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Wind R&D Newsletter

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New Reference Turbine Model Accelerates Development of Larger, Cost-Competitive Offshore Wind Systems

Multimegawatt reference turbine expands capabilities to assess technology for ever-larger and lower-cost designs

Improvements to wind turbine designs can range from incremental component enhancements to dramatic innovations that change entire systems. How can researchers collaborate with industry to more rapidly develop new, high-performance, cost-competitive turbines, or modify existing turbines, without compromising proprietary information? Reference wind turbines—open-access designs of complete wind turbine systems with supporting models for simulation and design tools—make it possible to evaluate the performance and cost of proposed modifications, relative to a well-known and understood reference point, before prototype development.

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Robotic Systems Improve Blade Reliability

Sandia National Laboratories' ARROW[(e)] system brings automated, high-tech wind blade inspections to the field

Wind turbine blades are the largest single-piece composite structures in the world, with some now exceeding the length of a football field. They undergo hundreds of millions of fatigue cycles during their life and are often located in remote areas, such as ridgelines or offshore platforms located many miles from the coast.

Ensuring the reliability of these skyscraper-sized structures over their lifetime is a difficult challenge—these blades can't be sent to a hangar in the same way airplanes and helicopters can when it's time for maintenance. Inspections are performed either with telephoto cameras from the ground or using aerial drones. These methods are reasonably good at finding visible damage but currently lack the ability to detect early, hidden damage.

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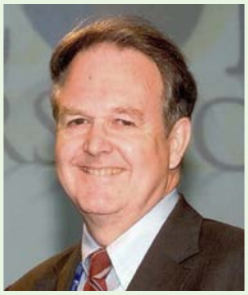
Letter from the Wind Energy Technologies Office Director



Robert C. Marlay

The U.S. wind energy industry continues its impressive run of growth over the last two decades. In late 2019, the U.S. Energy Information Administration reported that wind energy had become the number-one renewable electricity generation source in the country. This achievement, of course, may be attributed to the collective effort of many important players, including state and local officials, industry and investors, policy and regulatory officials, and other stakeholders.

But for those who know the historic course of wind technology's advancement, including the dramatic improvements in scale, cost, and performance, one must also share credit with the technical leadership and sustained research and development (R&D) of the U.S. Department of Energy (DOE), its National Laboratories and research partners, and its Wind Energy Technologies Office (WETO) within DOE's Office of Energy Efficiency and Renewable Energy.

This newsletter issue features some of WETO's recent R&D activities, which highlight partnerships with the National Laboratories and industry. WETO accomplished its goals for 2019, is on track to do the same for 2020, and plans to continue to be a driving force for innovation well into the future. Please take a moment to read about some of these ongoing R&D efforts:

- Research that demonstrates the commercial viability of cost-competitive carbon fiber composites tailored for use in wind turbine blades.
- An assessment of the degree to which wind and solar have influenced wholesale electricity prices.
- Crawler robots that are being deployed to detect subsurface damage on wind turbine blades before it becomes visible.
- A 15-megawatt (MW) reference wind turbine that expands capabilities to assess offshore designs.
- International efforts to apply utility-scale wind turbine innovations to smaller-scale distributed wind turbines.
- Ultrasonic acoustic deterrents to protect bats from wind power plant operations and boost conservation efforts.
- Workforce development efforts, like DOE's Collegiate Wind Competition, which are working to reduce the wind energy workforce gap.

These highlights are part of a comprehensive DOE R&D portfolio that includes 14 competitively selected research projects for offshore, land-based, and distributed wind, which recently got underway, as well as $20 million in new funding for offshore wind resource characterization and technology demonstration announced this spring.

On behalf of everyone at WETO, it's our pleasure to be working with many of you toward the continuing advancement of wind energy through research and innovation.

Sincerely,

Robert C. Marlay, Ph.D., P.E.
Director, Wind Energy Technologies Office

The new IEA Wind 15-MW reference wind turbine model addresses major advancements in the scale and features of turbines under development. This permanent-magnet, direct-drive, horizontal-axis offshore turbine has a conventional three-bladed upwind design with a rotor diameter of 240 meters (m); a 150-m hub height; a variable-speed, collective pitch controller; and a low-speed, direct-drive generator. The baseline support structure is a steel monopile sized at a 30-m water depth. *Graphic by Joshua Bauer, NREL*

New Reference Turbine Model *continued from page 1*

Since its release in 2005, a 5-MW reference wind turbine created by DOE's National Renewable Energy Laboratory (NREL) has proven invaluable to designers and researchers around the world. Additional reference wind turbines have been released by others since then, but the scale and features of turbine technology currently under development have advanced beyond the limits of these models.

Now, a new open-source reference wind turbine can be used to assess designs for offshore turbines up to 15 MW. This new reference wind turbine was developed by NREL, with funding from WETO, in collaboration with the University of Maine and the Technical University of Denmark through the International Energy Agency Wind Technology Collaboration Programme (IEA Wind) Task 37 on Systems Engineering in Wind Energy. It is available alongside two other open-source reference wind turbines recently completed by the IEA Wind Task 37 effort: a 3.35-MW land-based design and a 10-MW offshore design.

"As technology continues to evolve, having an IEA Wind task to coordinate international efforts to produce designs that keep up with or ahead of the pace of industry developments is crucial," said John McCann, IEA Wind chair. "This IEA Wind task enables relevant research on wind turbine systems analysis, component design innovation, controller development, and more."

In addition to their larger size, today's turbines have migrated toward lower-speed drivetrains, heavier rotors and nacelles, and lower specific power than those found in other reference wind turbines. Previous reference wind turbine designs were not meeting industry's current needs given recent trends in blade scaling, floating foundation design, wind plant control, logistic studies, and other capabilities. Offshore wind turbines also face distinct installation and maintenance challenges that were insufficiently addressed by earlier reference wind turbines.

"While there's been a lot of success over the years with existing reference turbines, they're no longer representative of the state-of-the-art or near-future turbine technology," said NREL postdoctoral researcher Evan Gaertner, who led the design effort.

The use of computer-based reference turbine models enables rapid and robust evaluation of new technologies against a well-defined baseline, accelerating higher-risk technology development. The new IEA Wind 15-MW reference wind turbine includes detailed design of major turbine subsystems (e.g., rotor, drivetrain, tower, foundation) and components (e.g., blades, generator, shaft, nacelle), plus mass summaries of smaller components (e.g., pitch and yaw motors), to enable the assessment of innovations at the wind plant, wind turbine, and subcomponent levels.

The IEA Wind 15-MW configuration was chosen to ensure that the new reference wind turbine's capabilities advance beyond those of the 10-MW to 12-MW turbines already in development by industry, but are similar enough to serve as a baseline for 15-MW to 20-MW next-generation designs and act as a valuable development resource for the foreseeable future.

"Offshore wind turbines have eclipsed the current slate of reference turbines in terms of size and utility," said Garrett Barter, NREL senior research engineer and project principal investigator. "We needed a new reference turbine to leap ahead of where industry is today—but not so far ahead that you'd need advanced technology to get there."

Offshore installations can capture high wind speeds close to population centers, with abundant resources approximately two times the combined generating capacity of all U.S. electric

> *The IEA Wind 15-MW reference wind turbine accommodates multiple software models and will provide a public domain tool for designing next-generation offshore wind turbines.*

power plants. However, complex construction and maintenance logistics for these systems pose challenges to making them cost competitive with land-based systems. The new reference wind turbine lets researchers and designers assess options for a fixed-bottom monopile support and a floating, semisubmersible support structure.

"We're seeing the first steel go into the water for fixed-bottom foundations," Barter said. "Hopefully, a commercial floating offshore wind project in the United States will come to fruition in the next 5 to 10 years."

The 15-MW reference turbine accommodates multiple software models and will provide a public domain tool for designing next-generation offshore wind turbines. The new reference wind turbine can be applied to a vast range of projects, making it possible to examine the potential impact of high-level rotor design specifications, such as airfoil profiles, rotor performance, power, pitch, torque, and thrust.

The IEA Wind 15-MW reference wind turbine was developed in partnership with research organizations and industry leaders around the world. NREL led design optimization studies for the rotor, generator, drivetrain, nacelle, tower, controller, and fixed-bottom supports. The Technical University of Denmark and the European Union COREWIND project provided extensive performance and load analysis. The University of Maine contributed design of the semisubmersible floating substructure. General Electric, EDF Renewables, Senvion, Sintef, and Atkins supplied information to calibrate design assumptions and input values.

Through the open-source GitHub portal, members of the broader research and design community can access input files that support analysis tools and contribute design variants. The open-source approach to the 15-MW reference wind turbine gives industry a public-domain baseline to collaborate with researchers without exposing trade secrets. As users provide model inputs, features will be added to the repository, expanding the tool's capabilities. This approach was also successfully taken for the other two reference wind turbines, the 3.35-MW and 10-MW, recently released by IEA Wind Task 37 and also on GitHub (https://github.com/IEAWindTask37/IEA-15-240-RWT).

Interest is spreading in the 15-MW reference wind turbine, which has already appeared in multiple proposals and papers. Wind Europe is using the reference wind turbine for a floating wind project, and DOE is using it as a baseline to evaluate next-generation, lightweight drivetrain designs.

"The IEA Wind 15-MW reference wind turbine represents the future of offshore wind in the United States and worldwide, both near shore and in deep water," Gaertner said. ■

Robotic Systems Improve Blade Reliability *continued from page 1*

However, recent innovations in robotics may allow for a pathway to introduce low-cost, high-tech inspections to the market: inspections that can detect deep, subsurface damage.

The DOE Sandia National Laboratories-led Blade Reliability Initiative, funded by WETO, builds upon Sandia's decades of aviation development experience. On the project, Sandia teamed up with International Climbing Machines (whose portable, remote-controlled devices can scale vertical or inverted surfaces) and Dolphitech (developers of advanced

Sandia National Laboratories researchers use crawling robots and drones with infrared cameras to look for hidden damage to keep wind turbine blades operating longer and drive down the costs of wind energy.
Photo: Randy Montoya, Sandia National Laboratories

ultrasound cameras for two-dimensional and three-dimensional inspection of materials) to design, build, and validate a crawling robot to conduct automated, full-penetration inspections of wind turbine blades.

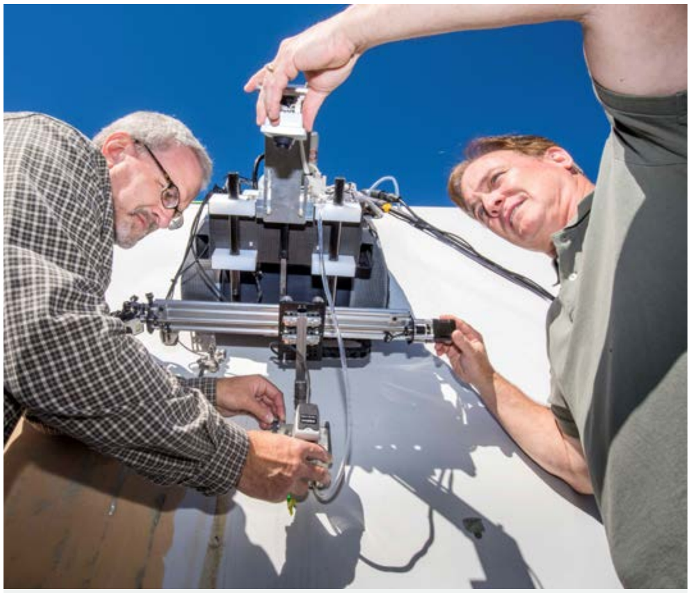
Controlled by an operator, the Assessment Robot for Resilient Optimized Wind energy, or ARROW[e], is deployed from the turbine nacelle and suctions itself to the vertical surface of a blade, crawling to where it is needed. Onboard cameras provide real-time, high-fidelity images to detect surface damage while phased-array ultrasonic imaging finds any nonvisible, subsurface damage.

“Autonomous inspection is going to be a huge area, in general, and it really makes sense in the wind industry given the size and location of the blades,” said Sandia Project Lead Josh Paquette. “I can envision each wind plant having a drone or a fleet of drones that take off every day, fly around the wind turbines, do all their inspections, and then come back and upload their data. Then, autonomous inspection systems look for differences in the blades based on previous inspections and note potential issues. An operator can then deploy a robotic crawler onto a blade with suspected damage to get a more detailed look and plan repairs.”

Dennis Roach, Sandia senior scientist and robotic crawler project lead, says that a phased-array ultrasonic inspection can detect damage at any layer inside the thick, composite blades.

“Impact or overstress from turbulence can create subsurface damage that is not visually evident,” Roach said. “The idea is to try to find damage before it grows to critical size and allow for less expensive repairs that decrease blade downtime. We also want to avoid any failures or the need to remove a blade.”

Future implementations of this technology could include the ARROW[e] inspection crawlers automatically moving to locations after results from visual inspections or service advisories from manufacturers indicate a need. The results of the inspections could also be viewed and analyzed by remote experts, much like a radiologist reviews patient X-rays or MRIs in today’s healthcare industry.



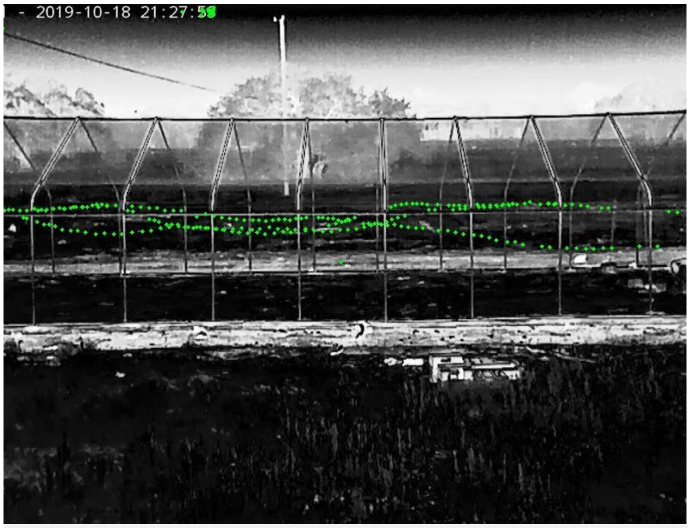
Tom Rice, left, and Dennis Roach, right, of Sandia National Laboratories set up a crawling robot to inspect a wind turbine blade segment.
Photo: Randy Montoya, Sandia National Laboratories

Roach said a large benefit of the ARROW[e] device is that it can automate phased-array ultrasonic inspections to detect surface and subsurface damage anywhere through the thickness of the blade. “In doing so,” he said, “it eases the reliance on expert inspectors to deploy the equipment.”

Sandia already demonstrated the technology at the Wind Turbine Blade Service & Maintenance conference in Dusseldorf, Germany, in late 2019. The next step is to deploy the robots in the field to complete the assessment of their viability to inspect all aspects of wind turbine blades. These tests will ensure their accuracy, repeatability, and ease of use. Once proven, the prototype system will be transferred to industry for widespread deployment. ■

Which Bats Steer Clear of Wind Turbine Deterrents—and When?

Flight-path monitoring aims to determine the effectiveness of ultrasonic acoustic deterrents



Preliminary field trials have demonstrated a new flight tracking method capable of measuring how various bat species behave in the presence of ultrasonic acoustic deterrents. The green dots show the flight track of an individual bat. The researchers must use four thermal camera images like the one shown here to cover the entire length of the flight cage. *Image by Brittany Stamp, Texas State University*

Technologies that can reduce impacts to bats, birds, and other wildlife not only boost species conservation efforts, but also the efficiency and productivity of wind power projects. DOE supports this environmental win-win with research efforts developing technological innovations that can detect and deter wildlife from approaching wind turbine blades.

Researchers at DOE's NREL are gaining new insights into one such solution—the use of ultrasonic acoustic deterrents (UADs)—as part of that larger effort.

The intent of UADs is to discourage bats from approaching wind turbines by emitting sounds tuned to the range of hearing for bat species found in the United States and Canada. These devices, which are typically mounted on the nacelle of a standard turbine, may offer wind energy facilities a more cost-effective solution for impact reduction than curtailing operations, or shutting down turbines, when the season and weather conditions indicate that bats may be likely to fly near wind turbines.

Preliminary laboratory and ground-based studies have demonstrated that UADs reduce wind-wildlife impacts for certain bat species. Based on this evidence, operational facilities are already installing UADs to help minimize fatalities. However, additional research is needed to understand variations in the technology's effectiveness that could be related to ultrasound frequencies, weather effects, and behavioral differences among bat species.

"This is a unique opportunity to study the effectiveness of UADs at the species level," said Cris Hein, the project's principal investigator and a senior researcher at NREL. "We need to take a closer look at bat behavioral responses to optimize the effectiveness of UADs for as many species as possible."

Along with Bat Conservation International, Texas Christian University, Texas State University, Bowman Consulting, Wildlife Imaging Systems, NRG Systems (the designer and manufacturer of the UAD being evaluated), and a leading wind power plant operator, the NREL-led project team developed a new experimental approach to measure UAD effectiveness. Specifically, the team constructed an open-air flight cage that is 60 meters (m) long, 10 m wide, and 4 m high, then covered it with netting. The researchers also developed software that identifies a bat as it flies back and forth in the cage, tracking and recording its movement. The resulting data allow for a quantitative analysis of bat behavioral responses relative to various UAD treatments.

NREL researchers are gaining new insights into the use of UADs as part of a larger effort to reduce impacts to bats, birds, and other wildlife to boost species conservation as well as the efficiency and productivity of wind power projects.

"We learned a lot from the preliminary trials conducted last fall when we built the cage and set up cameras to test the logistics," said Hein. "Now we have a really good system in place, thanks in no small part to the grad students at Texas State University."

The project team brings together a range of expertise in physics, biology, and technology, as well as representatives from government, academia, and industry. More flight trials

Members of the project team assemble an open-air flight cage on the campus of Texas State University. *Photo by Rob Tyler, Texas State University*

will be conducted at the Texas State campus this summer and fall, which will coincide with times when bat fatalities are highest at wind facilities.

"We think UADs can offer an effective solution, but we also know there is room for improvement," said Hein. "In the future, we may need a combined approach, including blade-mounted deterrents, a dim ultraviolet light source, or curtailment during times of highest risk to further minimize wildlife impacts."

By identifying the best wind-wildlife impact-minimization technologies for each wind project, research efforts like this enable the deployment of more efficient, cost-effective, and bat-friendly wind energy projects across the United States. ■

Innovative Carbon Fiber Materials Enable Longer Blades, Greater Energy Capture than Traditional Fiberglass

Study blows a hole in the theory that wind turbine manufacturers have avoided carbon fiber materials because of their high cost

The wind industry operates in a cost-driven market, meaning developers, manufacturers, and customers focus on bottom-line costs and how to do more but spend less. By contrast, the aerospace industry operates in a performance-driven market, where the focus is on high performance, with cost being important but secondary.

An example of how cost vs. performance can drive decisions in these two industries lies in the primary structural material each one uses to manufacture its products. Fiberglass is the primary structural material used in wind turbine blade manufacturing, whereas the aerospace industry uses carbon fiber materials in its military applications and airplanes.

Carbon fiber has well-known benefits for reducing wind turbine blade mass because of its significantly enhanced properties of stiffness and strength compared to fiberglass. However, the high relative cost of carbon fiber materials, originally developed for the aerospace industry, has prohibited broad adoption of their use within the cost-driven wind industry.

Carbon fiber is considered a key technology to enable the continued growth in wind turbine blade length for the land-based and offshore machines of the future. *Photo by Werner Slocum, NREL*

Now, the Optimized Carbon Fiber Project, funded by WETO—and implemented by researchers at DOE's Sandia and Oak Ridge National Laboratories and Montana State University—has demonstrated the commercial viability of novel, cost-competitive, carbon fiber composites derived using precursor material from the textile industry. The project also found system-level benefits for using carbon fiber composites to reduce the levelized cost of wind energy resulting from the lower mass and ability to design long, slender wind turbine blades.

"As wind turbine blades get longer, they become much more massive," said Brandon Ennis, principal investigator at Sandia. "Controlling blade mass is critical to allowing further growth in rotor size and reduction in the levelized cost of wind energy. Carbon fiber is an enabling technology for accomplishing these objectives, which will support increased wind energy deployment across the United States."

Ennis said the team's research demonstrates the significant opportunity for innovation in carbon fiber development to produce materials better suited for the unique loading demands of wind turbines.

"The textile carbon fiber material we studied performed at a higher value compared to existing commercial materials, and this type of material would enable broader adoption of carbon fiber into wind turbine blade designs, creating a larger market for fiber manufacturers," he said.

In the Optimized Carbon Fiber Project, researchers compared a novel, heavy-tow carbon fiber (i.e., more carbon filaments in each bundle of fibers), a baseline commercial carbon fiber material, and fiberglass. The study characterized each of these materials using a validated cost model and mechanical testing (for static tensile and compressive strengths and fatigue) in 3-MW and 10-MW land-based and offshore reference wind turbine models.

Compared to the commercial baseline carbon fiber, mechanical testing results show that the heavy-tow carbon fiber material:

- Performs with similar stiffness but at nearly 40% reduced tensile strength
- Is similar in compressive strength—with only a 20% reduction.

When compared on a cost-specific basis to the commercial baseline carbon fiber, the heavy-tow carbon fiber material:

- Has 100% more stiffness
- Performs with 56% more compressive strength.

In wind turbines, compressive strength matters more than tensile strength and drives demand for the type of material used; regardless of material performance, the final cost is typically the determining factor for material selection by the wind industry.

The study also revealed a 25% blade mass reduction when spar caps were made using either of the carbon fiber materials rather than fiberglass, highlighting the value of carbon fiber materials. The spar cap material costs for wind turbine blades with spar caps using the heavy-tow textile carbon fiber are 40% less than blades whose spar caps were made from the baseline commercial carbon fiber.

Visit the Sandia website to download a copy of the report and learn more about Sandia's research. ■

Mind the Wind Workforce Gap

Ensuring today's students meet tomorrow's wind energy workforce needs

In the past decade, U.S. wind power has tripled, becoming the largest source of renewable generating capacity in the country. Maintaining this strong growth trajectory requires an equally strong wind energy workforce—but it's not merely a question of labor supply and demand. According to a report from NREL, "The Wind Energy Workforce in the United States: Training, Hiring, and Future Needs," there are other dynamics at play.

For example, hiring managers in the wind industry have trouble finding qualified applicants to fill vacant positions. And, though students are seeking education tailored to careers in the wind industry, they're struggling to get hired.

The Collegiate Wind Competition is one of the ways that DOE is working to bridge a potential wind energy workforce gap. Above, a student from James Madison University installs his team's turbine in the wind tunnel for a test during the CWC 2019 Technical Challenge. *Photo by Werner Slocum, NREL*

NREL researchers reviewed modeling scenarios from DOE's Wind Vision report to pinpoint education and training program needs. They found that providing 20% of electricity generation from wind by 2030 would require at least 570 new training programs to educate potential workers and reduce a wind workforce gap. They also surveyed nearly 250 wind industry employers and 50 educational institution representatives, and an analysis of responses found that:

- More than two-thirds (68%) of those surveyed reported some or great difficulty finding qualified applicants across most wind energy occupations.
- Twenty-five percent of firms looked outside the United States for candidates with the necessary skill set and experience to fill a position.

- Most students graduating with degrees from wind industry education programs ultimately landed employment outside the wind energy industry.
- Those who manage renewable energy education and training programs reported difficulties in filling their courses.

WETO is working to effectively bridge this wind workforce gap through activities such as the Collegiate Wind Competition (CWC) that NREL manages on behalf of DOE. Since 2014, the competition has challenged undergraduate students from multiple disciplines to design, construct, and test a wind turbine and participate in project development-related design activities. The CWC inspires tomorrow's best and brightest wind energy minds to develop solutions to real-life energy challenges, putting their book learning to the test in real time.

Puerto Rico's Team Juracán competed in their third CWC in 2019. Because of their experiences following Hurricane María, the students were inspired to go above and beyond the competition requirements to develop real-world solutions that could save lives in the aftermath of a natural disaster. They chose to focus their efforts on providing backup energy to hospitals following a natural disaster.

"We chose locked-out regions that have no connections to anything when disasters happen—no food, no water, no electricity, no internet or way to communicate with anyone," said Luis Rafael Miranda Rodríguez, the team's mechanical division lead. "We also wanted to focus on something tangible, like a shelter technology that could power small refrigerators for medications like insulin."

Ultimately, the team built a prototype based on a simple 400-kilowatt turbine, employing an innovative resin to coat the turbine so that the blade best fit the island's wind profile.

"Students who participate in the CWC gain real-world experience that gives them a competitive edge in gaining wind energy industry employment after graduation," said NREL's CWC Project Lead Elise DeGeorge. "The CWC also allows industry to follow the teams' innovations and inspire future wind industry workers. In other words, it's a win-win for students and the industry."

Building a better wind energy workforce for tomorrow starts with inspiring young innovators today. ■

Labs Coordinate To Protect Wind Power from Cyberattacks

As wind generation increases, cybersecurity efforts will add resilience to critical infrastructure

A wind turbine hacked on the ground or through the internet could serve as an access point for cybercriminals to attack large-scale electricity infrastructure. *Graphic by Jake Gentle, Idaho National Laboratory*

More than 50,000 wind turbines with a combined capacity of about 100 gigawatts operate in the United States, providing more than 7% of the nation's electricity in 2019. However, the current state of cybersecurity readiness at U.S. wind power plants is generally behind in comparison to other types of large-scale power generation, such as coal and nuclear power plants.

To increase the resilience of critical wind infrastructure in the United States, researchers at DOE's Idaho National Laboratory (INL) are leading several research efforts funded by WETO.

The collaboration among industry and researchers from four DOE National Laboratories—INL, NREL, Sandia, and Pacific Northwest National Laboratory (PNNL)—also seeks to explore how wind energy could reliably and resiliently contribute to military and disaster-relief applications.

"As wind generation in the United States continues to grow, it becomes more of a critical generating asset of our bulk electric system," said Jake Gentle, a senior power systems engineer at INL. "This is why protecting U.S. wind infrastructure from cyberattacks is so important to safeguarding our entire electric system."

Cybersecurity researchers have shown that individual turbines are vulnerable to physical and electronic attacks that could disable or damage turbines or an entire wind plant. A wind turbine hacked on the ground or through the internet could serve as an access point for cybercriminals to attack large-scale electricity infrastructure.

In 2019, researchers at the four participating National Laboratories kicked off five related research projects that will make wind energy more secure now and in the future:

1. WETO's Roadmap for Wind Cybersecurity. This project lays out a strategy that DOE will use to guide future R&D investments in partnership with industry, outlining strategic priorities based on the National Institute of Standards and Technology's cybersecurity framework. The project team is also developing a proof-of-concept prototype for tactical military applications.

2. Microgrids, Infrastructure Resilience, and Advanced Controls Launchpad (MIRACL). The MIRACL project looks at securing distributed wind facilities, such as defense applications, rural communities, university campuses, and hospitals. The project focuses on wind infrastructure control systems and wind generation in the context of microgrids and hybrid distributed energy systems.

3. Defense and Disaster Deployable Wind Turbine (D3T). D3T could provide deployable energy in a secure system for military applications and disaster relief in conjunction with solar, storage, and other sources of energy.

4. Hardening Wind Energy Systems from Cyberthreats. This project helps secure wind energy technologies by protecting wind communication networks and constructing intrusion-detection systems. These techniques will be shared broadly with the wind industry to defend communication systems from cyberattacks and detect when these attacks occur.

5. Deployable Advanced Renewable Power System (DARPS). DARPS is a deployable 31-kilowatt wind/battery hybrid system that can be quickly installed without additional equipment or infrastructure. DARPS will have microgrid capabilities so it can operate in grid-connected or isolated off-grid modes.

"Renewable energy sources, including wind technology, are poised to alter the generation makeup of the electric grid in the future," said Sarah Freeman, an industrial control system cybersecurity analyst at INL. "This shift, however, requires that these resources remain resilient in the face of cyberattacks. This work aims to ensure the reliability of wind generation."

WETO's Roadmap for Wind Cybersecurity outlines a strategy that DOE will use to guide future R&D investments in partnership with industry.

Together, these projects will allow National Laboratories and industry to conduct R&D and implement technologies in a way that makes wind energy more secure. ■

Working To Ensure Wind Is Part of Distributed Energy Future

International team examines solutions to make wind systems competitive in the distributed energy market

The market for on-site, distributed solar photovoltaic installations has boomed in recent years, generating behind-the-meter energy at an affordable cost for homes, businesses, campuses, and industrial customers. Now, through a project called Enabling Wind to Contribute to a Distributed Energy Future, experts from around the world are exploring how wind energy can be successfully applied to this same distributed energy model.

IEA Wind has convened a team of global experts, led by researchers from DOE's NREL and PNNL, to study how wind energy can benefit distributed energy systems under IEA Wind Task 41.

While innovations have significantly decreased installation and operating costs for utility-scale wind power plants, smaller-scale distributed wind systems have not experienced the same cost reductions, limiting wind's role in the developing distributed energy market. At the same time, utilities, communities, and nations are looking to distributed generation as an effective way to meet future energy needs.

"Right now, roof-mounted solar is becoming common across the United States," said NREL Deployment Manager Ian Baring-Gould, who serves as the technical director and co-lead of the IEA Wind project. "Our hope is this IEA Wind research

Wind energy technologies can be used in a broad range of distributed applications, supplying power directly to homes, farms, businesses, and communities. Research convened by IEA Wind and sponsored by WETO is exploring how the highly successful distributed energy model employed by solar can be applied to wind energy. *Photo by Rural Electric Convenience Cooperative*

will lead to a similar level of affordability and flexibility for small-scale, localized wind installations. We want to increase the reach of this clean energy technology."

Under IEA Wind Task 41, a team of global experts from 11 participating countries is studying how wind energy can benefit distributed energy systems. Researchers from DOE's NREL and PNNL lead the effort.

To become cost competitive, distributed wind technologies will require a wide range of technical and nontechnical advances. Through IEA Wind Task 41, researchers are examining a broad spectrum of solutions involving wind turbines deployed in distributed applications in behind-the-meter, in-front-of-the-meter, microgrid, and off-grid applications, and in combination with other distributed energy and energy storage technologies. Turbine sizes under consideration range from small wind turbines to multimegawatt, large-scale turbines deployed in small numbers closer to loads.

Building on national research efforts supported by the United States and other nations, the IEA Wind Task 41 team is collaborating on activities that include:

- Identifying and documenting improved ways to integrate wind energy into distributed energy systems
- Improving distributed wind turbine design standards
- Developing ways to better share data and information to expand innovation
- Broadening the understanding of distributed wind's potential benefits to wider distributed energy markets.

IEA Wind Task 41 team members pose during a break from the project's kickoff meeting at Łódź University of Technology in Łódź, Poland. Ian Baring-Gould, NREL (first row, far left) and Alice Orrell, PNNL (first row, center), lead the task. *Photo courtesy of IEA Wind Task 41*

Researchers are also exploring how the grand challenges in the science of wind energy can be applied in the context of distributed wind technologies and the global energy markets where distributed energy systems are likely to be found.

The IEA Wind project brings together research organizations from 11 participating countries in a 4-year effort. In addition to the United States, participants include representatives from Austria, Belgium, Canada, China, Denmark, Germany, Ireland, Italy, Korea, and Spain, with additional nations expressing interest.

The team has already completed an assessment of the current international standards for small wind turbines through a series of industry stakeholder sessions. Following additional meetings planned for Asia and North America, a detailed international research plan will be developed to build the research case for updating international standards. A distributed wind data catalog is also being developed, which will make information on distributed wind operational data more readily available for future international collaboration.

"We're already gaining a better understanding of the technical requirements and marketplace realities," said Baring-Gould. "We're optimistic that this will lead not just to cost savings opportunities, but to an entirely new model for wind installations." ■

Wind Is Changing Pricing Patterns in Wholesale Power Markets

In some markets, wind power is having significant impacts on the timing and location of electricity prices

Wholesale electricity prices have fallen dramatically in most organized markets in the United States over the last decade, contributing to an increase in the retirement of thermal power plants. The price drops are largely because of a steep reduction in the price of natural gas. But growth in wind and solar generation, fairly flat trends in electrical load (demand), and new natural gas power plant capacity have also played a role.

A second tier of factors [for overall marketwide average price drops in wholesale power prices] includes wind and solar generation; expansion and retirement of thermal generation; changes in demand—and more.

A new report from DOE's Lawrence Berkeley National Laboratory analyzes the drivers of price changes using two approaches. First, price dynamics between 2008 and 2017 are assessed using a supply curve model. Second, hourly wholesale prices at more than 60,000 pricing nodes are used to highlight the impacts of wind, solar, and other factors on geographic and temporal pricing patterns.

The report, "The Impact of Wind, Solar, and Other Factors on Wholesale Power Prices: An Historical Analysis—2008 through 2017," finds that falling natural gas prices were the dominant driver of overall marketwide average price drops, reducing average annual wholesale prices by $7–$53 per megawatt-hour (MWh) over the last decade. The biggest declines were found in New York and New England, but reductions were substantial across all regions.

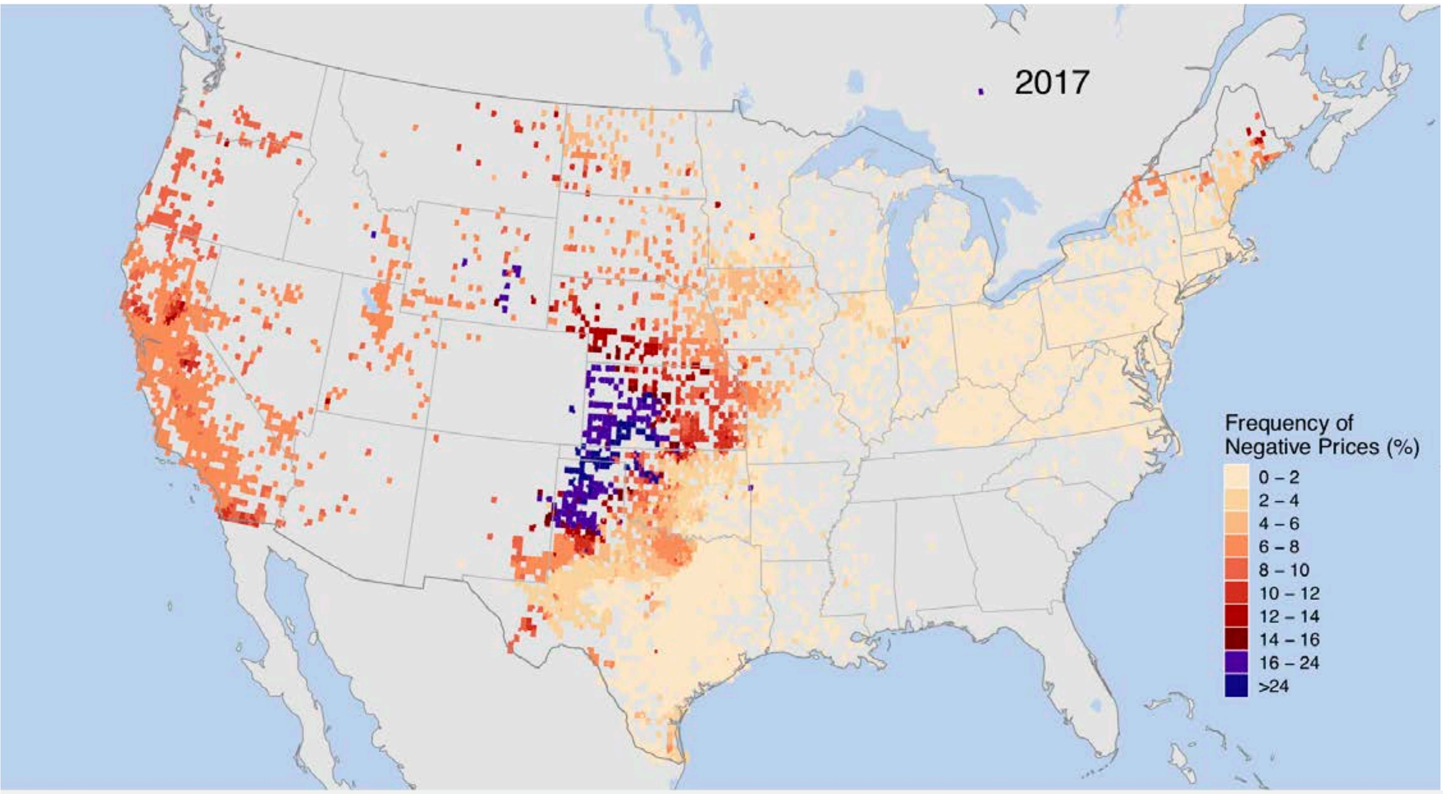


Figure 1. Frequency of negative locational marginal prices (LMPs), or real-time power prices, in 2017. This analysis determined that areas with high levels of wind and solar increased the frequency of negative prices. *Figure by Lawrence Berkeley National Laboratory*

A second tier of factors includes wind and solar generation; expansion and retirement of thermal generation; changes in demand; generator efficiency; coal prices; variations in hydropower; and emissions prices. An interactive version of data from the report is available online.

In most markets, growth in wind and solar reduced average, marketwide wholesale prices by less than $1.30/MWh over this period, although California was an exception, with solar reducing prices by $2.20/MWh. This may foreshadow greater impacts from solar in other regions as solar penetrations grow.

The analysis also looked at the impact of wind and solar on prices in specific times and places. Growth in wind and solar impacted time-of-day and seasonal pricing patterns and the frequency of negative prices, especially in areas with high levels of wind and solar and in the presence of transmission constraints (Figure 1).

Although negative price events are becoming more frequent, they vary widely by location and from year to year. Also, they have been mostly small in magnitude and have not heavily impacted annual average prices at most locations. Their biggest impact has been in parts of the Midwest in the Southwest Power Pool; in California; and in the northern areas of New York, New Hampshire, and Maine.

In 2017, negative prices decreased the average annual real-time energy price at nodes near wind power plants by about 6%, at nodes near solar plants by about 3%, and nodes near hydropower plants by about 3%. Pricing nodes near coal, gas, and nuclear plants saw a smaller reduction of about 1.5%, though those modest impacts have slightly increased over time.

Wind and solar power are just two of numerous factors that influence local pricing patterns but can be significant contributors to locational, time of day, and seasonal pricing patterns in some regions. Recent thermal-plant retirements in the United States are primarily the result of low natural gas prices, not growth in wind and solar.

These altered pricing patterns hold important implications for the grid-system value of wind and solar and related policy considerations, as well as for a host of other electric-sector operating, planning, and policy decisions related to transmission expansion and flexible supply, demand, and storage resources. ■

Buoys stationed off U.S. coasts collect meteorological and oceanographic data that can help the wind industry make informed decisions for offshore wind power plants. Feedback from industry spurred instrument upgrades that will help provide more meaningful data. *Photo by Ocean Tech Services, LLC, and PNNL*

It's No Li(dar): Buoys Equipped with More Powerful Instrumentation

$1.3-million upgrade extends lidar reach and data recovery rate; provides more accessible information

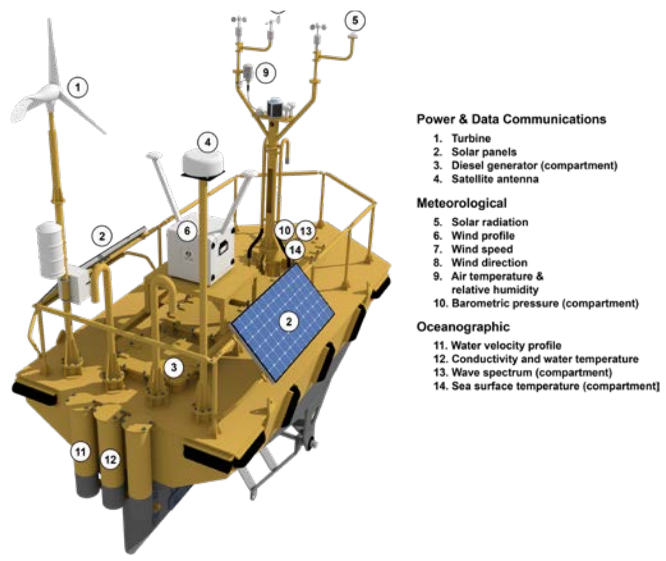
Harnessing the power of the wind blowing along the nation's coasts could potentially provide more than 2,000 gigawatts of generating capacity.

But the wind industry faces obstacles in developing offshore wind technology, including the ability to obtain wind measurements at turbine-blade height.

Over the past few years, WETO has commissioned PNNL to deploy buoys equipped with advanced scientific instrumentation off the coasts of the United States and analyze the data. The goal is to obtain meteorological and oceanographic measurements that provide the wind industry with the data needed to develop robust offshore wind plant technology while advancing the scientific understanding of offshore winds.

However, analysis of data obtained from two research buoys in 2016 and 2017 deployed off the coasts of New Jersey and Virginia found that the lidar signal was too weak to obtain satisfactory wind measurements at heights near the top of a wind turbine rotor. Without special data processing, the rate of change of the wind with height was also incorrect.

This finding spurred the wind industry to suggest instrument upgrades and best-practice validation that meets the recommended industry practices of a third-party organization. WETO, which funds much of the buoy research, listened, and a team of PNNL wind researchers led the $1.3-million upgrade.



The buoys are equipped with specialized advanced instrumentation, such as power and data communications, meteorological, and oceanographic capabilities for assessing offshore wind. Wind profile, which is #6 in the graphic, represents the lidar unit.
Illustration from Mike Perkins, PNNL

"The upgrades included more powerful lidar that reaches a height of 200 m and provides a high data recovery rate," said PNNL's Alicia Gorton, who led the effort. "Previous lidar capability reached about 90 m, which is now somewhat inefficient because offshore turbines are built much taller than those constructed and deployed 5 years ago."

Additionally, the team is moving the buoys' data management systems to an open-source environment for easier access and download of data by the wind community.

After the upgrades, the buoys were put back in the water to actively collect data as part of the validation stage. Validation involved comparing the data acquired on the buoys with data collected by a sanctioned reference lidar on the Woods Hole Oceanographic Institution Air-Sea Interaction Tower off the coast of Martha's Vineyard. The buoys, with their new lidar systems, have now been certified as compliant with published recommended practices for data recovery and accuracy.

The buoys will collect data for 1 year off the coast of California in support of the Bureau of Ocean Energy Management. ■

Funding News

DOE Awards $30 Million for Wind Energy Research, Development, and Demonstration Projects

DOE announced the selection of 14 projects to receive $30 million to advance wind energy nationwide. The selected projects span the technology development spectrum—including testing, demonstration, integration, and technical assistance—and cover all three wind energy sectors: distributed, offshore, and land-based utility-scale wind.

DOE Announces Grid Modernization Lab Call Projects

In late 2019, DOE announced the results of the latest Grid Modernization Lab Call with funding of approximately $80 million (subject to appropriations) over 3 years. This funding aims to strengthen, transform, and improve the resilience of energy infrastructure to ensure the nation's access to reliable and secure sources of energy now and in the future.

EERE Announces $21.3 Million for Small Business Innovation Projects

As part of the $53 million announcement by U.S. Secretary of Energy Dan Brouillette for Small Business Innovation Research and Small Business Technology Transfer research and development projects, the Office of Energy Efficiency and Renewable Energy (EERE) announced selection of 106 new projects across 26 states, totaling nearly $21.3 million in funding. The selected small businesses are receiving Phase I grants that demonstrate technical feasibility for innovations during the first phase of their research.

NREL Selects a New Project That Aims To Address Wind-Wildlife Operational Challenges

NREL has selected a new project to advance early-stage technologies for wildlife monitoring and minimization at wind energy facilities. This project is part of the Technology Development and Innovation program, which also provides recipients access to NREL facilities and expertise to develop emerging technologies that detect and deter birds and bats at wind plants.

DOE News

California Independent System Operator (CAISO) Shows Wind Can Play a Major Role in Renewable Integration

Large utility-scale wind power plants can provide essential reliability services to the electricity grid.

Boosting Speed and Accuracy of Wind Plant Optimization Model

NREL has released a new version of its FLOw Redirection and Induction in Steady State (FLORIS) model for wind plant performance optimization.

Energy Department Announces Participants of the 2021 Collegiate Wind Competition

DOE announced the 13 collegiate teams selected to participate in the 2021 CWC. Three new schools were selected along with 10 returning teams from previous competitions.

Wind Energy Professionals Share Tips for Breezing into the Wind Workforce

Employers report difficulty hiring well-qualified candidates to support wind industry growth while graduates have difficulty finding jobs.

U.S. Department of Energy Launches Energy Storage Grand Challenge

Energy Storage Grand Challenge will accelerate the development, commercialization, and utilization of next-generation energy storage technologies.

Sandia Patents Blade Design that Reduces Wake Effects

Sandia has developed a wind turbine blade design that would allow turbines to be installed closer to one another, due to a faster dissipating wake. The patented innovation changes how much the air slows down as it passes through the wind turbine rotor.

Offshore Wind Demonstration Aqua Ventus Project Secures Power Purchase Agreement

A DOE-funded offshore wind demonstration project proposed for deployment off the coast of Maine achieved a major milestone in December when Maine Aqua Ventus I and Central Maine Power Company signed the project's 20-year power purchase agreement, which allows the project to sell its electricity to the utility.

Addressing Wind Energy Innovation Challenges

An article in *Science* magazine, written by a team of wind energy researchers led by NREL, invited the scientific community to address three grand challenges in the physical sciences that will drive the innovation needed for wind to continue to contribute to the electricity grid as a low-cost energy source. By investing in science, research, and technology development, and rallying the scientific communities around the physical, environmental, and developmental challenges, WETO hopes for wind to reach its full potential as an environmentally sustainable source of power in the United States.

U.S. DEPARTMENT OF ENERGY | *Office of* ENERGY EFFICIENCY & RENEWABLE ENERGY

For more information, visit: energy.gov/eere/wind

Cover photo by Casey Joyce, RMT, Inc.

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