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

Wind R&D Newsletter

OCTOBER 2021

IN THIS ISSUE

National Offshore Wind Research and Development Consortium Hits Full Stride

With 40 offshore wind R&D awards issued so far, the NOWRDC is driving critical innovation in the U.S. offshore wind energy industry

The National Offshore Wind Research and Development Consortium (NOWRDC), established in 2018 as a nonprofit public-private partnership, focuses on advancing offshore wind technology in the United States through high-impact research projects and cost-effective, responsible development to maximize economic benefits. The NOWRDC supports research to accelerate the U.S. offshore wind energy industry. To date, the NOWRDC has issued 40 R&D awards, totaling $28.3 million across 25 states.

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The Future of Offshore Wind Is Big—Literally

Larger plant and wind turbine sizes could lead to cost cuts of more than 23%

Offshore wind turbines and wind power plants are getting bigger every year, a trend that already helps offshore wind reduce costs all over the world. But while recent research suggests that costs will continue to dip as wind turbines and plants get bigger, the amount of these potential savings and whether there's a maximum size where costs plateau remain unclear.

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

Dr. Robert C. Marlay

Offshore WINDPOWER 2021, convening October 13–15, provides a forum for wind energy stakeholders from government, industry, and academia to learn about and hear from a global community of top developers and experts in offshore wind. This year's conference comes at a time when there is much to be excited about in wind energy in all its forms—offshore, land-based, and distributed. With strong support from leaders across the country, wind energy is on the cusp of a major expansion.

The offshore wind energy industry is growing rapidly—a trajectory supported by the Biden administration's 30-gigawatt (GW)-by-2030 national offshore wind deployment goal. The U.S. Department of Energy's (DOE's) recently published "Offshore Wind Market Report: 2021 Edition" states that last year the U.S. offshore wind energy pipeline grew 24%—from 28,521 megawatts (MW) in 2019 to 35,324 MW in 2020. Permitting processes are being streamlined and show progress.

The "Land-Based Wind Market Report: 2021 Edition" and "Distributed Wind Market Report: 2021 Edition," also published in August, provide snapshots of the land-based utility-scale and distributed wind energy industries through the end of 2020. Be sure to check out all three reports, which compile data from public, confidential, and proprietary sources and then analyze 2020 trends in wind technology, cost, and performance.

Wind Energy Research Today
This issue of our newsletter provides information about wind energy research and development (R&D) projects that are currently underway or recently completed by our national laboratories and industry partners. You'll learn about several interesting projects, including:

- The National Offshore Wind Research & Development Consortium—Established by DOE in 2018, this nationally focused, nonprofit organization brings together many voices and technical resources to address research priorities for offshore wind energy. The article in this newsletter looks at version 3.0 of the consortium's technical guidance road map and provides an overall update of consortium activities.
- The impact of wind turbine and plant upsizing on the levelized cost of energy (LCOE)—Larger wind turbines and wind power plants could reduce costs by 23%, according to recent research funded by DOE's Wind Energy Technologies Office (WETO). This discovery could be a game changer, particularly for the offshore wind industry.
- Wind energy environmental and siting challenges—This newsletter features two articles about WETO's continued efforts to solve one of our top priorities. You'll want to read about a new project that's gathering extensive information about potential environmental effects of offshore wind power plant development. Similarly, ThermalTracker-3D has boarded one of two research buoys off the California coast to assess potential offshore wind energy development risks to birds and bats.
- The benefits of distributed wind on grid resiliency—Resiliency is the measure of a power system's ability to sustain itself during events such as extreme cold in Alaska or a hurricane in Texas. WETO funding supports a multilaboratory effort to define, demonstrate, and measure distributed wind's resiliency benefits. You might be surprised by the findings.

In Other Grid News
DOE released the North American Renewable Integration Study, which discusses the possibility of an interregional transmission system to support a future, low-carbon North American grid. This research, which was funded by WETO along with DOE's Solar Energy Technologies Office and Water Power Technologies Office and authored by the National Renewable Energy Laboratory (NREL), highlights opportunities for integrating large amounts of wind, solar, and hydropower into the continental grid system.

And the Winner Is…
The Pennsylvania State University claimed first place in DOE's 2021 Collegiate Wind Competition (CWC). I want to congratulate all 13 teams for their participation, creativity, and flexibility, and look forward to cheering on the 2022 CWC competitors.

In the meantime, we at WETO are excited to join all of you in further advancing wind energy as a viable, meaningful renewable energy solution for our country.

Sincerely,

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

The National Offshore Wind Research and Development Consortium (NOWRDC) is dedicated to managing industry-focused R&D of U.S. offshore wind energy. *Photo courtesy of Principle Power*

National Offshore Wind Research and Development Consortium Hits Full Stride

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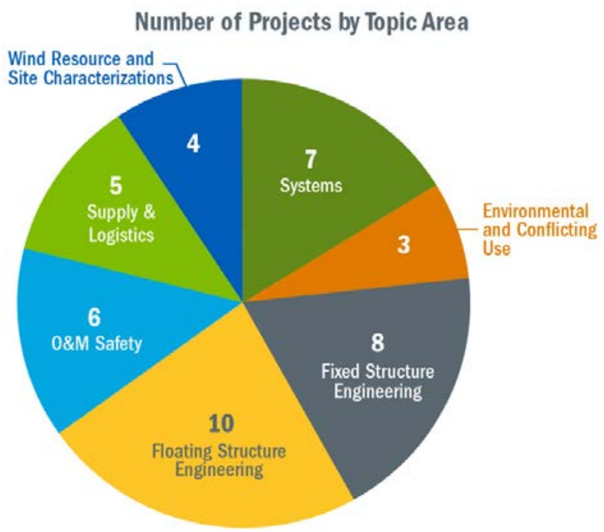
These projects generally focus on three research pillars that aim to guide technical solutions to barriers in the U.S. offshore wind energy industry:

1. Offshore wind technology advancement
2. Offshore wind power resource and physical site characterization
3. Installation, operation and maintenance (O&M), and supply chain.



NOWRDC projects span a wide range of offshore wind energy topic areas. *Figure from the NOWRDC*

All 40 projects will be spotlighted at the NOWRDC's upcoming Technical R&D Symposium—taking place virtually November 8–10, 2021. Each day of the symposium will feature a theme, project presentations, and keynote speakers. Building on the success of last year's Technical R&D Symposium, the upcoming 2021 event will provide updates on exciting technical innovations and discoveries made under NOWRDC projects. The symposium will also provide a forum for collaborative, insightful discussion among leaders in the U.S. offshore wind industry.

The NOWRDC also intends to bolster its project portfolio through a new solicitation. The first round was released late this summer relating to offshore wind supply, logistics, and O&M; one subsequent round will occur in spring 2022. Solicitations may draw from the NOWRDC's Roadmap 3.0—the overarching technical guidance document for offshore wind R&D topics. This document was updated in June 2021 to account for already-achieved research objectives and to incorporate new research priorities and objectives—including research priorities central to the Biden administration's goals for offshore wind.

"The consortium is making significant and critical industry-guided and prioritized investments to reduce costs and risks within the U.S. offshore wind industry and is a key part of meeting the Biden administration's offshore wind deployment goals," said Nate McKenzie, technology manager for offshore wind R&D at WETO.

Current funding for the consortium comes from DOE and the New York State Energy Research and Development Authority, each providing $20.5 million; the commonwealths of Virginia and Massachusetts; and the states of Maryland and Maine—for a total investment of approximately $48 million. In addition, the NOWRDC benefits from the dedicated engagement of its industry-spanning membership—comprising offshore wind energy developers, offshore wind equipment manufacturers, and independent entities. As a result of its diverse membership, the NOWRDC can build strong networks connecting technology innovators, investors, and industry.

You can register for the NOWRDC's National Offshore Wind R&D Symposium 2021, taking place in November. If you have questions or are interested in collaborating with the NOWRDC, please reach out to Carrie Cullen Hitt at info@nationaloffshorewind.org. ■

The Future of Offshore Wind Is Big—Literally

Continued from page 1

Now, in a recent study published in *Applied Energy*, researchers from NREL conducted one of the most comprehensive analyses currently available of the average cost per megawatt-hour to develop and maintain offshore wind power plants and how those costs could change if current trends toward larger plants and turbines continue.

To do that, the team combined three models and found that larger wind turbines and power plant projects alone can reduce a plant's average total cost per megawatt-hour over its lifetime (known as levelized cost of energy) by more than 23% relative to the average fixed-bottom offshore wind power plant installed in 2019.

"We expected to see the costs decrease," said Matt Shields, an NREL researcher who leads the lab's work on techno-economic analysis of offshore wind energy and headed the study. "But I was a little surprised about the magnitude. That's really a game changer."

The team's data provide a valuable touchstone. Now, the growing offshore wind industry can more confidently invest in the supply chain needed to build bigger turbines and larger projects—a chain that is not yet sufficient to achieve the Biden administration's goal of deploying 30 GW of offshore wind energy by 2030.

The study was funded by WETO and coauthored by NREL researchers Philipp Beiter, Jake Nunemaker, Aubryn Cooperman, and Patrick Duffy.

Offshore wind energy plants are part of a complex supply chain in which manufacturers design various parts, expert laborers make and assemble these parts at multiple ports, and specialized vessels transport the turbines offshore for installation. Every link in this chain comes with a cost that changes based on project and technology size and type. And, once the wind turbines are installed, O&M costs vary, too. But these costs don't necessarily increase with size.

For example, a power plant that upgrades to larger wind turbines will need fewer machines to generate the same amount of energy. Fewer turbines mean fewer installation vessel trips and less overall maintenance. Both reduce costs. And yet, because larger wind turbines and power plants often need bigger foundations and more cables to transfer energy back to shore, they cost more money up front. These conflicting cost trends make it hard to determine how wind turbine and power plant upsizing impact total cost and energy output.

To see if bigger really is better, Shields and his team blended three models for:

1. Balance-of-system costs (i.e., all capital costs—for foundations, cables, and installation—except for the wind turbine)
2. O&M costs
3. Annual energy production.

NREL researchers designed two of the models—the open-source Offshore Renewables Balance-of-system Installation Tool (ORBIT) and the FLOw Redirection and Induction in Steady State (FLORIS) tools. To evaluate operation and maintenance costs, the team used the commercial Shoreline O&M Design model.

Then, the researchers used the models to compare the cost of a representative 2019 fixed-bottom offshore wind power plant, which used 100 6-MW wind turbines for a total capacity of 600 MW, with various wind turbine and power plant sizes—up to a maximum of 20-MW wind turbines with a plant capacity of 2,500 MW. The models showed that scaling up both wind turbine and power plant size can reduce balance-of-system and maintenance costs through economies of scale (e.g., spreading export cable costs over larger projects) while reducing losses from wakes. Wakes, turbine-made turbulence that can decrease power production of downstream turbines, decline as turbines are spaced further apart in larger and larger wind plants.

Combined, these savings can add up to more than 23%. Still, more research is needed to achieve these savings, determine whether and how this reduction applies to floating offshore wind power plants, and learn whether the "bigger is better" tenet has a limit. Cost savings could plateau at a maximum wind turbine or power plant size.

Right now, the wind industry can't achieve that 23%. No manufacturer can build a 20-MW wind turbine—yet. And even when they can, the rest of the supply chain will need to catch up, too. For example, today's vessels and ports are designed to install wind turbines of 12 MW or less.

Shields and his team plan to take a closer look at how innovations in technology and the supply chain might help

To show that building bigger offshore wind plants could reduce overall costs, NREL researchers designed one of the most comprehensive analyses of the total cost needed to develop and maintain offshore wind power plants currently available. *Photo by Lyfted Media for Dominion Energy*

further reduce costs in the future. In the meantime, they are working on creating a supply chain road map to find missing links.

"We need to jump-start the domestic supply chain as quickly as possible to minimize project risks, make projects even cheaper, create local jobs, and grow a more sustainable industry," said Shields. "We want to build offshore wind power plants to reduce our carbon footprint, and we can do it in such a way that we are positively impacting local economies."

The supply chain must grow—quickly—to meet the 30-GW-by-2030 goal. And this study can help each link plan for a bigger future.

"That's going to be a huge challenge for us over the next decade," said Shields. "But it's one that's worth investing in." ■

Spotlight on SEER: Awareness for Offshore Wind Energy Development

Project to provide information about environmental risks, increase coordination among stakeholders

Offshore wind energy promises to be an important part of the nation's energy market over the next decade. In fact, the Biden administration and federal agencies are pushing to support development of 30 GW of offshore wind capacity by 2030.

But uncertainty among regulators, environmental advocacy groups, the fishing industry, and others surrounding environmental effects from technologies that have limited operational history in U.S. waters could slow down the environmental permitting and approval process for offshore wind power plants. Specifically, what are the potential effects to the environment—the whales, fish, birds, bats, and more—from offshore wind plant development?

While these uncertainties exist, much can be learned from wind energy power plants that have been built in other countries and projects already under construction in our nation's waters.

Growing Awareness Around Environmental Effects

Through the U.S. Offshore Wind Synthesis of Environmental Effects Research, or SEER, project, the Pacific Northwest National Laboratory (PNNL) and NREL are gathering feedback from offshore wind energy stakeholders and sharing that knowledge.

SEER, which is supported by WETO, is designed to shed light on the environmental effects of offshore wind energy

The U.S. Offshore Wind Synthesis of Environmental Effects Research project is working to identify and minimize uncertainties surrounding impacts from offshore wind energy development on the environment, including marine mammals, fish, birds, and bats. *Photo by Todd Cravens, Unsplash* development, identify existing gaps in information, and prioritize future environmental research efforts.

"In order to move the U.S. offshore wind industry forward, stakeholders need access to readily available information about the potential impacts of offshore wind development to reduce uncertainty," said Alicia Gorton, an ocean engineer who is managing PNNL's work on the project. "One of SEER's primary goals is to summarize the understanding of environmental effects, the monitoring tools and methods used to assess those effects, and the strategies in place to minimize potential impacts that could be caused by offshore wind development."

The SEER project analyzes existing research from around the world to develop educational material that will be made publicly available as research briefs and a webinar series, along with research recommendations to inform or guide future efforts on the U.S. Atlantic and Pacific coasts.

Engaging Stakeholders, Transferring Knowledge

"This project prioritizes a significant amount of stakeholder outreach and engagement across the public and private sectors," said Rebecca Green, a senior scientist who is managing NREL's portion of the project. "Working together with and transferring important knowledge to coastal communities are critical to minimize environmental effects from offshore wind development, increase coordination among stakeholder group activities, and advance monitoring and mitigating solutions."

The areas being studied under SEER include:

- Underwater noise
- Cable entanglement risk for marine life
- Wind turbine collision risk for birds and bats
- Disturbances to organisms on the seafloor
- Impacts to fish and their habitats
- Collision risks for ships and other vessels
- Displacement of birds and bats
- Electromagnetic field effects.

The SEER team will host a webinar series to share information from the briefs and is planning two regional workshops with offshore wind energy stakeholders on the Atlantic and Pacific coasts. The workshops will help researchers understand regional concerns and knowledge gaps, as well as collaborate on developing recommendations pertinent to each coast and the nation in general.

The Tethys website features educational research briefs about SEER research topics and more information about the webinar series, which will take place in late 2021. ■

Proposed Power Plants Point to a Clean-Energy Future

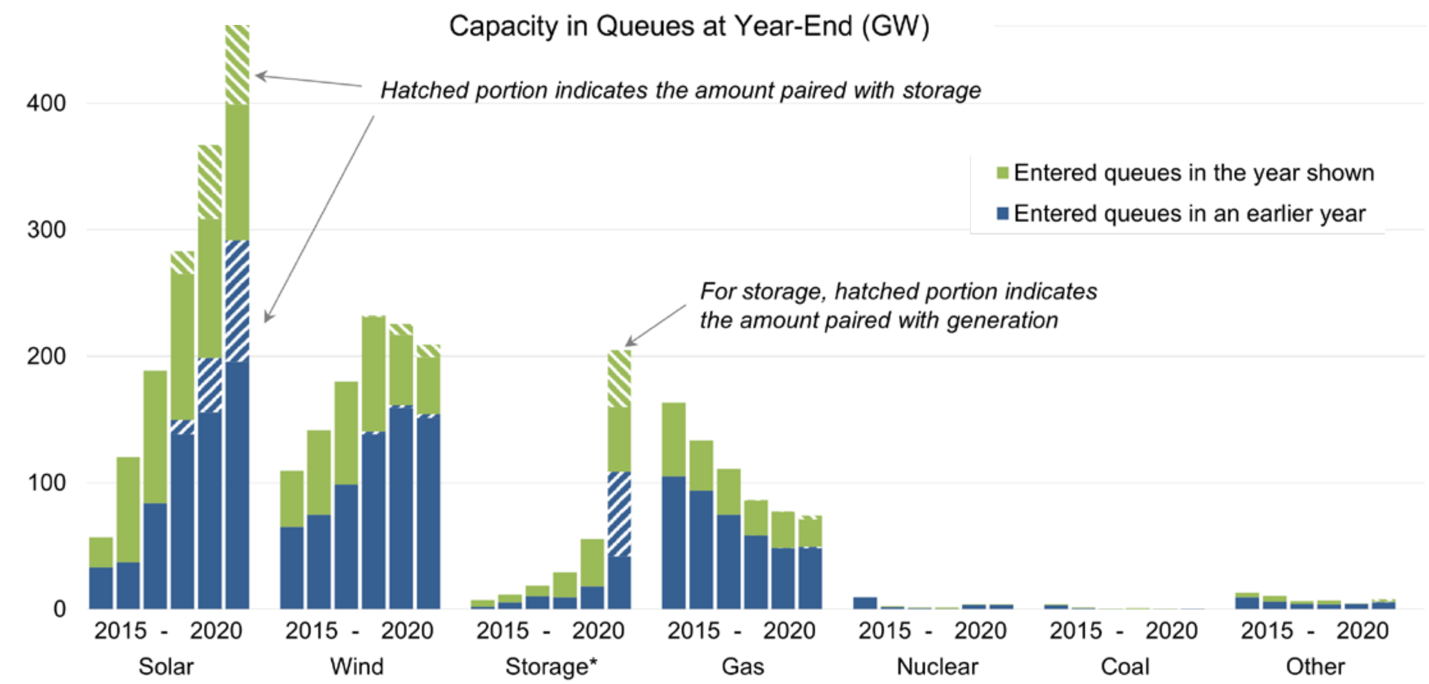
Report shows record renewable energy capacity proposed in interconnection queues

The amount of proposed power plant capacity lined up to connect to the electric grid across America has risen dramatically. As of the end of 2020, projects with more than 755 GW of electric-generating capacity and an estimated 200 GW of storage capacity were seeking access to the U.S. transmission system, according to new research by Lawrence Berkeley National Laboratory (Berkeley Lab). Nearly 90% (671 GW) of this proposed generating capacity is from solar (462 GW) and wind power plants (209 GW).

"Together, this proposed capacity represents more than half of the estimated 1,100 GW of wind and solar capacity that studies say is needed to deeply decarbonize the U.S. electricity supply," said Joseph Rand, a senior scientific engineering associate at Berkeley Lab and lead author of the study. "But our research also points to increasing lead times, high rates of withdrawn projects, and a large backlog of projects in the queues, which could be a potential bottleneck in the transition to zero-carbon electricity in the United States."

Large power plants and storage projects must connect to the electric grid to supply power to electricity consumers such as homes and businesses. Before connecting to the grid, proposed projects must apply to the grid operator, who then conducts a series of impact studies. The lists of projects applying for interconnection are known as "interconnection queues." While many projects that apply for interconnection are not subsequently built, data from these queues nonetheless provide a general indication of the types of projects under development.

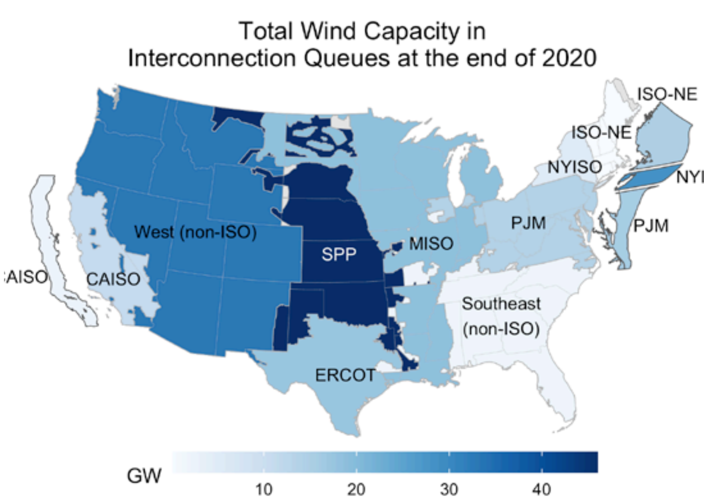
Berkeley Lab compiled and analyzed data from all seven large regional grid operators (known as independent system

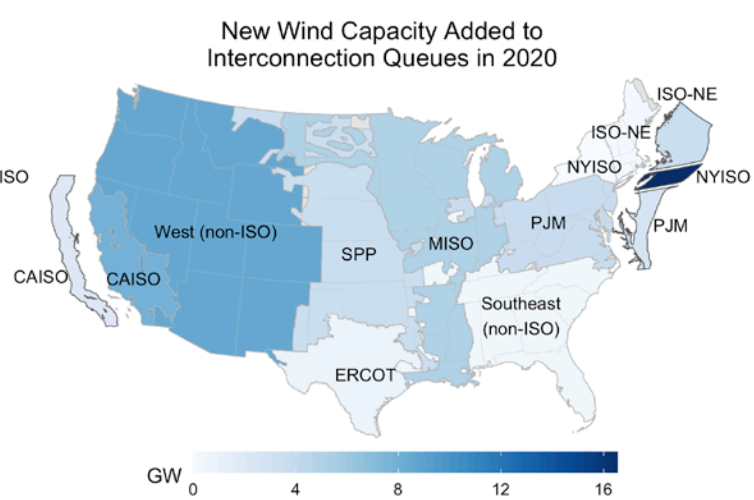


Total capacity in interconnection queues over time. Hybrid storage capacity was estimated for some projects using known generator-to-storage ratios, but not for years prior to 2020. *Image from Berkeley Lab*

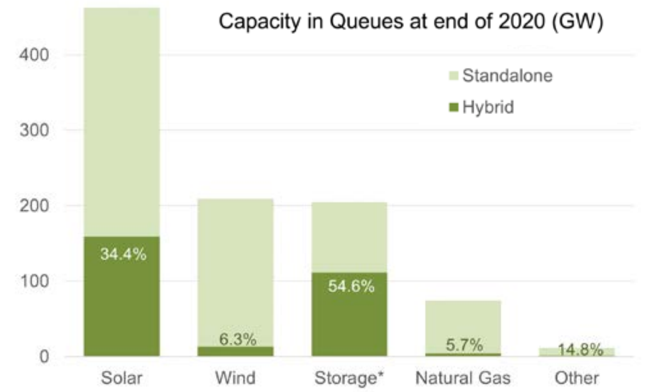
operators, or ISOs) in addition to 35 utilities not in ISO regions, together serving an estimated 85% of all U.S. electricity demand.

Solar (462 GW) accounts for a large and growing share of generating capacity in the queues. Substantial wind capacity (209 GW) is also in development, 29% (61 GW) of which is from offshore projects. In total, about 680 GW of zero-carbon capacity is currently seeking to connect to the grid, along with 74 GW of natural gas capacity. Proposed wind capacity is highest in New York (driven by offshore wind energy projects), the Great Plains, and the West, but with sizable amounts proposed in all regions except the Southeast, which has lower wind speeds. Although the amount of wind capacity





Location of cumulative proposed wind energy capacity at the end of 2020 (left) and of wind capacity that was first proposed in 2020 (right). *Image from Berkeley Lab*



Proportion of capacity in queues in a hybrid configuration as of the end of 2020. Hybrid storage capacity was estimated for some projects using known storage-to-generator ratios. *Image from Berkeley Lab*

in interconnection queues has decreased in some regions, it continues to grow in those with proposed offshore wind projects, such as the Northeast and Pacific Coast.

Hybrid power plants—those that combine two or more power plant types (such as wind and solar) and/or pair a power plant with electric storage (most often comprising batteries)—are of growing interest. At least 34% (159 GW) of all solar power capacity in the queues and 6% (13 GW) of wind power capacity are proposed as hybrid plants.

"While the numbers are impressive, much of this proposed capacity will never be built," said Ryan Wiser, a senior scientist at Berkeley Lab and coauthor of the report.

For context, among a subset of queues for which data are available, only 24% of the projects seeking interconnection from 2000 to 2015 were subsequently built. Completion percentages appear to be declining and are even lower for wind and solar than for other resources. Future research may determine the exact reasons why so many projects are withdrawn, but the available data do provide some insights.

"We know that the U.S. transmission system is constrained in many regions, and the upgrades required to connect new power plants can be very costly," said Rand. "And the developers of these proposed projects might be submitting multiple 'placeholder' projects to collect information on which to proceed."

Additionally, wait times are on the rise for projects that are built.

"In four regions that we studied, the typical duration from interconnection request to commercial operation increased from about 1.9 years for projects built from 2000 to 2009 to about 3.5 years for those built between 2010 and 2020," said Mark Bolinger, a research scientist at Berkeley Lab and coauthor of the report.

For these reasons, there are growing calls from power plant developers, nonprofit organizations, and policymakers for queue reform—and with it, an expansion of the transmission system. Such reforms would aim to reduce interconnection costs, lead times, and placeholder projects in the queues and, therefore, better enable the rapid transition to a clean energy future. In July 2021, the Federal Energy Regulatory Commission announced plans to overhaul the U.S. transmission planning process—of which the interconnection queues are a backbone.

These research findings are summarized in a slide deck, data file, and interactive visualization on the Berkeley Lab website. ■

Updated Weather Model Captures Subtleties of Cold Pool Events

New model developments could lead to improved wind power forecasts

Imagine cold air building up inside a valley or other topographic basin, like a cold swimming pool in the atmosphere. Known in meteorology as cold-air pools, or simply cold pools, these events affect wind plant power production in two key ways. Because they are associated with stagnant air and low winds near the ground, cold pools can severely limit wind energy output over periods of hours to days. Then, when cold pools dissolve, known as cold pool "erosion," increased wind speeds allow wind power production to recover.

"Accurate forecasts of cold pools and other weather events are vital to the success of the wind energy industry because they allow wind plant owners to plan for future energy production and grid operators to improve reliability," said Robert Arthur, a researcher at Lawrence Livermore National Laboratory who has previously investigated the effect of frontal passages on wind power plants.

However, cold pools are notoriously difficult to predict. They have challenged weather forecasters for decades, even prior to the advent of modern wind energy, because of the problems they cause in other sectors. For example, cold pools can trap pollution, leading to poor air quality in urban areas. They are also associated with fog and freezing rain, creating risks for air and ground transportation.

Weather models have difficulty forecasting the cold, near-ground temperatures found within cold pools. Because of this, models show high winds from aloft penetrating closer to the surface than they really do during cold pool events. This model error leads to an overprediction of wind speed in the wind turbine rotor region (roughly 50–150 meters above ground for a wind turbine with a hub height of 100 meters). A related issue causes cold pools to erode too early in models, causing the models to incorrectly predict the timing of the increase in wind speed following the event.

"These errors are subtle but can have a large impact on both the magnitude and timing of wind power predictions," Arthur said.

To address this forecasting need, Arthur and collaborators at Lawrence Livermore National Laboratory and the National Oceanic and Atmospheric Administration (NOAA) implemented a method that better predicts large temperature changes in regions of steep terrain, where cold pools generally form. In an article published in the journal *Monthly Weather Review*, the improved temperature prediction method was shown to reduce wind speed errors by as much as 20% when compared to a standard modeling approach.

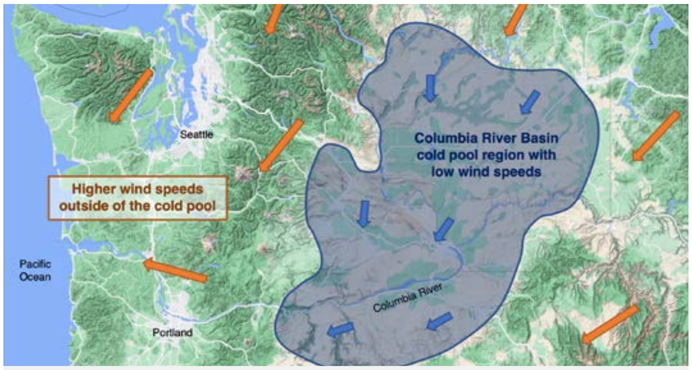
Development and testing of the method were completed as part of the Second Wind Forecast Improvement Project (WFIP2), a large, collaborative effort to improve weather models for use in the wind energy industry. Part of DOE's Atmosphere to Electrons initiative, WFIP2 also included an extensive campaign to gather meteorological observations in the Columbia River Basin of the U.S. Pacific Northwest. Arthur and his colleagues focused on a January 2017 cold pool event, observed during WFIP2, to validate their method. The team continues to work actively on this case study, examining important cold pool features, such as turbulence and low-level clouds.

Previous accomplishments of WFIP2 are documented in a series of articles in the *Bulletin of the American Meteorological Society*: general overview, observations, and model improvements.

"Improvement in cold pool forecasting, particularly cold pool erosion, was one of the big successes of WFIP2," said lead investigator Will Shaw of PNNL.

In fact, many previous WFIP2 model updates have been incorporated into NOAA's High Resolution Rapid Refresh model, a weather forecast model that is used throughout the wind energy industry. According to Dave Turner, a researcher at NOAA and head of its Atmospheric Science for Renewable Energy Program, the latest operational version of the model does a markedly better job forecasting the evolution of cold pools than its predecessors.

Arthur's new modeling method for steep terrain combines with other model developments in wind energy R&D to improve wind resource forecasting and, therefore, the reliability of energy production from such forecasts. ■



Schematic of a cold pool within the Columbia River Basin of the U.S. Pacific Northwest, showing low wind speeds within the cold pool region and higher wind speeds outside of it. *Map image from Google Maps; cold pool image by Robert Arthur, Lawrence Livermore National Laboratory*

DOE Commissions Open-Source Wind Turbine for Wake Control Research

National Rotor Testbed turbine will demonstrate new ways to lower energy costs using wake control approaches

Wakes—turbulent and complex air flows behind wind turbine rotors—cause wind to slow down through wind power plants, resulting in energy losses. Wakes also represent physical evidence of the power each wind turbine extracts from the air.

Wake dynamics can be simulated and studied with the new DOE computational fluid dynamics (CFD) code Nalu-Wind, which is part of the ExaWind tool suite. The challenge is that these codes require experimental data to validate the accuracy

The National Rotor Testbed turbine is designed to help wind power plant operators understand how they can lower energy costs using wake control approaches. *Photo by Chris Kelley, Sandia National Laboratories*

of their predictions. However, commercial wind turbine performance and experimental data are proprietary and not readily available for validation of new computational codes, especially for wake data.

The National Rotor Testbed (NRT), an open-source wind turbine designed at Sandia National Laboratories (Sandia) to study wind turbine wakes, solves this challenge by providing all design documentation to facilitate CFD code validation and collaboration among DOE laboratory researchers and academic research partners.

"The NRT wake control demonstration will enable a better understanding of how wind power plant operators can lower the LCOE using the tested wake control approaches, depending on different wind and electricity market conditions," said Christopher Kelley, rotor wake lead for Sandia.

The NRT was commissioned in 2021. Commissioning is the process of testing all the subsystems of the wind turbine prior to grid connection, full power production, and the start of a validation data field campaign.

The NRT blades include research instrumentation that measures acceleration, strain, and temperature across the blade span. The blade data, in conjunction with wake measurements, will be used to validate DOE's ExaWind tool suite, ensuring that it accurately simulates blade loads and the wake flow field for a variety of wind conditions.

Using these simulation tools, the Sandia research team is investigating how wind turbine wakes can be controlled within a wind power plant for different plant operator objectives—maximizing total power extraction, increasing blade lifetime, and offering grid ancillary services, such as grid frequency control. Alternative modes of operation provide a more flexible and customizable way for a wind power plant owner and operator to lower costs for an existing wind plant depending on electricity market conditions. These operational modes include:

- Yaw steering—deflecting wakes laterally so that they do not impact downstream wind turbines at the cost of greater fatigue damage
- Induction control—steadily reducing turbine power at the front of a wind plant so that downstream turbines produce more power
- Active wake mixing—dynamically changing turbine power at the front of a wind plant so that downstream turbines produce more power.

These methods will be evaluated experimentally to better understand which techniques best reduce the cost of energy.

NRT Commissioning Phases

After all components were installed, the NRT underwent commissioning—a process that ensured all systems were safe and operational. Commissioning of the NRT happened in phases:

- **Phase I**—showed that the wind turbine nacelle subsystems' yaw, pitch, and brakes operated safely and normally before the energy source, the NRT, was lifted and installed on the drive shaft.
- **Phase II**—showed that the yaw, pitch, and brakes functioned normally after the NRT was installed.
- **Phase III**—demonstrated the pitch system to control the rotor speed with good dynamic response.
- **Phase IV**—brought the wind turbine up to a fully operational state, spinning and producing power while connected to the grid.

After completing commissioning, the NRT began to collect data for wake validation of DOE wind turbine simulation codes.

The NRT will be used to demonstrate induction control and active wake mixing. Sandia will deploy a lidar on the NRT nacelle to measure the wake position and strength downstream of the wind turbine. Sandia will analyze these experimental data to validate the effect on a downstream turbine's power and loads as predicted from the CFD models. The results of the NRT experiment will show new ways of operating wind power plants to reduce the LCOE for varying electricity market conditions.

"Initial simulations of active wake mixing showed 6% increases in power production of two wind turbines operating near each other. This kind of power increase for closely spaced turbines has significant impacts to reducing LCOE and shows a way of reducing the geographic footprint of wind energy onshore and offshore," Kelley said. "The NRT experiment will validate this increase of power in a field experiment and make recommendations on when to use different wake control strategies."

The NRT is an open platform for testing new wind turbine technologies and collaborating among the national laboratories to validate advanced computational models for wind turbines. The turbine and instrumentation are well-suited to study wind turbine wakes and advanced wake controllers.

"Now that the NRT is commissioned and producing electricity, the team would like to develop new research partners, including blade manufacturers and wind farm owners and operators," Kelley said. "This will help increase the impact of wake control techniques on the deployment of commercial wind turbines."

For more information, visit the GitHub repository. ■

Resilience Metrics Offer New Ways To Gauge Benefits of Distributed Wind

Multilaboratory project explores improvements to system planning and operation

Reliability is a concept that has been widely understood in the electric power industry for a long time, but the concept of resilience is still evolving.

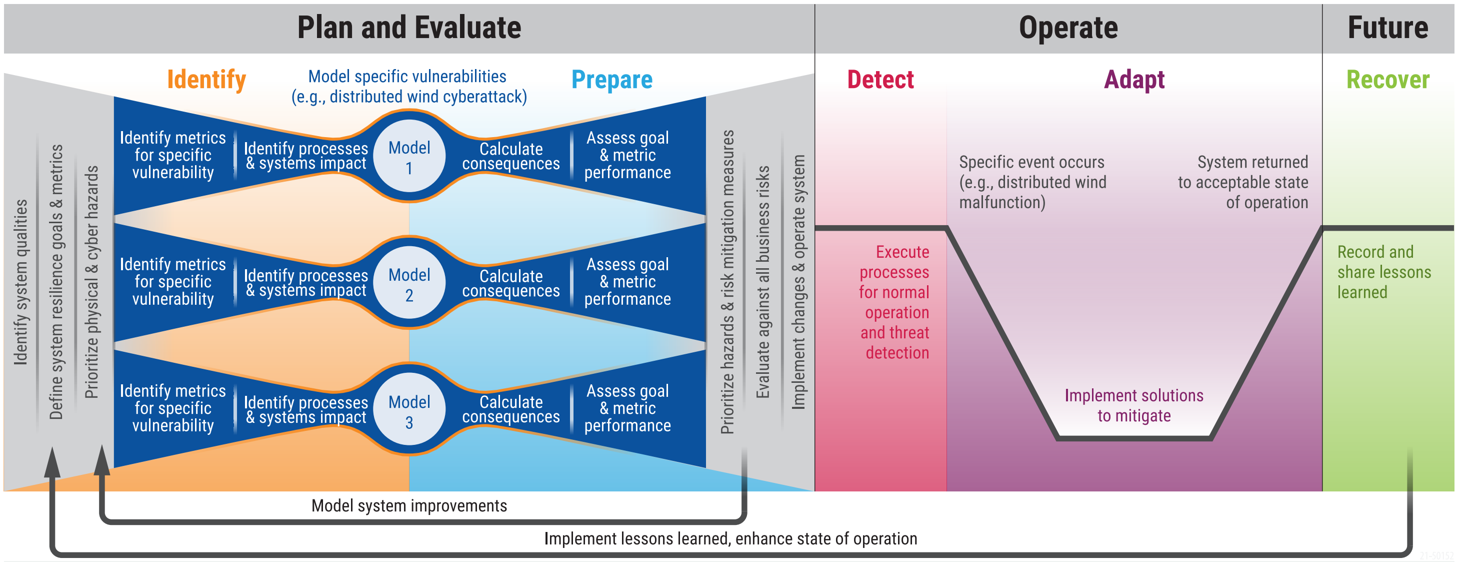
Reliability means there are adequate resources to supply customers with electricity on a consistent basis. But suppose a system has been shut down, either by extreme weather, ransomware from cybercriminals, or even a squirrel.

A power system should adapt to any hazard and recover to regular operation as quickly as possible—a quality not captured by reliability, but rather resiliency.

This is why WETO is funding an effort to craft definitions and metrics that demonstrate and measure the resilience benefits that distributed energy resources, including wind energy, provide. WETO's Microgrids, Infrastructure Resilience and Advanced Controls Launchpad (MIRACL) project, which involves four national laboratories, aims to improve the planning and operation of distributed wind systems. At Idaho National Laboratory (INL), a team of researchers is developing an electric-energy-delivery-system-focused resilience framework—a set of flexible guidelines that organizations can use to manage risk and inform capital investments.

Distributed wind energy systems exist to provide power locally—for example, to a community, family farm, factory, or microgrid—and can range in size from a 5-kilowatt wind turbine at a home to a multimegawatt wind turbine at a manufacturing facility. They can provide many resilience benefits, thanks to their ability to quickly change power output and support grid stability. They can even help bring power back online if the local grid experiences an outage.

This distributed wind turbine, which supplies backup power to the Center for Advanced Energy Studies at Idaho National Laboratory (INL), is an example of a system that could use the lab's resilience metrics and framework to evaluate the benefits of distributed wind. *Photo by J. Gentle, INL*



The INL resilience framework includes three high-level stages of resilience, five core functions of resilience, and multiple process steps within each stage to guide users through planning and evaluating the resilience benefits from distributed wind. *Figure from INL*

The term resilience comes from the Latin *resilio*, meaning to spring back or rebound. This might sound simple enough, but as the INL team studied research done by national laboratories, government agencies, and utilities, they concluded that the power industry lacks a standardized definition of resilience.

"Every electric energy delivery system has its own characteristics and vulnerabilities," said INL researcher Megan Culler. "A remote microgrid in Alaska might be resilient against extreme cold, and a distribution system in Texas might be resilient against hurricanes. Both of these systems are resilient against some hazards, but not necessarily against every threat out there."

In the comprehensive literature review, "Distributed Wind Resilience Metrics for Electric Energy Delivery Systems," the INL team zeroed in on a critical characteristic of resilience for electric energy delivery systems: each system has its own unique needs and perspectives as a result of different geographies, resources, and stakeholders—a characteristic the team labels as the distinctiveness property. Recognizing there is no "one-size-fits-all" process for resilience, the distinctiveness property encompasses factors such as likely threats, geography, stakeholders, risk tolerance, and mitigations.

The distinctiveness property is captured in each step of INL's new definition of resilience for electric energy delivery systems: "The resilience of an electric energy delivery system is described as a characteristic of the people, assets, and processes that make up the electric energy delivery system and its ability to identify, prepare for, and adapt to disruptive events (in the form of changing conditions) and recover rapidly from any disturbance to an acceptable state of operation."

Resilience metrics and, more specifically, distributed wind resilience metrics, must come from a process that addresses this distinctiveness quality and is separate from well-established reliability processes.

Applying qualitative and quantitative metrics to distributed wind resilience, the INL team developed a set of flexible guidelines—or a resilience framework—comprising three stages:

1. **Planning.** Uses future organizational needs and current system status to prepare for potential risks. Resiliency planning differs from traditional reliability planning in that it considers high-impact, potentially long-duration consequences.

2. **Operational.** Seeks to respond to active risks as prudently and efficiently as possible. This is the most "hands-on" portion of resilience because many decisions must be made quickly to maintain system viability. When a hazard occurs, the people, processes, and systems detect the event and react to the extent of their capabilities.

3. **Future.** Seeks to improve on current system resilience and feeds back into the planning stage to promote continuous improvement. This can involve direct work in the operational world to make repairs, upgrade components after they've failed, or make immediate changes to standard processes.

To guide a user through these three stages, the framework lays out five core functions that represent high-level capabilities a system must have for lifecycle resilience: identify, prepare, detect, adapt, recover. These core functions align closely with the core functions laid out in the National Institute of Standards and Technology cybersecurity framework for critical infrastructure. The INL resilience framework then walks users through resilience-planning scenarios.

INL will continue to contribute to the MIRACL initiative by providing an end-to-end, cyclical process for evaluating resilience and building it into the processes and assets that make up an energy delivery system. Ultimately, this process can be used to demonstrate the value of distributed wind beyond simple generation capacity and clean energy goals. ■

Buoys Provide Data about Birds and Bats Offshore

Research buoys, ThermalTracker-3D pulling in important data to inform offshore wind operations

Offshore wind has significant potential to bring abundant, renewable power into homes and businesses in coastal communities. But wind power plant operators need solid information about conditions, such as wind speeds at various times of day, to confidently make sound investments in technology and wind plant locations.

Such is the case for California, which is looking to add offshore wind to its power resources. In fall 2020, DOE's PNNL partnered with WETO and the Bureau of Ocean Energy Management to deploy two offshore wind research buoys off the northern and central California coastlines—near Humboldt and Morro Bay, California, respectively.

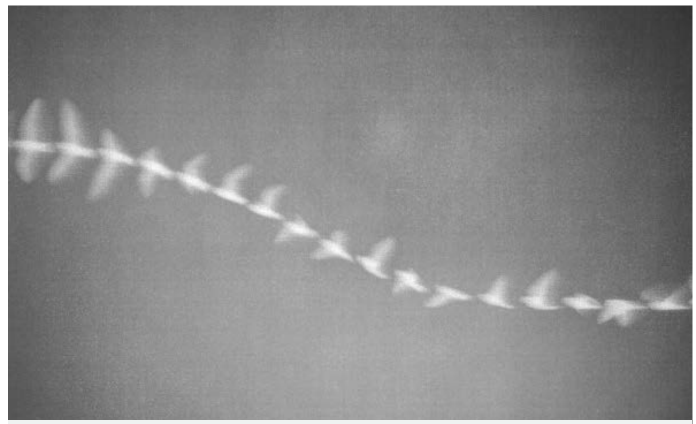
Earlier this year, the buoy stationed near Humboldt was taken offline for some technical upgrades. A research team streamlined that buoy's power use and incorporated more efficient data management capabilities.

The buoy also invited a new passenger on board.

Hitchin' a Ride Is for the Birds (and Bats)

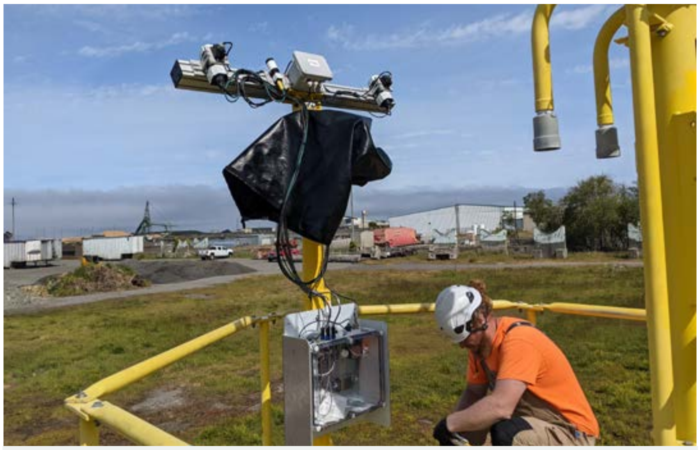
Enter ThermalTracker-3D, a technology developed by PNNL and supported by WETO. ThermalTracker-3D is designed to track bird (avian) and bat behaviors and attributes—such as flight height and speed—needed for assessing potential risks from offshore wind energy development.

The prototype technology, equipped with specialized software and a pair of thermal, stereovision cameras, hitched a ride on the Morro Bay buoy 20 miles off the coast of Humboldt County with the purpose of collecting information about seabird and bat activity. Paired with the buoy, avian and bat activity can be correlated with various weather and ocean conditions.



This image, created from a sequence of ThermalTracker-3D photo frames, shows the flight track of a bird over the Pacific Ocean. *Image courtesy of Shari Matzner, Pacific Northwest National Laboratory (PNNL)*

One of two offshore wind research buoys that are managed by PNNL, as depicted in an artist's rendering. The buoys are equipped with instrumentation that can take wind speed measurements as high as 250 meters, the height of today's wind turbines. Results will help wind power plant operators make decisions for states such as California on investments and locations. *Image by Mike Perkins, PNNL*



ThermalTracker-3D is installed on the Humboldt buoy as part of its update.
Photo by Shari Matzner, PNNL

The Results Bob In

The yearlong deployment is ending in fall 2021 for the Morro Bay buoy, with those results starting to land in the team's hands in real time.

"So far, we've noted a lot of variability in daily wind speed, especially in the upper part of the turbine rotor layer, at Morro Bay," said Raghu Krishnamurthy, a PNNL Earth scientist who is analyzing the data. "We are also finding that the wind speed increased roughly one and a half times at night."

At the Humboldt location off the northern coast, steady-state winds—winds that provide consistent power production during all hours of the day—are being observed at each altitude. These data will provide further insight about the minimum daily power production available from offshore wind power plants in California during all seasons.

The PNNL team continues to thoroughly analyze the buoy data as it comes in and will publish a technical report at the end of 2021.

ThermalTracker-3D also continues to pull in avian data—recording data continuously and transmitting the flight data to shore every hour. In its first 30 days at sea, the system recorded 699 flight tracks—the first time that continuous, "24/7" observations have been made in U.S. coastal waters.

Floating—and Flying—Into the Future

The Morro Bay buoy will also be recovered from the ocean and undergo similar upgrades as the Humboldt buoy, which will remain deployed until spring 2022. It will then take a tropical trip to the coast off Oahu, Hawaii, to support offshore wind energy planning for that state.

Meanwhile, once ThermalTracker-3D completes its first California stint, the research team plans to develop a system for potential future deployment on an offshore wind turbine. This effort will compare postconstruction seabird behavior with the baseline data collected off the buoy—completing the understanding of how seabirds are affected by offshore wind energy development.

The data from the buoy and ThermalTracker-3D deployments will be available to the wind energy research community on the Wind Data Archive and Portal, which is managed by PNNL. In August, *R&D World Magazine* announced that ThermalTracker-3D is a finalist for an R&D 100 award in the Software/Services category; winners will be announced later this year. ■

DOE News

DOE Releases New Reports Highlighting Record Growth, Declining Costs of Wind Power

DOE released three reports showing record growth in land-based wind energy, significant expansion of the pipeline for offshore wind projects, and a continued decline in the cost of wind energy generation—laying the groundwork for significant future gains as the Biden administration pursues rapid acceleration of renewable energy deployment to reach its goal of 100% clean electricity by 2035.

"These reports contain such terrific news: the U.S. installed a record-breaking amount of land-based wind energy last year. They underscore both the progress made and the capacity for much more affordable wind power to come—all necessary to reach President Biden's goal of a decarbonized electricity sector by 2035," said Secretary of Energy Jennifer M. Granholm. "At DOE, we will double down on efforts to deploy more wind energy around the country as we also pursue technologies to make turbines even cheaper and more efficient."
Read more

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Planning a Wind Energy Project? New WINDExchange Resources Can Help

To help local decision makers determine whether a wind project is right for their community, DOE's WINDExchange initiative released two information resources: a report titled "Land-Based Wind Energy Siting" and a web-based "Land-Based Economic Development Guide." Created by experts at NREL, these comprehensive, easy-to-read resources provide useful information to support a greater understanding of the siting considerations and economic opportunities associated with wind energy. These resources highlight the elements communities should consider when pursuing a wind energy project—from conception and construction of the project site to how the community coexists with the wind project once it's operating. Read more

The North American Renewable Integration Study (NARIS)

NARIS assesses opportunities to modernize and decarbonize the North American power system through the integrated planning and operation of generation and transmission infrastructures to meet end-use demand. In June, DOE and Natural Resources Canada (NRCan) announced the release of the U.S. Perspective Report and the Canadian Perspective Report. Launched in 2016, NARIS evaluated four scenarios for North American power systems through 2050, focusing on the effects of various renewable technology cost trajectories, emission constraints, demand growth, and outcomes. Among the key findings is that there are multiple combinations of electricity generation, transmission, and demand that can result in 80% carbon reduction by 2050.
Read more

U.S. Secretary of Energy Granholm, Canadian Minister of Natural Resources O'Regan Launch Cooperative Agreement on Clean Energy, Innovation, and Energy Justice

United States Secretary of Energy Jennifer M. Granholm and Canadian Minister of Natural Resources Seamus O'Regan held a bilateral meeting to launch an updated and revised memorandum of understanding that reinvigorates and expands energy cooperation between their departments, accelerates the clean energy transition to net-zero emissions by 2050, and provides reliable, efficient, and resilient grid operations. "The United States and Canada have a shared commitment to protect our planet and ensure that all pockets of North America have access to affordable, clean energy," said Secretary Granholm. "We can't tackle the climate crisis alone—we must work together to accelerate the flow of low-carbon electricity across our borders, spurring job growth and ushering in a 100% clean energy future."
Read more

Turning Oranges to Apples: A Cutting-Edge Price Comparison for Renewables

A new, comprehensive approach is now available for evaluating renewable energy project revenue and value holistically. Stakeholders increasingly compare renewable energy technologies based on prices from auctions and power purchase agreements (PPAs), but such face-value price comparisons can be misleading. Auction and PPA prices are often not directly comparable because they come from different value frameworks, jurisdictions, or points in time, each reflecting their own markets, taxes, and regulatory environments. To facilitate more meaningful comparisons, researchers from DOE and NREL—in collaboration with international researchers working under the International Energy Agency's Wind Technology Collaboration Programme—have developed a new approach that uses project revenue and value assessments to facilitate improved "apples-to-apples" comparisons between projects and against established cost metrics.
Read more

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National Offshore Wind Research and Development Consortium (NOWRDC) Announces Offshore Wind Supply Chain Roadmap Project

The NOWRDC announced a comprehensive U.S. offshore wind supply chain project. The purpose of the Supply Chain Roadmap is to present the collective benefits of a domestic supply chain and facilitate the acceleration of the offshore wind industry in the United States. The project is a partnership between NREL, the Business Network for Offshore Wind (the Network), the State of Maryland, the New York State Energy Research and Development Authority, and DOE. NREL, the Network, and DNV-GL are collaborating on the project. Read more ■

Funding News

Biden Administration's Budget Request Calls for Increase across Wind Energy Research Areas

President Biden's budget request for fiscal year 2022 includes nearly $205 million for WETO—an 86% increase from 2021 appropriations—with $100 million for offshore wind, $40 million for land-based wind, $18 million for distributed wind, and $47 million for grid integration and analysis. These proposed budget increases would support WETO's R&D strategies for scaling installed wind capacity from 122 GW today to more than 500 GW by 2035 through cost reductions, sustainable solutions to environmental and siting concerns, and grid integration. Read more

DOE Announces 2021 Technology Commercialization Fund Selections

DOE announced more than $30 million in funding for 68 projects supported by the Office of Technology Transitions Technology Commercialization Fund (TCF). With more than $34 million in matching funds from the private sector, these projects will advance commercialization of promising energy technologies and strengthen partnerships between DOE's national laboratories and private sector companies to deploy these technologies to the marketplace. TCF selections include $1.95 million in wind-energy-related projects for DOE national laboratories and their research partners. Read more

Small Businesses Receive Millions in Funding for Testing, Developing, Prototyping, and Commercializing Wind Energy Innovations

DOE announced funding awards for several wind-energy-related small business projects, part of a cross-cutting-technology package totaling $54 million funded by DOE's Small Business Innovation Research and Small Business Technology Transfer programs, which help American small businesses and entrepreneurs test and prototype clean energy breakthroughs with the potential toward commercialization. In June, the agency announced Small Business Innovation Research Phase I awards totaling $22 million for 110 American small businesses and entrepreneurs developing clean energy technologies. In August, eight small businesses received awards to develop wind technology as a cost-effective, reliable, and compatible distributed energy resource under the 2021 round of DOE's Competitiveness Improvement Project (CIP). The 2021 CIP selectees are expected to share about $2.2 million in DOE funding and leverage about $1.3 million of industry cost share. Awards for $57 million were also announced for 53 projects by 51 American small businesses and entrepreneurs to help tackle the climate crisis through market-oriented solutions and emerging technologies. That announcement is also part of DOE's Small Business Innovation Research and Small Business Technology Transfer programs. ■

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

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