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

Wind R&D Newsletter

OCTOBER 2018

IN THIS ISSUE

Letter from the Wind Energy Technologies Office Acting Director

With the American Wind Energy Association (AWEA) Offshore WINDPOWER 2018 Conference upon us, industry stakeholders can celebrate another year of progress for U.S. offshore wind. In fact, with more than 25,000 megawatts (MW) of generating capacity in the pipeline, the U.S. offshore wind industry is taking off.

To understand the latest U.S. wind facts and trends, check out three market reports recently released by the Wind Energy Technologies Office (WETO) at *energy.gov/windreport*. Together, these publications provide a realistic view of the state of the wind industry in America. Spoiler alert—it's strong and the future is bright.

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Stereo Vision Improves "Fly-By" Data for Offshore Wind Power

New capability enables 3D flight tracking of birds and bats in real time

When you're watching a 3D movie, you can thank stereo vision for knowing exactly when that dinosaur's head is close enough for you to flinch. Stereo vision gives people the ability to see where objects are located in space and how far away they are.

Researchers from PNNL have come up with a novel way to integrate that stereo vision feature into software to better "see" the flight patterns of birds and bats. This new, real-time capability will enable scientists to better identify the animal species and their flight patterns around offshore wind turbines.

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Letter from the Acting Director *continued from page 1*

Valerie Reed

At WETO, part of that bright future means investing in early-stage research and development (R&D) projects. Read this newsletter to learn more about what WETO is doing to advance offshore wind energy technologies, including:

- The novel feature that researchers at Pacific Northwest National Laboratory (PNNL) have developed to integrate stereo vision into software to better "see" the flight patterns of bird and bats.
- How research at the Scaled Wind Farm Technology facility in Lubbock, Texas, shows that a wind turbine can modulate real power for grid stability and provide regulating reserves using a frequency signal input to the wind turbine controller.
- A 4-year extension of the International Energy Agency's (IEA's) Task 30 to refine the accuracy of coupled engineering tools used to design offshore wind power plants.
- A new process for detecting wind turbine failures that could ultimately help improve maintenance planning and turbine availability.
- How the Wind Forecast Improvement Project has improved foundational weather forecasts in challenging areas of complex terrain.

Arguably, the year's most exciting news in U.S. offshore wind—the U.S. Department of Energy's (DOE's) selection of the New York State Energy Research and Development Authority (NYSERDA) to administer a $41 million offshore wind R&D consortium—will be explored during a session with WETO's Offshore Wind Technology Manager Alana Duerr at AWEA Offshore WINDPOWER. For more information on WETO's activities at the conference, please refer to page 3 of this newsletter.

I'm looking forward to an informative, inspiring, and productive Offshore WINDPOWER conference. Stop by the WETO booth on Wednesday afternoon to view demonstrations of online tools such as the U.S. Wind Turbine Database and Tethys environmental effects Knowledge Base.

Sincerely,

Valerie Reed
Acting Director
Wind Energy Technologies Office

Stereo Vision *continued from page 1*

That's where PNNL's ThermalTracker comes in. The software extracts flight tracks of birds and bats from thermal video recordings and quantifies them by time of day or night, direction of travel, and more. This information, combined with other characteristics inferred from the software, can be used to determine which species of animals live offshore and where they're flying. PNNL researchers made an open-source version of ThermalTracker available on GitHub in 2016.

> *ThermalTracker extracts flight tracks of birds and bats from thermal video recordings and quantifies them by time of day or night, direction of travel, and more. This information can be used to determine which species of animals live offshore and where they're flying.*

To make the tool even more valuable, the PNNL research team added stereo vision. The new version, called ThermalTracker2, processes the streams from two thermal cameras simultaneously. Going from one camera (two dimensions) to two cameras that have different perspectives (three dimensions) enables researchers to see the exact position of the birds and bats in the air.

"The resulting tracking data show flight height and depth in the area where the turbine blades would be turning, typically 50 to 250 meters above the water surface," said PNNL Engineer Shari Matzner. "Stereo vision also lets us estimate the body size and wing span of the flying animals, which helps us identify the species."

This photo shows two cameras equipped with ThermalTracker software, which is designed to capture the fight patterns of birds and bats and provide more accurate data about their behavior around offshore wind turbines. *Photo courtesy of PNNL*

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WETO AND WETO-FUNDED NATIONAL LABORATORY PARTICIPATION AT AWEA OFFSHORE WINDPOWER 2018

TUESDAY Oct 16

1:30 p.m.–2:45 p.m.

Status and Future Needs for Offshore Wind Dynamics Modeling; Lessons from IEA Wind Task 30

To advance offshore wind technologies to commercial maturity, the current suite of modeling tools used for designing offshore wind systems needs to be validated with high-quality data sets. Validation assesses the accuracy of the modeling tools, provides a better understanding of their uncertainties, identifies needed areas of improvement, and increases their acceptance within industry and research communities. The level of trust and acceptance of the tools directly translates to the perceived risk in the project, which impacts design methodology and bankability, both significant cost drivers. Validated modeling tools can then be used to develop optimized designs to reduce costs. To address the need for validated offshore wind modeling tools, a research task within IEA Wind was initiated in 2005. Task 30 has worked continuously since then to assess and improve coupled offshore wind modeling tools, identify their limitations, and determine future research needs.

Speaker:

- Amy Robertson, Senior Engineer, National Renewable Energy Laboratory (NREL)

WEDNESDAY Oct 17

9:35 a.m.–10:35 a.m.

U.S. Offshore Wind Program: The Federal Perspective and Beyond the Strategy

An overview and update on the federal Outer Continental Shelf Renewable Energy Program from the key officials in the two federal agencies most responsible for development of offshore wind energy—the Department of the Interior and DOE. The session will address both the east and west coasts and upcoming program activities. The panelists will look beyond the *2016 National Offshore Wind Strategy* from both the leasing/regulatory perspective as well as the R&D perspective into plans and priorities to support growth of this new industry in the United States.

Speakers:

- Alana Duerr, Offshore Wind Program Manager, WETO
- Jocelyn Brown-Saracino, Acting Market Acceleration and Deployment Program Manager and Environmental Research Manager, WETO
- James Bennett, Program Manager and Chief of the Office of Renewable Energy Programs, Bureau of Ocean Energy Management (BOEM), U.S. Department of the Interior
- Joan Barminski, Pacific Regional Director, BOEM

1:35 p.m.–2:35 p.m.

Utilization of Federally Funded Studies

This panel session will provide an overview of the technical and environmental studies programs within BOEM and the Bureau of Safety and Environmental Enforcement that provide information that may be used by federal agencies, developers, and other stakeholders during the approval process of construction and operations plans. States have also funded studies to provide baseline information to ease the burden on industry. Specific examples will be given of how this information can streamline the process.

Speakers:

- Mary Boatman, Environmental Studies Chief, Office of Renewable Energy Programs, BOEM
- Jocelyn Brown-Saracino, Acting Market Acceleration and Deployment Program Manager and Environmental Research Manager, WETO
- Daniel O'Connell, BOEM
- Dave Pereksta, Avian Biologist, BOEM

2:40 p.m.–3:40 p.m.

Innovating Together: The Latest on the National Offshore Wind R&D Consortium

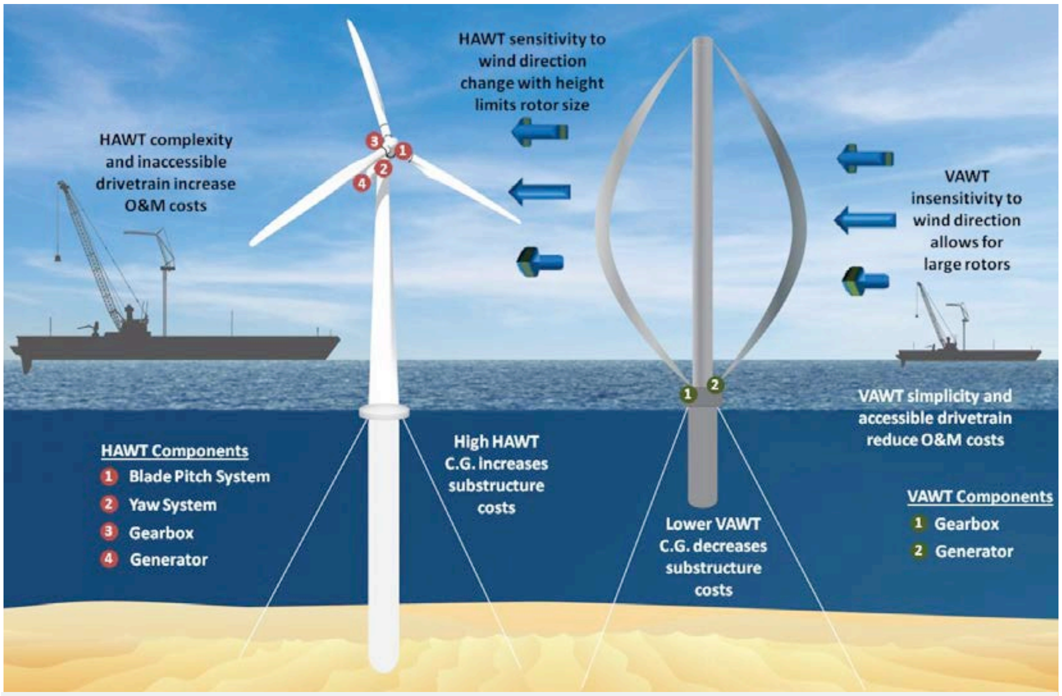
In June, DOE announced the selection of NYSERDA to administer an offshore wind R&D consortium—a cooperative innovation hub that will bring together industry, academia, government, and other stakeholders to advance offshore wind power plant technologies, develop innovative methods for wind resource and site characterization, and develop advanced technology solutions for installation, operation, maintenance, and the supply chain. The overall goal of the consortium is to reduce the cost of offshore wind in the United States. This session will allow attendees to learn about what has happened since the announcement, what the framework of the consortium is, the R&D road-mapping activities, and the different ways of participating in the consortium.

Speakers:

- Alana Duerr, Offshore Wind Program Manager, WETO
- Walt Musial, Principal Engineer, NREL
- Richard Bourgeios or Mark Torpey, NYSERDA
- Doug Pfiester, Managing Director, Renewables Consulting Group
- Jan Matthiesen, Director, Policy and Innovation, Carbon Trust
- Board of Directors Participants: TBD from Ørsted and Deepwater Wind

ThermalTracker2 runs in real time, with onboard processing that dramatically reduces the volume of data to be stored and transmitted.

"Because ThermalTracker2 only saves the images that contain flight tracks, it reduces the amount of data up to 300% or more," Matzner said. "This means users can put the cameras in a remote location and let them record for weeks without worrying about data storage running out."



In deepwater, vertical-axis wind turbines (VAWTs) have inherent advantages, including a lower center of gravity (or "C.G."), over horizontal-axis wind turbines (HAWTs), as illustrated in this graphic. A recent study examined the levelized cost of energy for a 5-MW VAWT with a Darrieus rotor architecture, which was identified as having the greatest ability to reduce the system levelized cost of energy. *Illustration by Sandia*

Soaring Toward Commercialization

The Biodiversity Research Institute, which conducts wildlife research worldwide, successfully tested the prototype system using two thermal cameras and ThermalTracker2 in Portland, Maine, in the summer of 2017.

After streamlining the stereo processing feature, the PNNL team plans to make the system more rugged to withstand a marine environment and conduct a field study at an offshore wind site in 2019. DOE's WETO funds the research.

Vertical-Axis Wind Turbines Could Reduce Offshore Wind Energy Costs

Sandia Study Provides Insight into Technical and Economic Feasibility of This Less-Common Turbine Design

A new study by Sandia National Laboratories (Sandia) provides a window into the technical and economic feasibility for deep-water offshore installations of a less-common wind turbine design: the vertical-axis wind turbine, or VAWT, as opposed to the horizontal-axis wind turbines commonly seen on and off shore.

The study identified an optimized system design to produce system levelized cost of energy (LCOE) estimates for five potential scenarios, such as what the LCOE might look like today, or what the cost might become as the technology matures. The LCOE projections for the optimized system in the study reflect an updated, in-depth analysis of new technology, system optimizations, and other factors related to VAWT designs.

Overall, the research predicts that LCOE could be as low as $110 per megawatt-hour (MWh) if the system includes anticipated technical advancements to reach an optimized design. The projected near-term LCOE, or what the system is estimated to cost today, was predicted to be $213 per megawatt-hour. The most significant contributors to a reduced cost? An optimized platform design, advances in materials and rotor structural design, control strategies to optimize energy generation, and a reduced finance rate equivalent to that of land-based wind turbines.

The larger scale of offshore wind turbines and improved materials indicate that VAWT designs may have certain advantages and benefits for floating offshore wind energy installations.

While the VAWT design has been studied in the United States since the 1970s, the initial designs studied were smaller, which was a disadvantage for VAWTs because they did not perform as well as horizontal-axis designs at smaller scales. Additionally, composite materials were uncommon. Studies produced by Sandia at the time relied on segmented aluminum blades, which were prone to fatigue.

Now, the larger scale of offshore wind turbines and improved materials indicate that VAWT designs may have certain advantages and benefits for floating offshore wind energy installations. For instance, VAWT designs have a lower center of gravity, which would reduce the platform costs.

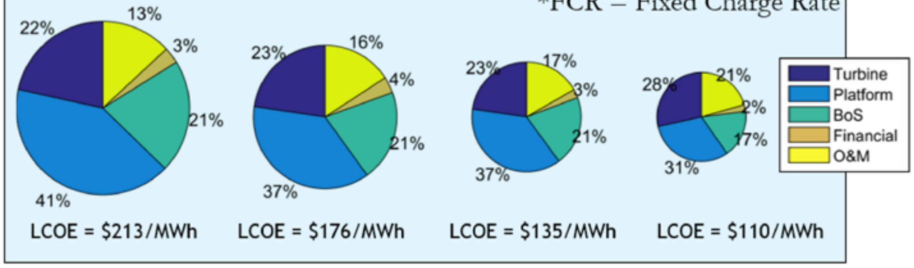
"From a systems perspective, that could be a huge breakthrough for floating offshore wind, where the platform is the single largest contributor to the system cost," said Brandon Ennis, Sandia's Wind Energy Technologies Department offshore technical lead. "The turbine represents approximately 65% of the system cost for land-based wind plants, compared to only around 25% for deep-water offshore sites. This distinction opens up the opportunities for radically different wind turbine designs than what would be developed for land-based applications, which could significantly reduce the cost for floating offshore wind energy."

As shown in the study, the reduced platform cost for the VAWT design decreased the LCOE, although a direct comparison to horizontal-axis design is merited to better understand the relative LCOE comparison.

The current report represents an effort to apply comprehensive cost data to a representative site and optimized design—outlining how an optimized VAWT system may impact LCOE and providing the cost data to understand the role of VAWTs in developing the vast energy resources available offshore. The final project reports from the floating offshore vertical-axis wind turbine project led by Sandia can be accessed by visiting energy.sandia.gov/energy/renewable-energy/wind-power/offshore-wind/

	Baseline LCOE	Upper-bound LCOE	Projected near-term LCOE	Project mid-term LCOE	Projected longer-term LCOE
AEP	Baseline	Baseline	16.1% increase from advanced controls	Advanced controls	47% increase in energy capture
Rotor costs	Baseline	Baseline	Rotor material optimization	Reduction from low-cost carbon fiber	78.2% increase in rotor cost
Platform and mooring	Most-likely value	Upper-bound estimate	13.6% reduction for optimal system platform	25% reduction for mid-term optimization	Mid-term optimization
Installation	Most-likely value	Upper-bound estimate	15.3% reduction for the improved installation procedure	25% reduction for mid-term optimization	Mid-term optimization
O&M direct costs	Baseline	Baseline	Baseline	19% reduction by eliminating jack-up vessel charters	Elimination of jack-up vessel charters
Levelized cost of energy (USD/MWh)	274	323	213	176 (FCR=10.3%) 135 (FCR=7.9%)	110 (FCR=7.9%)

*FCR = Fixed Charge Rate



The study details the effect an optimized design would have on each cost component, showing that technology advances to the platform, rotor structural design, and reduced operation and maintenance costs could reduce the LCOE to as low as $110/MWh. *Image courtesy of Sandia*

Offshore Wind Market Value Varies Significantly Along U.S. East Coast

DOE-funded study combines historical weather data and wholesale market outcomes

A study from Lawrence Berkeley National Laboratory (LBNL) finds that the market value of offshore wind—considering energy, capacity, and renewable energy certificate (REC) value—varies significantly along the U.S. East Coast and generally exceeds that of land-based wind in the region. The study's focus on the value of offshore wind complements the large body of existing work that has analyzed the cost of offshore wind.

A single 30-MW project operating off the coast of Rhode Island has driven interest in offshore wind development in recent years, particularly along the East Coast where there is a perception that offshore wind may provide greater value than some other forms of electricity generation. However, the economic value of wind power can vary significantly by location, depending on the time-varying wind resource profile at a given site, as well as local pricing and market rules within the regional power market. Specifically, differences in these variables can affect the local price of electricity and RECs that wind power earns, as well as wind's contribution to meeting peak demand.

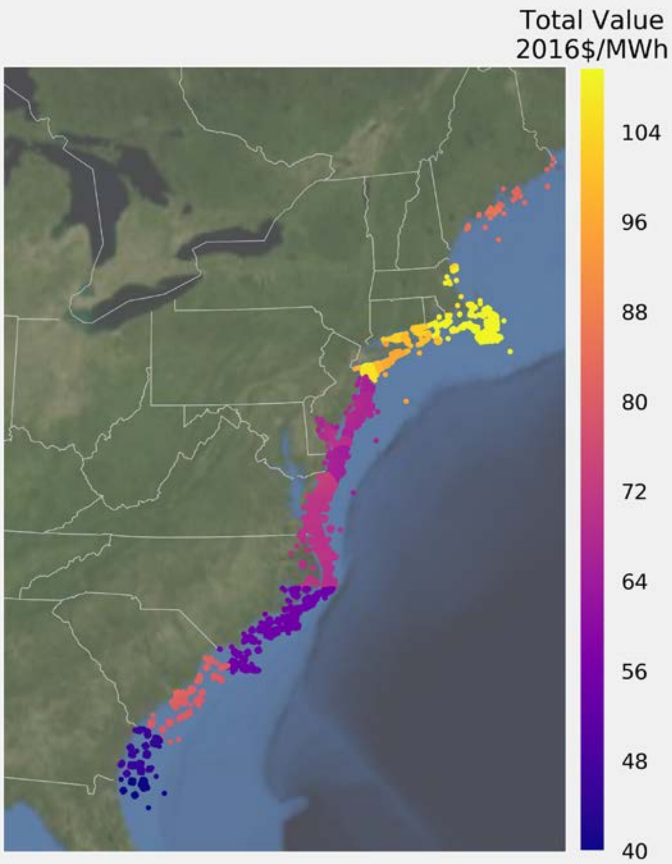
The new study, funded by DOE, unpacks these value components by exploring a hypothetical question: What would the marginal economic value of offshore wind projects along the East Coast have been from 2007 to 2016, had any such projects been operating during that time?

LBNL researchers answered this question by developing a rigorous approach based on historical weather data at thousands of potential offshore wind sites combined with historical wholesale market outcomes and REC prices. Specific value components that were examined both geographically and over time included energy, capacity, and REC value, avoided air emissions, and reductions in wholesale power and natural gas prices via the merit-order effect.

The research found that the historical market value of offshore wind—considering only energy, capacity, and REC value—varied significantly by project location. The average market value from 2007 through 2016 was highest for sites off the coasts of New York, Connecticut, Rhode Island, and Massachusetts—i.e., all areas where offshore wind is actively pursued—and lowest for sites along the southeastern coast (see graphic). The analysis also found that offshore wind can reduce air pollution emissions and wholesale electricity and natural gas prices, though effects varied in magnitude over time and across regions.

The historical market value of offshore wind was also found to have exceeded that of land-based wind because offshore

The new study, funded by DOE, unpacks the value components of offshore wind by exploring a hypothetical question: What would the marginal economic value of offshore wind projects along the East Coast have been from 2007 to 2016, had any such projects been operating during that time?



Total market value (energy + capacity + REC at each site, averaged over 2007–2016). *Graphic courtesy of LBNL*

wind sites are closer to major population centers and have time-varying profiles of electricity production that are more correlated with electricity demand. Yet, the cost of offshore wind is also higher than that of land-based wind, requiring important economic trade-offs. Cost reductions that approximate those witnessed recently in Europe may be needed for U.S. offshore wind to offer a credible long-term economic value proposition on a widespread basis along the Eastern Seaboard.

Finally, the research discusses how the various value components might change in the future and assesses multiple ways to potentially enhance the value of offshore wind, including by varying the location of grid interconnection and adding electrical storage.

These findings come with several caveats. For example, while the historical perspective taken in this study is instructive in terms of identifying key value drivers for offshore wind, the decision to build offshore wind going forward will depend on expectations of future benefits, which may differ from recent historical experience.

"Despite the caveats, this research can provide important insights to a variety of stakeholders—including offshore wind developers and purchasers, as well as energy system decision-makers—about where offshore wind projects are likely to provide the most value, or at least about what are likely to be the primary drivers of relative value," explains Andrew Mills, the study's lead author. "In addition, focusing on market value may help to inform the U.S. Department of Energy on its offshore wind technology cost targets, as well as the early-stage R&D investments necessary to reach them."

A 12-page executive summary, accompanied by a more-detailed slide deck that explains the study and a journal article submission, can be downloaded at *emp.lbl.gov/publications/estimating-value-offshore-wind-along*

> *This research can provide important insights to a variety of stakeholders … about where offshore wind projects are likely to provide the most value, or at least about what are likely to be the primary drivers of relative value.*
>
> Andrew Mills, Lawrence Berkeley National Laboratory

Oh Buoy! PNNL Researchers Dive into Data Delivered from New Jersey Coast

Wind behavior and variable data will help industry identify most productive offshore wind locations

The winds off the nation's coasts, which blow harder and more uniformly than winds on land, have the potential to provide more than 2,000 gigawatts of generating capacity. However, before offshore wind turbines can be deployed to harness this energy, researchers must answer important questions—such as how much wind energy a turbine can capture at certain offshore sites.

To help answer this question, WETO commissioned PNNL to deploy two research buoys off the New Jersey and Virginia coasts. The buoys were equipped with advanced scientific instruments for a multitude of research activities, such as measuring wind speed at multiple heights as well as air and sea surface temperature.

Researchers compared the data collected from the New Jersey and Virginia buoys

Here's what they found:

- New Jersey winds were generally similar over seasons to those off the Virginia coast.
- The strongest winds were from the south-southwest (occurring in the warmer months) and northeast-northwest (occurring in the colder months).
- For both locations, onshore flow conditions—for example, where wind blows from the direction of the warm Gulf Stream over the cooler seawater—were more stable and present up to half the time. These conditions influence how wind increases with height.
- Virginia conditions were slightly more stable, probably thanks to its closer proximity to the Gulf Stream.

PNNL researchers have presented these findings as follows:

Newsom, R.K., W.J. Shaw, and M.S. Pekour. 2017. *Results from the Deployment of the U.S. Department of Energy's Floating Lidar Systems Off the East Coast of the U.S.* Presented by Rob K. Newsom at IEA Wind Task 32, Stuttgart, Germany. PNNL-SA-130313.

Shaw, W.J., R.K. Newsom, M.S. Pekour, and J.E. Flaherty. 2018. *Buoy-Based Observations of the Wind Profile and Associated Conditions off the U.S. East Coast over an Annual Cycle.* Presented by William J. Shaw at AMS Ninth Conference on Weather, Climate, and the New Energy Economy, Austin, Texas. PNNL-SA-131555.

Shaw, W.J. 2017. *Application of Lidar Buoys to Offshore Wind Resource Characterization.* Presented by William J. Shaw at 2017 POWER-US Technology Workshop, Boulder, Colorado. PNNL-SA-129606.

Shaw, W.J. 2018. *Met-Ocean Observations—Critical Things We Need to Know.* Presented by William J. Shaw at International Offshore Wind Partnering Forum, Princeton, New Jersey. PNNL-SA-133598.

The Virginia buoy returned in 2016 after 19 months collecting data 42 kilometers (km) off the Virginia shore—providing the first open-ocean observations of hub-height winds over a full annual cycle in the United States.

In early 2017, the New Jersey buoy returned from a 15-month deployment 5 km east of New Jersey. During the past year, the team has looked at wind behavior and other variables of this data set.

A lidar buoy deployed off the coast of New Jersey has provided observational data that, in conjunction with data from another buoy, will help inform wind production capability for offshore locations. *Photo courtesy of PNNL*

In the case of wind behavior, the team found that the New Jersey winds were generally similar over seasons to those off the Virginia coast, despite being measured in a subsequent year. The strongest winds were observed from the south-southwest (occurring in the warmer months) and northeast-northwest (occurring in the colder months).

To address factors that control wind variability, the team observed that for both the New Jersey and Virginia coastal locations, onshore flow conditions—which result in wind blowing from the direction of the warm Gulf Stream over the cooler seawater near shore—showed that most of the time the air was warmer than the water. These conditions reduce the drag of the ocean on the winds and impact how wind increases with height. The team also noted that these conditions were more common for the Virginia deployment than the New Jersey deployment, either because of differences from year to year or—more likely—Virginia's closer proximity to the much-warmer Gulf Stream.

These data will help validate wind predictions derived from computer models, which have historically relied on limited real-world observational data. The data will also bolster the findings that will be obtained from future buoy redeployments, and PNNL has received funding from DOE to install more powerful lidars on the buoys this fall to support these activities. The lidar upgrade will include validation of the new systems consistent with practices recommended by the Carbon Trust.

These data will help validate wind predictions derived from computer models, which have historically relied on limited real-world observational data.

IEA Research Study Extended To Improve Accuracy of Offshore Wind Systems Design Tools

Floating and fixed-bottom structures can benefit from further design optimization

Researchers from NREL received a 4-year extension of IEA research that will advance the overall accuracy of offshore wind computer modeling tools.

The IEA Wind Technology Collaboration Programme's Executive Committee awarded the extension of Wind Task 30 research and by doing so created the Offshore Code Comparison

Offshore Code Comparison Projects by the Numbers

OC3 and OC4

- Created under IEA Wind Task 23 and Task 30, respectively
- Ran from 2005 to 2013
- Verified modeling tools by comparing simulation results from several different models
- Focused on verifying the coupled modeling tools through code-to-code comparisons of simulated responses for generic, representative offshore wind systems.

OC5

- Created under IEA Wind Task 30
- Ran from 2014 to 2018
- Validated modeling tools by comparing simulations to test data
- Focused on validating the tools by comparing the simulated responses to physical measurements of real systems.

OC3, OC4, and OC5 project objectives

- Assess simulation accuracy and reliability
- Train new analysts on how to run codes correctly
- Investigate capabilities of implemented theories
- Refine applied analysis methods
- Identify further R&D needs.

Collaboration, Continuation, with Correlation and unCertainty (OC6) project. This new project will dig deeper into differences between computer simulations and experimental measurements, building off of previous Task 30 research OC4 and OC5.

According to Amy Robertson, NREL project leader, the purpose of OC6 is to refine the accuracy of engineering tools used to design offshore wind turbines by improving their ability to estimate structural loads. The tools used to design offshore wind systems need to consider the coupling between the aerodynamic and hydrodynamic loading on the system, which are vital to optimization and stability.

Designing an offshore wind system involves running tens of thousands of simulations, which requires modeling tools accurate enough to provide realistic load results, but also fast enough to perform design iterations in a reasonable time frame.

"Coupled engineering-level tools (such as OpenFAST) that consider both the wind and wave loading simultaneously on the structure fit that need," Robertson said. "Improving these tools to better predict the actual behavior of offshore wind systems enables further design optimization and, therefore, cost reductions. Unvalidated models increase costs because the technology must be overdesigned to accommodate for large uncertainties in loading and operating conditions predicted by the numerical models."

The offshore code comparison projects are important for designers, certifiers, and research institutes that apply modeling tools for design, research, and instruction. In addition, many researchers have learned how to effectively model and simulate offshore wind turbines using information provided from these projects.

Including participants from the offshore wind industry as well as OC5 members, the OC6 project has the following objectives:

- Perform more focused validation projects based on the issues identified in previous IEA Wind Task 23 and Task 30 projects (Offshore Code Comparison [OC3], OC4, and OC5)
- Develop and employ more rigorous validation practices following American Society of Mechanical Engineers guidelines, with a strong emphasis on quantifying uncertainty in test campaigns used for validation
- Include higher-fidelity modeling solutions in the validation process (when possible), performing a three-way validation among engineering-level tools and measured data.

OC6 Validation Projects Identified

Researchers identified the following validation projects as the most relevant for OC6.

- **Work Package 1**
  Validation of nonlinear hydrodynamic loading on floating offshore wind support structures originating from the interaction of wave components, structure motion, and flow through a multibody structure.
- **Work Package 2**
  Incorporation and verification of advanced soil/structure interaction models to represent pile/foundation interaction.
- **Work Package 3**
  Validation of aerodynamic loading on a wind turbine experiencing wave motion caused by a floating support structure.
- **Work Package 4**
  Validation of the methodology for combining load models for floating offshore wind support structures.
- **Work Package 5** *(Optional fifth-year extension)*
  Validation of the full-scale dynamic behavior of a floating wind turbine.

OC5 focused on validation by comparing simulated results to actual measurements. Its three phases used test data from a cylinder in a tank, a floating semisubmersible prototype turbine and substructure in a tank (left), and the open-ocean testing of a jacket foundation (right). The IEA Wind Technology Collaboration Programme's Executive Committee recently awarded a 4-year extension of IEA Wind Task 30, creating OC6. *Photo credits: (Left) DeepCwind Research Program, NREL 19576; (Right) Gary Norton, NREL 27360*

Improved models that better predict the actual behavior of offshore wind systems enable further design optimization and, therefore, cost reductions.

The OC5 participants have already identified validation projects that are the most relevant to focus on within the extension and organized them into five projects, or "work packages" (see OC6 Validation Projects Identified). The objectives will be investigated through measurement data obtained across multiple test campaigns, including testing of several offshore turbine support structure types, including two floating semisubmersibles, a spar, and a monopile. When possible, multiple phenomena will be investigated using the data sets.

Turbines in Terrain: Wind Forecasting Study Completed in Columbia Gorge

Four-year study generates one of the most comprehensive data sets collected in complex terrain

In 2017, wind turbines accounted for more than 6% of the nation's electricity supply—enough to offset the consumption of 24 million homes.

But while wind is an up-and-coming energy powerhouse, its variable nature leaves wind farm operators uncertain about whether they will be able to deliver promised power, or if they might produce more power than the grid can accept. That question can lead to lost revenue.

To improve wind forecast accuracy, WETO funded the second Wind Forecast Improvement Project (WFIP2). Building on the first Wind Forecast Improvement Project, which examined the impact of improved initial conditions in advanced forecast models in areas with flat terrain, this combined modeling and field study was designed to improve forecasts in areas of complex terrain, where wind circulation and flow make predictability especially challenging.

In March 2017, the WFIP2 team completed the field phase in the Columbia Basin, an area of steep hills and rolling farmland along the Columbia River that extends more than 80 miles east of the Cascade Mountains in Washington and Oregon. This field phase:

- Focused on studying the effect of different variables in forecasting wind speed and turbulence at turbine heights averaging more than 262 feet and rotor diameters of more than 300 feet
- Generated one of the most comprehensive data sets collected to date in complex terrain—not just for density in observation, but for its 18-month duration—comprising the full spectrum of atmospheric conditions.

The team observed strong winds near the Earth's surface that eroded cold pools—regions of relatively cold, calm air that form particularly in the winter. This erosion in turn causes wind conditions to change significantly, sometimes in a matter of minutes, resulting in surges of power from the wind turbines that make accurate forecasting difficult. The team developed and implemented a new algorithm in their study that improved the timing accuracy for cold pool erosion. The algorithm has now been included in National Oceanic and Atmospheric Administration (NOAA)—a key research participant in this project—National Weather Service operational forecast models.

Data gathered, which are available to other scientists and the public to benefit the wind industry, will help inform future research to support offshore wind development in the United States. The data will also help energy planners determine whether they should buy more wind or use other energy sources. The full study concluded in September 2018.

A collaborative project, WFIP2 involved experts from Vaisala (the award Prime Recipient) and its team, including the University of Colorado, University of Notre Dame, Texas Tech University, Lockheed Martin Coherent Technologies Inc., and Sharply Focused LLC. Additional data and support were provided by Iberdrola Renewables, Southern California Edison,

The WFIP2 project field phase in the Columbia Basin resulted in observation of phenomena related to wind conditions at turbine height. *Photo credit: ShutterStock*

The team developed and implemented a new algorithm in their study that improved the timing accuracy for cold pool erosion, which results in surges of power from wind turbines. The algorithm has now been included in National Oceanic and Atmospheric Administration's National Weather Service operational forecast models.

Cowlitz County Public Utility District, Eurus Energy, and Portland General Electric. The project also involved NOAA and four of DOE's own national laboratories—Argonne National Laboratory, Lawrence Livermore National Laboratory, National Renewable Energy Laboratory, and Pacific Northwest National Laboratory.

Wind on the Waves: Floating Wind Power is Becoming a Reality

Part 1: Exploring offshore wind technical challenges that are different in the United States than in other countries.

Worldwide, 13,000 MW of offshore wind have been deployed—yet the United States only has one offshore wind farm.

For the last year, the Block Island Wind Farm has been operating off the coast of Rhode Island.

As the United States looks to deploy more offshore wind, several "U.S.-specific" technical challenges will need to be overcome. This blog addresses challenges posed by deep waters (stay tuned for future blogs on other U.S. offshore wind topics such as hurricanes, vessels, and installation techniques).

The Consortium

Recently, DOE announced a funding opportunity to establish an offshore wind R&D consortium. This consortium will bring together a diverse group of researchers who will add to the offshore knowledge base in an accelerated manner. It will include members of the offshore wind industry, who will contribute funds and expertise to the research results and validate technologies developed by the consortium.

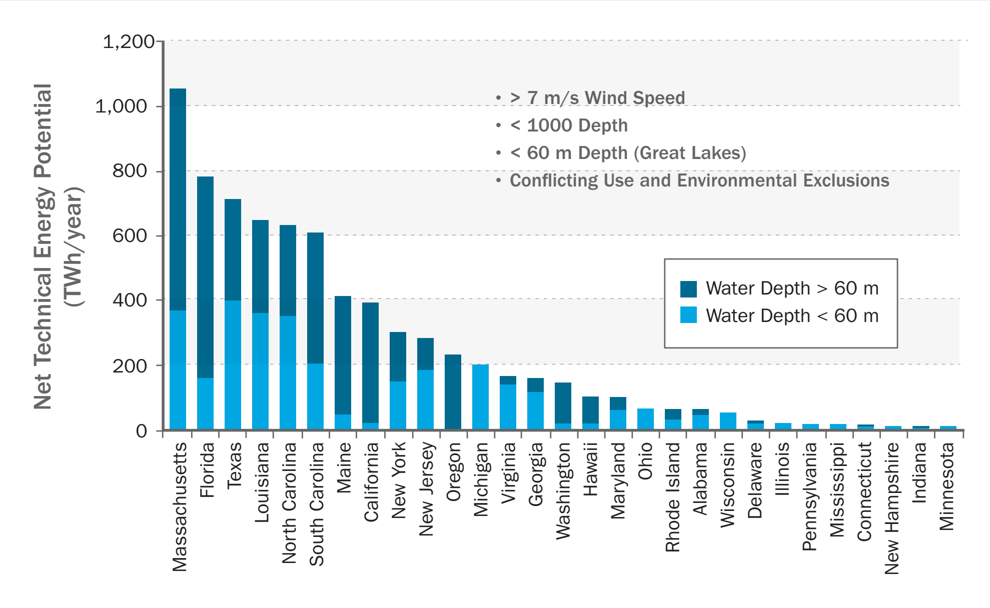
The Challenge

One significant challenge to building offshore wind turbines in the United States is the depth of the waters along many coastal areas. While most European installations to date have occurred in shallow waters, most (roughly 60%) of our nation's offshore wind resources are situated in deep waters—more than 60 meters down (or nearly 200 feet). This means traditional bottom-mounted foundations aren't economically viable in these areas.

The Technology

So, how does the United States overcome this challenge? It may seem like something out of a science fiction story, but researchers and engineers are finding ways to create platforms that float, while giving the top-heavy turbine enough stability to operate effectively. Tethered to the seafloor, floating foundations allow wind turbines to operate in areas where water depths may be greater than 165 feet. Floating foundation technologies make offshore wind feasible in locations, including California (where nearly 95% of the available offshore wind resource has a depth greater than 60 meters), Hawaii, and Maine.

This technology, largely adapted from the oil and gas industry, is already successful at the prototype stage, with more extensive test and demonstration projects underway. Currently, the most



Offshore wind floating substructure designs: spar buoy (left), semisubmersible (middle), and tension-leg platform (right). *Image by Josh Bauer, NREL 49054*

cost-effective installation method appears to be a "tow-out" concept, in which the foundation and turbine are constructed in port and then towed out to an anchor site. This method addresses several of the infrastructure and logistical challenges associated with constructing and maintaining offshore wind farms—the subject of a subsequent blog in this series.

Even so, the dynamic nature of wind turbines, along with the weight distribution needed to stay afloat, presents a number of engineering issues to overcome. A concept used by several floating offshore wind pilot projects to date is the semisubmersible platform concept (see center illustration below), which has several cylinders filled with water, serving as ballast for stability. The University of Maine plans to use this type of platform for their Aqua Ventus I project, which is supported by DOE's offshore wind advanced technology demonstration program. Another floating foundation option is a spar concept (see left illustration below), which relies on a large submerged mass to maintain stability.

Other nations are also working on innovative floating offshore wind technology solutions. The first project to scale up—using multiple large (6-MW capacity) offshore wind turbines on floating foundations—is Hywind Scotland, which uses a spar buoy foundation design that has one large ballast-stabilized spar. France also has an R&D program with three demonstration projects in early stages of development.

What's Next

While floating technologies may have the potential to become more cost-effective than traditional bottom-mounted foundations in the long term, significant research is needed to reduce costs and to validate the engineering tools used to design and optimize floating foundations. DOE has established the Offshore Wind R&D Consortium to conduct research on floating foundations and other technical innovations.

U.S. Conditions Drive Innovation in Offshore Wind Foundations

Part 2: Exploring offshore wind technical challenges that are different in the United States than in other countries.

While the first article in this series focused on the floating foundations needed for U.S. offshore wind development in deep waters, this article examines innovations in fixed-bottom foundations. With more than 40% of the U.S. offshore wind resource located where the water is less than 60 meters (100 feet) deep, foundations fixed to the seafloor are feasible in many locations.

Jacket Foundations and Monopiles

Most offshore wind installations to date (accounting for 80% of installed capacity worldwide) have used monopile foundations, which are cylindrical structures driven into the seafloor and attached to the bottom of the wind turbine tower.

As offshore wind projects move further from shore, jacket structures, which typically consist of four legs connected by braces, are becoming more common. Block Island—the first U.S. offshore wind farm—used a "gulf-style" jacket foundation with an installation method adapted from the offshore oil and gas industry.

Illustration by Josh Bauer, NREL 49055

However, there are several other fixed-bottom foundation types that may prove to be better options for U.S. conditions, including sandy seabeds, soil types that vary across small areas, and the need to comply with environmental regulations. For example, monopiles are driven deep into the seabed using large pile-driving hammers—a noisy process that can be harmful or annoying to marine animals, potentially leading to construction delays during seasonal migrations.

Offshore wind turbines are getting larger, complicating the use of monopile foundations. Most turbines being installed offshore today are 5–6 MW in capacity (compared to 2 MW for land-based turbines). The newest class of offshore wind turbines being developed are 9–9.5 MW with a rotor diameter over 500 feet, similar to the height of the Washington Monument. To support such a large turbine, the foundation needs to have a lot of mass, and therefore a lot of capital cost, under the water. This is one of the reasons why jacket foundations, which use a lattice structure to support the weight while using less steel, are becoming more common.

The Twisted Jacket

Offshore wind turbine with twisted jacket foundation. *Illustration by Josh Bauer, NREL 500052*

Louisiana-based Keystone Engineering has modified the traditional jacket design to create a "twisted jacket" with the legs angled around a central column, which uses less steel and is cheaper than traditional jacket foundations. The twisted jacket technology has been successfully demonstrated in the oil and gas industry as suitable for a wide range of seabed conditions. Keystone Engineering is one of several U.S. companies interested in leveraging their oil and gas experience to support renewable applications.

Another innovative type of foundation derived from the oil and gas industry is the suction bucket. An example is Universal Foundation's Mono Bucket, which combines a monopile with a suction bucket designed for soft soil conditions. Additionally, the foundation can be fitted with an "ice cone" at the water line. This can prevent ice from building up on the foundation—a potential problem for offshore wind in freshwater such as in the Great Lakes.

While the Mono Bucket has been demonstrated for use with meteorological towers, the first offshore wind project planning to use this new foundation type is the Lake Erie Energy

Universal Foundation Mono Bucket. *Image by Universal Foundation*

Development Corporation's (LEEDCo's) Icebreaker project, which is supported by DOE's offshore wind advanced technology demonstration program. The Mono Bucket will reduce installation time, costs, and environmental impacts compared to traditional foundations that require pile driving. It also has broader national applicability for offshore wind installations off the Atlantic and Gulf Coasts.

What's Next

With offshore wind just getting off the ground in the United States, there is still a need for more extensive site assessments to better understand seafloor conditions as well as to inform the design and siting of offshore wind. Improvements in offshore wind site characterization and technology advancement can reduce costs by increasing energy production, and by reducing development timelines, capital costs, and operation and maintenance costs. Some topics that the new offshore wind R&D consortium may tackle include validating innovative site characterization methodologies and models to minimize the need for extensive on-site data collection.

Alpha Ventus showing jacket structures in foreground, monopile in the background. *Image by Gary Norton, NREL 27363*

The diversity and ingenuity displayed in addressing this formidable engineering challenge reflects the obstacles overcome by American companies, supported by DOE's Office of Energy Efficiency and Renewable Energy. Whether the foundation floats or is fixed, offshore wind is poised to become a strong, steady, and reliable source of electricity.

Wind Turbines in Extreme Weather: Solutions for Hurricane Resiliency

Part 3: Exploring offshore wind technical challenges that are different in the United States than in other countries.

Offshore wind turbines on the Atlantic Coast (as well as the Gulf Mexico) have several challenges to contend with—including hurricanes. DOE is developing tools to help wind system designers lower the risk for offshore wind turbine systems located in extreme weather areas.

As noted earlier in this series, 13,000 MW of offshore wind have been deployed worldwide, yet the United States only has one commercial offshore wind farm in operation. The first article (Part 1) explained that technological advancements in floating foundations are needed to make offshore wind economically feasible in the deep waters off the U.S. Pacific Coast, as well as off the coasts of Maine and Hawaii.

This might be part of the reason why most near-term offshore wind development is planned for the East Coast from Massachusetts to North Carolina, where a substantial part of offshore wind resources involve water shallow enough for fixed-bottom foundations. However, offshore wind turbines on the Atlantic Coast (as well as the Gulf Mexico), have another challenge to contend with: hurricanes, which we'll explore next.

What's Too Windy?

Recent hurricanes Irma and Maria inflicted a lot of damage on infrastructure, including energy infrastructure. Wind turbines, whether they are land-based or offshore, have built-in mechanisms to lock and feather the blades (reducing the surface area that's pointing into the wind) when wind speeds exceed 55 miles per hour. Basically, the wind turbine is essentially in "survival mode," waiting for the storm to subside, so it can safely go back to producing energy.

Block Island Wind Farm, the first offshore wind farm in the United States. *Image by Gary Norton, NREL 41169*

Offshore, storms can be even stronger. In addition to the wind hitting the turbine, the turbine's foundation also has to contend with large, powerful waves. The engineers who design wind turbine systems use models to understand how different loads, like winds and waves, will impact a wind turbine and its foundation. The models they use need to be further refined to predict turbine loading in extreme conditions.

The Solution

DOE has previously funded work in this area through NREL. NREL, working with the University of Miami, linked its pre-existing wind turbine simulation software (called FAST) up with the atmosphere-wave-ocean forecast model. It is used for hurricane research and prediction to create a new "coupled hydro-aerodynamic interface for storm environments." This toolhelps wind system designers to lower the risk for offshore wind turbine systems located in extreme weather areas.

Offshore wind developments have already been proposed in hurricane-prone regions of the United States. In fact, research priorities of a new offshore wind R&D consortium to be funded by DOE may include a focus on improving the understanding of extreme meteorological ocean conditions—such as those experienced during hurricanes—to better predict potential failure modes of turbines operating in these areas, leading to the adoption of more robust engineering designs.

Designing Hurricane-Resilient Systems

Image by Gary Norton

While there is currently limited data due to the small number of deployments, the twisted jacket foundation discussed in the previous article in this series may be a promising design for hurricane-prone areas. A foundation of this type used by the oil and gas industry withstood a direct hit from Hurricane Katrina (category 5) in 2005 and emerged unscathed.

In another DOE-funded project, NREL designed and analyzed a hypothetical 500-MW offshore wind plant to be deployed in 25-meter (over 80-foot) waters in the Gulf of Mexico. Some of the features of this hypothetical wind farm included a twisted jacket foundation from Keystone Engineering and a customized, lightweight direct-drive generator from Siemens.

Perhaps the most surprising component of this system is the rotor designed by Wetzel Engineering. To optimize the project for hurricane resiliency and structural efficiency, the wind turbine uses a downwind orientation—opposite from the upwind design used in virtually all utility-scale wind turbines today. Upwind turbines use a wind vane and a yaw drive to constantly turn the top of the turbine to face into the wind. A downwind turbine avoids these components and lets the wind blow the blades away from the tower. This allows the blades to be more flexible, and permits them to bend in high winds without the risk of them hitting the tower, thereby reducing the risk of structural damage during a hurricane.

Although hurricanes and the damage they can cause remain difficult to predict, with current R&D, DOE is taking steps to alleviate potential risks to offshore wind systems that will eventually be deployed in the southeastern and mid-Atlantic regions.

Research Suggests Wind Turbines Can Provide Grid Reliability and Flexibility

Sandia researchers, collaborating with Group NIRE and Baylor University, demonstrated that modulating the rotation speed of wind turbine rotors can offer two important grid services—load balancing and stability management—among other potential benefits to provide flexibility and resilience on the grid.

Load Balancing

A typical generator in a power plant has the ability to respond to sudden increases in power demand by sensing that more energy is being pulled from the plant than what is being produced. This response is triggered by detecting the reduction of rotating kinetic energy of the generator's turbine. In other words, when the turbine slows down instead of remaining at its usual speed, the plant controls recognize that the plant needs to produce more power.

Wind turbines also have the ability to balance loads and support grid stability despite fluctuating energy demands. Sandia, Group NIRE, and Baylor demonstrated that by modulating the power output of a Vestas V27 wind turbine at the Scaled Wind Farm Technology (SWiFT) facility, they could provide up to six times the stored energy of a conventional synchronous generator (per megawatt nameplate) with only a 0.12% drop in aerodynamic efficiency. This research may help identify operating practices that could allow turbines to run at higher efficiencies while still being able to respond to surges in demand.

Stability Management

The research also demonstrated that controlled power modulation of a wind turbine can mitigate oscillations in the grid. Oscillations occur as power is transmitted across long transmission lines, such as region to region. If oscillations are poorly damped, they can jeopardize grid stability and lead to widespread outages during stressed grid conditions.

Using a modified control algorithm from a prior test of the Pacific DC intertie—a power transmission line spanning the Pacific Northwest to Los Angeles—Sandia, Baylor, and Group NIRE simultaneously tested whether it would be feasible to use the same rotor modulation technique to dampen interarea oscillations. Using a grid-connected Vestas V27 wind turbine at SWiFT, a control system at Sandia's Control and Optimization of Networked Energy Technologies Laboratory, and phasor measurement units on the grid, the team successfully tested the ability to use a wind turbine to supply load balancing reserve energy and stabilize a wide-area grid.

Although additional research is needed into the operation and maintenance costs of turbine modulation, initial results indicate that wind turbines could be a significant source of flexibility and resilience on the grid, in addition to contributing valuable grid services and a new, potential source of revenue for wind power plant operators.

The results are publicly available from Sandia in the report, "Use of Wind Turbine Kinetic Energy to Supply Transmission Level Services."

Wind turbines could be a significant source of flexibility and resilience on the electric grid, according to research conducted at the Scaled Wind Farm Technology facility. *Photo courtesy of Sandia*

Funding and Other Opportunities

Upcoming R&D Funding Opportunity for Advanced Manufacturing of Offshore Wind Technologies

Oak Ridge National Laboratory, in support of DOE's WETO and Advanced Manufacturing Office, intends to issue a request for proposals on "Advanced Materials and Manufacturing R&D for Offshore Wind Components" during the first quarter of fiscal year 2019. The focus of this opportunity will be on the additive manufacturing of materials and methods for offshore wind components. Please send an email with your name, affiliation, and email address to Dominic Lee *leedf@ornl.gov* to receive information about this opportunity as it becomes available.

NREL Releases Request for Proposals for Collegiate Wind Competition 2020

DOE's NREL has issued a request for proposals for colleges and universities interested in participating in the DOE Collegiate Wind Competition 2020. The organizers will select 10 to 12 teams of students to compete in the challenge, co-located with AWEA's WINDPOWER Conference in Denver, Colorado, on June 1–4, 2020. Interested students and faculty can learn more about the request for proposals and corresponding requirements by visiting the FedBizOpps listing at *FBO.gov* and searching for "Collegiate Wind Competition" in the keyword search box.

WIND INDUSTRY EVENTS

International Offshore Wind Technical Conference
November 4–7, 2018
San Francisco, California

Southeast Renewable Energy Summit
November 7–9, 2018
Atlanta, Georgia

NYSERDA Offshore Wind and Wildlife Workshop
November 13, 2018
Woodbury, New York

AWEA Wind Energy Fall Symposium
November 13–15, 2018
Colorado Springs, Colorado

Wind Wildlife Research Meeting XII
November 27–30, 2018
St. Paul, Minnesota

SciTech Wind Energy Symposium
January 7–11, 2019
San Diego, California

AWEA Wind Project O&M and Safety Conference
February 27–28, 2019
San Diego, California

2019 Business Network for Offshore Wind International Partnering Forum
April 8–11, 2019
New York, New York

AWEA WINDPOWER
May 20–23, 2019
Houston, Texas

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