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Wind R&D Newsletter

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IN THIS ISSUE

ExaWind Supercharges Wind Power Plant Simulations on Land and at Sea

Suite of open-source, HPC-powered physics codes allows engineers to do everything but collect their mail inside a virtual wind power plant

ExaWind is a confidence builder.

Until now, predicting the performance of entire wind power plants was a near-impossible task—from anticipating the various movements of turbine blades to understanding how varying wind conditions and blade motion can impact wind power plant operational efficiency. Designing and installing wind power plants is an expensive and time-consuming venture, and most current modeling and engineering tools are just not up to the task of tackling the intricacies of wind power plant flow dynamics, particularly in offshore environments.

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Wind Turbines with Large Rotors and Tall Towers Provide Double Dividends

Supersized turbines could reduce costs, enhance value of wind energy—and more

Researchers at DOE's Lawrence Berkeley National Laboratory (Berkeley Lab) analyzed the impact of large wind turbines on grid-system value and illustrated the importance of expanding wind turbine design to focus not only on minimizing direct costs, but also on a broader set of factors that impact the value of wind to the electricity grid. Findings were published in the journal *Wind Engineering.*

In recent years, significant increases in wind turbine size—nameplate (or rated) capacity, rotor diameter, and tower height—have been driven primarily by a goal of minimizing the levelized cost of energy (LCOE).

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Letter from the Wind Energy Technologies Office Director, Dr. Robert C. Marlay

Dr. Robert C. Marlay

Although recent circumstances have introduced an economic pause in some sectors, the U.S. offshore wind industry continues its steady progress toward a robust energy future with several offshore wind projects and related supply-chain investments in various stages of development. The U.S. Department of Energy's (DOE's) Wind Energy Technologies Office (WETO) anticipates this future by focusing its attention on an array of high-priority research and development (R&D) needs, broadly categorized as advanced technology, siting and environmental challenges, and the integration of wind power at scale with the electric grid. WETO's research and development is typically undertaken in partnership with industry and our National Laboratories and promises benefits, collectively, for all forms of wind, including offshore wind.

The fall issue of our newsletter features selected highlights of recent outcomes from our ongoing and broader R&D portfolio, including:

- The use of high-performance computing to create ExaWind, a supercharged, open-source suite of physics codes and data libraries that enable researchers to simulate the interactions among the wind resource, turbines, and power plant.
- Research that analyzed the impact of increases in wind turbine size on grid system value—and concluded that "supersized" turbines (larger than those currently envisioned) could continue to reduce costs and enhance the value of wind energy.
- Research that yields deeper understanding of wind turbine gearbox failures. Its findings on stresses, materials, and probability of failure modes may help future designs and reduce incidents of unplanned maintenance and costly downtime, reducing operation and maintenance costs.
- How research teams from Purdue University and the University of Minnesota are addressing certain environmental concerns by examining the vision and hearing physiologies of bald and golden eagles, with an aim to improve deterrents around wind turbines.
- A multilayered and scaled framework that simulates how wind plants work in their natural environment—a model that is vital to understanding wind plant performance.

And here's an update to a story we told you about in our Spring 2020 R&D Newsletter: DOE's upgraded lidar buoys have now been deployed off the California coast in partnership with the Bureau of Ocean Energy Management (BOEM). As part of this effort, the buoys are collecting atmospheric, oceanographic, and meteorological data to support potential wind development projects in West Coast areas, where BOEM may develop and lease wind sites.

WETO, in conjunction with the states of New York, Massachusetts, Maryland, and Virginia, supports the Offshore Wind R&D Consortium. The consortium issued its most recent solicitation on August 4, which includes three rounds reflecting challenge areas designed to develop new solutions that remove barriers and address issues essential for cost reduction, deployment, and industry growth specific to U.S. offshore wind regions. The first two rounds—enabling large-scale turbines and support structure innovation and supply chain—have closed. Submissions for the third round, which focuses on electrical systems and innovation and mitigation of use conflicts, are due October 19.

As the American Wind Energy Association's Offshore WINDPOWER 2020 Virtual Summit begins this week (October 13–14), it's clear that interest in offshore wind in the United States—by all parties, including many states—is burgeoning, with more than 28.5 gigawatts of power in the offshore wind pipeline at the end of 2019. However, even as plans move forward, there are technical challenges that continue to need attention, both offshore and on land.

The stories in this newsletter highlight selected and recent outcomes of WETO's ongoing R&D portfolio aimed at addressing these challenges. At WETO, we are committed to supporting research that contributes to solutions and enables wind to become an even greater clean-energy reality for generations to come.

Sincerely,

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

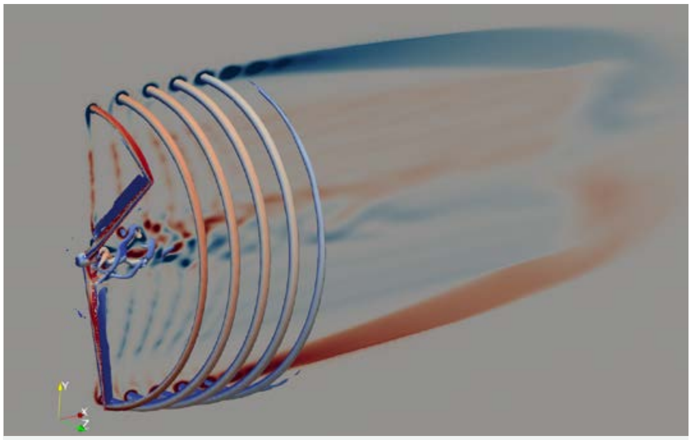


Figure 1. Image showing the flow structure around an NREL 5-megawatt wind turbine rotor generated by the ExaWind Nalu-Wind high-performance computational code. Red indicates regions of high-speed flow, and blue indicates regions with lower wind speeds. *Graphic by Shreyas Ananthan, NREL*

ExaWind Supercharges Wind Simulations *continued from page 1*

Driven by the immense power of high-performance computing (HPC), ExaWind is an open-source suite of physics codes and libraries that enables multifidelity simulation of wind turbines and wind power plants.

These groundbreaking simulation capabilities allow engineers to do everything but collect their mail inside a virtual wind power plant, creating a computer-generated environment where they can test their designs in real time and move forward in product development with confidence—minimizing industry risk and ensuring optimized performance down the road.

Prediction Powered by Petaflops and Exaflops

The DOE Exascale Computing Project (ECP), ExaWind, and the DOE WETO High-Fidelity Modeling project were launched in 2016, products of a close collaboration between the National Renewable Energy Laboratory (NREL) and Sandia National Laboratories (Sandia). With a multimillion-dollar budget and more than 40 researchers on the task, the project also includes partnerships with Oak Ridge National Laboratory, Lawrence Berkeley National Laboratory, the University of Texas at Austin, and Parallel Geometric Algorithms LLC as part of the broader ECP effort.

ExaWind is a marriage of three primary open-source physics codes: Nalu-Wind, an unstructured-grid computational fluid dynamics (CFD) code; AMR-Wind, a structured-grid CFD code built on the AMReX library; and NREL's OpenFAST, a whole-turbine simulation code. ExaWind essentially enables researchers to unlock the secrets of flow dynamics, allowing engineers to take a virtual peek inside the operations of a wind power plant and evaluate their designs within this computer-generated environment.

ExaWind aims to run the highest-fidelity wind power plant simulations to date. Employing the *Summit* supercomputer at the Oak Ridge Leadership Computing Facility, one of the world's fastest, as well as next-generation exascale-class supercomputers, the team hopes to one day graduate from utilizing petaflop computing power to exaflops (1,000 petaflops). *Summit* is capable of achieving 200,000 trillion calculations per second (200 petaflops), and the first exascale machines will be at least five times faster. The resulting high-fidelity models will enable a great leap in the understanding of, and ability to predict, complex flows and turbine responses in wind farms.

And better prediction leads to better outcomes.

"If you really understand a wind power plant system and can predict how it will respond to the wind flow, then you're in a strong position to optimize the design and operation of wind farms, both on land and offshore," said Michael Sprague, ExaWind principal investigator at NREL.

Amphibious Application

ExaWind's reach extends beyond the shoreline.

Offshore wind power plant simulation, particularly floating offshore wind, requires an additional modeling capability from that of land-based wind.

Offshore environments are characterized by complex interactions where the atmosphere meets the ocean surface, such as the proliferation of large, irregularly breaking waves. These interactions intensify the exchange of energy and momentum between the ocean and the atmospheric boundary layer above it.

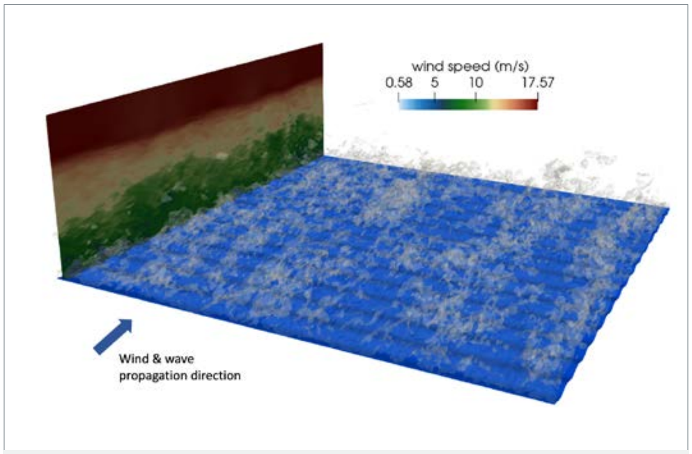


Figure 2. Simulation of wind over waves using ExaWind's Nalu-Wind flow solver. This snapshot highlights how ocean waves can enhance wind turbulence, which is important in designing floating offshore wind turbines. *Graphic by Georgios Deskos, NREL*

These environmental manifestations also play a key role in the wind- and wave-related forces that act upon floating offshore wind turbines.

To help capture these fundamental interactions, NREL's High-Fidelity Modeling team implemented a new moving-wave boundary condition in the ExaWind modeling and simulation environment for offshore atmospheric dynamics.

"With the ability to simulate ocean waves and gain a deeper understanding of how they impact the wind flow at turbine height, ExaWind can ultimately lead to improvements in offshore wind turbine design," said NREL postdoctoral researcher Georgios Deskos.

Promising Partnerships

The future looks bright for ExaWind, including a recently established partnership with General Electric (GE). GE and NREL are using *Summit* to study the impact of winds found in the lower levels of the atmosphere on the performance of Atlantic Coast offshore wind power plants, in a project funded by the New York State Energy Research and Development Authority. GE, NREL, and Sandia are also producing a high-fidelity modeling toolkit for wind resource characterization and wind power plant development in a project funded by the DOE Technology Commercialization Fund. In this project, the team will be adding features to ExaWind to help industry partners better integrate high-fidelity modeling tools into their design workflows. These additions will afford engineers the ability to predict the performance of their designs with confidence.

By fostering a deeper understanding of the dynamics at play in wind energy generation, coupled with its predictive capabilities, ExaWind can help scientists and engineers develop the designs that maximize energy capture, improve turbine life spans, and reduce the cost of wind-generated electricity.■

Wind Turbines with Large Rotors *continued from page 1*

Previous research by Berkeley Lab suggests that supersized turbines, featuring even larger rotor swept areas (relative to nameplate capacity) and taller towers, might enable further LCOE reduction of approximately $6 per megawatt-hour (MWh). Other research funded by DOE identifies potential solutions to the logistical challenges associated with deploying supersized turbines. But with wind's LCOE now comparable to that of other electricity-generating resources, design considerations in addition to cost minimization have grown in importance—particularly as wind penetration increasingly impacts the electricity grid and reduces wind's marginal value to the grid.

Berkeley Lab's new research addresses that expanded design need. Results demonstrate a possible double dividend—that larger rotors (relative to nameplate capacity) and taller towers might not only reduce LCOE but also enhance the value of wind energy and provide hidden benefits. These benefits largely come from the increased capacity factors that larger rotors and taller towers enable and the fact that such supersized turbines tend to have more consistent output throughout the year.

Specifically, the analysis leverages recent hourly wholesale pricing patterns and hourly wind profiles for wind power plants located in the seven U.S. wholesale markets (i.e., independent system operators, or ISOs). The study finds that in regions where wind penetration has reached around 20%—such as the Electric Reliability Council of Texas (ERCOT) and the Southwest Power Pool (SPP)—supersized turbines could already boost wholesale energy and capacity value by $2/MWh–$3/MWh, on average, compared with turbines deployed in the recent past (Figure 3). Across all regions, the average value boost is $1/MWh–$2/MWh. For specific power plants, the enhancement is already as much as about $5/MWh.

These wholesale market value benefits are augmented by three additional possible advantages of supersized turbines:

- Reduced transmission expenditure because of greater transmission utilization
- Lower balancing costs for the electricity system as a result of lower aggregate wind output variability
- Lower financing costs resulting from less long-term wind output uncertainty.

The analysis finds that these three benefits roughly total $2/MWh, adding to the $2/MWh–$3/MWh energy and capacity value boost observed in regions with higher wind penetrations (Figure 3).

When Berkeley Lab researchers consider all the benefits, the aggregate benefit averages $4/MWh–$5/MWh in higher wind-penetration areas. Moreover, these possible benefits add to the $6/MWh of potential LCOE advantage of supersized turbines assessed in earlier work, yielding total benefits of about $10/MWh. The degree to which these advantages are ultimately realized, and at what point turbine size plateaus, will be determined by future wholesale price patterns, the success of continued design and materials optimization, social acceptance and regulatory hurdles, and the logistical constraints of transporting and erecting even-larger blades, towers, and nacelle components.

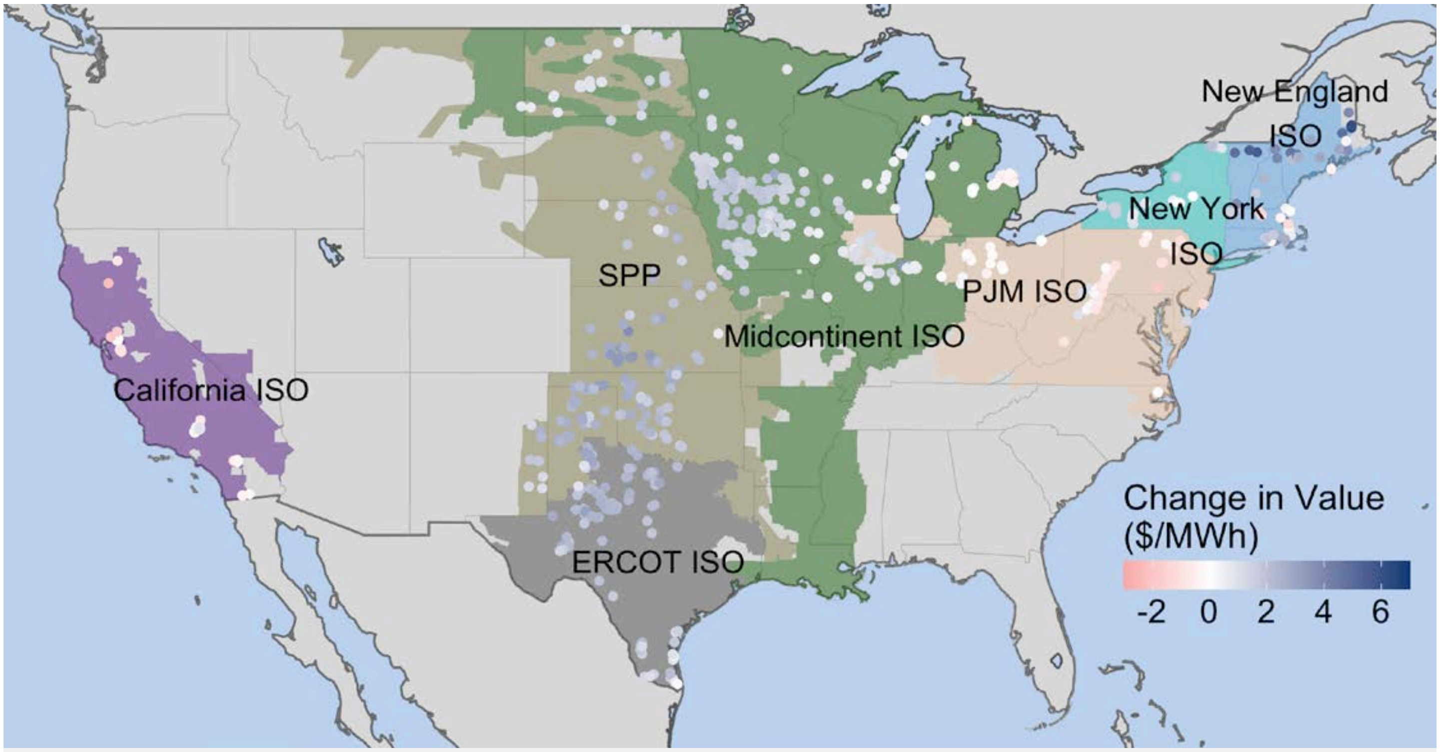


Figure 3. Market value increase from supersized turbine vs. 2018 average turbine. Analysis covers seven independent system operator regions, with each dot representing the results of the analysis for an individual wind power plant. *Image courtesy of Berkeley Lab*

More broadly, this analysis illustrates the growing importance of factors beyond plant-level costs in turbine and project design and operations. As wind penetrations increase, the output profile and characteristics of wind begin to impose challenges to the electricity grid. By expanding the analysis scope to consider supplementary factors that influence the system economics of wind—market value, transmission, balancing, and financing—turbine designers, project developers, and wind research and development experts can help ensure that wind power plants of the future seek a balance between minimizing costs and maximizing value. ■

Zeroing In on the No. 1 Cause of Wind Turbine Gearbox Failures

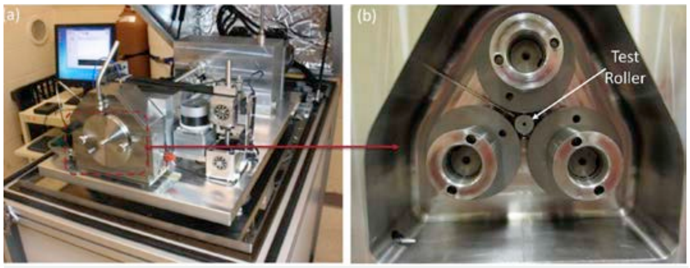
A deeper understanding of bearing axial cracking enables reliability assessments for individual turbines

The gearbox of a wind turbine is responsible for converting the relatively slow rotations of a turbine's blades into the high speeds needed to generate electricity. These hard-working components often do not reach their expected 20-year lifetime, despite meeting industry standards, because of a failure mode called axial or "white-etch" cracking in the rolling-element bearings inside the gearbox.

Given that gearbox bearing failures lead to costly unplanned maintenance and turbine downtime, there is an opportunity to reduce operation and maintenance costs at wind power plants by accurately predicting the probability of failure and implementing solutions to reduce the frequency of these failures.

"This issue is not unique to the wind industry," explained Jonathan Keller, a senior engineer at NREL and principal investigator of the Drivetrain Reliability Collaborative. "This failure happens in other industries, including automotive, rail, even washing machine bearings. However, when it occurs in a gearbox weighing 15 tons or more and suspended 250 feet up in the air, the cost implications are greater than, say, your car, which you can drive to a shop."

As wind turbines increase in size and capacity, gearbox failures are expected to continue being a problem for wind power plant operators unless bearing axial cracking can be reproduced in the laboratory, computationally modeled, and compared with actual power plant results. Funding from WETO has enabled Keller's



The Argonne benchtop rig (a), which contains a three-ring-on-roller contact shown in (b), was used to simulate rolling and sliding between a bearing roller and raceway. *Photos by Aaron Greco, Argonne National Laboratory*

team at NREL to join forces with Argonne National Laboratory (Argonne) and industry partners such as SKF, Winergy, GE, and Afton Chemical to undertake these challenges.

Argonne was able to reproduce the issue in the lab using a benchtop testing rig, which literally sits on top of a bench. About the size of an oven, Argonne's accelerated benchtop testing setup uses material specimens and oils to help determine the parameters that cause steel bearings to develop axial cracks. The Argonne team, led by Aaron Greco, examined the sliding that takes place between the bearing roller and the surface on the bearing ring that the roller rolls upon, called the raceway.

"We determined that, instead of a roller rolling, it sometimes slides across the two metal surfaces," said Greco. "These slipping or skidding conditions resulted in axial cracking, allowing us to confirm a causal link. Using the benchtop testing approach, we have also determined that certain chemical additives in the lubricant, and separately, the presence of electrical current across the bearing surface, can also lead to this axial cracking failure."

Next, NREL researchers outfitted a 1.5-megawatt wind turbine at NREL's Flatirons Campus with tailored instrumentation to gather experimental data at scale. Their findings, published in the journal *Tribology International*, confirmed that bearing slip occurs during wind turbine operations as a result of factors including bearing design, load, speed, lubrication, and temperature. Furthermore, NREL researchers used the data to develop a probability of failure model that fills an industry gap in evaluating component reliability, and a roller sliding model that is scalable to different turbine and gearbox platforms.

"These models leverage the benefits from both physics and data domains, with the former trying to capture the underlying mechanism for this investigated failure mode, and the latter trying to fine-tune based on individual turbine operational conditions and their impacts on component reliability progression," said Shawn Sheng, a senior engineer at NREL.

Because these experimental setups only partially represent conditions at commercial wind facilities, the researchers are currently working to compare their models with actual wind power plant failure data from more wind power plants. The researchers are working to validate their models against failure statistics and operational data from a wind power plant operating about 100 turbines over 10 years.

"It's a great start, but we need to work with many more wind power plants to access their data," said Keller. "With this hindcasting approach, we can see if our model is a good predictor of the actual failure numbers that have occurred in the past. That comparison will then tell us whether we have not just a contributing factor, but the primary factor for causing axial cracking."

To gather data on the true operating conditions of the turbine's drivetrain, NREL researchers replaced an existing gearbox (front) with a fully instrumented Winergy gearbox and SKF main bearing in the DOE-owned GE 1.5-megawatt wind turbine at NREL's Flatirons Campus. *Photo by Dennis Schroeder, NREL*

This combined research effort has yielded a reliability assessment and prognosis methodology for bearing axial cracking in individual wind turbines, comprising both the roller sliding model and the probability of failure model with data domain inputs. These findings, which connect the reliability forecast with bearing design, controller settings, and turbine operations, were recently published in the journal *Renewable & Sustainable Energy Reviews.* However, it remains difficult to implement effective mitigation techniques until the definitive cause—or causes—of bearing axial cracks in the field can be determined.

"We would love for more industry representatives to reach out to us so we can pinpoint exactly what's causing gearbox failures at wind facilities," said Keller. "Our goal is to help the entire wind industry reduce maintenance downtime and increase energy production." ■

Exploring Eagle Hearing and Vision Capabilities To Reduce Risk at Wind Farms

University researchers examine eagle physiology to inform and improve eagle deterrents

Purdue University (Purdue) and the University of Minnesota (UMN) are studying the visual and auditory capabilities of bald and golden eagles to help improve the effectiveness of deterrents used around wind energy facilities. Findings from this research, which is funded by WETO, will be made available to eagle deterrent technology developers.

Bald eagles were removed from the endangered species list in 2007 after a strong population recovery. Golden eagles were not listed, but both eagle species are federally protected under the Bald and Golden Eagle Protection Act (BGEPA), which prohibits the killing (or "take") of eagles, unless permitted. This act requires that wind energy developers and operators do everything they can to minimize risks to eagles through methods such as careful siting, deterrents, or sensors that monitor for incoming wildlife and shut down wind turbines if an eagle approaches.

One way to reduce risks is to develop technologies that produce sound or a visual cue to deter eagles from entering the airspace around wind turbines. To develop highly effective deterrents based on sound or visual stimuli to which eagles are most sensitive, Purdue University explored both eagle hearing and vision, whereas UMN researchers studied eagle hearing and identified possible surrogate species with hearing capabilities similar to bald and golden eagles.

Purdue University: A Blind Spot Near the Top of Eagles' Heads

The Purdue research team worked with seven raptor rehabilitation centers to evaluate eagle hearing and vision ranges. They found that both bald and golden eagles have a blind spot near the tops of their heads (Figure 4) that hinders the birds' ability to see a wind turbine ahead of them if looking downward (e.g., while hunting). This finding supports the need for a deterrent that is sufficiently alarming to an eagle to cause it to look up when hunting.

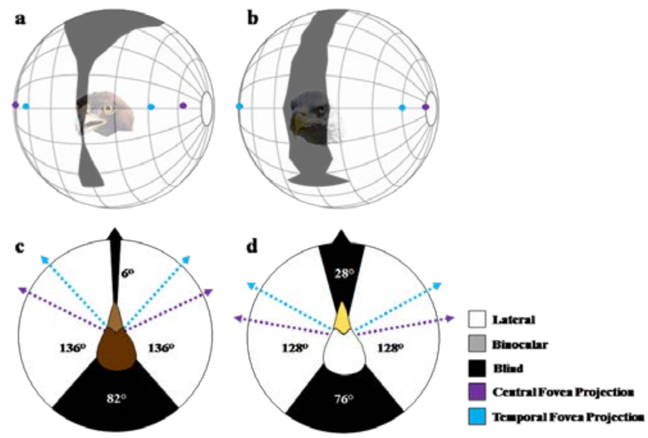


Figure 4. Visual field configurations of the golden eagle (left) and bald eagle (right). The Purdue University research team found that both species of eagles have a blind spot near the tops of their heads (bottom row). The blind spot hinders the birds' ability to see a wind turbine ahead of them if looking downward. *Illustration courtesy of Purdue University*

The Purdue team also found that it is highly unlikely that golden or bald eagles can detect ultraviolet light. They identified candidate colors (blue/indigo and orange/red) that would be most visible to eagles against various backgrounds.

Furthermore, golden eagles exhibited a higher proportion of stress-related behaviors to visual signals than to sound or light-plus-sound signals. Bald eagles showed a higher proportion of stress-related behavior to light-plus-sound signals. In other words, golden eagles are more likely to respond to visual signals, whereas bald eagles are more likely to respond to a combination of sight and sound. Both species showed some level of adaptation to stimuli over time, indicating the need for additional, randomized visual and auditory signal testing.

Purdue researchers concluded that the auditory systems of bald and golden eagles were sufficiently different to warrant species-specific deterrent signals. They discovered that:

- Both species responded strongly to tones between 0.5 kilohertz (kHz) and 5 kHz—roughly, the notes on the right half of a piano keyboard.
- Bald eagles' auditory systems were much better than golden eagles' at processing complex sounds with dynamic, rapid changes in amplitude or frequency modulation.
- In the presence of ambient noise, such as that of a wind turbine, sounds with rapid frequency or amplitude modulation were not as easily masked by the ambient noise.

The Purdue research team concluded that these types of signals would be good candidates for further testing with bald eagles—but that deterrents for golden eagles should be complex tonal harmonics or modulated sounds that do not change very rapidly.

University of Minnesota: Eagles Can Hear Frequencies Ranging Across Four Octaves

The UMN research team studied raptors admitted to the university's Raptor Center for treatment and worked with Sia: the Comanche Nation Ethno-Ornithological Initiative in Cyril, Oklahoma, to assess eagle hearing ranges. Once data were collected, they developed a suite of audio test signals and worked with eagles at the Raptor Center to evaluate which of the signals generated the strongest response.

Researchers found that eagles can hear over a frequency range of at least four octaves, centered on 2 kHz, which is roughly a "B" note on a piano, three octaves above middle C, with an upper limit between 6 kHz and 10 kHz at 80 decibels, and a lower limit that likely extends below 0.2 kHz.

In addition to evaluating eagles' physiological responses to synthetic tones, the research team evaluated the auditory properties of eagle vocalizations to better understand how their vocal repertoire might be used in a deterrent. The findings suggest that companies designing eagle deterrents should consider varying frequency and volume patterns to achieve the strongest and least-habituated responses. They also recommend against broadcasting sound outside the observed responsive frequency band of bald and golden eagles to avoid contributing unnecessarily to existing sound-pollution levels.

University of Minnesota: Red-Tailed Hawks May Be Auditory Surrogates

After exploring the usefulness of red-tailed hawks as potential surrogate species for field testing auditory deterrents, the UMN research team concluded that the hawks' auditory systems are similar enough to bald and golden eagles that they may be used as surrogate species when testing new deterrent devices or signals.

This finding is important because of regulatory protections afforded eagles under the BGEPA. Being able to test on red-tailed hawks will provide a significant benefit to technology developers looking to test the usefulness of their systems prior to field trials. However, researchers noted that testing with eagles in a real-world environment, in addition to any testing on red-tailed hawks, will be critical to any deterrent validation study.

The final technical report on this research is pending publication. The University of Minnesota has published one article about their research in the *Journal of Comparative Physiology*. ■

Multiscale Framework Simulates Utility-Scale Wind Power Plant in Its Natural Environment

First-ever simulation could lead to vital understanding of wind power plant performance

Wind power plant performance depends on local environmental conditions—and understanding those conditions is crucial in determining wind power plant performance. Factors such as sloping terrain, surface type and cover, atmospheric heating and cooling, and weather events all play a role in the wind resource and conversion to energy in wind power plants. However, most models used for wind power plant design and operation do not sufficiently account for environmental effects and their impacts on energy production potential. This limits our understanding of wind power plant dynamics and, thus, our ability to design, site, and operate wind power plants for maximum production and reliability.

Scale separation—differences in spatial and temporal scales between diverse atmospheric physical processes—is a key challenge to simulating wind power plants in their natural environments. For example, weather features, such as fronts or pressure systems, cover many kilometers (mesoscale) over minutes to hours. Turbulent flow phenomena that impact wind turbines are much smaller events (microscale) and occur in less than seconds. Capturing these differences in time and space scales over a broad range accurately, and in the same model, is extremely difficult.

"The ability to seamlessly simulate wind plant interactions with the surrounding environment could lead to major advances in wind energy science and operation," said Lawrence Livermore National Laboratory (LLNL) researcher Robert Arthur. "Predicting the response of wind farms to changing flow conditions would allow us to design and operate them more efficiently."

To meet this challenge, Arthur and other LLNL researchers partnered with scientists at the National Center for Atmospheric

Research; the University of California, Berkeley; the University of Colorado Boulder; and Texas Tech University to develop and demonstrate a novel, mesoscale-to-microscale wind power plant modeling framework. Built within the Weather Research and Forecasting (WRF) model, the framework combines the capability of a weather model to capture realistic meteorological and environmental conditions with the capability of a wind turbine model to capture flow interactions and wakes.

WRF was selected for its open-source code, worldwide user base, and ability to perform multiscale simulations. Additionally, the new framework leverages several WRF model improvements developed and implemented as part of DOE's Atmosphere to Electrons initiative. These include methods for improved modeling of turbulence across scales as well as an embedded wind turbine model that calculates the lift and drag forces on the turbine blade and the momentum exchanged between the turbine and the passing wind.

In an article published in the journal *Atmosphere*, the LLNL-led research team describes applying the new framework to examine a cold front passing through a utility-scale wind power plant in Oklahoma. The study, funded in part by WETO, demonstrated for the first time a seamless multiscale simulation of wind power plant performance under complex atmospheric conditions.

The study compared model output to radar measurements of the full, three-dimensional wind field within the plant as the cold front passes through. The model captures the dynamics of the frontal passage, including an abrupt increase in wind speed, change in wind direction, and increase in turbulence intensity. Additionally, the modeled turbines respond to the passing front by yawing (rotating) into the predominant wind direction, leading to an accurate representation of the wake structure (Figure 5). By capturing both the atmospheric dynamics and turbine behavior, power output is also well-predicted by the model.

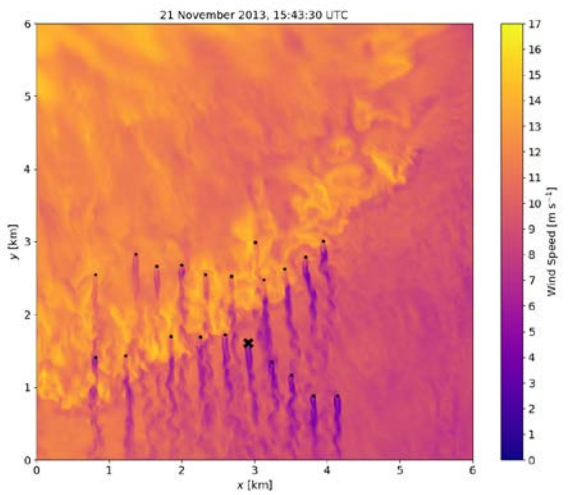


Figure 5. A new wind power plant modeling framework developed by LLNL and other partners allows large-scale weather features to interact directly with wind turbines for an improved representation of wakes and turbulence. Shown here is a snapshot of modeled hub-height wind speed as a cold front passes through a utility-scale wind power plant. *Image courtesy of Robert Arthur, Lawrence Livermore National Laboratory*

"The rapidly changing nature of this event would make it quite difficult to capture in a traditional wind turbine modeling framework," Arthur said. "But our new model captured both the dynamics of the passing weather front and the turbines' response."

Based on the promising results of this study, the new modeling framework is slated for further development and use in several upcoming DOE wind projects. These include the Wind Forecast Improvement Project 3 and American Wake Experiment, both of which involve extensive observational campaigns that will provide valuable data for model validation. ■

NREL's Techno-Economic Models Spotlight the Emerging Offshore Wind Opportunity

New open-source tool helps stakeholders assess U.S. offshore wind power plant balance-of-system costs

Over the past 5 years, offshore wind energy has developed into a robust industry characterized by rapidly evolving technologies and decreasing costs. This presents a challenge for modeling project costs, which is important for stakeholders seeking to understand the market trajectory of offshore wind in the United States.

Offshore wind stakeholders need a third-party, balanced, and up-to-date modeling approach to help them understand project costs, evaluate the potential impact of technological and process innovations, and manage uncertainty and risk.

A new open-source modeling tool from NREL can meet these needs. The Offshore Renewables Balance-of-system and Installation Tool (ORBIT), available now on GitHub, can be used to evaluate how major balance-of-system (BOS) costs vary as project characteristics, technology solutions, and installation methodologies change. More comprehensive than previous models, ORBIT's industry-reviewed methodology provides balanced estimates of the cost impacts of project size, turbine scaling, site characteristics, and a wide range of current and future technology alternatives that will be part of the emerging U.S. offshore wind industry.

"In order to identify cost-reduction opportunities, it's critical to understand how offshore wind costs are affected by novel technologies, industry growth, larger turbines, innovative installation processes, and operational constraints," said NREL Offshore Wind Lead Walt Musial. "ORBIT is one of several techno-economic tools NREL has created to help researchers and developers of wind power plants—both on land and offshore—understand project costs ahead of time."

BOS costs—which encompass all expenses required to construct a project other than the capital expenditures of the turbine—contribute around 40% of the lifecycle costs for a fixed-bottom offshore wind project. ORBIT can report and estimate costs for individual wind projects and can be used to assess how the capital costs of offshore wind will change at different locations or over time. The process-based, bottom-up cost model and simulation tool is valid for both fixed-bottom and floating projects and can model many different aspects of an offshore wind project, from component design through installation. ORBIT will be regularly updated with cost data and feedback from industry reviewers to maintain a state-of-the-art open-source model that can be used at any time by the offshore wind industry.

In addition to evaluating capital costs, ORBIT can capture installation times, weather impacts, marine mammal migrations, and other factors to generate a comprehensive view of project uncertainty and risk. By interfacing with NREL's system design tools, such as the Wind-Plant Integrated System Design & Engineering Model (WISDEM®) and FLOw Redirection and Induction in Steady State (FLORIS), ORBIT can contribute to integrated and optimized offshore wind power plant design. As an open-source model, ORBIT is a standardized, freely available tool that any stakeholder can use to evaluate novel scenarios against a baseline.

"ORBIT can answer questions like: How will individual component and overall system costs change as turbine ratings grow beyond current sizes? How do bottlenecks in at-port assembly impact installation times for floating turbines? Can a project benefit from foundations that may have a higher capital cost but do not require a wind turbine installation vessel?" said NREL Offshore Wind Engineer Matt Shields, who led ORBIT's development.

These questions all lead back to ORBIT's primary goal, which is to evaluate the BOS cost impact of technology and

NREL's new ORBIT modeling tool can help offshore wind industry stakeholders report and estimate balance-of-system costs at U.S. offshore wind projects. *Photo by Dennis Schroeder, NREL*

process innovations on the offshore wind industry. ORBIT is currently being used for a DOE-sponsored study on the sensitivity of BOS costs to turbine and plant upsizing (journal manuscript currently in preparation), an industry collaboration to evaluate the cost impact of novel concrete foundations and innovative installation methods, and a project providing technical assistance and cost modeling to BOEM to help with commercializing offshore wind in California. A similar model is being developed to assess operation and maintenance costs and the impact of different operational strategies on project performance, availability, and reliability; this model is expected to be publicly available early in 2021.

An August 2020 report details the functionality, background theory, and performance of ORBIT, which was developed with funding from WETO. ■

Technology Changes in U.S. Wind Industry Help Slow the Impacts of Aging on Wind Power Plants

First comprehensive study of the U.S. wind fleet shows that the performance of newer plants declines less with age than older plants

Ongoing technology changes within the U.S. wind industry are helping to slow the impacts of aging on wind power plants, according to a study by researchers at Berkeley Lab and published in the journal *Joule*. The study provides the first comprehensive evaluation of its kind for the United States. Results can be used by investors to help determine the financial viability of wind power plants and by energy system modelers to project the growth of wind power.

The study revealed that the oldest U.S. wind power plants maintained 87% of peak performance after 17 years, and newer plants showed almost no decline over the first 10 years. In addition, the U.S. wind fleet shows mild performance loss with age, and plants built after 2008 show the lowest levels of performance decline that have been found in a major fleet.

Encompassing data from 917 wind power projects in the United States (Figure 6), the study also examined the correlation between certain characteristics of wind power plants (such as plant size, site terrain, turbine technology, and ownership type) and the rate of performance decline with age. One of the most interesting plant characteristics to be linked to age-related performance decline was specific power, which measures the ratio of generator size to rotor size. Researchers found that turbines with lower specific power—those with longer blades relative to their generator size—were associated with lower rates of performance decline. Over the last decade, project specifications have shifted toward lower and lower specific-power turbines, representing one of the major technology changes within the U.S. wind industry.

The two findings—that newer plants have less performance decline with age than older plants, and that low specific-power turbines are directly correlated with reduced performance loss—provide evidence that ongoing technology changes within the U.S. wind industry are helping to slow the impacts of aging on wind power plants. Additional hypotheses for the cause of improvements in newer plants relative to older

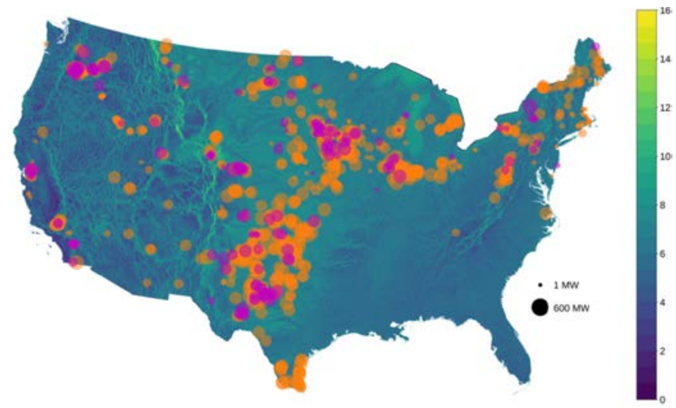


Figure 6. Map of wind projects included in the study. Pink projects were built prior to 2008, and orange projects were built in 2008 or later. Background color shows average wind speed in meters per second. *Image courtesy of Berkeley Lab*

plants include improved sensors and controls, reduced failure rates in certain components such as gearboxes, and general refinements to maintenance protocols.

"Despite the link between technology choices and aging, our research indicates that performance decline is more than a simple function of the underlying technology, but is also a managed process based on cost-benefit trade-offs that face plant operators," said Dev Millstein, a co-author of the study and research scientist at Berkeley Lab. "The evidence for this is seen in the fact that aging doesn't follow a linear process. Instead, it shows an acceleration in performance decline after 10 years of project life, coincident with the end of the production tax credit window."

Millstein and his co-authors hypothesize that operators are responding to reduced generation-based revenue associated with the end of the production tax credit window by reducing maintenance rigor and costs, and thereby reducing the cost of energy generated.

While performance loss with age is not limited to wind turbines, it is an inevitability across all types of electricity generation technologies, all of which face some form of performance loss with time.

"This research shows that, at least for wind power, the loss in performance can be partially offset through technological adaptation and managed through cost-benefit trade-offs," said Millstein. ■

ThermalTracker-3D Takes Flight

Testing validates system accuracy, provides comprehensive picture of bird and bat activity

Wind has the potential to provide a clean, efficient source of energy that is harnessed off the nation's coasts. WETO is advancing the development of technologies that will capture this abundant offshore wind while also showing a strong commitment to protecting wildlife, such as birds and bats that can fly into harm's way.

To protect bird and bat species, wind energy researchers must gather data, such as flight height and patterns, passage rates, and flight speed. This behavioral information serves as a source for offshore wind plant developers to make decisions about where and how to locate wind turbines. Yet, obtaining these data from remote offshore locations is challenging—limited to ship-based and aerial surveys in daylight hours and fair weather.

Commissioned by WETO, the Pacific Northwest National Laboratory (PNNL) developed ThermalTracker-3D (formerly called ThermalTracker2) in 2017 to help overcome these challenges. This software solution, equipped with a pair of thermal cameras and stereovision processing and streaming, is remotely deployed to provide the 3D data needed to understand how bird and bat behaviors are affected by the presence of offshore wind turbines.

ThermalTracker-3D tracks an unmanned aerial system (visible top, center) during testing at the NREL's Flatirons Campus. *Photo by Shari Matzner, PNNL*

PNNL developers recently evaluated the accuracy of ThermalTracker-3D. In a research paper published earlier this year in *Ecological Informatics*, the team demonstrated capturing 3D flight tracks. They used an unmanned aerial system (a drone) equipped with a global positioning system (GPS) as the target, flying for 15–35 minutes at a time in straight and curving patterns between 50 meters and 325 meters from the ThermalTracker-3D system. The research took place at NREL's Flatirons Campus.

"During the evaluation, we found that the tracking accuracy was within a few meters of the GPS, on average," said Shari Matzner, the PNNL scientist who led the development of ThermalTracker-3D and subsequent testing. "This level of accuracy is comparable to that of human estimates of flight height noted in other studies."

From this evaluation, the team determined that the 3D method has the potential to provide a more comprehensive picture, in real time, of all bird and bat activities around wind turbines than is possible with current survey methods.

The team has since adapted ThermalTracker-3D to collect baseline avian data at remote offshore wind locations and is planning to deploy the system on one of WETO's lidar buoys off the California coast for an initial sea trial. ■

INL Collaborates with National Labs To Bolster Cybersecurity and Resilience for Distributed Wind

Microgrids, Infrastructure Resilience and Advanced Controls Launchpad project supports distributed wind industry through cybersecurity, advanced controls, and valuation R&D

As more people look to distributed renewable energy to power homes, businesses, and communities, they often choose solar photovoltaic systems over wind turbines.

Distributed wind is less prevalent than solar, in part because wind presents a number of challenges, including siting, ease of installation, and finding the right-sized, commercially available wind turbine to match power needs, according to Jake Gentle, wind program manager at Idaho National Laboratory (INL).

Figure 7. To help advance cybersecurity for distributed wind power, an INL team is collaborating with researchers at three other National Laboratories and industry through the MIRACL project. *Illustration by Idaho National Laboratory*

Still, in locations with consistent wind, wind turbines offer several advantages, including greater long-term cost savings. Wind energy can provide grid support and resilience, increasing the value of hybrid energy systems, such as wind plus solar.

"The transition of the grid to greater renewables penetration will require a consideration of how this resilience will be maintained, if not increased," said Craig Rieger, chief control systems research engineer and directorate fellow at INL.

To maintain resilience and help advance cybersecurity for distributed wind power, an INL team is collaborating with researchers at three other National Laboratories and industry through the Microgrids, Infrastructure Resilience, and Advanced Controls Launchpad (MIRACL) project. The INL team recently launched a website focused on its cybersecurity and resilience efforts within MIRACL.

Together, NREL, PNNL, Sandia, and INL are conducting research and developing tools to help with the planning, design, and operation of distributed wind technologies. MIRACL provides opportunities for electric utilities and wind, microgrid, and distributed energy resource businesses to leverage national laboratory expertise and capabilities.

Funded through WETO, MIRACL focuses on three primary goals:

- Accurately valuing distributed wind's contributions to grid systems
- Creating advanced control systems for hybrid wind systems
- Developing ways to understand and respond to cyberattacks.

Putting a Dollar Figure on Reliability

The full value of distributed wind is more than just the cost of the electricity that a wind facility produces. That's why researchers are working to understand and evaluate other ways wind brings value to the grid.

For instance, distributed wind, when combined with other sources of distributed energy, can add resilience to microgrids and distribution networks that serve critical loads or isolated customers, such as military bases, remote communities, university and hospital campuses, and commercial and industrial facilities.

"Because the wind blows nearly all the time in some places, you can couple wind with solar and storage and have a microgrid that is reliable, resilient, and secure," Gentle said.

Increasing the control and communications compatibility of wind turbines is crucial in hybrid-energy systems that include other kinds of distributed energy resources. Without advanced communications and controls that can respond in near-real time to changing conditions, the full value of distributed wind won't be realized.

Finally, cybersecurity for wind power facilities, especially distributed wind facilities, lags behind other types of energy sources.

"Smaller distributed energy resources, like distributed wind, have not gotten as much focus on cybersecurity as larger facilities within the grid," said Stephen Bukowski, a senior power systems engineer at INL. "This is due, in part, to regulations. However, there has been a growing interest in securing all aspects of the grid, especially as adversaries have begun focusing on some of these less-visible connections and components."

Collaborative Modeling and Simulation

A big part of the MIRACL effort is using power systems models to simulate distributed wind facilities. Researchers are working together using PNNL's simulated microgrid platform in conjunction with INL's physical microgrid and the MIRACL Data Hub.

The MIRACL Data Hub, hosted at INL's Collaborative Computing Center, gives researchers from the different laboratories access to high-performance computing capabilities in a collaborative environment where they can share data, models, simulation results, and physical assets for research, demonstration, and validation purposes. Researchers plan to use the MIRACL Data Hub to work more closely with industry and academia. ■

Distributed wind technology, like this turbine stationed at the U.S. Department of Defense's Joint Base Cape Cod in Bourne, Massachusetts, can be adopted by entities such as federal agencies. A new training developed by PNNL, NREL, and FEMP will provide the knowledge needed to make decisions about distributed wind technology investments. *Photo by Steve Mellin, Joint Base Cape Cod*

A Gust-o for Training: Distributed Wind for Federal Agencies

New training covers basics and explains how and where systems could be installed

For nearly a decade, researchers at PNNL have collected annual market and technology data to identify trends about the use of wind as a distributed energy resource. The data are provided to utilities, communities, industry, federal and state agencies, and others to encourage informed decisions about wind technology investments.

Federal agencies, which operate using taxpayer dollars, must be judicious with how those dollars are spent. Adopting an alternative power source, such as distributed wind, could help them bolster energy cost savings.

To educate federal agency personnel about the benefits of distributed wind, PNNL recently partnered with NREL and DOE's Federal Energy Management Program (FEMP) to develop and offer a new training. "Selecting, Implementing, and Funding Distributed Wind Systems in Federal Facilities" is led by Alice Orrell, an energy analyst who leads PNNL's distributed wind research, and Rachel Shepherd, FEMP's distributed energy and procurement manager.

"This course provides information federal agencies need to make data-driven decisions about whether a distributed wind project would be appropriate and cost-effective for them," said Orrell.

Designed primarily for federal agency staff members who are responsible for renewable energy project development, the training covers the basics of distributed wind, explains how and where distributed wind systems could be installed at federal sites, and reviews wind project development and implementation issues encountered by federal agencies. These issues include common misunderstandings about wind; policies and incentives; logistical, technical, and economic considerations; and more.

After completing the training, participants should be able to navigate the basics of distributed wind project development and implementation in order to effectively contract with wind-industry professionals to install successful projects.

According to Orrell, WETO has played a critical role in developing distributed wind outreach and education for federal agencies.

"It began with funding two in-person workshops for federal agencies, led by PNNL," Orrell said. "From that initial funding, the impact of the workshops has substantially expanded because the online training using FEMP's platform is reaching and benefiting a much broader audience of federal government energy managers."

The 2-hour, on-demand course is free. ■

DOE News

From Concept to Commercialization—Bat Deterrent for Wind Energy Goes Global

One solution to protect bats at wind power plants is the development of an ultrasonic bat-deterrent technology that WETO has supported from initial concept to recent commercial deployment at wind farms domestically and abroad.

Request for Proposals Released for 2022 U.S. Department of Energy Collegiate Wind Competition

Applications for the 2022 Collegiate Wind Competition are being accepted through December 8, 2020.

New Study Reviews Additive Manufacturing of Soft Magnets for Wind Turbines

Oak Ridge National Laboratory and NREL published a new study that highlights the current status of additive manufacturing of magnetic components, such as rotors and stators, for large electrical machines.

CWC Alum Goes Far with Passion for Renewable Energy

Jane Sandoval graduated from Northern Arizona University in May. This fall, she enters a master's program in energy engineering through the Fulbright Scholar Program—with years of energy experience, including her work in DOE's 2020 Collegiate Wind Competition.

Top 10 Things You Didn't Know About Wind Power

Details about some lesser-known wind energy facts.

ARIES—a Visionary Energy Research Platform Addressing At-Scale Integration of Energy Systems

DOE announces the launch of the Advanced Research on Integrated Energy Systems platform at NREL.

U.S. Distributed Wind Manufacturers Selected to Advance Wind Technologies and Grid Support Capabilities through DOE Competitiveness Improvement Project

Eight new projects aim to drive down the cost of distributed wind energy, improve grid support capabilities, and increase turbine certification testing.

Celebrating American Wind Week: WETO Shows Wind Is the Answer

As we celebrate American Wind Week, let's look at some of WETO's most exciting wind energy research so far this year.

Wind Cybersecurity Roadmap Released

The roadmap outlines the increasing challenges of cyber threats to the wind industry and presents a framework of activities and best practices that the wind industry can use to improve its cybersecurity.

Collaboration Is Key for Washington State University Everett Wind Energy Team

WSU Everett's unique partnership with Everett Community College prepares the team for its first-ever participation in DOE's Collegiate Wind Competition.

How a Wind Turbine Works

The Office of Energy Efficiency and Renewable Energy's (EERE's) popular, interactive animation now includes an offshore direct-drive wind turbine view and other features. You can start and stop the turbine's movement, hover over parts to see their description, and use icons to switch views.

California State University Maritime Academy and James Madison University Claim Top Awards in First Virtual Collegiate Wind Competition

In a new era of social distancing, the 2020 Collegiate Wind Competition was held via webinar. Twelve collegiate teams replaced their poster presentations with digital slides, shared their computer screens with the judges, and presented their turbine designs and project development plans from their homes around the country.

EERE Success Story—Beyond Power, Wind Plants Can Provide a Full Suite of Essential Reliability Services to the Grid

New research demonstrates that wind plants have capabilities to provide ancillary services to the electric grid using plant-level controls—critical functions that help grid operators maintain a reliable electricity system. ■

Funding News

National Offshore Wind R&D Consortium Issues Second Request for Proposals

Applications are due October 19, 2020, for Round 3: Technologies to Mitigate Use Conflicts.

U.S. Department of Energy Announces Nearly $53.4 Million in Small Business Research and Development

Two wind energy projects were selected among 49 new Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) projects across 23 states. Projects were selected for Phase II funding and will build on successful SBIR/STTR projects that demonstrated technical feasibility in Phase I.

Department of Energy Announces 2020 Technology Commercialization Fund Selections

DOE announced selections of more than $33 million in funding for 82 projects supported by the Office of Technology Transitions Technology Commercialization Fund. More than $36 million in matching funds are included from the private sector.

National Offshore Wind R&D Consortium Announces New Project Awards

The National Offshore Wind R&D Consortium announced the competitive selection of twelve new research projects, bringing the total number of awards to date to 20, representing an investment of up to $17.3 million.

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

Cover photo by Gary Norton, DOE

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