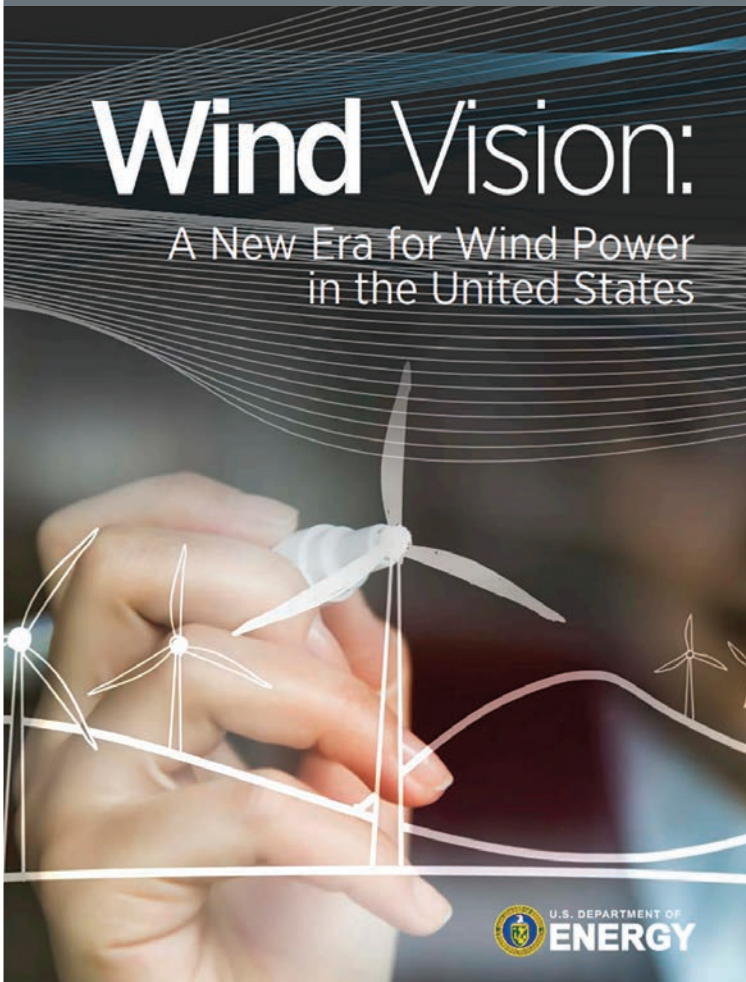
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Wind Program Newsletter
May 2015 Edition
wind.energy.gov



wind.energy.gov/vision

New *Wind Vision Report* Forecasts Clean Energy Future

Letter from the Wind Program Director

The Wind Program's recently released *Wind Vision Report* projects an extraordinarily clean energy future in America. Picture this: In 2050, more than 100 million U.S. homes are powered by wind energy, reducing costs for consumers while avoiding gigatonnes of greenhouse gas emissions, and the wind industry plays a pivotal role in strengthening U.S. manufacturing and the economy through the more than 600,000 people who will earn their living in wind industry-related jobs in the United States. American consumers come out on top, saving billions of dollars in avoided healthcare costs, economic damages, and energy bills.

Continued on page 2

New Wind Technology Resource Center Launched

The U.S. Department of Energy (DOE) recently announced the launch of its new, user-friendly online information resources portal, the Wind Technology Resource Center (WTRC). The WTRC provides a central repository for research reports, publications, data sets, and online tools developed by DOE's national laboratories and

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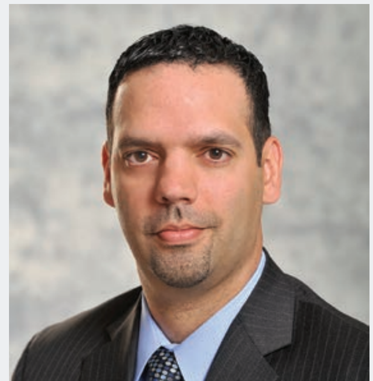
New *Wind Vision* Report

Letter from Wind Program Director continued from page 1



Jose Zayas, Director, Wind and Water Power Technologies Office

twitter@EnergyZayas

This edition of the Wind Program Newsletter highlights some of the recent research and development that is helping drive utility-scale technology advancements, the growth of domestic manufacturing, and the level of wind deployment seen in recent years. For example, new maps show that as wind turbine technology advances, areas with previously limited wind resources have the opportunity to add new wind power capacity using taller utility-scale technologies; the Energy Department's Atmosphere to Electrons Initiative is developing effective solutions to mitigate the adverse impacts of wakes shed from upstream wind turbines on downstream turbine performance; and a more efficient, reliable wind turbine drivetrain promises to further reduce the cost of wind energy. Together, innovative, research-driven efforts such as these contributed to the *Wind Vision Report's* positive findings for the future of U.S. wind energy.

In writing the *Wind Vision*, we recognized that the Energy Department is not the sole agent to drive a new future for the industry, but the Wind Program can provide focus and direction by leading efforts to accelerate the development of next-generation wind power technologies and assisting in solving key market challenges. The *Wind Vision* effort was underpinned by invaluable contributions from the wind industry, environmental stewardship organizations, academics, and national laboratories and is intended to push the boundaries of renewable energy further than ever before. As coexistence is the key to our success, I encourage the broader energy community to review the report and share its findings beyond our walls. Explore the findings of the *Wind Vision Report* and the *Wind Vision Roadmap* at wind.energy.gov/vision to learn more about key actions the research community, wind energy industry, and others can take to accelerate the deployment of wind energy nationwide.

Sincerely,

Jose Zayas

New Wind Technology Resource Center Launched continued from page 1

facilities. These information resources detail wind-energy-related analyses, studies, technology design, tests, and field experiments conducted by the labs from 1980 to the present.

Research indicated that stakeholders were interested in browsing high-caliber information resources based on scientific research and development (R&D) topics and technologies. However, no database offered the ability to browse articles in this manner until DOE developed the WTRC. By housing resources from labs all over the country in one central repository, the WTRC will help wind industry stakeholders find technical information more quickly and easily, supporting the Wind Program's goal to provide current, expert, objective, and accessible wind-energy-related information to the public.

The WTRC offers a variety of ways for users to browse resources, including by topic, technology, application, and state, or search based on keywords. Visitors to the resource center can begin their search with a keyword and continue narrowing the field using a host of filters on the results page. In addition to R&D topics, technology, application, and state, users can filter by organization and resource type to create a highly tailored list.

Check out the WTRC website at www4.eere.energy.gov/wind/resource_center/

DOE Wind Program Presentations at American Wind Energy Association WINDPOWER 2015

TUESDAY **May 19**	**Scientific Advancements in Wind, as Told by Industry Experts** **1:30 p.m.–2:45 p.m.** Sensitivity Study of Offshore Wind Turbine Support Structure Optimization in U.S. Waters **Rick Damiani,** Senior Engineer, *National Renewable Energy Laboratory (NREL)*
	Advances in Turbine Components & Subsystems R&D **3:15 p.m.–4:30 p.m.** Innovative Medium-Speed Drivetrain Design Program and Dynamometer Testing Results **Jonathan Keller,** Senior Engineer, *NREL* NREL's Modern Electrical Architecture Addressing New Turbine Utility and Siting Requirements **William Erdman,** Director, *Cinch, LLC*
WEDNESDAY **May 20**	***Wind Vision:* An Opportunity to Rally the Public Around a Future of Abundant Clean Energy** **10:30 a.m.–11:45 p.m.** Panel Presentation: The DOE *Wind Vision*: Wind Generation for the Next Generation **Jose Zayas,** Director, *Wind and Water Power Technologies Office, U.S. Department of Energy*
	Supply Chain Evaluations to Support Technology Trends **1:30 p.m.–2:45 p.m.** Addressing Major Component Technology Trends: Blades and Towers **Patrick Fullenkamp,** Director, *Technical Services, GLWN* Review of Current and Future Wind Turbine Technology Trends **Katherine Dykes,** Senior Engineer, *National Renewable Energy Laboratory (NREL)*
	The "Mostly Wind" Grid – Implications for Reliability, Markets, and Storage **3:15 p.m.–4:30 p.m.** The Missing Money Issue in Bulk Power Markets with High Wind Energy Penetrations **Michael Milligan,** Principal Researcher, *National Renewable Energy Laboratory (NREL)*
	Poster Reception 4:30 p.m.–6:00 p.m.
THURSDAY **May 21**	**Connecting the Dots: Understanding the Value of Improved Wind Energy Forecasts** **9:00 a.m.–10:15 a.m.** Why DOE is Funding Wind Energy Forecasting Improvement in the USA – Current Status of Efforts **Joel Cline,** Meteorologist, *Wind Program, U.S. Department of Energy*
	New Distributed and Community Wind—Success Stories and Strategies **9:00 a.m.–10:15 a.m.** Preview of 2014 Distributed Wind Market Report **Alice Orrell,** Energy Analyst, *Pacific Northwest National Laboratory*

Moving forward, the WTRC will support endeavors to meet DOE's goal of leading the nation's efforts to accelerate the deployment of wind power technologies by providing industry and the public with open access to information on improving performance, lowering costs, and reducing market barriers from its national laboratories.

Visit the Wind Resource Technology Center at *www4.eere.energy.gov/wind/resource_center/*

Twelve Collegiate Teams Gear Up to Compete at WINDPOWER 2016

Twelve collegiate teams are gearing up to participate in the U.S. Department of Energy's (DOE's) second Collegiate Wind Competition that will take place at the annual American Wind Energy Association (AWEA) WINDPOWER Conference and Exhibition in New Orleans, Louisiana, from May 23 to 26, 2016. The Collegiate Wind Competition challenges teams of undergraduate students to design and build a model wind turbine based on market research and siting considerations, develop a business plan to market their product, and test their turbine against a set of rigorous performance criteria. Students from a variety of engineering, business, communications, and social science programs are challenged to utilize individual skills to develop state-of-the-art wind energy solutions as a team. By combining academic coursework with tangible, hands-on learning, the Collegiate Wind Competition provides valuable real-world experience as students prepare to enter the workforce.

The 12 colleges and universities that will participate in the 2016 competition are:

1. Boise State University (Idaho)
2. The California Maritime Academy
3. California State University, Chico
4. Kansas State University
5. Northern Arizona University
6. Pennsylvania State University
7. Universidad del Turabo (Puerto Rico)
8. University of Alaska Fairbanks
9. University of Maryland
10. University of Massachusetts Amherst
11. University of Massachusetts Lowell
12. University of Wisconsin Madison

Hailing from across the United States, from Alaska to Puerto Rico, each team brings diverse experiences and unique perspectives to the competition.

DOE held the inaugural Collegiate Wind Competition in 2014 at AWEA WINDPOWER in Las Vegas, Nevada, where more than 150 students from 10 institutions helped lay the groundwork for what has become the country's preeminent undergraduate-level wind energy competition.

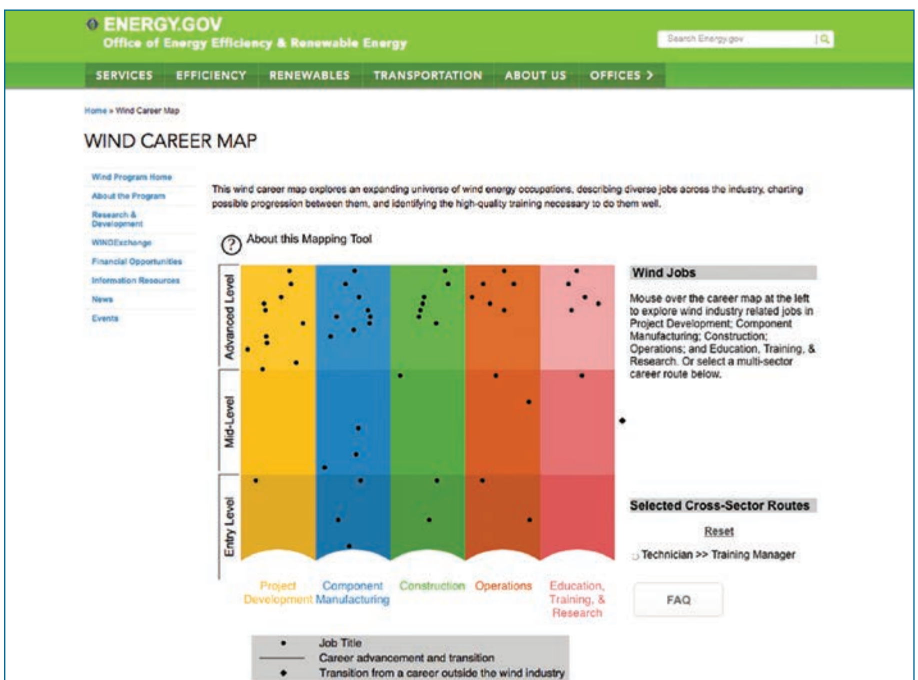
Learn more about the Collegiate Wind Competition by visiting *www4.eere.energy.gov/wind/windcompetition/home*

Wind Career Map Connects Skill Sets with Jobs

The U.S. Department of Energy (DOE) and the National Renewable Energy Laboratory (NREL) have developed a Wind Career Map—the first of its kind in the wind industry—that connects the skill sets needed to qualify for the many types of wind energy jobs generated by the wind industry.

To meet the wind deployment goals described in DOE's new *Wind Vision Report*, the United States will require an expanded and highly qualified workforce; however, a 2013 national study showed that many employers experience difficulty in recruiting qualified applicants. At the same time, few resources exist on wind energy career requirements. The Wind Career Map addresses these challenges for employers and prospective employees.

Based on data from the U.S. Bureau of Labor Statistics, the Wind Career Map is divided into the following categories:



www.energy.gov/eere/wind/wind-career-map project development; component manufacturing; construction; operations; and education, training, and research. The jobs are further divided by the levels of education necessary for each position. Featured careers include wind technicians, managers in manufacturing and construction, research scientists, regulators, product designers, educators, and trade workers. Detailed information, such as expected salary, experience expectations, and educational requirements, is available for each mapped occupation.

The Wind Career Map also includes career pathways that illustrate ways in which a worker in a particular wind industry occupation can transition to a different part of the industry. The pathways show possible routes for advancement at any stage in their career.

Learn more about the Wind Career Map at *www.energy.gov/eere/wind/wind-career-map*

For more information, see: *A National Skills Assessment of the U.S. Wind Industry in 2012* *www.nrel.gov/docs/fy13osti/57512.pdf*

New Wind Career Map Navigates Industry Jobs *www.energy.gov/eere/articles/new-wind-career-map-navigates-industry-jobs*

New Report Shows Downward Trend in LCOE for Wind

A new report recently published by the U.S. Department of Energy's National Renewable Energy Laboratory shows a downward trend in levelized cost of energy (LCOE) for both land-based and offshore wind projects since 2010. The *2013 Cost of Wind Energy Review* presents a picture of the levelized cost of land-based and offshore wind energy using real and modeled data that represents 2013 market conditions.

According to the report, the average LCOE for land-based projects was $66/megawatt-hour (MWh) and $215/MWh for offshore projects in 2013, compared to $71/MWh for land-based and $225/MWh for offshore in 2010. The LCOE analysis relied on inputs that included total capital expenditures, operating expenditures, fixed charge rate, net annual energy production, and net capacity factor. Although the analysis shows that LCOE can vary widely based on changes in any one of several key factors, the variable with the most dramatic effect on LCOE is capacity factor—which is the case for both land-based and offshore projects.

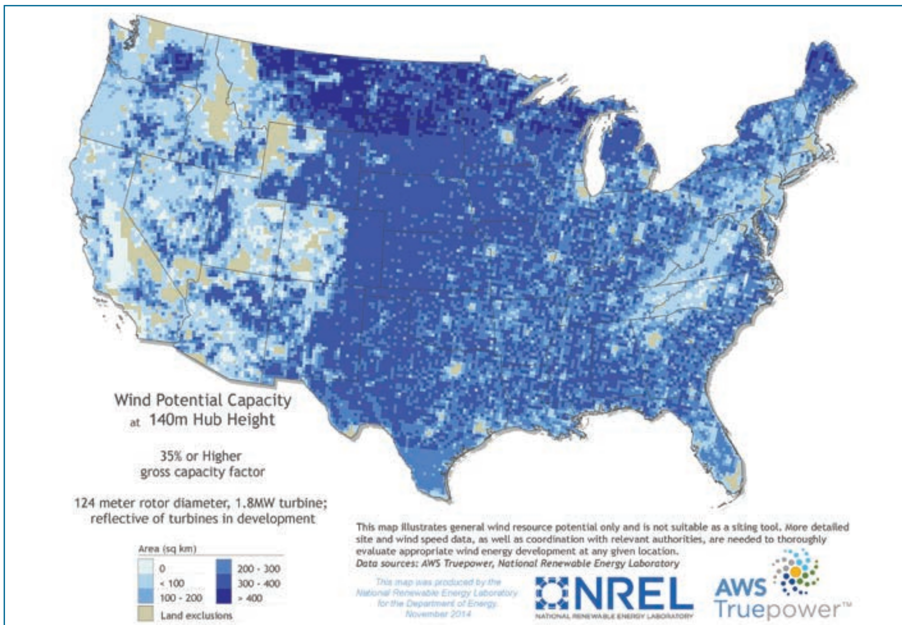
Additional conclusions in the 2013 report include:

- The decrease in LCOE from 2010 to 2013 for the land-based projects can be attributed more to the turbine technology and the offshore decreases to the balance-of-system costs.
- The majority of the land-based project cost (68%) is in the turbine itself, whereas it makes up only 32% of the offshore reference project cost.
- Although the reference project LCOE for land-based installations was $66/MWh, the full range of land-based estimates covers $50–$103/MWh.
- The reference project offshore estimate is $215/MWh, with a full range of $147–$282/MWh. This dramatic range is mostly caused by the large variation in capital expenditures ($3,200–$6,000/ kilowatt) reported by project developers.

Read the full report at *www.nrel.gov/docs/fy15osti/63267.pdf*

New Wind Resource Maps Illustrate Great Potential for Increased Wind Deployment

The U.S. Department of Energy's (DOE's) National Renewable Energy Laboratory and AWS Truepower LLC recently released maps that illustrate the



Learn more about DOE's new wind resource potential maps at *eere.energy.gov/wind/windexchange/windmaps/resource_potential.asp* potential for wind energy development using more advanced wind turbine technologies. Wind resource maps are one tool wind industry professionals use in the early stages of wind project planning to understand the potential for wind development in a region. Because stronger and more consistent winds are typically found at higher heights, these new maps show the concentration of land areas with capacity factors over 35% at turbine hub heights of 110 and 140 meters (361 and 459 feet), representing recent and planned turbine advancements. DOE estimates that enabling the cost-effective deployment of wind turbines with hub heights up to 140 meters will unlock additional wind power resource potential across 1,137,565 square miles of the United States.

Read more about the new wind potential capacity maps at *eere.energy.gov/wind/windexchange/windmaps/resource_potential.asp*

Two engineers working in the nacelle of a Siemens offshore wind turbine.
Photo from Siemens

New Model Demonstrates Offshore Wind Industry's Job Growth Potential

The U.S. Department of Energy's (DOE's) National Renewable Energy Laboratory (NREL) has developed a tool to estimate jobs and other economic impacts associated with offshore wind development in the United States. The modeling tool, which illustrates the potential economic impact and number of jobs associated with fixed-bottom offshore wind development, applies to areas of the country that have waters shallow enough for this technology.

To build the Offshore Wind Jobs and Economic Development Impacts (offshore wind JEDI) model, researchers worked with industry representatives in four regions of the country with shallow waters to develop geographic-specific offshore wind growth scenarios. NREL's *Offshore Wind Jobs and Economic Development Impacts in the United States: Four Regional Scenarios* technical report shares the results and shows that an offshore wind industry in the United States has the potential to support thousands of jobs—even at relatively conservative levels of deployment and domestic supply chain growth.

For example, in the Gulf Coast region, analyses show that in using existing port and manufacturing infrastructure, a 500-megawatt offshore wind project has the potential to support 14,500 full-time jobs during construction and up to 650 long-term jobs. NREL's analysis finds that the Gulf Coast's existing manufacturing workforce, supply chain, and infrastructure could be well utilized in offshore wind development, as the foundations and substructures needed for offshore wind development are similar to those used by the Gulf Coast's oil and gas industry.

The fixed-bottom offshore wind JEDI is one of several user-friendly NREL models that estimate the economic impacts of constructing and operating power generation and biofuel plants at the state and local levels. NREL is currently developing a related JEDI modeling tool that will estimate the economic impacts associated with floating offshore wind technology, which is necessary in water depths where fixed-bottom turbines are not feasible.

Read more about offshore wind JEDI and download the JEDI models at *www.nrel.gov/analysis/jedi/download.html*

Offshore Wind Jobs and Economic Development Impacts in the United States: Four Regional Scenarios www.energy.gov/eere/wind/downloads/offshore-wind-jobs-and-economic-development-impacts-united-states-four-regional

Learn more about the DOE's Wind Program offshore wind research and development efforts: www.energy.gov/eere/wind/offshore-wind-research-and-development

Offshore Wind Project Report www.energy.gov/eere/wind/downloads/offshore-wind-projects

DOE Launches High-Tech Research Buoys to Advance U.S. Offshore Wind Development

The U.S. Department of Energy (DOE) is exploring the immense potential for offshore wind energy development off the Atlantic and Pacific coasts using high-tech research buoys. In December 2014, researchers from DOE's Pacific Northwest National Laboratory (PNNL) deployed one of two specialized buoys near Virginia Beach, Virginia. The second buoy will be deployed near Coos Bay, Oregon.

Each buoy utilizes lidar (light detection and ranging) and other meteorological and oceanographic instruments that measure wind speed and direction while recording air and sea surface temperature, barometric pressure, relative humidity, wave height and period, water conductivity, and subsurface ocean currents. These measurements will help developers quantify the wind resource at particular offshore sites, and will allow scientists to better understand air-sea interactions and their impact on how much wind energy a turbine could produce at particular offshore sites.

A National Offshore Wind Energy Grid Interconnection Study published in August 2014 estimated that the United States has enough offshore wind energy resources to power 17 million homes. Currently, no offshore wind farms exist in the United States, but 14 are in various stages of development, with DOE funding three demonstration projects in New Jersey, Virginia, and Oregon. The buoys will initially be used to characterize the wind resource at the two demonstration sites near Virginia and Oregon.

Data from the high-tech buoys will help validate the wind resource models that have been used to predict the U.S. offshore wind potential, improve offshore turbine development, and reduce barriers to private investment in large-scale offshore wind energy development.

The buoys were purchased by DOE's Office of Energy Efficiency and Renewable Energy and are being operated and managed by PNNL. They initially arrived at PNNL's Marine Sciences Laboratory in Sequim Bay, in the Puget Sound northwest of Seattle, for a brief commissioning period in fall 2014. The buoys will operate for up to 1 year at their respective offshore wind demonstration projects.

To learn more about the buoys, read; *Ahoy, Offshore Wind: Advanced Buoys Bring Vital Data to Untapped Energy Resource* www.pnnl.gov/news/release.aspx?id=1073

To learn more about DOE's offshore wind energy research and development efforts, see: *National Offshore Wind Energy Grid Interconnection Study* www.energy.gov/eere/wind/downloads/national-offshore-wind-strategy-creating-offshore-wind-energy-industry-united

and visit the Wind Program's website, Offshore Wind Advanced Technology Demonstration Projects www.energy.gov/eere/wind/offshore-wind-advanced-technology-demonstration-projects

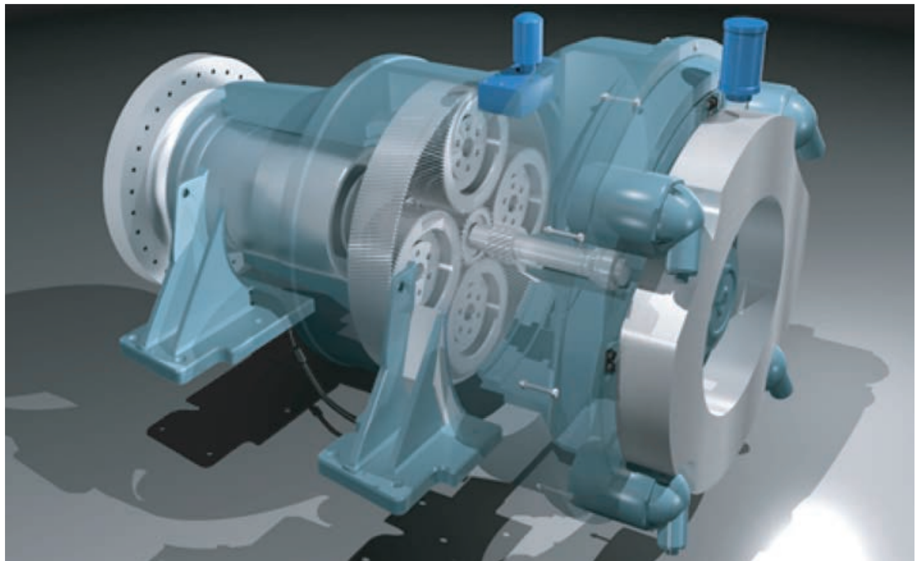
DOE Taking Wind Forecasting to New Heights

A 2013 study conducted for the U.S. Department of Energy (DOE) by the National Oceanic and Atmospheric Administration (NOAA), AWS Truepower, and WindLogics in the Great Plains and Western Texas, demonstrated that wind power forecasts can be improved substantially using data collected from tall towers, remote sensors, and other devices, and incorporated into improved forecasting models in near real time. The study also showed that the improvement increases with the number of observations as well as the area over which they are spread.

To expand on this study and further improve the forecasting models, DOE recently awarded $2.5 million to Vaisala of Louisville, Colorado, to investigate the atmospheric processes that generate wind in mountain-valley regions. Because of the complexity of terrain in these regions and varying degrees of soil moisture and surface temperatures, predicting specific wind conditions presents a major challenge to utility operators looking to optimize the performance of wind farms in these areas. This funding will allow Vaisala and its partners to use advanced meteorological equipment such as in situ and remote sensors to analyze specific physical environmental characteristics that affect wind flow patterns in the study area: the complex terrain of the Columbia River Gorge region of Washington and Oregon. By examining the physics of atmospheric phenomena that impact wind farms in mountain-valley regions, the study will improve the precision and reliability of short-term wind forecasting models, and consequently, increase wind farms' power production.

Data collected during the project will be shared in near real time with NOAA and the DOE's national laboratories, and will be used to develop improved atmospheric simulations for the Weather Research and Forecasting model, a widely used weather prediction system. These new wind measurements and simulations will also be incorporated into NOAA's numerical weather prediction models to improve short-term wind forecasts in complex terrain.

To learn more about the DOE's Wind Forecast Improvement Project, visit: *www.youtube.com/watch?v=24UjA6KbezU*



A new drivetrain designed by NREL applies a systems approach to improve all three major components: a single-stage gearbox, a medium-speed permanent-magnet generator, and a high-efficiency power converter. *Illustration by Josh Bauer, NREL*

NREL Readies New Wind Turbine Drivetrain for Commercialization

In February, engineers at the U.S. Department of Energy's (DOE's) National Renewable Energy Laboratory (NREL) assembled the innovative, medium-speed, medium-voltage wind turbine drivetrain that was the result of a study funded by DOE's Wind Program. The goal of the first phase of the project, which began in 2011, was to design an advanced wind turbine drivetrain that could be scaled to larger turbines and that would significantly reduce the cost of wind energy. The design produced by the NREL team, which included CREE, DNV KEMA, and Romax Technology, can increase reliability, improve efficiency, and reduce the cost of wind energy tremendously. In addition, the design can scale up to ratings as high as 10 megawatts (MW).

In 2013, the team was awarded follow-on funding to develop a prototype and demonstrate the technologies' commercialization potential. The prototype incorporates a systems approach that focuses on all three of its major components: a single-stage gearbox, a medium-speed permanent-magnet generator, and a high-efficiency power converter. The new gearbox consists of a single planetary stage that uses compliant flex-pins and journal bearings to support the planets, eliminating the lower-reliability, higher-speed stages found in traditional gearbox designs. Traditional three-stage high-speed gearbox designs have been plagued with reliability issues caused by the large and unpredictable loads imparted on the gears and bearings by the wind acting on the rotor, and by utility faults acting through the generator. This new configuration improves the load distribution and increases the drivetrain's overall reliability.

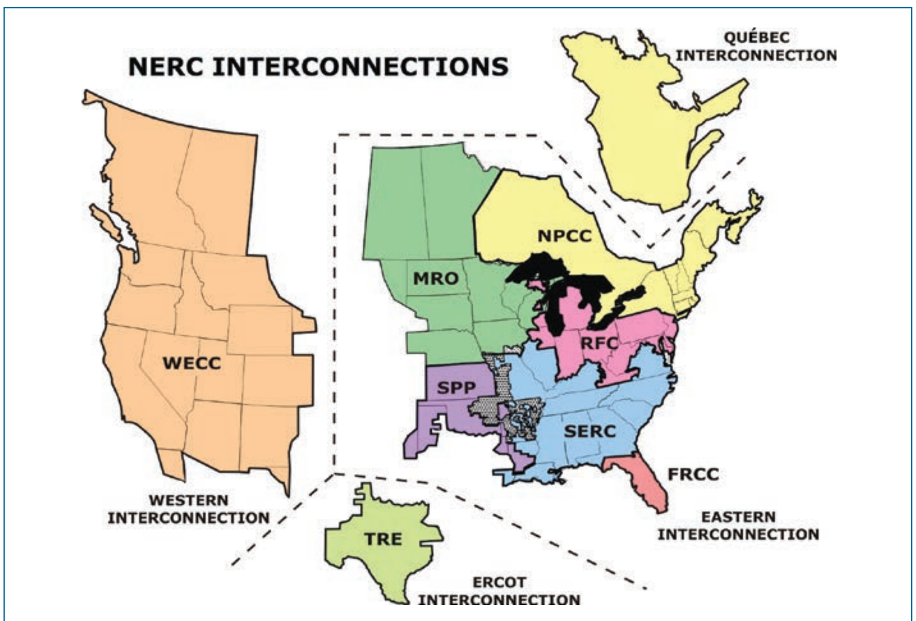
The team's new power converter incorporates innovative software algorithms that are grid-friendly, compliant with emerging requirements, and support the continued growth of wind power as a large contributor to power generation. The team also will be exploring medium-voltage, wide-band-gap, silicon-carbide power modules. These state-of-the-art power modules are expected to significantly reduce the losses within the power converter, leading to increased efficiency, energy capture, and revenue.

The team began testing the drivetrain prototype in the 2.5-MW dynamometer and the controllable grid interface at the National Wind Technology Center at NREL in April. Upon the successful completion of testing, technology readiness levels will be advanced and combined with a commercialization plan that will lead to global deployment of the drivetrain technologies. Successful deployment of the more efficient, reliable drivetrain will further reduce the cost of wind energy and ensure that U.S. companies are at the forefront of technical innovation within the global wind energy industry.

New Report Says Western Grid Can Weather Disturbances with High Wind, Solar Penetrations

A new report finds that with high penetrations of wind and solar on the grid, together with good system planning, sound engineering practices, and commercially available technologies, the Western Interconnection can withstand the crucial first minute after large grid disturbances. Acceptable dynamic performance of the grid in the fractions of a second to 1 minute following a large disturbance (e.g., loss of a large power plant or a major transmission line) is critical to system reliability.

The report, published by the U.S. Department of Energy's National Renewable Energy Laboratory and General Electric Energy Consulting, is titled *The Western Wind and Solar Integration Study Phase 3–Frequency Response and Transient Stability*. The report covers the third phase of the Western Wind and Solar Integration Study (WWSIS). WWSIS explores whether large amounts of wind and solar energy can be integrated into the western electric power system, and is one of the largest regional solar and wind integration studies to date.



The North American electricity grid interconnections (Western Interconnection on the left). *Illustration from the North American Electric Reliability Corporation*

The first phase of the WWSIS examined the operational impact of up to 35% penetration of wind, photovoltaic, and concentrating solar power energy on the electric power system. The goal was to understand the effects of the variability and uncertainty of wind and solar and investigate mitigation options. The study found that these levels of wind and solar could be integrated if certain operational changes could be made, such as intra-hour scheduling and balancing area coordination.

Phase two of the study examined the impacts of fossil-fueled cycling on emissions and wear-and-tear costs. It found that cycling did not significantly reduce the emissions benefits or avoid fuel savings that come from wind and solar.

Phase three of the study focused on reliability and stability. Large-scale transient stability and frequency response are critical to grid reliability, particularly for the Western Interconnection, which has a long history of dynamic performance constraints on its operation. The new report specifically addresses the dynamic performance of the Western Interconnection with high penetrations of renewable energy.

For more information, visit *www.nrel.gov/electricity/transmission/western_wind.html*

National Rotor Testbed Targets Future Wind Plant Research Needs

The U.S. Department of Energy's (DOE's) Atmosphere to Electrons (A2e) initiative has identified the evolution of wakes in turbulent inflow as a key physical process affecting power production and turbine loads in wind farms. Wind energy researchers know that wakes shed from upstream wind turbines lead to reduced power production, increased loading, and higher maintenance costs on downstream turbines. The result is a higher cost of energy.

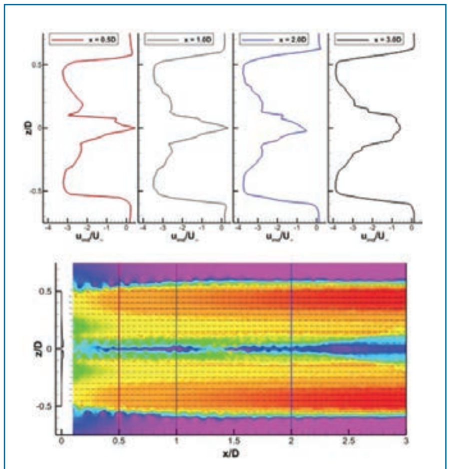
Although the impacts of wakes on wind energy economics is well documented from operating wind farms, potential solutions remain highly debated in the industry. Wind turbines are now large enough that researchers must rely on models using powerful computing resources to simulate potential solutions. High-quality field data are needed to determine the adequacy of current models and to invest in the development of future models. DOE's A2e initiative is embarking on a tightly-coupled experiment and modeling-simulation campaign to rigorously address this challenge.

DOE and Sandia National Laboratories' (SNL's) Scaled Wind Farm Technology (SWiFT) facility in Lubbock, Texas, is ideally suited for a large portion of these experiments. The site contains a carefully spaced array of three highly instrumented, research-scale wind turbines along with meteorological towers to measure and record mesoscale weather around the turbine array as well as inflow directly into each turbine. In a related project, SNL is developing a high-resolution imaging system to measure near-wake wind turbine effects (see *SNL Wake Imaging System Solves Wind Turbine Wake Formation Mysteries on page 11*).

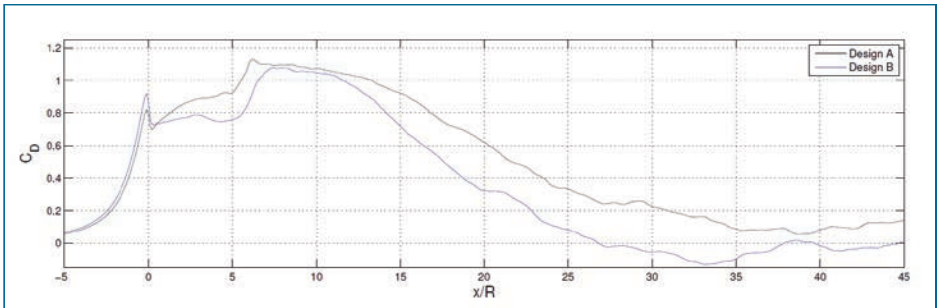
To support specific physical objectives and ambitious measurement objectives of this integrated test campaign, SNL is developing a new subscale rotor, the National Rotor Testbed (NRT), for the SWiFT turbines. Features of the new subscale rotor (27-meter diameter) are determined by scaling relevant aerodynamic performance parameters and design drivers from a representative megawatt-scale rotor (70-meter diameter and larger). The subscale rotor will be well-suited to support turbine-to-turbine interaction research at the SWiFT facility and will also represent full-sized turbines in the United States. This physical relevance is especially important for the coupled experimental and modeling-simulation campaign because it ensures that the credibility of numerical models is demonstrated within physical regimes that are directly relevant to full-scale industry applications.

The NRT team has performed preliminary numerical simulations to define the scope and configuration of future tests. Numerical simulations show how rotor design may affect wind turbine wake behavior in terms of wake recovery. The team is using medium-fidelity vortex and high-fidelity computational fluid dynamics methods to understand the potential tradeoffs of different rotor designs in a wind plant scenario. The codes are also used to inform the future test campaign at the SWiFT facility, which will in turn be used to determine credibility of the codes.

Preliminary numerical simulations have shown the potential of certain rotor designs to offer improved wake recovery at wind farms by deviating from typical, "high-efficiency" wind turbine rotor design practices. As an example, the SNL research team has demonstrated two conceptual rotor



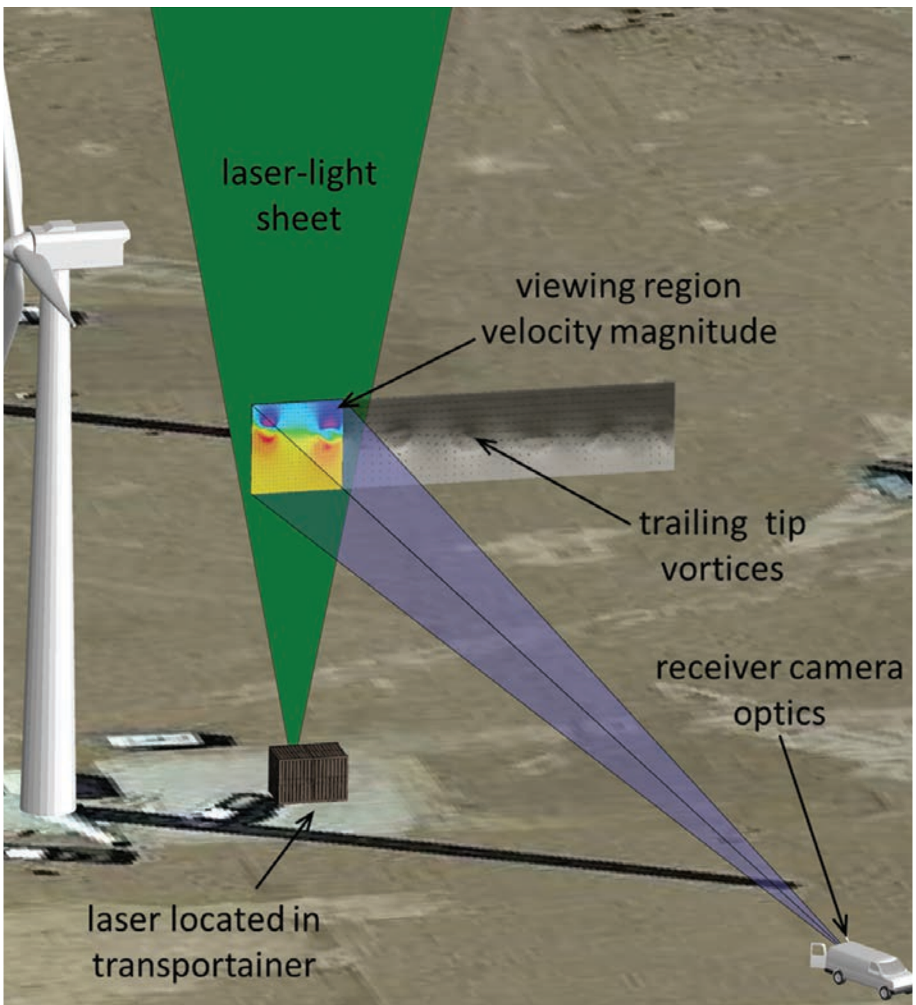
Results of vortex method analysis of SWiFT Rotor Design (colors show magnitude of velocity deficit)



Wake momentum deficit at various diameters downstream of the rotor plane showing how Design B (lower tip loading) recovers to the freestream conditions more rapidly than Design A (maximum CP design) designs. The figures below show the wake velocity deficit for the two designs at various diameters downstream of the rotor; the wake deficits were predicted by a relaxed-wake vortex method using steady, uniform inflow.

The first approach, referred to as maximum coefficient of power (CP) design, produces a maximum CP via a theoretical optimum distribution of axial induction. Axial induction is how much the incoming wind slows as it meets the wind turbine's rotor and energy is extracted. Too much or too little slowing causes the wind to pass around or through the rotor disc without extracting optimal energy. The second approach—lower tip loading design—exhibits a modified axial induction distribution while still operating at the same rotor thrust coefficient as the first blade and only a slightly lower rotor performance coefficient. This design shows potential for faster wake recovery, which enables closer turbine spacing and potentially higher wind energy capture from a given amount of land area.

Read more about SNL's SWiFT facility at *energy.sandia.gov/energy/renewable-energy/wind-power/scaled-wind-farm-technology-swift-facility/*



Example SWIS equipment configuration at the SWiFT facility for near-wake experiments.
Illustration from SNL

SNL Wake Imaging System Solves Wind Turbine Wake Formation Mysteries

Helping to Settle a Debate

The first motion picture in history was of a galloping horse captured by Eadweard Muybridge in 1878. The technique was developed in part to settle a popularly debated question regarding whether all four hooves of a galloping horse left the ground at the same time. The human eye is unable to break down the gallop action, and up until that time artists had painted horses with at least one hoof always on the ground. With this new technique, Muybridge unquestionably proved that, for brief moments, all four hooves of a horse are off the ground.

Today, even though wind energy researchers cannot see the airflow around wind turbines, they know that wakes shed from upstream wind turbines lead to reduced power production and increased loading on downstream turbines, driving up the cost of energy. Similar to the question of the galloping horse, wind researchers want to know how wakes form so they can develop effective solutions to mitigate the adverse impacts of the upstream wakes on the downstream turbine performance.

Wind turbines are now so large that iterative experiments in the field are prohibitively expensive. Instead, researchers must rely on models to simulate potential solutions using powerful computing resources. Successful models must accurately capture the physical environment, and thus require validation and calibration with high-quality field measurement data.

To address the need for a "motion picture" of wake formation, researchers at the U.S. Department of Energy's Sandia National Laboratories (SNL) are developing the SNL Wake Imaging System (SWIS) to provide detailed wake velocity data in the field. The system employs a velocity measurement technique termed Doppler global velocimetry (DGV), a method more suited for large-area measurements of coherent turbulent structures than previously developed methods such as lidar and particle image velocimetry. The DGV method provides velocity data by measuring the Doppler shift frequency of light scattered from aerosol particles within a flow field illuminated by a laser-light sheet.

Scaled Demonstration

The objective of the SWIS is to measure the near-wake flow structures of the turbines installed at SNL's Scaled Wind Farm Technology (SWiFT) facility in Lubbock, Texas. The DGV measurement technique implemented by SWIS would be risky and costly to implement in the challenging field environment of the SWiFT facility. Instead, SNL researchers completed a half-scale demonstration of the technique at their lab in Albuquerque, New Mexico, to quickly and cost-effectively gather and analyze performance data and refine system components. These data help demonstrate that the system can be successfully scaled-up to larger fields of view for deployment at the SWiFT facility.

In the coming years, SWIS hardware will be deployed at the SWiFT facility as part of a comprehensive near-wake experiment involving multiple measurement platforms to capture inflow, structural and aerodynamic rotor data, and wake formation just downstream of a wind turbine. When using the DGV technique, the measured velocity component and quality of the measurement depends on the specific configuration of the laser sheet, cameras, and viewing region. As a result of the complicated measurement dependence on the hardware configuration, and the need to meet the validation requirements at many locations in a wind turbine wake, SNL developed a simulation tool based on the half-scale demonstration results capable of modeling the SWIS physics to better predict and anticipate the system's performance when deployed at the SWiFT facility.

LLNL Predicts Wind Power with Greater Accuracy

The wind is a variable and uncertain power source that relies on a host of complex atmospheric forces. Reducing the uncertainty of wind power forecasts, upon which wind farm operators and power grid operators depend, is the goal of a team of researchers at the U.S. Department of Energy's Lawrence Livermore National Laboratory (LLNL), who combine fieldwork, advanced simulations, and statistical analysis in their efforts.

Observations Guide and Verify Simulations

LLNL field researchers are characterizing winds in numerous locations with distinct conditions. They have made significant discoveries studying the winds in the lower atmosphere and their effects on wind farm power output. A particularly important variable is turbulence, as it affects the power extracted from wind turbines as well as the reliability and life spans of turbine components.

Using field instrumentation and data from wind farms, LLNL researchers determine the effects of wind and other atmospheric variables on power production. Accurate descriptions of how wind velocity and turbulence vary across the turbine rotor disk are important in improving wind power forecasts. LLNL activities include the first effort to explore the relationship between three-dimensional turbulence and turbine power production.

Advanced Simulations Address Key Challenges

LLNL simulation and modeling efforts use high-performance computation to study atmospheric flows and turbine aerodynamics in fine detail. The task is enormous because the length scales involved span eight orders of magnitude—from regional weather patterns that include fronts, sea breezes, and flows over mountain ranges (~1,000 km) down to aerodynamic effects around the wind turbine's rotor (~1 mm).

To analyze the impacts of atmospheric flows and turbine aerodynamics on wind farm performance, LLNL adapted the National Center for Atmospheric Research's popular Weather Researching and Forecasting (WRF) atmospheric simulation code to include turbine models and improved turbulence simulations to extend capabilities to wind farm analysis. However, the standard WRF model is restricted to simple terrain with shallow slopes. To eliminate this restriction, LLNL developed the immersed boundary method (IBM) that simulates flow in highly complex terrain with near vertical slopes without compromising accuracy.

Minimizing Uncertainties

LLNL researchers are studying how to reduce uncertainties and errors in wind forecasts and power predictions using statistical modeling and uncertainty quantification. They have developed a statistical power curve that can adapt to changing conditions and greatly improve predicted power output. Traditional turbine power curves model power as a function of only the wind speed at the hub height of the turbine and can err by 50%. In reality, power output is a function of many additional variables.

To reduce uncertainties in wind forecasts, ensemble modeling is employed, which entails running a family of forecasts using slightly different assumptions. One of the chief advantages of ensemble modeling is the ability to spot outliers such as a wind ramp. Because power is proportional to the cube of the wind speed, it is important to be aware of outliers.

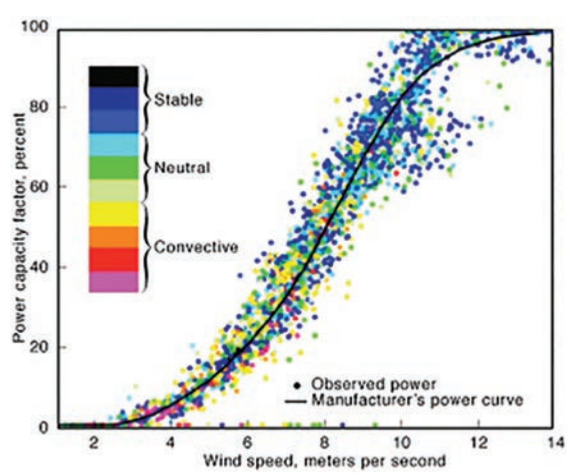
Accurate Predictions, Lower Costs for Everyone

Taken together, the field observations, simulations, and statistical modeling are significantly improving wind power predictions. LLNL is sharing this work with the wind industry and governing bodies to help them refine their power curves and incorporate findings about what atmospheric processes are important in wind power forecasting. With improved models, wind farm operators will know how to better maximize their sizable investments, more skillfully bid into the energy market, and plan new development.

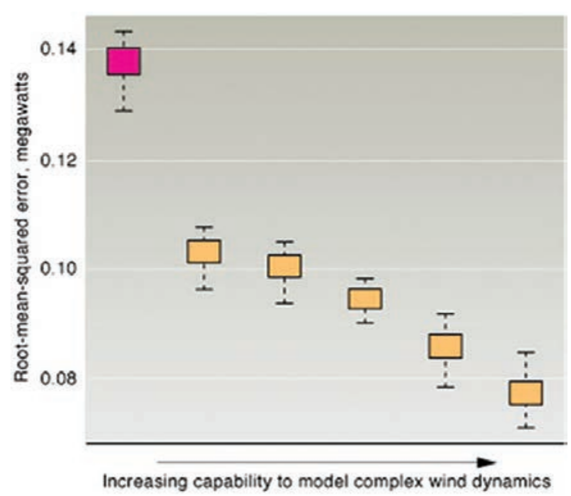
Read the full article, *Predicting Wind Power with Greater Accuracy*, at *str.llnl.gov/april-2014/miller*

SNL Researchers Assess Wind Turbine Blade Inspection and Repair Methods

Flaws in wind turbine blades emanating from the manufacturing process are an important factor in blade reliability. Blade failures can cause extensive down time and lead to expensive repairs, which increase both cost and cost-uncertainty for manufacturers and wind farm operators. Augmenting this risk, over the past decade, blades have become larger and relatively lighter with the use of carbon fiber. Because of the opacity of carbon fiber, it is not possible



Wind turbine manufacturers typically provide operators with a simple power curve, which shows power from the turbine as primarily the cube of hub-height wind speed. However, LLNL researchers are showing that power curves frequently err by 50% of actual power output, as seen in this plot of observed power versus wind speed at a northern California wind farm. The color map relates atmospheric stability conditions to reported power-output observations.



As statistical models account for increasingly complex information about wind dynamics, the root-mean-squared error associated with predicted power output from a wind turbine decreases significantly. LLNL researchers used lidar data as input to five power curve models (gold squares) and compared their results with a manufacturer's power curve (pink square) for a number of data sets. The power curve models incorporating successively more information about wind dynamics tended to have a much lower prediction error.

to visually inspect the blades, placing increased requirements on inspection technology to ensure their quality and reliability. To reduce uncertainty in the blade manufacturing process and improve their design and performance, the U.S. Department of Energy's Sandia National Laboratories (SNL) is working with industry to evaluate nondestructive inspection (NDI) technologies. There are many different types of NDI technologies including, but not limited to, ultrasonic, microwave, shearography, and thermography. As the name implies, NDI techniques are used as a means to evaluate the integrity of the blade while avoiding a destructive test such as cutting the blade cross section.

NDI requirements, methods, and practices currently vary widely within the wind industry. Different blade manufacturers and blade service companies use different NDI methods on blades in the factory and in the field,

Wind turbine blade nondestructive inspection evaluation panels in production. *Photo from SNL*

leading to uncertainty in the actual condition of the blades. A rigorous, statistical evaluation of NDI capabilities is a key step in SNL's efforts to improve blade reliability.

In 2010, SNL formed the Blade Reliability Collaborative (BRC) to bring together industry, labs, and academia to address current and emerging issues regarding wind turbine blade failures. Through the knowledge gained from the BRC, SNL scientists have now created the world's first set of wind turbine blade inspection panels and begun an experiment to quantify the performance of conventional and advanced inspection systems.

Based on extensive input from industry reviewers, the researchers designed the panels to replicate critical wind turbine blade structures, but with carefully designed flaws embedded in them. The first test campaign, Wind Inspection NDI Experiment (WINDIE), used a set of panels that contained flaw types, sizes, and locations that were known by the inspection technicians. This allowed manufacturers to screen and improve existing NDI technologies. WINDIE was completed in 2014. A follow-on probability of detection test campaign is ongoing and uses a set of panels that contain flaws of which the inspection technicians are not aware. This allows researchers to quantify the NDI technologies' flaw detection abilities. By studying NDI technologies' effectiveness and improving them, the results of these experiments will reduce uncertainty in the blade manufacturing process, improving the design and manufacturing of wind turbine blades. The results will also inform how blade inspections are conducted at manufacturing facilities and wind farms, thereby improving maintenance and repair procedures for wind turbine blades.

SNL is actively seeking participants for the probability of detection experiment from NDI technology vendors, blade service companies, and blade manufacturers in this study. To learn more about SNL's Blade Reliability Collaborative and its NDI inspection technologies research, visit: *energy.sandia.gov/energy/renewable-energy/wind-power/materials-reliability-standards/blade-reliability-collaborative/*

Wind Concurrent Cooling Could Increase Power Transmission Potential by as Much as 40%

Researchers at the U.S. Department of Energy's (DOE's) Idaho National Laboratory (INL) are working with industry to model wind's cooling effects on power transmission lines to dynamically couple transmission systems with concurrent cooling processes. In areas where wind farms are being developed, there is potential to take advantage of concurrent cooling—in which wind enables wind farms to produce power while cooling nearby transmission lines. Concurrent cooling helps power companies transmit greater amounts of electricity along power lines, increasing transmission capacity limits and reducing costs for power companies and wind facilities.

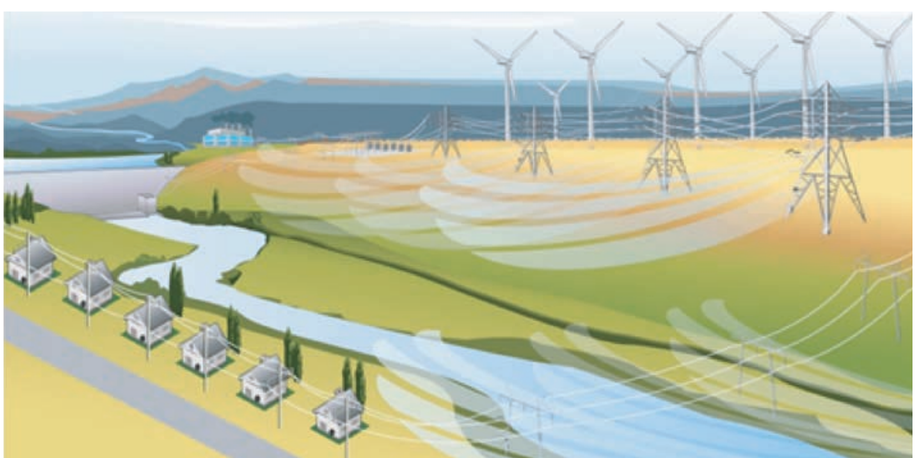
INL and the Idaho Power Company are gathering data from more than 40 weather stations positioned along 450 miles of transmission lines in windy southern Idaho. The data gathering targets two 230-kilovolt (kV) and two 138-kV lines, plus 345-kV and 500-kV lines within the 2,400-square-mile testing area. Using computational fluid dynamics (CFD) software, INL researchers are analyzing airflow and environmental data at these locations to measure how temperature and other weather conditions affect power lines.

The researchers first used the Institute of Electrical and Electronics Engineers' 738 Standard for Calculating the Current-Temperature Relationship of Bare Overhead Conductors, and a commercially available CFD program called WindSim, in their analysis. They then developed a new tool called General Line Ampacity State Solver (GLASS), which aggregates real-time data, system models, CFD model results, and physics-based calculations to estimate how wind flow impacts concurrent cooling of power lines. GLASS's reliable data will help transmission owners and operators better understand the benefits of concurrent cooling and the potential for increasing electrical transmission.

"Concurrent cooling depends on a complex relationship between the transmission system configuration and wind speed, wind angle of incidence, solar radiation, and ambient air temperature, but can create conditions that permit 10% to 40% additional usable transmission capacity," said Jake Gentle, an INL power systems research engineer. "Power companies typically use a conservative static rating system to decide how much power to transmit on their lines. Concurrent cooling, also known as dynamic line rating, enables utilities to operate their existing transmission systems more efficiently, reduce transmission congestion, and support wind integration."

"Manipulating transmission systems based on changing environmental conditions has proven to be advantageous for operations," said Mike West, another INL wind power researcher. "The unique approach that INL is developing links live weather conditions with CFD to safely transmit power above the static rating."

While continuing to validate their approach, Gentle and his colleagues are refining their CFD models and a dynamic line rating methodology that uses detailed weather, line loading, and conductor temperature information to speed up the models and data analytics and improve forecast accuracy in complex terrain environments. They are also working with power companies to train their personnel in generating transmission capacities and operating limits to move toward coupling transmission systems dynamically with concurrent cooling processes.



In areas where wind farms are being developed, there is potential to take advantage of concurrent cooling—where wind enables wind farms to produce power while also cooling existing transmission lines. *Photo from Idaho National Laboratory*

"This type of technology is a win-win for the industry because we are able to make better use of existing transmission infrastructure at the times we need it the most, when the wind is blowing the hardest," said Charlton Clark, DOE's program manager for grid integration in the Office of Energy Efficiency and Renewable Energy Wind and Water Power Technologies Office.

America's electrical grid has more than 160,000 miles of high-voltage power lines, which requires modernization and expansion to service the demand for electricity in the 21st century.

Read more about INL's research in *Windpower Engineering & Development* *www.windpowerengineering.com/featured/business-news-projects/adjusting-weather-conditions-helps-power-transmission/*

U.S. Leads International Collaborative to Address Wind Energy Development/Wildlife Challenges

The U.S. Department of Energy (DOE) is leading a new International Energy Agency (IEA) Wind Task to address concerns about the environmental effects of wind energy technology.

Task 34, also known as WREN (Working together to Resolve Environmental effects of wind eNergy), focuses on two key activities: developing an online platform to facilitate the broad sharing of information about the impacts of wind energy deployment and expedite collaboration; and developing white papers on environmental topics that are of importance to the large-scale deployment of wind energy.

DOE's Pacific Northwest National Laboratory (PNNL) is developing the online platform, WREN Hub, which will house all WREN-related information and serve as a central location accessible to both WREN member nations and the public. Built off of Tethys, an existing online knowledge management system developed by PNNL, WREN Hub will be a repository for key scientific papers, reports, and other literature on the environmental challenges pertaining to land-based and offshore wind energy development. Other key features of WREN Hub will include a calendar of upcoming meetings, webinars, and related events of interest to wind stakeholders; a repository for materials from WREN-sponsored events; and information on existing regulatory frameworks for a range of countries.

White papers will be developed by researchers in the WREN member nations to advance understanding of the wind energy community's global concerns. The first white paper will explore the successes, challenges, and risks associated with the use of adaptive management in monitoring and mitigating impacts to wildlife at land-based and offshore wind energy projects around the world. Based on real world examples, the paper will focus on technical, financial, and operational aspects of adaptive management. Potential future topics include the challenge of extrapolating from individual effects on wildlife around wind farms to population impacts, and reconciling the climate mitigation, water savings, and other global environmental benefits of wind energy with its local impacts on wildlife and habitat.

DOE's National Renewable Energy Laboratory is acting as operating agent for the new task, and member nations include Germany, Ireland, the Netherlands, Norway, Switzerland, and the United Kingdom. Several other countries have expressed strong interest in joining this collaborative.

To learn more, visit the IEA Task 34 website at *www.ieawind.org/task_34.html*

Wind Events

2015 Iowa Wind Power Conference and Iowa Wind Energy Association Midwest Regional Energy Job Fair
West Des Moines, Iowa—June 2–3, 2015
www.iowawindenergy.org/conferencesignup.php

North American Wind Energy Academy 2015 Symposium
Virginia Tech
Blacksburg, Virginia—October 15–7, 2015
www.energy.gov/eere/wind/events/north-american-wind-energy-academy-2015-symposium

Small Wind Conference 2015
Stevens Point, Wisconsin—June 15–17, 2015
www.smallwindconference.com/

The Energy Fair
Midwest Renewable Energy Association
Custer, Wisconsin—June 19–21, 2015
www.midwestrenew.org/energyfair

AWEA Offshore WINDPOWER 2015 Conference & Exhibition
Baltimore, Maryland—September 29–30, 2015
www.awea.org/events/event.aspx?eventid=31812

Photo front cover: The Wind Vision Report.
Photo illustration by Joelynn Schroeder, NREL

Stay current on important wind energy events around the United States by subscribing to the Wind Program Newsletter by email. *wind.energy.gov/subscribe.html*

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DOE/GO-102015-4597 • May 2015