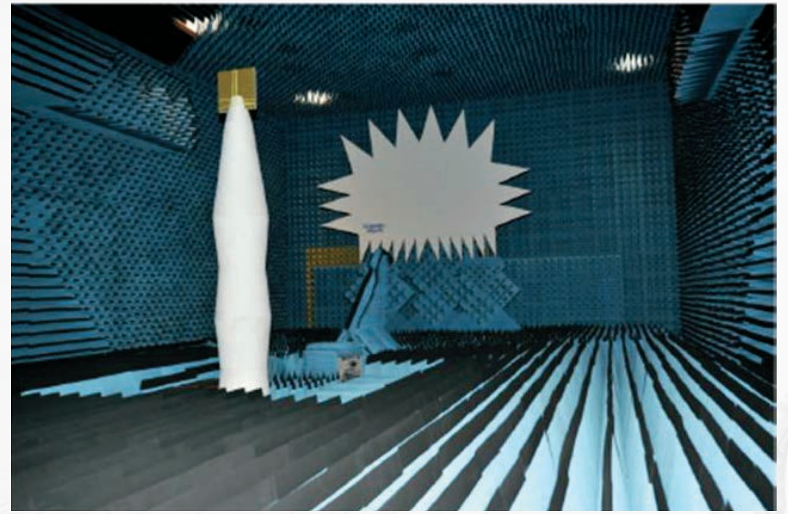
Performed by: NREL

Principal Investigator: Elise DeGeorge, Elise.DeGeorge@nrel.gov







## Environmental Impacts and Siting

The Wind Program works to remove barriers to wind power deployment and to increase the acceptance of wind power technologies by addressing siting and environmental issues. Wind power is a renewable, low-carbon footprint energy supply option. When properly sited, wind projects provide a net environmental benefit to the communities in which they operate and to the nation overall.

***First Wind Turbine Radar Modeling Toolkit Mitigates Radar Interference through Improved Siting***

Wind turbine structures and rotors reflect radar signals and cause clutter on radar screens that can result in aircraft tracks being "lost" in wind farms. The possibility of these wind turbine/radar interactions have delayed, and in some cases, prevented the development of wind plants in areas that were otherwise ideally suited for wind development.

SNL has developed the first wind turbine radar interference modeling toolkit to mitigate this potential barrier to deployment. The Tools for Siting, Planning, and Encroachment Analysis for Renewables toolkit enables developers to pinpoint the location of radar equipment, analyze impacts of the proposed wind turbines on that radar, and offer potential alternate locations for those turbines causing the chief problems. As a result, developers can better site and configure wind plants to minimize their detrimental impact on radars, making the airspace safer and more secure while opening more areas to wind development.

Performed by: SNL

Principal Investigator: David Minster, dgminst@sandia.gov

*Working Together to Resolve the Environmental Effects of Wind Energy*

For wind to truly succeed as a renewable energy resource it must not only be sustainable and affordable, but operate in harmony with the environment. Finding this balance means understanding potential environmental impacts and investigating demonstrated solutions to those impacts—and ultimately sharing that knowledge with the world. Specifically, these objectives are at the core of International Energy Agency Wind Task 34, otherwise known as WREN (Working Together to Resolve Environmental Effects of Wind Energy).

The United States has led WREN since 2012, with support from PNNL, NREL (serving as Operating Agent), and the DOE's Wind and Water Power Technologies Office. With a concerted effort from NREL, membership has grown from two to nine member countries: France, Germany, Ireland, Netherlands, Norway, Spain, Switzerland, United Kingdom, and the United States.

To enable teamwork on a global scale, the WREN team created WREN Hub. Housed on Tethys, the hub is an online resource that is continuously updated to provide the latest information on meetings, upcoming webinars, and publications related to the environmental effects of land-based and offshore wind energy (approximately 1,300 documents posted to date).

WREN members are also able to engage with each other via the quarterly webinar series hosted by NREL and by writing white papers on pertinent topics not currently covered in the database. Through this ongoing collaborative effort, WREN members are better able to inform the global wind community on what is needed to minimize impacts to wildlife and break down barriers to wind energy deployment.

Performed by: NREL and PNNL
Principal Investigators: Karin Sinclair, NREL, Karin.Sinclair@nrel.gov and Andrea Copping, PNNL, andrea.copping@pnnl.gov

## Grid System Integration

As the United States moves toward an electrical system with higher penetrations of wind energy, it is increasingly important for grid operators to know how they can reliably integrate large quantities of this type of energy into system operations. To accomplish this, the Wind Program conducts integration studies and develops models, demonstrations, and assessments at both the transmission and distribution levels.

### *Study Finds Interconnection can Withstand First Crucial Minute after Grid Disturbance*

Published by NREL and General Electric Energy Consulting, *The Western Wind and Solar Integration Study Phase 3* found that, with good system planning, sound engineering practices, and commercially available technologies, the Western Interconnection can withstand the crucial first minute after large grid disturbances with high penetrations of wind and solar on the grid (e.g., loss of a large power plant or a major transmission line). Acceptable dynamic performance of the grid in the fractions of a second to 1 minute following a large disturbance is critical to system reliability.

### *Interconnection can Support 30% Wind Penetration*

Using high-performance computing capabilities and new methodologies, researchers at NREL conducted the *Eastern Renewable Generation Integration Study*, modeling hundreds of gigawatts of wind and solar on system operations to examine their impacts on other generation sources such as thermal plants. The study found that the U.S. Eastern Interconnection—one of the largest power systems in the world—can reliably support up to a 30% penetration of wind and solar power.

Performed by: NREL
Principal Investigators: Kara Clark, Kara.Clark@nrel.gov and Aaron Bloom, Aaron.Bloom@nrel.gov

### *Software Modeling Package Acts as Premier Simulation Tool for the Electricity Market*

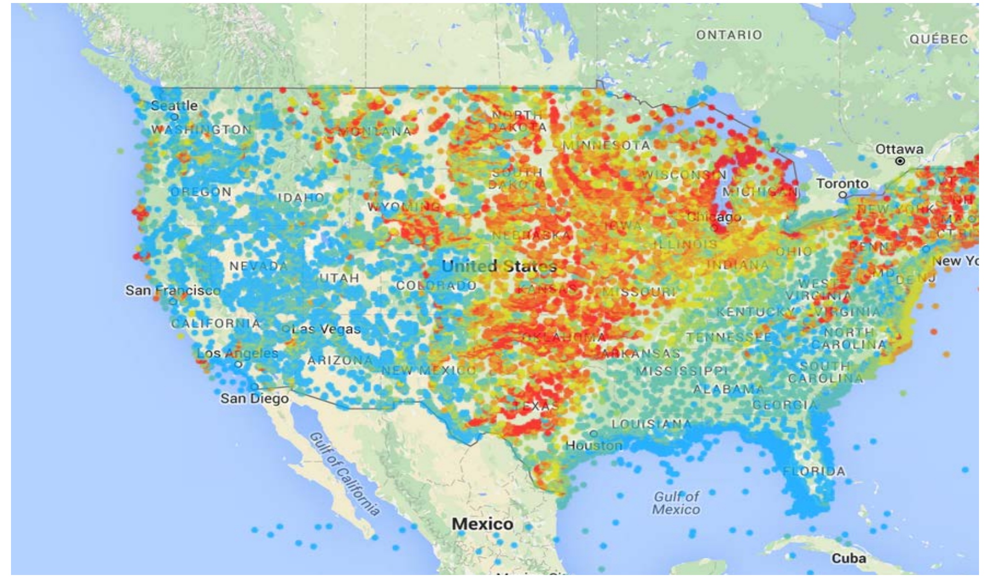
NREL released the first stable version of rplexos, a package that analyzes results from the production cost model PLEXOS, a simulation software tool for the electricity market. Developed for use with R—a popular, free, and open-source statistics software program—rplexos is optimized for large data sets, such as the simulation data provided in NREL's *Eastern Renewable Generation Integration Study*. Since its release, the package has been downloaded more than 3,000 times by operators all over the world and is in use by universities, consulting firms, and U.S. utilities and system operators.

Performed by: NREL
Principal Investigator: Gregory Brinkman, Gregory.Brinkman@nrel.gov

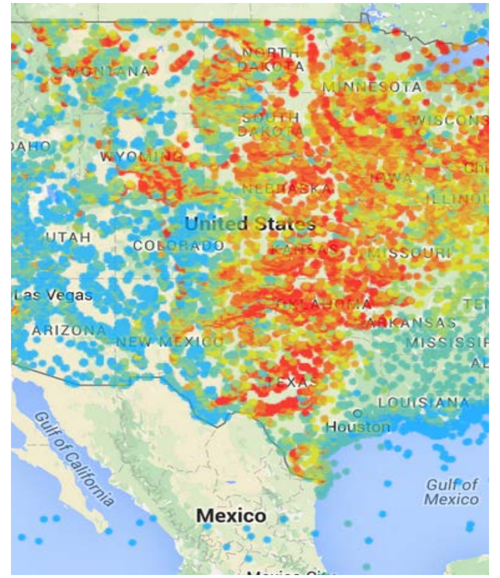
### *Electricity Markets Can Provide Incentives to Maintain Reliability with Increasing Shares of Wind Power*

The steady increase of wind power in the nation's power grid influences prices and incentives in the regional electricity markets. Wind power has a zero marginal production cost that tends to reduce the energy prices in wholesale markets. Moreover, wind power forecast uncertainty may increase the need for operating reserves to maintain system reliability, thereby increasing the prices for reserve products. Researchers at ANL have investigated the ability of electricity markets with high wind power penetrations to provide price incentives for sufficient capacity investments to maintain system reliability. They concluded that this can be achieved through several market mechanisms, from improved scarcity pricing to capacity markets.

Performed by: ANL
Principle Investigator: Audun Botterud, abotterud@anl.gov







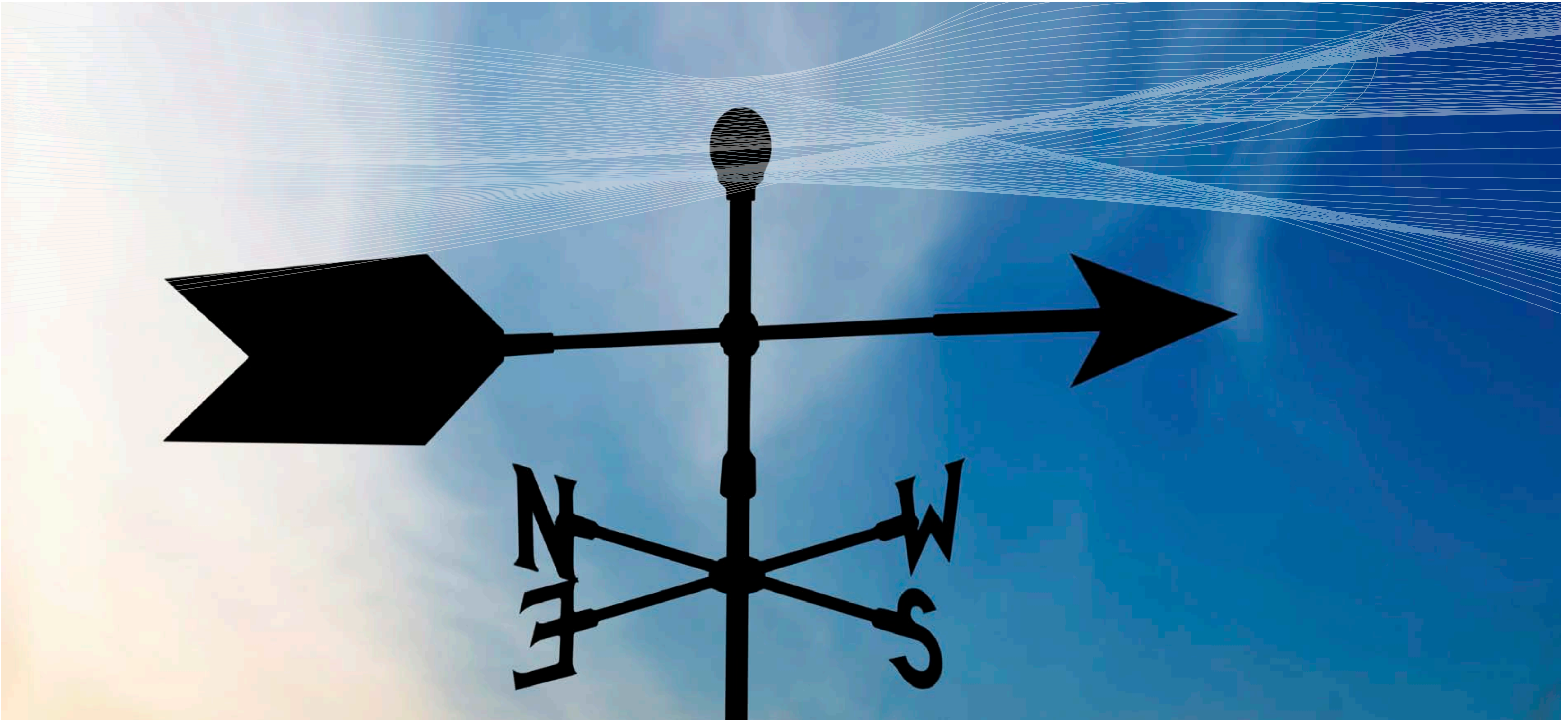

***Toolkit Provides Data for More Than 126,000 Locations***

Wind integration studies require simulated wind data to model future high-penetration wind scenarios because the planned wind plants have yet to be constructed, and therefore detailed wind profile data do not yet exist. The forward-looking nature of these studies requires data that can accurately represent the critical characteristics of the future wind plants for power systems planning and operations; however, a particular challenge of grid integration studies is that it is not possible to forecast future year loads with great accuracy; instead, historical load data are used together with simulations of new energy plants. Thus, simulated wind power forecast data are a foundational component of any wind integration study, and the quality of that data will drive the results of the power system simulations.

The Wind Integration National Dataset (WIND) Toolkit compiled by NREL is currently the largest, most complete, publicly available wind power data set in the world. It provides high spatial and temporal resolution wind power, wind power forecast, and met data for a 7-year period at over 126,000 locations throughout the continental United States.

Performed by: NREL

Principal Investigator: Bri-Mathias Hodge, Bri.Mathias.Hodge@nrel.gov



# Awards and Recognitions

| | Award | Recipient | Sponsor | Date |
|---|---|---|---|---|
| U.S. Department of Energy Wind and Water Power Technologies Office | Annual Achievement Award for the Wind Vision report | Jose Zayas, Rich Tusing, Jessica Lin-Powers, Ed Eugeni, Coryne Tasca, Fred Beck, and Eric Lantz | Utility Variable-Generation Integration Group (UVIG) | April 2015 |
| | Best "project" poster, American Wind Energy Association Offshore WINDPOWER Conference | Luke Feinberg | American Wind Energy Association (AWEA) | Sept. 2015 |
| | Honorary Ph.D. | Joel Cline | Texas Tech University, National Wind Institute, Lubbock, TX | Oct. 2014 |
| | 2015 Achievement Award for contributions to improve wind energy forecasts through the Wind Forecast Improvement Project | Joel Cline | UVIG | 2015 |
| | Certificate of Appreciation for contributions to the World Ocean Assessment Review Process | Hoyt Battey | Bureau of Oceans and International Environmental and Scientific Affairs at the U.S. Department of State | 2015 |
| | Outstanding Civilian Service Medal for outstanding project execution, leadership, and support | Megan McCluer | Office of Energy Initiatives and the Office of the Assistant Secretary of the Army for Installations, Energy & Environment | 2015 |
| National Renewable Energy Laboratory | Staff Award, Outstanding Performance | Paul Fleming | NREL | Feb. 2015 |
| | Annual Achievement Award for leadership in improving the understanding of power system dynamics under high variable generation conditions | Kara Clark | UVIG | April 2015 |
| | Technology Transfer: Outstanding Public Information Award for the Simulator fOr Wind Farm Applications | Matthew Churchfield, Paul Fleming, Sang Lee, Patrick Moriarty, and Avi Purkayastha | NREL | Aug. 2015 |
| | Technology Transfer: Outstanding Business Collaboration Partnership Award for a cooperative research and development agreement with Siemens to collect and analyze data on airfoil and blade performance | Andy Clifton, Lee Jay Fingersh, Dave Jager, and Scott Schreck | NREL | April 2015 |
| | Best "economics" poster, AWEA Offshore WINDPOWER Conference | Aaron Smith | AWEA | Sept. 2015 |



# Publications

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*Enabling Wind Power Nationwide. 2015.* *http://energy.gov/eere/wind/downloads/enabling-wind-power-nationwide*

*Environmental Projects Report 2006–2015.* 2015. *http://energy.gov/eere/wind/downloads/environmental-wind-projects*

*Offshore Wind Projects 2006–2015.* 2015. *http://energy.gov/eere/wind/downloads/offshore-wind-projects*

*Testing, Manufacturing, and Component Development Projects for Utility-Scale and Distributed Wind Energy: 2006–2014.* 2015. *http://energy.gov/eere/wind/downloads/testing-manufacturing-and-component-development-projects*

*Wind Integration, Transmission, and Resource Assessment and Characterization Projects: 2006–2014.* 2015. *http://energy.gov/eere/wind/downloads/wind-integration-transmission-and-resource-assessment-and-characterization*

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### Sandia National Laboratories

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# Patents and Records of Invention

| | Title | Patent/ROI Number | Date |
|---|---|---|---|
| Argonne National Laboratory | Method for Ultra-Fast Boriding | US 20150203980 A1 | 2015 |
| | Micro/Macro-Pitting Resistant Carbon Coatings for Gear and Bearing Applications | Application in process | |
| National Renewable Energy Laboratory | Wind Energy Conversion System | US 4,651,017 | 1982 |
| | Root region airfoil for wind turbine | US 5,417,548 | 1992 |
| | Airfoils for wind turbine | US 5,562,420 | 1992 |
| | Root Region Airfoil for Wind Turbines | EU 0663527 | 1992 |
| | Airfoils for Wind Turbine | EU 0675285 | 1992 |
| | Variable Speed Wind Turbine Generator System with Zero Sequence Filter | US 5,798,632 | 1993 |
| | Airfoils for wind turbine | US 6,068,446 | 1995 |
| | Cooling-tower fan airfoils | US 6,899,524 | 1999 |
| | Variable-speed wind power system with improved energy capture via multilevel conversion | US 6,900,998 | 2001 |
| | Resonance test system | US 7,953,561 | 2001 |
| | Quiet Airfoils for Small and Large Wind Turbines | US 8,197,218 | 2001 |
| | Wind Turbine Tower for Storing Hydrogen and Energy | US 7,471,010 | 2004 |

| | Title | Patent/ROI Number | Date |
|---|---|---|---|
| National Renewable Energy Laboratory | Adaptive Pitch Control for Variable-Speed Wind Turbines | US 8,174,136 | 2005 |
| | Dual-Axis Resonance Testing of Wind Turbine Blades | US 8,621,934 | 2007 |
| | Wind Turbine Blade Testing System Using Base Excitation | US 8,677,827 | 2007 |
| | Base-Excitation Testing System Using Spring Elements to Pivotally Mount Wind Turbine Blades | US 8,601,878 | 2008 |
| | Variable-Speed Wind Power System with Improved Energy Capture Via Multilevel Conversion | ROI-01-50 | 2001 |
| | Resonance Test System | ROI-01-51 | 2001 |
| | Creation of a Resonant Test System for Wind Turbine Blades | IN 07-22 | 2007 |
| | Creation of a Resonant Test System for Wind Turbine Blades | IN 07-24 | 2007 |
| | The Blade Rotation and Transportation (BRAT) System is Being Designed to Allow for the Improved Transportation and Rotation of Test Blade Specimens | IN 07-25 | 2007 |
| | Dual Axis Resonance Testing of Wind Turbine Blades | ROI-07-20 | 2007 |
| | Wind Turbine Blade Testing System Using Base Excitation | ROI-07-21 | 2007 |
| | Double-Sided and Universal Mobile Oscillatory Fatigue Operator Test Systems for Wind Turbine Blades | ROI-07-35 | 2007 |
| | Universal Mobile Fatigue Operator (UMOFO) Ability to Perform Dual-Axis Testing Solely by Oscillating the Test Standbase | ROI-07-36 | 2007 |
| | Rotational Universal Mobile Oscillatory Fatigue Operator | ROI-08-02 | 2008 |
| | B.E.T.S. - Base Excitation Test System | ROI-08-46 | 2008 |



| | Title | Patent/ROI Number | Date |
|---|---|---|---|
| National Renewable Energy Laboratory | Non-torque Loading | ROI-08-75 | 2008 |
| | Dynamometer Speed Control by Field Weakening | ROI-08-78 | 2008 |
| | Distributed Drive System for a Wind Turbine Dynamometer | ROI-08-79 | 2008 |
| | Blade-Mounted Tri-Axial Blade Actuation System | ROI-09-02 | 2009 |
| | Inclined Blade-Mounted Tri-Axial Blade Actuation System | ROI-09-17 | 2009 |
| | Shaft-Mounted System for Wind Turbine Drivetrain Testing with 6 DOF Load Capabilities | ROI-09-67 | 2009 |
| | Individual Coil-Controlled Generator | ROI-11-50 | 2011 |
| | Torroidal Winding Electric Machine | ROI-11-93 | 2011 |
| | Lidar Wind Speed Measurements of Evolving Wind Fields | ROI-12-35 | 2012 |
| | Combining Independent Blade Pitch Control with Wake Redirection for Wind Turbines | ROI-14-82 | 2014 |
| | Particle Filters for Tracking Wind Turbine Wakes | ROI-14-83 | 2014 |
| | Control System for Wind Farm Control | ROI-15-22 | 2015 |
| | Combing Independent Blade Pitch Control, Feedforward Control and Wake Redirection for Wind Turbines | ROI-15-23 | 2015 |
| | Autonomous Untethered Floating Wind Turbines | ROI-15-50 | 2015 |
| | Multidisciplinary Generator Modeling Tools and Drivetrain Systems Analysis Capabilities for Generators Used in Wind, Water and Transportation Systems | ROI-15-78 | 2015 |

| | Title | Patent/ROI Number | Date |
|---|---|---|---|
| Sandia National Laboratories | Ultrafine Cementitious Grout | Inactive | 1994 |
| | Load-Attenuating Passively Adaptive Wind Turbine Blade | H002,057 | 2003 |
| | Modal Analysis of Wind Turbines | Inactive | 2008 |
| | Monitoring of Wind Turbines | Filed | 2009 |
| | Renewable Energy Microgrid Control Via Energy Storage | Inactive | 2011 |
| | Customized Electric Power Storage Device for Inclusion in a Microgrid | Filed | 2012 |
| | Aeroelastically Coupled Blades for Vertical-Axis Wind Turbines | Filed | 2012 |
| | Computing an Operating Parameter of a Unified Power Flow Controller | Filed | 2014 |
| | Systems, Turbines, and Methods for Wind Farm Energy Production | Filed | 2014 |
| | Systems and Methods for Monitoring Wind Turbine Structural Health | Filed | 2015 |
| | Automatic Computation of Transfer Functions | 9009640 | 2015 |



# Software Licenses and Deployment

| | Title | Deployment | Release Date |
|---|---|---|---|
| Argonne National Laboratory | ARGUS-PRIMA (Prediction Intelligent Machine), a licensed software platform with novel statistical algorithms for point and uncertainty forecasting of wind power based on information theoretic learning and conditional kernel density estimation. Developed by INESC Porto and Argonne National Laboratory. | Licensed | 2015 |
| National Renewable Energy Laboratory | FAST simulation tool containing methods for predicting the dynamic response of wind turbines | Open Source Software | 2008 |
| | AirfoilPrep.py | Open Source Software | 2013 |
| | CCBlade | Open Source Software | 2013 |
| | pBEAM | Open Source Software | 2013 |
| | DrivePy | Open Source Software | 2013 |
| | Gear Spline Coupling Program: "Gear SCouP" | Open Source Software | 2013 |
| | Nacelle Systems Engineering model and hub Systems Engineering Model | Open Source Software | 2013 |
| | Turbine cost Systems Engineering Model | Open Source Software | 2013 |
| | NREL Wind Energy Cost and Scaling Model | Open Source Software | 2013 |
| | GIS tool for appending accurate road grade data to vehicle GPS traces | Pursue Copyright | 2013 |
| | rotorSE | Open Source Software | 2013 |

| | Title | Deployment | Release Date |
|---|---|---|---|
| National Renewable Energy Laboratory | towerSE | Open Source Software | 2013 |
| | NREL Wind Integrated System Design and Engineering Model | Open Source Software | 2014 |
| | Simulator for Wind Farm Applications | Open Source Software | 2014 |
| | Land-Based Balance of System | Open Source Software | 2014 |
| | FLOw Redirection and Induction in Steady-state | Open Source Software | 2014 |
| | PyFrame3DD | Open Source Software | 2014 |
| | JacketSE | Open Source Software | 2014 |
| | Framework for Unified Systems Engineering and Design of Wind Plants cost models and case analyzer | Open Source Software | 2014 |
| | Aeroelastic Systems Engineering Module | Open Source Software | 2014 |
| | Floating Turbine Systems Engineering Model | Open Source Software | 2015 |

| | Title | Deployment | Release Date |
|---|---|---|---|
| Sandia National Laboratories | Wind Package | Commercial | Expires 5/23/10 |
| | FAROW | Commercial | Expires 7/18/15 |
| | NuMAD v2.0 | Open Source | 3/25/18 |
| | Code for Axial and Cross-flow Turbine Simulation v1.0 | Open Source | 7/25/18 |
| | Offshore Wind Energy Simulation Toolkit | Open Source | 1/24/18 |
| | VALMET v1.0 | Open Source | 6/9/19 |
| | Vertical-Axis Wind Turbine Mesh Generator v1.0 | Open Source | 1/24/19 |

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