NREL
Transforming ENERGY

WIND ENERGY

Accomplishments and Midyear Performance Report

FISCAL YEAR 2023

Notice

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Foreword

Current indicators point to Fiscal Year (FY) 2023 being a year of trailblazing accomplishments for NREL's wind energy program. Aligning with the U.S. Department of Energy's (DOE's) Wind Energy Technologies Office (WETO) priorities of creating clean energy jobs, combating climate change, and promoting energy justice, the National Renewable Energy Laboratory's (NREL's) wind energy program is on track to achieve an exceptional year of wind energy innovation across its entire portfolio.

On top of that, the National Wind Technology Center (NWTC) is celebrating 30 years of advancing wind energy science. Based at NREL's Flatirons Campus since 1993, the NWTC has attracted many dedicated scientists, researchers, partners, and supporters who are turning WETO's national wind energy vision into a clean energy reality. In fact, NREL's wind energy program welcomed 19 new staff members in the first half of FY 2023, bringing the program's total head count to about 500.

By definition, an accomplishments report requires a look back at milestones met, goals achieved, and progress toward a shared vision. This FY 2023 *Wind Energy Accomplishments and Midyear Performance Report* does all of that and more. In reflecting on our past achievements, we set the stage for the innovative research to come.

For the NREL wind energy program, innovation is a driver for advancing wind energy. It is a core element of our strategy and an integral part of our identity. We define innovation broadly—not by relying on traditional research and development alone but by leveraging the great potential for creativity throughout the lab environment.

Wind is the United States' largest source of renewable energy, and renewable energy is NREL's sole research focus. It makes sense that the lab's wind energy program, anchored by the NWTC and supported by the breadth of capabilities available at a world-class research lab, is catapulting the wind energy industry into a remarkable future.

Just look at the program's FY 2023 midyear accomplishments through the lens of WETO's ambitious goals. They aim to:

1. Solve critical energy challenges. NREL's wind energy program is leading the charge on tackling several clean energy obstacles, both technologically and on a grand scale. NREL wind energy researchers organized a meeting with more than 100 wind energy experts from 15 countries to revisit the grand challenges in wind energy science, first compiled at an U.S.-led International Energy Agency Wind Technology Collaboration Programme meeting hosted by NREL in 2017.

2. Create clean energy jobs. The wind energy industry is poised to bring more than 100,000 new jobs to the nation's workforce. In this report, you will learn how NREL's wind energy program contributed to DOE's mission through projects like the National Wind Workforce Assessment and the WINDExchange Webinar Series.

3. Promote energy justice. How can DOE and WETO ensure that the nation's transition to clean energy improves energy justice? NREL stands at the forefront of this question, leading projects like the Los Angeles 100% Renewable Energy Study. NREL's wind energy program is addressing the impacts of factors that contribute to energy inequities through the Wind Energy Equity Engagement project, for one, which gathers information from stakeholders and communities that host wind energy facilities to define and study the implications of large-scale, land-based and offshore wind energy facilities on equity.

These are just a few examples of how NREL's Wind Program is contributing to America's clean energy future. This report provides more details on the achievements and accomplishments by the lab in support of WETO's vision for the program and its partners during the first half of FY 2023 (between Oct. 1, 2022, and March 31, 2023).

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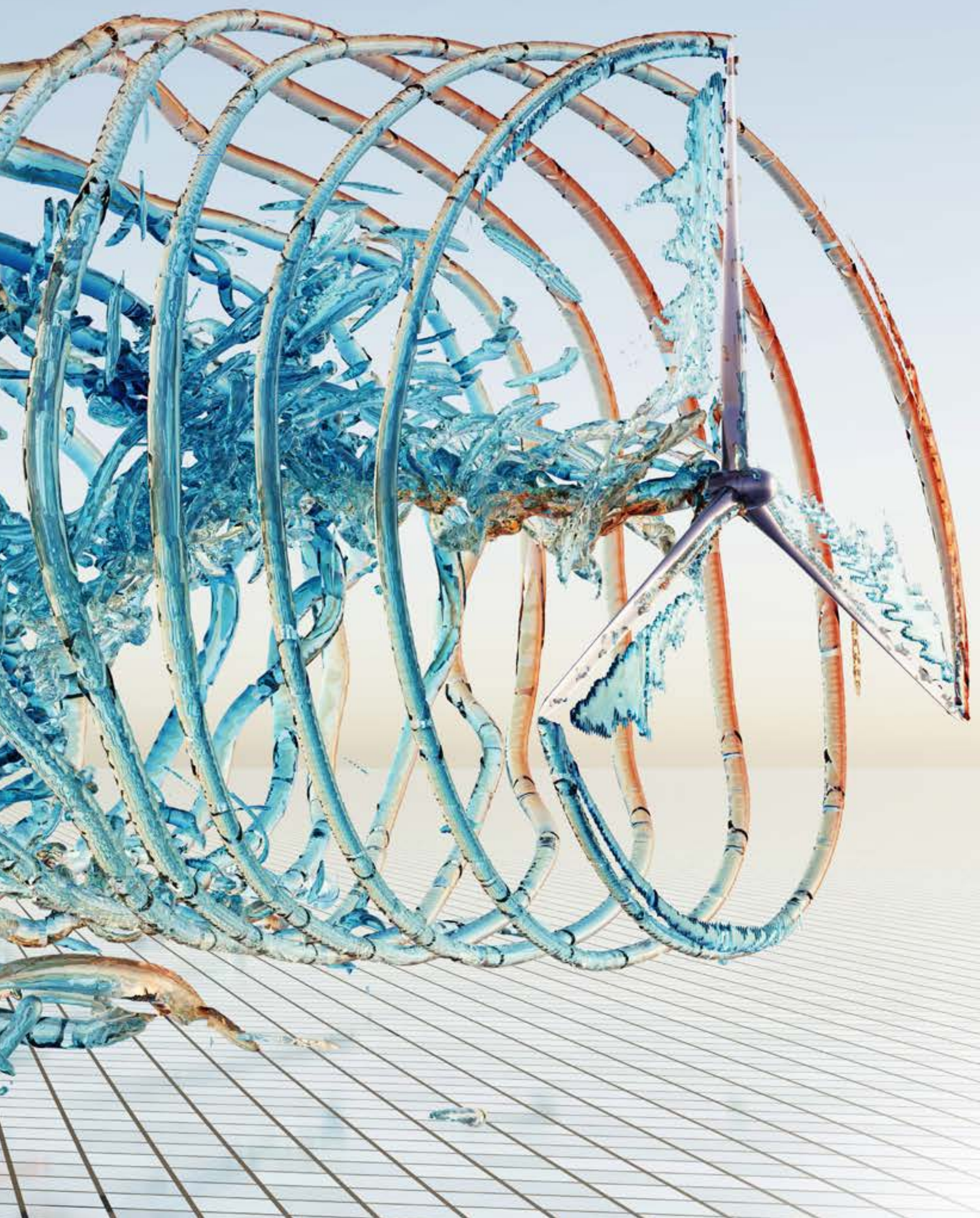
People and Partnerships



The People Behind NREL's Wind Energy Research Accomplishments

Behind the Blades is a regular feature in the NREL wind energy program's *The Leading Edge* newsletter. The articles have become a successful form of engagement on social media, revealing the faces, stories, and work behind advancing wind energy. (The following article, originally from the October/November 2022 newsletter, has been edited for length.)

Stefek Studies the Intersection Between Wind Energy and the Workforce Needed To Support It

One of the dedicated team members behind NREL's investigations into how many wind energy jobs are needed, in what roles within the industry, and what challenges they might face, is Jeremy Stefek, a workforce and economic development researcher.

Stefek has always been interested in the intersection between energy and people. When an internship opportunity opened in NREL's wind energy program that bridged the economic and societal impacts of wind energy, the then-graduate student at the University of Colorado Boulder thought it would be a perfect fit.

"I grew up in a rural community in Texas, so understanding wind energy's challenges and benefits to the community hit close to home," Stefek said.

That internship was in 2017. Now, 6 years into a career as a workforce and economic development researcher at NREL, he'll say what keeps him here are the variety of projects he gets to work on, the opportunity to grow in his field of economic and workforce development, and the people at the lab dedicated to advancing renewable energy in the United States.

"While technology and R&D are super important to advancing clean energy, I think people and their decisions will also be a primary mover in renewable energy deployment," Stefek said. "Increasing our social science research can help us understand how people think and feel about renewable energy, and we can help support them to increase their understanding of the technology impacts on their communities."

Stefek was instrumental in providing research for two economic- and workforce-related studies at NREL. One, published in the *U.S. Offshore Wind Workforce Assessment*, looked at the demand and supply of workers for the emerging offshore wind energy industry. The other, documented in *Defining the Wind Energy Workforce Gap*, looked at the reasons why wind energy industry employers have difficulty finding a qualified workforce while students report difficulty finding jobs.

Stefek is constantly looking forward, determined to put people first as our nation deploys more wind energy.

"I hope the wind energy workforce can become more diverse, have access to training opportunities, and that deploying renewable energy can support communities with economic opportunities," he said. "That includes ensuring that wind energy installations are manufactured, constructed, and operated with a domestic workforce."

Putting people first is key to Stefek's success at NREL and, it turns out, may be key to wind energy's success as well.

Jeremy Stefek (right) at a wind farm in Colorado. Also shown are former NREL colleagues Suzanne Tegen (left) and Anna Kaelin (center). *Photo by Owen Roberts, NREL*

Awards and Recognition

NREL's Brent Summerville (left) received the Windustry Distinguished Service in Community Wind Award in February 2023 for his work on distributed wind energy projects. The winner of a different award, Devon "Rocky" McIntosh (right) of Sonsight Wind, is also a recipient of several Competitiveness Improvement Project awards. *Photo from the Distributed Wind Energy Association*

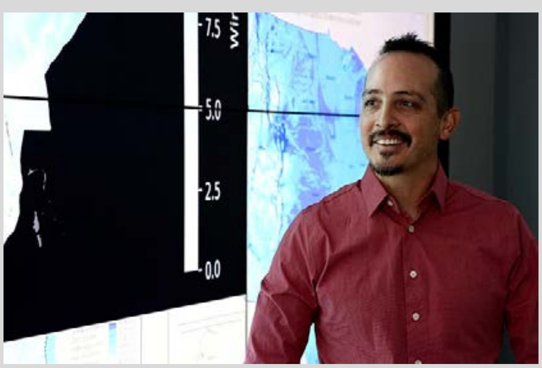
Summerville Receives Award for Contributions to Community, Distributed Wind

Brent Summerville, an NREL systems engineer, received the Windustry 2023 Distinguished Service in Community Wind Award from the Distributed Wind Energy Association. The award is given annually to a person or program that has made significant contributions, over several years, "to the establishment and growth of locally owned and distributed wind as a uniquely valuable form of clean, renewable energy." This award recognizes Summerville's work on numerous distributed wind energy projects—including standards development, the Competitiveness Improvement Project, and deployable wind energy systems—as well as his outstanding dedication, excellence, and achievement in furthering the goals of community wind and distributed renewable energy.

Jonkman Awarded for Advancing Floating Offshore Wind Energy

NREL researcher Jason Jonkman received the 2022 Viterna Award for Engineering Excellence from the Business Network for Offshore Wind, honoring his contributions to the advancement of floating offshore wind energy. The award recognized Jonkman's role in developing NREL's FAST software, a first-of-its-kind engineering tool for simulating the coupled dynamic response of wind turbines. FAST helped launch the first generation of floating offshore wind turbines and continues to serve the industry today. Jonkman and his NREL research team have worked to expand the functionality of the original software to its latest version, OpenFAST.

The Business Network for Offshore Wind recognized NREL researcher Jason Jonkman (left) for contributions to advancing the development of floating offshore wind energy. *Photo from the Business Network for Offshore Wind*

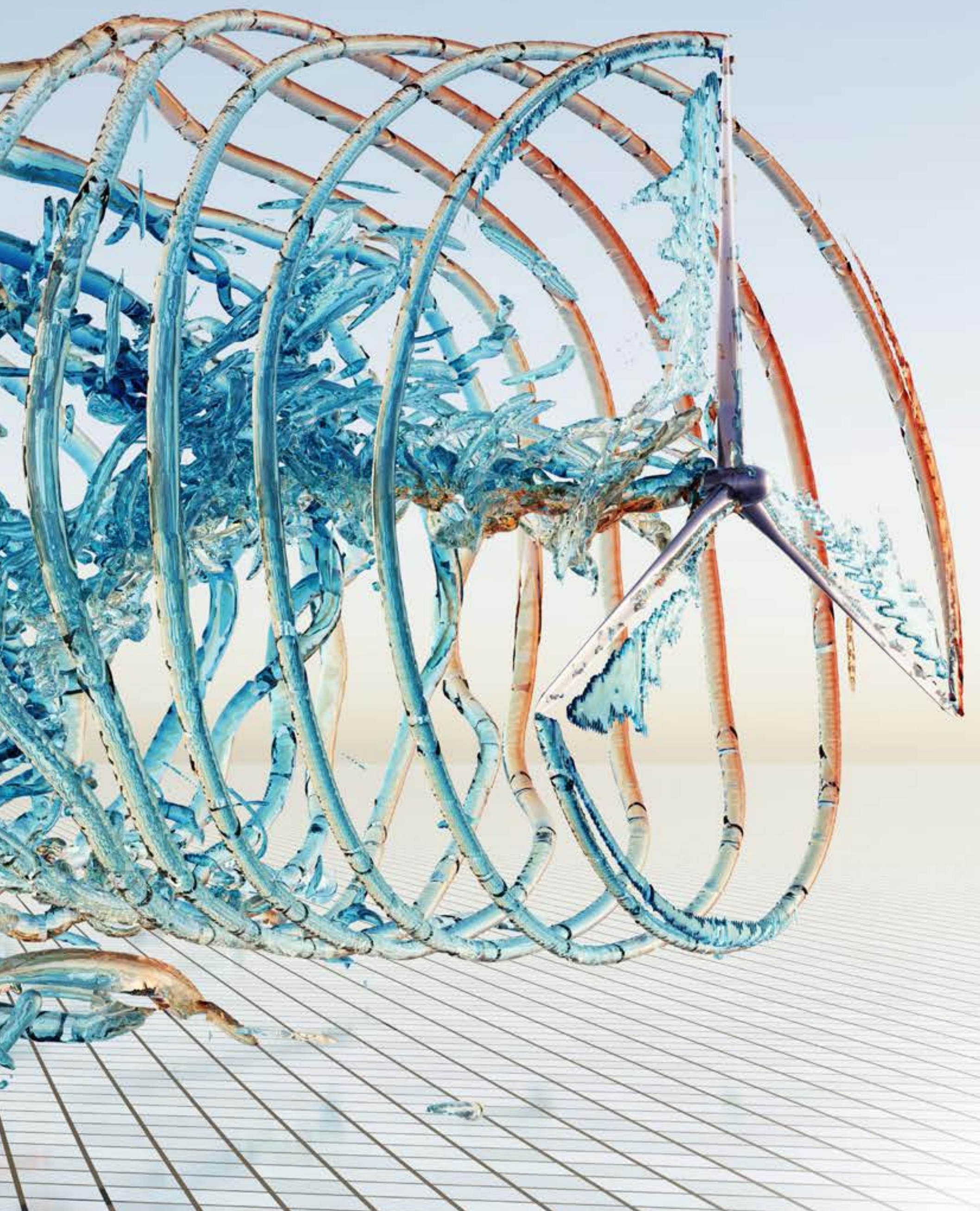


Anthony Lopez was named the Most Promising Scientist by Great Minds in STEM for his work mentoring young Hispanic generations to pursue careers in STEM and motivating professionals to meaningfully engage with the Hispanic community. *Photo by Deb Lastowka, NREL*

Lopez Named Most Promising Scientist by Great Minds in STEM

An NREL senior researcher, Anthony Lopez was named the Most Promising Scientist by Great Minds in STEM, an organization dedicated to keeping the United States technologically strong by promoting science, technology, engineering, and mathematics (STEM) careers in underserved communities. The award honors the highest-achieving scientists and engineers from the Hispanic community across the country. With more than a decade of achievements in geospatial data science at NREL, Lopez was recognized for his work mentoring and inspiring younger Hispanic generations to pursue careers in STEM subjects.

Testing Infrastructure, Standards Development, and International Engagement

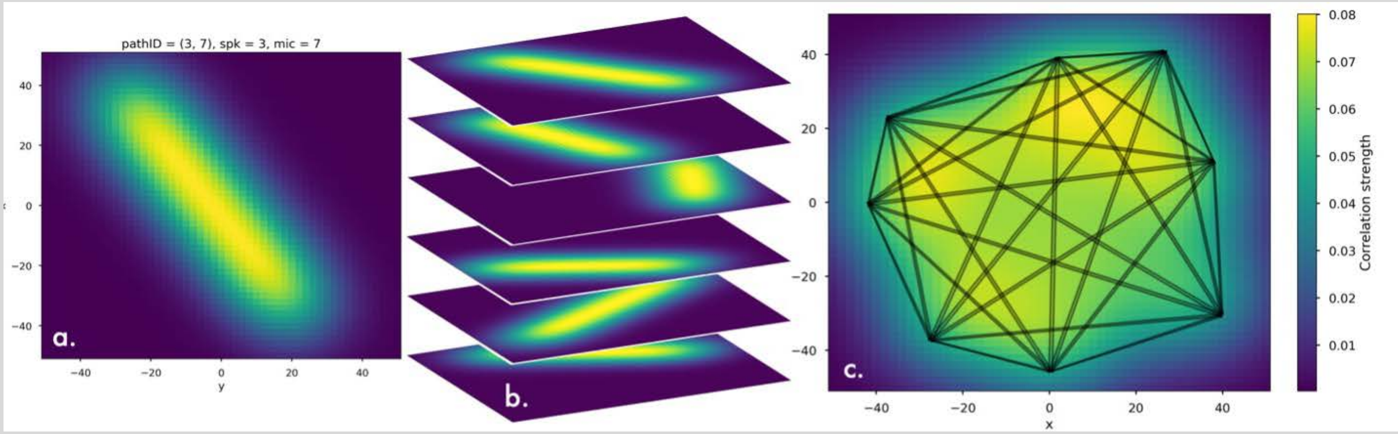


Point of Contact: Emina Maric, Emina.Maric@nrel.gov

Research Underway To Expand NREL Acoustic Tomography Capabilities

Acoustic tomography is a remote-sensing technique that uses the travel times of audio signals to determine turbulent velocity and temperature measurements. These measurements will help advance wind turbine design, wind power plant control, and the validation of high-fidelity numerical models.

NREL researchers are working to expand the Flatirons Campus acoustic tomography array to make 3D measurements that can calculate wind turbine wakes and other industrial flows. Researchers Nicholas Hamilton and Emina Maric recently published an NREL report reviewing the underlying theory behind acoustic tomography, the current configuration of the NREL acoustic tomography array, and the future array's configurations and capabilities. In January 2023, they presented their work at the American Meteorological Society's 24th Symposium on Boundary Layers and Turbulence.



Correlations between direct measurements and assumed models for travel paths obtained at the acoustic tomography array at NREL. For wind energy research and development applications, acoustic tomography offers a promising path forward for high-resolution measurements. *Graphic by Nicholas Hamilton, NREL*

Point of Contact: Jason Jonkman, Jason.Jonkman@nrel.gov

Floating Offshore Wind Turbine Design Standard on Track for International Release

The International Electrotechnical Commission (IEC) 61400-3-2 technical specification was first published to provide guidance for the emerging floating offshore wind turbine industry to ensure the engineering integrity of prototypes. Given the growth in floating offshore wind turbine maturity in recent years, an international maintenance team within the IEC was formed in 2020 to address known limitations of the technical specification and to upgrade it into a full-fledged standard, establishing international design requirements. A draft of the newest version of IEC 61400-3-2 was completed and is undergoing review and approval by international committees before final approval and publication. NREL co-led the initiative with experts from the United States, South Korea, and Germany, as well as participants from across Europe, Asia, and the Americas—and solicited feedback from the U.S. national committee. Approval and publication of IEC 61400-3-2 as an international standard should further advance the commercial maturity of the floating offshore wind turbine industry.

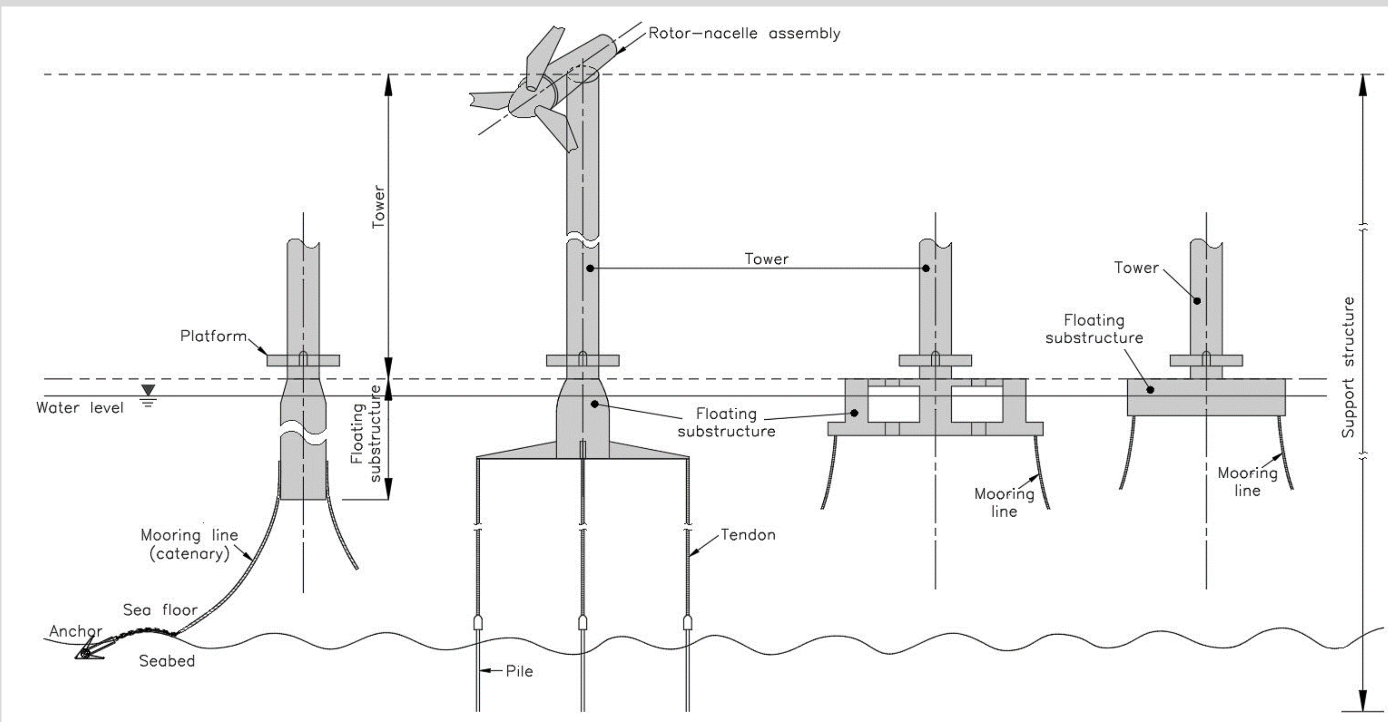
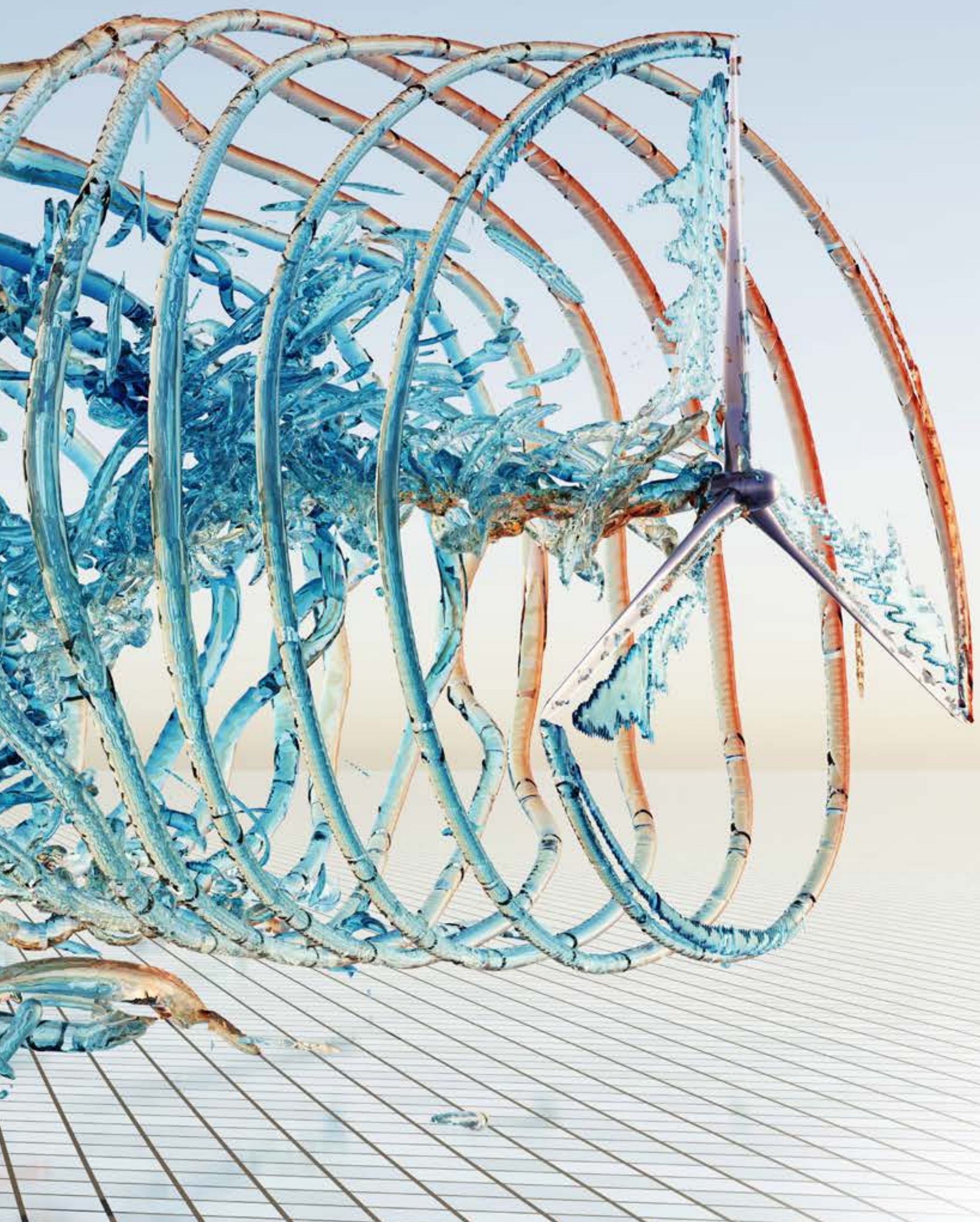


Illustration of a floating offshore wind turbine. NREL co-led an initiative to upgrade the IEC standard that establishes international design requirements for these machines. *Graphic from Hyun Kyoung Shin, University of Ulsan*

Distributed Wind Research and Development



Distributed Wind Research, Development, and Testing

Point of Contact: Brent Summerville, Brent.Summerville@nrel.gov

Twelve New Distributed Wind Energy Projects Awarded Through the Competitiveness Improvement Project

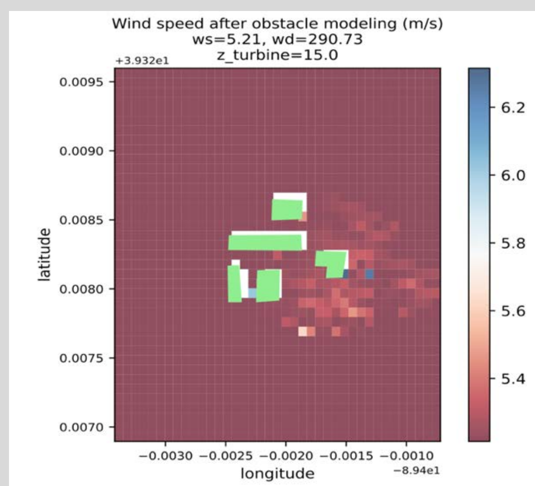
The NPS 100 distributed wind turbine installed on the campus of Appalachian State University. NPS Solutions received a CIP award to complete the electrical certification of the wind turbines power electronics to UL 1741-SA, a requirement for the U.S. market. *Photo by Brent Summerville, NREL 73713*

The U.S. Department of Energy and NREL announced 12 new projects selected from the November 2022 Competitiveness Improvement Project (CIP) request for proposals—a record number. CIP awards help manufacturers of distributed wind energy technology optimize their designs to reduce cost and improve performance, develop advanced manufacturing processes, support distributed wind energy adoption through turbine and component certification, and accelerate pathways for commercialization. Since its debut in 2012, CIP has helped more than two dozen small businesses across the United States develop new and innovative distributed wind energy technologies. These historic funding levels and number of projects in the latest round are timely for the U.S. distributed wind energy industry as original equipment manufacturers gear up for a long-term, favorable policy environment. Two of these projects fall under a new topic area focused on commercialization and market development: Bergey Windpower Co. will develop customer financing to expand its market, and Eocycle America will build partnerships with agricultural companies for large-scale deployment.

Tools Assessing Performance

Point of Contact: Heidi Tinnesand, Heidi.Tinnesand@nrel.gov

New Feature Allows Users To Visualize Wind Speed Deficit Behind Trees and Buildings



An illustration produced by the TAP software shows wind speed over a 10-minute period across a proposed distributed wind turbine site that includes five main buildings. A new feature enables TAP users to determine precisely how close to obstacles (such as buildings and trees, which are represented by green shapes above) the wind turbine can be installed. *Graphic by Dmitry Duplyakin, NREL*

The Tools Assessing Performance (TAP) software allows users to estimate the average wind speed and direction at prospective distributed wind energy project sites. One of the newest features added to the software is a heat map—a high-resolution image of the wind speed at several hundred points within the project domain. This new feature allows stakeholders in the wind energy industry to understand the extent of the disturbed flow in the lee or wake of building and vegetation obstacles. Users can then determine precisely how close to the obstacles the distributed wind turbine can be installed. The software's heat maps leverage two obstacle modeling approaches, one from Los Alamos National Laboratory and the other from Argonne National Laboratory.

On-Site Wind for Rural Load Centers

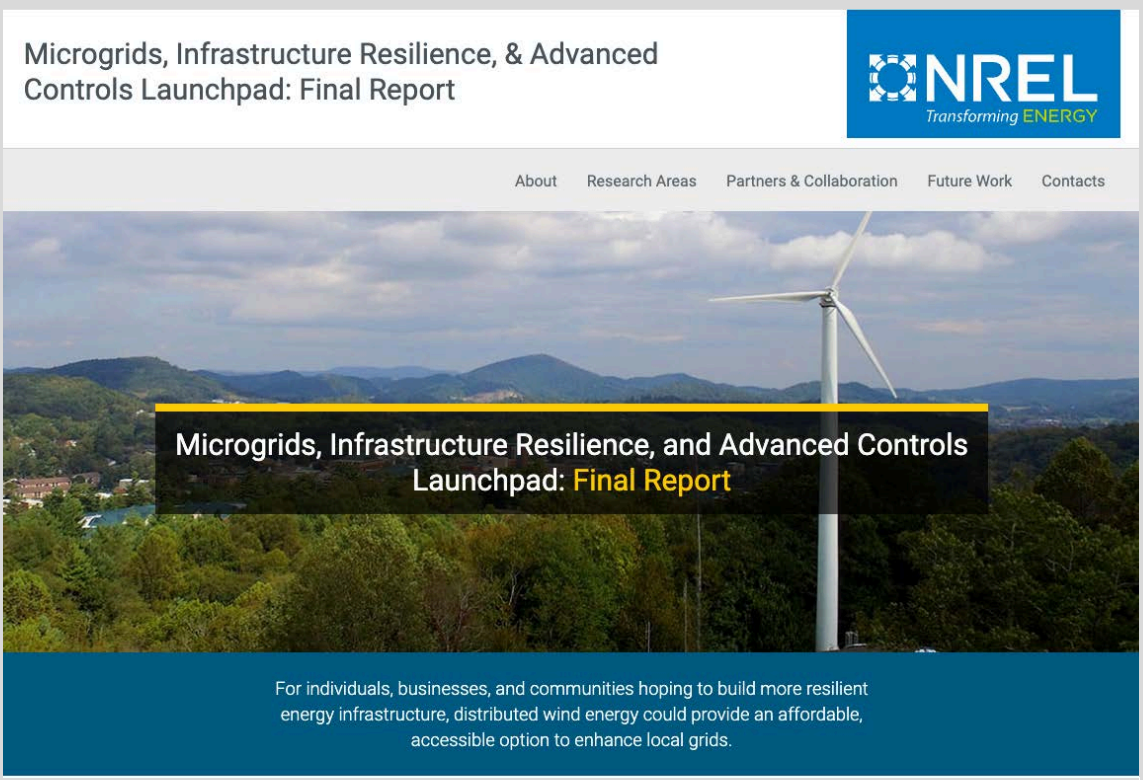
Point of Contact: Caitlyn Clark, Caitlyn.Clark@nrel.gov

Multilab Team Collaborates With Communities To Enhance Resilience Through Hybrid System Design

The On-Site Wind for Rural Load Centers project focuses on providing tools and templates that maximize value streams and meet local resilience requirements by matching resources to local electricity demands in rural areas. In partnership with Algona Municipal Utilities, the team (researchers from Iowa State University, Idaho National Laboratory, Pacific Northwest National Laboratory, and NREL) conducted a case study to design a resilient-optimal hybrid power plant based on local electricity needs, existing backup generation assets, hazards, and resilience goals. To do this, the team integrated NREL's Hybrid Optimization and Performance Platform, Idaho National Laboratory's Resilience Framework for Distributed Energy Systems, and Pacific Northwest National Laboratory's Valuation Tool. Algona Municipal Utilities will use the results of this research to justify grid investments. NREL also completed a follow-up study quantifying the incremental value of capacity increases in decreasing loss of load expectation, enabling stakeholders to make more informed decisions in asset investments based on outage avoidance.

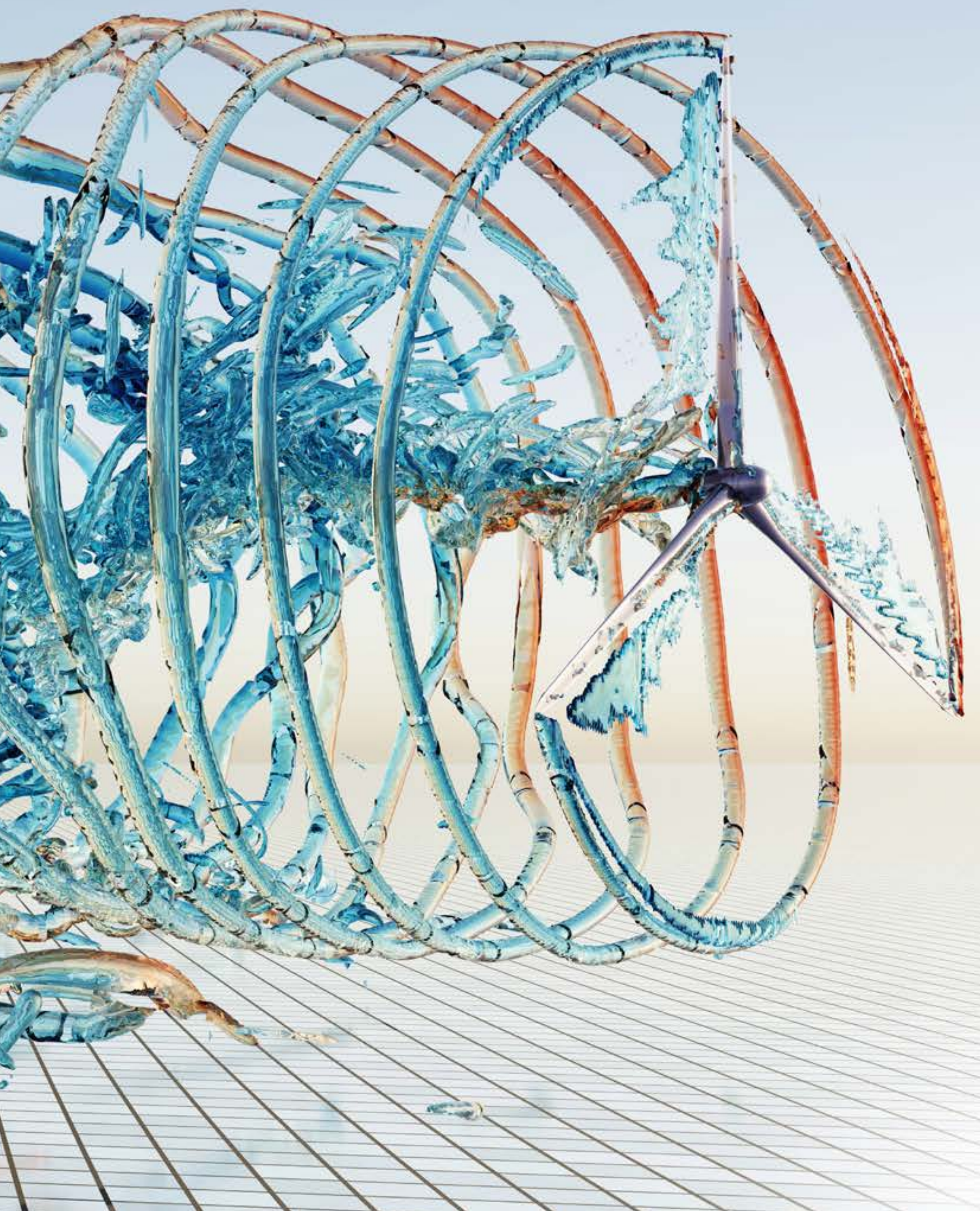
MIRACL Team Publishes Results Compendium

Making their project's outcomes more accessible to a broader audience, researchers working on the Microgrids, Infrastructure Resilience, and Advanced Controls Launchpad (MIRACL) project recently published a publicly accessible digital compendium. This compendium assembles all project outputs, including models, code, reports, data, presentations, and articles. The multilab, multiyear MIRACL project officially ended in Fiscal Year 2022.



The landing page of the new MIRACL Compendium, which provides public access to the results of the multiyear research project. *Photo by Brent Summerville; compendium by NREL*

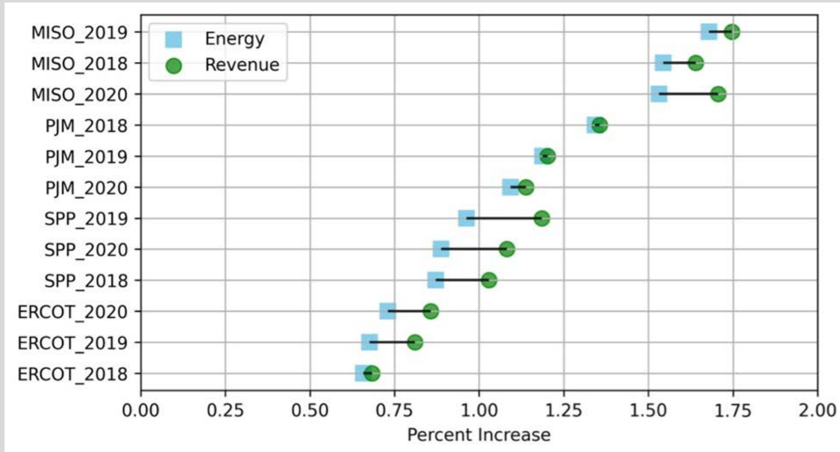
Atmosphere to Electrons



Advanced Control and System Design for Offshore Wind Turbines and Wind Plants

Point of Contact: Eric Simley, Eric.Simley@nrel.gov

Wake Steering Wind Plant Control Can Provide Value to U.S. Electric Grid



The additional increase in value (revenue) from wake steering above the energy gain shown as annual regional values for the following electricity market regions: the Midcontinent Independent System Operator (MISO), the PJM regional transmission organization, the Southwest Power Pool (SPP), and the Electric Reliability Council of Texas (ERCOT). *Graphic by Paul Fleming, NREL*

Wake steering is a wind power plant control method in which turbines are misaligned with the wind to deflect their wakes away from downstream turbines, increasing total power production. Researchers from NREL and Lawrence Berkeley National Laboratory used the FLOw Redirection and Induction in Steady State (FLORIS) wind power plant control modeling tool, together with historical hourly wind resource data and electricity prices for 2018–2020, to assess the potential increase in market value from wake steering for 15 U.S. wind power plants. For all plants, spanning four electricity market regions, the relative increase in market value from wake steering exceeds the relative increase in energy production—by 10% on average—because the energy gains tend to occur when electricity prices are highest. Also, the additional increase in market value from wake steering relative to the increase in energy is highest in regions where a greater portion of electricity is generated by wind. For example, in the Southwest Power Pool region, which spans 14 states in the central portions of the United States, wind energy contributes 31% of the electricity generation and the average increase in market value from wake steering is 21% higher than the increase in energy. These results suggest that the value offered by wake steering to the electric grid will increase as the amount of wind energy in the United States continues to grow.

Rotor Wake Measurements and Predictions for Validation

Point of Contact: Paula Doubrawa, Paula.Doubrawa@nrel.gov

Machine Learning Opens Door To Recreate Real-World Wind Events in Simulations

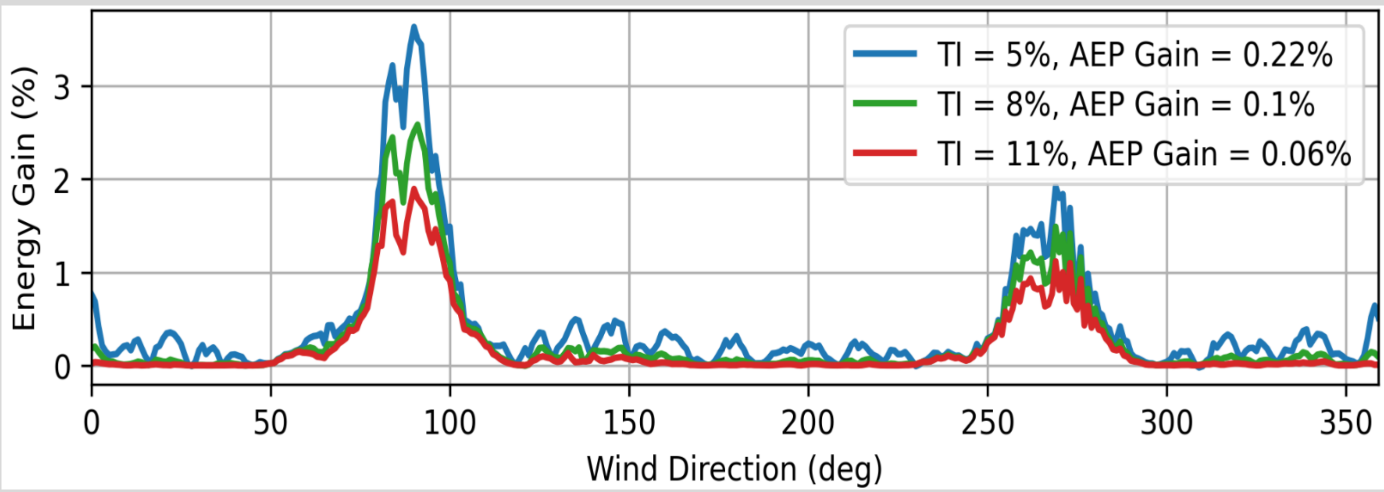
NREL researchers successfully applied machine-learning algorithms to embed instantaneous wind inflow measurements into computer simulations. The algorithms use localized wind measurements from a network of sensors and generate full 3D turbine inflow fields. This achievement will enhance the ability of high-fidelity supercomputer codes to recreate real-world wind events. Preliminary analysis suggests these new simulations can accurately track measured inflow wind speeds over the lifetime of a turbulent gust, providing more realistic flow conditions to drive computer simulations of wind turbine behavior and enable greater understanding of the linkage between component behavior and specific flow patterns. This linkage will help the wind energy industry design and operate wind turbines more efficiently, so they produce more power and have longer lifetimes.

American WAKE ExperimeNt

Point of Contact: Patrick Moriarty, Patrick.Moriarty@nrel.gov

AWAKEN Set To Begin Cutting-Edge Research Thanks to New Project Agreement

A cooperative research and development agreement (CRADA) was signed by partners in the American WAKE ExperimeNt (AWAKEN) project, allowing for proposed research to begin. The CRADA, involving General Electric (GE), Engie, and three national laboratories (NREL, Sandia National Laboratories, and Pacific Northwest National Laboratory), allows researchers to share detailed data of wind turbine operation and response and enables researchers to install state-of-the-art sensors on wind turbines to measure surrounding winds and turbine structural response. The study will begin with the implementation of wind farm controls on a large subset of wind turbines at the King Plains wind farm in Oklahoma that are predicted to increase overall wind energy production of the farm.

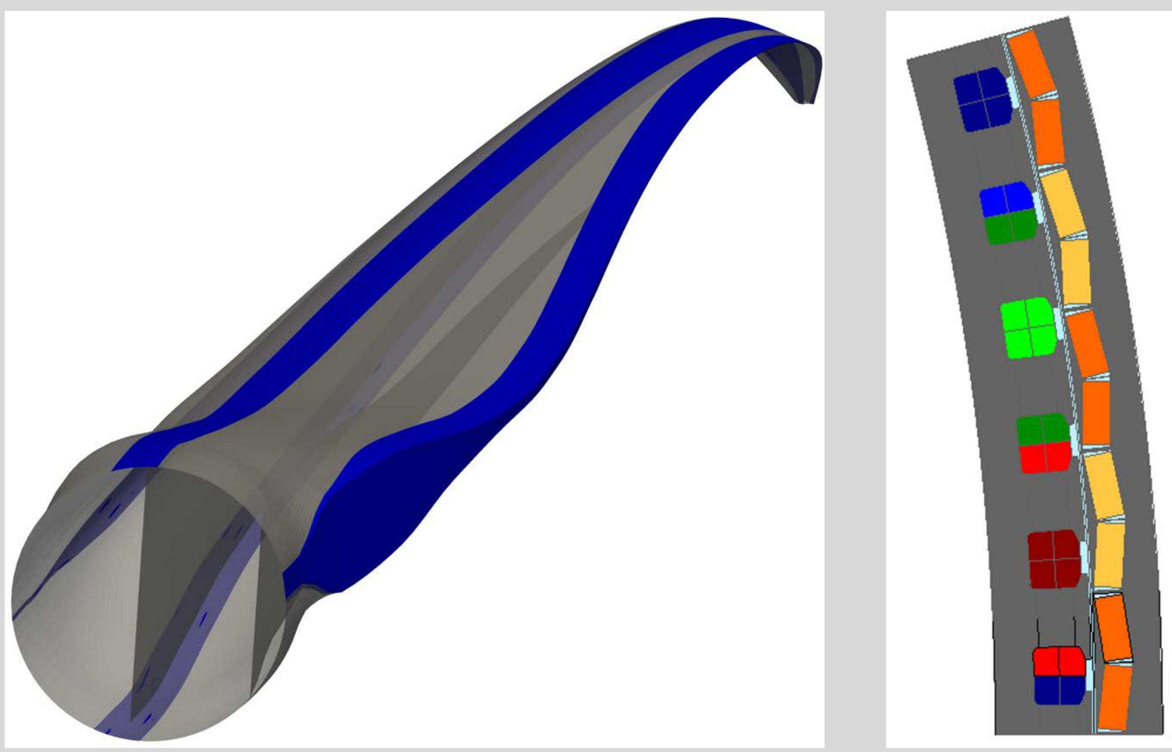


Predicted energy gains from the AWAKEN controls study, shown as a function of wind direction and turbulence intensity (TI). An agreement was signed that allows proposed research to start. *Graphic by Eric Simley, NREL*

Point of Contact: Garrett Barter, Garrett.Barter@nrel.gov

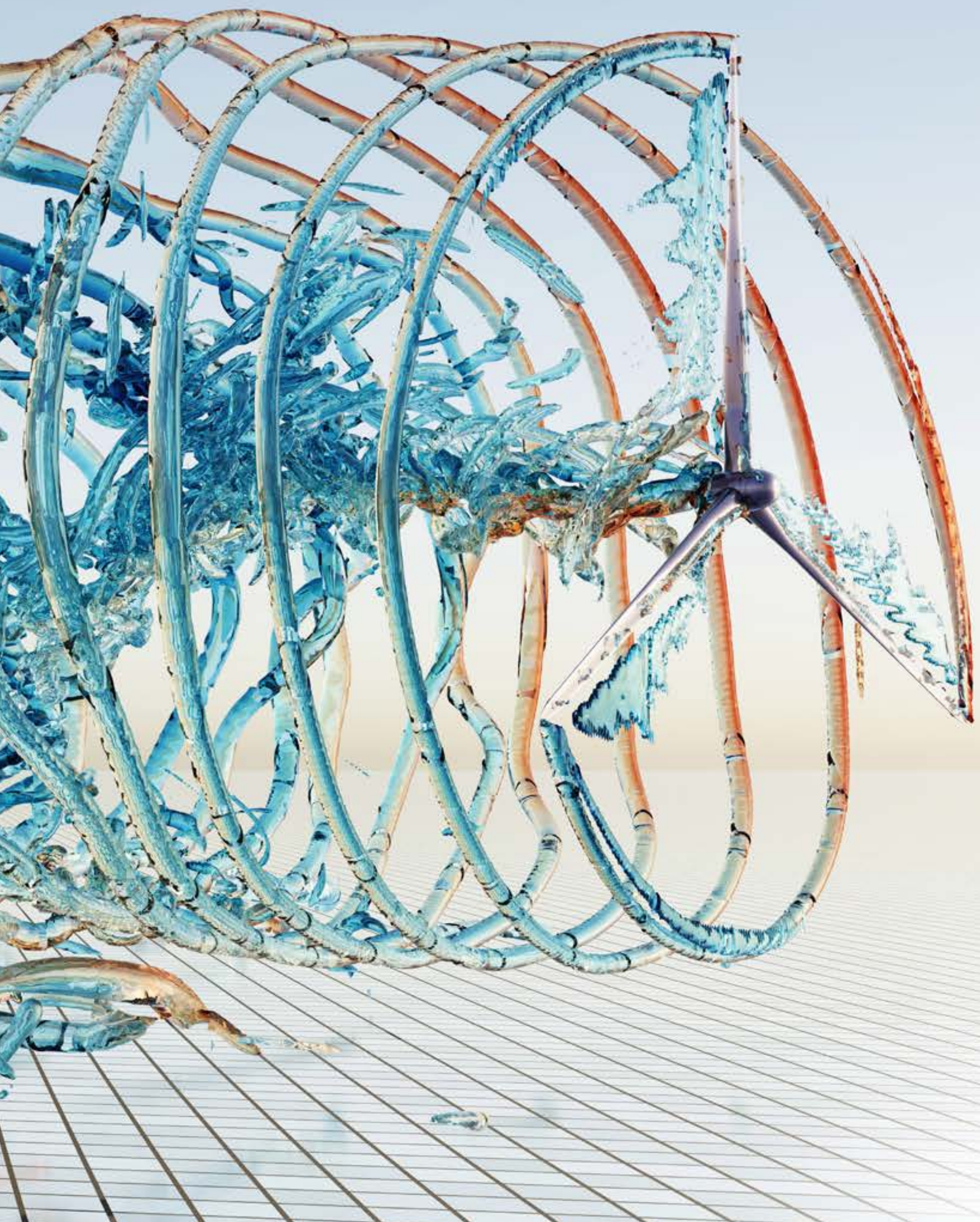
Preliminary Model Design Completed for IEA Wind 22-MW Reference Wind Turbine

NREL researchers are leading a project that assesses how a change in a single design element may affect the performance and cost objectives of an entire wind energy system. It is a holistic, integrated, systems engineering approach to wind energy research design, development, and operation. As part of this project, NREL, in conjunction with the Technical University of Denmark, co-leads the International Energy Agency's Wind Technology Collaboration Programme (IEA Wind) Task 37. In 2022, the task released a preliminary design of a 22-megawatt (MW) offshore wind reference turbine in both fixed-bottom and floating configurations. This initial design was publicly presented at the Task 37 annual meeting and in a webinar of interested stakeholders. NREL conducted a survey to solicit feedback on the new design from the broader wind energy community. NREL also led the detailed design of a direct-drive generator and the initial design of a offshore monopile and semisubmersible floater. The team released a conceptual design, making it publicly available to early adopters in the wind energy community so they could evaluate the model and identify issues that should be corrected before the official release at the end of FY 2023. This model design has the potential to impact improvements in overall system performance and cost reductions in wind energy.



Conceptual design of the IEA Wind 22-MW reference wind turbine blades (left) and electromagnetic configuration (right) of the direct-drive generator. *Image by Frederik Zahle and Hannes Labuschagne, NREL*

Offshore Wind Specific Research and Development



Great Lakes Offshore Wind

Point of Contact: Rebecca Green, Rebecca.Green@nrel.gov

Huge Potential of Offshore Wind Energy in the Great Lakes Is Just the Tip of the Iceberg

NREL assessed the opportunities and challenges around the development of offshore wind energy in the Great Lakes of North America. *Photo from The Great Lakes page in the National Aeronautics and Space Administration's Ocean Color Image Gallery*

The potential amount of offshore wind energy in the Great Lakes region of the United States could be substantial. More than enough, in fact, to accommodate the electricity consumption of most nearby states. But the lakes' freshwater environment poses different challenges than those faced by ocean-based offshore wind energy development. Freshwater ice, for example, is stronger than sea ice and more prevalent in the Great Lakes than in Atlantic offshore wind energy project sites, meaning that more robust offshore wind energy structures will be required for operation in the Great Lakes.

Summarizing research conducted on behalf of WETO, NREL's *Great Lakes Wind Energy Challenges and Opportunities Assessment* identifies a commercial pathway for Great Lakes wind energy that begins before 2035. In addition to outlining the wind energy potential, the report identifies the key issues that need to be tackled for this potential to be realized and defines a comprehensive research program to address these challenges.

Offshore Wind Resource Science

Point of Contact: Caroline Draxl, Caroline.Draxl@nrel.gov

Wind Forecast Improvement Project Offshore Field Campaign Sites Identified

NREL researchers began work on the Third Wind Forecast Improvement Project (WFIP3) offshore field campaign, which will take place in the Northeast U.S. Outer Continental Shelf and run for at least 1 year, starting early 2024. The first large field campaign focused on offshore wind energy in the United States, WFIP3 is a comprehensive observational and modeling study of coupled atmospheric and oceanic boundary layers. Results of the study will dramatically improve offshore wind resource measurement and modeling. In fall 2022, NREL scientists, along with those from other WFIP3 research partners (including national laboratories and universities), visited the area and identified specific locations where a variety of meteorological instruments will be deployed. This was a first, essential step in ensuring the timely planning of the field deployment. The WFIP3 research team is currently finalizing the field campaign's logistical and permitting aspects in preparation for the project's 2024 launch.

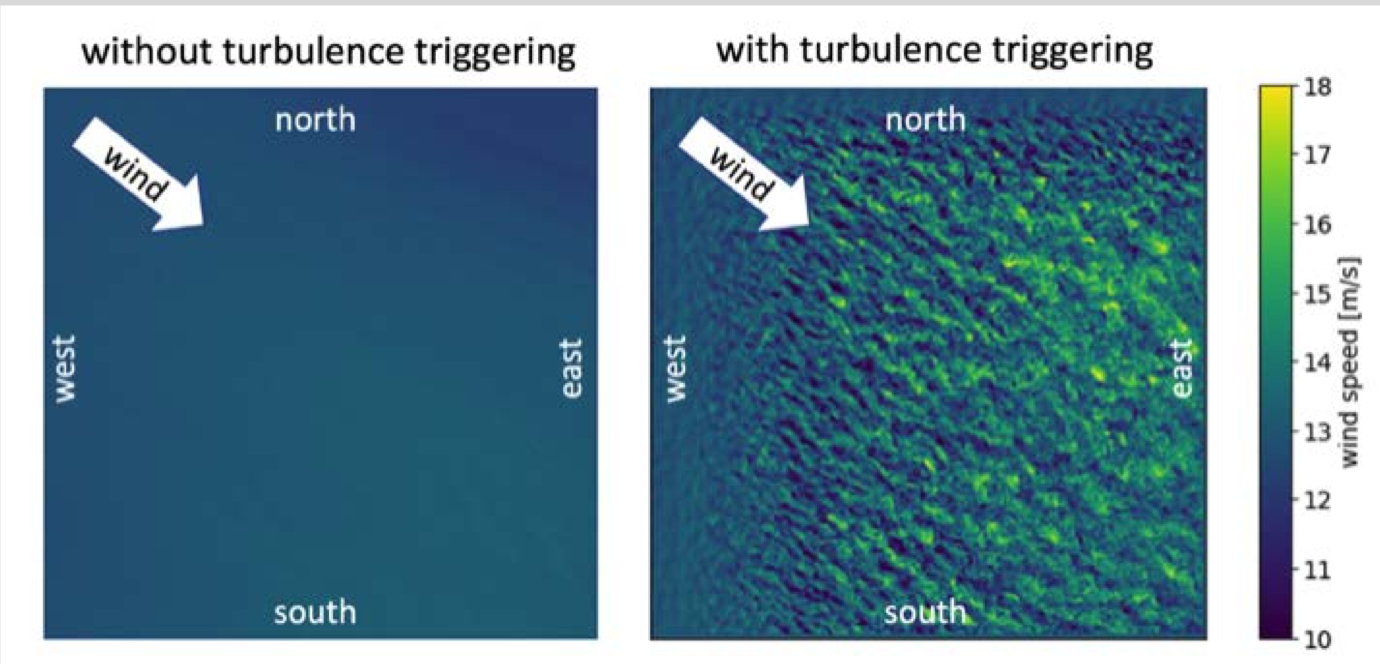
Camp Varnum, one of the instrumentation sites identified for the WFIP3 field campaign. *Photo by Nicola Bodini, NREL*

MMC Model Development

Point of Contact: Matt Churchfield, Matt.Churchfield@nrel.gov

Offshore Wind Projects Come to Successful Conclusions

Coming to a successful close in the first quarter of FY 2023, the Offshore Wind Atmospheric Coupling (OWAC) and Mesoscale-Microscale Coupling (MMC) projects resulted in robust strategies for connecting regional-scale weather information with wind-power-plant-scale turbulent flow simulations. The figure shows a bird's-eye view of the wind 100 meters (m) above the ocean from two turbulence-resolving simulations. Wind data from a regional-scale weather model, which does not resolve turbulence, are fed into this high-resolution turbulent simulation from the northwest. One critical aspect of coupling such models is how to trigger turbulence in the simulation. The simulation (shown in the figure on the right) uses a turbulence-triggering method to effectively spin up realistic turbulence, whereas the one in the left figure does not, showing just how important these triggering methods are. These coupling strategies vastly increase the realism and range of conditions under which industry and researchers can simulate plantwide flows. The projects culminated with a symposium hosted by the OWAC/MMC team and a *Wind Energy Science* journal article, "Lessons Learned in Coupling Atmospheric Models Across Scales for Onshore and Offshore Wind Energy." Findings are now informing new DOE-funded projects that would not be possible without the OWAC/MMC research, including research to simulate and better understand U.S. Pacific Coast weather and winds and U.S. Atlantic Coast hurricane weather and winds. Understanding operational and extreme conditions is important in both locations, which are planned for many offshore wind farms.

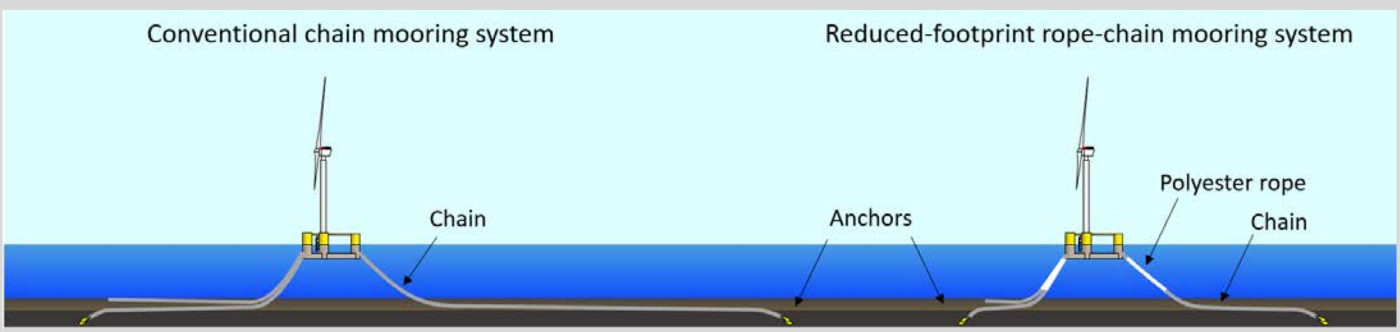


A bird's-eye view of the computed wind speed in a 5-kilometer-by-5-kilometer plane 100 m above the surface (at typical offshore wind turbine heights) at an offshore location using simulations without (left) and with (right) turbulence triggering. *Image by Regis Thedin, NREL*

Point of Contact: Matthew Hall, Matthew.Hall@nrel.gov

Compact Mooring Design Could Improve Social Acceptance of Floating Offshore Wind Energy

Floating offshore wind turbines often have chain mooring lines that spread a relatively large distance across the seabed, posing a potential obstacle for certain fishing activities. To address this issue, NREL researchers studied two types of mooring system designs for the Gulf of Maine: conventional chain mooring designs and a new reduced-footprint mooring design developed by the University of Maine, which is more compact and uses both polyester rope and chain to reduce the required mooring line length. NREL's analysis comprised two parts. The first was holding discussions with stakeholders, including those in the fishing industry and regulators, to understand the social acceptance of the two types of mooring designs. These discussions involved understanding the requirements of other ocean users, their potential interactions with the different mooring designs, and how acceptable and accessible the designs would be based on their needs (e.g., for fishing gear and vessels). The second part of the analysis involved using NREL design tools to study the suitability of both mooring designs for a range of water depths and compare their costs. In terms of other ocean users, the study found a modest increase in accessibility and acceptance for a single turbine using the rope-chain hybrid mooring system design. The results of the cost analysis show that the new mooring design can significantly reduce the mooring system's size without greatly affecting its cost over a range of water depths in the Gulf of Maine.



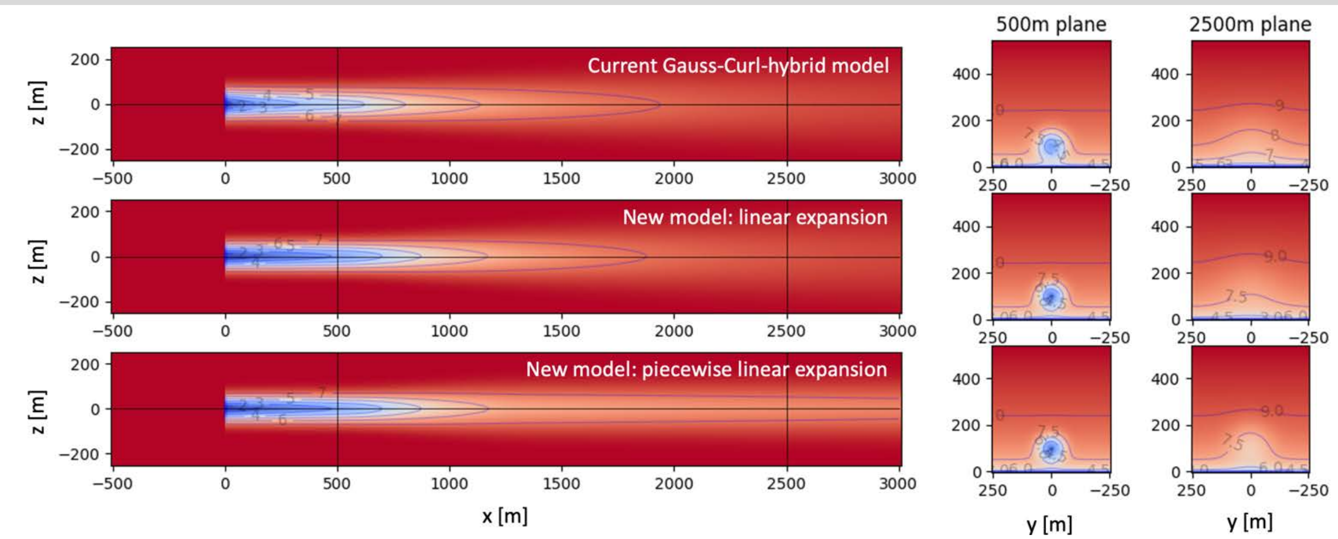
NREL researchers analyzed two floating offshore wind turbine mooring system designs: conventional (or slack) chain mooring system (left) and reduced-footprint rope-chain mooring system, which combines polyester rope and chains (right). *Image by Stein Housner and Matt Hall, NREL*

Offshore Wind Plant Controls

Point of Contact: Paul Fleming, Paul.Fleming@nrel.gov

New Wind Turbine Wake Model Designed To Be Easily Tuned to Observed Data

Experimental campaigns for advanced control strategies involve comparing simulation model results to data collected from operational wind power plants, highlighting ways in which the models can be improved. Physics-derived models, such as the Gauss-curl-hybrid model, work well in the situations for which they have been designed and tested but are difficult to adapt to circumstances outside of the original design set, such as larger wind power plants, offshore wind conditions, or different data formats. To address this gap, researchers at the National Wind Technology Center on NREL's Flatirons Campus developed a new wind turbine wake model specifically designed to be easy to adapt to observed data. The model draws inspiration from earlier physics-derived models but simplifies the model structure by limiting the number of parameters and avoiding any single parameter impacting multiple aspects of the model simultaneously. This design enables more rapid and accurate data fitting, allowing researchers to expand their analysis of experimental data and produce new specialized controls solutions for wind power plants.



The new, easy-to-tune wake model can be adapted to not only closely match (middle row) existing physics-derived wake models (such as the Gauss-curl-hybrid model, top row) but also quickly modified to better match observed features of operational wind power plant data, such as more persistent wakes (bottom row). Left-hand plots show a top-down view of the wake deficits while right-hand plots show a cross section of the wake near the wind turbine (500-m plane) and further downstream (2,500-m plane). *Figure by Misha Sinner, NREL*

NREL Researchers Increase Modeling Capabilities for Floating Offshore Wind Turbines

Floating offshore wind turbines enable development of previously inaccessible wind energy areas. As a result, researchers at NREL added the necessary capabilities to capture the performance impacts and characteristics of floating turbines in the FLORIS wind farm control modeling tool. These impacts include changes to the wind turbine's power and thrust as well as vertical wake deflection due to the tilt of the floating turbine's platform. These new capabilities will support NREL researchers, industry partners, and academic colleagues in the design and development of floating offshore wind power plants, empowering the nation's wind energy goals.

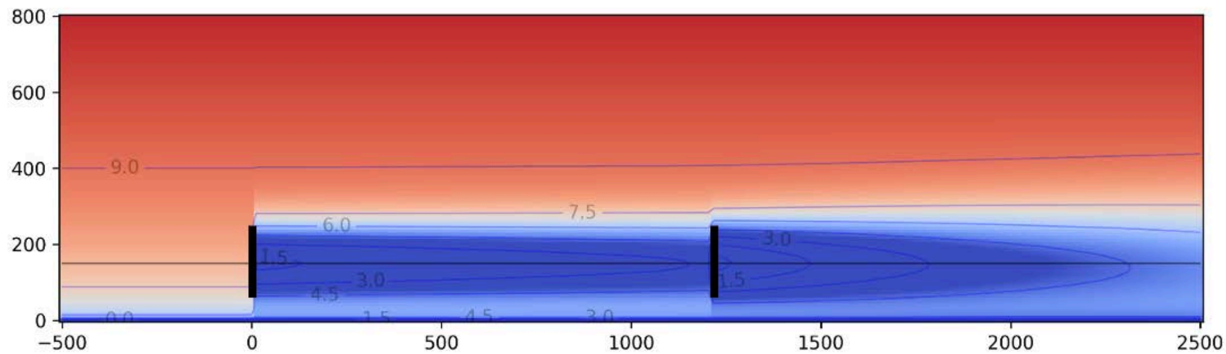


Figure 1a. Array of IEA 15MW turbines at 0 degrees of tilt.

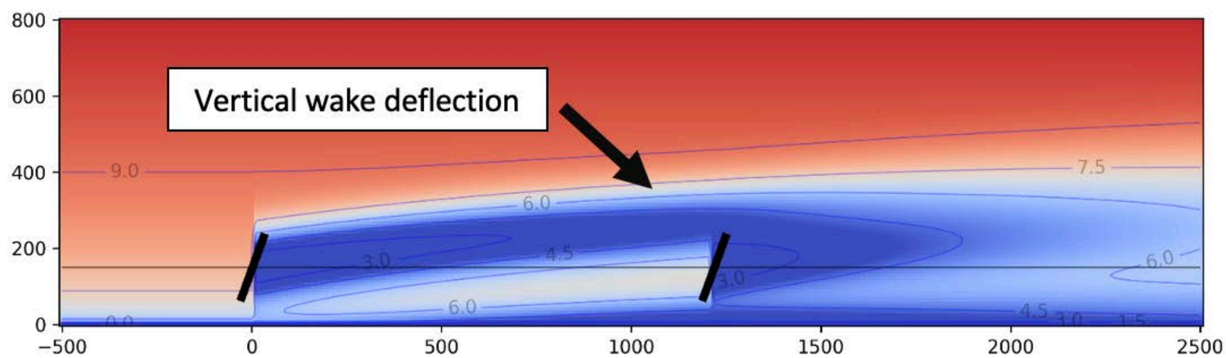


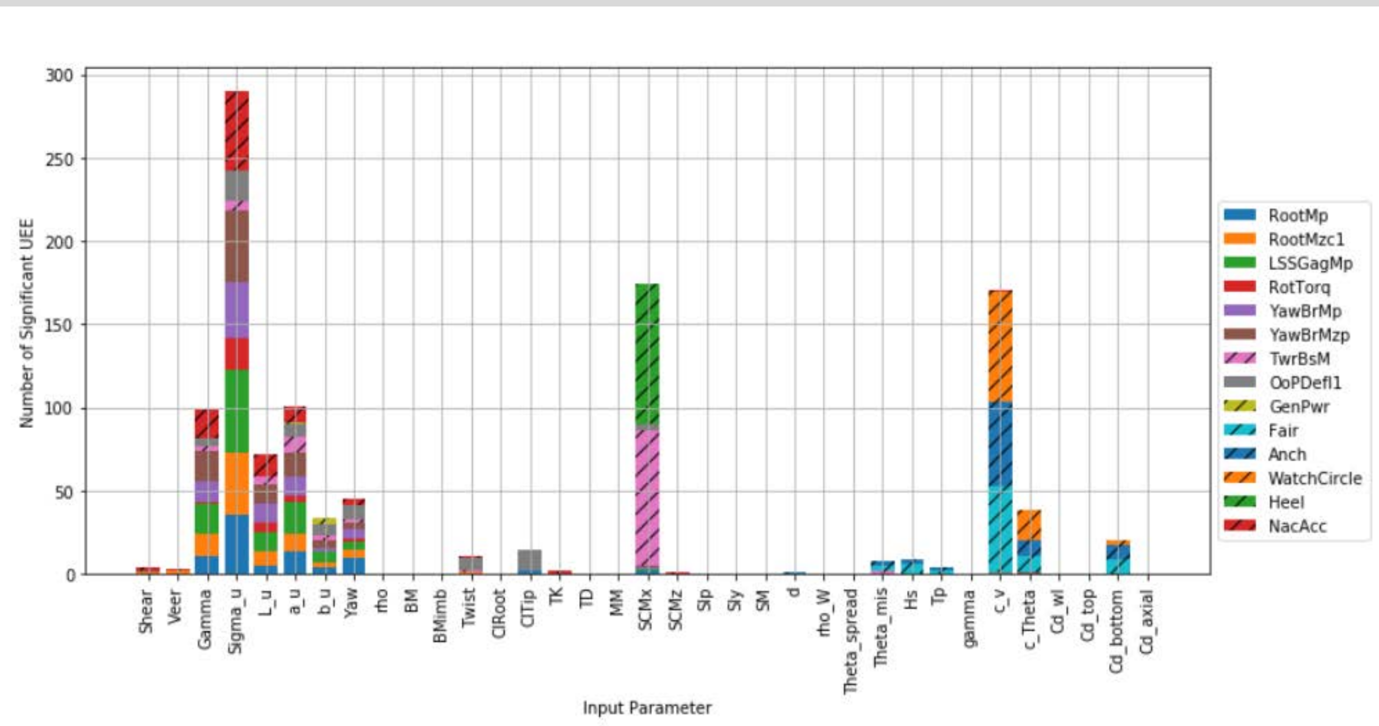
Figure 1b. Array of IEA 15MW turbines at 20 degrees of tilt.

The vertical wake deflection due to the tilt of the floating offshore wind turbine is captured in Figures 1a and 1b, where, in 1b, an upward displacement of the wake is shown. This effect is driven by the amount of tilt of the floating turbine, which is determined by the current wind condition and operating state of the wind turbine. *Image by Christopher Bay and Michael Sinner, NREL*

Point of Contact: Jason Jonkman, Jason.Jonkman@nrel.gov

Sensitivity Assessment Identifies Most Influential Parameters Effecting Floating Wind Turbine Loading

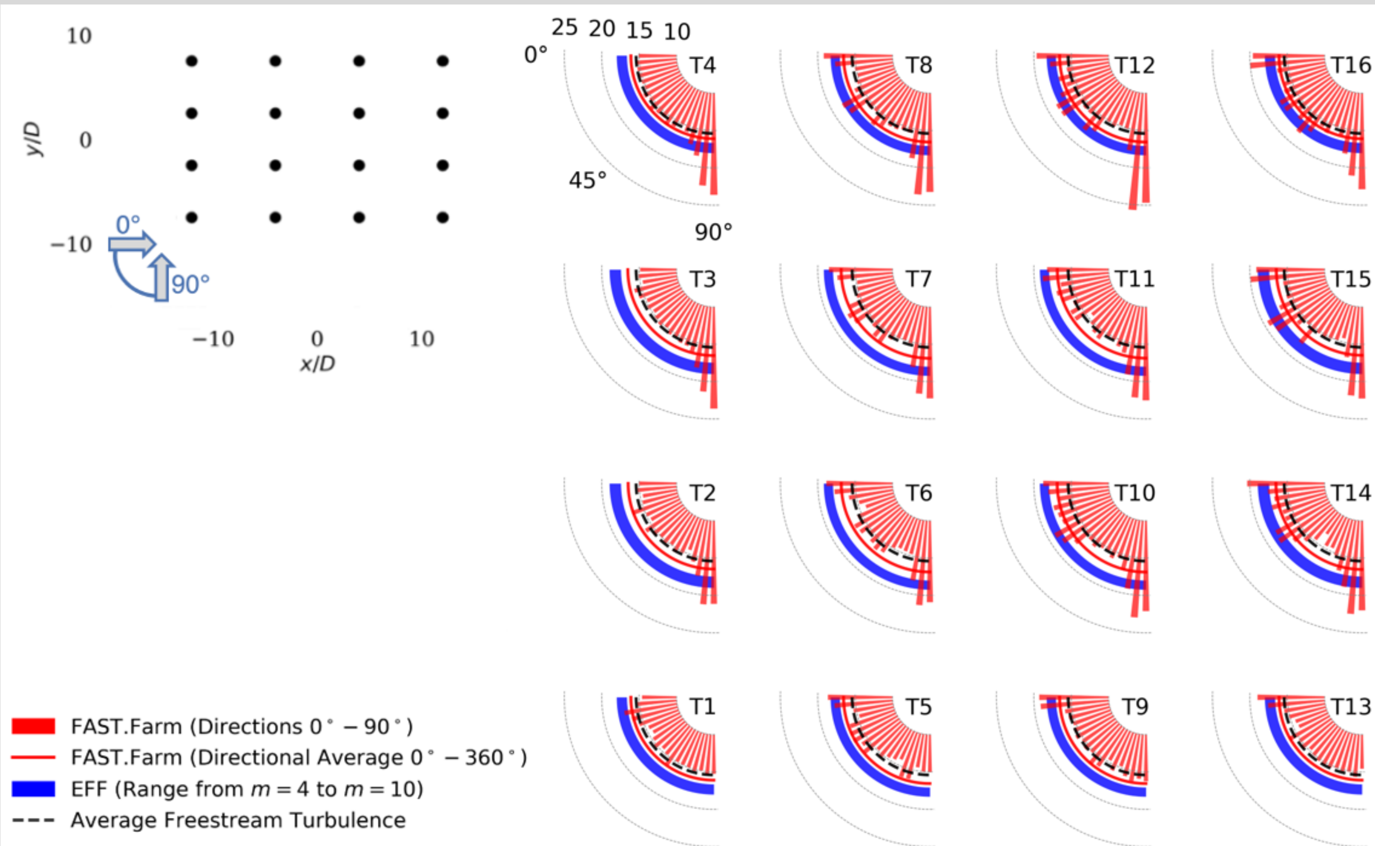
As designers move to advance and optimize floating offshore wind turbine technology, it is important to better understand how uncertainties impact modeling predictions. As a result, NREL researchers performed a sensitivity assessment to identify the information put into engineering models that likely has significant uncertainty and/or variability, such as inflow turbulence, sea state, and system properties, which are most influential to the resulting floating offshore wind turbine design loads. As a case study, researchers used the NREL 5-MW wind turbine atop the Offshore Code Comparison Collaboration Continuation (OC4)-DeepCwind semisubmersible under normal operating conditions. A paper, summarizing the methodology and results, was submitted for review and publication in *Wind Energy Science*. The results of this work will better inform the wind turbine design process and site-suitability analyses as well as help when wind turbine measurement project planning.



Results of a sensitivity assessment for ultimate loads showing the relative importance of various input parameters influencing floating offshore wind turbine loads and motions. *Graphic by Will Wiley, NREL*

Assessment of IEC Effective Turbulence Model Encourages Use of FAST.Farm to Improve Wind Plant Design

Now that physics-based, high-fidelity, and engineering models that capture the power and loading of wind turbines in a full wind power plant are becoming more accurate and available, it is likely that turbines can be better designed and optimized based on more realistic inflow conditions and wake and array effects. Two models are recommended in the IEC wind turbine design standards for accounting for wake effects in design and site-suitability analyses. NREL researchers compared the IEC effective turbulence model (EFF) and the dynamic wake meandering model (DWM) as implemented in [FAST.Farm](), an engineering tool for predicting the power performance and structural loads of wind turbines within a wind farm. An idealized four-by-four array of 5-MW wind turbines with a spacing of 5-by-8 rotor diameters and three wind-speed scenarios was simulated with both models. The results were compared in terms of ambient turbulence, wind power plant turbulence, and structural response. A paper summarizing the methodology and results was submitted for review and publication in *Wind Energy Science*. This work should encourage the wind energy community to apply physics-based models, such as FAST.Farm or similar models, to improve the wind turbine and plant design process.

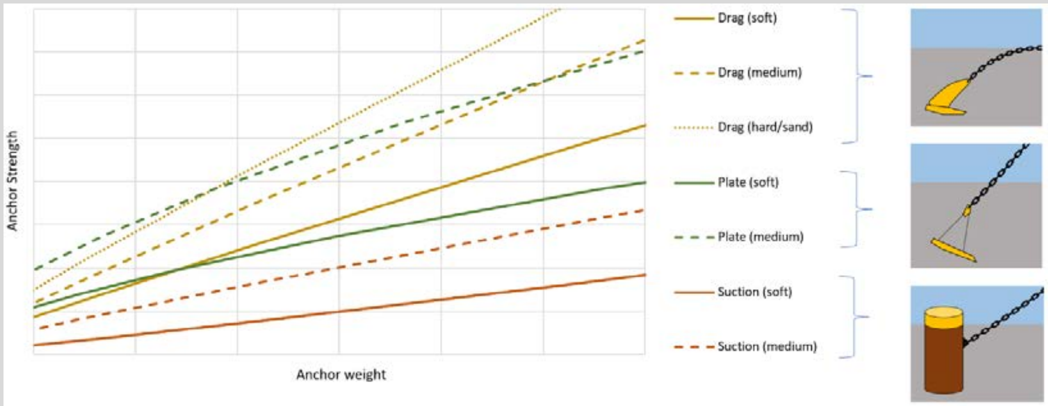


Two graphs showing the wind plant layout with wind direction convention (upper left) and the turbulence intensity results dependent on wind direction for each wind turbine in the wind plant (right). *Graphic by Paula Doubrawa, NREL*

Floating Wind Array Design

Point of Contact: Matthew Hall, Matthew.Hall@nrel.gov

Anchor Performance Models Added to Mooring Open-Source Design Tool



Anchor performance curves showing strength as a function of weight for different anchor types and soil classes. *Image by Brian Duong and Matt Hall, NREL*

Large-scale floating offshore wind farms will be key contributors to meeting offshore wind energy targets, but the design of their layout, anchors, mooring lines, and subsea power cables makes for a complex engineering challenge. As a result, NREL's Floating Wind Array Design project is developing design optimization tools and example wind farm designs to enable more holistic approaches to designing large floating wind farms. Recently, the NREL team gathered information about different anchor technologies and created models for their performance over a range of soil conditions. These models are being integrated into the open-source mooring system analysis tool MoorPy.

Floating Offshore Wind Platform Industrialization Support

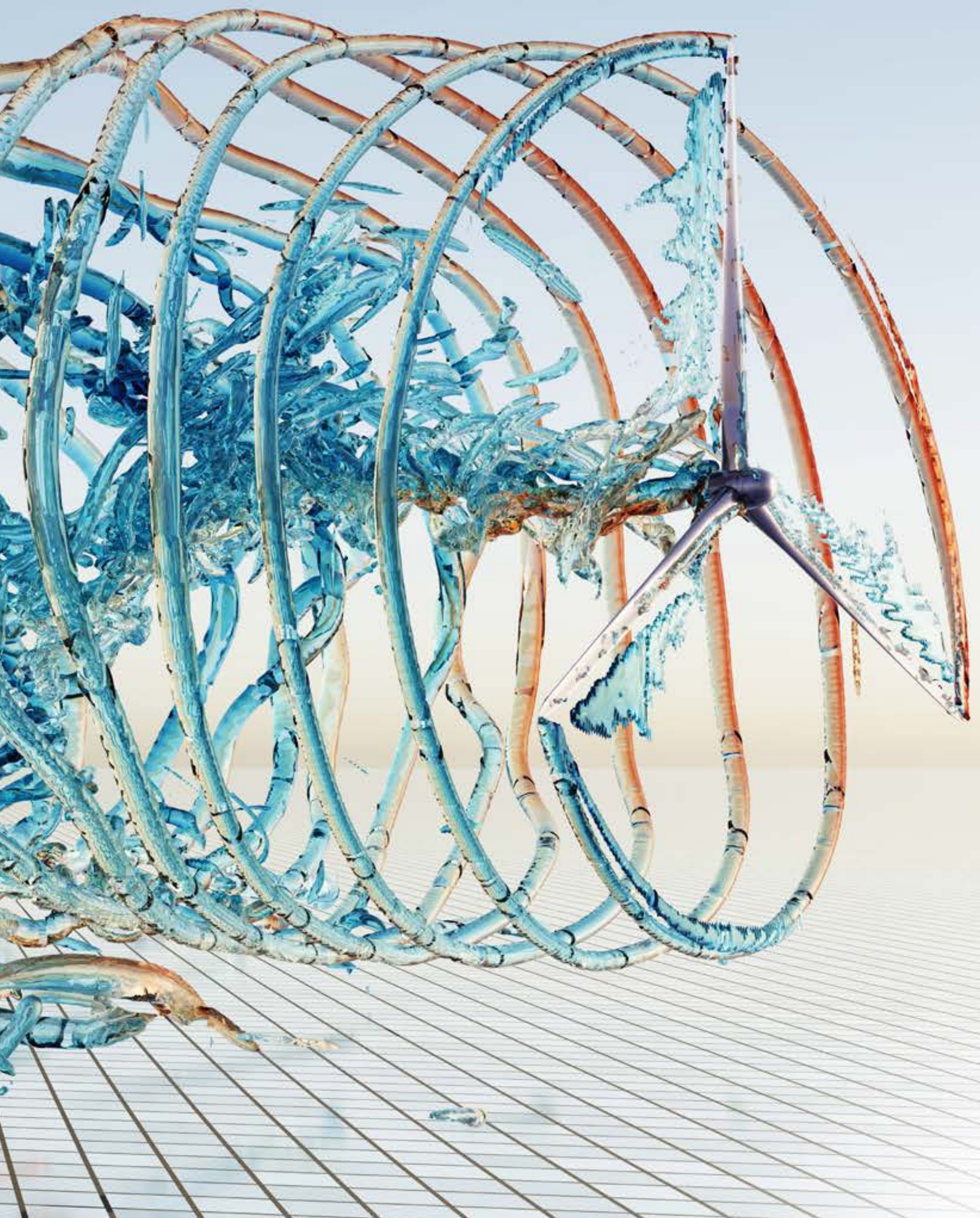
Point of Contact: Amy Robertson, Amy.Robertson@nrel.gov

Floating Offshore Wind Energy Supply Chain Prize Moves to Phase Two

The FLoating Offshore Wind ReadINess (FLOWIN) Prize is an American-Made competition designed to accelerate the market readiness of U.S. floating offshore wind energy technologies. *Graphic by Besiki Kazaishvili, NREL*

In March 2023, DOE announced nine winners of the first phase of the NREL-administered American-Made FLoating Offshore Wind ReadINess (FLOWIN) Prize, kicking off Phase Two. Launched as WETO's first-ever wind energy prize in September 2022, the three-phase competition aims to bridge manufacturing and logistics gaps to help meet the nation's goals to deploy 15 gigawatts and reduce the cost (by 70%) of floating offshore wind energy by 2035. In Phase One, teams submitted floating offshore wind turbine platform designs that can help tackle the offshore wind energy industry's biggest manufacturing and supply chain challenges. Each Phase One winning team receive $100,000 in cash and $75,000 in vouchers for technical support provided by DOE national laboratories, including NREL. Winners from Phase One are eligible to move into the second phase of the competition, in which each team develops a pathway for mass manufacturing and deployment of its floating offshore wind energy substructure design.

Materials, Manufacturing, and Design Innovation



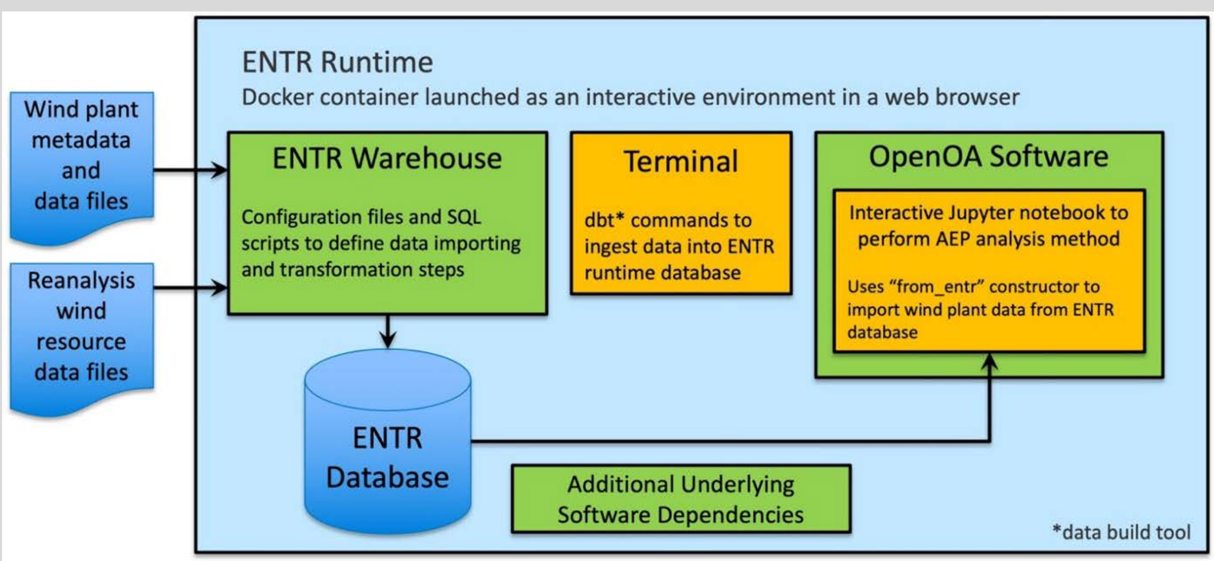
Point of Contact: Eric Simley, Eric.Simley@nrel.gov

ENTR Software Environment Improves Efficiency of Wind Power Plant Data Analysis

The wind energy industry faces several wind power plant data analysis challenges, including the significant amount of time required to import and prepare operational data because of missing data standards as well as uncertainty in analytical results, which stem from a lack of reference wind power plant performance assessment methods. To address these challenges, NREL teamed up with the ENergy TRansition (ENTR) Alliance, a wind energy data standardization industry consortium, as part of a DOE Technology Commercialization Fund project to create a standard data analysis environment. In summer 2022, the team released an initial version of the ENTR Runtime, which comprises the following components packaged in an easy-to-run software container:

- The ENTR Warehouse, a set of configuration files and software scripts for importing and transforming raw operational data into the standard ENTR data model
- A database for storing the imported data
- NREL's Open Operational Assessment (OpenOA) library of reference operational wind power plant performance assessment methods
- Example wind power plant data, with which analyses can be performed.

This ready-to-use software package can improve efficiency in the wind industry by allowing wind analysts to assess the performance of their wind power plants across their fleets while avoiding time-consuming data standardization processes. Since its initial release, the project team has demonstrated the ENTR Runtime software by using OpenOA to compute long-term expected annual energy production using data from three wind power plants operated by project partner Apex Clean Energy.



Overview of the ENTR Runtime operational wind plant data analysis environment. Raw operational data are imported and mapped to the standard ENTR data model using the ENTR Warehouse. NREL's OpenOA software is used to perform operational wind plant assessments using data in the ENTR data model format. Users interact with the data through a series of well-documented Jupyter notebooks in OpenOA, which highlight the analysis steps. *Graphic by Eric Simley, NREL*

Offshore Wind Roadmap Development

Point of Contact: Shawn Sheng, Shawn.Sheng@nrel.gov

Offshore Wind O&M Road Map Preliminary Findings Released

Researchers from NREL and Sandia National Laboratories released preliminary findings from the offshore wind operations and maintenance (O&M) road map development project at the 2023 International Offshore Wind Partnering Forum. The findings include top O&M research and development opportunities (e.g., condition-based maintenance, digitalization, automation, and O&M modeling) that can help improve efficiency, cost effectiveness, reliability, and performance at U.S. offshore wind power plants. The final road map is planned for release by the end of September 2023.

Recommendations identified in the offshore wind energy operations and maintenance road map will help lower costs and improve sustainability of U.S. offshore wind plants. *Photo from Siemens AG, NREL*

Wind Turbine Drivetrain Reliability

Point of Contact: Jon Keller, Jonathan.Keller@nrel.gov

NREL Helps Envision the Future of Wind Energy Operations, Maintenance, and Digitalization

Nearly 200 participants from industry, academia, the federal government, and national labs attended the annual NREL-hosted Drivetrain Reliability Collaborative Workshop on Feb. 21–23, 2023. The collaborative, which is funded by WETO and led by NREL wind energy researchers, unites wind energy industry members around the goal of increasing drivetrain reliability and reducing wind power plant O&M costs, which make up a sizable share of the levelized cost of wind energy (LCOE). Feedback from the workshop will guide future drivetrain reliability research and partnerships and inform offshore wind energy O&M strategy and digitalization efforts.

Through the Drivetrain Reliability Collaborative, NREL researchers and their colleagues are working to reduce wind plant operations and maintenance costs through increased drivetrain reliability and other initiatives. *Photo by Dennis Schroeder, NREL*

Big Adaptive Rotor

Point of Contact: Pietro Bortolotti, Pietro.Bortolotti@nrel.gov

Stability Analysis of Modern Prototype Wind Turbine Aids Understanding of Wind Energy Physics

The Big Adaptive Rotor (BAR) project aims to develop technologies for the next generation of land-based wind turbines in a collaborative effort between NREL and Sandia National Laboratories. Launched in 2018, BAR is now in its second phase, which focuses on maturing technology readiness for large wind turbine designs. Modern wind turbines are increasingly large, slender, and flexible. This design helps reduce the cost of wind energy but may also cause undesired and possibly dangerous phenomena of aeroelastic instability. To tackle this problem, BAR researchers partnered with the Rotor Aerodynamics, Aeroelastics, and Wake (RAAW) project, a 3-year effort funded by WETO in which researchers from NREL, Sandia National Laboratories, the University of Wyoming, and GE have been instrumenting a modern 2.8-MW wind turbine located in Lubbock, Texas. These researchers completed a detailed stability analysis of the turbine that shows how the numerical modeling tools developed at NREL can accurately predict the dynamic behavior and performance of this prototype wind turbine used within RAAW. This analysis provides a foundation for future efforts that aim to develop innovative methods to better understand the physics of wind energy.

The 2.8-MW wind turbine used within the RAAW experiment and located in Lubbock, Texas. BAR researchers completed a detailed stability analysis of the turbine that will aid in understanding the physics of wind energy. *Photo from General Electric*

High Efficiency Ultra-Light Superconducting Generator for Offshore Wind

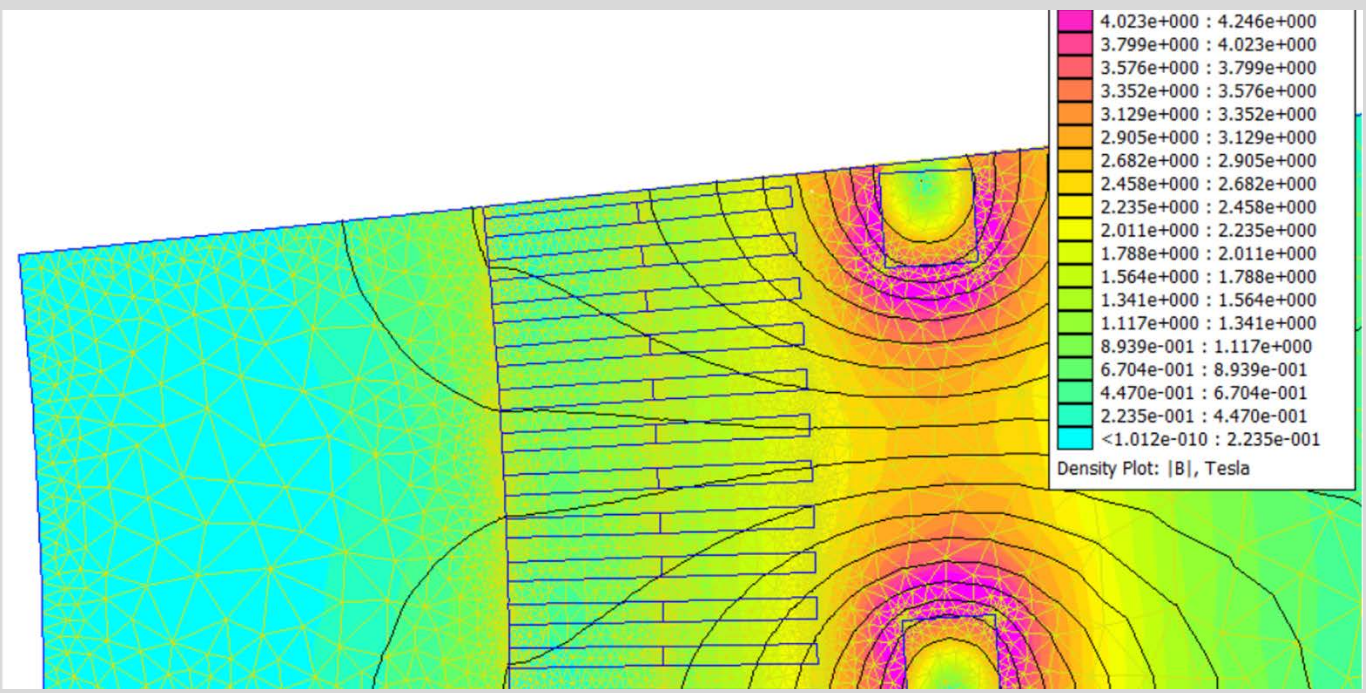
Point of Contact: Pietro Bortolotti, Pietro.Bortolotti@nrel.gov

NREL, GE Researchers Compare Drivetrain Technologies for Next-Generation Offshore Wind Turbines

Offshore wind turbines keep growing in both size and capacity, so drivetrain technologies have to keep up. The next generation of advanced drivetrain technologies can potentially reduce:

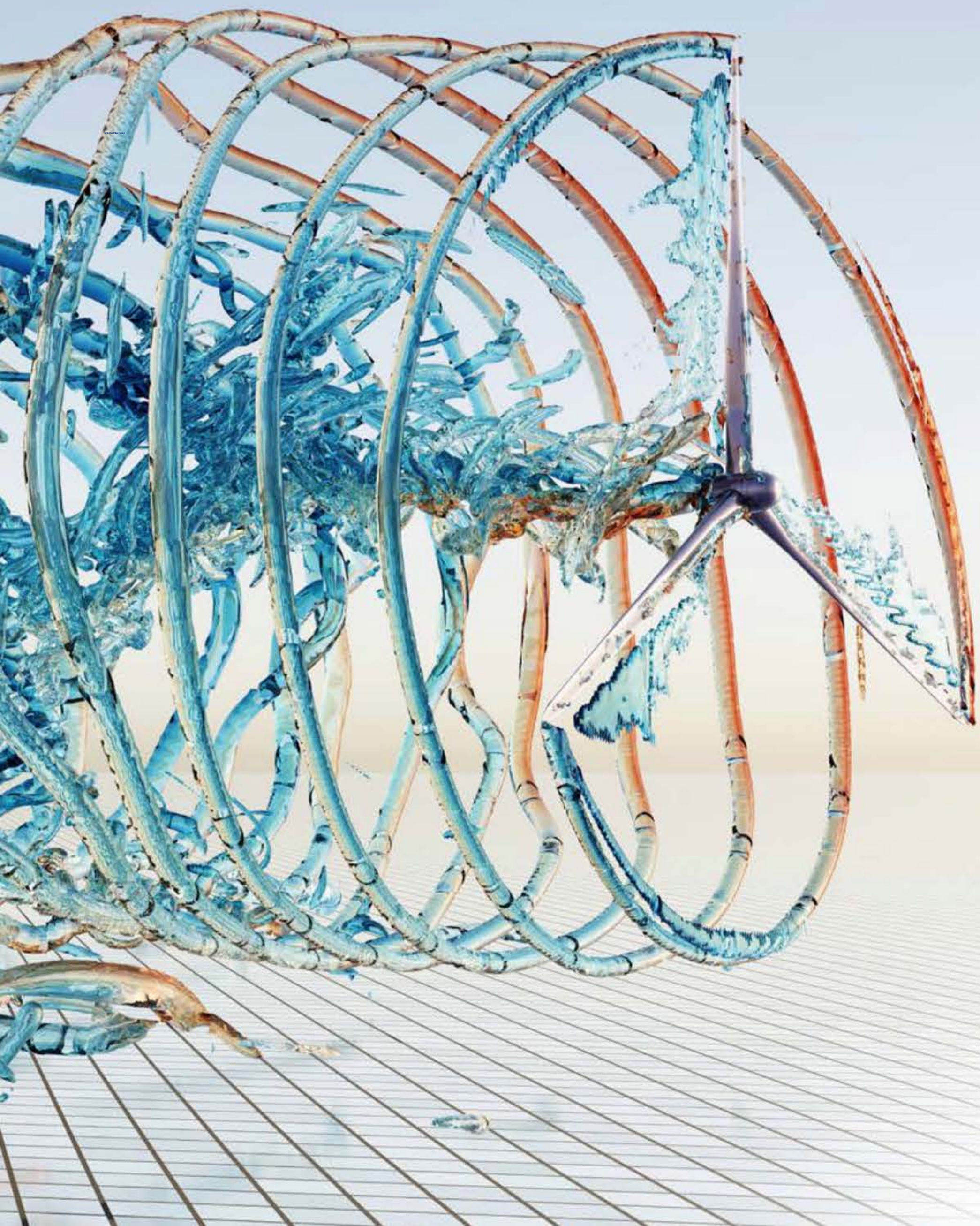
- The cost of energy through direct impact on capital costs by decreasing structural mass
- O&M costs by reducing maintenance and replacements
- Lifetime energy production by improving performance.

An NREL and GE research team documented the design studies that compared three drivetrain technologies (direct-drive interior and medium-speed permanent-magnet synchronous generators and a low-temperature superconducting generator) at five power ratings (15, 17, 20, 22, and 25 MW) for fixed-bottom and floating turbine designs. The resulting journal articles and conference papers (forthcoming) will discuss the challenges and opportunities of low-temperature superconducting generators and medium-speed permanent-magnet synchronous generators compared with the more popular direct-drive interior permanent-magnet synchronous generators.



Visualization of the magnetic field of a 15-MW superconducting generator, a promising technology for the next generation of offshore wind turbines documented by an NREL-GE research team that compared three drivetrain technologies. *Image by Pietro Bortolotti, NREL*

Systems Integration



Wind Consortium Cyber Threat Model

Point of Contact: Zoe Dormuth, Zoe.Dormuth@nrel.gov

NREL Researchers Develop Combined Wind Power Plant and Turbine Reference Architecture Model and Simulation

Reference architectures provide advantages to analyzing a complex system, especially for cybersecurity, such as by accelerating the design process for new technology integration and identifying potential gaps in standards and security best practices. As a result, a combined reference architecture of a wind power plant and wind turbine was developed by NREL researchers and simulated to perform research that can identify and mitigate cybersecurity risks to wind energy systems. The simulation is modularly designed to be integrated into additional work, such as NREL's cyber range and future wind cybersecurity projects. This combined reference architecture model and simulation will help the wind energy industry by providing the ability to analyze and evaluate wind energy systems, incorporate security by design, integrate new technology, and improve system best practices and standards.

Atlantic Offshore Wind Transmission Study

Point of Contact: Melinda Marquis, Melinda.Marquis@nrel.gov

Atlantic Offshore Wind Transmission Study Enters Second Year

NREL researchers, along with Pacific Northwest National Laboratory research partners, completed several planned tasks within the 2-year, WETO-funded Atlantic Offshore Wind Transmission Study. The study is designed to:

- Evaluate coordinated transmission solutions that will enable offshore wind deployment along the U.S. Atlantic Coast in support of the national goal of 30 gigawatts of offshore wind energy by 2030
- Compare different transmission technologies and topologies (which are layouts of transmission lines), quantify costs, assess reliability and resilience, and evaluate key environmental and ocean co-use issues
- Quantify economic, environmental, reliability, and resilience impacts of different transmission topologies.

Researchers identified, developed, and performed cost modeling of two potential 2050 offshore wind energy transmission topologies, radial and interregional, and plan to perform production cost modeling soon for an intraregional and a backbone topology.

Wind Power as Virtual Synchronous Generation

Point of Contact: Vahan Gevorgian, Vahan.Gevorgian@nrel.gov

Researchers Develop Computer Models for Type-5 Wind Turbines

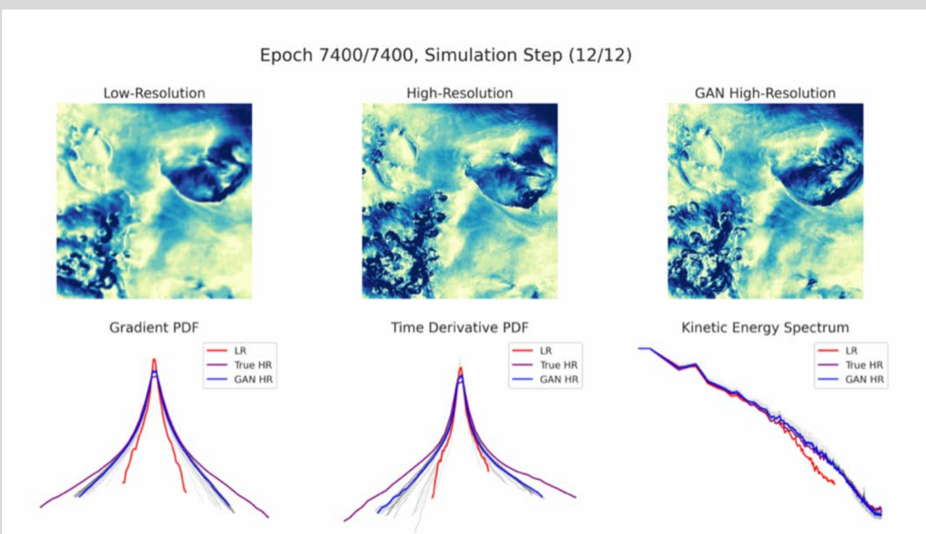
A Type-5 wind turbine uses a hydraulic torque converter between the gearbox's low-speed shaft and the generator's high-speed shaft to match the generator speed with the electrical synchronous speed. This type of machine then uses a synchronous generator directly connected to the medium-voltage grid. The Type-5 configuration has many advantages over other wind turbines, including the ability to provide high levels of fault currents, maintain grid strength, and provide inertia to the grid. A team from NREL and Idaho National Laboratory developed computer models for Type-5 wind turbine generators and wind power plants that comprise multiple Type-5 wind turbines. Testing of a 2.5-megavolt-ampere Type-5 machine will be conducted in at the NREL dynamometer facility to validate the models.

National Wind Power Production Database

Point of Contact: Ryan King, Ryan.King@nrel.gov

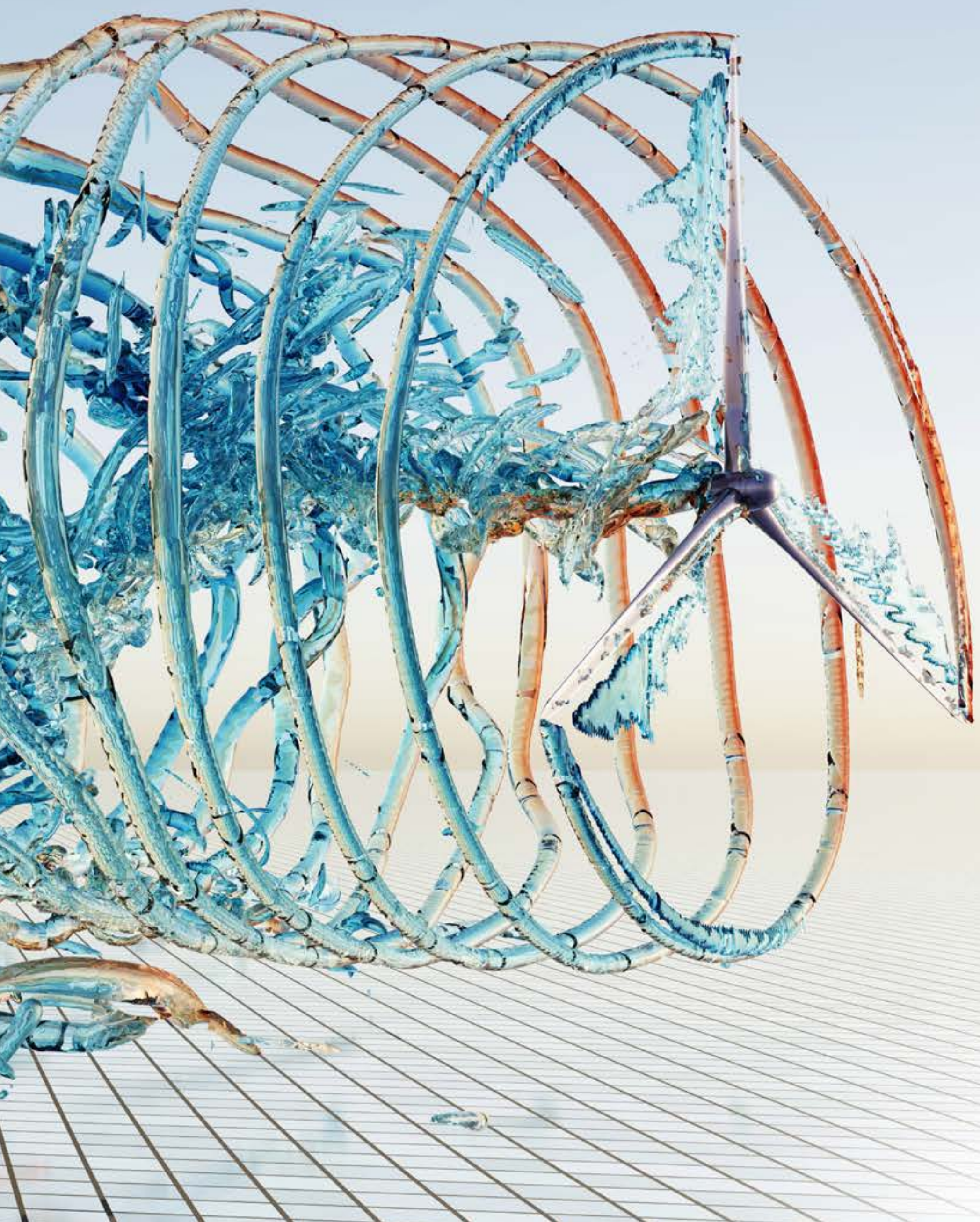
Machine-Learning Approach Captures Detailed Wind Data

High-resolution temporal and spatial (or time- and space-based) wind data are crucial for resource assessment, grid integration, and wind energy deployment studies but computationally expensive to obtain. NREL researchers developed and implemented a novel machine-learning approach, called Super Resolution, that results in a high-resolution data set providing unprecedented detail and duration. Using Super Resolution, NREL researchers enhanced the existing, low-resolution Wind Toolkit Large Ensemble (WTK-LED) data set by a factor of 2 spatially and 12 temporally to create a continuous, 20-year data set. In addition, this data set provides 2-kilometer- and 5-minute-resolution data at computational costs considerably lower than previous approaches using numerical weather prediction models.



Training a generative adversarial network (usually referred to as a GAN) to provide high-resolution hub-height wind data. The model produces increasingly accurate results throughout the training when measured by a variety of turbulence metrics. *Graphic by Brandon Benton, NREL*

Environmental Research



Enabling the Coexistence of Wind Energy and Wildlife (ECO Wind)

Point of Contact: Cris Hein, Cris.Hein@nrel.gov

Joining Forces To Minimize Wind Energy Impacts on Birds and Bats

NREL, in partnership with the Renewable Energy Wildlife Institute and the Consensus Building Institute, hosted a workshop with technology innovators, wind industry operators, researchers, and government agencies to discuss strategies to protect birds and bats from wind energy technologies. Proceedings from the workshop highlight the need for greater engagement between technology innovators and wind turbine manufacturers to integrate mitigation technologies with wind turbines. Additional needs include streamlining funding mechanisms to increase accessibility and reduce the administrative burden of proposal development and project management and reviewing the regulatory framework to incentivize research and development of solutions for wind energy and wildlife interactions.

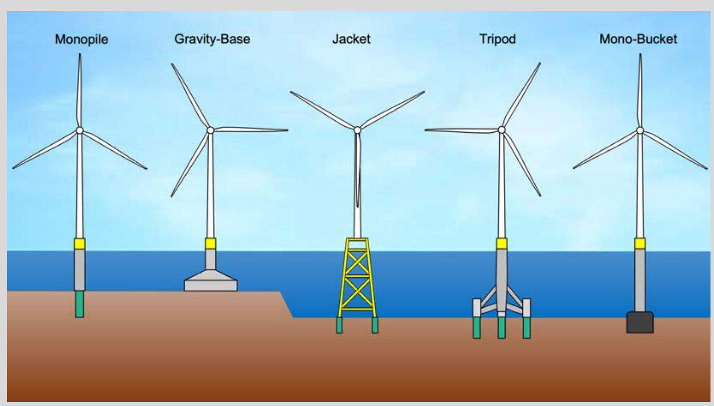
Identiflight reduces interactions between raptors and wind turbines by using cameras to curtail selective wind turbines when raptors approach. *Photo by Dennis Shroeder, NREL*

Wind Operational Issue Mitigation

Point of Contact: Kendra Ryan, Kendra.Ryan@nrel.gov

Workshop Addresses Offshore Wind Energy Noise Reduction

In December 2022, researchers from NREL and the Pacific Northwest National Laboratory hosted the U.S. Offshore Wind Energy Noise Reduction Workshop on behalf of WETO in collaboration with the U.S. Department of the Interior's Bureau of Ocean Energy Management and National Oceanic and Atmospheric Administration. The 2-day virtual workshop convened 125 industry representatives, subject-matter experts, and regulators to discuss foundation types, installation methods, noise-abatement strategies and monitoring, and the barriers to reducing noise during offshore wind farm construction activities. A final report will document 596 responses given in these discussions, analyzes 13 offshore wind energy construction and operation plans, and summarizes 18 responses to an industry participant questionnaire. The report then synthesizes this information to provide recommendations on future research that fills existing knowledge gaps in an effort to reduce the impact and increase efficiencies of fixed-bottom offshore wind energy installations.

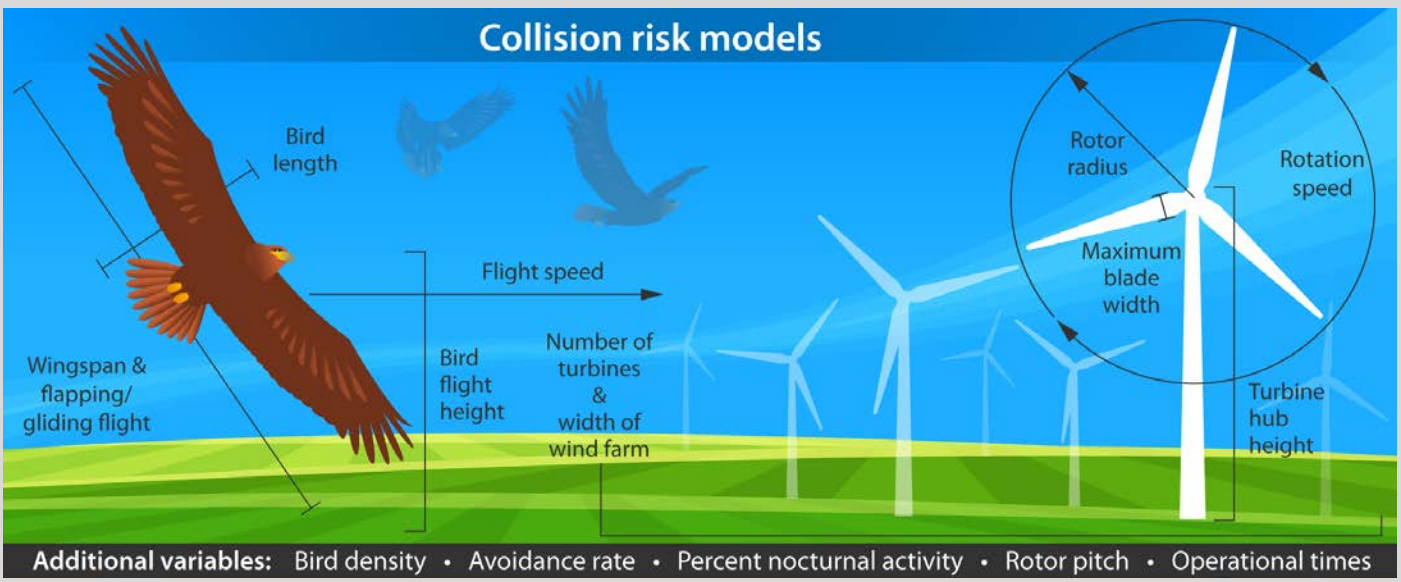


Workshop discussions focused on comparing these various fixed bottom foundation types, their installation methods, noise abatement strategies to their installation, monitoring, and the barriers to reducing noise. *Graphic by Stein Housner, NREL*

Point of Contact: Cris Hein, Cris.Hein@nrel.gov

Bat and Raptor Interactions Are Subject of Two IEA Wind Task 34 Forums

Members of IEA Wind Task 34, Working Together to Resolve Environmental Effects of Wind Energy, conducted two expert forums to discuss complex issues surrounding bat and raptor interactions with wind turbines. There is an ongoing debate about whether bats succumb to barotrauma—injury resulting from rapid pressure changes near wind turbine blades. Forum participants discussed the conflicting data and concluded it may make little difference whether bat fatalities are a result of barotrauma or collisions because, in either case, bats are near wind turbine blades. Therefore, the approach to reducing bat fatalities is the same regardless of the interaction. For raptors, collision models are often used to predict risk. These models often have a high degree of uncertainty because of the difficulty in predicting how different species of raptors behave near wind turbines. Forum participants discussed the challenges of quantifying several parameters, such as avoidance rate and flight speed, and recommended models incorporating habitat and species-specific data that can provide useful information on collision risk and help inform wind energy project developers and operators' siting and operational decisions.



Parameters often used to calculate collision risk for raptors. *Graphic by NREL; modified from Cook and Masden (2019)*

Offshore Wind Synthesis of Environmental Effects Research

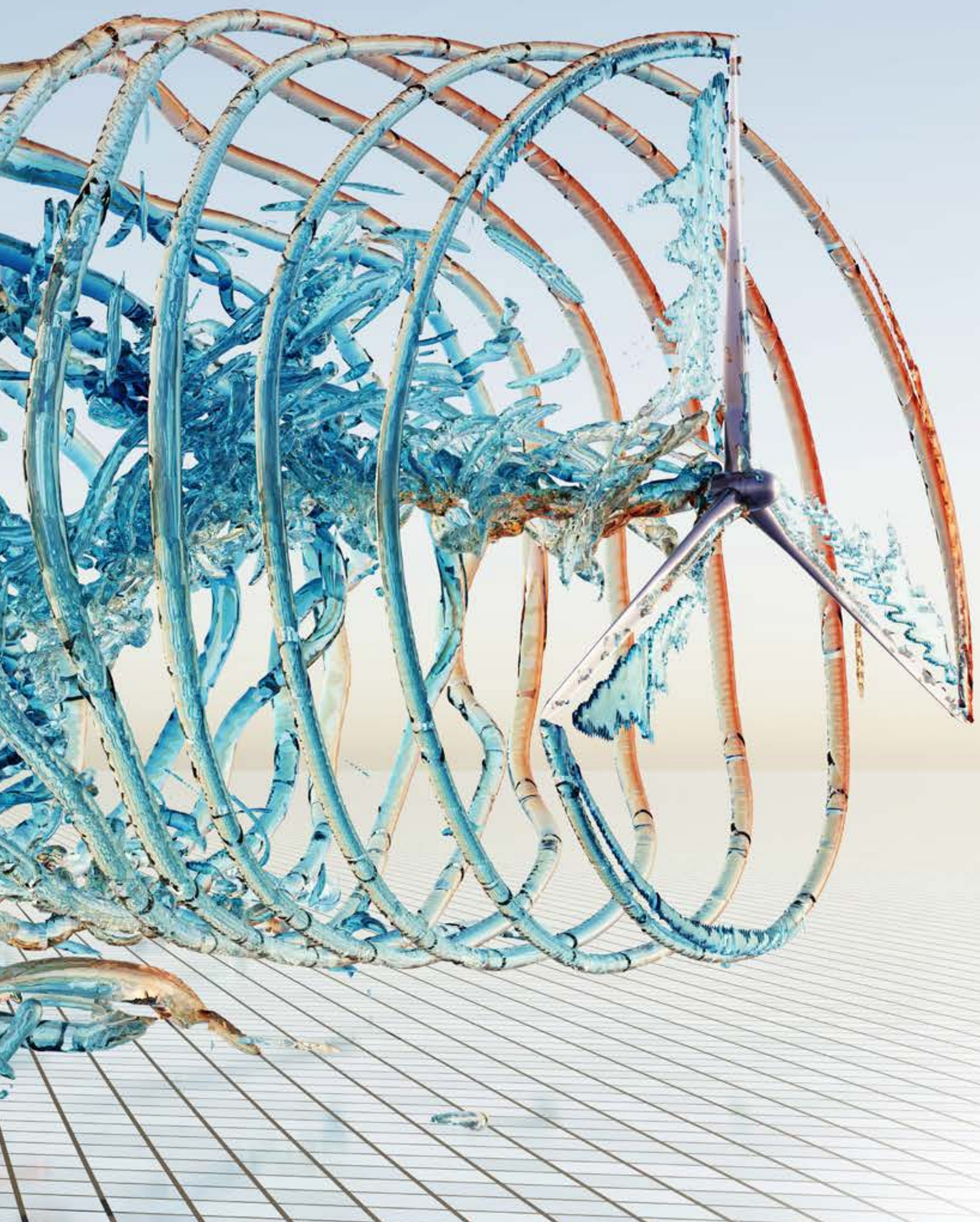
Point of Contact: Cris Hein, Cris.Hein@nrel.gov

Databases Share Offshore Wind Energy Environmental Research Recommendations

Through the U.S. Offshore Wind Synthesis of Environmental Effects Research project, NREL and the Pacific Northwest National Laboratory gathered feedback from offshore wind energy stakeholders and compiled hundreds of environmental research recommendations from dozens of sources to help identify data gaps and environmental research needs. The information is compiled into two databases—one for the U.S. Atlantic Coast and one for the U.S. Pacific Coast—that are easily accessible by government agencies, industry, researchers, funding entities, and others. The data can be sorted and prioritized based on the area of interest. These online tools highlight overarching research recommendations, such as conducting baseline activity surveys, validate minimization technologies, and provide links to relevant sources.

Northern gannets are one of several seabird species that may be impacted by offshore wind energy development. New databases compiled by NREL and Pacific Northwest National Laboratory are designed to provide information that could help minimize potential impacts caused by offshore wind energy development. *Photo from iStock*

STEM and Siting Research and Development



Point of Contact: Elizabeth Gill, Elizabeth.Gill@nrel.gov

Community Engagement Series Will Help Improve Wind Energy Equity

As wind energy development increases, community considerations and impacts are of growing importance so the country can ensure deployment is both equitable and meets community values. Through the Wind Energy Equity Engagement project, NREL is gathering information from stakeholders and communities that host wind energy facilities to define and study the equity implications of large-scale, land-based and offshore wind energy facilities. In 2022, the NREL team designed and distributed a questionnaire to stakeholders who participated in DOE's WINDExchange initiative in addition to interviewing 13 subject-matter experts from academia, government agencies, and nonprofit organizations. NREL also hosted a workshop to bring together diverse stakeholders to discuss wind energy equity. The workshop lasted 2 days and included expert speakers and breakout-room discussions. Following the workshop, the NREL team wrote a report highlighting what was learned up to this point in the project, which will be published later in 2023.

WINDExchange Webinar Series Addresses Stakeholder Needs

The NREL Stakeholder Engagement and Outreach team hosted two webinars in the WETO WINDExchange initiative's Offshore Wind Basics Webinar series focused on stakeholder concerns and impacts. The first webinar, "Navigating the Offshore Wind Energy Decision-Making Process," featured speakers from the U.S. Bureau of Ocean Energy Management, Rhode Island Sea Grant, and the Special Initiative for Offshore Wind. The second webinar, "Gearing Up for 2030: Building the Offshore Wind Supply Chain and Workforce Needed to Deploy 30 Gigawatts and Beyond," featured NREL's offshore wind energy supply chain expert, Matt Shields, and wind energy workforce expert, Jeremy Stefek. The webinar series increases awareness of offshore wind energy basics as the industry grows in the United States. Both webinars were recorded and made accessible to the public.

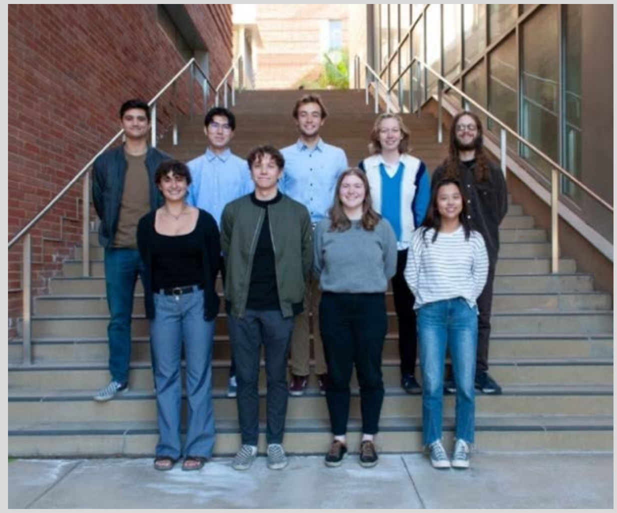
The "Gearing Up for 2030: Building the Offshore Wind Supply Chain and Workforce Needed to Deploy 30 Gigawatts and Beyond" WINDExchange webinar covered solutions for building and sustaining a domestic offshore wind energy supply chain. *Photo from Lyfted Media for Dominion Energy*

Collegiate Wind Competition

Point of Contact: Elise DeGeorge, Elise.Degeorge@nrel.gov

Collegiate Wind Competition Selects 13 Teams To Advance to Final Event

DOE's Collegiate Wind Competition selected 13 teams to advance to Phase 2 of the 2023 competition. Organizers from NREL, which manages the competition on DOE's behalf, selected these teams from 30 Phase 1 teams based on the quality of their work during the first half of the 2022–2023 school year. Phase 2 culminates at the Collegiate Wind Competition final event in May 2023, where the teams will present their work to a panel of judges. Among the Phase 2 teams are three Hispanic-serving institutions, three Asian American and Native American Pacific Islander-serving institutions, and one community college. This is the first school year the competition has used the two-phase structure, which made it more accessible to schools that had not participated in the past and broadened the reach and impact of the competition. The annual competition aims to prepare college students for jobs in the wind energy workforce through real-world technology, project development, and outreach experience. Teams that were not selected to compete in the final event were invited to continue to learn along by testing their turbines in the wind tunnels and sharing their results in all contests with an alternate panel of reviewers for input and guidance.



A team of students from the University of California, Los Angeles (UCLA) will advance to the Collegiate Wind Competition 2023 final event in Boulder, Colorado, in May 2023. UCLA, which is an Asian American and Native American Pacific Islander-serving institution, participated in the competition for the first time during the 2022–2023 school year. *Photo from the UCLA Wind Project*

Wind Energy Workforce

Point of Contact: Chloe Constant, Chloe.Constant@nrel.gov

National Wind Workforce Assessment To Help United States Meet Wind Energy Targets

NREL expanded a survey effort across stakeholders of the wind energy workforce gap, such as industry employers, wind energy industry employees, students, and educators, to gain additional insight into the key factors influencing the development of the expanding wind energy industry' workforce. The resulting U.S. Offshore Wind Energy Workforce Assessment builds on the 2019 report *The Wind Energy Workforce in the United States: Training, Hiring, and Future Needs*. Additionally, NREL researchers developed a new systems dynamics tool to model industry workforce needs and show how different elements can affect workforce projections. The expanded survey effort and systems dynamics model will:

- Empower an updated national assessment of the wind energy workforce by providing new wind energy workforce forecasts based on new deployment targets
- More realistically display the effects of actions taken to mitigate the wind energy industry's workforce gap
- Provide industry and educators with information to develop the workforce to meet U.S. wind energy deployment goals.

Seed Grant Program To Improve Wind Energy Education

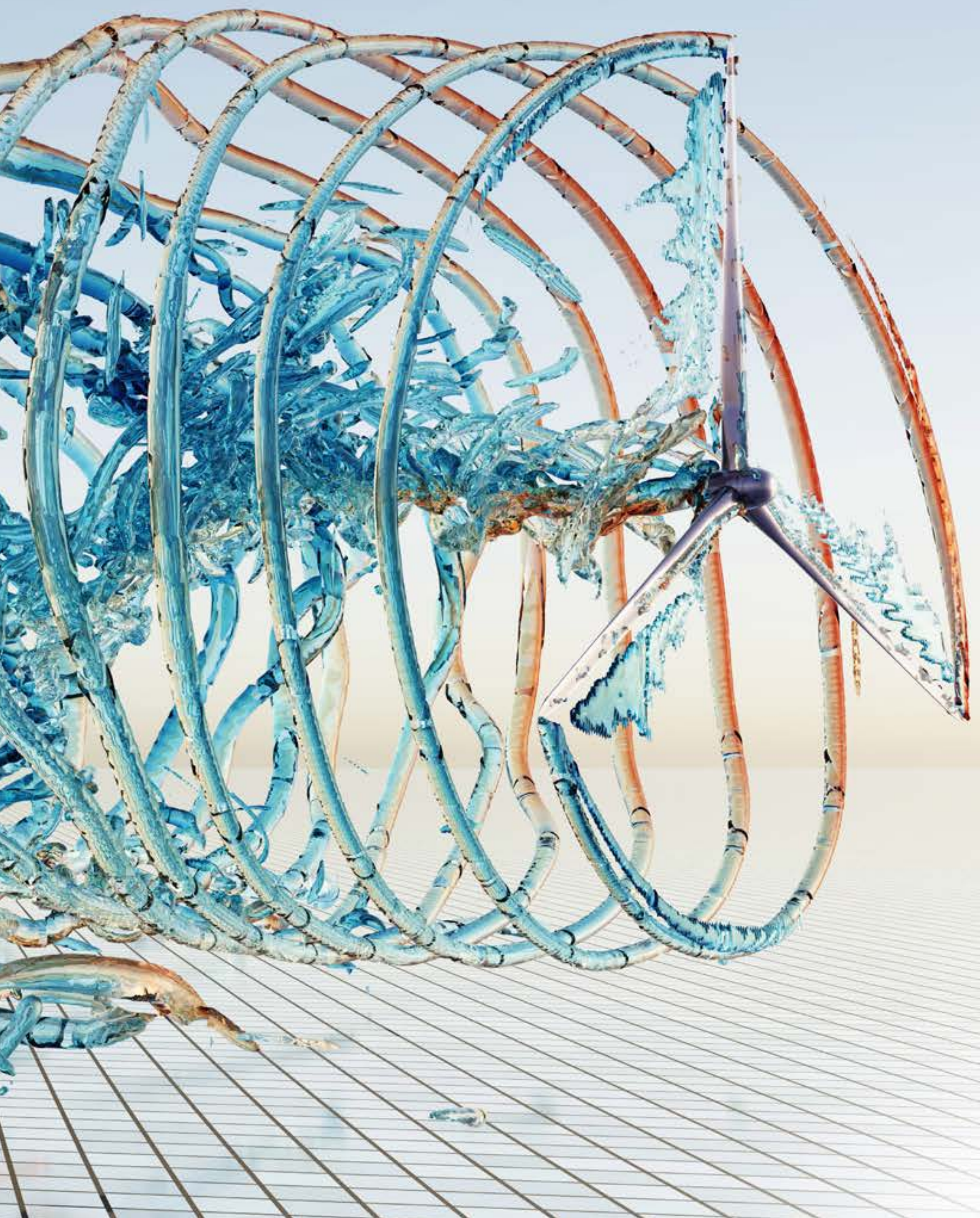
NREL created a 1-semester pilot Academic Seed Grant program to help universities and community colleges across the nation provide more wind- and renewable-energy-specific academic programming. The program was designed to support the need for a greatly expanded U.S. land-based and offshore wind energy industry workforce. Minority-serving educational institutions and institutions that had not previously worked with NREL were especially encouraged to apply for up to $6,000 in seed funding. The Academic Seed Grant program was conducted by NREL in partnership with REpowering Schools.

NREL's pilot Academic Seed Grant Program helped U.S. universities and community colleges provide more wind- and renewable-energy-specific academic programming to meet the need for a future wind energy workforce. *Photo by Werner Slocum, NREL*

Events Help Build Wind Energy Industry Workforce

In the first half of FY 2023, NREL supported several events designed to encourage wind energy industry workforce development. For the third year, NREL organized the U.S. Offshore Wind Workforce Summit, in conjunction with the Business Network for Offshore Wind's 2023 International Partnering Forum in March 2023, to foster partnership, collaboration, and the formation of new programs to address offshore wind energy industry workforce needs. More than 250 participants representing stakeholder groups across workforce development discussed ways to connect stakeholders that do not currently interact. In addition, NREL hosted International Partnering Forum roundtable discussions about K–12 education on wind energy and state collaboration on workforce development. NREL also helped REpowering Schools host a student symposium at the Distributed Wind Energy Association's Distributed Wind 2023 conference, providing an opportunity for students researching small wind turbines to connect directly with members of the industry.

Modeling and Analysis



Wind Analysis for Priority Needs

Point of Contact: Eric Lantz, Eric.Lantz@nrel.gov

NREL Provides Analysis Support for Clean Energy Policy Decisions

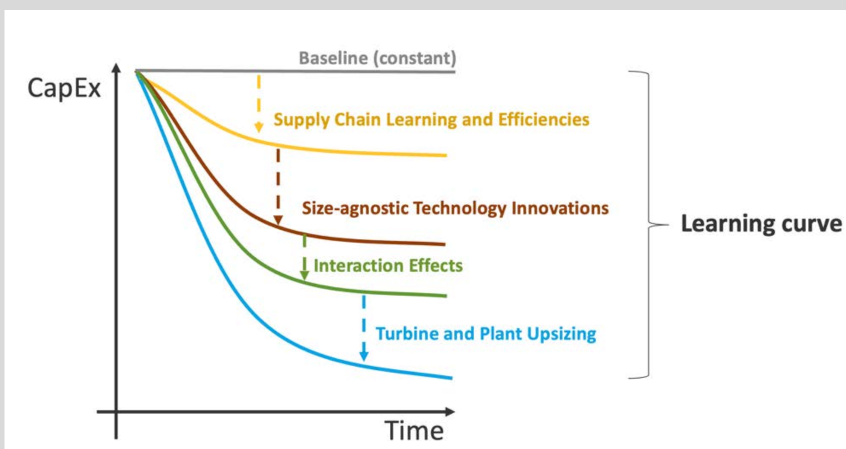
The nation's current focus on offshore wind energy, coupled with the passing of the Inflation Reduction Act in 2022, generated an array of critical questions from decision makers. These questions are heavily focused on policy implementation and understanding the structure and make-up of the industry. An NREL analysis team provided quick-turnaround responses on an array of fronts to support these impactful decisions. Specifically, the team: 1) reviewed and compiled component and electrical equipment cost data to help inform estimates and analysis of the value of equipment coming from U.S. sources, 2) examined and synthesized literature on local and regional content policies to inform strategy around offshore wind energy content and economic development questions, 3) evaluated vessel demand and inventories to help inform potential investments in the offshore wind energy industry's vessel fleet analysis, and 4) evaluated the potential impacts of inflation on contracted project viabilities. Overall, this work provided timely expert insight and perspectives to inform clean energy policy decision making at local, state, and federal levels.

Wind Plant Technology Characterization

Point of Contact: Matt Shields, Matt.Shields@nrel.gov

New NREL Model Estimates Future Offshore Wind Energy Costs

Understanding the future costs of offshore wind energy projects can help developers make informed decisions. However, predicting the future is notoriously challenging and full of uncertainty. NREL researchers have developed the Forecasting Offshore Wind Reductions in Cost of Energy model to forecast the cost of offshore wind energy for a given year with ranges based on historical trends, technology assumptions, site conditions, and future deployment levels. The model estimates the average levelized cost of offshore wind energy could decrease from $75/megawatt-hour (MWh) in 2021 to $53/MWh in 2035 for fixed-bottom offshore wind energy and from $207/MWh to $64/MWh in 2035 for floating offshore wind energy. The team's NREL report provides further details.

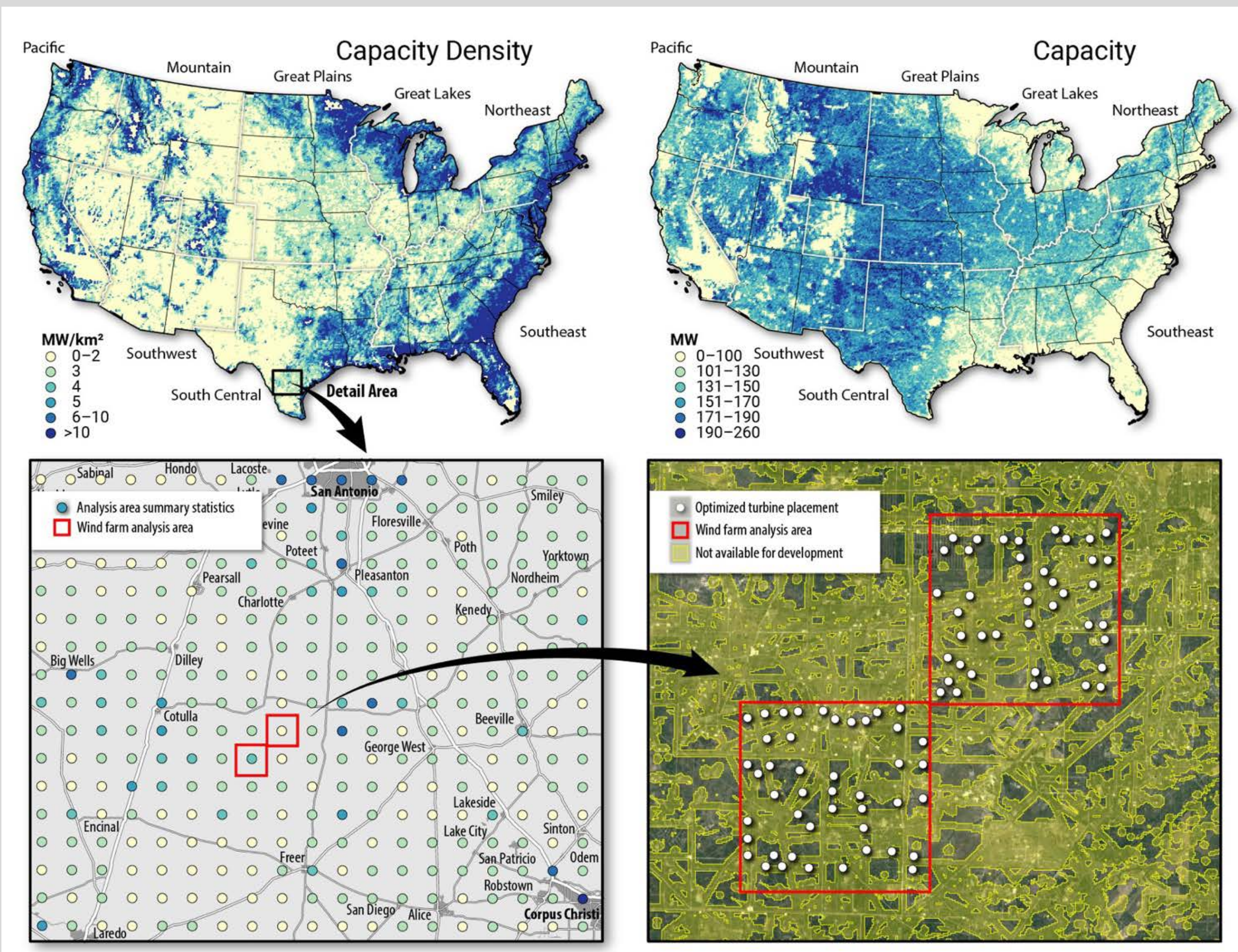


The Forecasting Offshore Wind Reductions in Cost of Energy model calculates a learning curve based on historical wind energy cost data on global installed offshore wind energy projects and future anticipated deployment. The monetary investment required for wind energy project development, or the capital expenditure (CapEx), decreases at faster and faster rates from a flat baseline because of effects such as supply chain and learning efficiencies. These effects are captured by the FORCE model, ultimately determining the shape of the learning curve and the forecasted cost of offshore wind energy. *Graphic by NREL*

Point of Contact: Anthony Lopez, Anthony.Lopez@nrel.gov

U.S. Wind Potential Assessment Optimizes Turbine Placement Using Details at Scale

NREL researchers developed a wind potential assessment for the United States using a new methodology that spatially optimizes wind turbine placement by considering technology design, plant layout, and the vast array of regulatory, land use, and infrastructure conflicts that exist in today's environment. This project highlights wind technology's unique ability to be sighted in and among the built and natural environments while acknowledging the substantive constraints that siting challenges impose. The new methodology shows that current wind energy technology has a capacity potential of 7.8 terawatts across 3 million square kilometers (km^2) of land, which could grow to 11.9 terawatts on just 2.6 million km^2 of land with modest continued technology improvements. But uncertainty in siting could reduce developable land down to 0.76 million km^2—potentially reducing wind's potential role as a backbone of the zero-carbon energy system.



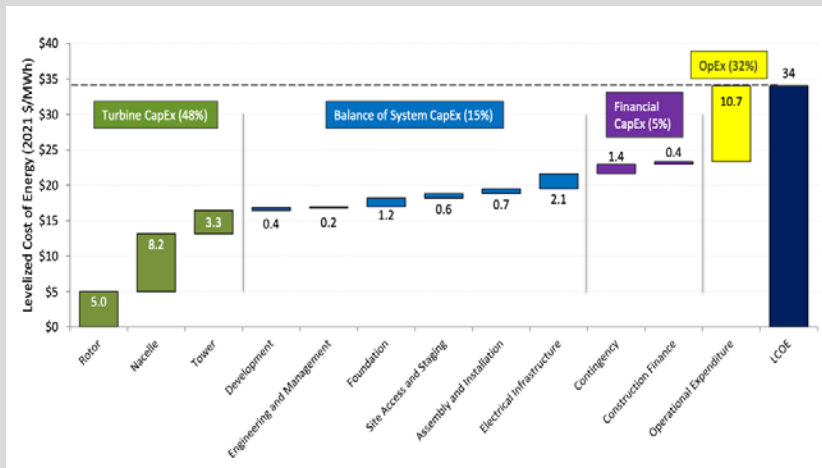
National wind capacity and capacity density results demonstrating the detail at scale. Each dot on the map represents a wind energy site and its resulting capacity density (upper left map) and capacity (upper right map) for one siting scenario and a 2018 market average turbine. The bottom left map shows the density of wind sites for a detailed area, whereas the bottom right map shows yet more detail and the optimized wind turbine locations. I*mage by Billy J. Roberts, NREL*

Data Collection and Annual Reporting

Point of Contact: Tyler Stehly, Tyler.Stehly@nrel.gov

NREL Wind Energy Researchers Publish Estimates on the Cost of Wind Energy

NREL researchers published the *2021 Cost of Wind Energy Review*. The 11th edition of this annual report estimates LCOE for representative land-based and offshore wind power plants as well as residential- and commercial-scale distributed wind energy projects in the United States. LCOE estimates are based on U.S. commissioned plants and wind resource data from 2021 and calculated with the aid of state-of-the-art modeling capabilities and data accumulated from throughout the global wind energy industry. The results of this report provide cost data to DOE to meet the annual reporting requirements set by the Government Performance and Results Act and offer component-level costs that aid researchers, developers, investors, and utilities.



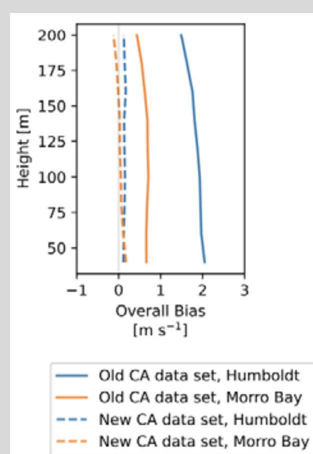
A snapshot of the component-level cost breakdown for the land-based-wind reference project based on U.S. commissioned plants and wind resource information in 2021, with the support of state-of-the-art cost models. *Graphic by NREL*

National Wind Resource Data

Point of Contact: Caroline Draxl, Caroline.Draxl@nrel.gov

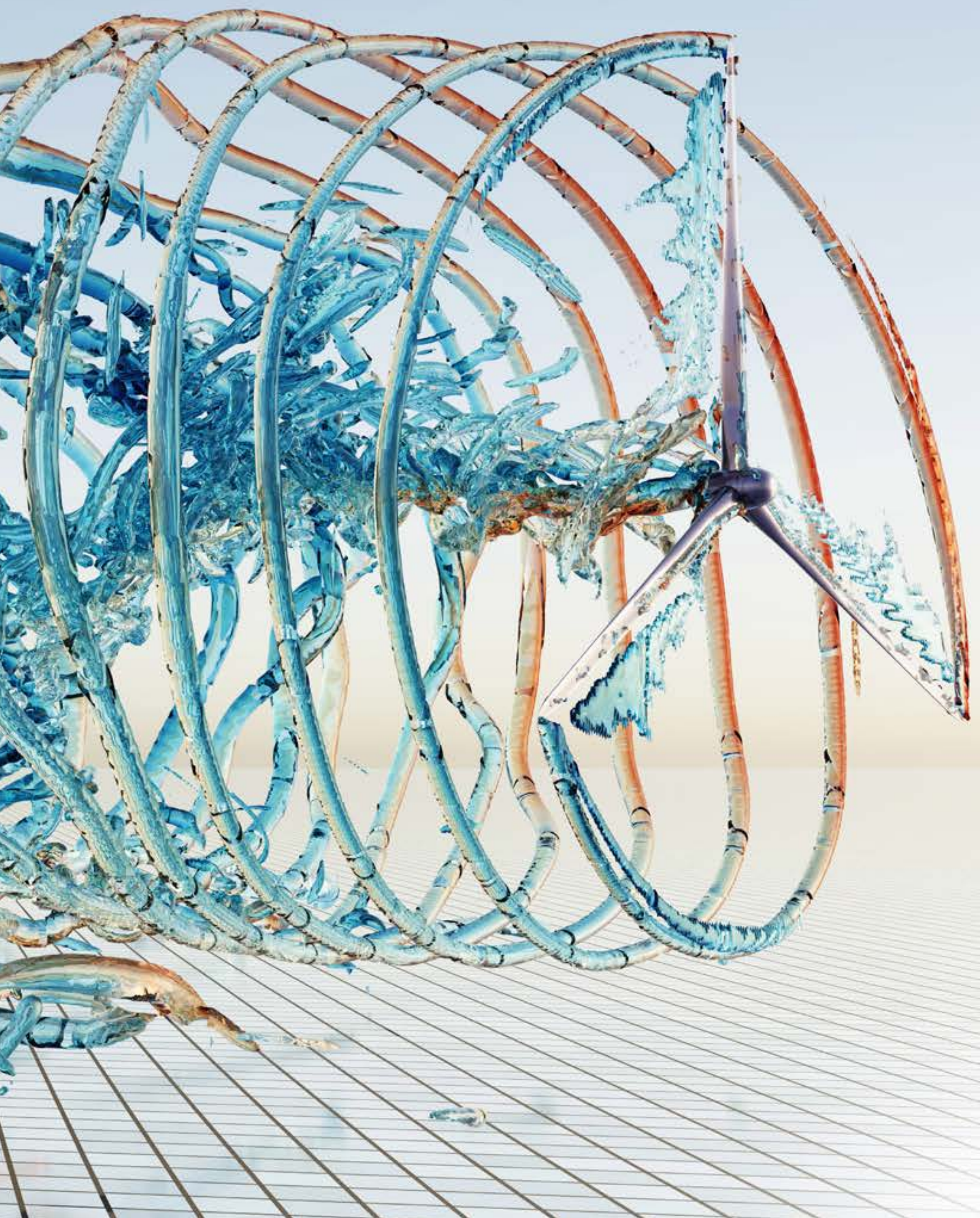
NREL Paves the Way for Improved California Offshore Wind Energy Data Set

NREL scientists, in collaboration with Pacific Northwest National Laboratory colleagues, have paved the way for an improved, more accurate wind energy data set for the offshore California region, which will be used by stakeholders for future offshore wind energy development in the region.



The change of bias with height in the old and new wind data set for offshore California, at the Humboldt and Morro Bay locations. *Image by Nicola Bodini, NREL*

Programmatic Support



NREL Technology Management and Support

Point of Contact: Brian Smith, Brian.Smith@nrel.gov

Sound Programmatic Support Cultivates Wind Research Impact

NREL's wind energy program actively manages a diverse project portfolio that advances technologies for offshore, land-based, and distributed wind energy, as well as wind energy's integration with the electric grid. NREL supports WETO's main objectives of achieving aggressive cost reduction addressing environmental and siting challenges, providing grid services, ensuring cybersecurity, and advancing hybrid systems. To meet the significant acceleration and scale-up of wind energy deployment needed to achieve carbon-emissions-free electricity by 2035 and net-zero greenhouse gas emissions across the economy by 2050, NREL wind energy research includes workforce development and education, social science and acceptance, analysis and modeling, and energy equity and environmental justice. Achievements include:

- Coordinating development of international research strategies through the IEA Wind Grand Challenges summit and implementing national renewable energy goals through the Floating Offshore Wind Shot™
- Increasing the impact of WETO's mission through strategic engagement with key wind energy stakeholders, fostering innovative and integrative programs, and establishing a unique, portfoliowide perspective
- Leading high-level executive outreach and engagement efforts to amplify the office's research and development portfolio
- Leading technology-to-market initiatives that create pathways for market readiness and resource access, including supporting projects funded through DOE's Technology Commercialization Fund and providing three NREL research teams opportunities to strengthen U.S. competitiveness through the Energy I-Corps program
- Serving in strategic leadership roles within IEA Wind
- Providing support to NREL's Flatirons Campus and NREL's Advanced Research on Integrated Energy Systems research platform through the development of state-of-the-art equipment and facilities that enable fundamental wind energy research and innovative, integrated renewable energy solutions.

Attendees of the IEA Wind Topical Expert Meeting, Grand Challenges in the Science and of Wind Energy, at the University of Colorado Boulder. *Photo by Werner Slocum, NREL*

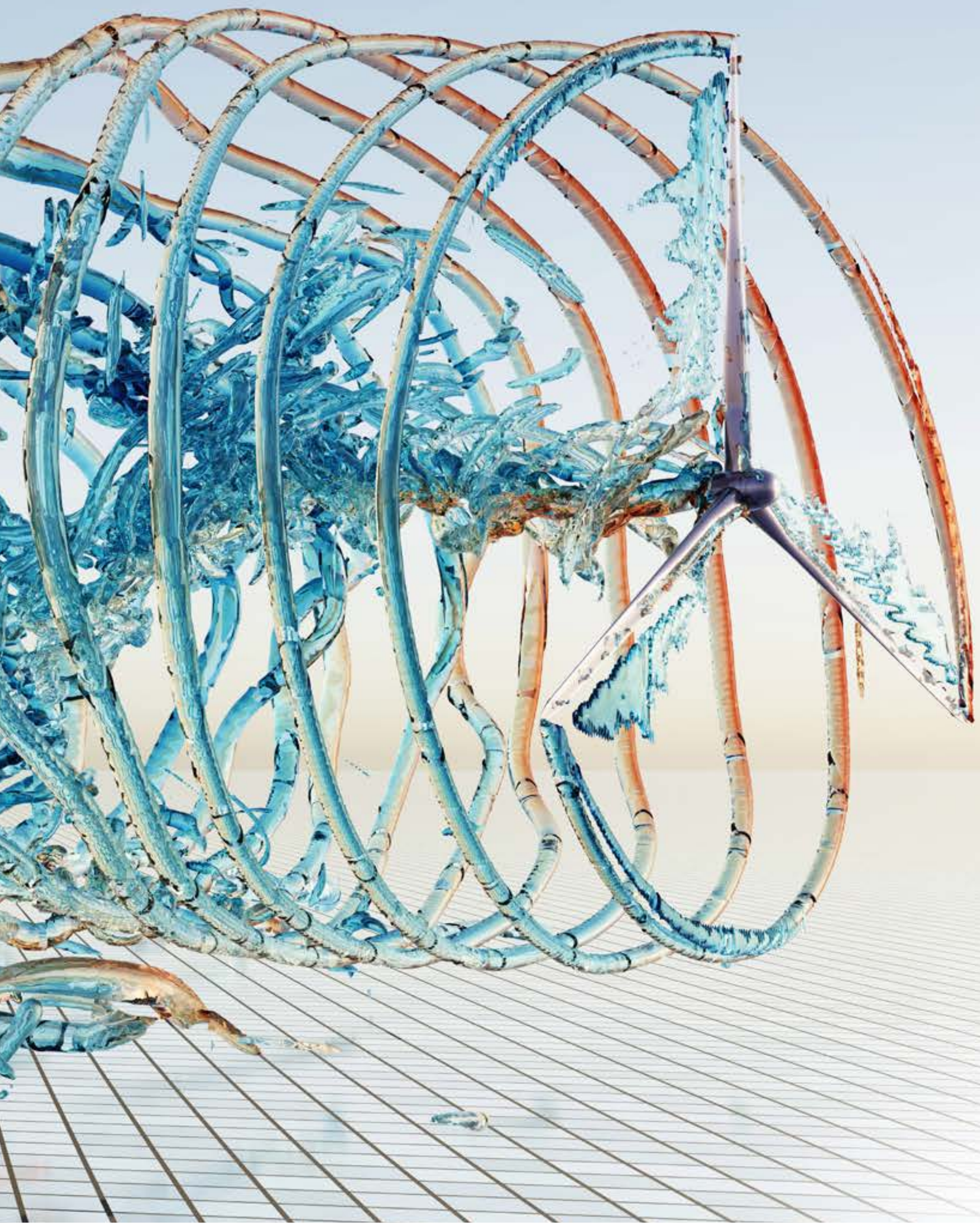
Communications Support

Point of Contact: Pardeep Toor, Pardeep.Toor@nrel.gov

Reevaluating Communications Content To Better Serve Audiences

The NREL wind energy program's communications team worked to reevaluate WETO's editorial content and strategy by developing a search engine optimization report. This report will measure how WETO audiences arrive on the office's webpages by evaluating search engine keywords and reader habits that drive online traffic. The recommendations that result from the report will help WETO reach its core audience, identify gaps in content, and grow its email distribution lists. The communications team is also finalizing a messaging guide to share with communicators at all national labs. The messaging guide will include plain language guidelines for wind energy technologies, high-level talking points for each subject area, and key messaging that aligns with the current administration's wind energy goals. The purpose of the guide is to unify WETO's messaging nationally across labs and communicators so WETO's prose are as dynamic as the research being funded.

Non-AOP

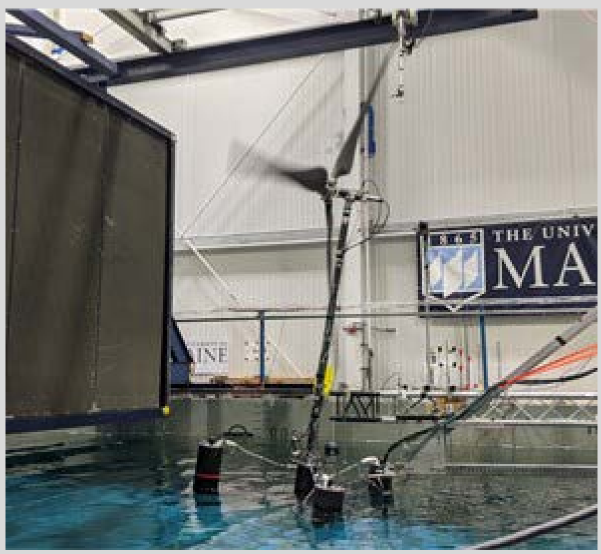


ARPA-e ATLANTIS FOCAL Project

Point of Contact: Amy Robertson, Amy.Robertson@nrel.gov

Public Validation Data Set Released To Enable Floating Wind Control Codesign

The Floating Offshore-wind and Controls Advanced Laboratory project, which is part of the Advanced Research Projects Agency – Energy (ARPA-E) Aerodynamic Turbines Lighter and Afloat with Nautical Technologies and Integrated Servo-control program, aims to streamline floating wind platform designs using control codesign methodologies (i.e., the controller and support structure of a floating offshore wind turbine are designed together). The Floating Offshore-wind and Controls Advanced Laboratory project generated the first public floating offshore wind turbine data set to include advanced turbine controls, floating hull load mitigation technology, and hull flexibility to enable the development of better floating wind energy platforms using a control codesign approach. The project comprised four model-scale floating offshore wind turbine experimental campaigns in the University of Maine's Alfond Wind-Wave Ocean Engineering Laboratory using a scaled version of IEA 15-MW reference wind turbine supported by the VolturnUS-S steel semisubmersible hull. These campaigns addressed two notable limitations of existing experimental data sets: the influence of flexibility on system response and limited control strategy implementation. The data set is publicly available on the ARPA-E website and can be used to validate modeling tools essential for performing control codesign optimization. This validation enables the codesign of the controller and support structure to help future floating offshore wind turbines achieve optimal performance.

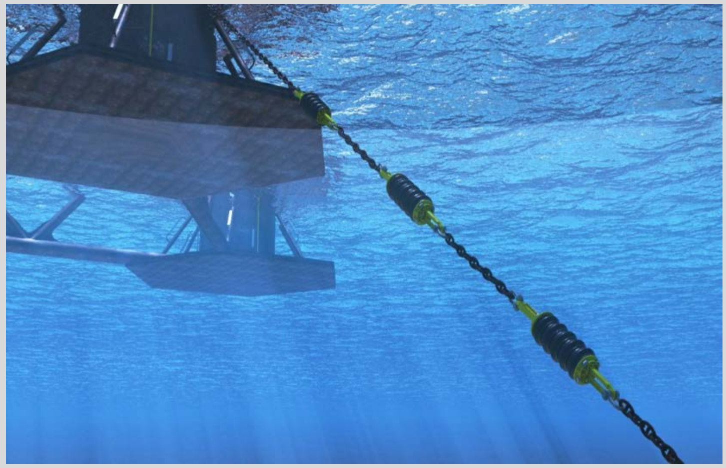


Scaled version of the IEA 15-MW wind turbine atop the VolturnUS-S floater operating under combined wind and wave loading. *Photo by Matt Fowler, University of Maine*

Demonstration of Shallow-Water Mooring Components

Point of Contact: Ericka Lozon, Ericka.Lozon@nrel.gov

Polymer Springs Improve Shallow-Water Mooring System Performance



Shallow-water mooring system with polymer springs attached near the platform. *Graphic by Tfl Marine Ltd*.

Shallow-water mooring systems for floating offshore wind turbines are subject to large tension fluctuations and snap loads, which increase the required size of mooring components and their cost. The ShallowFloat project is evaluating polymer springs with nonlinear tension-strain response curves as a potential method to mitigate against peak loads on shallow-water mooring systems. To accomplish this, an NREL team has improved MoorDyn, the mooring dynamics module, to allow accurate modeling of these polymer spring components. Using MoorDyn and working with partners Principle Power and Tfi Marine Ltd, NREL researchers designed and analyzed mooring systems with polymer springs to evaluate the benefits and drawbacks of these components. Through this work, researchers found that mooring systems with polymer springs can reduce extreme tensions up to 60% and improve fatigue life, thus lowering the required chain diameter by 20% compared to a traditional catenary-chain system. These results show clear benefits in reducing line diameter, anchor radius, and anchor loads when using polymer springs in shallow-water mooring systems, which will lower cost and allow more flexibility in siting floating wind turbines.

Wind Energy With Integrated Servo-Control

Point of Contact: Daniel Zalkind, Daniel.Zalkind@nrel.gov

Expanded Capabilities Planned for Floating Offshore Wind Turbine Toolset

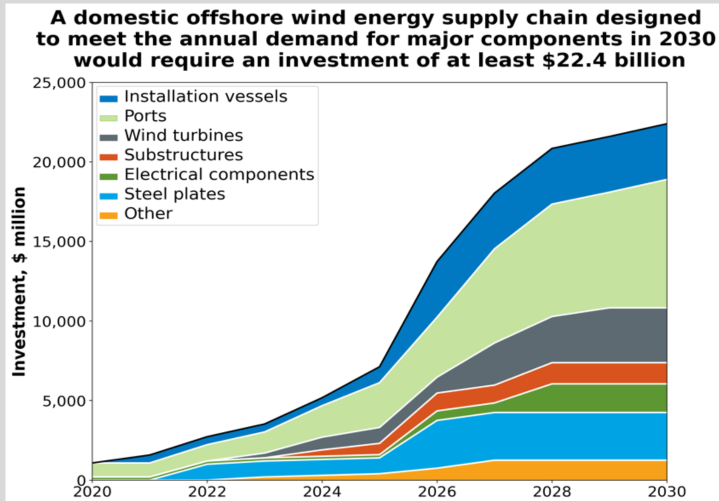
The second phase of the WEIS project will improve the open-source, user-friendly toolset designed to help offshore floating wind energy system engineers design radically new systems at greatly reduced costs. *Photo by Senu Sirnivas, NREL*

The Wind Energy with Integrated Servo-control (WEIS) toolset, a resource to enable the next generation of efficient and cost-optimized floating offshore wind turbine designs, is slated to get even better. Set to begin later in FY 2023, Phase II of the project will improve the user experience and expand the capabilities of the WEIS modeling suite, including environmental conditions, control schemes, and improved physics. A primary focus of the WEIS team in Phase II is to work with industry to understand their software needs and find partners interested in solving real-world engineering challenges using the toolkit. NREL is developing the user-friendly, open-source, flexible, and modular toolset under the ARPA-E Aerodynamic Turbines Lighter and Afloat with Nautical Technologies and Integrated Servo-control program.

Offshore Wind Consortium Supply Chain Roadmap

Point of Contact: Matt Shields, Matt.Shields@nrel.gov

U.S. Offshore Wind Supply Chain Road Map Identifies Challenges and Solutions to Meeting National Goals



Cumulative investment over time in the major components of a domestic offshore wind energy supply chain. *Image by Matt Shields, NREL*

The United States has an ambitious goal of installing 30 gigawatts of offshore wind energy by 2030 and developing a domestic supply chain to support this target. Achieving this goal will require a significant increase in domestic manufacturing, ports, vessels, and workforce. NREL led a study to develop a road map that identifies challenges and solutions to developing a nationally focused offshore wind energy supply chain. *A Supply Chain Road Map for Offshore Wind Energy in the United States* estimates the potential impacts of a domestic supply chain on deployment, cost, workforce, and energy justice. The report suggests short-, medium-, and long-term actions to overcome barriers to development and create a resilient, equitable, and comprehensive offshore wind energy supply chain.

Grand Challenges in Wind Energy Science

Point of Contact: Paul Veers, Paul.Veers@nrel.gov

International Experts Revisit Wind Energy's Grand Challenges

More than 100 wind energy experts from 15 countries attended an IEA Wind Topical Experts Meeting in late February 2023 to revisit the grand challenges in wind energy science. Organized by NREL wind energy researchers, the meeting sought to create better understanding of how the social and environmental impacts of wind energy should be integrated into future research on the grand challenges of wind energy research: the atmosphere, turbines, power plants, and the grid. Meeting outcomes will provide guidance for researchers at NREL—and around the world—to ensure future wind energy projects consider the social and environmental impacts of increased wind energy deployment.

Alejandro Moreno, DOE's acting assistant secretary for energy efficiency and renewable energy, kicked off the meeting by laying out the direction and goals for the 2-day event. *Photo by Werner Slocum, NREL*

The Laboratory Directed Research and Development Program at NREL

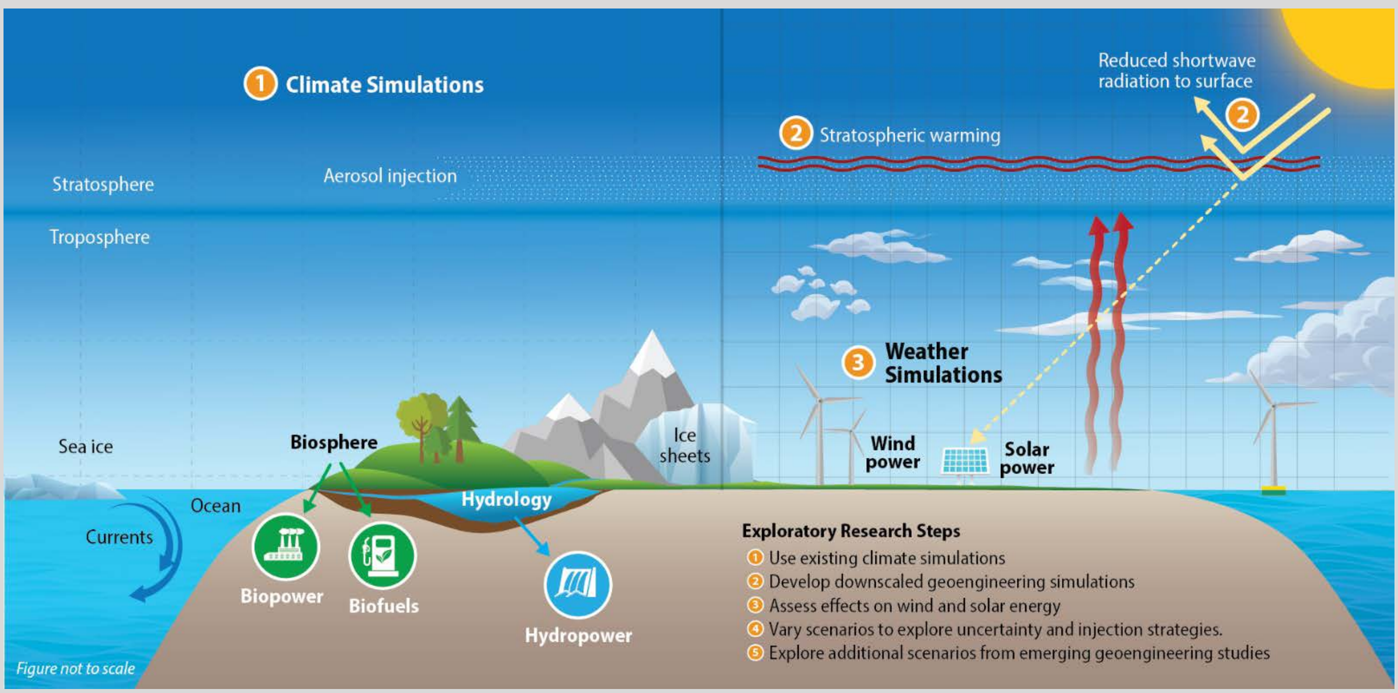
Each year, NREL is a proud contributor of innovations built through DOE's Laboratory Directed Research and Development (LDRD) program. Read about three of the innovative LDRD projects at NREL that aim to shape the future of wind energy and wind energy deployment.

Wind and Solar Geoengineering

Point of Contact: Caroline Draxl, Caroline.Draxl@nrel.gov

Geoengineering Project Leverages Cutting-Edge Climate Science

Geoengineering refers to a set of emerging technologies that could change the environment to partially offset some of the impacts of climate change. NREL's Effects of Solar Geoengineering on Renewable Energy LDRD project aims to develop analytic techniques that simulate geoengineering effects on the climate system to estimate the associated impacts on wind and solar energy resources. Project results will help wind energy investors and planners better understand climate and geoengineering risks. To support the project's goals, the NREL research team formed a technical review committee comprising leading climate scientists who are analyzing geoengineering.



Using existing climate and weather simulations, the Effects of Solar Geoengineering on Renewable Energy research team will assess the impacts of solar geoengineering on wind and solar energy and connect with the community to discuss whether to use geoengineering approaches. *Graphic by Joelynn Schroeder, NREL*

Autonomous Urbanization for Mobility and Communities

Point of Contact: Jennifer King, Jennifer.King@nrel.gov

Demonstration Shows Renewable Energy Technologies Could Replace Building Energy Storage

NREL researchers working on this LDRD project demonstrated that scalable, coordinated control of different renewable energy technologies could replace batteries and other energy storage technologies in buildings. Using a distributed approach to manage the power consumption and generation of each asset on the electricity grid, researchers simulated integrated electric-vehicle-charging infrastructure and distributed renewables at the community scale—including more than 100 buildings, ranging from multifamily homes to commercial buildings. Results indicated that coordinated control across multiple technologies not only yields significant flexibility by shifting when electricity is used but can also be used instead of relying solely on investments in large batteries or other storage technologies. The project is designed to develop large-scale control strategies that can operate across multiple technologies to accelerate the integration of renewables.

A Revolution in Tunable Material Systems

Point of Contact: Robynne Murray, Robynne.Murray@nrel.gov

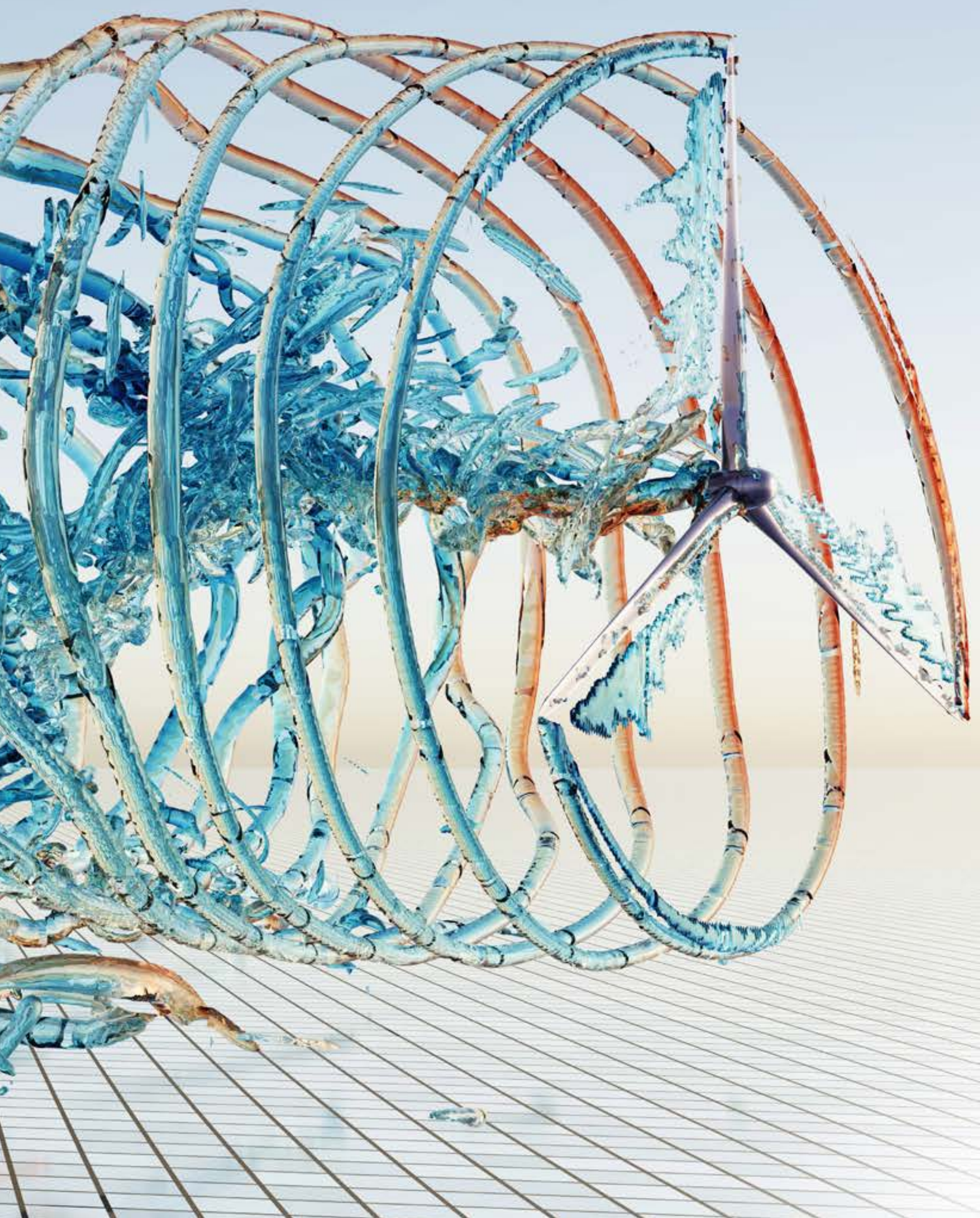
Plant-Based Resin Offers Recyclability and Better Performance Than Traditional Wind Turbine Blade Materials

NREL researchers have developed a recyclable, plant-based resin—the polyester covalently adaptable network (or PECAN) formulation—that has similar, if not better, performance over thermoset and thermoplastic composite materials used in manufacturing wind turbine blades.

The team manufactured 24-ply-thick fiberglass composites similar to a turbine blade root section using several PECAN formulations. The material system's scalability and comparable structural properties mean that PECAN is an excellent drop-in replacement for nonrecyclable, petroleum-based materials currently used for large wind turbine blades.

NREL's recyclable, plant-based polyester covalently adaptable network (or PECAN) composite demonstrates better performance than thermoset and thermoplastic composite wind turbine blade materials. *Image by Robynne Murray, NREL*

Publications Overview

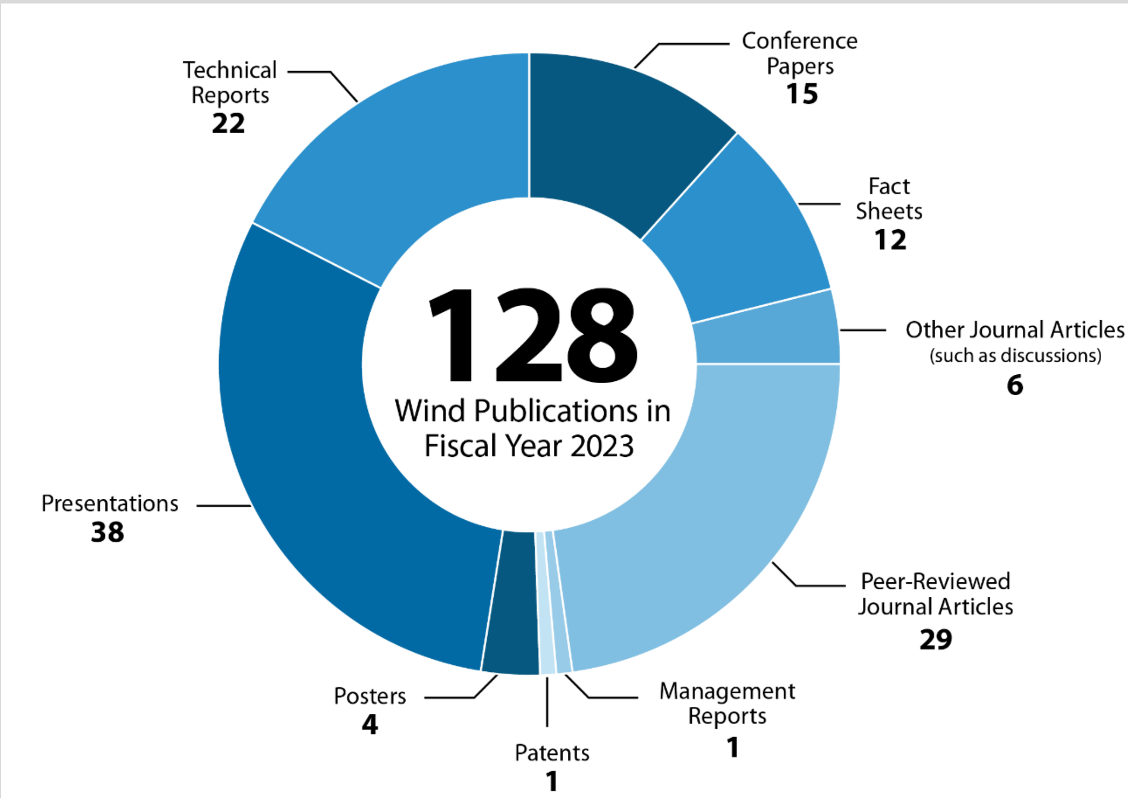


Publications Overview

Publications produced by NREL wind energy program staff provide information about the many areas of wind energy research conducted at the lab. In the first half of FY 2023, NREL researchers published their latest scientific findings and breakthroughs in 191 technical reports, peer-reviewed journal articles, conference papers, fact sheets, and other publications.

Fiscal Year 2023 NREL Wind Energy Publications as of March 31, 2023

These publications provide reliable, unbiased information that researchers from academia, other national laboratories, government agencies, and private industry organizations can use to advance wind energy science.



In FY 2023, as of March 31, 2023, NREL published 128 wind energy documents.

Notable Publications

Bianchini, Alessandro, Galih Bangga, Ian Baring-Gould, Alessandro Croce, Jose Ignacio Cruz, Rick Damiani, Gareth Erfort, et al. 2022. "Current Status and Grand Challenges for Small Wind Turbine Technology." ***Wind Energy Science***. https://www.nrel.gov/docs/fy23osti/84624.pdf.

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Roberts, Owen, Travis Williams, Anthony Lopez, Galen Maclaurin, and Annika Eberle. 2023. *Exploring the Impact of Near-Term Innovations on the Technical Potential of Land-Based Wind Energy*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5000-81664. https://www.nrel.gov/docs/fy23osti/81664.pdf.

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View all wind energy-related journal articles and technical reports published in the first half of FY 2023.

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NREL/MP-6A42-86346 • May 2023

This graphic provides a visual representation of NREL's ExaWind model, which can produce highly detailed air flow data around wind turbines. With the support of an Energy I-Corps grant, NREL researchers are working to bring this capability to the wind energy industry. *Front and back cover image by Nicholas Brunhard-Lupo, NREL*