2015 Key Wind Program and National Laboratory Accomplishments
Powering the Energy Revolution through Wind Evolution

The U.S. Department of Energy’s (DOE) Wind Program is committed to helping nation secure cost-competitive sources of renewable energy through the development and deployment of innovative wind power technologies. By investing in improved wind plant design, technology development, and operation, as well as developing tools to identify the highest quality wind resources, the Wind Program is better able to make wind energy technologies more competitive with traditional forms of energy and a larger part of our nation’s renewable energy portfolio. Better 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.
2015 Key Wind Program and National Laboratory Accomplishments

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. This is one of the many examples of how DOE’s Wind Program provides a nucleus for the research community by bringing together its many diverse stakeholders to achieve a common goal—powering the nation’s energy revolution through wind evolution.

Achieving 35% wind energy by 2050 can:

- Provide a stable source of renewable electricity in all 50 states
- Support more than 600,000 jobs in manufacturing, installation, maintenance, and related services
- Help offset 12.1 gigatones of greenhouse gases, equivalent to $400 billion in avoided carbon emissions at current global economic values
- Help offset 2.6 million metric tons of sulfur dioxide, 4.7 million metric tons of nitrogen oxides, and 0.5 million metric tons of fine particulate matter, equivalent to $108 billion in savings from avoided healthcare costs and economic damages
- Save 260 billion gallons of water that would have been used by the mid-20th century energy sector, equivalent to roughly 400,000 Olympic-size swimming pools.

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 120 to 140 meters and larger rotors—currently under development by DOE and its private sector partners—can bring wind energy potential to thousands of new locations across the United States. These advancements, coupled with the average 60 meter wind turbine blade installed in 30 states today,
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 near the Earth’s surface up to a few kilometers. It affects the performance of turbines within a wind plant, but also the larger rotors of the upstream turbines 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 farms. 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 all the environmental factors that affect turbine performance.

New National Laboratory Pilot Opens Doors to Small Businesses

Small businesses have a huge impact on America’s economy, adding more than 1 million employees last year. They are central to developing the new clean energy technologies and new markets for new clean energy technologies for America’s future.

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 the 2015 pilot 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).

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

Atmosphere to Electrons—Transforming Today’s Wind Plant

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The goal of DOE’s research and development (R&D) efforts is to accelerate the adoption of advanced technologies by 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 places high risks, high-reward R&D and invests in government-sponsored projects to drive innovation.

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. It 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 air 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 electric power 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 electric power markets. Data include market penetrations; industry trends; cost, price, and performance trends; policy and market drivers; and future outlooks.

Market Analysis | 8 | 9 | Wind Research and Development

Research and Development
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.

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 new technologies—such as Doppler remote sensing systems—promise the potential to collect high-resolution data using observation of atmospheric fields. However, it is not clear how well current measurement systems can actually map atmospheric fields at the relevant time and spatial scales to provide the temporal and spatial detail required.

In 2015, the DOE Wind Program assembled a team of researchers from the National Oceanic and Atmospheric Administration Earth System 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 to validate these simulations and gain new physical insights using observation of atmospheric fields. 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.

Resource Characterization
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-get 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, especially 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 on the western hemisphere. ANL scientists and wind equipment manufacturing experts use this $1-billion facility to shine the Advanced Photon 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 test field 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 identifies 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 collecting data at the field site, helping with experimental support 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 need to understand wind flow (or turbulence) structures and the forces involved.

The researchers at SNL have developed the Sandia Wake-Imaging System (SWIS) that wakes shed by upstream turbines, showing 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 researchers 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
The National Rotor Testbed developed by SNL will do for the wind industry what the Bell X-1 (experimental supersonic) aircraft did for the aeronautics industry—help produce a machine designed for ultimate performance. 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 testbed will be an essential public resource for future wind energy research. Public 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 and rotor research.

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. The physical relevance is especially important for the coupled experimental and modeling/simulation campaign led 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.

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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 NREL’s National Wind Technology Center. 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 pressure taps, surface pressure taps, 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 occur 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 nonlinear finite-element beam theory that is capable of modeling anisotropic composite materials, highly nonlinear deflections, beam-bending coupling, and transverse loads. BeamDyn’s advanced features enable it to perform stress-based analysis of the highly flexible and non-straight blades. FAST8’s AeroDyn aerodynamics module was also overhauled to support the analysis of advanced semi-active load alleviation blades.

The new FAST addresses the greatest weaknesses of prior versions with its new capabilities for modeling highly flexible and non-straight blades. With these model upgrades and validation, wind energy developers can employ FAST8 as a verification benchmark for their work and continue improving research and design models and innovative concepts 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 NREL developed a feed-forward control system to reduce wake loads and wind turbine noise by “looking ahead” at incoming wind conditions and eliminating the delayed control response time that usually exists when the controller senses a wind gust and the mechanical adjustment to the rotor torque happens only minutes later. The new control algorithms reduce the impacts of wind gusts and turbulence even when the controller responds with a time delay.

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 NREL. 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 data from anemometer data upwind of the turbine. The lidar’s measured wind speeds were found to be within 5% of the anemometer data. Further tests of the system were conducted in early 2016.

In 2016, the lidar for feed-forward control system testing was installed and tested to gather more than 300 hours of lidar data at the NREL. 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 the wind speed measurements to data from anemometer data upwind of the turbine. The lidar measured wind speeds were found to be within 5% of the anemometer data. Further tests of the system were conducted in early 2016.

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

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Technology Development
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. Ten 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 residents of Block Island, provide substantial clean energy to the mainland towns of the southern region of Rhode Island, and generate up to 150 jobs during construction.

Performed by: NREL  
Principal Investigator: Walt Musial, Walt.Musial@nrel.gov
Lidar Buys 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 to the turbine manufacturer. 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 already yielding valuable insights. The second buoy will be deployed off New Jersey after a short detour through Washington, D.C., for public viewing.

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 challenging. Statoil, an international energy company, embarked on the development of offshore wind in 2009, and the company partnered with NREL to design the Hywind technology as it applies to U.S. waters.

NREL’s software program FAST7 was used to build a model of Statoil’s Hywind turbine design to investigate how to design turbines based on international standards and allow Statoil to compare the resulting data against their own findings. Researchers also studied wave 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 in a high-performance computing system

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

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Performed by: NREL
Principal Investigator: Senu Sirnivas, Senu.Sirnivas@nrel.gov

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Performed by: NREL
Principal Investigator: Senu Sirnivas, Senu.Sirnivas@nrel.gov
Distributed Wind

Coastal environments are harsh. Ocean waves and currents create continuous stresses to submerged structures and the surrounding seabed that can lead to failure and damage critical infrastructure. Despite these ongoing and ever-present conditions, offshore wind structures and associated infrastructure must remain dependable and resistant to failure. A major part of the offshore wind industry’s success depends on efficient and accurate analysis and design to overcome these harsh challenges. To meet this industry-wide need, SNL has developed tools to accurately assess seabed stability, helping reduce financing, installation, and maintenance costs throughout the structure’s lifetime. 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 seabed infrastructure.

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

Distributed 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 robust export market for U.S. manufacturers. Distributed wind exports accounted for nearly 18% of U.S. manufacturing sales in 2014. 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

Small Wind Exports Generate More Than Just Power

Sediment Stability Tools Minimize Risks of Offshore Wind Development

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.

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Principal Investigator: Alice Orrell, alice.orrell@pnnl.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 failure and damage critical infrastructure. Despite these ongoing and ever-present conditions, offshore wind structures and associated infrastructure must remain dependable and resistant to failure. A major part of the offshore wind industry’s success depends on efficient and accurate analysis and design to overcome these harsh challenges. To meet this industry-wide need, SNL has developed tools to accurately assess seabed stability, helping reduce financing, installation, and maintenance costs throughout the structure’s lifetime. 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 seabed 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 robust export market for U.S. manufacturers. Distributed wind exports accounted for nearly 18% of U.S. manufacturing sales in 2014. 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
Innovative Distributed Wind Model Shows Potential for Market Growth

NREL developed an innovative distributed wind market diffusion software 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 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

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 installed 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, thus increase market share and reduce their share of the market. It combines high-resolution wind resource data; utility customer data for residential, commercial, and industrial customers; and diffusion models describing new technologies entering the marketplace. It also includes quantitative data for the cost and performance goals 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.

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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.

NREL’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 wind grid. NREL and Clemson in South Carolina 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. NREL completed the connection of its 7-MW CGI to the utility-scale wind turbines and energy storage at the NREL’s National Wind Technology Center (NWTC) in 2015 and established real-time data connections to the Energy System Integration Facility (ESIF) at NREL’s main campus. By conducting virtual and real-world testing, NREL is expanding its system compatibility capabilities, resources, and industry partners’ visualization systems in a virtual environment and observing enhanced real-time testing schemes that broaden the flexibility of NREL’s CGI and 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 15-MW and 5-MW dynamometers and a 15-MW grid simulator. Clemson’s Electric Grid Research Institute and Development Center housed at the Energy Innovation Center supports education, research, and economic development to speed new electrical technologies to market and use similar the electronic grid of any country in the world.

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

Meteorological Data Vitality to Research Worldwide

NREL’s 135-m-tall met towers with research-grade instrumentation at the NWTC provide a reliable and long-term climate dataset for DOE. After some initial pre-processing and data validation, and after a three-year wait, the data are now publicly available and accessible online by anyone. These data are being used by wind-energy developers and researchers worldwide to improve the design of wind turbines and develop the next generation of wind systems. In the future, these data will enableCreation of an atmospheric conditions with turbines loads and performance, and planned grid integration works with the utility-scale wind turbines at the NWTC.

Performance 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, and static load tests, and wind towers and includes optimized features for these applications.

The EtherCAT data acquisition system:

- Is built around National Instruments hardware that enables researchers to construct a distributed network of sensors to be measured out at 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 combination of signals with measurements from other independent systems while maintaining data synchronicity.
- Enables signals from wind towers and turbine automation operating data to be integrated seamlessly with measurements of the shaft and blade load 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 Programs’ 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-energy 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. The year’s competition took the inaugural Collegiate Wind Competition 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 (first place), 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 better prepare for a future in the wind-energy industry.

Boise State
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 the public overall.

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

Wind turbine structures and rotors reflect radar signals and cause interference on radar screens that can result in aircraft “tracks being lost” in the radar screens. The building of these radar obstacles in wind farms has delayed, and in some cases, prevented the development of new or expanded projects in areas that otherwise would be suitable for wind development.

SNL has developed the First Wind Turbine Radar Modeling Toolkit to mitigate this potential barrier to deployment. The Tools for Siting Planning and Environmental Impact Analysis for Renewable Projects toolkit enables developers to pinpoint the location of radar equipment, analyze impacts of proposed wind turbines on that radar, and offer potential alternative locations for those turbines causing interference problems. As a result, developers can better site and configure wind projects to ensure their detrimental impact on radars, making the airspace safer and more secure for opening up areas to wind development.

SNL
Principal Investigator: David Minster, dgminst@sandia.gov

Environmental Impacts and Siting

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SNL
Principal Investigator: David Minster, dgminst@sandia.gov
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 the balance between renewable energy and the environment means understanding potential environmental impacts and investigating demonstrated solutions to those impacts—and actively 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 the Environmental Effects of Wind Energy).

The United States has lead 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 environmental effects of wind 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 electric system with higher penetrations of renewable 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 Interconnection can Support 30% Wind Penetration study performed by NREL investigated the ability of electric energy systems to reliably support up to a 30% penetration of wind and solar power.

Study concludes that with good system planning, sound engineering practices, and commercially available technologies, the Western Interconnection can withstand the first crucial minute after large grid disturbances without violating operational and safety constraints on system operation to reserve resources other generation sources such as fossil 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.

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 price for reserve services. Researchers at ANL have investigated the potential for electricity markets with high wind power penetrations to provide price incentives for sufficient investment in system reliability. They concluded that this can be achieved through several market mechanisms, from improved scarcity pricing to capacity market incentives.

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

Software Modeling Package Acts as Premier Simulation Tool for the Electricity Market
NREL released the first stable version of rplexos, a package that analyses 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.

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

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Grid System Integration

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 extensive 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 and power forecast data are a foundational component of any wind integration study, and the quality of these 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

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<thead>
<tr>
<th>Award</th>
<th>Recipient</th>
<th>Date</th>
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<tbody>
<tr>
<td>Annual Environmental Award for the Wind Vision report</td>
<td>Jose Diaz, Rob Tuning, Jessica Lin-Powers, and Ben Lipman</td>
<td>April 2015</td>
</tr>
<tr>
<td>Annual Environmental Award (MAR)</td>
<td>Jose Diaz</td>
<td>June 2016</td>
</tr>
<tr>
<td>Certificate of Appreciation for contributions to the U.S. Wind Ballot and the National Renewable Energy Laboratory’s Renewable Power Systems Program</td>
<td>Megan McCluer</td>
<td>April 2015</td>
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<td>Best &quot;economics&quot; poster, AWEA Offshore Windpower Conference</td>
<td>Aaron Smith (AWEA)</td>
<td>September 2015</td>
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<td>Best &quot;project&quot; poster, American Wind Energy Association Offshore Windpower Conference</td>
<td>Scott Schreck, NREL, Aug. 2015</td>
<td></td>
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<tr>
<td>Best &quot;technology&quot; poster, American Wind Energy Association Offshore Windpower Conference</td>
<td>Patrick Moriarty, Joel Cline, and Avi Purkayastha, NREL</td>
<td>Aug. 2015</td>
</tr>
<tr>
<td>Outstanding Civilian Service Medal for outstanding project execution, leadership, and support</td>
<td>Megan McCluer, UVIG</td>
<td>April 2015</td>
</tr>
<tr>
<td>Certificate of Appreciation for contributions to the World Ocean Assessment through the Wind Forecast Improvement Project</td>
<td>Joel Cline, UVIG</td>
<td>April 2015</td>
</tr>
<tr>
<td>Honorary Ph.D. Joel Cline</td>
<td>Joel Cline, Texas Tech University, National Wind Technology Center, Lubbock, TX</td>
<td>Oct. 2014</td>
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<tr>
<td>Energy Vision Prize</td>
<td>Joel Cline</td>
<td>Sept. 2015</td>
</tr>
<tr>
<td>Annual Achievement Award for leadership in improving the understanding of and support for variable generation</td>
<td>Megan McCluer, UVIG</td>
<td>Apr. 2015</td>
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<td>Energy Laboratory</td>
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### Technology Publications

- Lawrence Berkeley National Laboratory

### Laboratory Publications

- Argonne National Laboratory

### Journal Articles

- Lawrence Berkeley National Laboratory

### Technical Reports

- Lawrence Berkeley National Laboratory

### Publications

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<tr>
<th>Publication</th>
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</table>

**Notes:**
- All links are to the official websites of the respective organizations.
- DOIs are provided for articles published in peer-reviewed journals.
- All publications are in English unless otherwise noted.


Ahlstrom, Mark, Smith, Charlie, Piwko, Dick, Lew, Debra, Bloom, Aaron, Mai, Trieu, Clark, Kara, Milligan, Michael. 2015. Value of Improved Short-Term Wind Power Forecasting


Milson, C., Smith, A., Hand, M., Ciglar, B., Hand, M. 2015. Value of Improved Short-Term Wind Power Forecasting

Scientific Instruments

Implementation of a New Autonomous Sensor Fish to Support Advanced Hydropower Development.


Santos, Rick, van Dam, Jeroen. 2015. Turbine Mechanical Loads Test Report for the U.S. Department of Energy 1.5-Megawatt Wind Turbine


NREL, Golden, CO (US).

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<tr>
<th>Title</th>
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<tbody>
<tr>
<td>Adaptive Pitch Control for Variable Speed Wind Turbines</td>
<td>US 8,174,136</td>
<td>2005</td>
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<tr>
<td>Dual-Axle Resonance Testing of Wind Turbine Blades</td>
<td>US 6,640,084</td>
<td>2001</td>
</tr>
<tr>
<td>Wind Turbine Blade System Using Base Excitation</td>
<td>US 6,874,257</td>
<td>2005</td>
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<tr>
<td>Base Excitation Testing System Using Spring Elements to Pionally Mount Shrink Turbine Blades</td>
<td>US 6,033,678</td>
<td>2006</td>
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<tr>
<td>Variable-Speed Wind Power System with Improved Energy Capture for Variable Wind Conditions</td>
<td>ROI-01-04</td>
<td>2000</td>
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<tr>
<td>Continuation of Resonance Test System for Shrink Turbine Blades</td>
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<td>Wind Turbine Blade System Using Base Excitation</td>
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<td>Blade-Mounted Truncated Blade Aspiration System</td>
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<td>Advanced Untethered Floating Wind Turbines</td>
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