Accomplishments & Mid Year Performance

REPORT

WIND ENERGY PROGRAM: FISCAL YEAR 2021

Foreword

The U.S. Department of Energy's (DOE's) National Wind Technology Center (NWTC) at the National Renewable Energy Laboratory's (NREL's) Flatirons Campus has provided an ideal setting for research and development (R&D) of advanced wind energy technology for 45 years.

In the first half of Fiscal Year (FY) 2021, NREL continued to provide the technical expertise, world-class research facilities, and workforce education needed to advance U.S. wind energy technology, address market and deployment barriers, and drive down costs with more efficient, reliable, and predictable wind energy systems.

Now, bolstered by the Biden administration's commitment to tackle climate change and revitalize the U.S. economy through increased investment in renewable energy—particularly in offshore wind—NREL stands poised to lead the way to a clean energy future that powers America with significant levels of reliable, low-cost, accessible wind energy.

This report provides an overview of the achievements NREL delivered on behalf of DOE's Wind Energy Technologies Office (WETO) and other partners during the first and second quarters of FY 2021.

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Flatirons Campus
Research Facilities

Point of contact: David Simms, David.Simms@nrel.gov

ARIES Microgrid Infrastructure Powers NREL Campus Through Outage

NREL's Advanced Research on Integrated Energy Systems (ARIES) research platform was used to repower the Flatirons Campus after an outage cut power to the entire site. With ARIES capabilities, the NREL response team created a microgrid to repower the site, enabling the Flatirons Campus to run on 100% renewable energy for 24 hours. This event proved to be an opportunity for ARIES to run on 100% renewable energy for 24 hours. This event proved to be an opportunity for ARIES to demonstrate how the renewable microgrids of the future can be used to restore power during similar outages.

The microgrid at NREL's Flatirons Campus validated a core principle of ARIES: renewables can enhance resilience and flexibility across power systems large and small. The ARIES platform achieved 24 hours of continuous runtime on 100% renewables after the utility-scale power outage: a critical demonstration of ARIES proof of concept. *Photo by Dennis Schroeder, NREL*

Annual Meteorological Tower Instrument Change-Outs Ensure Mission Readiness and Reliable Operations at Flatirons Campus

The Flatirons Research Operations team completed annual instrument updates to maintain calibration and traceability on the Flatirons 80 meter (m) M-2 weather monitoring meteorological tower and the 135-m M-5 atmospheric research meteorological tower at site 4.0, which supports the DOE 1.5 megawatt (MW) research wind turbine. This work ensures mission readiness and reliable operation of meteorological tower sensors and measurement systems needed to enable DOE and industry-partner field research activities.

Annual change-outs to meteorological tower instruments ensure these assets can reliably facilitate DOE and industry-partner field research activities. *Photo by Jerry Hur, NREL*

Flatirons Campus Receives Letter of Accreditation

The Flatirons Campus received a letter of reaffirmation from the American Association of Laboratory Accreditation, signifying successful renewal of all Flatirons-accredited research measurement processes. All Flatirons Campus research activities conducted in accordance with International Electrotechnical Commission (IEC) standards are accredited by the American Association of Laboratory Accreditation, which is an independent organization that audits and monitors labs to ensure quality-control procedures and processes are followed to produce internationally recognizable reliable test results.

Flatirons Campus Initiates Procurement of CGI-2 Electrical and Civil Construction Work

The research team initiated the procurement of electrical and civil construction work for a second controllable grid interface (CGI-2) at the Flatirons Campus. The CGI helps the U.S. electrical grid evolve by enabling a greater contribution from variable power generators like wind and solar, increased levels of energy storage, and "smarter" grid devices like electric car charging during off-peak hours and autonomous grid services. When complete, the CGI can reduce certification time and costs while providing system engineers with a better understanding of how wind turbines, photovoltaic inverters, and energy storage systems react to disturbances on the grid.

This converter assembly is a central component of the second controllable grid interface (CGI-2) at the Flatirons Campus. When complete, the CGI-2 will help the U.S. electrical grid evolve by allowing a greater contribution from variable power generators, increased levels of energy storage, and smarter grid devices. *Photo courtesy of ABB Group*

Wind Energy Research Continues to Soar With Priority Access to Eagle Supercomputer

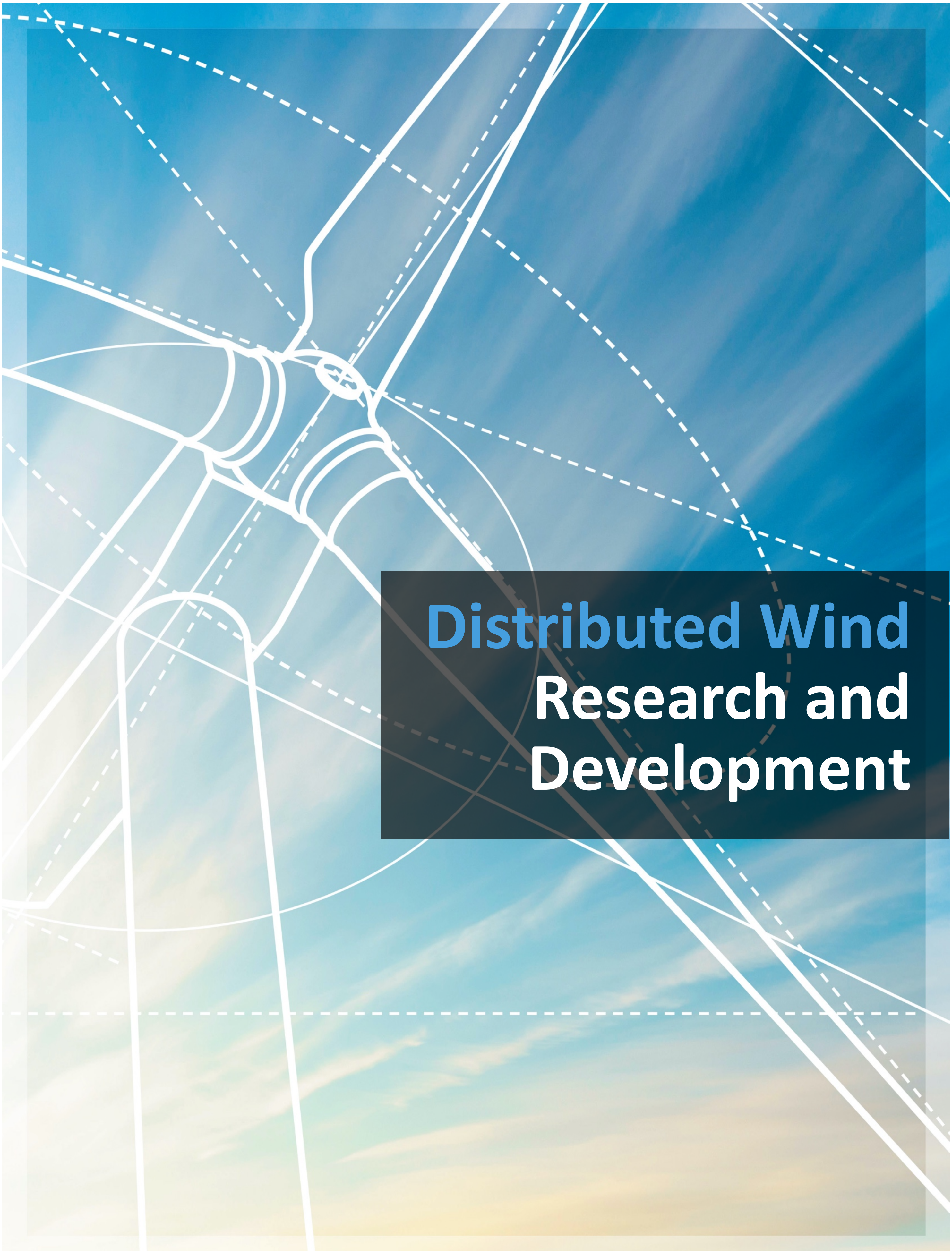
Point of contact: Brian Smith, Brian.Smith@nrel.gov

Through additional Office of Energy Efficiency and Renewable Energy investments and space allocations, many critical WETO projects have been able to take advantage of the enhanced computational capabilities of Eagle in the first and second quarter. Such projects include the Wind Capacity Credit, Distributed Wind – Tools Assessing Performance, and high-fidelity modeling (HFM). Specifically:

- The Wind Capacity Credit project has used Eagle to identify sites in the United States that have particularly high capacity credits, indicating where wind patterns are highly correlated with times of high demand for electricity.
- The Distributed Wind – Tools Assessing Performance project has used Eagle to create high-resolution wind resource simulations to yield uncertainty estimates for the planned 20-year long simulations. Ultimately, these wind resource simulations will be used to capture long-term resource quality and site conditions for distributed wind resource assessment and performance estimation tools.
- The HFM project used Eagle to perform the first high-fidelity, blade-resolved, validation-quality simulations of a megawatt-scale wind turbine in turbulent flow as part of the International Energy Agency (IEA) Wind Task 29 validation campaign, which will enable new designs to help reduce the levelized cost of wind energy.

By allocating priority space and time on the Eagle, WETO projects have access to a critical research asset that will help illuminate underlying complexities in wind energy systems and dynamics to help wind energy achieve its lowest cost.

NREL researchers used the Eagle supercomputer to visualize flow fields for the IEA Wind Task 29 validation campaign, which will enable new designs to help reduce the levelized cost of wind energy. *Photo by Dennis Schroeder*



Distributed Wind Research and Development

Point of contact: Ian Baring-Gould, Ian.Baring-Gould@nrel.gov

Workshop Helps Small Wind Manufacturers Generate Successful Proposals

For wind manufacturers interested in applying to DOE Competitiveness Improvement Project (CIP) solicitations, NREL hosted an all-day virtual workshop in December 2020. Speakers provided an overview of the CIP process, evaluation criteria, certification requirements, and NREL's technical support opportunities. To further support manufacturers interested in applying for CIP awards, NREL also posted the workshop presentations and the workshop recording.

NREL Invites U.S. Manufacturers To Partner on Distributed Wind Technology Innovation

In January, NREL issued a request for proposals for the CIP for distributed wind. This latest request focuses on projects that:

- Develop new, innovative distributed wind concepts
- Transform and optimize existing designs for lower cost, increased energy production, and expanded capabilities, such as advanced grid support to enhance power system resiliency
- Conduct wind turbine and component testing to national standards to verify performance and safety
- Develop advanced manufacturing processes to reduce hardware costs.

The request for proposals closed in March, and awardee selections will be made before the end of 2021. NREL manages CIP on behalf of WETO. Since 2012, NREL has awarded 44 subcontracts to 23 companies, totaling $10.62 million of DOE funding while leveraging $5.41 million in additional private-sector investment.

The CIP provides financial and technical support that enables small U.S. wind manufacturers to develop innovative distributed wind technology like the Bergey Excel 15 wind turbine shown here, which reduces energy costs by 50% compared to older models. *Photo courtesy of Bergey Windpower*

Flatirons DW Turbine Procurement and Installation

Point of contact: Ian Baring-Gould, Ian.Baring-Gould@nrel.gov

NREL Selects U.S. Manufacturers To Help Advance Distributed Wind Technologies

Expanding on investments under the ARIES research platform, NREL is procuring and installing three distributed wind turbines at the NREL Flatirons Campus. Following a notice of intent issued in fall 2020, NREL selected three U.S. manufacturers of small- and medium-sized wind turbines to install their turbines on the campus over summer 2021. The turbines will be used to conduct research focused on integrating wind energy in distributed applications, including hybrid systems, microgrids (isolated and grid connected), and distribution feeders ("in front of" and "behind the meter"), partially in support of the Microgrids, Infrastructure Resilience, and Advanced Controls (MIRACL) research project.

Tools Assessing Performance

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

Mesoscale Modeling To Enable Alaska Time Series Data

To characterize the uncertainty within models that estimate wind resource, a key concern in areas with limited ground-based measurements, the Tools Assessing Performance project team adapted a process to develop new, higher-fidelity wind resource time series data for Alaska. This process was completed by running a wind resource estimation simulation multiple times with slightly different input parameters, resulting in a statistical variation of the possible spread of wind resource estimates. The time series also enables the team to select a set of input parameters that produces the lowest possible bias (error) for Alaska. The configuration can then be used to conduct production runs to create a new 20-year time series data set of wind resources for the state.

Automatic Obstacle Detection Capability To Reduce Input Errors

For rural or industrial areas that could benefit from distributed wind but feature obstacles that might impede power generation, the Tools Assessing Performance computational team has developed a prototype for automatic obstacle detection using digital surface model data. The prototype proposes two alternative methods—an unsupervised learning approach and one that involves image processing techniques. Additionally, the team developed an obstacle description file format and revised the Tools Assessing Performance application programming interface to accommodate obstacle definitions.

Automatic obstacle detection methods could help increase distributed wind deployment by automating an error-prone, manual obstacle assessment process and quantifying existing large-scale opportunities. *Photo by NERGICA Wind and IEA Wind Task 41*

Simplified Obstacle Models Evaluate Distributed Wind Wake Deficits

The Tools Assessing Performance team leveraged hundreds of high-fidelity simulations for different building shapes to create two simplified obstacle models that can be easily used by the distributed wind industry to evaluate wind speed deficit in wakes. The team combined simulations with machine-learning approaches to refine the models and improve accuracy.

These new obstacle models will leverage the automatic obstacle detection capability (mentioned earlier in this section), along with the best methods for spatial and vertical interpolation (also introduced earlier), to calculate accurate, site-specific wind resource estimates for distributed wind projects.

Microgrids, Infrastructure Resilience and Advance Controls Launchpad (MIRACL)

Point of contact: Jim Reilly, James.Reilly@nrel.gov

Publications Expand Knowledge About Wind as a Distributed Energy Resource

On behalf of DOE, NREL leads the multi-year, multi-laboratory MIRACL project to accelerate distributed wind technology development by validating wind technology as a plug-and-play resource with electric grids, solar, storage, and other distributed energy resources in hybrid systems.

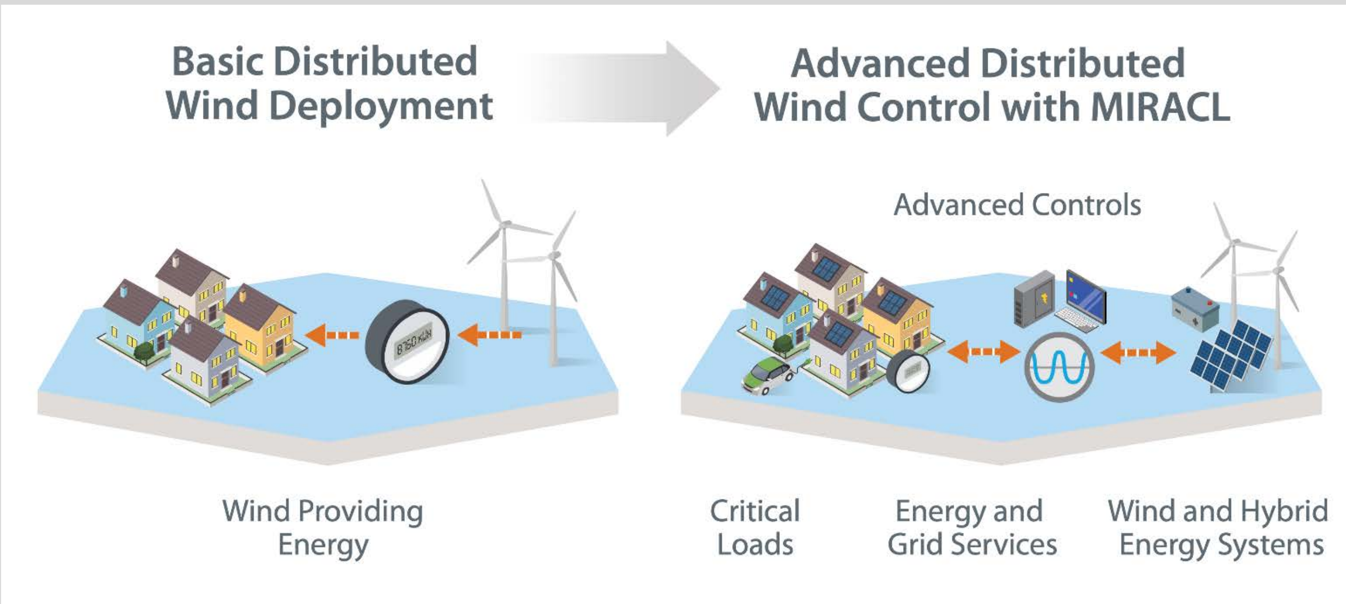
In support of this effort, NREL conducted research and analysis in the primary research areas of valuation and modeling, advanced controls, and resilience and cyber security. This work resulted in the following publications, which provide key information to wind turbine manufacturers, inverter manufacturers, distributed energy resource implementors and technology developers, storage manufacturers, electric utilities, and others.

MIRACL publications include:

- Microgrids, Infrastructure Resilience, and Advanced Controls Launchpad (MIRACL) Fact Sheet
- Distributed Wind Controls: A Research Roadmap for Microgrids, Infrastructure Resilience, and Advanced Controls Launchpad (MIRACL)
- Microgrids, Infrastructure Resilience, and Advanced Controls Launchpad (MIRACL): Use Cases and Definitions
- Microgrids, Infrastructure Resilience, and Advanced Controls Launchpad (MIRACL) Research: Controls
- Integration of Storage in the DC Link of a Full Converter-Based Distributed Wind Turbine: Preprint
- Distributed Wind Considerations From the IEEE 1547-2018 Revision.

Research Demonstrates Advanced Controls for Distributed Energy Systems Can Support Isolated Grids

Advanced controls research conducted through the MIRACL project generated models of the NREL Flatirons Campus and Sandia National Laboratories' (Sandia's) Scaled Wind Farm Technology facility. Featuring distributed wind turbines, battery storage, solar photovoltaics, a diesel generator, and dynamic loads, the models perform dynamic desktop simulations. The MIRACL team used these models to demonstrate how high contributions of wind in isolated grids can be supported by advanced controls of distributed wind turbines.



Traditional wind and distributed wind deployments installed by utilities (left) supply energy in kilowatt-hours to distribution systems and to homes and businesses. The graphic on the right illustrates how MIRACL research will demonstrate advanced wind turbine controls that benefit distribution grids of the future. The sine wave in the center represents how wind, using advanced controls (such as inverters and human-machine interfaces), can support grid frequency for distribution systems. *Illustration by Fred Zietz, NREL*

Simulations Reveal Performance of Advanced Controls in Isolated Grids

NREL performed desktop simulations using the Flatirons Campus MATLAB Simulink model configured as an isolated grid to evaluate how the controls are currently performed, how they may be done in the future, and what the technical benefits of these advanced controls are for a wind turbine in an isolated grid. These simulations resulted in a forthcoming technical report that shows how high contributions of wind in isolated grids can be supported by advanced controls of distributed wind turbines.

Point of contact: Tony Jimenez, Tony.Jimenez@nrel.gov

Analysis Specifies Design Guidelines for Deployable Defense and Disaster Turbines

As part of DOE's Defense and Disaster Deployable Turbine (D3T) project, NREL researchers conducted a technical analysis to determine the largest wind turbines that could fit and be transported within 20- and 40-foot (ft) shipping containers. Results revealed that:

- A 20-ft shipping container can accommodate a wind turbine with a rated capacity of up to roughly 20 kilowatts (kW).
- A 40-ft shipping container can accommodate a turbine with a rated capacity of up to roughly 90 kW.

This information will help inform the D3T design guidelines and procurement specification and is general enough to support multiple potential technology providers. The D3T effort will help determine whether a viable market for defense and disaster-deployable wind turbines exists, and if so, how to best meet the needs of that market.

Traditional wind and distributed wind deployments installed by utilities (left) supply energy in kilowatt-hours to distribution systems and to homes and businesses. The graphic on the right illustrates how MIRACL research will demonstrate advanced wind turbine controls that benefit distribution grids of the future. The sine wave in the center represents how wind, using advanced controls (such as inverters and human-machine interfaces), can support grid frequency for distribution systems. *Illustration by Fred Zietz, NREL*

Microgrid Technical Requirements Released for Public Consideration

Point of contact: Robert Preus, Robert.Preus@nrel.gov

NREL researchers participated on a standards committee comprising representatives from Germany, France, China, Thailand, Canada, Australia, and Spain in support of developing new technical requirements for microgrid power systems. In winter 2021, the committee released for public circulation a draft of the Microgrids Technical Requirements Part 3-3: Self-regulation of dispatchable loads (IEC WD-1.1 62898-3-3). This guidance focuses on addressing load behavior that can support grid stabilization in response to frequency and voltage excursions. While the work of this committee was only for standards for controllable loads in a microgrid, the same issues will develop on main grids as they become dominated by inverter-based power generation and motor and resistor loads are replaced with power-electronic-connected loads. This guidance could ultimately be used to improve the requirements for loads in general.

Simplified Method Proposed for Modeling Fatigue Spectra of Small Wind Turbine Blades

Point of contact: Scott Dana, Scott.Dana@nrel.gov

Small-scale wind turbines have market opportunities in distributed energy generation applications but face future challenges from the high cost of turbine units when calculating fatigue loads of key structural components.

To address the challenges mentioned earlier, NREL researcher Scott Dana collaborated with international university researchers on a study published in *Wind Energy*. Using the aeroelastic wind turbine design tool FAST, the study highlights the conservative nature of the IEC 61400-2:2013 small wind turbine design standard for calculating fatigue life using the simplified loads model. The authors present a modified method for calculating the fatigue spectra of small wind turbine blades, which does not require complex aeroelastic simulations or field measurements. For implementation early in the blade design stage, the method allows for rapid comparison of multiple rotor configurations.

Minimizing material use and manufacturing cost while increasing annual energy production is important for the continued adoption of small wind turbines like these Southwest WindPower Skystream turbines shown here on NREL's Flatirons Campus. NREL researchers used the FAST aeroelastic model of a 2.6-kW turbine in the foreground as one turbine design option in their research published in Wind Energy. *Photo by Dennis Schroeder, NREL*

University Collaborations Extend International Distributed Wind Research Efforts

Point of contact: Ian Baring-Gould, Ian.Baring-Gould@nrel.gov

The IEA Wind Technology Collaboration Programme (IEA Wind) Task 41 – Enabling Wind to Contribute to a Distributed Energy Future, which is led by NREL, launched the Distributed Wind University Research Collaboration. By engaging university professors, researchers, and students on pressing distributed wind research topics, the collaboration will facilitate global distributed wind research. With a goal of matching the pace of cost reductions seen in other renewable energy technologies, specific research efforts include determining opportunities to scale down large wind turbine designs and upscale small wind turbine designs to be appropriate for distributed wind turbines. Task 41 researchers facilitated a series of virtual workshops at the end of November 2020, resulting in four university teams joining the collaboration.

International Collaboration Works To Change Worldwide Standards for Distributed Wind Technology

Point of contact: Ian Baring-Gould, Ian.Baring-Gould@nrel.gov

NREL, in collaboration with the Technical University of Denmark, is leading efforts by IEA Wind Task 41 to develop domestic and international standards for small and midsized wind turbines. This work is critically important to build international support for a revision of the IEC 61400-2 standard. The Task 41 team is summarizing the shortcomings of the current standards, developing a research plan to update domestic and international standards, and working with partner organizations to change the standards.

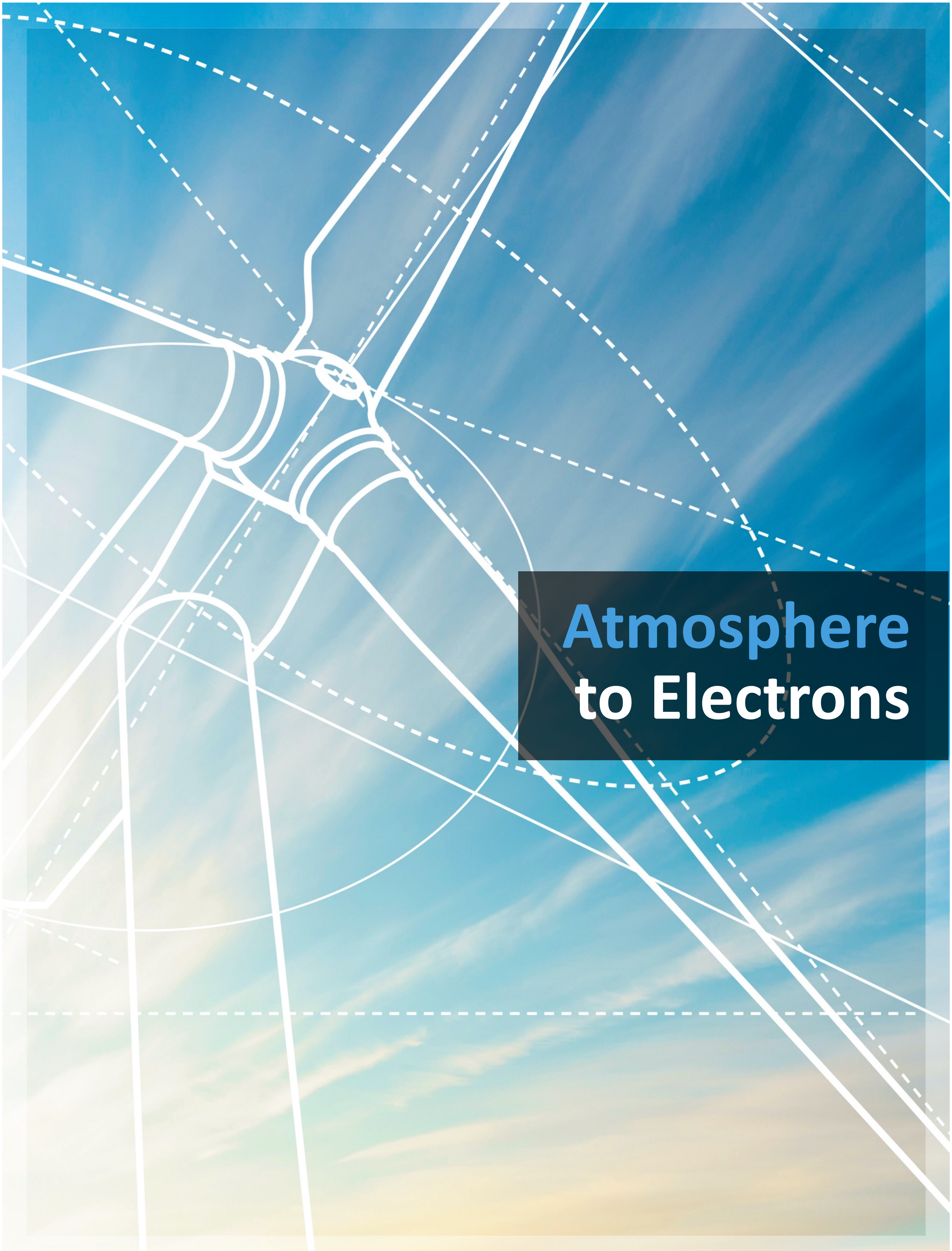
New Modeling Capabilities Reveal Distributed Wind Balance-of-System Cost Drivers

Point of contact: Parangat Bhaskar, Parangat.Bhaskar@nrel.gov

NREL researchers developed a new extension to the Land-Based Balance-of-System Systems Engineering (LandBOSSE) model to estimate balance-of-system capital costs for distributed wind turbine systems installed in the United States. Balance-of-system costs such as installation, site preparation, and construction can account for 50% of distributed wind project costs.

Using this model, NREL analysts found that for projects with smaller wind turbine sizes (less than 100 kW), the primary cost drivers are turbine foundations and turbine erection and installation. For projects with larger machines (greater than 100 kW), the grid-connection costs are primary.

The complete findings of the study are detailed in NREL's technical report, "Technology Innovation Pathways for Distributed Wind Balance-of-System Cost Reduction."



Atmosphere to Electrons

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

Simulated Mountain Waves Help Predict Impacts to Wind Power from Mountain Wave Events

Researchers investigated the ability of the Weather Research and Forecasting model to simulate mountain waves and their impact on hub-height wind speed. They found that the model can simulate and consistently predict the impacts of mountain wave events about an hour earlier than actual observations. Wave events can be triggered as air moves over mountain barriers and can impact wind power generation over areas where these occur, so predictions of the details of mountain wave events can be valuable for the wind energy community for designing, building, and forecasting for wind farms.

The ascent of stably stratified air over a mountain barrier can trigger the generation of mountain waves that can impact annual energy production at wind facilities. *Photo by Iberdrola Renewables, NREL 16105*

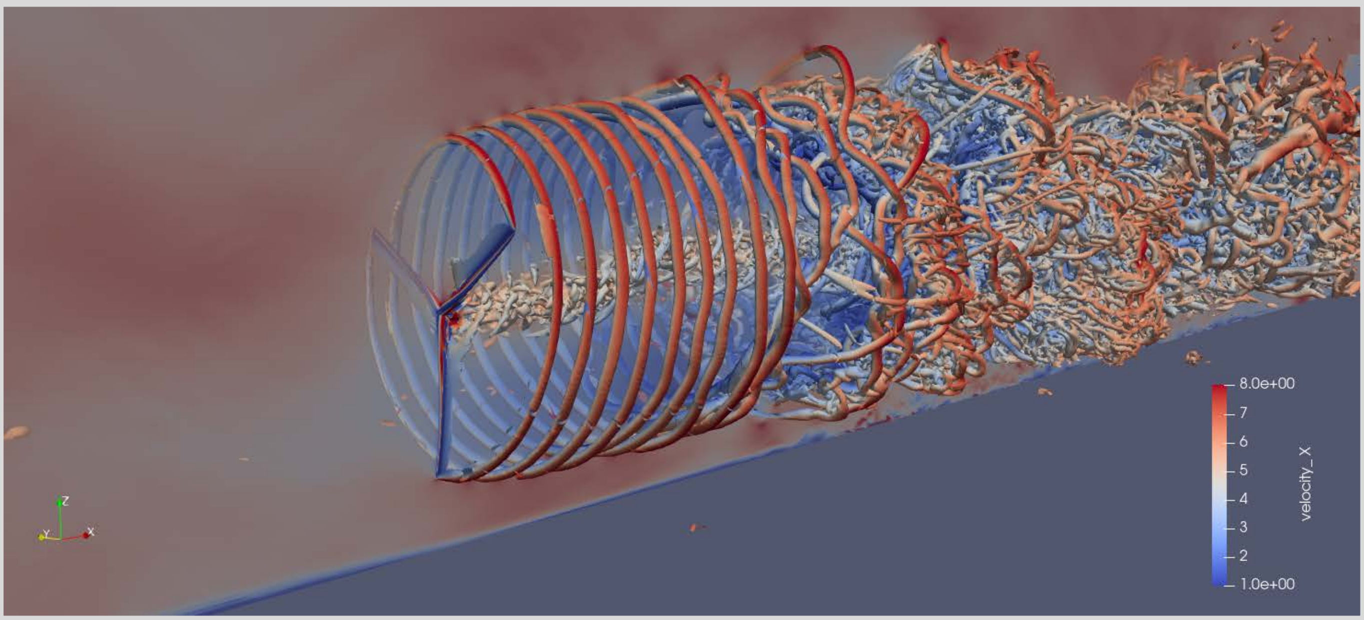
Impacts of Land Surface Modeling on Hub-Height Wind Speed

NREL researchers investigated the impact of land surface models in the Weather Research and Forecasting model on hub-height wind speeds, using observations from the second Wind Forecast Improvement Project. They found that over dry soil, there is a strong physical connection between the land surface and hub-height wind speeds through near-surface turbulent mixing—the chaotic mixing of air fluid dynamics. Insufficient model physics representing the surface energy budget and inaccurate initial land surface states were identified as main sources of model uncertainties. Understanding these model uncertainties can help identify solutions to overcome them and improve wind energy forecasting to ensure sustainable growth and development of wind energy in the United States.

Researchers Demonstrate a New Hybrid Computational Fluid Dynamics Capability and Establish a New Paradigm for Wind Farm Simulations

Point of contact: Michael Sprague, Michael.A.Sprague@nrel.gov

In collaboration with the Exascale Computing Project and researchers at Lawrence Berkeley National Laboratory and Parallel Geometric Algorithms LLC, NREL researchers successfully demonstrated a new hybrid computational-fluid-dynamics solver for blade-resolved wind turbine simulations. In the hybrid approach, the near-blade flow is solved by the unstructured-grid-code Nalu-Wind, which is embedded into and two-way coupled with the structured-grid-code AMR-Wind using overset meshes. Global linear systems are solved through a loosely coupled approach described in an article by the team recently published in the *Journal of Computational Physics*. The hybrid approach is the "best of both worlds" in that Nalu-Wind can capture the thin boundary layers around blades, whereas the highly efficient data structures and algorithms of AMR-Wind can be leveraged in the far-field flow. The new approach is seen as being key to successfully predicting wind farm flow dynamics in a turbulent atmosphere.



Visualization of the flow field around the 2-MW NM80 wind turbine under turbulent inflow. The isosurfaces highlight vortical structures and the colors indicate velocity magnitude. The simulation was performed to validate the code against the DanAero experiment as part of IEA Wind Task 29 using NREL's Eagle supercomputer, producing 120-million grid points. *Image courtesy of Ganesh Vijayakumar, Shreyas Ananthan, and Michael Brazell, NREL*

Energy Research and Forecast Modeling

Point of contact: Eliot Quon, Eliot.Quon@nrel.gov

Energy for Harvest Gets Boost from Energy Research and Forecasting Model

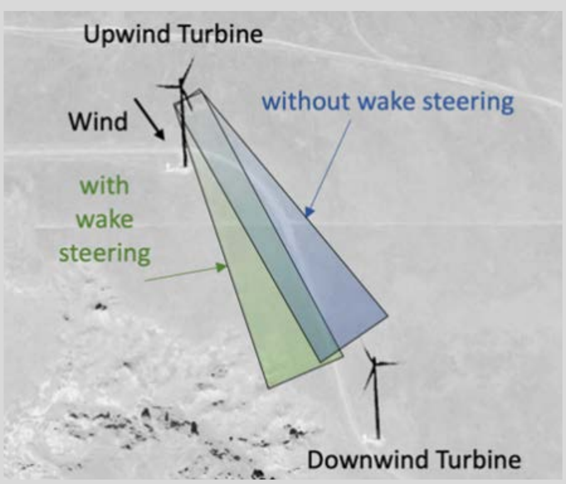
Built on the AMReX software framework, NREL researchers in collaboration with colleagues across DOE's national laboratory complex, have finalized the requirements, design, and documentation of the library within the Energy Research and Forecast GitHub to help validate code verification. This development sets the stage for further advances by identifying gaps in the physical fidelity of high-performance-computing models and improving our ability to render high-fidelity representations of environmental flow fields, improving our understanding of energy available to harvest.

The Energy Research and Forecast model supports several open-source visualization and analysis software tools like VisIt, which provide a way to observe and compare between different model configurations to improve system performance. *Photo by Dennis Schroeder, NREL 61634*

Researchers Assess the Structural Load Impacts of Wake Steering

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

Researchers Assess the Structural Load Impacts of Wake Steering



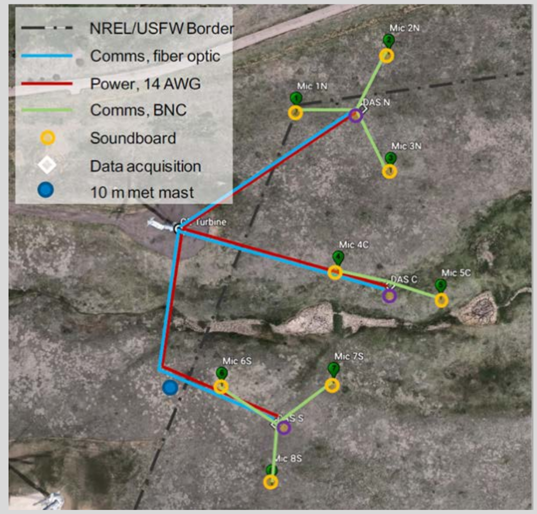
The Energy Research and Forecast model supports several open-source visualization and analysis software tools like VisIt, which provide a way to observe and compare between different model configurations to improve system performance. *Photo by Dennis Schroeder, NREL 61634*

NREL engineers instrumented a pair of utility-scale wind turbines on the edge of a wind farm to assess the structural effects of wake steering, finding wake steering a viable control approach that does not push the load envelope beyond normal operational values when considering a pair of turbines. For the experiment, the upwind turbine was steered into and out of the wind in intervals through the wind turbine yaw mechanism, which can push the wind turbine wake to the side (corresponding figure) so that it does not fully impact downwind machines. The aerodynamic footprint on a downwind turbine will change based on how much of the upstream wake it experiences. By analyzing the loads on the blade, tower, and turbine shaft of the downstream turbine, the researchers found minimal differences in loading when the upstream rotor is aligned versus misaligned with respect to the wind.

Point of contact: Nicholas Hamilton, Nicholas.Hamilton@nrel.gov

An Ear for Aeroacoustic Impacts of Modern Wind Controls Strategies

The project team developed new aeroacoustic measurement capabilities for making full-field noise observations and deployed instrumentation on the DOE 1.5-MW wind turbine at Flatirons Campus, collecting data on noise emissions that result from modern controls strategies. Data collected from the real-world operations were validated against aeroacoustic models in OpenFAST, which will later be made publicly available through the Atmosphere to Electrons (A2e) Data Archive and Portal. Acoustic noise produced by wind turbines is one of the limiting factors on their operation and one of the constraints placed on the development of wind power plants. This project demonstrated that aeroacoustic noise emissions decrease when operating under yaw, supporting the widespread use of this control strategy to mitigate wake losses.

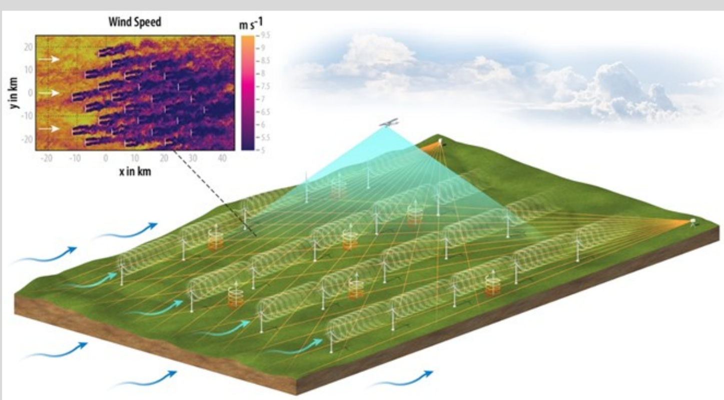


NREL's new distributed aeroacoustics measurement capability can make full-field noise observations and can be configured to target a wide range of science goals of phenomena of interest including overall sound pressure levels, low-frequency noise and infrasound, and noise propagation. *Graphic by Nicholas Hamilton, NREL*

American Wake Experiment (AWAKEN)

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

Report Sets Stage for Successful Field Campaign in Oklahoma



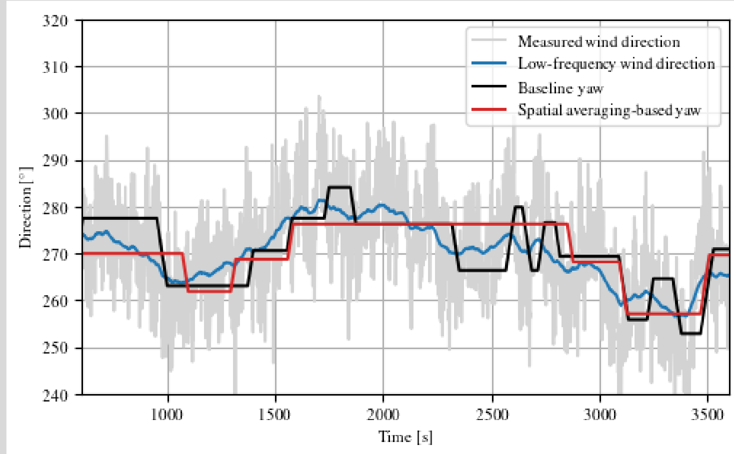
The AWAKEN team will deploy advanced instrumentation and partner with wind farm owners who wish to learn more about wake impacts within their wind farms, turbine manufacturers who want to study turbine response in wind farm environments, and remote-sensing technology companies with a desire to demonstrate their own advanced instrumentation applied to the wind turbine/plant wake problem. *Illustration by Besiki Kazaishvili, NREL*

The American Wake Experiment (AWAKEN) team completed its instrumentation development road map that outlines proposed deployment of this project. The project team will soon publish a Sandia technical report, representing first steps toward developing advanced instruments to gather unique observations and enable improved understanding of wind power plant performance. Wake interactions are among the least understood physical interactions in wind plants today, leading to unexpected power losses. Replete with highlights on promising technologies for development, the report sets the stage for a successful field campaign in northern Oklahoma, which will provide a data set that is unique among wake studies.

Enabling Autonomous Wind Plants Through Consensus Control (TCF)

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

Consensus Control Demonstration Shows Promise for Improved Power Output



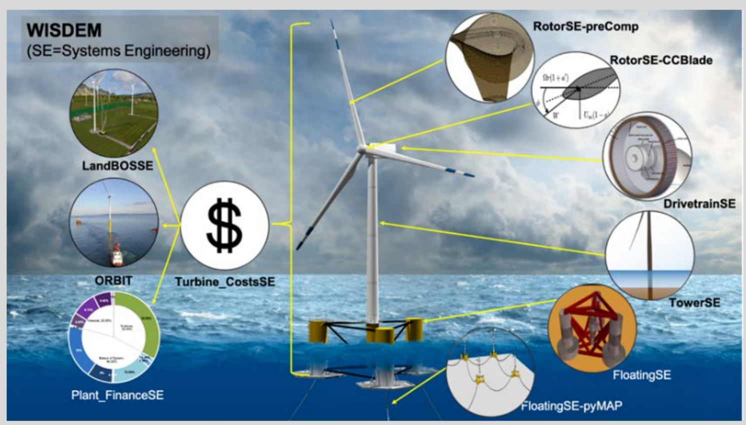
Simulation showing the reduction in yaw activity when using wind direction measurements aggregated across wind turbines (red) versus using only turbine information (black)

Researchers demonstrated the effectiveness of Collective Consensus Controller for Performance Optimization technology—a cooperative wind farm controller that incorporates information from local sensors in real time to better align wind turbines to the prevailing wind direction—in new analysis using wind farm data. The study, conducted in partnership with Renewable Energy Systems, showed that yaw activity of turbines can be significantly reduced while potentially boosting power production. This work advances a growing body of research that treats the entire wind farm as a control system with individual turbines in the network acting as separate agents. Findings from this work and elsewhere can do much to boost wind farm production by improving communication between wind turbines in a network.

Systems Engineering and Optimization

Point of contact: Garret Barter, Garret.Barter@nrel.gov

Moving Beyond Conventional WISDEM: Open-Source Software Upgrades User Experience



WISDEM modules cover the full turbine engineering and cost of energy balance sheet to capture system-level cost-benefit trade-offs. *Illustration by Josh Bauer, NREL*

Recently upgraded to enhance usability, the Wind-Plant Integrated Systems Design and Engineering Model (WISDEM©) software creates a virtual, vertically integrated wind power plant from components to operation. WISDEM couples engineering and cost modeling to capture important system interactions to help engineers improve system-level performance and reduce costs.

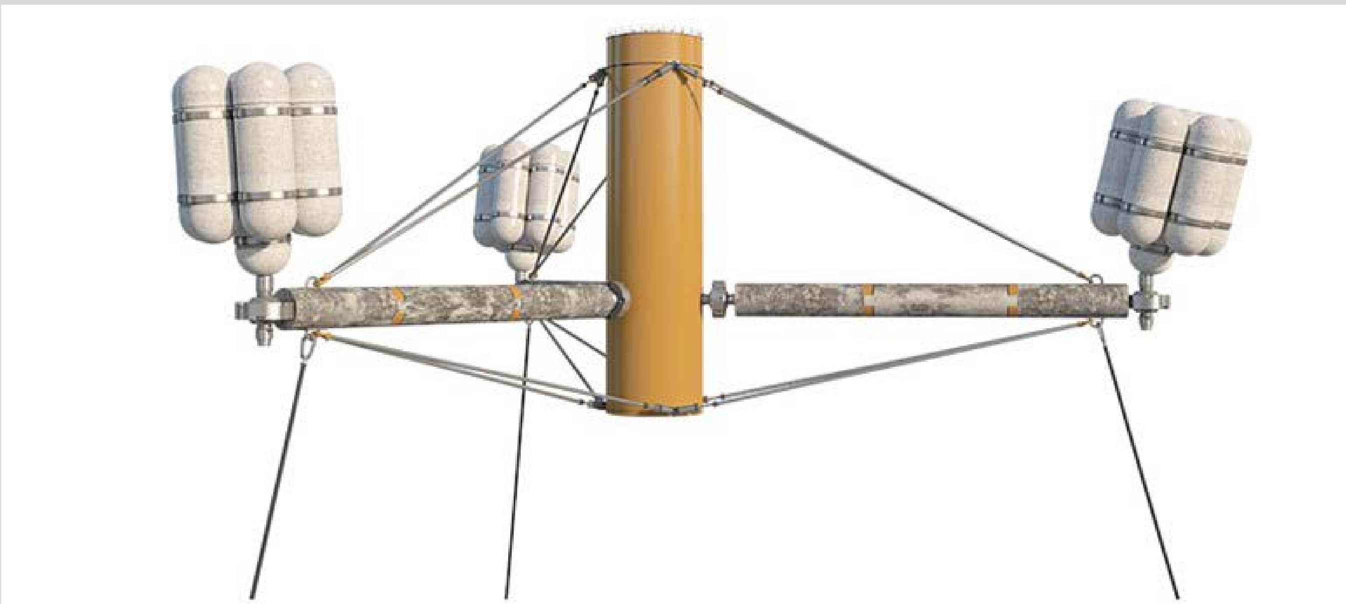
Offshore Wind Research & Development

Point of contact: Senu Sirnivas, Senu.Sirnivas@nrel.gov

Survey Benchmarks Models for Innovative Offshore Floating Systems Against Real-World Wind Power Plants

The new Innovative Offshore Floating Wind System design approaches being explored by NREL researchers could significantly reduce floating offshore wind systems' levelized cost of energy (LCOE). Initial results from an earlier numerical analysis identified the potential of nontraditional design features to increase substructure flexibility, minimize wave-induced loads and motions, and reduce overall substructure cost/mass.

NREL completed a survey of three U.S. wave basins and model-building facilities, which help to assess the suitability of methods to evaluate new design features of the innovative substructure concept for floating offshore wind platforms. Eventually, the test campaign will characterize each innovative design feature separately, comparing different model configurations (e.g., fixed vs. jointed/moving buoyancy tanks).



New design approaches could increase the flexibility and decrease the mass of floating platform substructures. *Image by Josh Bauer, NREL 49054*

Offshore Wind Resource Sciences Work

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

Wind-Wave Interaction Simulations with Nalu-Wind Show a Large Impact of the Moving Waves on the Mean Wind Speed and Wind Speed Fluctuations

To assess the impact of propagating waves on the airflow aloft waves, the Wind Forecast Improvement Project 3 team undertook both direct numerical simulations of turbulent flow over waves as well as large-eddy simulations of an atmospheric boundary layer over swells (depicted here). *Graphic by Georgios Deskos, NREL*

Using high-fidelity computational-fluid-dynamics code Nalu-Wind, researchers conducted simulations to better understand the impacts of complex wind-wave interactions on offshore wind plant power production, mechanical loads, and optimization. Nalu-Wind—a validated, open-source, high-fidelity computational-fluid-dynamics code—can be used to study wind-wave interaction through a waving boundary condition, mesh-motion algorithms, and a wide range of wave-generation classes to enable more efficient and robust designs for offshore wind energy systems. Numerical simulations showed dependence on the wave age as well as the wave steepness, confirming the team's hypothesis regarding the important role of waves in the dynamics of the marine atmospheric boundary layer. The insights gained from these simulations can be used to assess wind power plant designs, whereas the data obtained can be used to extract important information and drive the development of lower-fidelity engineering tools.

Floating Turbine HFM Simulation

Point of contact: Michael Sprague, Michael.A.Sprague@nrel.gov

New Multiphase Flow Solver Positions ExaWind for High-Fidelity Simulations of Floating Offshore Wind Turbines

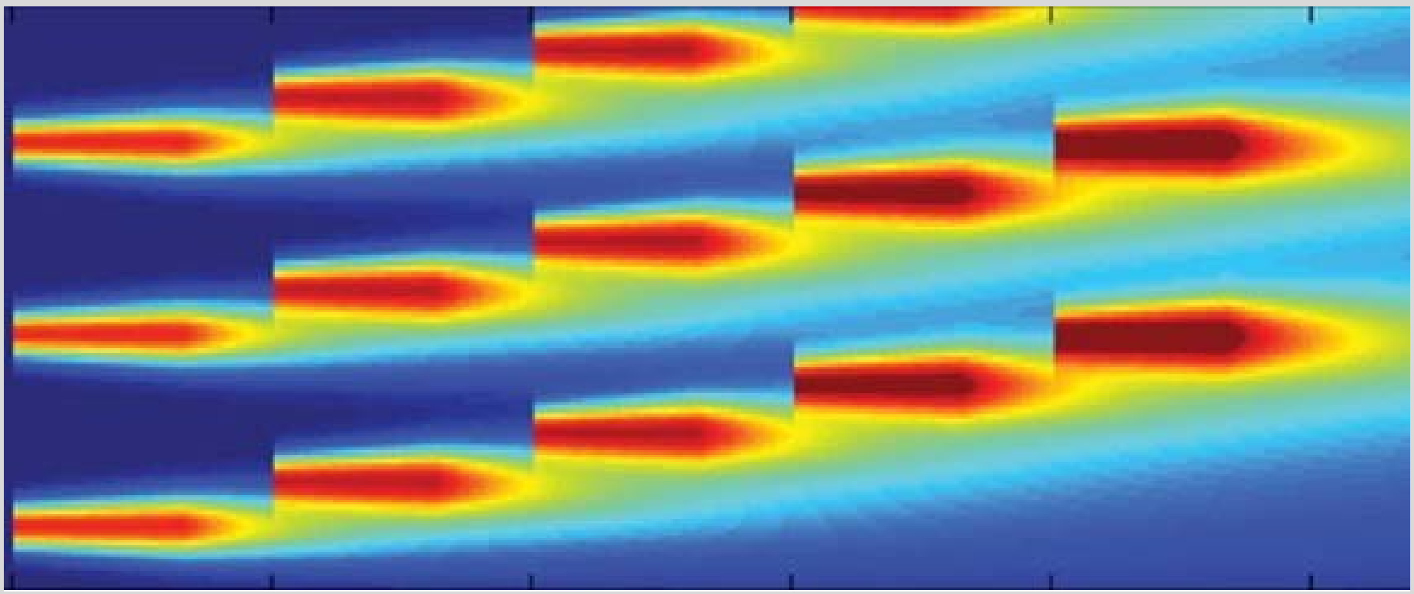
Advances in HFM can lead to significant reductions in the cost of offshore wind energy by improving our understanding of the fundamental physics governing floating wind power plant performance. *Graphic by Michael Sprague*

Significant reductions in the cost of offshore wind energy rely on an improved understanding of the fundamental physics governing whole wind power plant performance. HFM and simulation provide the means to virtually test and develop new technologies, helping mitigate adverse effects and enhance energy-capture potential. NREL's Floating Turbine High-Fidelity Modeling and Simulation project is advancing wind turbine and power plant development with three integrated open-source codes in the ExaWind software stack: Nalu-Wind, AMR-Wind, and OpenFAST. The collaborative project between NREL and Sandia recently implemented and validated a proof-of-concept, volume-of-fluid method in the AMR-Wind code (a highly efficient structured-grid background solver), the first step in establishing multiphase flow for simulations of offshore wind floating platforms and the air-sea interface. It also introduced actuator-line turbine-model capabilities to enable midfidelity offshore wind simulations when AMR-Wind is coupled to OpenFAST, a whole-turbine modeling and simulation environment.

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

Major Updates to FLORIS Add Multiple Features for Offshore Wind and Hybrid Systems

Wind power plant controls, which coordinate activities of multiple wind turbines, can substantially improve the performance of offshore wind systems, optimizing the performance of large turbines and in challenging atmospheric conditions. NREL researchers recently completed a major update to the FLOw Redirection and Induction in Steady State (FLORIS) framework to include new models of wakes and wind farm solvers that better predict effects on large offshore wind arrays, along with a new blockage model. Improved models of wake velocity and combination for arrays of wind turbines, developed in collaboration with Majid Bastankhah and Bridget Welch of Durham University, have been incorporated into FLORIS. The team also incorporated electrical and nonwind generation models and dispatch strategies into FLORIS and completed optimization features for dispatch/design of hybrid systems that combine wind with solar energy sources and energy storage.



New design approaches could increase the flexibility and decrease the mass of floating platform substructures. *Image by Josh Bauer, NREL 49054*

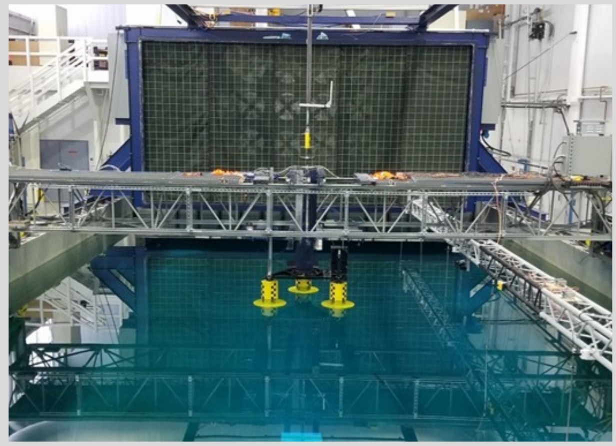
Model Comparison Accounts for Flow Conditions Near Wind Turbine Wakes

A new study published in Renewable and Sustainable Energy reviews the underlying theory for analytical wake models, outlines quality-control procedures for observational data, and compares model results with observational data from the Lillgrund Wind Plant in Sweden. Findings indicate that velocity deficit models that account for flow conditions near wake can better reproduce power production for wind turbines in the first four rows of a wind power plant. By comparison, deep-array, wake-superposition schemes were the largest influence in error reduction. Taken together, these models can benefit wake loss reduction strategies to raise annual energy production (AEP) at wind energy facilities.

New Data Set and Wave Tank Testing Expand Understanding of Hydrodynamic Loads on Floating Systems

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

The team conducted a new wave tank validation campaign to obtain data at a component level to better understand how multiple elements of an offshore wind platform interact with one another, including how scaling and orientation affect the interaction. The experimental campaign was conducted at the Alfond W2 ocean engineering laboratory at the University of Maine, which helps highlight and assess the needs for floating offshore wind research to support the emerging U.S. industry. The data will be uploaded to the DOE Data Archive and Portal for public use and will be incorporated into the Offshore Code Comparison Collaboration, Continued, with Correlation and unCertainty (OC6) project.



Advances in HFM can lead to significant reductions in the cost of offshore wind energy by improving our understanding of the fundamental physics governing floating wind power plant performance. *Graphic by Michael Sprague*

Coupling of a Soil-Structure Interaction Model With Other Modeling Tools Provides Verified Prediction of Loads

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

The OC6 Phase II project, led by NREL, focused on integrating the new REDWIN soil-structure-interaction modeling capability into coupled aero-hydro-servo-elastic modeling tools used to design offshore wind energy systems, and verifying the new capability. Researchers successfully implemented the new REDWIN soil-structure-interaction capability in a variety of industry design tools, setting the stage for more accurate loads analysis of fixed-bottom offshore wind designs that decrease conservancy and/or risk.

FAST.Farm Publicly Released for the First Time

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

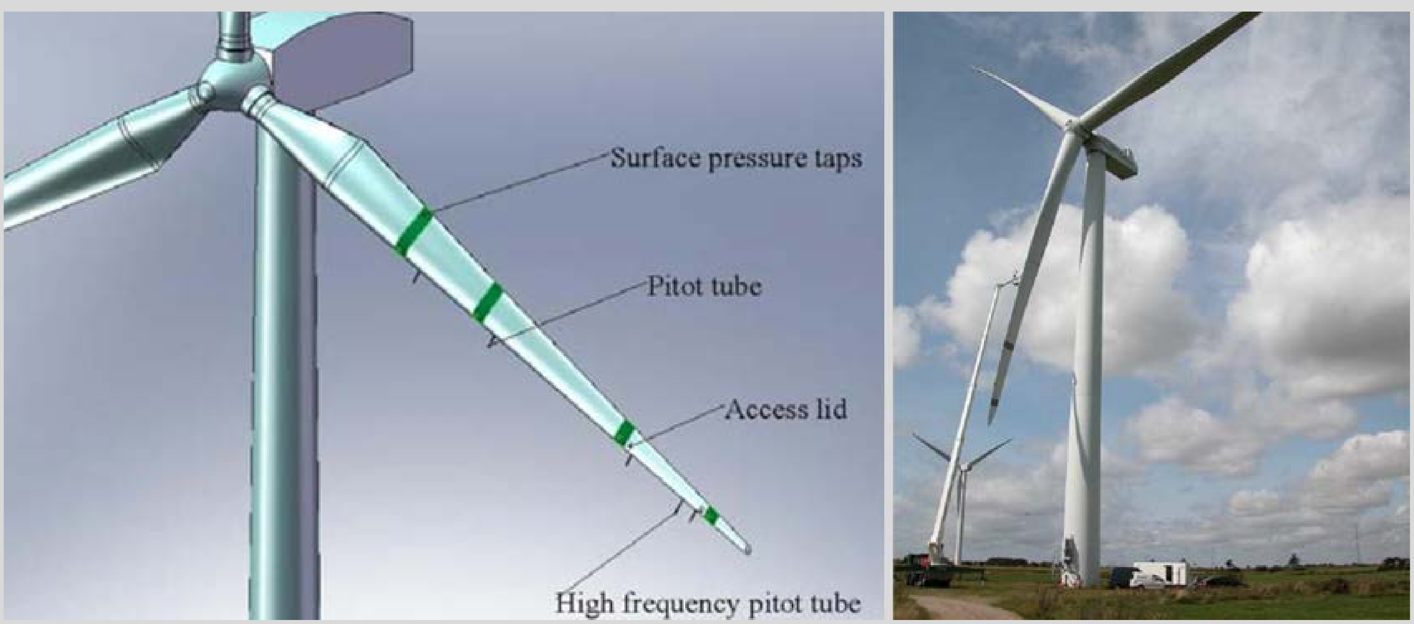
Developed, verified, and validated by NREL over the past several years, FAST.Farm has been publicly released for the first time (previously, FAST.Farm was made available only to specific collaborators). FAST.Farm extends the capabilities of OpenFAST to provide physics-based engineering simulation of multiturbine land-based, fixed-bottom offshore, and floating offshore wind farms with the ability to:

- simulate each wind turbine in the farm with an OpenFAST model
- capture relevant physics for predicting wind farm power performance and structural loads, including windfarm-wide ambient wind, super controller, and wake advection, meandering, and merging
- maintain computational efficiency through parallelization to enable loads analysis for predicting the ultimate and fatigue loads of each wind turbine in the farm.

Completed Verification of Rotor Aeroelastics Within IEA Wind Task 29

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

IEA Wind Task 29 (Analysis of Aerodynamic Elements) focused on using data from the Danish DanAero field experiment of the heavily instrumented NM80 2-MW wind turbine at Tjaereborg, Denmark, to validate and improve wind turbine aeroelastic models under design conditions. NREL participated in the task, verifying and validating OpenFAST for cases involving uniform, sheared/yawed, and turbulent inflow and FAST.Farm for a case involving the wake from one upstream wind turbine. Task 29 was recently completed and a follow-on task—Task 47—was approved by IEA Wind and will launch to focus on experiments, validation, and improvement of aeroelastic models for multimegawatt wind turbines.

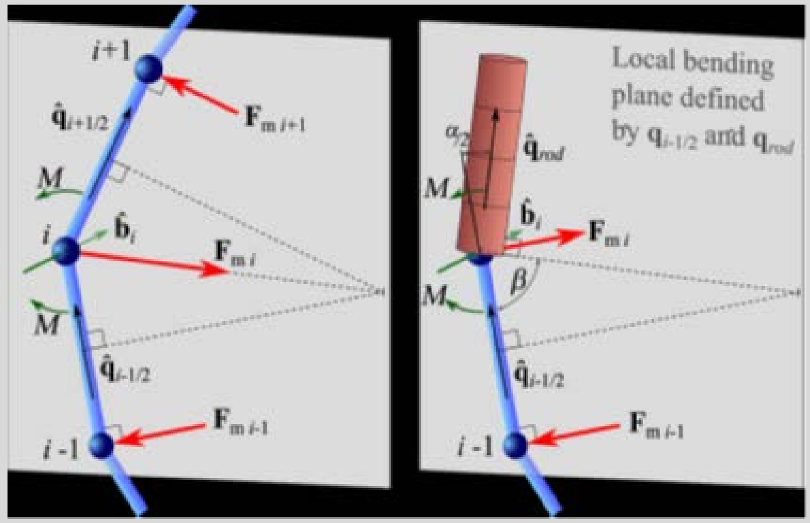


The NM80 2-MW wind turbine at Tjaereborg, Denmark, (right) and blade instrumentation (left). *Images courtesy of Technical University of Denmark Wind Energy*

Enhancements to MoorDyn Model Address Challenges to Dynamic Power Cable Durability

Point of contact: Senu Sirnivas, Senu.Sirnivas@nrel.gov

Dynamic power cables pose challenges in the design of floating wind turbines, wave energy converters, and tidal turbines because of their exposure to significant wave-induced motion. This exposure can lead to bending deformations, axial tension, and related fatigue, eventually resulting in internal damage and shortening lifespan. NREL recently added simulation of dynamic power cables to the capabilities of its MoorDyn lumped-mass mooring dynamics model. Often used for floating wind energy and wave energy converter simulations, the enhanced MoorDyn model will be able to more accurately capture the dynamics of power cables with a bending stiffness model that approximates cable curvature based on the difference in tangent vectors of adjacent elements. Verification simulations are currently underway, and the updated model will soon be available to assess a wide range of cable and mooring system scenarios, leading to more durable components and reliable systems.



The enhanced MoorDyn model makes it possible to simulate bending forces applied along a cable (left) or at an end attached to a rod (right)

Advanced Components, Reliability, and Manufacturing

Additive Manufacturing in Wind Turbine Components and Tooling

Point of contact: William Scott Carron, William.Carron@nrel.gov

Evaluating the Value of Advanced Manufacturing for Wind Turbine Components and Tooling

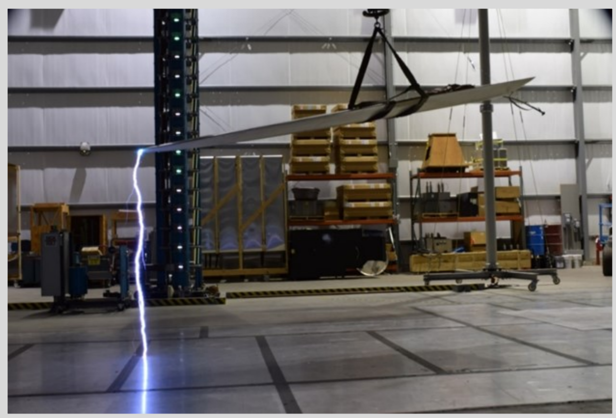
NREL supported research efforts aimed at evaluating the materials, functionality, and industrial competitiveness of additive manufacturing for U.S. manufacturing. Employing data on manufacturing methodologies supplied by Oak Ridge National Laboratory and Vestas, NREL completed a techno-economic analysis of three methods for manufacturing a structural element located in a wind turbine nacelle. Advanced manufacturing—including additive manufacturing and automation—can significantly advance wind energy technology research. This project will provide DOE, industry, and researchers with insight into the potential for additive manufacturing to enable new design and manufacturing pathways that can lead to greater efficiencies, supply chain resiliency, and increased domestic production.

Fusion Joining of Thermoplastic Composites Using Energy Efficient Processes (TCF)

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

Evolving Business-As-Usual Blades: NREL Advanced Manufacturing Paves the Way to Tomorrow’s Recyclable Wind Turbine Blade

Thermoplastic resins, combined with thermal-welding techniques pioneered by NREL and partners, offer the potential for stronger, less expensive, and longer wind turbine blades. These resins will increase energy capture, decrease energy and transportation costs, and increase blade reliability—critical to advancing the wind energy market. This project aims to make fusion-welding technology commercially viable for the wind industry by proving that it is possible to manufacture utility-scale, fusion-joined components and protect these components from lightning strikes as they increase in scale. NREL researchers designed and manufactured a lightning protection system for a 5-m-long, thermally welded blade tip and then applied high-voltage and high-current lightning validation to it, finding that their proposed design was able to protect the fusion-welded bond lines from significant lightning damage. The team submitted the results of this validation in a manuscript to *Wind Engineering*. The resin system used for all components of this design was developed in concert with Arkema Inc. Coupled with NREL's thermal-welding technique, this resin system allows many of the materials used to construct wind turbine blades to potentially be recycled and reused at the blade’s end of life. This novel, thermoplastic resin system for wind turbine blades was a recipient of a 2020 R&D 100 Special Recognition Award.



Both high-voltage leader strike attachment tests and high-current physical damage tests were performed on the wind turbine panel and the 5-m tip. *Photo by NREL*

3D Printed Core Structures for Wind Turbine Blades

Point of contact: William Scott Carron, William.Carron@nrel.gov

Building Next-Generation Blade Core Structures Through 3D Printing

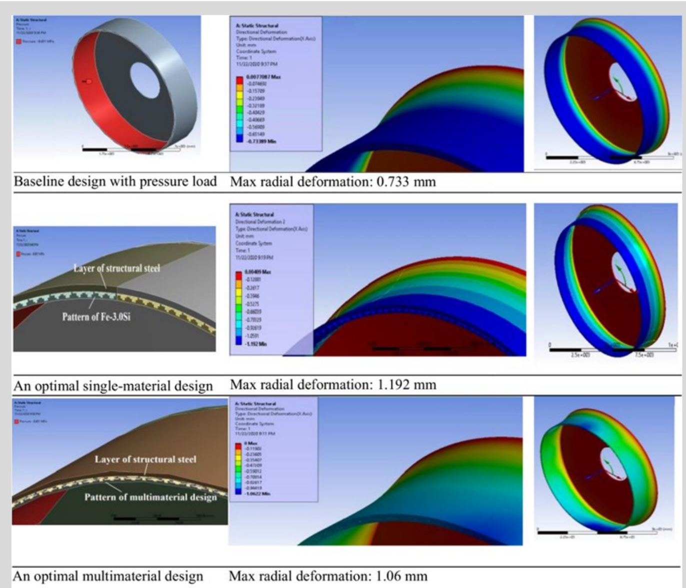
NREL is leading a project that is examining how the use of three-dimensional (3D) printing, advanced materials, and advanced design procedures can improve the core structure of a wind turbine blade. Specifically, this project is evaluating how large-scale, 3D-printing technologies and advanced automation can be leveraged to design and manufacture a 3D-printed-blade core structure, which can outperform current solutions in terms of strength, stiffness, mass, cost, and durability. The project moves the state of the art in the wind turbine blade industry from additively manufactured blade mold and tooling applications into directly 3D-printed, large-scale-blade core structures. Direct printing enables new solutions that can better optimize stiffness-to-weight and strength-to-weight ratios, produce complex nondevelopable surfaces, reduce resin absorption, and utilize domestically sourced recyclable materials. The research and knowledge gained through this work can lay the foundation for developing cost-effective advanced manufacturing processes that can 3D print the entire blade structure, which could revolutionize the wind blade manufacturing industry.

MADE3D (Manufacturing and Additive Design of an Electric Machine Enabled by 3D Printing)

Point of contact: Latha Sethuraman, Latha.Sethuraman@nrel.gov

Employing Advanced Machine Learning and Manufacturing To Trim the Fat from Tomorrow's Generators

NREL researchers explored the magnetic optimization potential for the rotor of the IEA Wind 15-MW reference wind turbine generator using an advanced design framework developed using NREL's newly developed software, Manufacturing and Additive Design of Electric Machines enabled by 3-Dimensional printing – advanced machine learning (MADE3D-AML). The team trained algorithms within MADE3D-AML to identify an optimal distribution of additively manufacturable hard and soft magnets that also resulted in highest torque per rotor active mass and the potential to minimize the use of rare-earth magnets. A comparison of the MADE3D-AML approach with conventional optimization techniques suggests a significant reduction in computational time and improvements in accuracy of performance predictions up to a 15-ton weight reduction from the rotor and more than a 30% increase in mean torque per rotor active mass. MADE3D-AML helped further identify a wider choice of 3D-printable novel single- and multimaterial compositions for the rotor core and magnets with the potential to save costs by up to 8.75%. Study results were made available in a technical report and published in the *Springer Journal of Engineering Research*.



NREL's team is leading the charge on the design and manufacture of cost-effective, fully additively manufactured direct-drive electric generators, exploring comparisons between single and multilateral designs.

Wind Turbine Drivetrain Reliability

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

Drivetrain Reliability Collaborative: Taking a Deeper Look at Main Bearing Failures

Wear-related failures of spherical roller bearings in the main bearing of three-point mount wind turbines have been higher than expected and can contribute to increased operation and maintenance costs. In a 3-year collaborative project with bearing supplier SKF, the NREL team analyzed the main bearing loads and motions measured in the DOE 1.5 turbine at the Flatirons Campus and compared them to a model NREL researchers developed that is scalable to different wind turbines.

The findings confirmed that axial motion of the main bearing caused by natural time variations in rotor thrust (e.g., gusts and turbulence) is well below the threshold that would be disruptive to the proper lubrication of the bearing, causing potential damage. The team's goal now shifts to further examine the measured bearing loading and lubrication characteristics to examine the factors that may result in premature wear, ultimately helping to reduce wind power plant operation and maintenance costs and increase wind plant productivity.

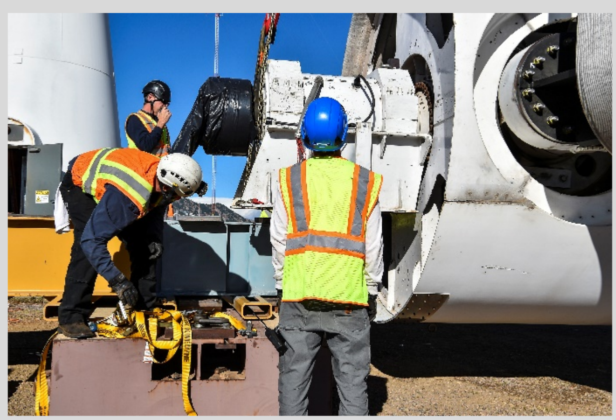
Grease is often used as a lubricant for rolling bearings to alleviate friction and wear. Over time, main bearing failures can still occur, which can increase maintenance costs and decrease wind power plant productivity. *Photo by Photo by Mark Dunn, SKF*

Wind Turbine Drivetrain Reliability Assessment and Remaining Useful Life Prediction (TCF)

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

Shifting From Diagnostics to Prognostics: New Modeling Software Assesses Potential Wind Turbine Bearing Failures

NREL has developed modeling software that allows operators and designers to more effectively assess and proactively address potential bearing failures. Existing design standards and models do not account for the prevalence of gearbox failures, and condition monitoring systems only identify damage after it has already occurred. A partnership with wind power plant optimization specialist WindESCo will make it possible to evaluate and speed up commercialization of the NREL tools based on data and expertise from real-world wind plant operations. Eventually, these tools will allow designers and operators to predict reliability of individual components for wind plants of all types and sizes while considering design parameters, operation strategies, and control objectives. These models can encourage growth in the industry, reducing risk, and stimulating investment.

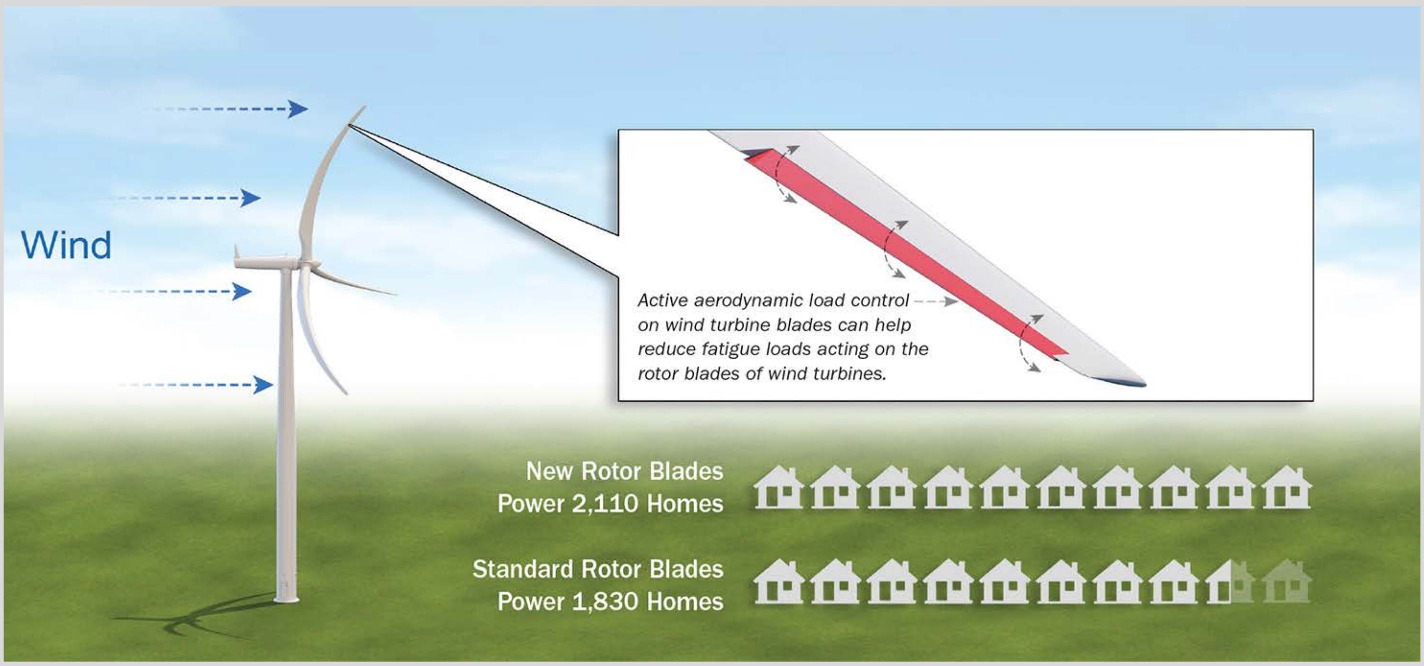


New tools from NREL are making it possible to predict individual component reliability for the entire wind power plant. *Photo by Dennis Schroeder, NREL 49410*

Point of contact: Nick Johnson, Nick.Johnson@nrel.gov

Flexing the Limits of Land-Based Rotor Growth

Researchers will release the Phase-One final report for the Big Adaptive Rotor project, featuring a techno-economic analysis of a downwind turbine with highly flexible blades, along with recommendations to enable the development of 5-MW, 206-m, land-based rotors. The report will also highlight the model development completed as part of Phase One. These next-generation land-based wind turbines have the potential to increase capacity factors by 10% or more over a typical land-based turbine. A multilab team from NREL, Sandia, Oak Ridge National Laboratory, and Lawrence Berkeley National Laboratory will continue to research and develop technology to enable land-based wind at medium- and low-wind-speed sites to be competitive in future power markets by delivering low-cost, unsubsidized, high-value, reliable electricity, with innovative rotor designs. This project will not only result in lower wind LCOE, but also open a significant number of low-wind-speed sites, thereby facilitating access to wind energy nationwide.



Bigger can be better: NREL’s Big Adaptive Rotor team is working to supersize land-based wind turbines—and their capacity. Graphic by Besiki Kazaishvili

Standards Support and International Engagement

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

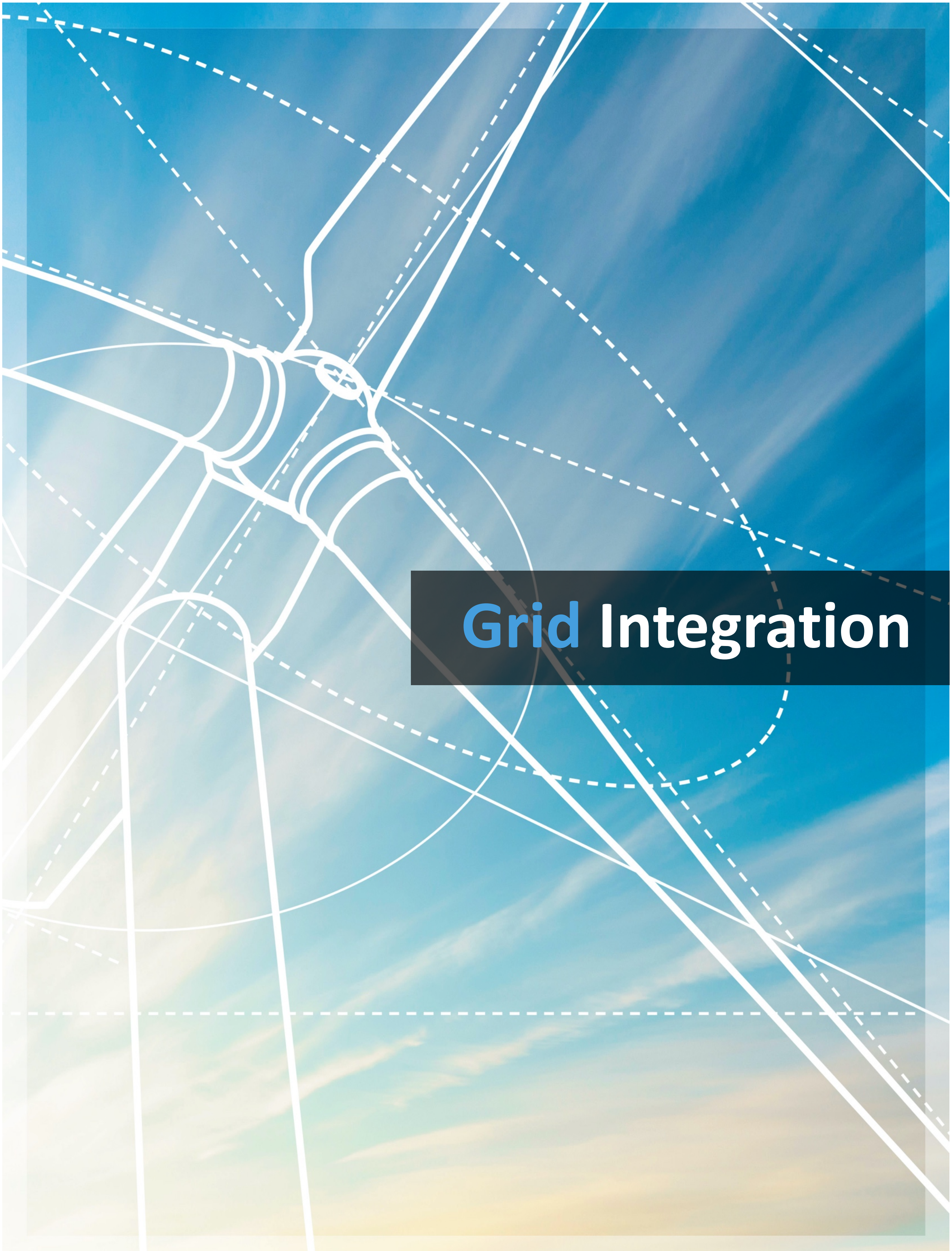
Global Research Efforts Strengthen U.S. Wind Leadership

NREL's involvement with IEA Wind strengthens the nation's presence and influence among member countries, the European Commission, the Chinese WindEnergy Association, and WindEurope. NREL researchers lead or co-lead 10 IEA Wind research efforts:

- Task 26: Cost of Wind Energy
- Task 28: Social Acceptance of Wind Energy Projects
- Task 30: OC6
- Task 31: Wakebench: International Wind Farm Flow Modelling and Evaluation Framework
- Task 34: Working Together to Resolve Environmental Effects of Wind Energy (WREN)
- Task 37: Systems Engineering in Wind Energy
- Task 41: Enabling Wind to Contribute to a Distributed Energy Future
- Task 43: Digitalisation of Wind Energy
- Task 44: Wind Farm Flow Control
- Task 45: Enabling Wind Turbine Blade Recycling.

IEA Wind is an international cooperation of 24 countries and sponsor members that share information and research activities to advance wind energy deployment. *Graphic by John Frenzl, NREL*

Additionally, NREL Wind Energy Laboratory Program Manager Brian Smith serves as vice chair and U.S. alternate member of the IEA Wind Executive Committee. He and the NREL team helped establish the new Task 44: Wind Farm Flow Control and Task 45: Enabling Wind Turbine Blade Recycling Wind Blades. They also proposed new tasks on floating offshore wind arrays, airborne wind energy, and hybrid power plants.



Grid Integration

North American Renewable Integration Study

Point of contact: Greg Brinkman, Greg.Brinkman@nrel.gov

Project Sets Forth Vision for Interconnected Grid Across North America

The North American Renewable Integration Study (NARIS) project team completed its analysis of pathways forward to modernize the power grid of Canada, Mexico, and the United States through efficient planning of transmission, generation, and demand. The culmination of 5 years of work, NARIS produced a new model that demonstrates the efficacy and reliability of bringing more renewable energy technologies—especially wind and solar—onto the power grid under various penetration-level scenarios. Based on these models, this project helps lay the groundwork for cross-border and interregional energy integration that will help inform power systems planners and operators, government agencies, and regulators. Body text is Times New Roman 12.

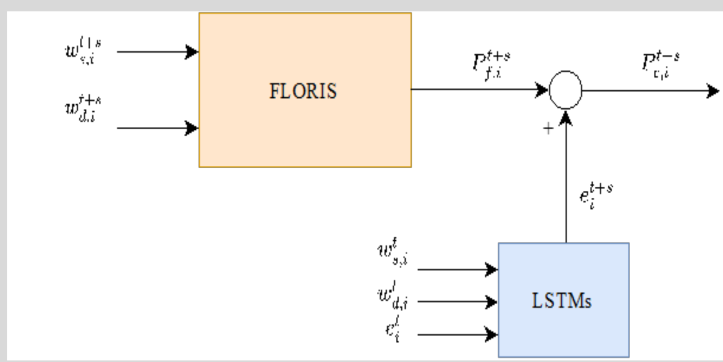
Among other findings, NARIS describes how an integrated grid can be reliable, economically efficient, and enable high contributions of renewable resources throughout the continent. *Photo by Dennis Schroeder, NREL*

Atmosphere to Electrons to Grid (A2e2g)

Point of contact: David Corbus, David.Corbus@nrel.gov

FLORIS Learns New Connection for Improved Forecasting

NREL's Atmosphere to Electrons to Grid (A2e2g) wind power plant controller has been updated to include estimations of more accurate wind plant power curves for short-term (e.g., 10 minute) and day-ahead forecasts. The method developed for robust power predictions is time-efficient and uses an integrated approach using NREL's FLORIS model along with a Gaussian process, data-driven approach that uses learned long short-term memory (LSTM) connections. FLORIS handles unseen conditions and the Gaussian process can learn the mismatch between the model and data. Further, it is updated online a few times per day with a runtime on the order of tens of minutes. These developments enhance our forecasting and can inform future improvements by continually upgrading FLORIS.



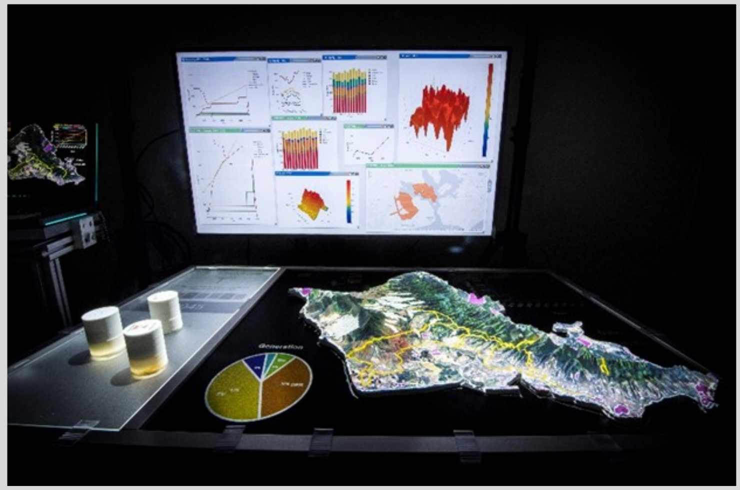
Data from the Biglow wind power plant were used to estimate improvements to the controller and are being documented in a forthcomingConference on Decision and Control paper entitled, "Wind Power Forecasting using LSTMs."

Continental-Scale Planning Tools

Point of contact: Gregory Brinkman, Gregory.Brinkman@nrel.gov

To Weave an Interconnected Grid, Wind Fills Out the Seams

This project refines methods and data parameterization for improved modeling of transmission congestion within capacity planning tools and grid operations models across the continental United States. This year, the project team completed improvements to the Regional Energy Deployment System that better assess the value impacts of the long-distance transmission of wind energy. While full details on this work will be prepared later in the year, improvements build on the work of the Interconnection Seams Study. By improving how we understand energy choke points, we can better model the potential contributions of wind to the reliability and resilience of a continental-scale U.S. power grid, increasing our confidence that such a grid can operate stably with high penetrations of renewable energy.



The ability to model transmission congestion allows grid operators to analyze and communicate the trade-offs and interdependencies between energy resources, improving grid dispatchability and resiliency. *Photo by Dennis Schroeder, NREL 57780*

Continental-Scale Planning Tools

Point of contact: Gregory Brinkman, Gregory.Brinkman@nrel.gov

NREL Provides Leadership To Develop International Standard for Interconnection and Interoperability of Inverter-Based Resources

The creation of a new standard for interconnection and interoperability of inverter-based resources interconnecting with associated transmission electric power systems is a high priority for both WETO and the Solar Energy Technologies Office, as modern wind and solar power plants all interface with the electric grid through inverters. NREL is working closely with the wind industry and IEEE, as this standard will impact how wind plant systems are designed. Recent input to IEEE 2800 helps inform the standardization of a verification framework and makes it compatible across the wide range of plants covered by the standard.

Advanced Modeling, Dynamic Stability Analysis, and Mitigation of Control Interactions in Wind Power Plants

Point of contact: Shahil Shah, Shahil.Shah@nrel.gov

Scanning Tool Helps Provide Dynamic Stability to Wind Power

NREL has developed a python-based impedance scan tool for power systems computer-aided design models that can characterize the response of power electronics devices such as wind turbines, wind power plants, static synchronous compensators, and high-voltage direct-current converters at different frequencies to understand their impact on grid stability at different time scales. Vendors provide models of power electronics devices only in the black-box form to protect their intellectual property. The NREL-developed impedance scan tool can leverage high-fidelity black-box models of power electronics devices to characterize their dynamic behavior and use that information for evaluating their impact on grid stability. This tool can help us understand how future grids can stably operate in the presence of large amounts of wind generation.

The analytical and simulation tools NREL is developing to understand grid stability with very high levels of renewables were featured in an IEEE Electrification Magazine article, "Impedance Methods for Analyzing Stability Impacts of Inverter-Based Resources: Stability Analysis Tools for Modern Power Systems." *Image courtesy of IEEE*

Continental-Scale Planning Tools

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

Grid-Forming Controls Enhance Wind Stability

The NREL/GE project team is planning to implement and demonstrate grid forming controls in a GE 2.8 MW Type 3 wind turbine generator installed at NREL's 5 MW dynamometer facility. 7 MVA controllable grid interface (CGI) coupled with 3 MVA load bank and power-hardware-in-the-loop (PHIL) real-time platform will be used to emulate operation of grid forming wind power plants in both grid connected and islanded modes. The project will demonstrate the reliability benefits of grid forming wind power plants and their ability to provide essential and advanced reliability services to the gird. Resiliency services in the form of black-start, islanded operation and participation in power system restoration schemes will be demonstrated as well.

NREL researcher Vahan Gevorgian is part of the team working on solar, wind, and battery storage grid integration research at the NWTC. *Photo by Dennis Schroeder, NREL*

Mitigating Market Barriers

NREL and Project Partners Team Up to Advance Species Conservation and Wind Energy Deployment

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

NREL and Defenders of Wildlife launched *Wildlife and Wind Energy: Considerations for Monitoring and Managing Impacts*, a nine-part webinar series to help familiarize stakeholders with the nuances of land-based wind energy development in the context of species conservation. Held from September through December 2020, the webinar series helped attendees understand a variety of topics ranging from species-specific discussions and methodologies for reducing impacts on wildlife to regulatory and financing perspectives on effective mitigation strategies for species protection.

The *Wildlife and Wind Energy: Considerations for Monitoring and Managing Impacts* webinar series, hosted by NREL and project partners, focused on land-based wind energy development in the context of protecting vulnerable species like this silver-haired bat. *Photo by Cris Hein, NREL*

Knowing How Golden Eagles Use Wind Flow Patterns May Help Reduce Interactions with Wind Turbines

Point of contact: Eliot Quon, Eliot.Quon@nrel.gov

NREL scientists along with fellow researchers at the U.S. Geological Survey, Western EcoSystems Inc., and Conservation Science Global Inc. are developing a state-of-the-art computational framework for modeling golden eagle behavior near wind farms. At this stage, the team has focused their atmospheric modeling for a specified region in the United States and has begun validating the behavioral component of the framework with eagle telemetry data that represent eagle flight patterns collected by Conservation Science Global and the U.S. Geological Survey. With the updated atmospheric modeling, the team can pair this atmospheric data with behavioral data on golden eagles to create a tool that can help guide wind power plant siting decisions and dynamic curtailment strategies informed by real-time eagle flight path prediction.

The wind energy industry has investigated various strategies and technologies that can help protect golden eagles like the one shown here, such as installing tools like IdentiFlight in wind plants. However, understanding eagle flight behavior to predict how these animals move in and around a wind power plant remains challenging. *Photo by Dennis Schroeder, NREL*

Advancing Technological Solutions Will Help Reduce Bat Interactions with Wind Turbines

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

NREL published the findings of the workshop, "State of the Science and Technology for Minimizing Impacts to Bats from Wind Energy" in a technical report. These findings characterize the status of current technologies, identified emerging technologies, and discussed the R&D opportunities to facilitate implementation of effective strategies for minimizing bat interaction with wind turbines. In addition, the workshop focused on the biological, economic, and regulatory aspects associated with validating and integrating deterrents or smart curtailment systems at wind energy facilities.

NREL Identifies Approaches to Understanding the Potential Population-Level Impact of Wind Turbines on Bats

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

NREL released a technical report highlighting research methods to assess the population status and trends of bats that are vulnerable to wind energy development. Systematic acoustic surveys and genomic data collected over time can assess whether bat populations are stable, increasing, or decreasing. This information will help wind energy project developers determine whether wind turbines pose a population-level risk to bats and, if so, what level of minimization is necessary to ensure viable populations persist.

Assessing whether populations of species like this hoary bat are stable, increasing, or decreasing will help wind energy project developers determine whether wind turbines pose a population-level risk to an area's bats and, if so, what level of minimization is necessary to ensure viable populations persist. *Photo by Cris Hein, NREL*

NREL Researchers Publish Investigation into the Potential for Wind Turbines to Cause Barotrauma in Bats

Point of contact: Mike Lawson, Mike.Lawson@nrel.gov

NREL researchers published an article in PloS One examining the potential for air-pressure variations caused by rotating wind turbine blades to injure or cause bat fatalities at wind power plants. Combining analyses of bat physiology and simulations of the aerodynamics of operating wind turbines, the article concluded that barotrauma is unlikely to be responsible for a significant number of turbine-related bat fatalities. This research is critical for developing strategies to reduce impacts to bats at wind energy facilities.

FOA 1924 - Evaluating Advanced Ultrasonic Acoustic Deterrent (NREL)

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

Thermal Imaging Helps NREL Researchers Investigate Effectiveness of Ultrasonic Acoustic Deterrents

Ultrasonic acoustic deterrents may represent an effective and flexible bat impact reduction strategy. NREL researchers investigated the effectiveness of a deterrent technology, developed by NRG Systems, by using thermal imaging to track the movements of various species of bats in response to different ultrasonic signals in an open-air flight cage. The team then presented these findings at the 13th North American Coordinating Collaborative Wind Wildlife Research Meeting. Preliminary results for red bats suggest that deterrents can be used to influence flight and echolocation behaviors, which may encourage wind farm operators to incorporate these deterrents into wind projects and minimize bat-turbine interactions.

NREL researchers investigated the effectiveness of an ultrasonic acoustic deterrent by using thermal imaging to track the movements (dots in the image) of various species of bats in response to different ultrasonic signals in this open-air flight cage, pictured here. *Image courtesy of Brittany Stamp, Texas State University*

Working Together to Resolve Environmental Effects of Wind Energy (WREN)

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

NREL and Partners Scan Horizon for Environmental Issues Associated with Land-Based and Offshore Wind Energy Development

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

Working Together to Resolve Environmental Effects of Wind Energy (WREN) and IEA Wind Task 34 are supporting the deployment of wind energy technology around the globe through a better understanding of environmental issues, efficient monitoring programs, and effective mitigation strategies. As part of its duties, WREN launched a "horizon scan" to systematically identify priority issues for land-based and offshore wind energy development based on perspectives within the international community. The scan will be developed at a global scale and will include stakeholders from private industry, government, academia, and nongovernmental organizations. Results from the horizon scan will be publicly disseminated to help facilitate knowledge transfer and collaboration.

WREN's "horizon scan" project will systematically identify priority issues for land-based and offshore wind energy development based on perspectives within the international community. *Illustration by Alfred Hicks, NREL*

Short Science Summaries Provide Up-to-Date Information on Vulnerable Species

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

Short Science Summaries provide concise, up-to-date information on species that may be impacted by land-based and offshore wind energy development, offer risk monitoring and management strategies, and identify research priorities for impacted species. In the first and second quarter of FY 2021, the team produced two additional summary documents for soaring raptors and European grouse species. The information in these summaries can help communities and developers make environmentally responsible decisions about area wind energy projects.

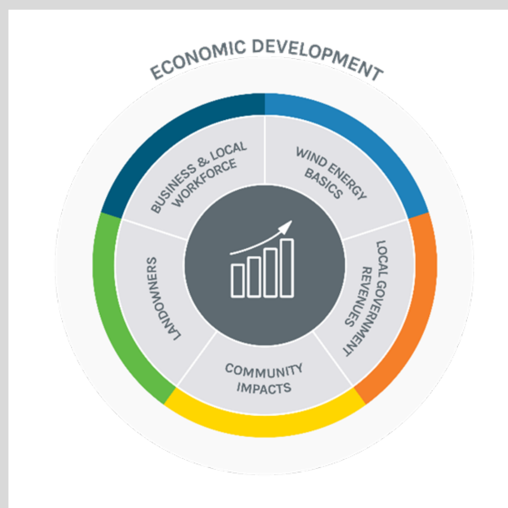
WREN's Short Science Summaries can help communities and developers make environmentally responsible decisions about wind energy development. *Photo by Dennis Schroeder, NREL*

WINDExchange Stakeholder Engagement and Outreach

Point of contact: Mary Hallisey, Mary.Hallisey@nrel.gov

Incoming Wind Siting Guides Offer Comprehensive Resources for Communities

NREL researchers developed the Wind Energy Siting Resource and Economic Development Guide—two resources intended to provide community decision makers with foundational information about the common concerns and potential benefits of utility-scale, land-based wind energy. No two wind farms are alike, and much of this diversity can be attributed to the ordinances that stipulate various characteristics of the project. The siting guides are created to focus squarely on community needs, offering consolidated, comprehensive resources for decision makers at the community level when considering wind energy projects.



By exploring five sections of the economic development guide, community leaders can support their residents, collaborate with developers, and make informed decisions. *Graphic by NREL*

Video Tutorial Helps Users Understand Wind Resource Maps

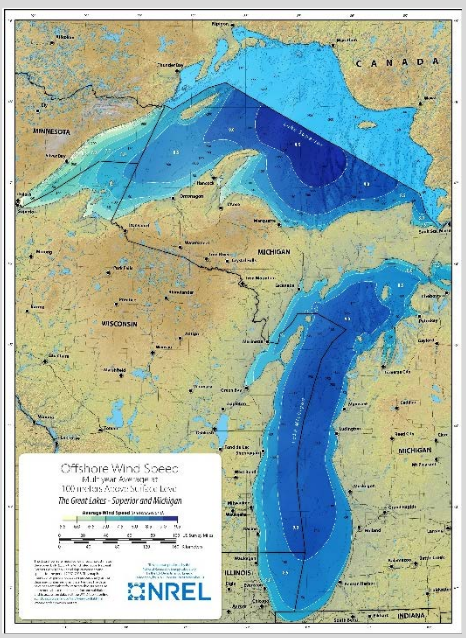
NREL developed a new video tutorial on DOE's WINDExchange wind resource maps. WINDExchange, which NREL manages on behalf of DOE, continues to publish 100-m wind resource maps to provide users with snapshots of wind energy potential based on validated data specific to different regions in the United States. The tutorial explains how to read the new maps, where to access them, and the differences between land-based and offshore wind resource maps—facilitating better understanding of an area's comprehensive wind resource potential.

WREN's Short Science Summaries can help communities and developers make environmentally responsible decisions about wind energy development. *Photo by Dennis Schroeder, NREL*

WINDExchange Publishes Additional 100-m Wind Resource Maps

Point of contact: Mary Hallisey, Mary.Hallisey@nrel.gov

In FY 2021, NREL produced and published additional 100-m wind resource maps for the Great Lakes region and the West Coast. Offshore wind maps were produced for Lake Superior and Lake Michigan and Lake Huron, Lake Erie, and Lake Ontario, as well as for Washington, Oregon, and California. Land-based maps were produced for Michigan, Indiana, Ohio, Illinois, Wisconsin, and Minnesota. The team is currently working on 100-m maps for the Gulf Coast and the Southeast. These maps provide wind developers and community leaders with a tool to help assess and characterize a region's available wind resources, which will support the development, siting, and operation of wind energy projects around the United States.



NREL leads several efforts to accurately define, measure, and forecast the nation's land-based and offshore wind energy resources and distribute those findings to the community with help from WETO funding. These maps help wind developers and community leaders assess and characterize a

STEM

Collegiate Wind Competition

Point of contact: Elise DeGeorge, Elise.DeGeorge@nrel.gov

Collegiate Wind Competition Organizers Transition to Virtual Format and Select 2022 Teams

For a second time, the Collegiate Wind Competition (CWC) organizers, led by NREL, facilitated the competition's transition to a virtual format to accommodate health concerns related to the ongoing pandemic. With potential obstacles posed by the virus in mind, CWC organizers integrated the theme of adaptability into the 2021 challenge, which calls on teams to research, design, and build a wind turbine for deployment in highly uncertain times, with a large degree of unknown risks and delays. This challenge helps students prepare for careers in the wind energy industry by giving them the opportunity to proactively plan for projects and practice active risk management—crucial skills for any line of work. Organizers also selected 11 teams from a field of 18 that will participate in the 2022 competition.

The organizers of the CWC integrated the theme of adaptability into the 2021 challenge, which calls on teams to research, design, and build a wind turbine for deployment in highly uncertain times, with a large degree of unknown risks and delays. *Photo by Werner Slocum, NREL*

Wind for Schools & Wind Workforce

Point of contact: Ian Baring-Gould, Ian.Baring-Gould@nrel.gov

Wind Workforce Webinar Series Offers Insights, Information, and Solutions

To help industry recruit the best and brightest people and to provide students with the essential resources to set them on a path toward a rewarding career in the wind energy workforce, NREL, in partnership with American Clean Power, hosted a three-part Wind Workforce Webinar Series as part of American Wind Week. Speakers discussed wind workforce challenges, highlighted programs that are helping to develop the future wind workforce—programs like KidWind and the CW C—and identified opportunities for industry members and others to engage in these ongoing efforts. Through this webinar series, NREL brought together industry, educators, and technical experts to support a robust wind energy workforce of tomorrow.

The Wind Webinar Series featured examples of wind workforce development programs, such as the KidWind Challenge, which introduces kids and teens to the excitement of wind energy at an early age by giving them the opportunity to build and test their own wind turbines. *Photo by Werner Slocum, NREL*

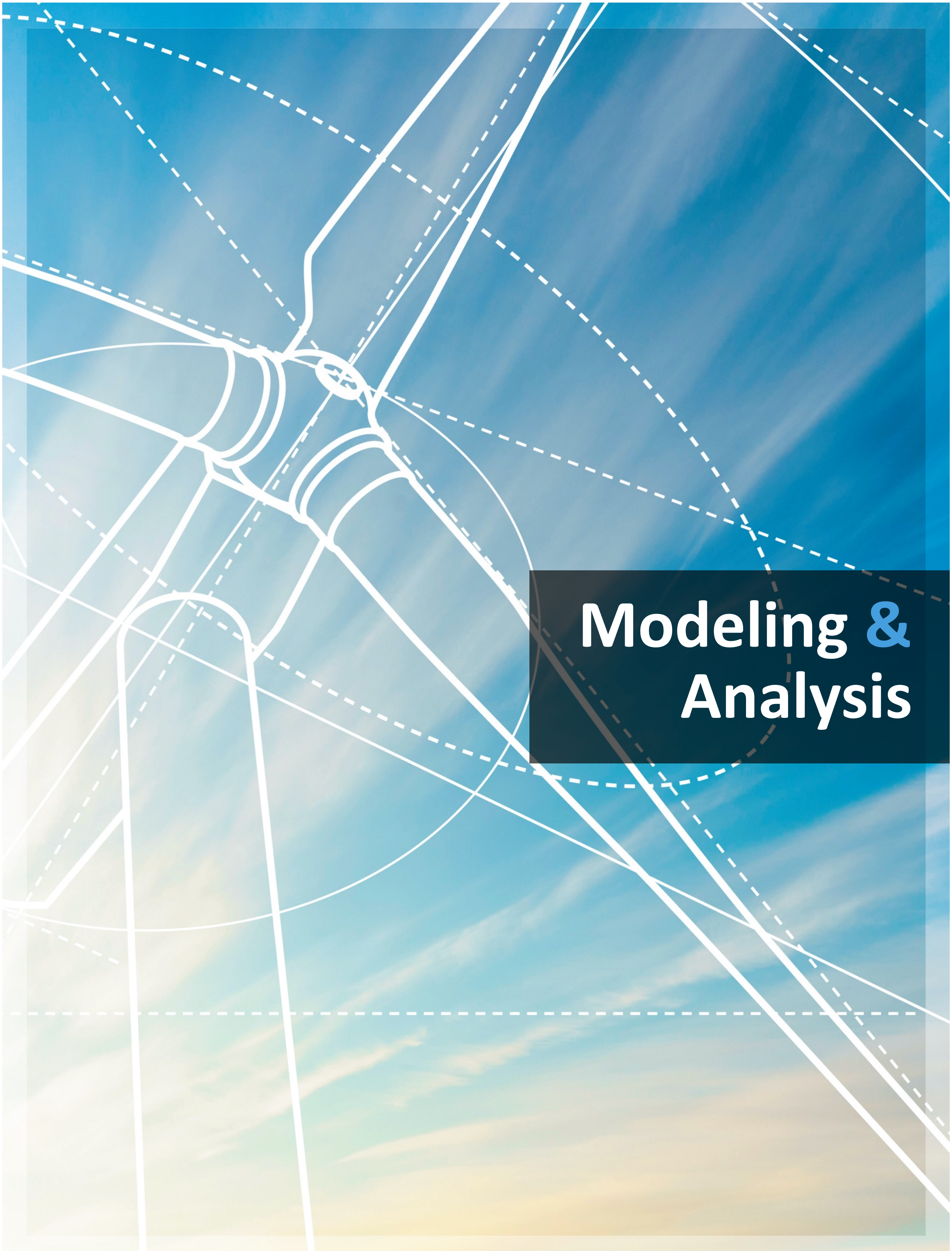
Research Bridges Gap Between Wind Energy Employers and Applicants

Wind energy industry employment grew more than 50% over 5 years—from 77,000 workers in 2015 to 115,000 at the end of 2019, according to the U.S. Energy Employment Report. However, 68% of wind energy employers have difficulty filling entry-level jobs, and 83% of students or recent graduates who applied say it is hard to find a position in the industry. To address this "wind workforce gap," NREL conducted a survey to pinpoint reasons why organizations have difficulty filling entry-level positions and why graduates struggle to enter the industry. Based on survey responses from 296 industry representatives, there is difficulty filling entry-level positions because of:

- Lack of training or education (29.7%)
- Lack of experience (27.6%)
- Not enough applicants (22.7%).

Survey findings can help us understand how we might better connect students, recent graduates, education institutions, and industry together to develop a highly qualified workforce to meet the growing demands of the wind industry

Despite the challenges they encounter finding wind energy employment, students and recent graduates reported high levels of satisfaction with the industry aligning with their environmental priorities while offering promising career pathways in terms of pay, benefits packages, and growth opportunities. *Photo by Dennis Schroeder, NREL*

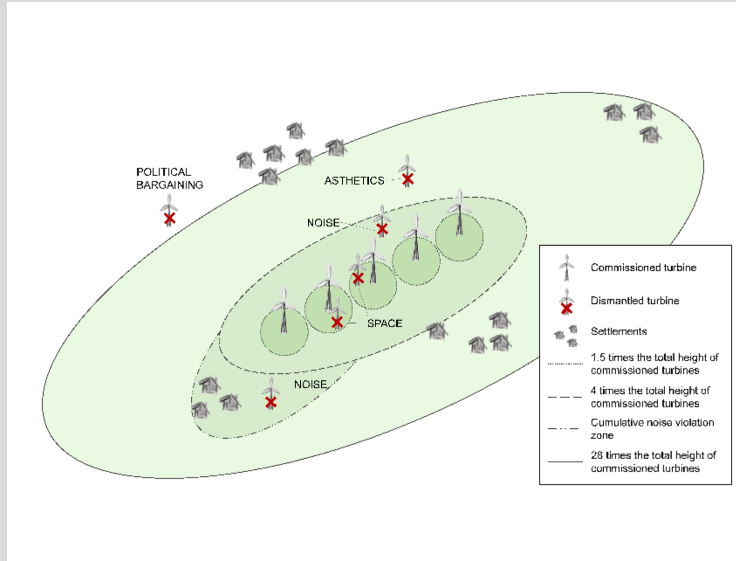


Modeling & Analysis

Wind Repowering Helps Set the Stage for Energy Transition

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

A *Nature Energy* article written by members of the IEA Wind Task 26 Cost of Wind Energy (https://iea-wind.org/task26/), which is led by NREL, explores the drivers influencing decisions about onshore wind energy repowering. Despite its low profile, wind repowering—the combined activity to dismantle or refurbish existing wind turbines and commission new ones—will play a crucial role in future wind industry investments. Through an analysis of repowering efforts in Denmark, the researchers found that space was the primary motivation for repowering. Other reasons included lowering noise emissions, aesthetics, and political considerations. Such findings recognize repowering as a negotiated process between host communities and wind developers and a crucial element for unlocking the full potential of wind energy as part of the world's energy transition.

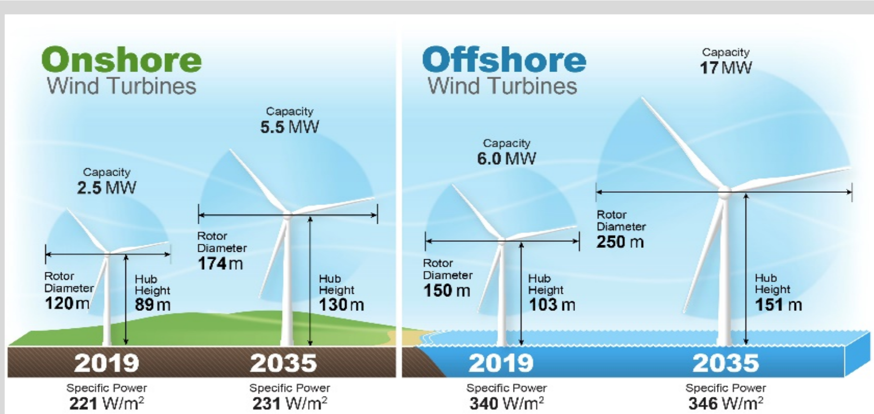


This fictional Danish repowering wind energy project demonstrates common reasons for wind repowering decisions, including zones of construction for new wind turbine projects based on their size relative to the existing commissioned turbine (600 kW in this case). *Graphic by L. Kitzing and M. K. Jensen, Technical University of Denmark. First published in Kitzing et al. (2020)*

Experts Predict Wind Cost Declines of 37% to 49% by 2050

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

Experts anticipate wind energy cost reductions of 17%–35% by 2035 and 37%–49% by 2050, driven by bigger and more efficient wind turbines, lower capital and operating costs, and other advancements. These findings are described in full in a *Nature Energy* journal article led by Lawrence Berkeley National Laboratory but with significant contributions from researchers and officials within NREL, DOE, the University of Massachusetts, and other IEA Wind Task 26 partner organizations. IEA Wind Task 26 is an international collaboration led by NREL that includes researchers from nine participating countries. The work was informed by an expert elicitation survey of 140 of the world's foremost wind power experts, which leveraged the professional networks of IEA Wind Task 26 participants to identify and solicit global input. Wind has experienced accelerated cost reductions in recent years, both on land and offshore, making previous cost forecasts obsolete. Results of this study provide the energy sector with a current assessment.



Anticipated growth in land-based and offshore turbine size, based on responses to a global expert survey. Wind turbine size represents a significant driver in lowering the cost of wind energy. *Graphic by John Frenzl, NREL*

Wind Energy Costs Continue to Fall

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

NREL released the ninth annual Cost of Wind Energy Review, which details the continued downward trend of utility-scale wind energy costs—56% for land-based wind and 68% for fixed-bottom offshore wind since 2010. This is the first time the report has included costs for residential- and commercial-scale distributed wind energy systems. The research estimates the LCOE for residential distributed wind energy at $159 per megawatt-hour and $104 per megawatt-hour for commercial distributed wind energy. The data provide insight into current component-level costs as well as a basis for understanding variability in wind energy LCOE across the country.

NREL Research Identifies Methods for Achieving a Circular Economy for Wind Energy

Point of contact: Aubryn Cooperman, Aubryn.Cooperman@nrel.gov

Large wind turbine blades made from sturdy composite materials can be difficult to recycle. While numerous alternatives have been put forth to recycle and reuse those materials, landfilling remains common. Recent NREL research analyzes current and future wind energy capacity in the United States to estimate the quantity of end-of-life composite material and points to several process alternatives to recover material and energy from wind turbine blades.

Many wind turbines installed decades ago are reaching the end of their lifetimes, which has prompted NREL researchers to understand what can be done with old turbine parts. *NREL photo*

Wind Analysis for Priority Needs

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

Wind Analyses Support WETO Priorities

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

Since the beginning of FY 2021, the priority analysis task has handled several significant and important tasks including:

- Perform final peer review, publication, and dissemination of the wind turbine blades quantities, costs, and end-of-life options journal manuscript
- Complete and release the “Power Curve Repository”
- Initiate assessment and analysis for two WETO reports to Congress on offshore and airborne wind energies
- Assess offshore wind targets scenarios, supply chain, and workforce/employment impacts.

Report Provides Insight into Community Benefits of Wind Energy Development

Point of contact: Jeremy Stefek, Jeremy.Stefek@nrel.gov

Wind power plants and their associated workforce affect the local and surrounding communities in both concrete and indirect ways. These impacts vary from spending at local businesses to the role that these companies and workers play in the quality of life within the community. NREL released a report detailing the positive long-term economic impact wind plant operation and maintenance workers bring to their communities. The report estimated that 8,204 operation-and-maintenance-specific workers—who have the potential to live in or near communities where wind power plants are built and contribute economic value that extends well beyond the date a wind plant goes live—were employed to support 94,971 MW of operational wind capacity as of 2019. Data from this report provide additional insight into the community benefits of wind energy development.

Almost 99% of wind turbines in the United States exist in rural areas—like the ones shown here, near Dumas, Texas—making research on workforce impacts in these communities a critical area of study. *Photo by Werner Slocum, NREL*

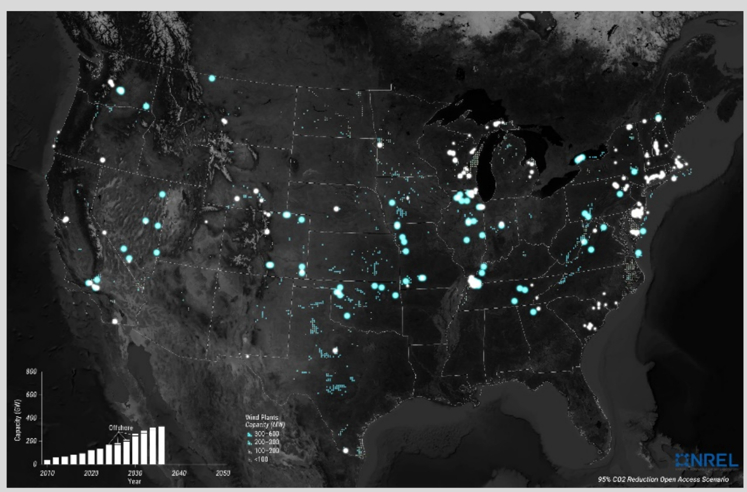
Energy Sector Modeling and Impacts Analysis

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

Geospatial Modeling Reveals How Siting Considerations Impact Wind Energy's Technical Potential

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

To reflect the complex dynamics of wind energy, NREL analysts used uniquely detailed geospatial modeling and high-resolution data sets to examine U.S. land-based wind resource potential. They published their findings in *Energy*. Analysts factored in siting constraints, regulations, landscape, and infrastructure, including 124 million buildings and every road, railway, transmission line, and radar tower in the United States. Simulations by NREL's Renewable Energy Potential Model revealed that wind has a technical potential of 7,800 gigawatts (GW) in the continental United States, but under a more restrictive siting regime, this potential could decline to 2,280 GW. Among the factors considered, road setbacks, or the required boundary around infrastructure where wind turbines cannot be developed, have the biggest impact on technical potential—because the taller the turbine, the larger the setback.



NREL analysis demonstrates how different siting considerations and carbon-dioxide reduction strategies can impact wind power plant sizes and the expansion of wind plant capacity across the United States. These siting decisions impact how many wind facilities are built in the United States and how quickly we move toward decarbonization. *Map by Billy Roberts, NREL*

Wind Siting Considerations Can Impact Future Wind Energy Development

Point of contact: Trieu Mai, Trieu.Mai@nrel.gov

To study the interactions between wind siting considerations and the evolution of the U.S. power system, NREL analysts used resource potential estimates and siting constraints from a companion analysis as inputs to NREL's publicly available Regional Energy Deployment System capacity expansion model. The researchers modeled 24 scenarios of how the U.S. electricity system might evolve from now until 2050 to study the impacts of different degrees of siting constraints, ranging from open access (least restrictive) to limited access (most restrictive). Published findings in *Energy* reveal that despite vast U.S. land-based wind resource potential, siting restrictions can have measurable impact on future wind energy development.

Siting can lead to substantial differences in emissions and the cost to decarbonize the grid—and can also interact with future transmission expansion and plant design in complex ways. *Photo by iStock*

PRUF - Wind Plant Performance Benchmarking

Point of contact: M. Jason Fields, Michael.Fields@nrel.gov

Journal Raises Worldwide Awareness of OpenOA Software

Point of contact: M. Jason Fields, Michael.Fields@nrel.gov

NREL's Open Operational Assessment (OpenOA) development team published an article in the *Journal of Open Source Software*, an academic journal with a formal peer review process designed to improve the quality of the software submitted. Publishing in this journal required rigorous backend modifications to the OpenOA software—NREL's open-source operational analysis toolkit for wind power plant operational data—to make it conform to the journal's standards. As part of the required process, the OpenOA team created a Zenodo entry that can be continuously updated with new versions of OpenOA. Upon acceptance into the journal, OpenOA received a CrossRef digital object identifier that makes OpenOA research easier to find, cite, link, assess, and reuse—which raises awareness of the software among academic and professional research communities worldwide.

Annual Energy Production Uncertainty Calculations: More Than the Sum of the Squares

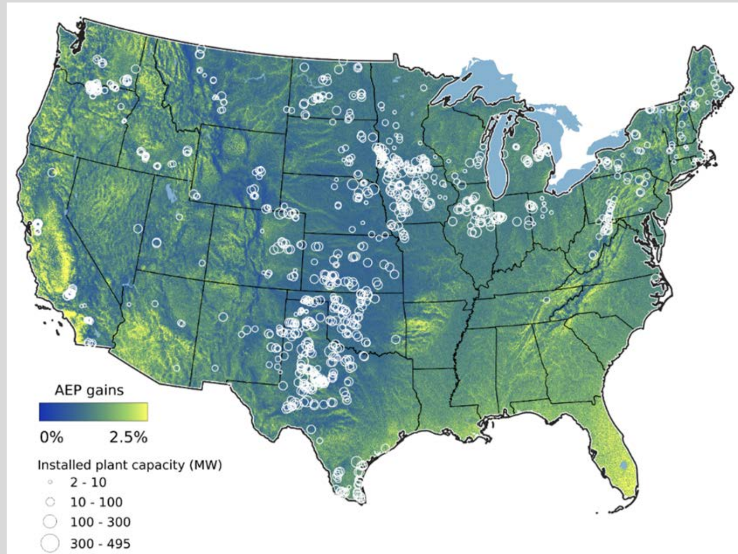
Point of contact: Mike Optis, Mike.Optis@nrel.gov

Accounting for uncertainty when calculating AEP helps quantify risk and determine financing terms. A popular industry practice is to assume that different uncertainty components within an AEP calculation are uncorrelated and can therefore be combined as the sum of their squares. In this *Wind Energy Science* journal article, NREL researchers assess the validity of this assumption for operational-based uncertainty. By performing operational AEP estimates for more than 470 U.S. wind power plants, researchers found that correlations between the identified uncertainty components should be considered to assess the total AEP uncertainty more accurately.

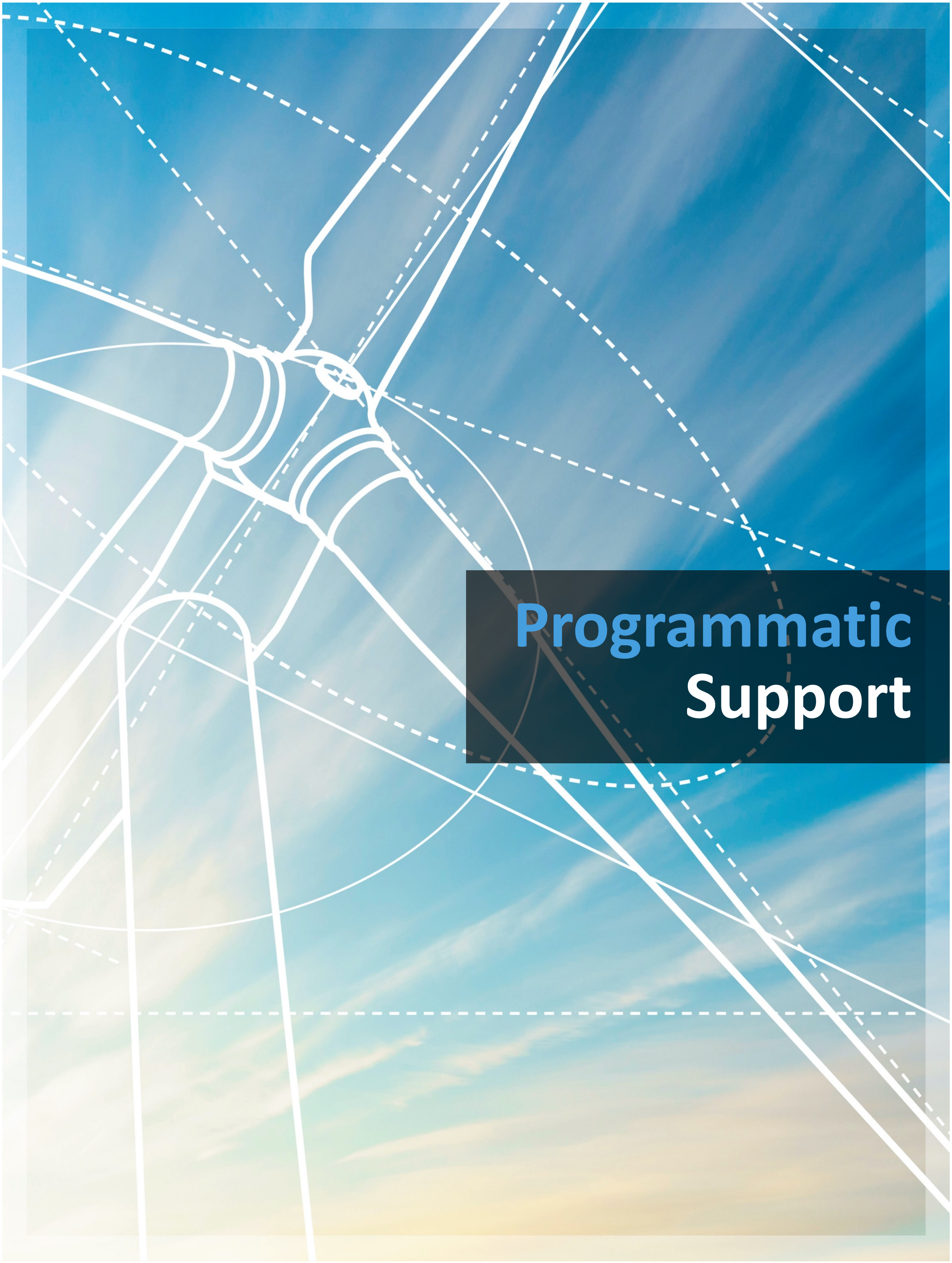
Surrogate Models Show New Opportunities for Wind Power

Point of contact: Dylan Harrison-Atlas, Dylan.HarrisonAtlas@nrel.gov

NREL researchers have developed scalable surrogate models that provide unprecedented geographic insight into new regional opportunities for wind power made possible by wind technology innovations. The surrogate models are trained on millions of simulations produced by FLORIS and can accurately predict annual energy production for arbitrary plant layouts in any location. Application of the surrogate models nationwide reveals that regions previously considered unsuitable for wind energy deployment because of moderate wind resources can be enhanced by wake-steering strategies, resulting in boosts to AEP. Sensitivity analyses suggest that wake steering could help overcome land constraints and inflexible layout options, potentially identifying new deployment opportunities. The models can be scaled rapidly across large geographic regions, improving techno-economic analysis capabilities and exploration of future technology advancements.



In contrast to current patterns of wind energy deployment, annual energy production gains from wake-steering strategies are most pronounced in regions of the country that have historically not experienced significant wind development. For instance, regions with higher AEP gains tend to have less installed wind plant capacity. *Graphic by Dylan Harrison-Atlas, NREL*



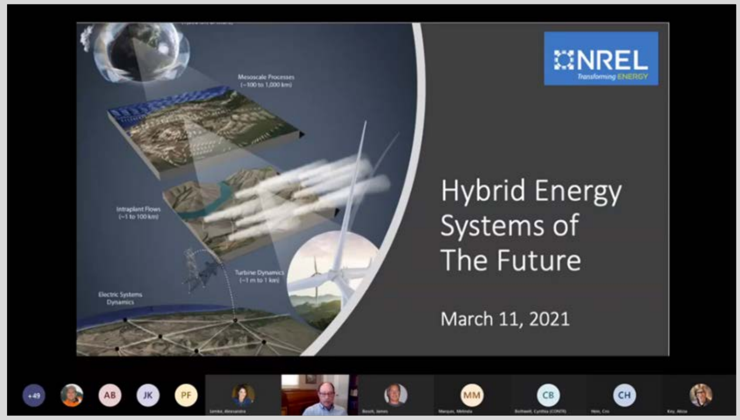
Programmatic Support

NREL Technology Management and Support

Point of contact: Brian.Smith@nrel.gov

Leadership Series Advances Wind Energy Science Conversation

Point of contact: Alex Lemke, Alexsandra.Lemke@nrel.gov



Participants from the March webinar, Hybrid Energy Systems of the Future, discussed the design and control of the wind energy systems of the future. *Screen capture by Brendan Davidson, NREL*

The Wind Energy Science Leadership Series is an ongoing series of educational webinars highlighting NREL wind energy research that includes presentations and discussions that advances participant understanding of the challenges facing wind energy and the pathways forward for making wind one of the most prevalent energy sources of the future. In the first half of FY21, speakers covered critical topics including the increasing size of land-based wind turbine rotors, floating offshore wind systems off the coasts of the United States, and hybrid energy systems with wind at their core. To date, the webinar series has covered six separate topics reaching an audience of well over 10,000 people.

Wind Research Impact Cultivated Through Sound Programmatic Support

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

The NREL Wind Program actively manages one of the largest wind-energy-dedicated R&D portfolios in the world, with 79 WETO-funded projects. Through this effort, NREL engages with WETO leadership in regular, open communications to review progress and facilitate early identification and mitigation of issues. Such efforts help to develop and deploy technologies that enable growth of the U.S. wind energy industry, enhance U.S. competitiveness, increase U.S. energy security and independence, strengthen domestic manufacturing, reduce carbon emissions, and provide local economic opportunities across the country. Achievements include:

- increasing the impact of WETO's mission through strategic engagement, fostering innovative and integrative programs, and ensuring a unique, portfolio-wide perspective is understood
- providing strategic guidance and assistance in developing new strategic initiatives and opportunities in support of amplifying the WETO's research and contributing to program collaboratives consisting of multiple national laboratories, universities, and industry
- leading high-level executive outreach and engagement to amplify the Office's research and development portfolio and gather information on industry trends and emerging issues and use the information to inform the research portfolio, making sure the portfolio is relevant and on target
- leading technology-to-market initiatives that focus on eliminating the common barriers preventing market exploration of transformative energy technologies and create a pathway for market readiness and resource access
- acting as a liaison between third parties and WETO's multi-disciplinary experts, ensuring that collaborations are successful and add value for all parties, including serving in a strategic leadership role of the IEA Wind TCP.

Point of contact: Amy Howerton, Amy.Howerton@nrel.gov

Strategic Communications Amplify the Wind Energy Technologies Office Mission

NREL's communications team successfully led the rebrand of WETO's wind energy newsletter, *Catch the Wind*. The rebrand has helped boost the engagement rate (the number of clicks and opens in bulletins in relation to subscriber count) from 16% in FY 2019 to 26% in FY 2020, driving more web traffic to DOE's wind energy website.

The communications team also received accolades from the Center for Plain Language for revisions to the "How Do Wind Turbines Work?" page. In addition, the revised animation received 571,873 pageviews in FY 2020, up from 465,033 in FY 2019. These accomplishments help reinforce WETO's mission by ensuring thousands of stakeholders and members of the public have access to critical information about wind energy through the dissemination of fact sheets, technical reports, brochures, web content, newsletters, social media posts, and other collateral.

NREL's communications team institutes experiments with varying communications strategies, regularly adjusting visual designs and exploring new narrative frameworks to captivate readers. *Graphic by John Frenzl*

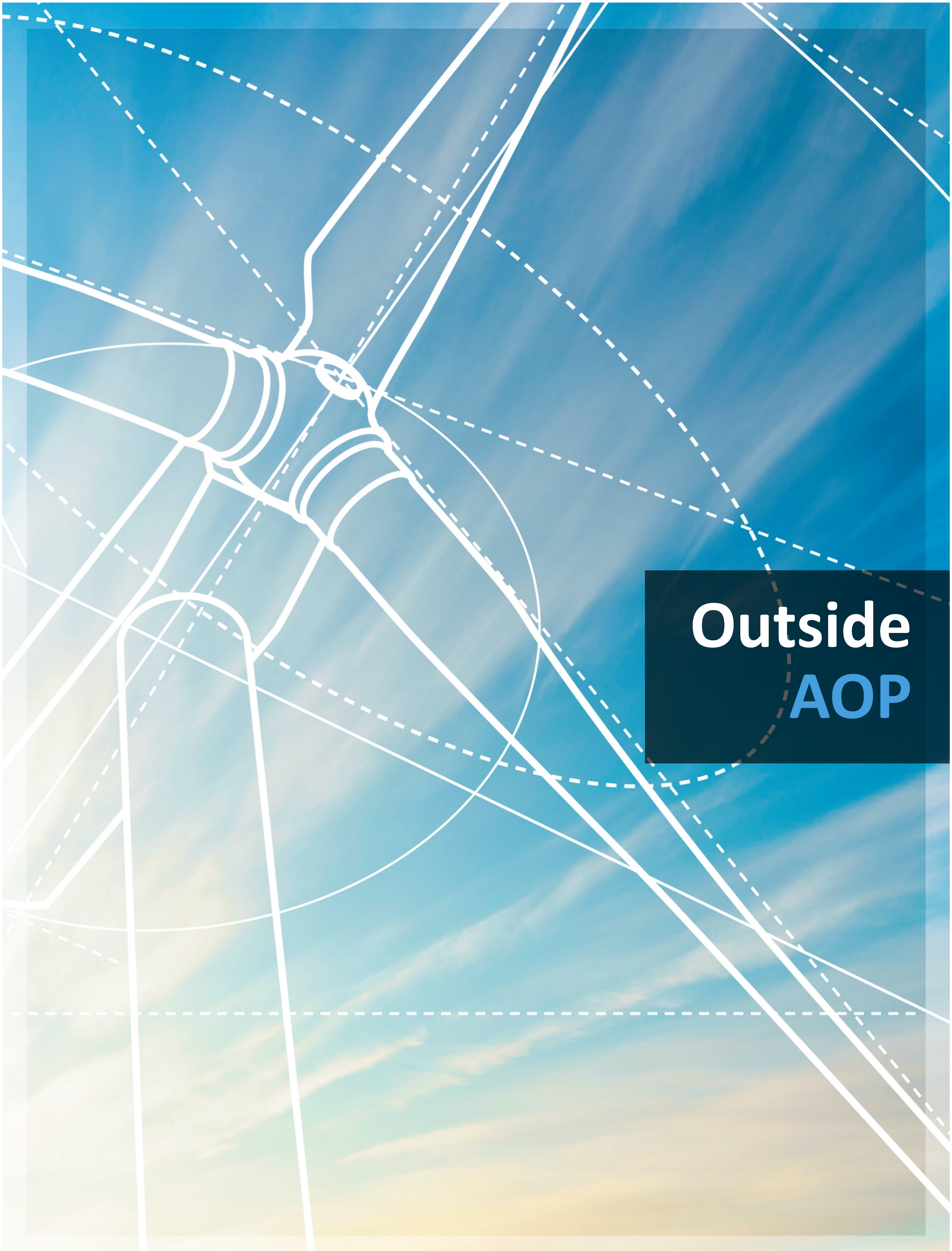
Point of contact: Brian Smith, Brian.Smith@nrel.gov

Energy I-Corps Helps Bring Ideas to Market

A year since OpenOA's first launch and guided by user feedback through Energy I-Corps, NREL released OpenOA Version 2, which includes features designed to help wind power plant operators identify and analyze the factors that drive wind plant performance. The opportunity to collaborate with industry professionals, researchers, and analysts through Energy I-Corps helped shape the new release of the OpenOA software framework, as the development team was able to work with eight major wind power plant owners and 10 third-party consultants. Working with the owners and consultants, the OpenOA team conducted wind plant performance modeling to identify an industry gap—the lack of existing standards for conducting detailed operational assessments—which OpenOA helps fill.

OpenOA is an open-source software tool for working with renewable energy plant operational data. *Graphic by Jennifer Breen-Martinez, NREL*

The Hybrid Optimization and Performance Platform software team also benefited from Energy I-Corps, by working with industry partners across several different sectors to tailor the development of the software to provide the greatest benefit to participants. By engaging with industry through the Energy I-Corps program, the project will inform the optimal path for developing new renewable energy technology avenues in the United States. Ultimately, this software can greatly expedite the development of the Hybrid Optimization and Performance Platform, greatly accelerating the development of the U.S. hybrid renewable energy industry.



Outside AOP

Renewables Can Help Stabilize Power Grids

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

As energy providers explore new ways to integrate renewable energy sources reliably into the electric grid, they can now look to wind plants to supply more than just power. With the help of inverter technologies, the guidance of NREL's Vahan Gevorgian, and an NREL algorithm, Luz del Norte photovoltaic power plant in Chile provides concrete evidence for how renewable energy technologies can provide ancillary services to the electric grid using plant-level controls—critical functions that help grid operators maintain a reliable electricity system. Beyond the example of solar and Luz del Norte, Gevorgian, in collaboration with the California Independent System Operator, Avangrid, and GE, recently helped demonstrate wind-farm-specific grid support from Avangrid's 131.1-MW Tule Wind Farm near San Diego. Taken together, these efforts combined with further research into hybrid power plants show that the right mix of renewables and controls can create a new, uniquely capable type of power plant.

Grid-scale utility assets and numerous renewable energy and storage technologies could work together to provide stability to the power grid. *Photo courtesy of First Solar*

Offshore Wind Data Release Propels Wind Prospecting

Point of contact: Mike Optis, Mike.Optis@nrel.gov

Floating lidars, also known as "flidars," such as this DOE wind resource characterization buoy managed by Pacific Northwest National Laboratory, collect wind speed and direction measurements up to 250 m from the surface of the ocean. These measurements, combined with satellite-based measurements of near-surface U.S. offshore wind speeds, help update and enhance the DOE's Wind Integration National Dataset Toolkit with updated data. *Photo by Frederick Driscoll, NREL 27947*

NREL researchers continually roll out updated offshore wind data sets on the Wind Integration National Dataset (WIND) Toolkit. Using state-of-the-art modeling tools and sophisticated resource assessment technologies like floating lidars, the team provides more accurate data sets to the public that can improve offshore wind plant site selection, design, and operations.

Part of a larger study funded by the Bureau of Ocean Energy Management (BOEM), researchers published a report that presents state-of-the-art wind resource data produced off the California Pacific Outer Continental Shelf. The report found significantly higher mean wind speeds modeled in the new data set compared to the Wind Integration National Dataset Toolkit, which will impact economic and energy modeling and planning for offshore wind energy in the region.

Study Finds Offshore Wind Energy Costs in California Could Decrease by 44%

Point of contact: Philipp Beiter, Philipp.Beiter@nrel.gov

The deep waters along the California coast are well-suited to floating offshore wind energy technology, which is currently in a precommercial phase. A BOEM-funded study provides site-specific cost and performance data for floating offshore wind to inform California's long-term energy planning. The analysis focused on five geographically dispersed study areas that represent regions where offshore wind energy has development potential. Key results from the study include a 44% average decrease in estimated LCOE between 2019 and 2032, reaching levels of $53–$64/megawatt-hour.

Wind Turbine Rotor Rotation and Inflow Conditions Can Influence Wake Behavior

Point of contact: Julie Lundquist, Julie.Lundquist@nrel.gov

A new study investigates the relationship between wind turbine rotor rotation and wind inflow profiles and the resulting impacts on wind turbine wakes. Veering profiles, or increases of wind direction with height, are common in nighttime conditions in the Northern Hemisphere. Using large-eddy simulations, the research team evaluated combinations of rotor rotation and inflow wind conditions and found that in veering conditions, the direction of rotor rotation can change the behavior of the wake, impacting power output at a wind facility.

The Future Is Autonomous: NREL's Autonomous Energy Grids Research Leads to 85% Drop in Resident Utility Bills

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

A housing complex in Basalt, Colorado, is interconnected through a microgrid that allows 27 households to seamlessly share electricity, providing residents with utility bills that are estimated to be 85% lower than typical electrical bills in the state. NREL partnered with the local electrical utility Holy Cross Energy to implement the autonomous energy grid (a grid capable of self-organization and control that can respond to energy demands in near real time), and additional autonomous energy grid applications could feature wind energy. An autonomous-energy-grid-enabled future means that control techniques like the ones deployed at Basalt Vista will autonomously manage large wind farms using consensus control.

The Basalt Vista housing project, a collaboration between NREL and Holy Cross Energy, demonstrates the real-life applications of NREL's autonomous-energy-grid research. *Photo by Scott Randall, NREL*

Research Puts Forth Best Practices for Validating U.S. Offshore Wind Resource Models

Point of contact: Mike Optis, Mike.Optis@nrel.gov

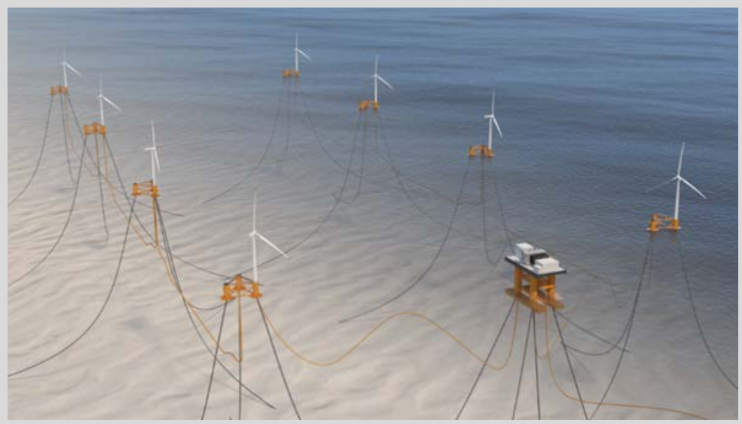
NREL researchers provided a comprehensive set of best practices for working with both modeled and measured U.S. offshore wind resource data sets in a new technical report for BOEM. Comprising nine recommendations, researchers determine the most reliable data sources and methods for validating modeled wind resource estimates as well as methods for vertically extrapolating near-surface wind speed measurements to heights that span the rotor-swept area of modern offshore wind turbines. Among other findings, researchers found that a machine-learning approach was able to extrapolate near-surface winds to hub height at much greater accuracy than conventional methods. These best practices can help inform improved offshore wind resource characterization efforts, thereby aiding future offshore wind energy deployment efforts.

Advancing Innovation Through Awards from the National Offshore Wind R&D Consortium

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

NREL researchers across multiple centers are contributing to state-of-the-art technology and supply chain advances for offshore fixed-bottom and floating wind systems, which will help accelerate national targets for offshore wind energy generation. To date, approximately $6.3 million in funding is advancing NREL's research with strategic partners in multiple areas, including:

- Shared mooring systems and anchoring systems for deep-water floating wind farms
- Wind farm control and layout optimization for U.S. offshore wind farms
- Validated national offshore wind resource data sets.



The Basalt Vista housing project, a collaboration between NREL and Holy Cross Energy, demonstrates the real-life applications of NREL's autonomous-energy-grid research. *Photo by Scott Randall, NREL*

NRELians Recognized for Excellence by Energy Systems Integration Group

Three NREL researchers—Bob Thresher, Bethany Frew, and Shawn Sheng—have received 2021 Excellence Awards from the Energy Systems Integration Group, a nonprofit educational organization dedicated to critical analysis of wind energy for utility applications.

Sheng received an excellence award for expanding the characterization and understanding of phenomena in wind turbine component operations and technical issues. Frew received an excellence award for contributions to market design for a renewable energy future. Emeritus researcher Thresher received a lifetime achievement award for his contributions to advancing wind energy technology internationally through his work at NREL.

The Energy Systems Integration Group awards recognize energy professionals like Shawn Sheng (left), Bethany Frew (right), and Bob Thresher (bottom) for their contributions to the planning and operation of energy systems across multiple pathways and geographical scales in ways that are reliable, economic, and sustainable. *Photos by Dennis Schroeder, NREL*

Publications

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National Renewable Energy Laboratory
15013 Denver West Parkway
Golden, CO 80401
303-275-3000 • www.nrel.govs

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