2020–2021 Accomplishments Report

Water Power Technologies Office

Acknowledgments

The U.S. Department of Energy's Water Power Technologies Office 2020–2021 Accomplishments Report reflects the steadfast commitment and work of the national laboratory, university, and industry staff members who led and supported each of these projects. This document showcases these efforts and the ways in which they continue to advance the hydropower and marine energy industries. The following individuals were instrumental in writing, reviewing, and verifying the impacts of these projects:

Libby Arnold

Hoyt Battey

Jennifer Breen Martinez

Kiki Carpenter

Laura Carter

Carter Christensen

Kelly Dwyer

Brittany Enos

John Frenzl

Karen Heinold

Ali Hewett

Maxine Hillman

Erica Holloway

Allison Johnson

Hannah Lassiter

Carol Laurie

Megan Lennox

Taylor Mankle

Caitlin McDermott-Murphy

Tara McMurtry

Kathleen Morton

Rachel Palmour

Heather Queyrouze

Nate Rivi

Betsy Stratton

Pardeep Toor

Josh Zaklis

Thank you to all.

Disclaimer

Letter From the Principal Deputy Assistant Secretary

Dear colleagues,

It has been an exciting year at the U.S. Department of Energy (DOE) and in the Water Power Technologies Office (WPTO). Partners across the country led and supported dozens of WPTO-funded research, development, and demonstration projects, contributing to crucial efforts to address climate change and transition our energy system. The hydropower and marine energy industries have essential roles in achieving the Biden administration's goals of creating a carbon-free power sector by 2035 and a net-zero-emissions economy by 2050.

WPTO and its partners are helping to meet these goals with projects that include a new methodology and tool to value pumped storage hydropower and other long-duration storage assets on the electricity grid. These resources will help developers and investors better predict revenue and regulators better understand these projects' value. In addition, WPTO supported in-water demonstrations of varied marine energy devices, helping to advance these renewable energy technologies that can support decarbonization goals.

These projects—and the many others featured in WPTO's 2020–2021 Accomplishments Report—demonstrate the incredible value of water power technologies in our clean energy future. DOE will continue to invest in these technologies and build on the accomplishments of the water power research community with funding provided in the Bipartisan Infrastructure Law, which includes nearly $1 billion for hydropower and marine energy programs under DOE. More information on these investments is available in DOE's fact sheet.

I congratulate everyone who worked on the projects described in this report—and the dozens of additional projects still underway—and look forward to what you accomplish in the coming year.

Sincerely,

Kelly Speakes-Backman
Principal Deputy Assistant Secretary
Office of Energy Efficiency and Renewable Energy
U.S. Department of Energy

Letter From the Water Power Technologies Office Director

Dear friends,

On behalf of the U.S. Department of Energy's (DOE) Water Power Technologies Office (WPTO), I am pleased to present our 2020–2021 Accomplishments Report. This report highlights numerous achievements and results from WPTO-supported research across our Hydropower and Marine Energy programs, including new tools and resources for project developers, numerous in-water deployments of emerging technologies, and innovative science, technology, engineering, and math outreach efforts.

This vital work took place across the country—in DOE national laboratories, on university campuses, in rivers and along coastlines, and in remote villages and communities. Collectively, these efforts are helping our country transition to a clean energy economy while supporting the resilience of communities already experiencing the effects of climate change. Throughout the year, our partners maintained an unwavering commitment to these projects and many others. Our clean energy future can only be realized with the help of people like you, so thank you—to the engineers, students, scientists, community organizations, and countless others—for your hard work.

I hope you enjoy learning more about these projects and are inspired by our opportunities to transform our energy systems. I am also looking forward to what we can achieve over the next year, which includes holding our next WPTO virtual Peer Review in summer 2022 to gather feedback on the past and future direction of the office. This report represents only a fraction of the work our office supports nationwide, and so I encourage you to stay up to date on WPTO's work and our upcoming events throughout the year by signing up for our Water Wire, Hydro Headlines, and Water Column newsletters. If you have questions about WPTO's work or the projects featured in this report, please do not hesitate to contact us via email.

Sincerely,

Jennifer Garson
Director, Water Power Technologies Office
Office of Energy Efficiency and Renewable Energy
U.S. Department of Energy

Acronyms and Abbreviations

AMEC – Atlantic Marine Energy Center

Argonne – Argonne National Laboratory

BioPA – Biological Performance Assessment

DOE – U.S. Department of Energy

ETIPP – Energy Transitions Initiative Partnership Project

FERC – Federal Energy Regulatory Commission

FOSWEC – floating oscillating surge wave energy converter

HBET – Hydropower Biological Evaluation Toolset

HESC – Hydropower Energy Storage Capacity

HydroWIRES – Hydropower and Water Innovation for a Resilient Electricity System

IEA – International Energy Agency

IEC – International Electrotechnical Commission

INL – Idaho National Laboratory

MECC – Marine Energy Collegiate Competition

MHKiT – Marine and Hydrokinetic Toolkit

MODAQ – Modular Ocean Data Acquisition

NARIS – North American Renewable Integration Study

NASA – National Aeronautics and Space Administration

NEED – National Energy Education Development

NOAA – National Oceanic and Atmospheric Administration

NPD – non-powered dam

NREL – National Renewable Energy Laboratory

OC6 – Offshore Code Comparison Collaboration, Continued, with Correlation and unCertainty

ORNL – Oak Ridge National Laboratory

PNNL – Pacific Northwest National Laboratory

PRIMRE – Portal and Repository for Information on Marine Renewable Energy

PSH – pumped storage hydropower

PTO – power take-off

R&D – research and development

RHT – Restoration Hydro Turbine

Sandia – Sandia National Laboratories

SBIR – Small Business Innovation Research

STEM – science, technology, engineering, and mathematics

SWEPT – Sandia Wave Energy Power Take-Off

TC114 – Technical Committee 114 for Marine Energy Systems

TEAMER – Testing Expertise and Access for Marine Energy Research

WEC – wave energy converter

WEC-Sim – Wave Energy Converter SIMulator

WPTO – Water Power Technologies Office

Table of Contents

Hydropower

Hydropower Program Overview

Hydropower, which uses the flow of moving water to generate electricity, is one of the oldest and largest sources of renewable energy. In 2020, it accounted for more than 7% of U.S. electricity generation and nearly 37% of U.S. renewable electricity generation. Meanwhile, pumped storage hydropower (PSH) remains the largest contributor to U.S. energy storage with an installed capacity of 21.9 gigawatts, which accounts for 93% of utility-scale energy storage capacity in the United States.

The Hydropower Program within the U.S. Department of Energy's (DOE) Water Power Technologies Office (WPTO) conducts R&D and applied science to advance transformative, cost-effective, reliable, and environmentally sustainable hydropower and pumped storage technologies; better understand and capitalize on opportunities for these technologies to support the nation's rapidly evolving grid; and improve energy-water infrastructure and security. The program's vision is a U.S. hydropower and pumped storage industry that modernizes and safely maintains existing assets, responsibly develops new low-impact hydropower, promotes environmental sustainability, and supports grid reliability, integration of other energy resources, and energy-water systems resilience.

To achieve this mission and vision, the Hydropower Program comprises five R&D activity areas, which represent the program's strategic approach to addressing the challenges facing U.S. hydropower stakeholders. Success stories in the WPTO 2020–2021 Accomplishments Report are presented within these activity areas:

- Innovations for Low-Impact Hydropower Growth
- Grid Reliability, Resilience, and Integration (HydroWIRES Initiative)
- Fleet Modernization, Maintenance, and Cybersecurity
- Environmental and Hydrologic Systems Science
- Data Access, Analytics, and Workforce Development.

Readers can learn more about the Hydropower Program and its projects by visiting the WPTO website, subscribing to the Water Wire and Hydro Headlines newsletters, and exploring the WPTO Projects Map.

INNOVATIONS FOR LOW-IMPACT HYDROPOWER GROWTH

If hydropower plants can plan for changes in weather or waterflow, these critical energy resources can better support the nation's evolving power grid. Now, a new tool can help hydropower operators manage future climate and water risk with artificial intelligence-powered weather and water forecasts. *Photo courtesy of Andrea Walls, U.S. Department of Energy's Make a Splash Photo Contest*

Forecasting Technology Provides Reliable Streamflow Predictions To Inform Hydropower Projects

PROJECT NAME: Hydropower Decision-Support with Machine Learning and Satellite Driven Forecasts

PROJECT TEAM: Natel Energy

LOCATION: Alameda, California

Upstream Tech, a subsidiary of Natel Energy, applied machine learning and satellite images to provide the industry with more accurate streamflow forecasts. Supported by a Small Business Innovation Research (SBIR) Phase I award, the company deployed HydroForecast, an artificial-intelligence-powered forecasting software package, at more than 300 locations, allowing a wide array of hydropower developers to plan, operate, and assess risks of hydropower facilities. Forecasts from this software will enable hydropower developers and regulators to make more informed decisions that save costs, while also increasing operational flexibility and environmental performance of hydropower projects. To demonstrate the accuracy of its forecasting efforts, Upstream Tech competed in the Streamflow Forecast Rodeo, a forecast skill competition run by the U.S. Bureau of Reclamation, placing first in the all-around competition and winning 23 of 25 performance categories.

Encouraged by these results and an SBIR Phase II award, Upstream Tech will develop additional weather forecast resources using a scalable, resilient, and secure cloud-based system. The company will continue quantifying water power technologies' technical and financial benefits to continue moving its forecasting technologies toward commercialization. ■

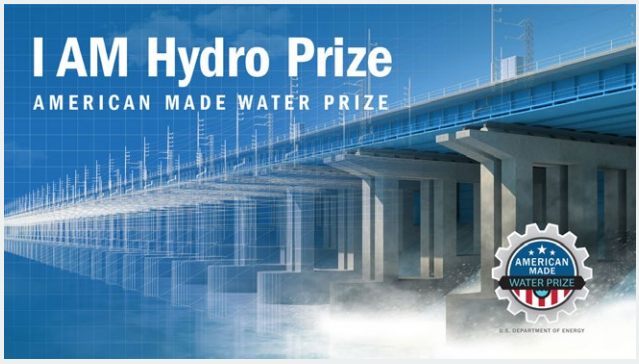
I AM Hydro Prize Winners Use Advanced Manufacturing To Reduce Costs of Hydropower Components

PROJECT NAME: I AM Hydro Prize

PROJECT TEAM: National Renewable Energy Laboratory (lead) and Oak Ridge National Laboratory

In December 2020, WPTO announced 11 winning teams of the Innovations in Advanced Manufacturing for Hydropower (I AM Hydro) Prize. The single-stage competition, administered by the National Renewable Energy Laboratory (NREL), in collaboration with Oak Ridge National Laboratory (ORNL) and with support from partners, invited participants who may not normally affiliate with the hydropower industry to innovate solutions that decrease costs of hydropower components and systems, as well as leverage advancements in manufacturing and materials. Each winner received a cash prize from a pool of $175,000 to further evolve and develop their concept throughout 2021.

The top-placing innovation was Cadens LLC's Utility of Large Area AM for Small Hydro, which involves the design and construction of 3D-printed turbine components via additive manufacturing to produce a low-cost, readily customizable, modular small hydropower system. Other prize-winning concepts included retrofitting of non-powered dams (NPDs) using 3D concrete printing, additive manufacturing technology paired with modern advances in robotics to enable superior repair, artificial intelligence to optimize turbines, antifouling coating for hydropower cost reductions, and magnets to increase generator efficiency and lower energy production costs. All 11 concepts explored the potential applications of advanced manufacturing for hydropower and revealed various possibilities to improve conventional hydropower manufacturing. ■



The Innovations in Advanced Manufacturing for Hydropower Prize awarded 11 winning teams up to $175,000 for their concepts to leverage the rapid innovations enabled by advanced manufacturing to solve hydropower's critical challenges. *Image courtesy of the National Renewable Energy Laboratory*

The new IrrigationViz tool can help farmers and other irrigation system managers update their aging technologies and add hydropower to generate clean energy on site while saving water and money. *Photo courtesy of Andrea Walls, U.S. Department of Energy's Make a Splash Photo Contest*

New Tool Advances Irrigation Modernization With Hydropower

PROJECT NAME: Irrigation Modernization: Accelerating Modern Investment Across the United States

PROJECT TEAM: Idaho National Laboratory (lead), Pacific Northwest National Laboratory, and Farmers Conservation Alliance

LOCATION: Idaho Falls, Idaho

In the western United States, nearly 90% of consumptive water use is for irrigation, yet reliable supply of water is increasingly threatened due to the combination of growing demand and climate change. Irrigation modernization has the potential to promote the economic well-being of farmers and rural communities, generate more renewable energy, and advance environmental stewardship. Cutting carbon emissions within the farm sector, too, can aid in the work of combating climate change.

Researchers from Idaho Idaho National Laboratory (INL) and Pacific Northwest National Laboratory (PNNL), along with the Farmers Conservation Alliance, developed a decision support and visualization tool, IrrigationViz, to help irrigators and farmers redesign and reinvest in their irrigation systems. Over the past year, the team developed a working prototype of the tool, performed extensive outreach to ensure it meets stakeholder needs, and assessed options to identify financially viable opportunities for hydropower and other renewable generation in these settings.

By assisting irrigation districts in performing planning activities and enabling them to identify the highest priority projects for their system, IrrigationViz can help many irrigation districts access federal funding programs, such as those from the U.S. Department of Agriculture.

IrrigationViz has since been used in three case studies, one each in Utah, Idaho, and Washington. In testing the tool, users were able to determine the cost of piping a given segment of their existing irrigation system, weighing the cost against the projected benefits to determine which segments of the system should be prioritized. Each case study was used by the team as an opportunity to improve the tool's functionality.

The IrrigationViz tool and the team's work will help irrigation districts use modern technologies to make decisions about reinvesting in their systems and solve the challenges they face today. ■

Natel Restoration Hydro Turbines Increase Fish Passage Without Compromising Hydropower Generation

PROJECT NAME: Funding Opportunity Announcement 2080 Support – Natel

PROJECT TEAM: Natel Energy (lead), Oak Ridge National Laboratory, Pacific Northwest National Laboratory, and Kleinschmidt Group

LEAD RECIPIENT LOCATION: Alameda, California

To support the safe passage of fish through hydropower facilities, Natel Energy completed two successful fish passage tests with 100% survival rates. While most industry fish passage tests focus on passing small fish through large turbines, Natel Energy's initial testing assessed the ability for large adult rainbow trout (200–400 millimeters long) to safely pass through the Restoration Hydro Turbine's (RHT) relatively small turbine diameter (1.9 m) at the company's Monroe Hydro Project in Madras, Oregon.

These high fish survival numbers indicate the RHT may eliminate the need for expensive screens or plant-level structures that redirect fish away from turbines. Validation of the RHT's fish-safe performance, coupled with hydraulic efficiency, offers the potential for new modes of operation of hydropower facilities while meeting or exceeding environmental goals with respect to fish passage and protection.

Biologists from PNNL confirmed 100% survival of all 60 trout that passed through the turbine. Natel Energy is continuing to conduct turbine passage testing of relevant species in its closed-loop hydraulic test facility in Alameda, California. PNNL also conducted a passage test of 47 American eels measuring 34–49 cm in length. The eels passed through a 55-cm-diameter RHT unit operating under 10 m of hydraulic head at 670 revolutions per minute, again concluding with 100% survival.

Natel Energy's RHT is uniquely suited for small, modular hydropower due to its compact and cost-effective design, which leverages advanced manufacturing techniques from other industries, such as wind energy, automotive, and aerospace. Accomplishments from these successful tests have potential to help future projects meet environmental standards for fish passage without the need for screening. ■

Natel Energy used its closed-loop hydraulic test facility in Alameda, California, to assess fish passage rates of various species. *Photo courtesy of Natel Energy*

New Analysis Estimates Costs of Adding Hydropower Generation Capability to Non-Powered Dams

PROJECT NAME: Cost Analysis of Hydropower Options at Non-Powered Dams

PROJECT TEAM: Oak Ridge National Laboratory (lead) and Small Hydro Consultants LLC

LEAD RECIPIENT LOCATION: Oak Ridge, Tennessee

Researchers at ORNL developed the *Cost Analysis of Hydropower Options at Non-Powered Dams Report* to provide hydropower developers with better insights into the potential costs of adding hydropower generation capability or powering existing NPD projects and to explore ways to reduce these costs. Using available data and assisted by hydropower design experts from Small Hydro Consultants, researchers identified key characteristics of potential NPD hydropower projects and grouped them into classes that aligned similar projects with one another. Researchers then evaluated detailed design, initial construction costs, and hydropower generation for a representative project within each group. This report provides a critical update to cost estimates for NPD projects and insights into the site and design features that drive costs. Results for the representative sites will serve as templates to support more accurate estimates for thousands of prospective NPD projects, saving stakeholders time, effort, and millions of dollars when assessing sites for NPD hydropower development. ■

Groundbreaking Hydro Prize Winners Develop Concepts To Reduce Costs and Time for Building Foundations for Hydropower Projects

PROJECT NAME: Groundbreaking Hydro Prize

PROJECT TEAM: Oak Ridge National Laboratory and National Renewable Energy Laboratory

In April 2021, WPTO announced two winners of the Groundbreaking Hydro Prize, which challenged innovators to create new solutions to support hydropower project development by starting at square one—the foundation. The prize, developed by WPTO in collaboration with NREL and ORNL, was open to a multidisciplinary field of applicants, from those in hydropower and dam construction and safety to advanced manufacturing and beyond.

Team GZA (GeoEnvironmental Inc. and Littoral Power Systems) won the Groundbreaking Prize for their concept, Terra-Modulor Project concept to prefabricate a modular hydropower foundation for a wide range of soils and substructures. Team Chemventive won the Innovator Prize for their WaterJet Drill concept, a deep array of high-tension cables drilled through solid rock, using a water-jet drilling robot, to secure a steel dam in tension. ■

The Water Power Technologies Office launched the Groundbreaking Hydro Prize to encourage the development of new ideas to cut the costs, timelines, and risks associated with hydropower development. This competition challenged innovators to come up with new solutions to support hydropower project development by starting at square one—the foundation. *Graphic courtesy of the National Renewable Energy Laboratory*

Research Explores Connections Between Water and Power Systems To Enhance Their Resiliency

PROJECT NAME: Integrated Water Power Resilience Project

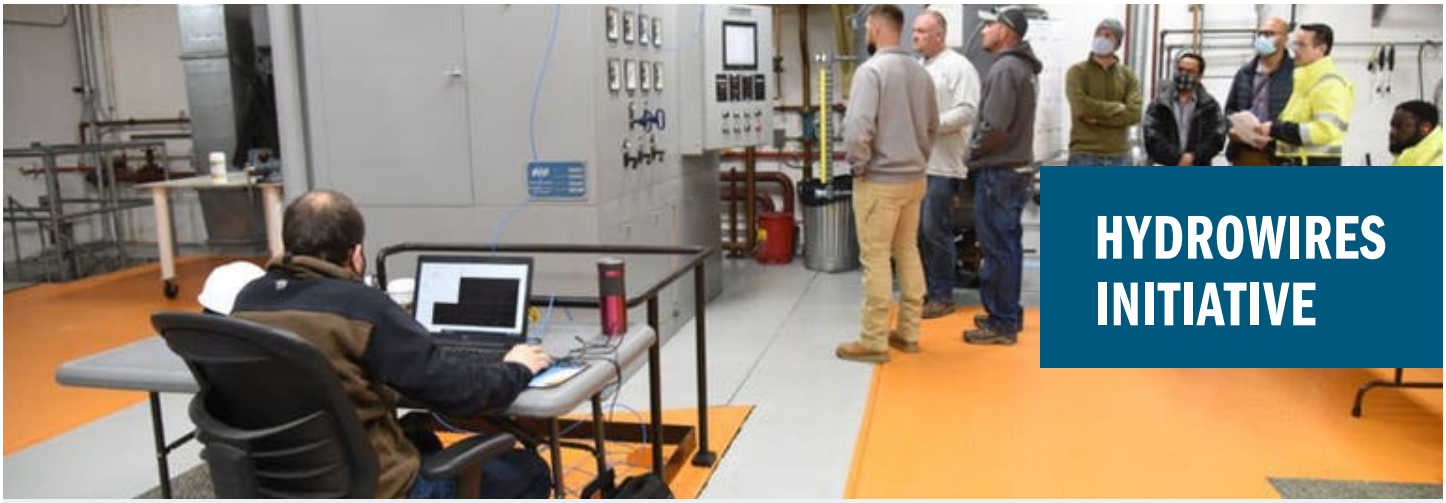
PROJECT TEAM: Pacific Northwest National Laboratory (lead) and Idaho National Laboratory

LEAD RECIPIENT LOCATION: Richland, Washington

As part of an effort aimed at improving grid and water system resilience, a project team from PNNL and INL hosted a workshop to collect industry feedback to guide further research into resilience. After collecting feedback, researchers developed Sankey diagrams depicting the interconnections of water and power generation, as well as a report on how electric utilities are currently planning for water variability and climate change.

The goal of this exploratory project is to better understand and support the interdependencies between water and power systems to improve overall resilience of each. Overall, this project has the potential to provide knowledge and measurements that will make water and power systems more resilient to both natural and man-made disasters. ■

Disasters—like droughts, floods, and even cyberattacks—are rare but can cause significant disruptions in water power. Now, a team of researchers is developing a comprehensive toolkit to help hydropower plants prepare for and weather the worst. *Photo courtesy of Katelynn English and Kimberlee Craig, U.S. Department of Energy's Make a Splash Photo Contest*



HYDROWIRES INITIATIVE

Idaho National Laboratory collaborated with Idaho Falls Power to test ultracapacitors in their ability to provide grid resiliency for local communities during times of electricity generation disruption. *Photo courtesy of Idaho National Laboratory*

First-of-a-Kind Tests Demonstrate How Small Hydropower Plants and Energy Storage Can Enhance Grid Reliability and Resilience

PROJECT NAME: Integrated Hydropower Storage Systems

PROJECT TEAM: Idaho National Laboratory (lead), Idaho Falls Power, and National Renewable Energy Laboratory

LEAD RECIPIENT LOCATION: Idaho Falls, Idaho

In April 2021, INL and Idaho Falls Power performed first-of-a-kind tests to determine how the utility's five small hydropower plants could provide electricity generation during regional grid disruptions. This required developing innovative hydropower controls and integrating energy storage technologies with the plants. The data gathered from the week of field testing is helping Idaho Falls Power better serve its customers during power emergencies and improving INL's models of how hydropower integrated with energy storage can provide similar capabilities to other communities across the United States.

INL and Idaho Falls Power have been working toward these tests since 2015, following an outage in December 2013 that left about 53,000 southeast Idaho residents without power for hours in freezing temperatures. The outage forced the utility to shed 35 megawatts of power in just 30 minutes, putting the entire system at risk. Idaho Falls Power and INL subsequently began investigating so-called "black start" and "islanding" capabilities. Black starting is the process of jump starting a local grid with available equipment and electricity, and islanding is powering the local grid independent of the regional grid. While large hydropower plants are backbones of black start capabilities in many regions, most small hydropower plants do not respond quickly enough on their own to balance the sudden changes in load. Integrating these smaller plants with energy storage, such as a battery or ultracapacitor, means these systems can provide the immediate response while the hydropower catches up. Together, they can provide enough frequency and voltage stabilization to support the local community's power system.

The tests used ultracapacitors, which are ideal for releasing and absorbing quick, large bursts of energy on demand, but not the sustained outputs batteries are known for, relieving pressure from hydropower plants and giving them time to catch up to demand. In preparation for the field tests, the team first created a digital model of the Idaho Falls power system in INL's Energy Systems Integration Laboratory to test and validate a simulated version of the approach in a controlled environment. NREL also helped characterize and model the hydropower plants using a non-real-time digital platform.

To isolate the city's generators and simulate the critical loads on the system, two 6-megawatt load banks were brought in. Load banks are used to test an electric power source that has been disconnected from its normal operating load, drawing the current and dissipating it in the form of heat. The team proceeded to connect the hydropower plants and ultracapacitors to the load banks to test different combinations of solutions to provide black start and grid islanding capabilities.

Ultimately, the tests showed the ultracapacitors worked as expected when connected to the hydropower plants and demonstrated how local communities can use their power systems to achieve grid reliability and resilience while utilizing zero-emissions energy sources. INL and Idaho Falls Power are currently assessing the test results to determine how close the microgrid is to becoming a reality. The results could prove that small hydropower plants, when combined with innovative controls and energy storage technologies, can keep the lights on for local customers regardless of the stress on the regional grid. ■

National Labs Partner With General Electric To Understand Value of Pumped Storage Hydropower Under Increasing Renewables

PROJECT NAME: Value and Role of Pumped Storage Hydro Under High Variable Renewables

PROJECT TEAM: General Electric

LEAD RECIPIENT LOCATION: Niskayuna, New York

To fill knowledge gaps on the full value and capabilities of PSH, a General Electric team studied the value and role of PSH under high variable renewables (or electricity grids with increased wind and solar resources). The team found that PSH could help bring more renewables online faster and cheaper. They also determined that the addition of just one 4-gigawatt-hour PSH facility in California would reduce electricity production costs by $62 million annually and carbon dioxide emissions by 0.5 million tons per year, which is equivalent to the emissions from 110,000 passenger vehicles.

The team published these results in a report in March 2021 to help utilities, public utility commissions, developers, and regional planning organizations better understand the value of PSH and overcome a range of market barriers. Researchers also developed a PSH scheduling tool that can be used to maximize PSH revenue by optimizing energy and ancillary services. In addition, researchers developed grid models for simulating the most recent pumped storage technologies with additional features for boosting grid reliability and resiliency. ■

Pumped storage hydropower facilities can store huge amounts of clean energy and help ease the nation's transition to a renewable energy grid. A report lays out this and many more benefits of this valuable form of hydropower. *Photo courtesy of Karl Specht, U.S. Department of Energy's Make a Splash Photo Contest*

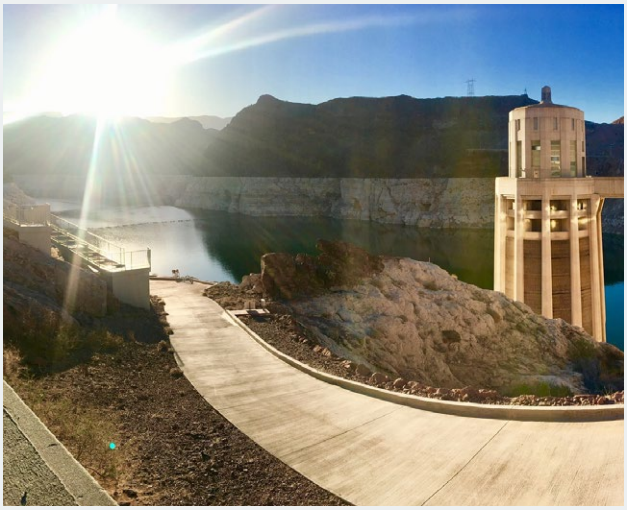
National Labs Identify Modeling Gaps in Studies Needed To Improve Understanding of Hydropower Capabilities

PROJECT NAME: Power Flow and Stability Models for Hydropower Plants

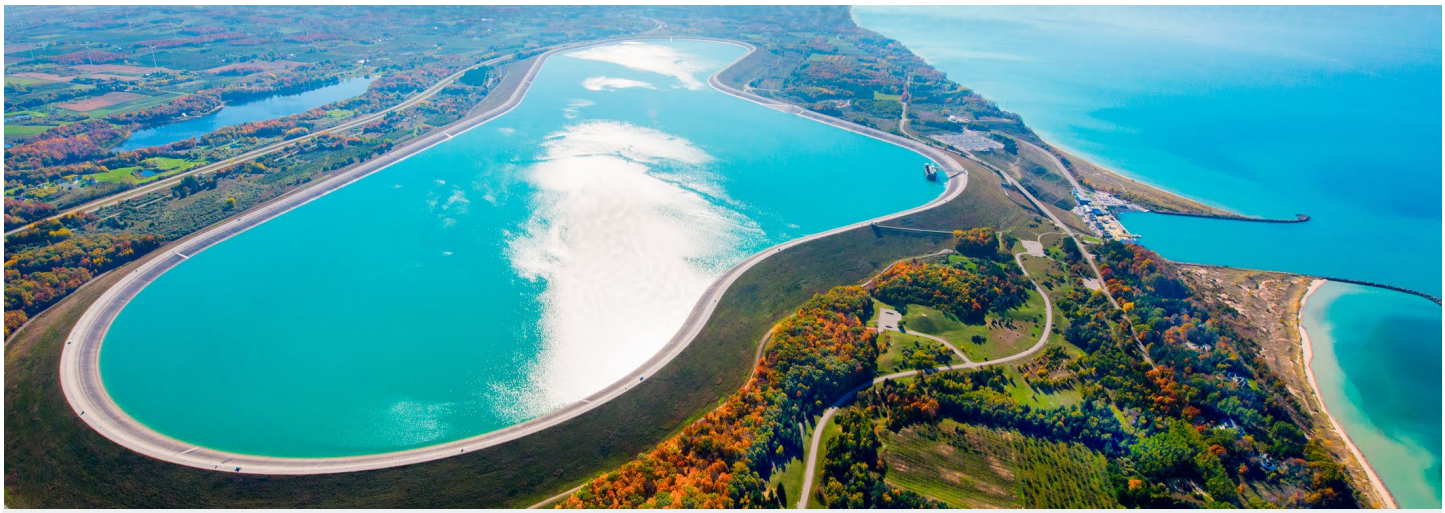
PROJECT TEAM: Pacific Northwest National Laboratory (lead), Idaho National Laboratory, and National Renewable Energy Laboratory

LEAD RECIPIENT LOCATION: Richland, Washington

PNNL, with support from INL and NREL, developed a report outlining how hydropower modeling could be improved to better represent its dynamic role in a changing grid. During discussions with national laboratory experts, industry stakeholders identified the need for differentiated approaches to hydropower modeling at different scales, improvements in the organization of publicly available data, improved approaches for validating and characterizing uncertainty, new modeling frameworks that can address multiple competing objectives, and increased collaboration and interaction among the hydropower and power grid modeling communities. These priorities are based on engagement with industry stakeholders, including experts in power grid and hydropower modeling, reservoir operations, and representatives from hydropower system operators, grid managers, national laboratories, DOE, and other federal agencies to identify gaps and prioritize solutions in modeling hydropower plants in steady-state and dynamic models used by grid operators. Future work in this area will seek to resolve these gaps in power system modeling for hydropower, helping to properly evaluate this resource's ability to support a clean electricity grid. ■



Hydropower is typically part of two systems: water management and power systems with fundamental differences in representation of hydropower associated with contrasting modeling objectives. The lack of information exchange and the inconsistency in the modeling representations might lead to suboptimal use of hydropower in both systems. *Photo courtesy of Natalie Starfish, U.S. Department of Energy's Make a Splash Photo Contest*



The Pumped Storage Hydropower Valuation Guidebook outlines step-by-step valuation guidance that developers, plant owners or operators, and other stakeholders can use to assess the value of existing or potential new pumped storage hydropower plants and their services. *Photo courtesy of Consumers Energy, Ludington Pumped Storage Hydropower Facility*

New Guidebook and Tool Help Developers Calculate the Value of Potential Pumped Storage Hydropower Projects

PROJECT NAME: Valuation Guidance and Techno-Economic Studies for Pumped Storage Hydropower

PROJECT TEAM: Argonne National Laboratory (guidebook lead), Pacific Northwest National Laboratory (tool lead), Idaho National Laboratory, National Renewable Energy Laboratory, and Oak Ridge National Laboratory

LEAD RECIPIENTS' LOCATIONS: Lemont, Illinois, and Richland, Washington

To help solve challenges related to calculating the value of PSH plants and their many services, a team of U.S. national laboratories developed detailed, step-by-step valuation guidance that PSH developers, plant owners or operators, and other stakeholders can use to assess the value of existing or potential new PSH plants and their services. A team led by Argonne National Laboratory (Argonne) developed the PSH Valuation Guidebook, and a PNNL-led team created an online tool to help guidebook users navigate the valuation process.

The project team aimed to develop comprehensive and transparent guidance to support consistent valuation assessments and comparisons of PSH projects or design alternatives. To achieve this goal, the team developed a cost-benefit and decision analysis valuation framework structured as a 15-step process. The steps are grouped into four main activities highlighting the key stages of the valuation process: defining the scope of the analysis, developing valuation criteria, designing the analysis, and determining and evaluating the results. The valuation framework is designed to account for all PSH project costs and benefits, helping to determine the economic value of the project for the owner, system, and/or society as a whole. In addition, the framework allows for cost-benefit analyses to be performed from specific perspectives of different stakeholders, such as regulators and policymakers.

The PSH Valuation Guidebook was disseminated among industry stakeholders to build understanding of the true potential of this vital clean energy storage technology. The companion PSH Valuation Tool was demonstrated during the National Hydropower Association's Clean Currents conference in October 2021 and released in November 2021.

With the PSH Valuation Guidebook and Tool, key decision makers will have the resources necessary to properly evaluate new PSH or upgrade projects, leading to additional plants coming online to help decarbonize the power sector. ■

New Report and Accompanying Toolkit Highlight Hydropower's Contributions to Grid Resilience

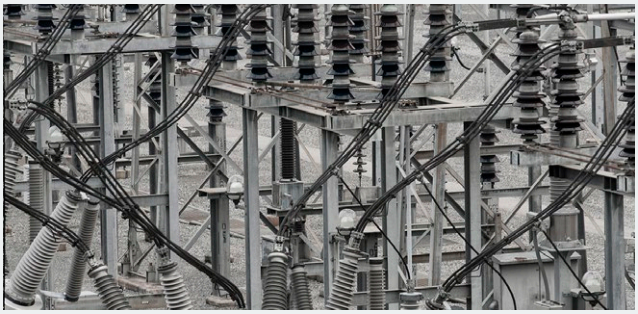
PROJECT NAME: Hydropower's Contributions to Grid Resilience

PROJECT TEAM: Pacific Northwest National Laboratory (lead), Argonne National Laboratory, Idaho National Laboratory, National Renewable Energy Laboratory, and Oak Ridge National Laboratory

LEAD RECIPIENT LOCATION: Richland, Washington

As part of the HydroWIRES Initiative, a PNNL-led team developed a report highlighting the importance of hydropower to increasing the U.S. electricity grid's resilience and enhancing its ability to respond to and recover from extreme events. An accompanying framework and toolkit also allow grid operators, regulators, and policy analysts to assess hydropower's role under various extreme grid conditions. The project team also included experts from Argonne, INL, NREL, and ORNL.

The report outlines hydropower's characteristics that enable grid resilience and identifies methods, tools, models, and data to analyze hydropower's impact on resilience. Insights from this report exemplify hydropower's essential role in stabilizing the grid after sudden, large losses of energy generation and extreme weather impacts. The report also highlights hydropower's storage capabilities and flexibility as critical assets for ensuring grid reliability during extreme weather events. ■



Hydropower can help stabilize the power grid during and after emergencies and outages—a new report examines how. *Photo courtesy of Diane Kirkland, U.S. Department of Energy's Make a Splash Photo Contest*

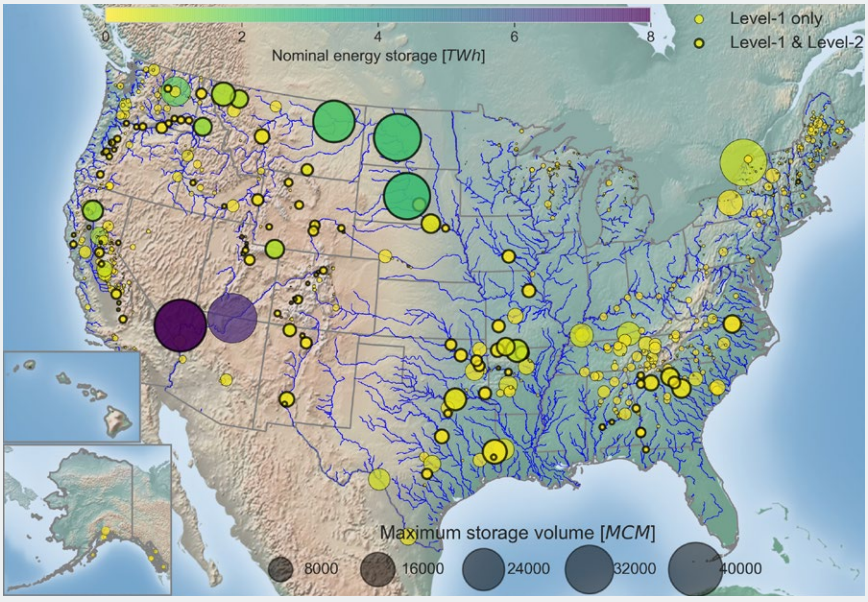
Oak Ridge National Lab Fills Critical Data Gaps in Hydropower Resource and Energy Storage Potential

PROJECT NAME: Hydropower Storage Capacity Dataset

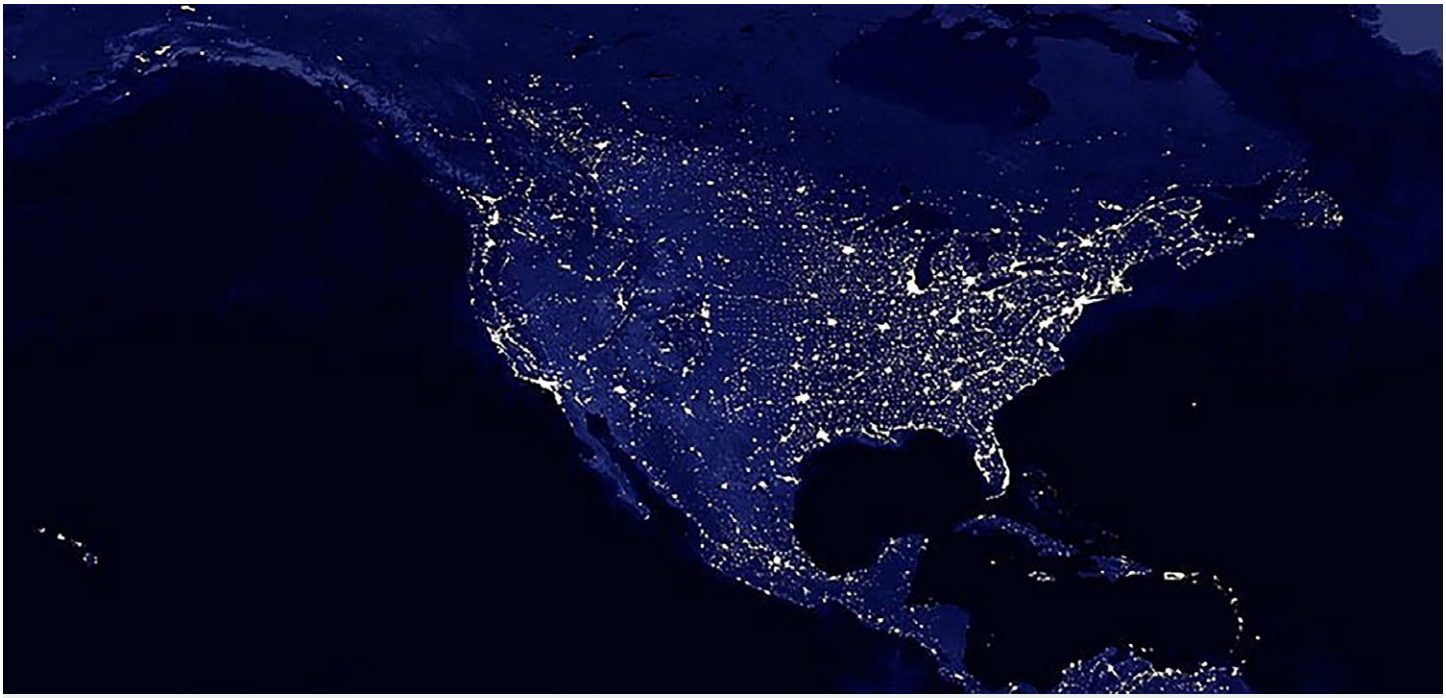
PROJECT TEAM: Oak Ridge National Laboratory

LEAD RECIPIENT LOCATION:
Oak Ridge, Tennessee

ORNL created the Hydropower Energy Storage Capacity (HESC) dataset, which combines a variety of data sources to offer a complete view of available resources at existing hydropower facilities and their energy storage potential. This dataset addresses a challenge the hydropower community has long faced accessing the centralized, accurate information needed to assess available water and energy storage at hydropower facilities in the United States. This collection of data sets a foundation for understanding available resources that could increase grid reliability and provide support for intermittent energy sources. As the HESC dataset advances, ORNL will update the platform to incorporate additional details, and use modeling and case studies to explore opportunities and limitations for conventional hydropower facilities. ■



Distribution of water and energy storage for hydropower reservoirs in the United States. *Graphic courtesy of Oak Ridge National Laboratory*



The multiyear North American Renewable Integration Study found that multiple combinations of electricity generation (including hydropower), transmission, and demand can result in 80% carbon reduction by 2050. *Graphic courtesy of the National Renewable Energy Laboratory*

New Study Assesses the Future of Renewables Across North America

PROJECT NAME: North American Renewable Integration Study

PROJECT TEAM: National Renewable Energy Laboratory, U.S. Department of Energy, and Natural Resources Canada

LEAD RECIPIENT LOCATION: Golden, Colorado

A multiyear study of the North American power grid found that increasing electricity trade and expanding transmission could have significant benefits, highlighting opportunities for a coordinated, low-carbon continental grid. The study also shows that a future low-carbon grid can be achieved through multiple pathways that can balance supply and demand using a variety of flexible resources. The North American Renewable Integration Study (NARIS), the largest study of its kind from a geographical perspective, focused on the potential role of cooperation across North America and how transmission can support sharing of supply and demand diversity across the continent.

By analyzing the entire continent in detail while studying higher renewable energy generation than previous studies, researchers learned that:

- Multiple pathways can lead to 80% power-sector carbon reduction continentwide by 2050.
- The future low-carbon system can balance supply and demand in a wide range of future conditions, with all technologies contributing to resource adequacy.
- Interregional and international cooperation can provide significant net system benefits through 2050.
- Operational flexibility comes from transmission, electricity storage, and flexible operation of all generator types, including hydropower, wind energy, solar power, and thermal power generation.

The NARIS hydropower research compared similar scenarios with and without the ability to adjust power output from U.S. and Canadian hydropower generators, showing that annual system costs are $2.3 billion (or 3%) higher without this flexibility. These results help improve the water power industry's understanding of the value of hydropower and PSH in an evolving North American grid.

Leveraging NREL's high-performance computing capabilities, NREL researchers used a suite of models to understand the impacts of renewable technology cost trajectories, emission constraints, and demand growth on key outcomes.

NARIS builds on decades of previous work studying power systems with high levels of renewable generation, including the Western Wind and Solar Integration Study, Eastern Renewable Generation Integration Study, Interconnections Seam Study, and Pan Canadian Wind Integration Study. ■

U.S. National Laboratories Contribute to Global Information Sharing on Hydropower's Role in Transitioning to a Clean Energy System

PROJECT NAME: IEA Annex IX

PROJECT TEAM: Argonne National Laboratory (lead), Pacific Northwest National Laboratory, and Oak Ridge National Laboratory

LEAD RECIPIENT LOCATION: Lemont, Illinois

A team of experts from Argonne, PNNL, and ORNL conducted a global survey and contributed case studies that formed the foundation for a report from the International Energy Agency's (IEA) Technology Cooperation Programme on Hydropower. The survey, which was conducted in 14 global markets, and seven case studies demonstrate that hydropower can provide short-term stability and long-term seasonal storage services to power systems around the world. This report showcases hydropower's key role in shifting to cleaner electricity systems, lowering carbon footprints and supporting other resources such as wind and solar, and is part of IEA's efforts to facilitate the sharing of information and best practices between countries and regions. ■

A new report showcases how hydropower can be a global backbone to a low-carbon, high-renewable-energy future. *Photo courtesy of Casey Cranston, U.S. Department of Energy's Make a Splash Photo Contest*

Known as The Marvel in the Mountain, South Carolina's Bad Creek Hydroelectric Station started operating in 1991. The pumped storage hydropower plant can hold up to 1,065 megawatts of renewable energy. *Photo courtesy of the National Hydropower Association*

National Laboratory and International Industry Organization Develop Recommendations To Enable Deployment of Pumped Storage Hydropower

PROJECT NAME: U.S. Engaging With International Partners to Promote Opportunities for Pumped Storage

PROJECT TEAM: Pacific Northwest National Laboratory

LEAD RECIPIENT LOCATION: Richland, Washington

PNNL partnered with the International Forum on Pumped Storage Hydropower to develop a series of reports on how policy and markets, sustainability, and capabilities, costs, and innovation can support or hinder the development of PSH. The team also provided key recommendations and findings based on their research.

The series of reports includes the *Working Paper on Sustainability of Pumped Storage Hydropower*, *Pumped Storage Hydropower Capabilities and Costs*, *Pump It Up: Recommendations for Urgent Investment in Pumped Storage Hydropower To Back the Clean Energy Transition*, and *Innovative Pumped Storage Hydropower Configurations and Uses*.

The policy and market working group made seven key recommendations to help ensure PSH will be deployed at the scale needed to support an efficient and reliable energy transition. These recommendations include:

- Policymakers should assess the long-term storage needs of their future power system now, so that the most efficient options, which may take longer to build, are not lost.
- Comparisons between energy storage and flexible options must follow a consistent, technology-neutral approach that considers all impacts and benefits.
- Providers of essential electricity grid, storage, and flexibility services should be remunerated for all services they provide.
- Licensing and permitting arrangements must be timely and proportionate and take advantage of the range of internationally recognized sustainability tools.
- Investors in long-lasting assets, such as PSH, must have long-term visibility of revenues with risk that is shared fairly to deliver the lowest overall cost to society in the long term.
- Existing hydropower assets and prospective sites should be assessed and mapped for their potential to provide the most efficient long-duration storage.
- Green recovery programs should include and support PSH, and green finance mechanisms should incentivize PSH.

The sustainability working group developed five key findings to illustrate the wide range of tools and methods that can help ensure PSH is sustainable. These findings include:

- PSH should be considered as a key enabler of the clean energy transition, alongside other energy storage technologies.
- The development of PSH projects should rely on a multilevel approach, including an assessment of the storage, flexibility, and ancillary services that a given power system needs and an assessment of the options available to meet those needs. Once selected, the PSH project should be managed to avoid, minimize, and mitigate social and environmental impacts.
- PSH projects are site-specific and sustainability cannot be defined by a simplistic classification. Existing sustainability tools for conventional hydropower projects are flexible and sophisticated to allow for these nuances as the application of

-continued

life cycle analysis to PSH projects is still nascent and mainly in the research domain.

- While potentially of value, specific attention must be given to the boundaries and functional units of the power system, such as the underlying energy mix. There is no evidence to suggest a material difference in greenhouse gas emissions from PSH reservoirs compared to conventional hydropower reservoirs, which fall between those of wind energy and solar power on average.
- PSH projects, as with many hydropower projects, can generate one-time or permanent local benefits, which should be considered in their sustainability assessment.

The capabilities, costs, and innovation working group found that simplistic capital expenditure comparisons could be misleading as PSH has a much longer life than many other energy storage technologies. The group also highlighted three categories with emerging innovations:

- Furthering PSH potential: Installing PSH at disused mines, underground caverns, NPDs, and conventional hydropower plants, as well as location-agnostic underground, off-river, and seawater PSH, represent vast untapped potential.
- Retrofitting and upgrading PSH systems: The latest technological advancements, such as the use of variable-speed pump turbines and hydraulic short circuit, can enhance the services provided by existing PSH.
- Developing hybrid systems: Coupling PSH with batteries, floating solar photovoltaic, heat storage, and desalination can provide additional services with reduced costs and environmental impacts. ■

FLEET MODERNIZATION, MAINTENANCE, AND CYBERSECURITY

A new digital tool is compiling real-world data from hydropower plants, so plant operators can more accurately monitor their facility's health and diagnose issues to keep their plants running smoothly. *Photo courtesy of Andy Baumgartner, U.S. Department of Energy's Make a Splash Photo Contest*

National Laboratories Advance Effort To Create Digital Models of Hydropower Systems To Support Plant Operations and Decision Making

PROJECT NAME: The Digital Twin for Hydropower Systems Project

PROJECT TEAM: Oak Ridge National Laboratory (lead) and Pacific Northwest National Laboratory

LEAD RECIPIENT LOCATION: Oak Ridge, Tennessee

As part of an effort to support digital twin technology and hydropower industry digitalization, researchers from ORNL and PNNL elicited information from hydropower stakeholders to scope digital models for hydropower systems. The goal of this effort is to collect data from real-world hydropower systems and continuously update models for various components of hydropower systems. This will allow hydropower plant operators, hydropower systems equipment manufacturers, academics, and other stakeholders to optimize real-world plant operations, test potential operations, and use real-time data for fault diagnosis and systems health monitoring.

These efforts are underway as part of a Digital Twin for Hydropower Systems–Open Platform Framework research project. Researchers also defined the appropriate scope for the framework and published a value proposition to help developers determine the economic benefit of a hydropower project.

Once the framework is online, users can develop unique digital twins for their systems. With continuous data and feedback, the Digital Twin for Hydropower Systems–Open Platform Framework can develop capacities for autonomy to learn from and reason about its environment, creating a continuously evolving digital profile of physical hydropower assets and processes.

As the hydropower industry moves toward full-scale digitalization, the long-term vision of this project is to support widespread adoption of a Digital Twin for Hydropower Systems–Open Platform Framework as a best practice for the design, operation, and management of hydropower assets. This effort will help the U.S. hydropower industry enhance reliability, performance, and value, and continue to serve as an integrated piece of the country's power grid. ■

ENVIRONMENTAL AND HYDROLOGIC SYSTEMS SCIENCE

A new tool can help hydropower developers and operators assess how to protect fish and their bottom line, too. *Photo courtesy of Karl Specht, U.S. Department of Energy's Make a Splash Photo Contest*

HydroPASSAGE Transfers Fish Survival Tools to the Hydropower Community

PROJECT NAME: HydroPASSAGE

PROJECT TEAM: Pacific Northwest National Laboratory (lead) and Oak Ridge National Laboratory

LEAD RECIPIENT LOCATION: Richland, Washington

In Fiscal Year 2021, the HydroPASSAGE project team from PNNL and ORNL expanded the use of two toolsets—the Biological Performance Assessment (BioPA) toolset and Hydropower Biological Evaluation Toolset (HBET)—developed to advance hydropower facility design to benefit both fish survival and hydropower operations.

The HydroPASSAGE team produced materials and conducted outreach activities—including best practices documents, instructional videos, and customized workshops—to engage with hydropower facility owners, turbine manufacturers, resource agencies, and other stakeholders that can use the information and toolsets to increase fish survival through turbines and past dams.

The BioPA toolset uses computational models to evaluate the relative impact that passage through a given hydropower turbine can have on a species of fish. This allows users to provide the specifics of a given turbine system and calculate a numerical score of its potential rate of fish injury and mortality. HBET provides similar information, but its findings are based on data collected by field-based sensors that are sent through hydropower facilities to determine the potential injury or mortality of a given species of fish.

The HydroPASSAGE team held 20 customized workshops for current and potential users of the tools, quadrupling its goal of five workshops. The team took its work to the international stage, speaking with representatives from not only the United States, but also from Europe, Australia, South America, and Asia. This effort focused on increasing the number of tool users and resulted in a doubling of executed licenses.

Biological response data gathered by PNNL and ORNL researchers and others was integrated into the BioPA toolset and HBET for more than 20 species of fish including adult American eel, juvenile Chinook salmon and juvenile American shad. A comprehensive technical report published in February 2021 summarized information on how these species respond to the physical conditions found within hydropower turbines.

As the HydroPASSAGE project concludes, these resources will remain publicly available to the hydropower community to support their decision making around the design and operation of hydropower facilities by clarifying design requirements, constraints, and methods to evaluate and improve fish passage. ■

DATA ACCESS, ANALYTICS, AND WORKFORCE DEVELOPMENT

Permitting and federal authorization processes can increase the costs, risks, and timelines of licensing (or relicensing) hydropower projects, like Washington's Ross Lake Dam (pictured here). Now, a new report examines which factors affect this process and how. *Photo courtesy of Pablo McLoud, U.S. Department of Energy's Make a Splash Photo Contest*

New Report Examines the U.S. Hydropower Permitting Process

PROJECT NAME: An Examination of the Hydropower Licensing and Federal Authorization Process

PROJECT TEAM: National Renewable Energy Laboratory (lead), Oak Ridge National Laboratory, and Kearns & West

LEAD RECIPIENT LOCATION: Golden, Colorado

In October 2021, NREL and ORNL published a report, *An Examination of the Hydropower Licensing and Federal Authorization Process*, that examines the factors that have the greatest impact on the hydropower licensing process. Although the report does not propose any specific recommendations to change the current hydropower licensing and authorization process, the findings will aid decision makers in identifying areas for potential reform. It is also intended to help policymakers, regulators, and other key decision makers—including the Federal Energy Regulatory Commission (FERC), U.S. Army Corps of Engineers, federal land management agencies, federal and state resource agencies, and Indian tribes—engage in informed discussions with hydropower industry stakeholders such as utilities, developers, consultants, trade associations, and nongovernmental organizations.

The report's key findings are:

- Greater environmental complexity can lead to longer licensing timelines, especially for relicensing.
- Licensing costs often disproportionately impact new and/or smaller projects.
- Disagreements in negotiations over environmental studies can prolong licensing timelines.
- Incomplete and/or inadequate information can result in longer licensing timelines and disagreements.
- The Integrated Licensing Process has the shortest and least variable timeline of the three licensing processes.
- The hydropower permitting process differs between countries and with other national energy or water infrastructure processes.
- The U.S. hydropower licensing process can improve environmental coexistence with hydroelectric plants.

In the next two decades, more than 600 hydroelectric projects' licenses will expire. If those projects fail to be relicensed, the United States will lose the amount of clean energy needed to power about 5.5 million homes—equivalent to the entire state of Pennsylvania. Further, DOE estimates that new and modernized hydropower projects could grow from 101 to nearly 150 gigawatts of hydroelectricity and storage capacity by 2050. These new findings about the hydropower licensing and relicensing process can help speed progress toward a clean energy future. ■

New STEM Curricula Pumps Up the Future Hydropower Workforce

PROJECT NAME: STEM and Workforce Development for Hydropower

PROJECT TEAM: National Renewable Energy Laboratory (lead), the National Energy Education Development Project, and KidWind

LEAD RECIPIENT LOCATION: Golden, Colorado

The long-established hydropower industry needs to revitalize its workforce and develop high-demand skills to meet growing U.S. energy demand. In Fiscal Year 2021, NREL, with funding from WPTO, collaborated with the National Energy Education Development (NEED) Project to create a hydropower curriculum that helps primary, elementary, intermediate, and secondary students learn about the water cycle, kinetic energy transformations, and electricity. NEED held an initial workshop to introduce the curricula to educators and will make regular updates based on feedback. The curriculum and other hydropower educational resources are available on NREL's Hydropower Science, Technology, Engineering, and Mathematics (STEM) portal.

Also in Fiscal Year 2021, NREL supported KidWind in developing the first hydropower-focused "teach the teacher" training session, which provided an introduction to modern hydropower and sample hydropower learning activities for primary, elementary, intermediate, and secondary educators to implement in their classrooms. The session was part of the 2021 Virtual RECharge Academy, KidWind's flagship educator training program focused on renewable energy. ■

The National Renewable Energy Laboratory collaborated with the National Energy Education Development Project to create a hydropower curriculum that helps primary, elementary, intermediate, and secondary students learn about the water cycle, kinetic energy transformations, and electricity. *Photo courtesy of the National Energy Education Development Project*

HydroSource Data Platform Offers Additional Data Sets, Tools, and Resources

PROJECT NAME: HydroSource

PROJECT TEAM: Oak Ridge National Laboratory

LEAD RECIPIENT LOCATION: Oak Ridge, Tennessee

Researchers from ORNL made significant enhancements to the HydroSource data-housing application over the past year, implementing 20 new data sets and tools to help stakeholders better understand hydropower data. Researchers published the HydroSource Data Explorer, which simplifies exploration and visualization of data sets housed in the application. ORNL also hosted a successful workshop to collect feedback on the HydroSource Data Story and published interactive visualizations on basin-scale relicensing. The HydroSource team also collaborated with the Internet of Water, a nonprofit focused on expanding access to water data repository, to add HydroSource to its existing archive of data hubs.

Recent enhancements to HydroSource allow various hydropower stakeholders—including researchers, developers, government agencies, nongovernmental organizations, academia, and policymakers—to make more informed decisions.

The HydroSource project, spearheaded by ORNL, is a comprehensive digital platform housing all publicly available hydropower-related data sets. The hydropower industry and decision makers can use HydroSource in a variety of ways, such as to inform policy decisions, increase transparency about hydropower projects, support analysis of hydropower operations, enable research, assess the potential for new project development, develop new tools for data-driven environmental assessment, and inform environmental permitting and mitigation. ■

The HydroSource project is a comprehensive digital platform housing all publicly available hydropower-related data sets. *Photo courtesy of Katelynn English and Kimberelee Craig, U.S. Department of Energy's Make a Splash Photo Contest*

New Tool To Support Hydropower Licensing Released for Testing

PROJECT NAME: Environmental Decision Support: Science-Based Tools for Hydropower Stakeholder Collaboration

PROJECT TEAM: Oak Ridge National Laboratory (lead), Kearns & West, a mission advisory board, and a science advisory board

LEAD RECIPIENT LOCATION: Oak Ridge, Tennessee

Over the past year, ORNL led a project team that developed a new tool—an online, interactive, and science-based River Function Indicator Questionnaire—to provide hydropower stakeholders with a systematic and transparent method for identifying the potential environmental impacts of a hydropower project. The tool's questions address a checklist of 42 river function indicators derived from an extensive literature review of environmental metrics. This review integrated the viewpoints of multiple types of hydropower stakeholders and the scientific research community. Stakeholders—including a hydropower owner/operator, several environmental nongovernmental organizations, and a federal agency—are currently conducting pilot tests in New Hampshire, Vermont, and Kansas.

Most privately owned U.S. hydropower facilities are required to obtain an operating license from FERC. This licensing process is heavily stakeholder driven and typically takes five to seven years per project. During the study negotiation phase of the licensing process, environmental and energy stakeholders, as well as regulators from tribal, state, and federal agencies, must collaboratively determine the proposed project's impacts and whether any additional studies or mitigation will be required. Applicants have indicated this is one of the most challenging parts of the FERC licensing process due to the diverse priorities and perspectives among hydropower stakeholders, which can lead to communication breakdowns and delays. The new River Function Indicator Questionnaire, part of the Environmental Decision Support Toolkit, is designed to support hydropower stakeholders during the licensing process by giving everyone at the negotiating table a standardized set of metrics. ■

Environmental regulations are essential to protect the health of the country's waterways and wildlife. Now, a new tool provides hydropower developers with clear, easy-to-navigate information on these regulations to help speed hydropower development and protect the environment, too. *Photo courtesy of Rafael Kaup, U.S. Department of Energy's Make a Splash Photo Contest*

Researchers Highlight Needs and Opportunities To Improve Access to Water Data

PROJECT NAME: Improving Discovery, Access, and Usability of Data for Basin-Scale River Management

PROJECT TEAM: Pacific Northwest National Laboratory (lead), Oak Ridge National Laboratory, Stanford Woods Institute for the Environment, University of New Hampshire, and University of Maine

LEAD RECIPIENT LOCATION: Richland, Washington

In May 2021, a team from PNNL, ORNL, and three universities concluded a two-year project with a workshop on the opportunities and issues surrounding discoverability, access, and usability of data needed for U.S. river basin management. This workshop, along with a series of "data stories"—visual, interactive, and data-driven stories, such as a dive into water management efforts in Wisconsin or an overview of hydropower in the Penobscot River—is the culmination of a project focused on understanding the challenges of improving access to water data for decision making.

Decision-making processes for water resource management are data hungry due to increasing uncertainty about the effects of climate change, energy needs, water use, ecosystem health, and other factors. Many entities maintain this data or it can be part of other data sources, making it difficult to discover, access, and use. The team hosted the workshop to share project results and discuss water data needs with a diverse group of stakeholders from across the hydropower and broader water management community, including federal and state agencies, tribes, nongovernmental organizations, academia, and industry.

In highlighting the importance of accessible and usable water data, the team seeks to build support among key water data producers and consumers to form alliances and support broader initiatives to improve access to data. This will allow for more informed decision-making processes when it comes to clean energy and water management. ■

NOTABLE FISCAL YEAR 2021 INVESTMENTS

Hydropower can serve the nation's evolving power system in far more ways than just energy production. In 2021, WPTO invested in three projects that examined new hydropower opportunities. *Photo courtesy of Casey Cranston, U.S. Department of Energy's Make a Splash Photo Contest*

WPTO Selects Industry Partners for Technical Assistance Projects To Further Understand Hydropower's Value to the Evolving Power Grid

PROJECT NAME: Selections for Notice of Opportunity for Technical Assistance: Improving Hydropower's Value through Informed Decision Making

SELECTEES: Great River Hydro, LLC; Idaho Power Company; and Energy Exemplar

SELECTEE LOCATIONS: Westborough, Massachusetts; Boise, Idaho; and Salt Lake City, Utah

In July 2021, WPTO selected three industry partners for a notice of opportunity for technical assistance for improving hydropower's value through informed decision making. The selected partners include Great River Hydro, LLC, Idaho Power Company, and Energy Exemplar.

The Great River Hydro, LLC project team will assess the value of inflow forecasting tools and practices associated with hydropower generating resources on the Connecticut River in New Hampshire and Vermont. Meanwhile, the Idaho Power Company project team will identify hydrogen production technologies that could be effectively deployed at a hydropower facility to meet energy storage capacity needs and potentially use the oxygen byproduct to help mitigate water quality conditions. Finally, the Energy Exemplar project team seeks to strengthen the capability of energy production models to assess economic impacts of hydropower capabilities, as well as peripheral impacts, such as bringing more renewables online, electric vehicle adoption, natural gas, energy storage, and other transmission impacts.

This work can equip these organizations, and the clean energy community broadly, with further understanding of how hydropower can most effectively support an evolving power system. The selected partners will begin their technical work with PNNL and INL in 2022. ■

Marine Energy

Marine Energy Program Overview

Marine energy resources—such as wave, tidal, and ocean and river currents—are abundant, geologically diverse, energy dense, predictable, and complementary to other renewable energy sources. Marine energy technologies are at an early stage of development because of the fundamental challenges of generating power from a dynamic, low-velocity, and high-density resource while withstanding corrosive marine environments. High costs and lengthy permitting processes associated with in-water testing intensify these challenges.

The Marine Energy Program (formerly the Marine and Hydrokinetics Program) within WPTO conducts transformative research that advances the development of reliable, cost-competitive marine energy technologies and reduces barriers to deployment. The program's vision is a U.S. marine energy industry that expands and diversifies the nation's energy portfolio by responsibly delivering power from ocean and river resources.

To achieve this mission and vision, the Marine Energy Program comprises four core R&D activity areas and one initiative, which represent the program's strategic approach to addressing the challenges facing U.S. marine energy stakeholders. Success stories in the WPTO 2020–2021 Accomplishments Report are presented within these areas:

- Foundational R&D
- Technology-Specific System Design and Validation
- Reducing Barriers to Testing
- Data Access, Analytics, and Workforce Development
- Powering the Blue Economy™.

Readers can learn more about the Marine Energy Program and its projects by visiting the WPTO website, subscribing to the Water Wire and Water Column newsletters, and exploring the WPTO Projects Map.

FOUNDATIONAL R&D

Developed by national laboratory researchers, Wave Energy Converter SIMulator can be used to simulate the ocean for more than marine energy purposes. One example is the Orion Crew Module Uprighting System, which was designed to inflate five airbags after the spacecraft and its crew splash down upon returning from deep-space missions, enabling the capsule to upright itself. *Photo courtesy of NASA*

Open-Source Wave Energy WEC-Sim Software Receives R&D 100 Award and Contributes to Space Exploration

PROJECT NAME: Wave Energy Converter SIMulator (WEC-Sim)

PROJECT TEAM: National Renewable Energy Laboratory (lead) and Sandia National Laboratories

LEAD RECIPIENT LOCATION: Golden, Colorado

Wave energy holds the largest theoretical power for the United States, and a substantial amount of ongoing marine energy research and development is focused on designing and building wave energy converters (WECs) that work efficiently, reliably, and robustly in the ocean's dynamic environment. But the ocean and wave environment can lead to substantial uncertainty and increase costs, which makes the commercialization of WECs that much more challenging. The Wave Energy Converter SIMulator (WEC-Sim), which received a 2021 R&D 100 Award, is an open-source software tool developed by NREL and Sandia National Laboratories (Sandia) that can help developers simulate their early-stage designs using a robust modeling platform. In 2020 and 2021, the WEC-Sim team released several updates to the software (v4.2 in December 2020, v4.3 in July 2021, and v4.4 in October 2021).

WEC-Sim provides versatility for a broad range of WECs, device components, and scenarios. It can model devices made of rigid or flexible bodies, joints, power take-off (PTO) systems, and mooring systems. The computer simulation models the forces on floating objects and calculates their dynamic behavior. Numerical simulations using WEC-Sim can reduce development time and lower costs, allowing stakeholders to refine and optimize their floating concepts before deployment in the water for physical trials—whether that be an expensive wave tank or an unpredictable ocean testing site—preparing for real-world deployment faster.

WEC-Sim became available as part of the Testing Expertise and Access for Marine Energy Research (TEAMER) program, supporting multiple selectees from TEAMER's requests for technical support. For example, Ocean Motion Technologies used WEC-Sim to model and improve its engineering efforts and is now able to advance quickly to wave-tank and open-water testing in the next year. The tool also helped stakeholders worldwide, including United Kingdom-based Marine Power Systems and Italy-based Ente Nazionale Idrocarburi.

The WEC-Sim team continues to explore differences between computer simulations and experimental measurements through its participation in the IEA's Offshore Code Comparison Collaboration, Continued, with Correlation and unCertainty (OC6) research project. Over four years, this project will validate tools used in the design of offshore wind systems. The third of the project's four phases was completed in early 2021.

Not only is WEC-Sim advancing marine energy technologies, but it is also helping to ensure the safety of the future crew of NASA's Artemis I mission. NASA and Lockheed Martin are using WEC-Sim to help ensure the Orion crew module lands upright upon its return to Earth. Researchers are using WEC-Sim to model forces on and the motion of the crew module in the ocean. This work will help prevent the crew module from landing upside down, a position that can submerge hatch doors and communications antennae and impede recovery operations.

WEC-Sim is already supporting wave energy device designs and NASA missions; soon, the motion of the ocean could be powering offshore activities, island communities, and coastal populations with clean energy, thanks in part to WEC-Sim-tested devices. ■

AquaHarmonics Completes First Industry Developer Testing at Sandia Wave Energy Power Take-Off Lab

PROJECT NAME: AquaHarmonics Testing Support

PROJECT TEAM: Sandia National Laboratories (lead) and AquaHarmonics

LEAD RECIPIENT LOCATION: Albuquerque, New Mexico

WECs use the motion of waves to generate electricity and so require unique testing facilities that can recreate those rhythmic but highly varied motions. At one of those specialized facilities, located at Sandia, Oregon-based AquaHarmonics tested its PTO system, the part of the device that produces electricity from the mechanical energy the WEC collects. This marked the first test by an industry developer at the Sandia Wave Energy Power Take-Off (SWEPT) Lab. SWEPT recreates the dynamics and interactions of waves using hydraulic actuators and a dynamics tracking control system that allows for real-time control, reliability analysis, system identification, and grid interface simulations. The SWEPT Lab was designed, developed, and commissioned in 2021, leveraging internal investment from Sandia and knowledge gained from the WPTO-funded Next-Generation WEC Power Take-Off Co-Design project.

The SWEPT Lab test helped confirm the capabilities of AquaHarmonics' WEC components and refine numerical models, which will be used to further improve the economics of the device. With the results of this test, AquaHarmonics will next deploy a scaled-up prototype of its WEC device at Hawaii's Wave Energy Test Site to validate operation in an open-ocean environment. ■

The Sandia Wave Energy Power Take-Off Lab simulates the motions and interaction of ocean waves, which offered AquaHarmonics the ability to test its power take-off system. The results will help prepare for the next step in testing, which involves testing a scaled-up version of the company's wave energy converter in Hawaii's open ocean. *Photo courtesy of Sandia National Laboratories*

Wave-Powered SeaRAY Completes On-Land Preparation Before Offshore Trial

PROJECT NAME: C-Power's SeaRAY Autonomous Offshore Power System Validation at the National Renewable Energy Laboratory

PROJECT TEAM: C-Power (lead) and National Renewable Energy Laboratory

LEAD RECIPIENT LOCATION: Charlottesville, Virginia, with work completed in Arvada, Colorado

Offshore work, like marine research and aquaculture, can require significant amounts of energy. Now, an autonomous, wave-powered, renewable energy device—called the SeaRAY autonomous offshore power system—could power a variety of offshore industries and missions and help protect the oceans and climate, too. To help prepare the C-Power-designed SeaRAY for its first ocean trial in Hawaii, researchers at NREL outfitted the device with a customized Modular Ocean Data Acquisition (MODAQ) system, which collects, stores, and transmits precise field data.

Originally designed to standardize and increase the quality and breadth of field data collection, the first MODAQ could do basic data acquisition and condition monitoring (meaning it kept track of how a wave energy device performed). SeaRAY's MODAQ not only collects field data, but it also sends information to the cloud and connects to the web. That means handlers can monitor SeaRAY live, receive data on how a device is functioning, and even control those functions from afar. ■

Andrew Simms smiles as he stands over the SeaRAY autonomous offshore power system's Modular Ocean Data Acquisition system, which he and other National Renewable Energy Laboratory researchers built to give remote operators the ability to control the SeaRAY device and receive data from the vehicles it powers. *Photo courtesy of the National Renewable Energy Laboratory*

The Water Power Technologies Office supports collaboration among its national labs and the marine energy industry to deliver the resource data necessary to design the next generation of marine energy technologies. *Photo courtesy of the National Renewable Energy Laboratory*

Labs Release New Data and Report on the Powerful Potential of U.S. Marine Energy Resources

PROJECT NAME: Marine Energy Resource Assessment and Characterization

PROJECT TEAM: National Renewable Energy Laboratory (lead), Pacific Northwest National Laboratory, and Sandia National Laboratories

LEAD RECIPIENT LOCATION: Golden, Colorado

Understanding the potential for marine energy in the nation's oceans requires analysis to detail the theoretical potential of wave, tidal, current, ocean thermal, and river hydrokinetic resources. With support from WPTO, a multilab team of oceanographers, engineers, and data scientists this year produced a comprehensive report detailing renewable marine energy resources.

Motivated by its pioneering work on the importance of turbulence in wind turbine design, the team developed new measurement systems that produce the marine resource statistics needed for tidal, current, and wave energy device design. In 2021, the team—made up of staff from NREL, PNNL, and Sandia—published a report detailing the latest resource estimates based on new datasets and made these new datasets publicly available in an online mapping tool.

In February 2021, the labs released *Marine Energy in the United States: An Overview of Opportunities*, a technical report summarizing the location and quantity of utility-scale wave, tidal and ocean current, ocean thermal, and river hydrokinetic resources in the United States. The information presented in the report will help improve understanding of the locations and characteristics of marine energy resources and how they might contribute to the future energy portfolio of the United States. The analysis from this study can help developers design the next generation of marine energy devices.

Datasets cited in this report can be found in the Marine Energy Atlas, an interactive mapping tool that explores the potential for marine energy resources in the United States In 2021, this publicly accessible tool was updated with a new high-spatial-resolution ocean surface wave hindcast dataset. Developed by a team led by NREL with PNNL, Sandia, North Carolina State University, and University of Hawaii, the new dataset provides a more complete accounting of how U.S. wave energy totals are estimated.

The Marine Energy Atlas also received several other updates this year in the form of new features designed to enhance the user experience, including a filterable and searchable data library; new data layers, including wave models for Pacific, Atlantic, and Hawaiian regions; and back-end upgrades that increase performance for on-the-fly visualization of high-resolution datasets.

The Marine Energy Atlas can help technology designers determine how well their devices are suited for a particular part of the ocean and project developers identify promising sites for building wave energy farms. By making this valuable data available to the public, the atlas can help the marine energy industry chart a smooth course forward. ■

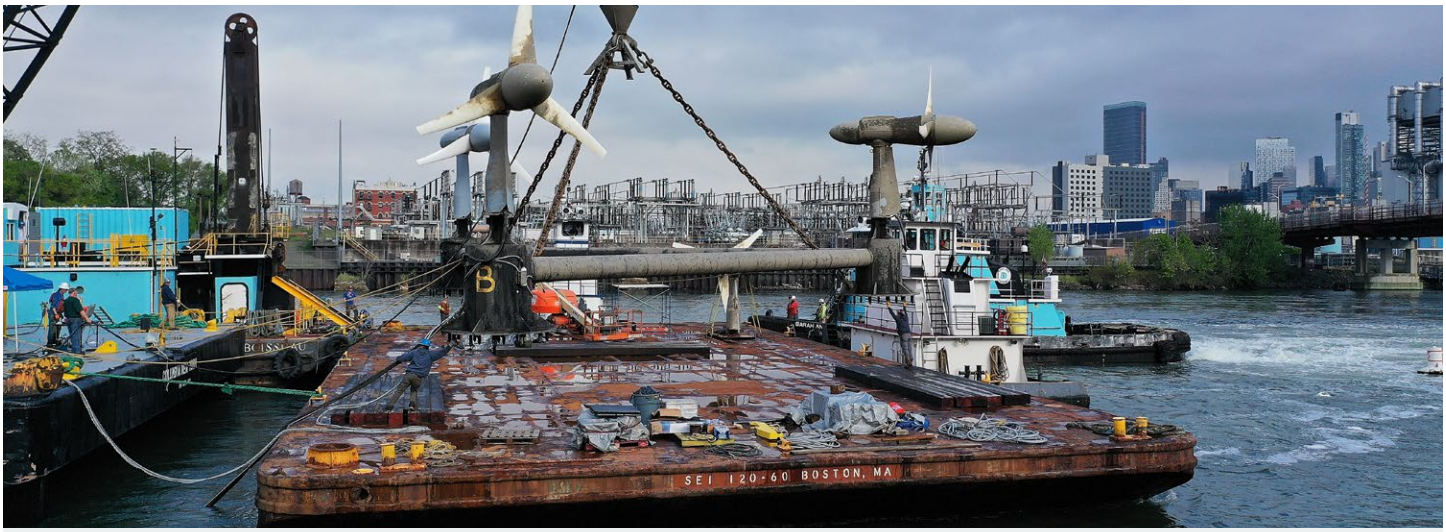
Inaugural R&D Showcase Cultivates Awareness of Novel Projects at National Labs

PROJECT NAME: Seedling Water Power Innovation and R&D Showcase

PROJECT TEAM: Pacific Northwest National Laboratory, National Renewable Energy Laboratory, Sandia National Laboratories, Argonne National Laboratory, Oak Ridge National Laboratory, and Idaho National Laboratory

On Aug. 11, 2021, WPTO hosted a virtual showcase in which researchers from the DOE national labs presented the projects they conducted through the Seedlings Program. This program, which WPTO established in 2019, has provided more than 60 smaller funding awards to national lab researchers—often junior researchers—to explore new projects and creative ideas in marine energy and hydropower. During the four-hour event, 41 researchers presented 39 projects and their solutions, failures, and lessons to an audience of more than 150 attendees that included peers, WPTO staff, industry stakeholders, and the general public. By providing a platform for researchers to exhibit their work, the showcase increased the visibility of several projects led by DOE's national laboratories and WPTO's novel funding mechanism. ■

Under the Water Power Technologies Office's Seedlings Program, researchers explore new ideas and unproven concepts in water power. The Seeding Water Power Innovation and R&D Showcase gave researchers the chance to share work they'd conducted under the Seedlings Program with peers, Water Power Technologies Office staff, other lab staff, and the general public. *Photo courtesy of David Becker, Unsplash*



In May 2021, Verdant Power performed a retrieve-and-replace operation, during which one of the turbine rotors was replaced with a rotor comprising three thermoplastic blades manufactured by the National Renewable Energy Laboratory. *Photo courtesy of Drone Altitude*

Tidal Power Turbine Demonstrates Thermoplastic Blades

PROJECT NAME: Manufacturing and Testing of Thermoplastic Composite Turbine Blades

PROJECT TEAM: National Renewable Energy Laboratory (lead) and Verdant Power

LEAD RECIPIENT LOCATION: Arvada, Colorado, and New York, New York

In June 2021, Verdant Power, a U.S. tidal energy company, announced it had produced more power than any other marine energy project in the United States to date, but that was not the only first for this project. In collaboration with Verdant Power, researchers from NREL constructed and validated the performance and durability of thermoplastic composite blades on Verdant Power's tidal turbines in New York City's East River. This was the first time thermoplastic composite blades had been applied to a large-scale tidal power turbine. These materials have the potential to revolutionize the marine energy industry by improving performance and sustainability, and can make the manufacturing process faster and more energy efficient.

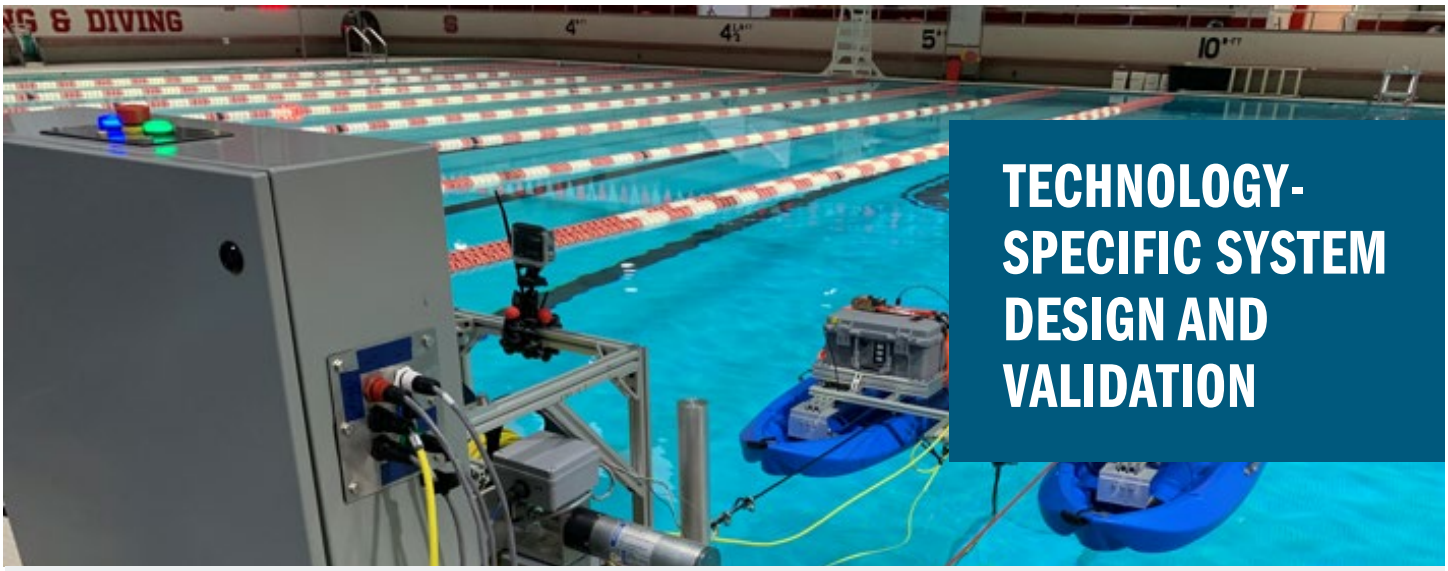
In October 2020, Verdant Power's TriFrame mount, which holds three three-bladed underwater tidal turbines, was installed at the Roosevelt Island Tidal Energy project site in New York City's East River. With strong tidal currents that change direction multiple times per day, the river offers an ideal location for demonstrating the performance of marine energy turbines. During their first six months in the water, the tidal turbines, which featured thermoset epoxy resin blades, generated more than 275 megawatt-hours of energy—a U.S. record for marine energy production.

The project's next step was to determine how the same tidal turbines would perform with thermoplastic composite blades. Using blade tooling and geometry details provided by Verdant Power, NREL researchers working at the lab's Composites Manufacturing Education and Technology Facility produced full-scale thermoplastic composite blades nearly identical to the traditional thermoset epoxy blades initially used on the TriFrame mount.

By swapping one set of the thermoset epoxy resin blades in the TriFrame mount with thermoplastic composite blades manufactured by NREL, researchers could compare the underwater performance of each type of blade. Thermoplastic composite blades have shown improved structural properties when submerged and have the potential to be recycled and reused at the end of their lives. The research will confirm whether the innovative thermoplastic composite blades experience less structural degradation in water than traditional thermoset epoxy resin blades.

In May 2021, the Verdant Power team raised the TriFrame out of the river and replaced the thermoset epoxy resin blades on one of the tidal turbines with three new, NREL-manufactured thermoplastic composite blades. In October 2021, the Verdant Power team once again raised the TriFrame out of the river—this time retrieving NREL's thermoplastic composite blades. During the underwater deployment, the thermoplastic composite blades produced the same amount of energy as the thermoset epoxy resin blades.

Next, the team will measure the blades' structural properties to determine the impact of seawater on the thermoplastic materials. NREL's research demonstrates the potentially game-changing thermoplastic composite material for marine applications at a meaningful scale. ■



During the 2021 pool test, researchers used a computer to control and monitor the kite's performance as two blue structures floating on the pool's surface pulled the device along the length of the pool. *Photo courtesy of North Carolina State University*

Successful Test of New Underwater Kite To Generate Energy from Slow-Moving Waters

PROJECT NAME: Device Design and Robust Periodic Motion Control of an Ocean Kite System for Hydrokinetic Energy Harvesting

PROJECT TEAM: North Carolina State University (lead), East Carolina University, Florida Atlantic University, and University of Maryland

LEAD RECIPIENT LOCATION: Raleigh, North Carolina

The ocean packs great speed and power—but not everywhere. Offshore work, such as marine research and undersea military missions, must go where missions dictate. However, these locations may not always be where the highest energy flows. That can be a problem for the budding marine energy industry. Now, a flying underwater kite—developed through a collaboration between North Carolina State University, East Carolina University, Florida Atlantic University, and the University of Maryland—could harness and store energy from even slow-moving currents. Built with far less material—and, therefore, at a lower cost—the kite flies underwater figure eights to generate substantially more energy per unit mass than some other marine energy designs.

The flying underwater kite was designed to deliver much-needed power even in relatively energy-poor environments. To validate performance, the research team first conducted trials at the North Carolina State University pool in spring 2021. These tests provided critical data on how to optimize the kite's geometry and power system for enhanced energy production. In the fall, the team tested its endurance in the first of a series of two tests in North Carolina's Lake Norman. During these tests, the team flew the kite for hours and miles at a time. These trials will help the researchers refine their design, so it could soon power even more than remote, offshore work. In the future, farms of near-shore kites could provide coastal and island communities with clean, reliable, renewable energy. ■

Researchers Test Model of New Floating Oscillating Surge Wave Energy Converter

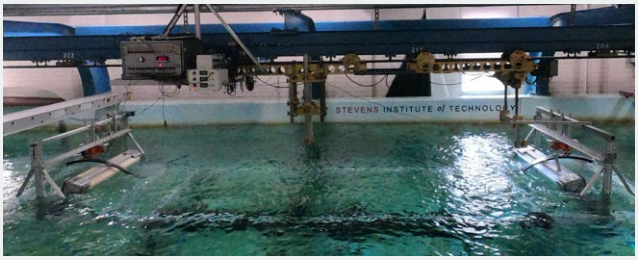
PROJECT NAME: Floating Oscillating Surge Wave Energy Converter Using Controllable Efficient Power Take-Off System

PROJECT TEAM: Stevens Institute of Technology (lead), Virginia Tech, Resolute Marine Energy, Sandia National Laboratories, and National Renewable Energy Laboratory

LEAD RECIPIENT LOCATION: Hoboken, New Jersey

Floating oscillating surge wave energy converters (FOSWECs) can transform the energy from ocean waves into usable power without needing to be fixed to the seafloor, enabling them to be deployed in deeper waters and avoid impacting the underwater environment. However, these unique devices require specific facilities for testing. Now, researchers from Stevens Institute of Technology, Virginia Tech, and Resolute Marine Energy have tested a one-tenth-scaled model of their new FOSWEC design using the physical and numerical marine testing capabilities at the Davidson Laboratory and DOE funding. The FOSWEC design is an improvement to the prior national lab-developed Reference Model 5 and consists of a floating platform, two pivoting flaps, and an innovative, out-of-water PTO system.

The tests validated the responses of the flaps that operate out of sync and help in stabilizing the FOSWEC, the need to control the platform mooring because of its potentially significant negative impact on the flaps' motions, and the importance of quality control in the manufacturing process of different components (e.g., the belts of the PTO system) to ensure optimal performance. The team is also working closely with Sandia on control co-design and NREL on PTO testing using its dynamometer. Next, working with NREL with funding from the TEAMER program through its second request for technical support, the team will leverage the lab's modeling expertise on mooring systems. Through these collaborations, the team is advancing the FOSWEC device design and moving one step closer to the goal of building and deploying an efficient 1:2-scaled device with low levelized cost of energy. ■



A two-flap floating oscillating surge wave energy converter is tested. The tests demonstrated the out-of-phase-motion of the two flaps resulted in reduced loads and motions of the supporting platform, which reduces the cost of deployment in deep water. *Photo courtesy of Stevens Institute of Technology*

United States Contributes to New International Marine Energy Standards

PROJECT NAME: Standards Development for Marine Energy

PROJECT TEAM: National Renewable Energy Laboratory (lead); Sandia National Laboratories; Pacific Northwest National Laboratory; Verdant Power; British Standards Institute; Resolute Marine; PB Mechanical Consulting Service, LLC; and Cardinal Engineering

LEAD RECIPIENT LOCATION: Golden, Colorado

The International Electrotechnical Commission (IEC) Technical Committee 114 for Marine Energy Systems (TC114) develops standards and completes conformity assessments for marine energy systems. In Fiscal Year 2021, the committee published the first edition of IEC Technical Specification 62600-202 on scale testing of tidal stream energy systems and the second edition of IEC Technical Specification 62600-10 on the assessment of mooring systems for marine energy converters. The project team, led by NREL, recruited subject-matter experts to develop these documents and provided them with the resources needed to publish documents. In addition, the team managed the U.S. review process for all committee documents and provided feedback to the international teams. Finally, the team supported the United States-led effort to revise the TC114 Strategic Business Plan with the goal of updating the priorities for TC114 and identifying new work items that should be initiated in the next few years. These activities help the most promising marine energy technologies achieve commercialization by providing a foundation for certification, promoting international trade of uniform high-quality products, and supporting the transfer of expertise from traditional energy system. ■

The retrieved RivGen 2.0 (foreground) and the ready-for-deployment RivGen 2.1. Eventually, RivGen 2.0 will be installed downstream of 2.1, providing even more energy to the local community. *Photo courtesy of Igiugig Village Council*

River Currents Power Remote Alaskan Village

PROJECT NAME: Next-Generation River Power System

PROJECT TEAM: Igiugig Village Council (lead), Ocean Renewable Power Company, University of Alaska Fairbanks, National Renewable Energy Laboratory, and Pacific Northwest National Laboratory

LEAD RECIPIENT LOCATION: Igiugig, Alaska

For the past 50 years, the Alaska Native village of Igiugig on the Kvichak River has depended on diesel fuel to power its homes and businesses, making the community dependent on a costly and sometimes unpredictable fuel delivery network. But in 2021, village members partnered with Maine-based Ocean Renewable Power Company to retrieve their first river energy device from the Kvichak River for maintenance and—with support from DOE's Office of Indian Energy—deployed a second device, marking important progress in the village's goal to quit diesel by 2025.

These recent activities build on a partnership among WPTO, the Igiugig Village Council, the state of Alaska, and Ocean Renewable Power Company to design and install a device that could generate energy from currents in the Kvichak River and help to reduce the village's dependency on diesel fuel. As of 2021, this fully submerged 35-kilowatt river energy device, called the RivGen Power System, is the longest operating current energy converter in the United States and can provide nearly half of the village's energy needs.

Critical to the success of Igiugig's transition to clean energy is the experience and training of local community members during every stage of the project, including deployment, operations, maintenance, and retrieval of the RivGen system, which is 51.5 feet long, 46.9 feet wide, and 11.5 feet tall. As soon as summer 2022, both RivGen systems will operate concurrently, providing even more energy to the local community.

This project is one of the first long-term operational deployments of a river current device in the United States and has resulted in numerous collaborations with national laboratories and universities, including NREL, PNNL, University of Alaska Fairbanks, University of Washington, and University of Maine. Igiugig is also the first tribal entity to receive a FERC permit for a hydrokinetic project. ■

Because the Water Horse's electronics, bearings, and gears stay above the river's surface, the risk of damage from fast-flowing debris is low, making it a potentially more reliable choice for rivers with higher levels of sediment. *Photo courtesy of University of Alaska Fairbanks*

Water Horse Device Completes Two Test Runs on Alaskan River

PROJECT NAME: University of Alaska Fairbanks' Water Horse Hydroelectric Harvester Development

PROJECT TEAM: University of Alaska Fairbanks (lead) and Renerge, Inc.

LEAD RECIPIENT LOCATION: Alaska

With funding from WPTO, researchers at the University of Alaska Fairbanks worked with Renerge, Inc. to create and test a river-based device that sits above the water—as opposed to other designs that rest on or near a riverbed or seabed. The so-called Water Horse submerges just one steel pipe to "gallop" in river currents.

Rivers and oceans can be inhospitable environments for technology. Salt corrodes; rocks, sand, and ice can tumble at sometimes aggressive speeds; constantly churning waters can slowly wear materials down. Positioning the Water Horse above the water helps to avoid the water's most destructive forces altogether.

The device might not produce as much energy as other designs. However, because it is better protected and could be built with less expensive, off-the-shelf materials, it could require less maintenance and last longer in the water, making it a potentially more reliable, lower-cost, long-term source of clean energy.

The Water Horse design harnesses energy from river currents with a technique called vortex shedding. A steel pendulum, like a small crane, hangs in flowing water. As the current rushes around the tip, that motion rocks the pendulum up and down, like a galloping horse. Renerge, Inc. created the design and asked the University of Alaska Fairbanks for help designing a PTO, that translates that galloping motion into electricity to power a generator.

The Alaskan research team took the Water Horse out for two runs in their Tanana River test site in Nenana, Alaska. The first five-day trial in 2020 gave the team enough data to improve their prototype. During the second gallop, which took place over 10 days during the summer of 2021, they installed two devices, one upstream of the other, to examine how wakes from the upstream system affected the performance of the one downstream. Because the gallop motion creates uneven bursts of energy, they also developed a way to smooth it into a steady stream.

The results were even better than they hoped. Their new design proved to be more efficient and half the price of their previous device. And in Alaska, cost is especially important. The state's energy prices are the second highest in the United States. Today, many communities still rely on expensive and polluting shipments of diesel. But a clean source of energy flows near almost every Alaskan community, no matter how remote: water.

Because Renerge, Inc.'s priority is to build an affordable hydrokinetic technology, the researchers plan to use the summer 2021 data to calculate the device's levelized cost of energy—how much it costs versus how much energy it produces over its lifetime. The design could be even more cost-effective if communities use pre-existing structures, like bridges, to mount the device and if the Water Horse is built with readily available materials, making it simpler to maintain and repair.

The above-water design helps, too. Because the more fragile electronics, bearings, and gears stay out of the river, the risk of damage from fast-flowing debris is low. Even if damage occurs, it's easier and less expensive to fix than an underwater turbine. So, for debris-prone rivers, the Water Horse may be the more reliable choice. As one University of Alaska Fairbanks researcher put it, the quest to design marine energy devices for Alaskan rivers is still a horse race. And the Water Horse has a strong gallop. ■

REDUCING BARRIERS TO TESTING

New additions to the Marine and Hydrokinetic Toolkit are intended to help the marine energy community accelerate learning and process more data from laboratory and open-water testing. *Photo courtesy of Texas A&M University*

Critical Advancements Made Available in Marine Energy Data Processing Tool

PROJECT NAME: MHKiT: Marine and Hydrokinetic Toolkit

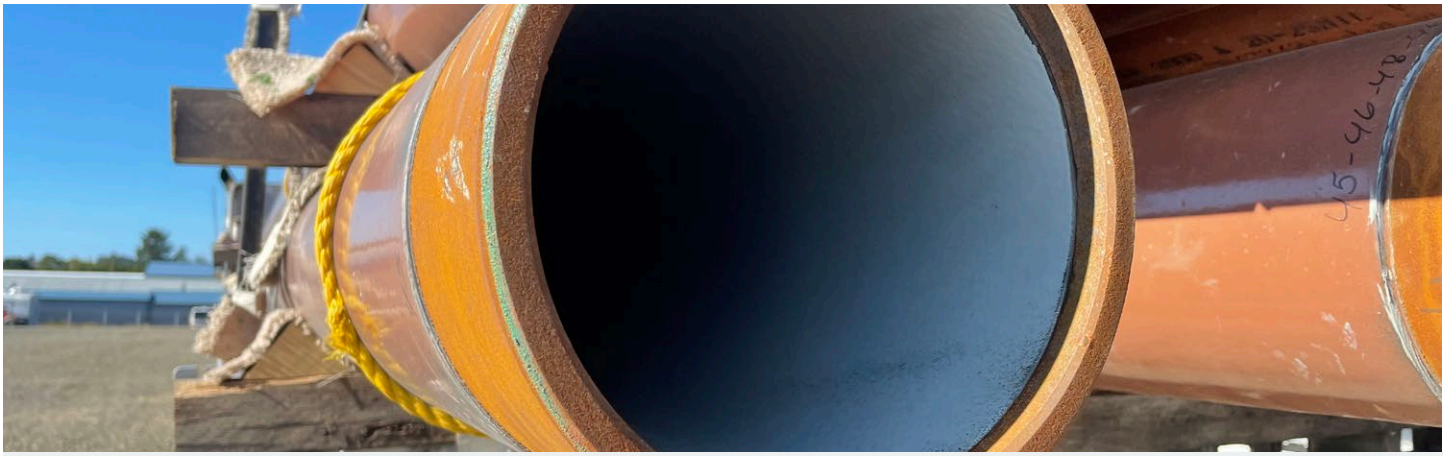
PROJECT TEAM: National Renewable Energy Laboratory (lead), Sandia National Laboratories, and Pacific Northwest National Laboratory

LEAD RECIPIENT LOCATION: Golden, Colorado

Researchers from NREL, PNNL, and Sandia made significant advancements to the data processing toolkit known as the Marine and Hydrokinetic Toolkit (MHKiT). Tools and software are essential to model and validate new technologies during their development. MHKiT helps fill this need with tools for data processing, visualization, quality control, and other activities.

Already capable of real-time data processing, standardization, and visualization, researchers collected industry feedback and added new features to MHKiT, including functions to download and process new types of data. MHKiT can now process data from the Coastal Data Information Program data repository for coastal environmental data. Researchers also implemented capabilities to process Simulating WAves Nearshore model data, allowing for increased insight into wave power in coastal regions.

Additions to this toolkit are designed to help the marine energy community accelerate learning and process more data from laboratory and open-water testing. With marine energy data more widely accessible to the industry, device design processes can be improved, paving the way for commercialization. ■



In 2021, four nearly 1-mile-long sections of conduit—one for each of PacWave South's four 5-megawatt, grid-connected wave energy converter test berths—were installed. As the facility prepares for operation, customized cable will be pulled through the conduit along the way to the test site 7 miles offshore. *Photo courtesy of PacWave*

Wave Energy Test Facility Nears Subsea Construction Milestone

PROJECT NAME: Enabling Cost-Effective Electricity from Ocean Waves: PacWave

PROJECT TEAM: Oregon State University (lead), European Marine Energy Centre, Aquatera Ltd., Pacific Energy Ventures, 3U Technologies, National Renewable Energy Laboratory, Williwaw Engineering, H.T. Harvey & Associates, HDR, and Stoel Rives

LEAD RECIPIENT LOCATION: Newport, Oregon

Construction began in 2021 on PacWave South—the first accredited, grid-connected, open-ocean wave energy testing facility in the United States and one of only a few worldwide. Wave energy devices must be able to survive in harsh ocean environments. Simulations in a scaled test facility can't replicate myriad challenges like damage caused by biofouling or the drag on anchoring tethers from strong ocean currents. PacWave will enable technology developers to prove how their wave energy devices perform in highly energetic seas over long periods of time.

Funded by WPTO and featuring a team of partners led by Oregon State University, PacWave will include two test-site locations. PacWave North, already in use by wave energy device developers, is in shallower waters and is not grid connected. PacWave South will be about 12 miles northwest of Oregon's Driftwood Beach State Park and 7 miles offshore. The site will support 20-megawatt, grid-connected, utility-scale testing as well as small-scale, off-grid testing. A subsea cable system, grid interconnection, and a utility connection and monitoring facility will transmit wave energy-produced power from PacWave South to the local utility grid.

Construction activities in 2021 included completing four directionally drilled bores and then installing cable conduits in each bore where power cables will be laid. The conduits—each about 1 mile long—start at the Driftwood Beach State Park parking lot, descend as deep as 150 feet under the dunes and beach, and break through the seafloor at a water depth of about 45 feet. Divers capped the cable conduits—one for each of PacWave South's four 5-megawatt WEC test berths—to protect them until cable installation begins.

Once fabricated and transported to the site, the four customized cables—each about 12 miles long and featuring three medium-voltage copper conductor cores and 12 fiber-optic elements per cable—will be installed. The inner mile of cable will be pulled through the conduit from the cable ship to the park. The remaining 11 miles of cable will be buried about 3 feet under the seafloor from the conduit to the test site. The cables will provide power and data connectivity between developers' wave energy conversion systems and a utility connection and monitoring facility on land. The next step, which has already begun, is snaking conduit underground from shore, under a highway, and up a hill to the future location of the 1.2-acre utility connection and monitoring facility.

As PacWave is prepermitted for most wave energy device types, technology developers can avoid a costly and time-consuming permitting process prior to testing at the site. This will allow for more rapid optimization of designs. By enabling users to demonstrate technical viability, determine methods for cost reduction, and advance technologies toward cost-effective power delivery and commercial readiness, PacWave will set the standard for wave energy device testing over the next few decades. ■

TEAMER Testing Network Grows and Initiates 37 New Technical Support Activities

PROJECT NAME: Testing Expertise and Access for Marine Energy Research (TEAMER) Program

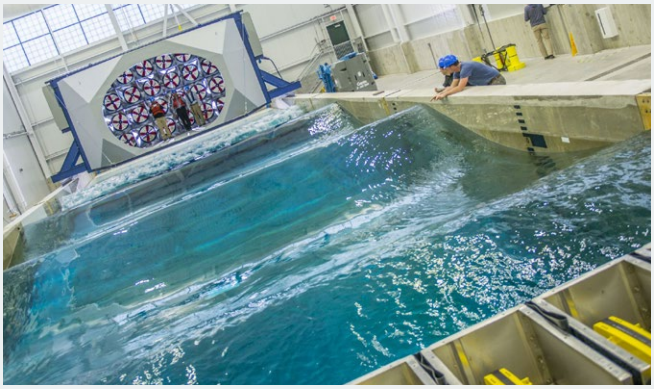
PROJECT TEAM: Pacific Ocean Energy Trust (lead) and more than 30 institutions offering more than 90 capabilities throughout TEAMER's facility network.

LEAD RECIPIENT LOCATION: Portland, Oregon, with TEAMER-supported activities taking place nationwide

Navigating new marine energy technologies from idea to commercial viability, with testing and development challenges in between, represents a substantial barrier to the commercialization of these systems. The TEAMER program, sponsored by WPTO and directed by the Pacific Ocean Energy Trust, accelerates the idea-to-market process by providing support for developers seeking access to the nation's best marine energy testing facilities and leading marine energy experts.

During Fiscal Year 2021, TEAMER selected 23 projects through its second request for technical support and 14 projects through its third request, and closed its fourth request. These technical support awards will grant these projects access to numerical modeling, lab testing, and tank/flume testing within TEAMER's expanded facility network.

Through these activities, TEAMER gives early-stage technology developers access to world-class testing infrastructure and expertise, helping them advance their devices, build knowledge, foster innovation, and drive commercialization of marine energy technologies. ■



Testing Expertise and Access for Marine Energy Research accelerates the viability of marine renewables by providing access to facilities and expertise to solve critical challenges, build knowledge, foster innovation, and drive commercialization. *Photo courtesy of University of Maine*

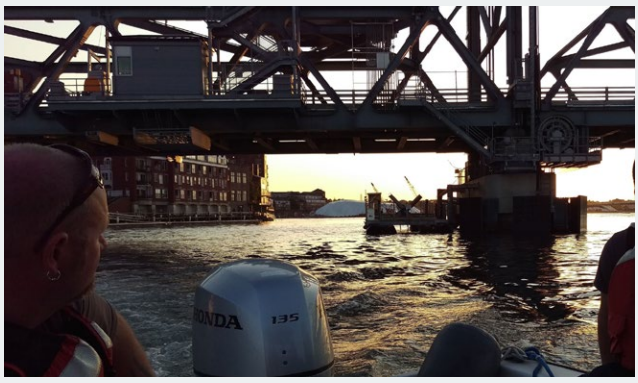
New National Marine Energy Center Established Focused on the Blue Economy

PROJECT NAME: Atlantic Marine Energy Center Launch

PROJECT TEAM: University of New Hampshire (lead), Stony Brook University, Lehigh University, Coastal Studies Institute, Old Dominion University, National Renewable Energy Laboratory, Pacific Northwest National Laboratory, Sandia National Laboratories, and European Marine Energy Centre

LEAD RECIPIENT LOCATION: Durham, New Hampshire

The University of New Hampshire—partnered with various universities, national labs, and the European Marine Energy Center—won a $10 million award to develop an Atlantic Marine Energy Center (AMEC) on its campus. One of 10 projects funded by a $22 million DOE award for marine energy foundational R&D and testing infrastructure, this facility will conduct marine energy testing and to address the need for ongoing research into marine energy and to support the Powering the Blue Economy initiative. This center will utilize open-water, laboratory, numerical, and analytical test capabilities to upgrade wave and tidal device testing infrastructure, including digital twinning capabilities, with the goal of improving alignment with industry needs and enhancing our testing capability under the TEAMER program. Research performed at AMEC is expected to address various issues in marine energy, including foundational R&D, wave and tidal energy conversion, marine energy power conversion, and storage integration. ■



The new Atlantic Marine Energy Center at the University of New Hampshire will be a valuable resource for both academic and industry developers to validate and analyze their technology designs. *Photo courtesy of Ian Gagnon, U.S. Department of Energy's Make a Splash Photo Contest*

Triton Initiative Tests New, Cost-Effective Environmental Monitoring Technologies and Methods

PROJECT NAME: The Triton Initiative

PROJECT TEAM: Pacific Northwest National Laboratory (lead), University of New Hampshire, University of Alaska, and Scripps Institution of Oceanography at the University of California San Diego

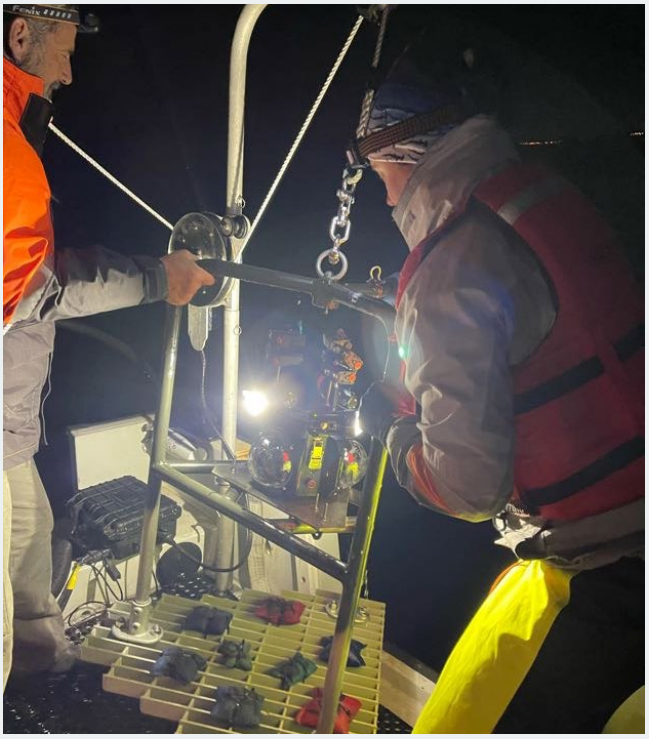
LEAD RECIPIENT LOCATION: Sequim, Washington

The Triton Initiative—led by PNNL and supported by the University of New Hampshire, University of Alaska, and Scripps Institution of Oceanography at the University of California San Diego—made significant advancements researching technologies used to measure four key environmental stressors—electromagnetic fields, collision risk, underwater noise, and changes in habitat—associated with marine energy devices. This research will be featured in a special issue of the peer-reviewed *Journal of Marine Science and Engineering* in early 2022.

Triton tested underwater acoustic camera technology to evaluate fish interactions around deployed marine energy devices in Alaska and New Hampshire. Information from these tests helped to fill data gaps related to the use of acoustic cameras to detect fish behavior around tidal and current energy devices. The team also used hydrophones, 360-degree video cameras, and magnetometers, which aided the development of recommendations to monitor for underwater noise, changes in habitat, and electromagnetic field research, respectively.

The results from these tests were valuable in providing a use case and recommendations for cost-effective, off-the-shelf technologies and methods for environmental monitoring at marine energy sites. For instance, a 360-degree camera, drifting hydrophone, acoustic camera, and a towed magnetometer were tested and evaluated for performance in monitoring environmental stressors for changes in habitat, underwater noise, collision risk, and electromagnetic fields, respectively. The recommendations from this work demonstrate the technology effectiveness for site-specific conditions and each stressor. A drifting hydrophone is an effective technology approach for monitoring underwater noise in a tidal channel. Likewise, a towed magnetometer effectively measures magnetic fields from powered cables on the seafloor.

The Triton Initiative was approved to move onto the third phase of the project, which will take place over the next three years. Reaching this phase opens the door to research biological receptor responses to physical stressors related to marine energy devices. This new research will help improve understanding of interactions between marine wildlife and marine energy devices using above and underwater technologies. Efforts will also focus on developing improvements in data analysis and processing with machine learning. This data is necessary for regulators, marine energy stakeholders, and developers to make permitting decisions, and the development of cost-effective technologies and methods supports compliance with permitting requirements. ■



Pacific Northwest National Laboratory tested the impacts of marine energy devices on the ecosystem by deploying a 360-degree optical video camera in the water near the CalWave wave energy converter off the Scripps Institution of Oceanography's pier in La Jolla, California. *Photo courtesy of Pacific Northwest National Laboratory and Scripps Institution of Oceanography*

DATA ACCESS, ANALYTICS, AND WORKFORCE DEVELOPMENT

Resources from the National Renewable Energy Laboratory's water power workforce development portals are on display in a public ocean energy exhibit at Connecticut's Mystic Aquarium. *Photo courtesy of Mystic Aquarium*

WPTO Hosts Second Marine Energy Collegiate Competition and Expands STEM-Focused Activities

PROJECT NAME: Marine Energy STEM and Workforce Development

PROJECT TEAM: National Renewable Energy Laboratory

LEAD RECIPIENT LOCATION: Golden, Colorado

DOE's Marine Energy Collegiate Competition (MECC) provides college students the opportunity to build real-world experience and professional connections that will help them land jobs in marine energy and the blue economy. Managed by NREL on behalf of DOE, MECC calls on participants to explore opportunities for marine energy technologies to benefit other existing maritime industries via real-world concept development experiences.

The 2021 MECC pitches and award ceremony took place as part of the virtual 2021 International Conference on Ocean Energy. During the closing plenary session, Principal Deputy Assistant Secretary for Energy Efficiency and Renewable Energy Kelly Speakes-Backman recognized the winners, and the team from Purdue University, which claimed first place overall, presented their winning concept.

The 17 teams that participated in the 2021 competition hailed from around the world, representing 12 U.S. states and several universities from Mexico. Since its inception in 2020, the MECC has engaged an estimated 480 students and 48 teams from 47 different institutions. These institutions have included one historically Black university, one community college, 14 U.S.-based minority-serving institutions, seven Hispanic-serving institutions, eight Asian American and Native American Pacific Islander-serving institutions, and 10 international or non-U.S. institutions.

In Fiscal Year 2021, the MECC introduced the Build & Test Challenge, which gave teams the opportunity to build and test a scaled model of their concept and present them to potential investors and future partners. Also this year, the competition organizers at NREL began establishing new partnerships with organizations that commit to helping the lab increase engagement, create networking opportunities for the students, and ensure MECC continues to engage diverse talents necessary for the future marine energy workforce. Initial partnerships include the Interdisciplinary Environmental Association and the Society of Hispanic Professional Engineers.

Additionally, WPTO supports tools and resources to help students learn about marine energy technologies and potential career tracks, ensuring that training for tomorrow's workforce begins today. The STEM for Marine Energy Portal offers those interested in marine energy the resources they need to embark upon rewarding careers in this emerging field.

Some of the portal's resources are featured in a public ocean energy exhibit at Connecticut's Mystic Aquarium as part of a two-year collaboration between WPTO, NREL, and industry partner Ocean Power Technologies. The exhibit includes a large screen that displays a marine energy animation showing seven different marine energy technologies, among other educational and interactive displays. To celebrate the exhibit's debut, Mystic Aquarium hosted a virtual tour and panel discussion, which included remarks from WPTO Director Jennifer Garson and industry leaders.

These efforts are part of WPTO's support for STEM and workforce development programs that aim to recruit the best and brightest workers into the burgeoning marine energy industry. ■

PRIMRE Corrals Broad Range of Marine Energy Data Into a Single Search Engine

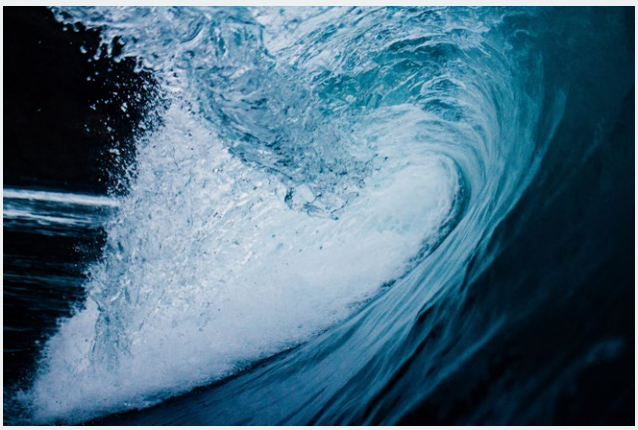
PROJECT NAME: Portal and Repository for Information on Marine Renewable Energy (PRIMRE)

PROJECT TEAM: Pacific Northwest National Laboratory (lead), National Renewable Energy Laboratory, and Sandia National Laboratories

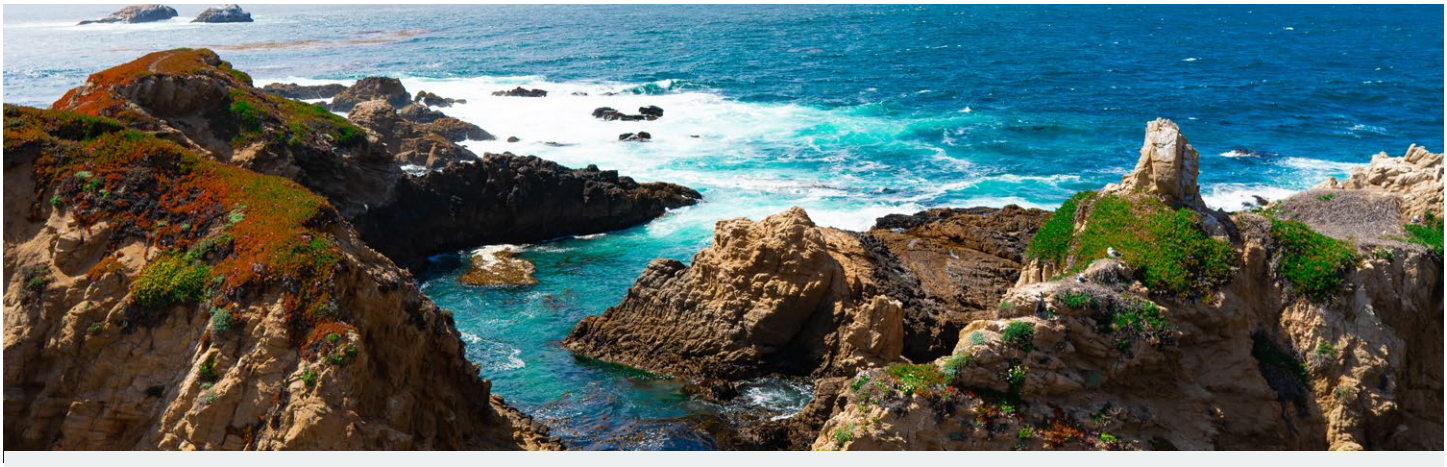
LEAD RECIPIENT LOCATION: Seattle, Washington

In 2021, the Portal and Repository for Information on Marine Renewable Energy (PRIMRE) team—which includes experts from PNNL, NREL, and Sandia—aggregated information from seven knowledge hubs into a centralized system accessible with a single search engine. PRIMRE consolidates marine energy information into one centralized, publicly accessible entry point. Data, analyses, papers, reports, and guidance are organized into the following knowledge hubs: the Marine Hydrokinetic Data Repository, Tethys, Tethys Engineering, the Marine Energy Technology Database, Marine Energy Software, Telesto, and the Marine Energy Atlas.

The PRIMRE team also kicked off a lessons-learned documentation effort with marine energy developers and crafted guidelines and best practices for data sharing across the U.S. and international marine energy community. These efforts ensure the marine energy community can access and contribute to comprehensive, trustworthy information, which will help accelerate marine energy development nationally and globally. ■



WPTO's Portal and Repository for Information on Marine Renewable Energy provides broad access to information on marine renewable energy projects and technologies, engineering, resource characterization, device performance, and environmental effects. *Photo courtesy of Tim Marshall, Unsplash*



The new Marine Energy Environmental Toolkit for Permitting and Licensing eases the process for developers to acquire permits and start creating clean ocean energy, all while protecting fragile marine environments. *Photo courtesy of Bradley Lembach, Unsplash*

New Permitting Toolkit Released to Speed Marine Energy Development

PROJECT NAME: Improving the Efficiency and Effectiveness for MHK Permitting: A Toolkit and Engagement for Success

PROJECT TEAM: Kearns & West (lead), EcoQuants, Electric Power Research Institute, European Marine Energy Centre Ltd., H.T. Harvey & Associates, Integral Consulting Inc., Ocean Renewable Power Company, Pacific Energy Ventures, and Sandia National Laboratories

LEAD RECIPIENT LOCATION: San Francisco, California

In the United States, only a few marine energy devices have successfully moved from the lab to the water, and only 20 projects have pursued a federal permit to date, in part because both project developers and regulators are still unfamiliar with their potential environmental effects. That knowledge gap adds both time and costs to securing the permit necessary to make that critical jump. Now, to close that gap, a team led by Kearns & West created a new online tool called the Marine Energy Environmental Toolkit for Permitting and Licensing.

The toolkit compiles and distills environmental, spatial (or geographic), regulatory, and scientific data in one easy-to-use, interactive web platform to help accelerate and reduce the cost of marine energy development, all while protecting vulnerable ocean environments. It builds on and draws from other informational resources WPTO has supported, such as PRIMRE.

The new toolkit is designed as a one-stop shop for informational resources regulators and developers can use to more easily navigate the permitting process. For example, users can select their deployment site on a map to find information on how noise could affect the local marine species, which marine wildlife lives or migrates there, and even whether humans work or use the space for recreation. They can also use keywords to find studies on specific interactions, including whether previous marine energy projects recorded interactions between wildlife and their devices. (In most cases, few or no wildlife impacts have been detected.) Users can even learn the economic potential for the site.

Using flowcharts, both inexperienced and seasoned developers can select tags to quickly locate relevant studies housed in two extensive repositories: the Tethys Knowledge Base and the FERC's eLibrary. Then, they can download a report—one document with all the economic and environmental information a project developer or regulator might need.

To create such a comprehensive tool, Kearns & West assembled a large team of experts from both the private and public sectors with expertise across diverse disciplines, such as offshore energy permitting, data science, spatial mapping, oceanography, environmental engineering, and marine ecology. The team also included representatives from organizations experienced in navigating the U.S. permitting process from the applicant perspective.

Prior to WPTO awarding the permitting toolkit project, from 2016 to 2020, Kearns & West worked with Sandia on a fact-finding mission to understand what challenges marine energy developers faced throughout the environmental permitting and compliance process. These findings helped identify opportunities to help make the permitting process run more smoothly, and they recommended six new strategies and 24 actions that could enable projects to more efficiently and effectively earn the necessary permits and licenses. Called the Marine Environmental Compliance Cost Assessment, this work provided the foundation for the new marine energy permitting and licensing toolkit, which could increase stakeholder and regulator confidence in marine energy projects and lower some risks associated with deployment.

The team's next step to further improve the toolkit will be to apply it to two permitting processes and gather feedback on how the toolkit affected users' experience. Two marine energy developers, one with a project in Alaska and another with a project in Florida, agreed to use the new tool during their permitting processes and report any snags or successes. Users can help keep the toolkit up to date by adding new studies, permitting documents, and more—helping accelerate the nation's progress toward a carbon-free energy future. ■

POWERING THE BLUE ECONOMY INITIATIVE

In many remote, island, and islanded communities, transitioning to clean energy can have insurmountable cost or logistical barriers. The Energy Transitions Initiative Partnership Project provides technical assistance to help these communities move toward a clean energy future. *Photo courtesy of iStock*

Community-Centric Program Launched to Accelerate Energy Transition to Clean Energy

PROJECT NAME: Energy Transitions Initiative Partnership Project

PROJECT TEAM: National Renewable Energy Laboratory (lead for program administration and technical assistance), Alaska Center for Energy and Power (lead for stakeholder engagement and capacity building), Lawrence Berkeley National Laboratory, Pacific Northwest National Laboratory, Sandia National Laboratories, Coastal Studies Institute, Hawaii Natural Energy Institute, Island Institute, and Renewable Energy Alaska Project

PARTICIPATING COMMUNITIES: Alaska Longline Fishermen's Association in Sitka, Alaska; Dillingham, Alaska; Eastport, Maine; Honolulu, Hawaii; Islesboro, Maine; Kauai, Hawaii; Nags Head, North Carolina; Ocracoke Island, North Carolina; Ouzinkie, Alaska; Sitka, Alaska; and Wainwright, Alaska

In April 2021, DOE announced 11 competitively selected communities in four states for the first Energy Transitions Initiative Partnership Project (ETIPP) cohort: Sitka, Dillingham, Ouzinkie, and Wainwright in Alaska, along with the Alaska Longline Fishermen's Association; Ocracoke Island and Nags Head in North Carolina; Eastport and Islesboro in Maine; and Honolulu and Kauai in Hawaii. These projects focus on efforts to reduce reliance on fossil fuels, increase energy efficiency and resilience, and optimize renewable resources and battery technologies.

ETIPP—supported by WPTO, Energy Transitions Initiative, Geothermal Technologies Office, Solar Energy Technologies Office, and Wind Energy Technologies Office—connects competitively selected remote, island, and islanded communities with regional stakeholder organizations and experts from national laboratories to help develop strategies to shift to a clean energy future that is equitable, sustainable, and resilient.

Energy is a particularly complex and costly challenge for remote, island, and islanded communities. Many of these communities face high risks of natural disasters and climate change impacts, on top of high energy costs and unreliable energy infrastructure that is vulnerable to outages or damage. ETIPP provides technical assistance to these communities to empower them to make informed decisions regarding their energy choices and build greater community resilience.

Through a community-centric, stakeholder-driven approach, regional partner organizations and national labs will help these communities reach their clean energy goals. ETIPP is an ongoing program and DOE will offer more opportunities in the future for new communities interested in working with the Department to advance their energy transitions. ■

National Renewable Energy Laboratory researchers designed a wave-powered desalination device that can be configured to produce electricity or direct hydraulic conversion to ensure similar devices competing in the final stage of the Waves to Water Prize can be evaluated fairly. *Photo courtesy of the National Renewable Energy Laboratory*

Waves to Water Prize Concludes Two Stages and Prepares for Final Testing To Demonstrate Wave Energy-Powered Desalination Systems

PROJECT NAME: Waves to Water Prize

PROJECT TEAM: National Renewable Energy Laboratory (lead) and Coastal Studies Institute

FINAL TEST LOCATION: Nags Head, North Carolina

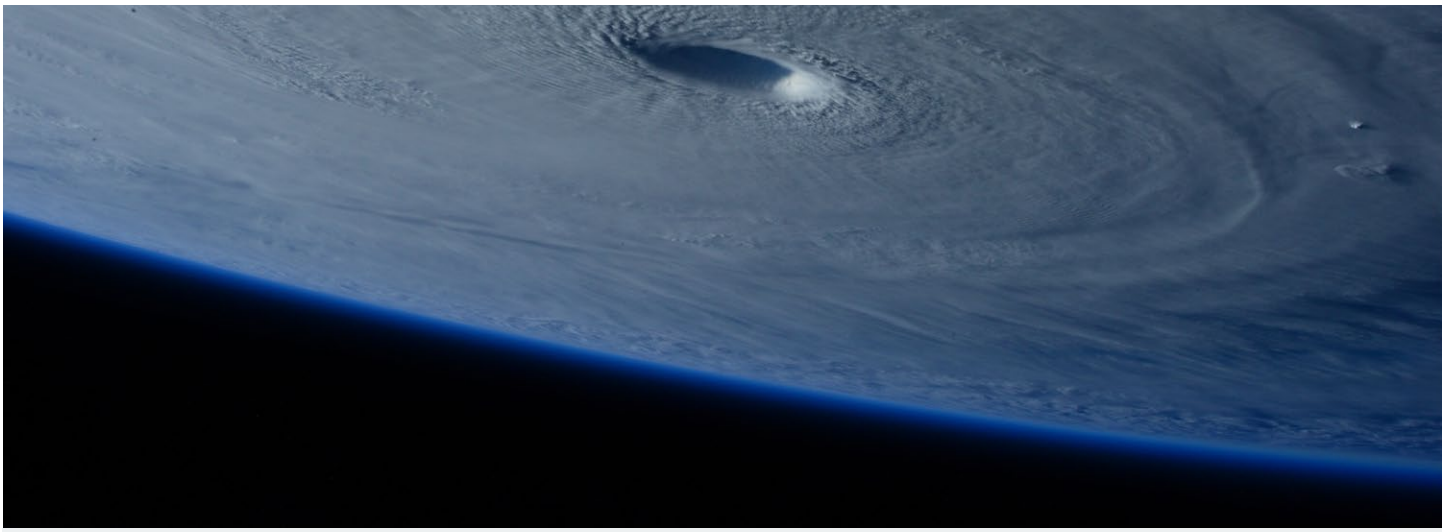
Wave-powered desalination technologies have the potential to turn the ocean's salt water into drinking water using energy from the ocean itself. To accelerate the development of this budding new technology, WPTO launched the five-stage, $3.3 million Waves to Water Prize in which teams compete to design small, modular desalination systems. Part of the Powering the Blue Economy initiative and administered by NREL, this prize seeks to create sustainable water delivery systems to create clean drinking water in communities that need it the most. In 2021, WPTO and NREL advanced competitors through two stages and selected the remaining five finalists that will test their devices off the coast of North Carolina in 2022.

Through the Waves to Water Prize, WPTO seeks to accelerate the development of wave energy-powered desalination systems and encourage creative, interdisciplinary solutions. The prize pairs world-class researchers with an entrepreneurial support system—including partners such as Engineering for Change and Coastal Studies Institute, and sponsors such as the International Desalination Association and Janicki Industries—to prime competitors for private investment and commercial scale-up.

In 2021, the prize successfully completed two full stages: ADAPT and CREATE. The ADAPT Stage welcomed new and continuing competitors and 36 teams participated, including rising entrepreneurs from small businesses, industry, academia, and the U.S. military. During this stage, teams had 180 days to document a detailed and robust design tailored to the environment at Jennette's Pier in Nags Head, North Carolina, where the final systems will be tested in the ocean. The 10 winning teams from the ADAPT Stage split a prize pool of $800,000 and went on to compete in the CREATE Stage.

Between February and August 2021, these 10 remaining teams developed their desalination ideas further and used a combination of comprehensive engineering analysis, design drawings and documentation, and videos highlighting device performance to provide evidence they could build and deliver their technology. In August 2021, WPTO awarded five CREATE Stage winners $100,000 each to bring their ideas from concept to prototype.

The finalist five teams are currently building and preparing fully functional wave-powered desalination devices for the prize's final stage, the DRINK Stage. The DRINK Stage will include a final test event off the coast of North Carolina in 2022, organized in partnership with the Coastal Studies Institute ■



Climate change will likely forge more destructive hurricanes, which is why it is important scientists watch the oceans for signs of storms. Now, to power this critical work, the Ocean Observing Prize is helping accelerate the development of novel ocean observing technologies that run on clean, renewable ocean energy. *Photo courtesy of NASA*

Competitors Advance Marine Energy-Powered Ocean Observing Platforms

PROJECT NAME: Ocean Observation Prize Update

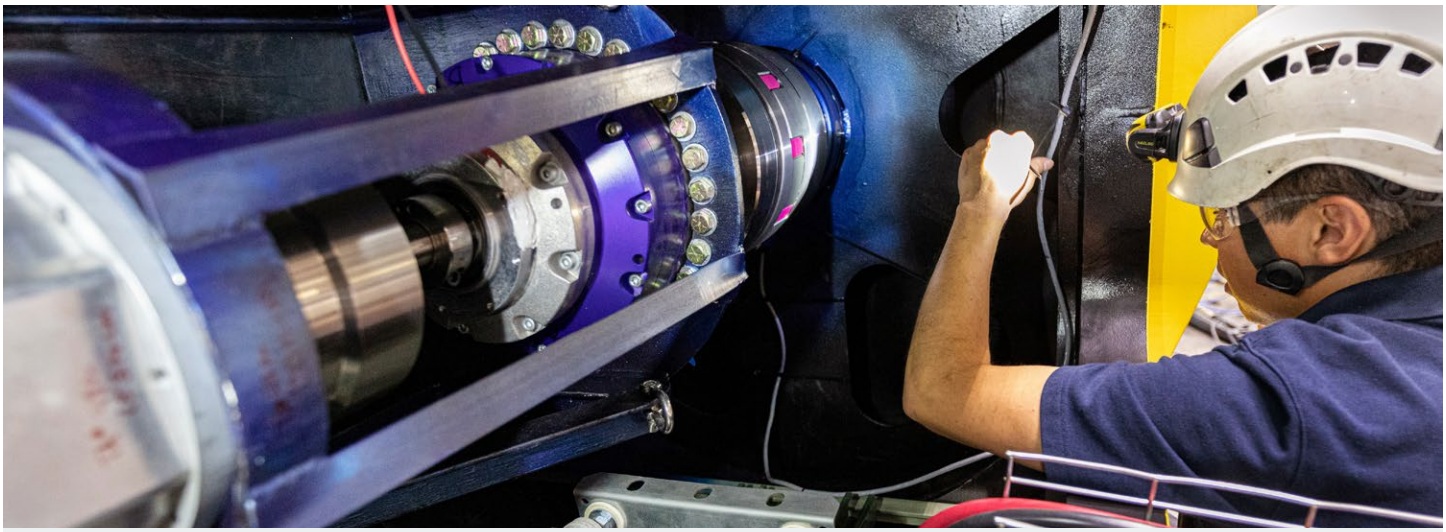
PROJECT TEAM: National Renewable Energy Laboratory and Pacific Northwest National Laboratory

Today, more than 80% of the ocean remains unmapped, unobserved, and unexplored. To help monitor, track, and learn more about the oceans, WPTO, in partnership with the National Oceanic and Atmospheric Administration's (NOAA) Integrated Ocean Observing System, launched the Ocean Observing Prize as part of the Powering the Blue Economy initiative. Administered by NREL and PNNL, the prize challenges innovators to integrate marine renewable energy with ocean observation platforms and develop innovative technologies that can help fill the data gaps that make it difficult to predict the intensity of hurricanes. Accurate forecasting could better protect coastal communities from the disastrous impacts of oncoming storms.

Following the completion of the first competition, DISCOVER, the prize moved into the second competition, DEVELOP, which is made up of three distinct contests: DESIGN, BUILD, and SPLASH. Over the course of the competition, contestants turn their theoretical designs for wave-powered autonomous underwater vessels into prototype systems for hurricane monitoring. In late 2020 and into early 2021, 16 teams competed in the DESIGN Contest. WPTO announced seven winners, which were awarded a total of $400,000 and invited to compete in the BUILD Contest.

The BUILD Contest began in April 2021 and will identify promising technologies relevant to NOAA's mission that could be tested in an open water environment. The seven teams refined their DESIGN Contest concepts in preparation to build and test their prototype designs in a controlled environment that will create realistic ocean conditions. This testing will be performed in 2022 at the Maneuvering and Seakeeping Basin within Naval Surface Warfare Center Carderock Division, a world-class test facility in Bethesda, Maryland. Winners of the BUILD Contest will advance to the final stage of the prize: the SPLASH Contest. During this stage, which PNNL will host, competitors will test their prototypes on the Olympic Peninsula in Washington.

The Ocean Observing Prize is designed to be repeatable and future competitions may focus on other themes. Through this competition, innovators will be able to tap into DOE's network of national laboratories, energy incubators and accelerators, subject-matter experts, and other resources across the nation to build novel technologies that collect critical ocean data. ■



A researcher at the National Renewable Energy Laboratory makes some adjustments to an autonomous offshore power system, which provides in-situ power, energy storage, and real-time data and communications support set to advance the marine economy toward a future of autonomous, connected and resident technologies. *Photo courtesy of the National Renewable Energy Laboratory*

First Foundational R&D Efforts Identified and Launched To Integrate Marine Energy with Blue Economy Applications

PROJECT NAME: Foundational Research and Development for Powering the Blue Economy

PROJECT TEAM: National Renewable Energy Laboratory and Pacific Northwest National Laboratory

LEAD RECIPIENT LOCATION: Golden, Colorado, and Richland, Washington

In support of WPTO's Powering the Blue Economy initiative, a team of researchers from NREL and PNNL mapped and implemented 10 initial research areas related to fundamental challenges in marine energy. This mapping was a result of collaborative work between the two labs that sought to catalogue some of the most critical and crosscutting opportunities for blue economy applications. This included market exploration and analysis, design and development of prototypes, and deployment and testing of marine energy systems.

This effort, paired with continuous engagement of end users and identification of fundamental engineering challenges, serves as the initial set of topics critical to analyzing future research topics to help overcome challenges associated with integrating marine energy with blue economy applications, such as ocean observation technology or desalination and water treatment devices for remote, coastal, and island communities. The topics ranged from modeling small wave systems, expanding work on salinity and thermal gradients, and increasing attention on the shifting requirements for moorings, among others. Highlights of key areas and their findings include:

- Mooring Key for Data Dropout: Data dropout can be a key challenge in ocean observing. A multilab team analyzed the reliability of NOAA National Data Buoy Center buoys and consulted with NOAA engineers to refine causes of data drop out. This analysis identified the mooring system, which holds the buoys in place, as a common failure during operation. Following these results, the research team will explore potential mitigation strategies for mooring failures as well as design a tool to analyze mooring reliability.
- Understanding Arctic Opportunities: Researchers explored the marine energy resources available at high latitudes, including in the Arctic, and identified the potential for marine energy to supplement ocean observation needs. As a result of this effort, the team is well positioned to engage with arctic field researchers to design and test wave and tidal energy devices that can perform under these conditions.
- Modeling WECs at Smaller Sizes: Many of the WECs being pursued for blue economy applications are smaller than those traditionally designed and modeled for the grid. To better understand how performance scales in wave energy devices, the team completed a large-scale simulation of four WEC concepts. These simulations could help developers evaluate the potential of a wave energy device more quickly and accurately, provide performance results for techno-economic feasibility studies, and allow engineers to develop WECs without hydrodynamic modeling expertise.
- Examining the Role of Gradients to Unlock Power at Different Scales: Technologies based on ocean thermal and salinity gradients are fundamental to capture energy in parts of the ocean where other renewable energy resources are limited, such as locations with no light and little motion. In alignment with congressional mandates, laboratory research

-continued

investigated the potential for energy conversion technologies based on ocean thermal and chemical (salinity) gradients to power autonomous underwater vehicles and autonomous ocean sensing systems. Thermoelectric generators, phase-change materials, Stirling engines, and shape memory alloys are among the promising technologies that present a high level of compatibility (dimensions, operating temperatures, etc.) with autonomous underwater vehicles and autonomous ocean sensing systems.

- Efficient Power Systems for Wave and Tidal Devices: Optimizing controls and balancing electrical and mechanical systems to ensure efficient operation for wave and tidal energy generation devices are identified needs that the Foundational PBE team is tackling. For tidal resources, the team developed, modeled, and simulated a tidal energy device and implemented a unique control strategy. The results indicate the proposed control strategy is capable of efficient operation and lays the groundwork for next-stage prototype development. For wave resources, the team developed and analyzed electrical and mechanical models for a wave energy device to better understand the relationship between torque, cost, efficiency, power takeoff (PTO) system size, and how annual energy production can be optimized. The findings provided insights into PTO scaling for determining optimal wave energy device ratings and established a framework for a novel methodology to rate an electric PTO's energy capture for wave energy devices.

The NREL and PNNL research team achieved these initial outcomes through partnerships with universities and industry and will continue this collaborative model. Through these efforts, WPTO aims to advance the foundational research necessary to better enable the integration of marine energy with blue economy applications and sustainably support energy needs in and near the ocean. ■

NOTABLE FISCAL YEAR 2021 INVESTMENTS

With funding from the U.S. Department of Energy, 10 projects are focused on addressing challenges that limit commercial adoption and advancement of marine energy. *Photo courtesy of Torsten Dederichs, Unsplash*

WPTO Awards $22 Million to Marine Energy Projects to Support Foundational R&D and Testing Infrastructure

PROJECT NAME: Selections for Funding Opportunity: Marine Energy Foundational Research and Testing Infrastructure

SELECTEES: Monterey Bay Aquarium Research Institute, Oregon State University, Tufts University, University of Alaska Fairbanks, University of Illinois at Urbana-Champaign, University of Maine, University of Washington, University of New Hampshire, Pacific Ocean Energy Trust, and IDOM Incorporated

SELECTEES LOCATION: Moss Landing, California; Corvallis, Oregon; Medford, Massachusetts; Fairbanks, Alaska; Champaign, Illinois; Orono, Maine; Seattle, Washington; Durham, New Hampshire; Portland, Oregon; and Minneapolis, Minnesota

In December 2020, DOE announced 10 projects in four topic areas to receive funding under the Marine Energy Foundational Research and Testing Infrastructure funding opportunity. The projects collectively received approximately $22 million to advance foundational research, create an AMEC, establish a new Foundational Research Network Facilitator, and build current energy technology testing infrastructure. This funding will help the industry tackle complex scientific and technical challenges, move marine energy technologies toward commercial adoption, and help develop intellectual capital for U.S. technology leadership in ocean sciences and marine energy. The projects cover a range of marine energy topics including in-water device design, modeling, materials and manufacturing, grid integration, and efforts related to the Powering the Blue Economy initiative. ■

Reflecting on a Year of Achievements

In 2020 and 2021, U.S. Department of Energy's Water Power Technologies Office (WPTO) supported research across the country in national laboratories and communities and along waterways and coastlines. With partners across the nation, WPTO advanced hydropower and marine energy technologies with a goal to realize water power's full potential to contribute to a carbon-free power sector by 2035 and a net-zero-emissions economy by 2050 in the United States.

As part of WPTO's Hydropower Program, projects focused on research, development, demonstration, and commercial activities to advance transformative, cost-effective, reliable, and environmentally sustainable hydropower and pumped storage technologies; better understand and capitalize on opportunities for these technologies to support the nation's rapidly evolving grid; and improve energy-water infrastructure and security.

Partners developed tools and resources—such as more accurate streamflow forecasting and digital representations of hydropower systems—to help hydropower developers and other stakeholders make more informed decisions about potential and existing facilities and save time and money. Projects also supported environmental sustainability related to the development and modernization of hydropower facilities. For example, newly created technologies and tools help advance hydropower facility designs to support the safe passage of fish. Partners also explored how hydropower can contribute to a more resilient power grid and the potential to combine technologies, such as hydropower and energy storage.

Projects supported through WPTO's Marine Energy Program contribute to realizing the vision of expanding and diversifying the nation's energy portfolio by responsibly delivering power from ocean and river resources. Several projects involved preparing marine energy technologies, including devices that could harness the power of the ocean itself to enable deep ocean research, for open-water demonstrations. Partners also provided technical assistance and deployed new technologies to support clean energy transitions in remote, island, and islanded communities. Meanwhile, researchers identified the potential of marine energy resources and advanced data collection and information-sharing efforts, providing public access to marine energy knowledge created with public funds.

Across both the Hydropower and Marine Energy programs, projects also focused on expanding science, technology, engineering, and math resources to support the next-generation workforce. For example, partners supported 17 student teams in the second Marine Energy Collegiate Competition, developed new hydropower curricula, organized trainings for teachers, and created marine energy animations, which are featured in an interactive display at Connecticut's Mystic Aquarium.

Water power technologies are essential to achieving the United States' climate and emissions-reduction goals. The projects highlighted in WPTO's 2020–2021 Accomplishments Report—and the many more not included in these pages—are helping to advance marine energy and next-generation hydropower and pumped storage systems for a flexible and reliable grid, and set the stage for continued innovations for years to come.

2020–2021

Accomplishments Report

Water Power Technologies Office

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

For more information, visit:
energy.gov/water

DOE/EE-2287 · March 2022