U.S. DEPARTMENT OF
ENERGY

Office of
ENERGY EFFICIENCY &
RENEWABLE ENERGY

2019–2020

Water Power Technologies Office

Accomplishments

Disclaimer

Acknowledgments

The U.S. Department of Energy Water Power Technologies Office's 2019–2020 Accomplishments Report could not have been completed if it were not for the tireless efforts of all the national laboratory, university, and industry staff members who drove each and every one of these projects toward excellence. This document serves as a testament to their work and the continuing impact that it is having throughout the hydropower and marine energy industries. Additionally, in crafting this report, the following individuals were instrumental in writing, reviewing, and verifying the impacts of these projects:

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Thank you to all.

Letter from the Director

Dear friends and colleagues,

On behalf of the U.S. Department of Energy Water Power Technologies Office (WPTO), I am delighted to present our 2019–2020 Accomplishments Report. In this report, we summarize some of the significant results from WPTO-supported research across the Hydropower and Marine and Hydrokinetics programs. While not intended to be a comprehensive overview of all the impactful projects within WPTO's portfolio, this report highlights some of the achievements from the past 2 years. These accomplishments include successful laboratory and in-water tests of promising technologies, commercialization of environmental monitoring instrumentation, the release of new modeling code and decision-support tools, and efforts to improve open access to data. Many of these projects were supported through our traditional funding opportunity announcements, as well as by leveraging a variety of support mechanisms such as prizes, competitions, and notices of technical assistance.

I would also like to sincerely thank all our awardees, partners, and staff who contribute so much time and energy to making the important work we support possible. It is their efforts, taking place in laboratories, rivers, and oceans across dozens of states, that drive important scientific advances in hydropower and marine renewable energy technologies. And it is this work that will prepare the U.S. hydropower fleet to be a keystone of our renewable energy future and allow the sea itself to become a source of low-cost, renewable energy that ocean industries and coastal communities increasingly depend on.

Additionally, I want to express my appreciation for all the valuable feedback we receive from stakeholders and industry experts. One of our formal feedback mechanisms is our biannual Peer Review, a comprehensive and public evaluation of our program strategies and projects. We organized our most recent review in late 2019 and received valuable feedback on our work, including new areas where water power technologies can have significant impacts like leveraging hydropower's full range of grid benefits and marine energy applications in the Blue Economy. We also receive helpful input regularly via requests for information (published via the Federal Register) and public workshops. We continually apply these insights to improve our work.

For this first compilation of accomplishments, we cover successes achieved in 2019 and 2020. In the "Looking Forward to 2021" section, we highlight a few projects we predict will have significant results in 2021. I hope readers enjoy learning about the different areas of our portfolio, and I encourage them to get in touch with associated project teams for more information—email addresses for project points of contact are listed within each write-up. For more general inquiries, readers can also email the WPTO inbox. This document is a testament to the hard work and devotion of our partners who lead these research and development projects; thank you all again.

Sincerely,

Alejandro Moreno
Director, Water Power Technologies Office
Office of Energy Efficiency and Renewable Energy
U.S. Department of Energy

Acronyms and Abbreviations

3D – three dimensional

3G-AMP – third-generation Adaptable Monitoring Package

Argonne – Argonne National Laboratory

BioPA – Biological Performance Assessment tool

CHEERS – Conventional Hydropower Energy and Environmental Systems

C-Power – Columbia Power Technologies

DAISY – Drifting Acoustic Instrumentation System

DOE – U.S. Department of Energy

EPRI – Electric Power Research Institute

FAST – Furthering Advancements to Shorten Time

FERC – Federal Energy Regulatory Commission

FY – Fiscal Year

GE – General Electric

GLIDES – Ground-Level Integrated Diverse Energy Storage

GW – gigawatt

HBET – Hydropower Biological Evaluation Toolset

HFI – Hydropower Fleet Intelligence

HydroWIRES – Hydropower and Water Innovation for a Resilient Electricity System

HVS – Hydropower Value Study

IEC – International Electrotechnical Commission

INL – Idaho National Laboratory

kW – kilowatt

MCRL – Marine and Coastal Research Laboratory

MECC – Marine Energy Collegiate Competition

MHK – marine and hydrokinetics

MW – megawatt

MW – megawatt-hour

NOAA – National Oceanic and Atmospheric Administration

NREL – National Renewable Energy Laboratory

NYSERDA – New York State Energy Research and Development Authority

ORNL – Oak Ridge National Laboratory

ORPC – Ocean Renewable Power Company

OSU – Oregon State University

POET – Pacific Ocean Energy Trust

PNNL – Pacific Northwest National Laboratory

PRIMRE – Portal and Repository for Information on Marine Renewable Energy

PSH – pumped-storage hydropower

Penn State – Pennsylvania State University

PTO – power take-off

R&D – research and development

Sandia – Sandia National Laboratories

SSP – solid-state processing

STEM – Science, technology, engineering, and mathematics

T-PSH – ternary pumped-storage hydropower

TEAMER – Testing Expertise and Access for Marine Energy Research

UCMF – Utility Connection and Monitoring Facility

WEC – wave energy converter

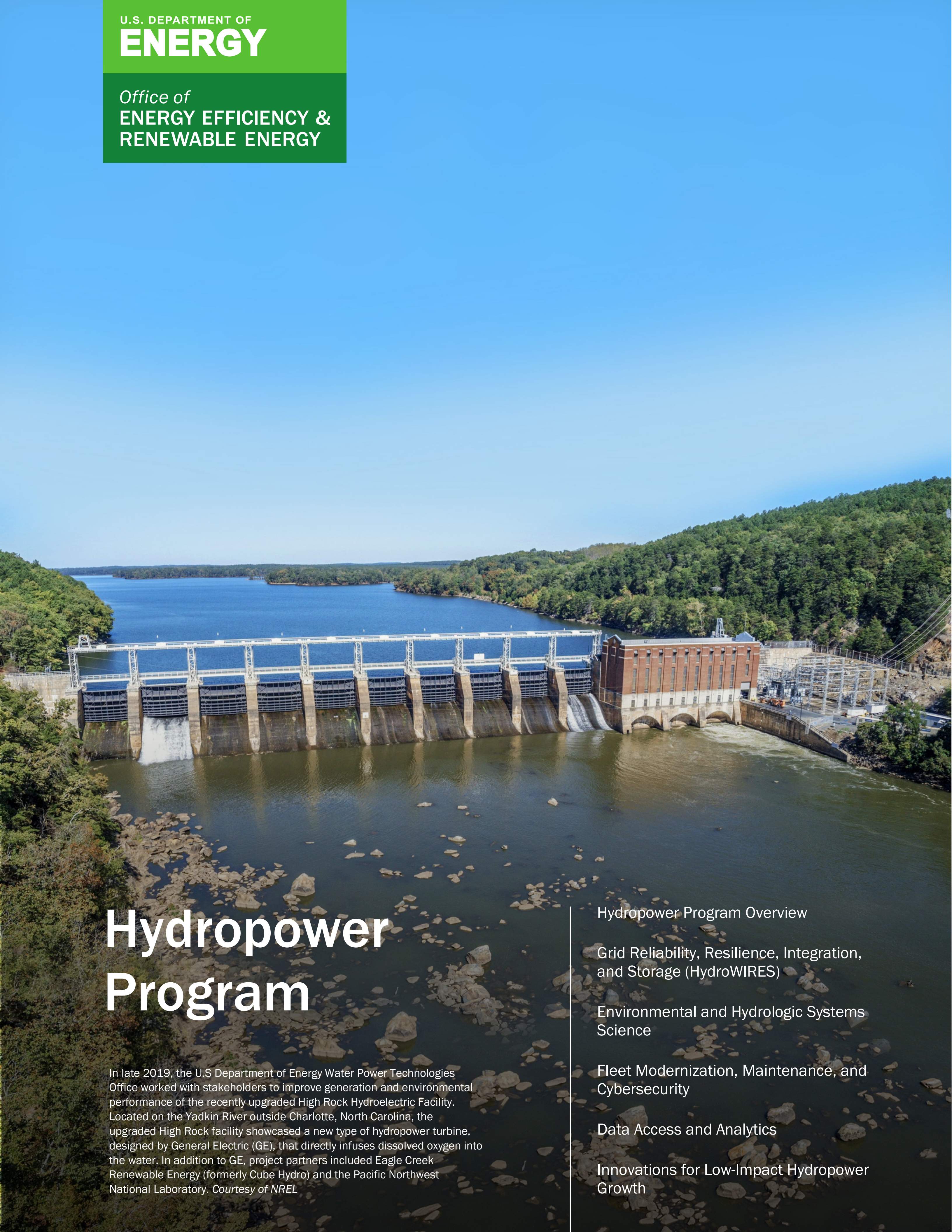
WPTO – Water Power Technologies Office

Table of Contents

List of Figures

U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY



Hydropower Program

In late 2019, the U.S Department of Energy Water Power Technologies Office worked with stakeholders to improve generation and environmental performance of the recently upgraded High Rock Hydroelectric Facility. Located on the Yadkin River outside Charlotte, North Carolina, the upgraded High Rock facility showcased a new type of hydropower turbine, designed by General Electric (GE), that directly infuses dissolved oxygen into the water. In addition to GE, project partners included Eagle Creek Renewable Energy (formerly Cube Hydro) and the Pacific Northwest National Laboratory. *Courtesy of NREL*

1. Hydropower Program Overview

Hydropower is the United States' oldest source of renewable electricity, comprising nearly 7% of U.S. generation. In 2018, hydropower accounted for roughly 40% of U.S. renewable electricity generation, whereas pumped-storage hydropower (PSH) remains the largest contributor to U.S. energy storage with an installed capacity of 21.6 gigawatts (GW), or roughly 95% of all commercial storage capacity in the United States.

The Hydropower Program at the U.S. Department of Energy (DOE) Water Power Technologies Office (WPTO) conducts early-stage research and development (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 vision of the Hydropower Program 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 the mission and realize the vision, the Hydropower Program comprises five R&D activity areas, which represent the program's strategic approach to addressing the challenges faced by U.S. hydropower stakeholders. Success stories within this year's publication are presented within these activity areas:

1. Grid Reliability, Resilience, Integration, and Storage
2. Environmental and Hydrologic Systems Science
3. Fleet Modernization, Maintenance, and Cybersecurity
4. Data Access and Analytics.
5. Innovations for Low-Impact Hydropower Growth

Readers can learn more about the Hydropower Program and its projects by visiting the WPTO website, following the Office's Water Wire e-newsletter, or exploring the WPTO Projects Map.

Grid Reliability, Resilience, and Integration

Rapid changes in the U.S. electricity system, including changes in the generation mix as well as markets and policy, have created new needs for storage, flexibility, and other grid services that hydropower and PSH are well-suited to provide. In response to these opportunities, WPTO recently launched Hydropower and Water Innovation for a Resilient Electricity System (HydroWIRES), a new initiative designed to investigate additional value streams, enhanced flexibility, new operational strategies, and innovative technology solutions that enable new roles for hydropower and PSH. Efforts encompass industry- and national laboratory–led modeling, analysis, tool development, technical assistance, and technology R&D.

HydroWIRES—New Hydropower and Grid-Focused Initiative Produces New System Designs, Prize Results, Analyses, and Specialized Technical Assistance

Launched in April 2019, the HydroWIRES (Water Innovation for a Resilient Electricity System) Initiative is designed to elucidate, enable, and improve hydropower and PSH's contributions to reliability, resilience, and integration in the rapidly evolving U.S. electricity system. The unique characteristics of hydropower, including PSH, make it well-suited to provide a range of storage, generation flexibility, and other grid services and support the cost-effective integration of variable renewable resources. Specific research areas in HydroWIRES are motivated by pressing industry challenges and have been developed with external input from the hydropower industry and power system stakeholders. The HydroWIRES Initiative represents a significantly increased and targeted focus for WPTO on hydropower's changing role in the power system.

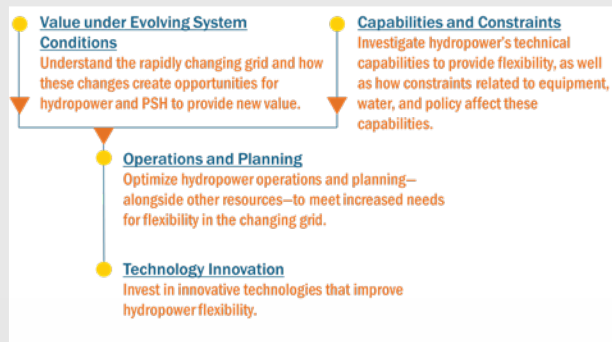


Figure 1. HydroWIRES research areas motivated by industry challenges.

Courtesy of WPTO

Though HydroWIRES only formed in 2019, the initiative builds on and integrates previous work funded by WPTO. The 2016 *Hydropower Vision* report illustrated challenges and opportunities associated with expansion of the hydropower fleet but also highlighted research gaps in understanding the past, present, and future value of hydropower. Such questions motivated two flagship projects in what later became the foundational efforts for the HydroWIRES Initiative: the Hydropower Value Study: Current Status and Future Opportunities (HVS), which describes the current operational landscape of the hydropower fleet, and a techno-economic guidebook, which provides an assessment of two proposed PSH projects to evaluate their long-term valuation and refine national lab–developed valuation guidance. A draft valuation methodology and tool has been applied to the two proposed sites that were competitively selected through a 2017 Notice of Opportunity for Technical Assistance (NOTA—the Banner Mountain site in Wyoming and the Goldendale site on the Oregon and Washington border. An early report published as part of this effort is the "Energy Storage Technology and Cost Characterization Report," which compares PSH with other storage technologies.

In addition, a number of technology development projects under HydroWIRES have identified new approaches to designing and configuring PSH projects while reducing capital costs and reducing potential environmental impacts. For example, Obermeyer's design would reduce excavation costs by eliminating the underground powerhouse, and Oak Ridge National Laboratory (ORNL) put forward a modular configuration of PSH that uses pressurized air in tanks to increase the effective head. Additionally, a PSH-focused prize solicited new ideas to reduce the total time to commissioning projects, resulting in awards to investigate new approaches to modularity, civil works, and materials. Other work seeks to increase the grid service provision of run-of-river hydropower by coupling it with other energy storage technologies such as batteries and flywheels. Further details about these foundational efforts are provided in the project descriptions in this section.

To ensure HydroWIRES research is informed by industry input and expertise, WPTO has also released a draft HydroWIRES Research Roadmap in March 2020 for public comment. This roadmap describes the motivating challenges and strategic goals of the HydroWIRES Initiative, as well as future research plans. A range of stakeholders provided detailed feedback on the roadmap, generally affirming its focus and approach. After incorporating these comments, the final roadmap is expected to be published in 2021.

Finally, informed by the roadmap development and associated stakeholder feedback, several new HydroWIRES efforts have kicked off in the past year. For example, in October 2020, WPTO released a NOTA—the second time the office has publicly issued competitive opportunities to apply for technical assistance. Through the notice, WPTO will arm hydropower decision makers—such as hydropower operators, utilities, and system operators—with national lab expertise and capabilities to address current challenges and capture new opportunities for their systems. Experts from the national labs will provide specialized technical assistance on topics such as opportunities to participate in new markets and hydropower representation in integrated resource planning. Through these partnerships, the labs will refine draft methodology, models, and tools and make them available to the public and the hydropower community at large. WPTO will publish selections and progress updates in the coming year.

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Halving the Commissioning Timeline for Pumped-Storage Hydropower Development—FAST Prize Successfully Produces Promising Technical Solutions

In October 2019, four grand prize winners were selected for a total of $550,000 in cash prizes and vouchers for follow-on technical support from several DOE national labs as part of the final stage of the Furthering Advancements to Shorten Time (FAST) Commissioning for Pumped-Storage Hydropower Prize. Beginning with a pool of 31 competitors, the three-stage FAST prize was designed to encourage new technical solutions to accelerate PSH development and reduce commissioning times from the industry average of 10 years to less than 5. After pitching ideas ranging from reducing excavation timelines to cutting costs with scalable, modular concepts, FAST prize winners were selected by a panel of judges from academia, government, and the private sector. The winners are currently working with the national labs to refine their concepts.

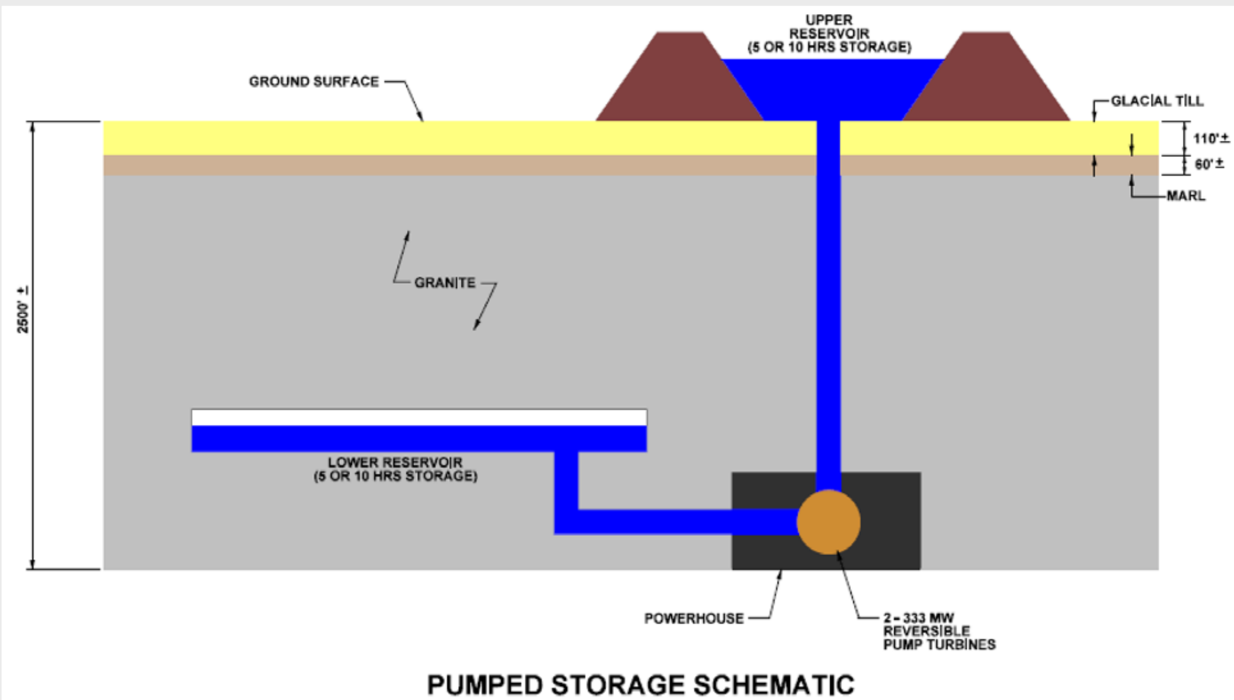

Figure 2. Conceptual closed system underground pumped hydroelectric storage concept by Nelson Energy.

Courtesy of Nelson Energy

Although the U.S. PSH fleet comprises 43 projects providing 95% of the country's utility-scale electricity storage, only one new PSH facility has come online in the past 20 years. Unrecognized energy storage valuation, permitting challenges and construction risks, competition from other storage technologies, and high up-front project costs have all been contributing factors to a slowdown in deployment. To further investigate development challenges, a pumped-storage hydropower FAST technical analysis report developed in tandem with the competition found that civil works, including the upper and lower reservoirs and water conveyance components, and equipment, most notably the powertrain, comprise the largest portions of overall project capital costs. Similarly, the upper and lower reservoirs, water conveyances, and transmission interconnection components require the longest development times.

WPTO launched the FAST Prize in April 2019 to solicit ideas, designs, and strategies to reduce the costs and timelines of PSH development. The first hydropower competition within the American-Made Challenges series received solutions ranging from new layouts and creative construction management and improved construction equipment to application of advanced manufacturing or standardization of equipment.

The following grand prize winners continue to advance their concepts:

Doug Spaulding from Nelson Energy proposed the use of tunnel-boring machines for underground excavation, which can decrease excavation time by 50% and reduce costs. The team is collaborating with Pacific Northwest National Laboratory (PNNL) and Argonne National Laboratory (Argonne) to identify groundwater sources, as well as produce both an economic and a cost-benefit analysis of the project. The team is also studying the feasibility of employing underground pumped hydroelectric storage in Granite Falls, Minnesota, as well as looking into other possible sites in Minnesota and Wisconsin.

Gordon Wittmeyer and Biswajit Dasgupta from the Southwest Research Institute presented a modular steel concept for dams that proposes to reduce costs by one-third and cut construction schedules in half. The team produced a series of charts to assist developers in pinpointing their specific project needs in terms of PSH capacities and steel dam heights. From there, developers can choose which configuration is best suited for an upper reservoir site and which design will require the least structural and plate steel per module, thereby reducing construction costs.

Tom Eldredge and Hector Medina from Liberty University presented a modular, closed-loop, scalable PSH system with a capacity range of 1–10 megawatts (MW), adaptable to sites without natural bodies of water. The team is scouting potential locations in the Southwest Virginia region, where this technology could be successfully implemented, while continuing to carry out hydrodynamic calculations for their PSH system.

The National Renewable Energy Laboratory (NREL) continues to track the winners' progress and publish updates on a semiannual basis. Following the grand prize announcement, winners worked to further advance their concepts throughout 2020, with the help of voucher support and funding to accomplish a range of activities, such as feasibility studies as well as engagement with developers, equipment vendors/suppliers, and other demonstration projects designed to facilitate upscaling and commercialization.

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Integration of Run-Of-River Hydropower with Energy Storage Creates Additional Grid Value, New Market Participation Opportunities

Throughout 2019–2020, Idaho National Laboratory (INL) worked closely with Argonne and NREL to demonstrate the technical potential and economic benefit of co-locating and coordinating multiple run-of-river hydropower plants with different types of energy storage devices, creating "virtual reservoirs" with potential to function similarly to conventional reservoir-based hydropower plants. Partnering with Siemens, the project team developed a centralized control scheme, the Smart Energy Box, to coordinate operation of different energy storage devices at one or multiple hydropower plants. The project also succeeded in applying market participation modeling to assess the ability of hybrid energy storage systems to perform similarly to conventional hydropower plants in responding to grid needs, opening the door for potential new markets for run-of-river owner/operators to participate in.

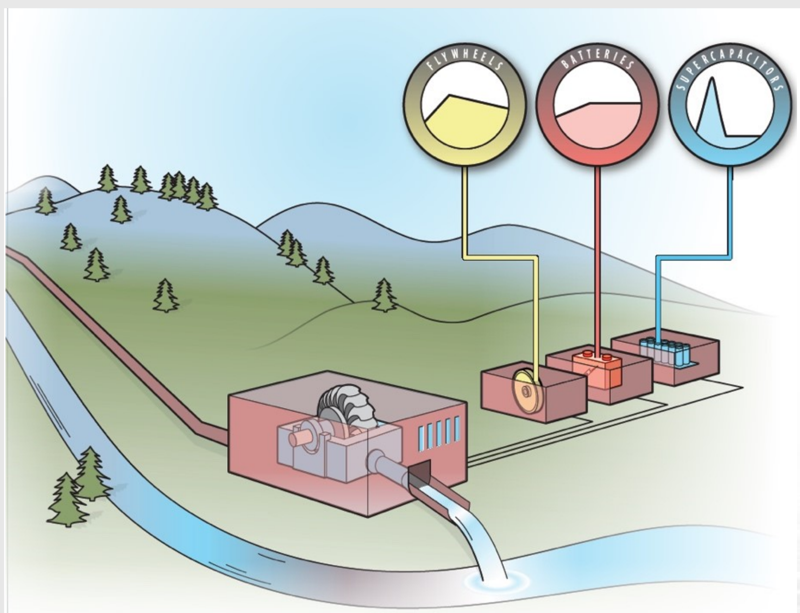

Figure 3. Concept design of INL's Integrated project.

Courtesy of INL

Initiated in 2016 with support from WPTO, the first phase of the project (2016–2019) looked at demonstrating the technical feasibility and financial performance of combining energy storage systems with run-of-river hydropower plants to provide a greater range of grid services. Nearly half of the U.S. hydropower fleet operates as run-of-river. Whereas reservoir-based plants have usable storage that allows them to shift or withhold water releases for generation during higher value times of the day, run-of-river facilities have little to no ability to control the timing of water releases. The team demonstrated that integration of energy storage (e.g., batteries, flywheels, and/or ultracapacitors) can enable a run-of-river hydropower plant to perform similarly to a hydropower plant with reservoir storage.

A key accomplishment from the team is the development of Siemen's innovative Smart Energy Box, which coordinates operation of multiple units/plants and energy storage devices and can be optimized for providing services and performance desired by the owner/operator. The Smart Energy Box monitors grid operator signals and determines how to meet programmed objectives using all connected devices most effectively. It can be used to enable a broad range of benefits, including provision of ancillary services, or reduction of ramping speed and the frequency of hydropower generators, which can have positive outcomes on wear-and-tear rates.

Another accomplishment was the application of Argonne's Conventional Hydropower Energy and Environmental Systems (CHEERS) model to simulate and optimize market participation of integrated hydropower and energy storage systems. CHEERS optimizes day-ahead scheduling and real-time operations for hydropower by considering multiple objectives (e.g., cost, power, environmental considerations) to support decision-making on unit commitment and turbine-level operating points. For this project, the team expanded the capabilities of CHEERS to include energy storage configurations and ensure all the complexities of modeling a storage device (e.g., state of charge, storage life) were accurately represented. This capability allowed CHEERS to not only readily analyze the value of different integrated hydropower and energy storage systems, but also develop an understanding of how the value of such a system could be maximized.

To demonstrate these concepts in a real-world scenario, researchers completed a case study in partnership with Idaho Falls Power, the local municipal utility, which owns and operates four cascaded run-of-river hydropower plants. Using the utility's operational data, the team performed real-time simulations of energy storage hardware with the run-of-river hydropower plants to assess the performance enhancements from hybrid energy storage systems, demonstrating that a run-of-river hydropower plant integrated with energy storage can respond to a frequency event like a conventional hydropower plant. Using Argonne's CHEERS model and real-world market, water, and plant capability data, the team found integrating energy storage with Idaho Falls Power's hydropower facilities can boost revenue by 12% to 16%.

Phase II of the project began in 2019 and focuses on applying the tools, models, and capabilities developed in Phase I to a series of use cases. The first use case is being explored in partnership with Idaho Falls Power and uses ultracapacitors integrated with a run-of-river hydropower plant to enable black-start capability. Black-start capabilities at the distribution level would enhance system reliability and allow hydropower owners/operators to restore services in islanded mode, reducing downtime for customers if an event occurs and improving grid resilience. This capability will be demonstrated in a field test with Idaho Falls Power during 2021.

Follow-on work will include increasing the set of services that can be provided using the technology, demonstrating the technology through field deployments in partnership with industry, and developing guidance on topics such as sizing optimization to accelerate implementation. Additionally, in 2021 INL plans to develop a prototype energy storage selection tool to help hydropower owners/operators that are considering hybridizing their plants to select appropriate technologies and optimal sizes based on their storage needs.

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Low-Cost, Modular Pumped-Storage That Can Be Installed Anywhere—ORNL GLIDES Project Nears Commercial Readiness

ORNL concluded a 4-year research, testing, and analysis project investigating a new lab-developed PSH technology, and results indicate promising cost and commercialization potential. The Ground-Level Integrated Diverse Energy Storage (GLIDES) project concluded R&D of a new form of PSH targeting the gap between small-scale batteries and large grid-scale PSH options. Throughout 2019–2020, ORNL completed modeling and simulation of GLIDES to verify its viability as a storage option for a number of scales in utility and behind-the-meter applications, and completed market analysis that confirmed the technology's ability to provide essential reliability services across diverse U.S. electricity markets. To cap off the project, ORNL evaluated the economic value of co-locating GLIDES within a run-of-river hydropower plant and co-optimizing their joint operations to reduce systemwide energy costs and open up new opportunities to participate in ancillary markets, a capability traditionally unavailable for run-of-river facilities.

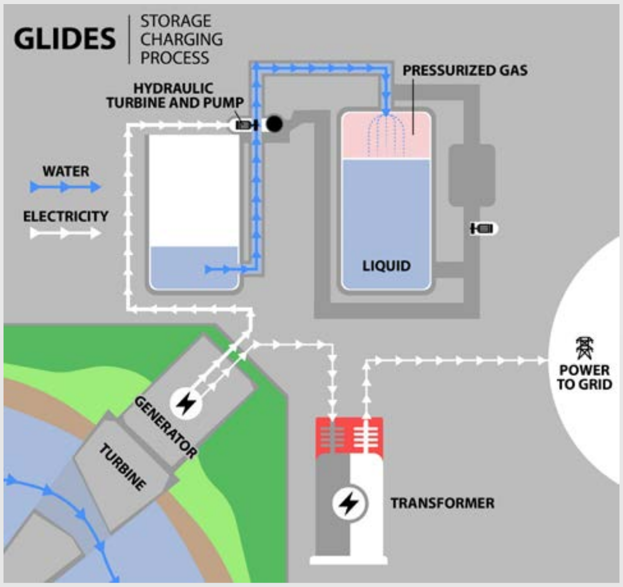

Figure 4. GLIDES during the charging phase of operations.

Courtesy of ORNL

GLIDES is a modular, scalable energy storage technology designed for a long life (>30 years), high round-trip efficiency (ratio of energy put in compared to energy retrieved from storage), and low cost. The technology works by pumping water from a reservoir into vessels that are prepressurized with air (or other gases). As the liquid volume inside the pressure vessel increases, the liquid acts as a piston and compresses the gas in the vessel, storing energy. When electricity is needed, a valve opens and the compressed gas in the pressure vessel pushes the high-head water through the GLIDES system's hydraulic turbine to generate electricity.

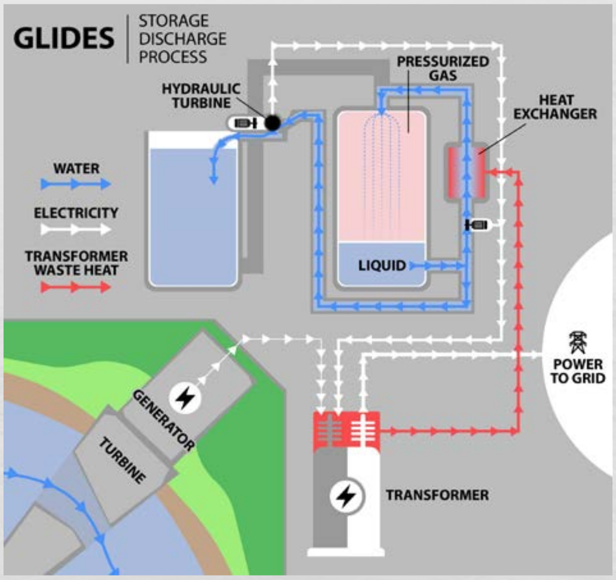

Figure 5. GLIDES during discharge.

Courtesy of ORNL

Over the course of the multiyear (2016–2020) project, ORNL focused on validating the GLIDES system performance, reducing the capital cost of the pressure vessels, which account for 75%–90% of total system costs, and evaluating revenue potential through market participation. The researchers built and demonstrated two proof-of-concept prototypes at ORNL using carbon steel and carbon-fiber pressure vessels and supplied air and water as the working gas and liquid. To study the behavior of the prototype systems, the research team developed and validated physics-based and techno-economic models using experimental data from the prototypes. Round-trip efficiencies as high as 82% were achieved in the experiments, and ORNL identified multiple pathways for increasing GLIDES system performance and minimizing capital costs. Market analyses conducted in 2019 also showed the technology can provide essential reliability services across diverse U.S. electricity markets. A case study performed for a grid-scale 60-megawatt-hour (MWh) system demonstrated that GLIDES can produce yearly revenues of as much as $10 million by providing ancillary services such as arbitrage, operating reserve, and regulation services. Based on the estimate of annual revenue and capital costs, the expense of a 60-MWh GLIDES system can be recouped in as little as 3 years.

Complementary to the lab's earlier analysis, during 2019–2020 ORNL was also able to conduct additional simulated studies for GLIDES leveraging available hydropower data from INL's Integrated Hydropower Storage Systems project. The objective was to evaluate the financial performance of GLIDES when incorporated within four cascading run-of-river hydropower plants. As these types of facilities are typically not configured to have an impoundment, they have limited operational control and ancillary services. Because GLIDES is a form of energy storage, ORNL saw an opportunity to evaluate the technology as part of an integrated hydropower and energy storage system to not only provide energy but also participate in ancillary markets and thus create more revenue streams. The Integrated Hydropower Storage Systems project had previously evaluated the financial performance of these four cascading run-of-river hydropower plants when combined with other types of energy storage, including flywheels and Lithium-ion batteries. Partnering with the integrated team allowed for an apples-to-apples comparison of the potential benefits of hybridizing run-of-river hydropower plants with different types of energy storage.

In the case study, each run-of-river plant was assumed to be equipped with a 1-MW, 4-hour-duration GLIDES system. Researchers then estimated the annual profit based on typical selected days using the collected downstream water flow rate data and a price profile generated by the integrated team. The simulation looked at scenarios wherein it was more efficient to use the generation from the run-of-river plants to charge GLIDES versus when it was more optimal to sell to an energy market directly. Results showed that, when incorporated into the run-of-river system, GLIDES could be highly profitable within a 4- to 6-year payback period, with each megawatt-hour of energy or ancillary service provided by the integrated hydropower energy storage system to the power grid reducing energy production costs, including decreased transmission congestion and losses.

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New Pumped-Storage System Could Significantly Reduce Geologic Risk and Increase Market Viability

Obermeyer Hydro and its project partners NREL, Microtunneling, Inc., and Small Hydro Consulting found that, compared to conventional pumped-storage resources, Obermeyer's novel PSH system could reduce initial capital costs by 33%, increase the number of potentially viable sites, decrease potential environmental impacts of PSH projects, and reduce geologic risks of underground powerhouse construction. Geological surprises can make the complex underground excavation and construction associated with PSH susceptible to unexpected costs and delays; therefore, risks can be mitigated by reducing the volume and complexity of such excavations. The company's configuration is uniquely designed to only require construction of a vertical shaft to position a submersible pump-turbine/motor-generator sufficiently deep, instead of an elaborate underground cavern that would involve much larger excavation. By providing the PSH pump-turbine in a shaft instead of an underground powerhouse, Obermeyer's technology will help reduce costs and time of construction for future deployments.

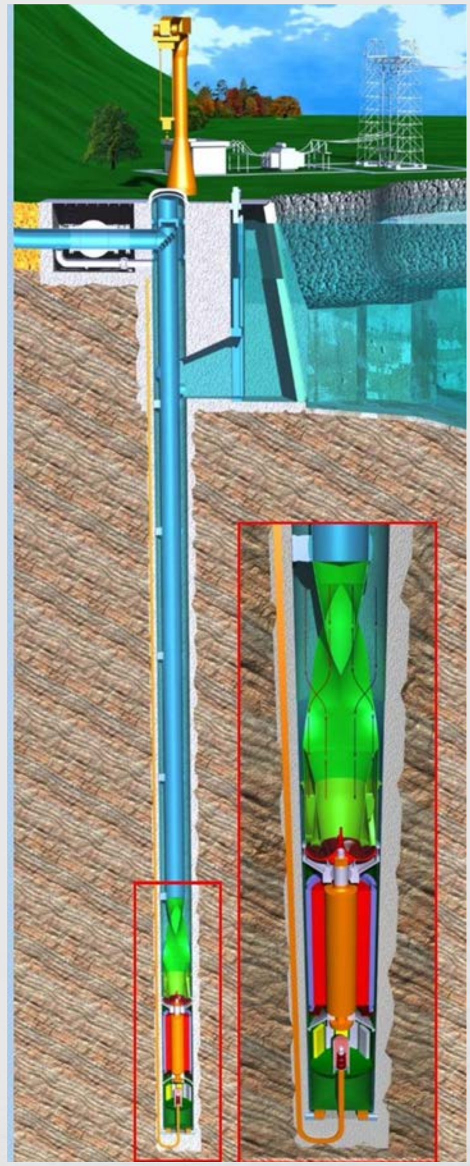

Figure 6. In Obermeyer's PSH configuration, a turbine-generator is placed at the bottom of a shaft with a lifting mechanism to facilitate future maintenance. In generation mode, water flows through the penstock into an inner pipe to run the turbine-generator and comes out through the outer pipe to the tailrace. An underground powerhouse is not required, allowing for more economical development while reducing geological risk.

Courtesy of Obermeyer Hydro, Inc.

To enable broader development of PSH, both cost and scale reductions are important. To help shorten deployment times and reduce project costs and other vulnerabilities, WPTO awarded funding to Obermeyer Hydro, Inc., to design a cost-effective, small-scale, adjustable-speed PSH system optimized for U.S. energy storage requirements. According to WPTO's *Hydropower Vision* report, the United States has the potential to add 36 GW of PSH by 2050—more than doubling the country's current capacity. But since 2000, only one new PSH project has been constructed in the United States. Historically, PSH projects must be very large to justify the high fixed costs associated with engineering complex underground structures that come with inherent geological risk. Reversible-pump turbines have strict, design-specific submergence requirements and are typically installed in a large, excavated underground powerhouse—but such facilities are also expensive and require suitable geology.

Obermeyer's project focused on the design of an adjustable-speed PSH motor-generator and also took a lens to the integration of several subsystems, including electromagnetic and mechanical components and weights, into a complete PSH system design while developing a breakdown of estimated costs. The required subsystems include the pump turbine itself, the motor-generator, the power converter, the control system, and the water conveyance structures, including penstock, draft tube, shaft with liner access cover, and pressure relief valve. The novel permanent-magnet motor-generator with heat pipe cooling promises higher power density than traditional permanent-magnet designs. Hydraulic efficiencies of 94%–95% were achieved through computational fluid dynamics modeling and independent verification of the system.

A publication capturing these results, methodologies, and further data is expected to be released in early 2021.

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Lower Environmental Impacts for Closed-Loop Pumped-Storage—New National Lab Study Published

Although pumped-storage hydropower comprises 95% of utility-scale energy storage in the United States, one of the challenges to developing new pumped-storage projects is potential environmental impacts; however, new closed-loop pumped-storage projects are being developed internationally and are expected to produce minimal environmental impacts versus traditional open-loop designs.

To assess this idea, PNNL led the 2020 release of “A Comparison of the Environmental Effects of Open-Loop and Closed-Loop Pumped-Storage Hydropower.” Supported by the HydroWIRES Initiative, the report’s goals were to (1) distinguish between open- and closed-loop environmental effects, (2) describe how these impacts are being avoided, minimized, or mitigated at existing projects in other countries and proposed projects in the United States, and (3) discuss the significance of the environmental issues.

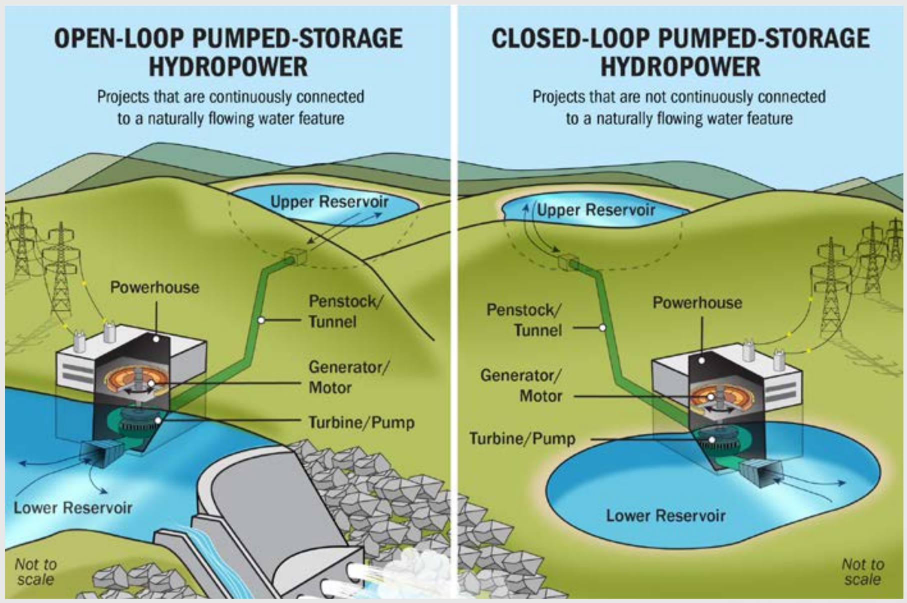

Figure 7. Generic comparison of open- and closed-loop PSH projects.

Courtesy of NREL

PSH is characterized as either open-loop (continuously connected to naturally flowing water) or closed-loop (not continuously connected to naturally flowing water). Because the majority of PSH projects—operating both internationally and in the United States—are open-loop, the environmental effects of closed-loop projects have not yet been well-documented. PNNL’s report concluded that closed-loop projects generally affect the environment on a more localized level and for a shorter duration than open-loop because of their location being “off-stream.” They found closed-loop configurations to potentially minimize aquatic and terrestrial impacts; however, for both above-ground and underground closed-loop projects using groundwater, impacts to geology, soils, and groundwater could generally be higher than those of open-loop projects. Additionally, by not being continuously connected to a naturally flowing body of water, closed-loop projects likely have greater siting flexibility than open-loop projects.

WPTO prepared this report to address the knowledge gap about the potential environmental effects of closed-loop PSH, but additional research is needed to better characterize and assess those environmental effects for all potentially affected resources. While it discusses the environmental effects of both open- and closed-loop PSH projects, it does not imply that PSH projects have environmental effects that cannot be mitigated. In addition, many PSH projects under development have their own unique characteristics, such as being built in a pre-existing mine or quarry, or otherwise taking advantage of existing infrastructure. In all cases, the impacts of any specific facility need to be considered individually. As a next step, the report team recommended conducting in-depth interviews with PSH developers (including some who developed closed-loop

PSH projects in other countries), resource agency staff, staff from nongovernmental organizations, and other stakeholders to solicit their input to better characterize the potential environmental effects of closed-loop PSH projects.

For more information about the report and associated findings, visit the HydroWIRES website.

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Environmental and Hydrologic Systems Science

Although hydropower has tremendous value to the power system as a flexible, renewable resource, its long-term value depends on maintaining a high level of environmental performance across the fleet. The WPTO Hydropower Program develops new technologies, tools, and data to better understand and improve the environmental performance of hydropower facilities. WPTO's work focuses particularly on issues related to fish passage, water quality, and water release management. In addition, this activity area aims to provide a better understanding of potential ecological and economic risks associated with long-term hydrologic variations. The Environmental and Hydrologic Systems Science activity area focuses on: (1) developing monitoring and mitigation technologies to improve environmental performance, 2) supporting foundational and applied biological, environmental, and hydrologic systems science research to understand environmental impacts, and (3) establishing relevant standardized metrics to understand environmental impacts and improved performance.

National Labs Commercialize Proven Environmental Evaluation Tools for Industry Use

From Fiscal Year (FY) 2019 to FY 2020, WPTO's HydroPASSAGE project, a multiyear R&D collaboration between PNNL and ORNL, successfully tested, licensed, and commercialized a number of tools to reduce fish injury and mortality of entrained fish as well as lower the regulatory costs of licensing and operations. HydroPASSAGE leverages more than 25 years of research to develop novel instruments and software tools that can be used by turbine manufacturers, hydropower facility owners, consultants, and scientists carrying out fish impact evaluation studies of hydropower turbines and facilities.

Tools and technologies developed under HydroPASSAGE use biological design criteria from scientific, validated predictions of impacts to fish from turbine passage. Two cornerstone tools within the project's portfolio include the Biological Performance Assessment (BioPA) Tool and Hydropower Biological Evaluation Toolset (HBET), which use hydraulic condition-based information to provide predictions on the impacts to fish for both existing and new turbines being designed. While BioPA applies modeled, computational fluid dynamics data often supplied from turbine manufacturers, HBET enhances the design process by using biologically-based field data from the Sensor Fish—a small, autonomous instrument filled with sensors that analyze the physical stresses fish may experience when passing through or around dams. A smaller Sensor Fish Mini has also been developed, which focuses on gathering data from smaller hydropower structures.

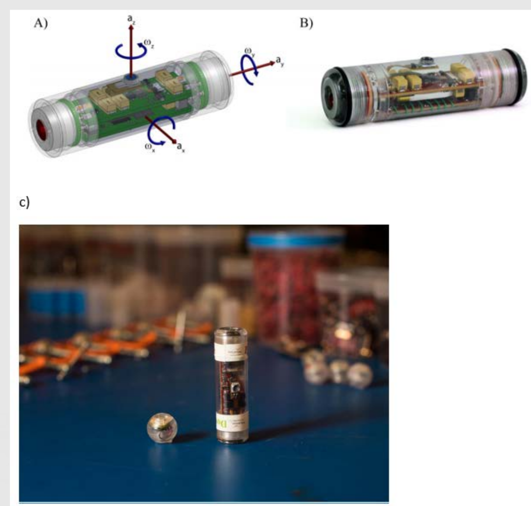

Figure 8. The Sensor Fish device: A) three-dimensional (3D) model, B) photo of the actual device, and C) Sensor Fish Mini size comparison with the Sensor Fish.

Courtesy of PNNL

In 2019, with support from the DOE Technology Commercialization Fund, Oregon's Hood River Valley provided an ideal field-testing location for several HydroPASSAGE tools, including the Sensor Fish and HBET, as well as the Sensor Fish Mini, which made its debut field trial. PNNL led the study, which sought to evaluate the effectiveness of fish passage after installing a series of screens designed to enable safe downstream passage for fish at irrigation structures. During testing, only one Sensor Fish Mini experienced any kind of issue in migrating through the screens. These data are important for validating the use of new screens for improved fish passage and verifying that the Sensor Fish technology can be applied in other tests to evaluate the integrity of hydraulic passage structures.

Building off of the 2019 tests in Oregon, in early 2020 PNNL worked with the U.S. Army Corps of Engineers on a more expansive field test of the Sensor Fish at Ice Harbor Dam in Washington State. PNNL researchers released and collected data from more than 900 Sensor Fish at three different elevation levels throughout the testing campaign. Ice Harbor is a major dam within the Federal Columbia River Power System, and recently had some of its turbines replaced with the primary goal of improving fish passage survival. Using the Sensor Fish and its associated suite of computational tools, PNNL characterized the physical conditions of one of the dam's turbines and compared its passage conditions with the results from a 2015 baseline assessment of the original turbine. Overall, the preliminary results showed the new turbine's fish passage hydraulic conditions had significantly improved, with an estimated 98% survival rate calculated for juvenile salmon.

Currently available for purchase, the intellectual property for the Sensor Fish was recently licensed to Advanced Telemetry Systems, which has gone on to manufacture and deploy the technology in several countries. Additionally, two new BioPA and four new HBET licenses were also executed in FY 2020, with licensees comprising a combination of owner/operators, original equipment manufacturers, environmental and engineering consultants, and research institutions. Between licensing, field testing, and other lab-based work, the HydroPASSAGE team was also able to publish three new peer-reviewed publications in FY 2020, which can be accessed on the project website for further reference.

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Industry-Led Research Provides Accurate, Artificial Intelligence–Based Approach for Analysis of Sensitive Species Passing Through or Around Dams

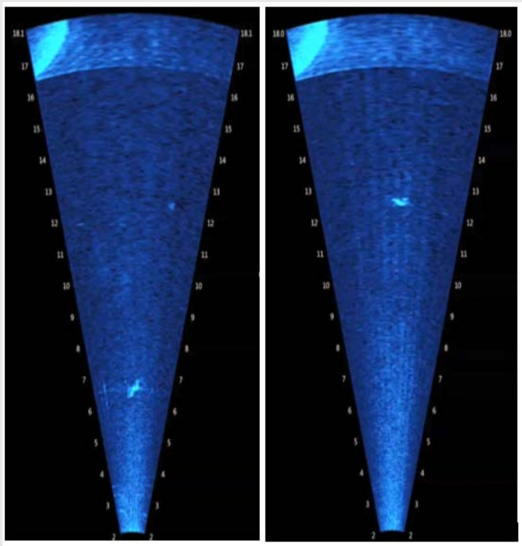

Figure 9. Sonar tracks used in the Electric Power Research Institute's project on Deep Learning for Automated Identification of Eels.

Courtesy of EPRI

The Electric Power Research Institute (EPRI) successfully achieved proof of concept for automated identification of silver phase American eels in multibeam sonar data, providing evidence of a new mechanism to more accurately detect and analyze species of concern in the United States. One of the key industrywide challenges to improving fish passage outcomes at hydropower dams across the country is effective monitoring of population, movement, and behavior of different aquatic species. By applying convolutional neural network (a type of artificial intelligence) tools to automate time-consuming processes for eel identification, EPRI was able to achieve greater than 98% accuracy in laboratory-based testing and almost 90% in field-testing results in distinguishing between eels and similar-sized naturally occurring river debris such as sticks. These results are comparable to the classification accuracy achieved by analysts in previous studies and provide a promising application for studies of other fish species in different environments.

The American eel has experienced population declines in eastern North American rivers and is a species of concern in the United States. To address this challenge, EPRI's Eel Passage Research Center has explored new use cases and analytical methods for sonar-based detection of migrating American eels near hydropower dams. In 2017, the institute conducted a series of field tests at New York's St. Lawrence River, which not only provided needed monitoring data but also established the Adaptive Resolution Imaging Sonar as a promising tool for eel detection within 20 meters during periods of high river flow. The crux of their most recent WPTO-funded analysis was how to accurately automate eel detections using these sonar data. Convolutional neural networks have recently shown superior automated imaging analysis over a variety of artificial intelligence approaches and are capable of "learning" features from data at varying levels of resolution.

To expand on the 2017 field data, EPRI partnered with PNNL to conduct laboratory tank tests, comparing American eels with other moving objects to demonstrate the validity of convolutional neural networks data analytics methods. Testing results proved to be exceedingly promising: while lab and field-test evaluations yielded high accuracy rates (approximately 98% and 90%, respectively), EPRI found that convolutional neural network algorithms trained on a combination of laboratory and field data achieved 100% classification accuracy for eels versus similar-sized sticks and other objects in the field. Automating sonar-based detection with such high accuracy rates has the potential to save time and reduce costs of monitoring fish passage and, ultimately, fully automate fish passage systems. Key next steps for this project include acquiring more data, modifying tools to identify other species of fish, integrating hydroacoustic software tools, and more.

Given the results of this study, EPRI and PNNL are also conducting outreach with both hardware and software providers to further develop and commercialize the technology. In 2020, PNNL received a Technology Commercialization Fund award from WPTO to establish a sonar image database of eels and other objects and to transition the convolutional neural network algorithms into user-friendly software with a graphical interface. The award will also provide an opportunity for the project team to acquire more field data from partners, including the Technical University of Munich, the U.S. Geological Survey, Hydro Tasmania, and the Great Lakes Fishery Commission. The resulting open-source tools developed throughout the rest of the project will be provided at no cost to the public.

Software tools developed by this project are posted at github.com/xzang/Deep-learning-for-sonar-images.

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Smallest-Ever Acoustic Transmitter with Advanced Battery Improves Juvenile Fish Tracking and Analysis

In 2020, PNNL completed its Eel/Lamprey Tag Development project to miniaturize its Juvenile Salmon Acoustic Telemetry System technology. The project represents a major step forward in the ability to more safely and accurately study the migratory patterns of aquatic species of concern. Using a novel microbattery to develop a tag small enough to specifically monitor juvenile eels and lampreys, the tag will also apply to many other small fish species or juveniles throughout the United States.

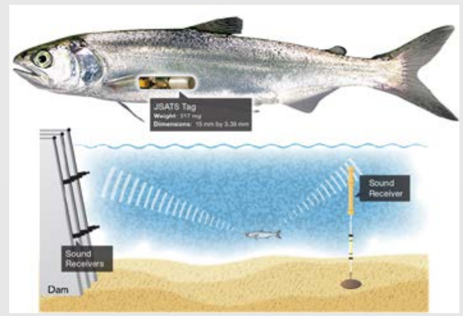

Figure 10. The original Juvenile Salmon Acoustic Telemetry System tag.

Courtesy of PNNL

Once abundant throughout all tributaries of rivers flowing into the Atlantic Ocean and upstream through the St. Lawrence River to Lake Ontario, American eels are facing dramatic population declines, ranging from 50% to 90% across various locations. Because dams may impede the migration patterns of eels and fragment and/or reduce available habitats, understanding the impacts of hydropower and providing effective mitigation and passage are necessary for managing eel populations. In addition to the American eel, in the Columbia River Basin, the Pacific lamprey population—a valuable cultural and ecological resource for Native Americans—has severely declined in the past 40 years.

PNNL's work sought to design, prototype, and perform lab and field tests of an acoustic micro transmitter to study the behavior and survival of juvenile eels and lampreys, and to ultimately provide researchers with an improved tool for understanding migration routes and timing, habitat use, and hydropower dam survival rates for species of concern. PNNL's project team, consisting of researchers from the lab, government organizations, tribes, and state agencies, developed a miniature monitoring device—the smallest acoustic transmitter in the world—to implant into fish to better understand their movement through hydropower dams. The resulting tag, which was surgically placed in the body cavity of the species, is capable of transmitting data over relatively long distances and tracking 3D positions of fish as they move through streams. During the 38-day study, there were zero fatalities as well as minimal tag losses. Researchers also concluded that for both species, the implantation created no significant change to swimming ability.

The next phase of the project is focused on providing the eel/lamprey tag tool and related protocols to the hydropower community that will enable new sensitive species monitoring. In June 2020, this project was selected to receive funding under the Technology Commercialization Fund to optimize the tag design with enhanced firmware, improving frequency accuracy, acoustic signal strength, and reducing the size of the transmitter; optimizing and commercializing the devices' microbatteries by conducting two trial runs of battery production; and developing an advanced manufacturing process for the transmitter.

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Innovators Offer New Solutions for Protecting Fish via Collaborative Interagency Prize

On September 25, 2020, WPTO and the Bureau of Reclamation selected three winners for the Fish Protection Prize, a three-staged competition designed to inspire innovators to develop solutions to keep fish away from water diversions and intakes. From employing air bubbles and netting systems to using sounds and pulsating light, competitors offered and developed a wide range of new solutions, designs, and strategies to improve fish exclusion technologies, decreasing the numbers of entrained fish from river and canal diversions, diversion pipes, and intakes at hydropower plants. The prize was a joint effort between WPTO, the Bureau of Reclamation, NREL, and PNNL that engaged 20 innovators through multiple competitive stages, resulting in three winners sharing a pool of cash prizes and in-kind support to make their technologies ready for market. This effort was informed by the initial Fish Exclusion Prize—a competition administered by the Bureau of Reclamation that focused on early-stage concepts—and is one of several American-Made Challenges competitions designed to spur U.S. entrepreneurial leadership in energy innovation and domestic manufacturing.

Figure 11. The Fish Protection Prize inspired innovators to develop solutions to improve fish protection, or exclusion, technologies, like the fish guidance netting system designed for cost-effective maintenance and sustainability.

Courtesy of Nicholas LaBry's Team, 2nd place grand prize winners, Fish Protection Prize

When the flow of water moves fish into pipes and dam intakes, fish become separated from their natural habitat, impacting native populations, threatening biodiversity, and impeding recovery efforts for threatened and endangered species. Launched in January 2020, the Fish Protection Prize inspired innovators to compete for $700,000 in cash prizes and national lab voucher support, drawing in experts from academic and industry backgrounds to develop innovative ideas to enable improved fish passage outcomes.

The one-year, three-stage prize began with a 90-day CONCEPT round, in which competitors proposed an idea for cost-effective fish exclusion at water diversions and intakes. The subsequent INCUBATION stage spanned 90 days, wherein winners were paired with PNNL and received up to 50 hours of technical assistance. During the PITCH CONTEST, the final stage of the prize, competitors presented their refined innovations to a live, virtual audience at the annual meeting of the American Fisheries Society.

Nine teams participated in the PITCH CONTEST, presenting their concepts and the technical and market feasibility of each, as well as their overall R&D plans. Out of these nine teams, three winners were selected. The prize-winning teams, receiving both cash and voucher support from PNNL, included the following:

- **Grand prize:** Benjamin Mater of Alden Research Laboratory and Charles Coutant, Making a Deal with the Devilfish: Biometric-Informed Screening Technology, an efficient new bar shape for fish exclusion screens inspired by filter-feeding fish. To be developed using computer models and a lab flume.

- **Second place:** Nicholas and Kenneth LaBry of Prometheus Innovations LLC, Fish Diversion Material & Inspection Improvements, which includes improving current fish diversion implementations by developing acoustically sensitive materials to facilitate easier inspection.
- **Third place:** Sterling Watson and Abe Schneider of Natel Energy, The Center Sender, which is a physical or combined physical/electrical device designed to guide fish to the safest path through a hydropower intake or water diversion.

The three winning teams will use the prize pool and additional support from PNNL to advance their concepts through fall 2021 in hopes of bringing their technologies to market. More information about the prize, participants, recent updates, and supporting analysis can be found at herox.com/FishProtection.

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Public-Private Partnership, New Autonomous Dissolved Oxygen Sensor Enables Hydro Plant's Improved Energy Generation and Water Quality

In fall 2019, a new autonomous, mobile water quality sensor platform for measuring dissolved oxygen was rigorously field-tested at an operational hydropower plant in North Carolina for the first time. The new sensor package, developed by PNNL under WPTO's Real-Time and Autonomous Water Quality Monitoring System project, takes water quality measurements in difficult and sometimes dangerous environments around hydropower intakes and discharges and enables safer, timelier, and a more complete picture of dissolved oxygen levels at hydropower plants. The technology was put into practice at a hydropower facility in North Carolina, where the system monitored the performance of a newly installed aerating turbine. Important partners in this collaborative effort included Eagle Creek Renewable Energy (Eagle Creek; formerly Cube Hydro) and General Electric (GE).

For Federal Energy Regulatory Commission (FERC) licensing, hydropower operators are often required to collect environmental data, which is an essential building block for optimizing environmental and energy operational outcomes. Data collection plays an important role in managing and mitigating the impacts hydropower operation can have on aquatic life, such as water temperature shifts and fluctuating levels of dissolved oxygen and nutrients in the waters upstream and downstream of the facilities. Maintaining levels of dissolved oxygen outlined in state water quality standards, for example, is crucial to the health of fish and other freshwater organisms, though it is often challenging during seasons of drought or when the facility is passing a large quantity of water through the turbines. Collecting more comprehensive water quality data, such as dissolved oxygen data, can help overcome this challenge; however, capturing these data points can be difficult because of the hazardous conditions near hydropower plants, particularly around intakes and tailraces.

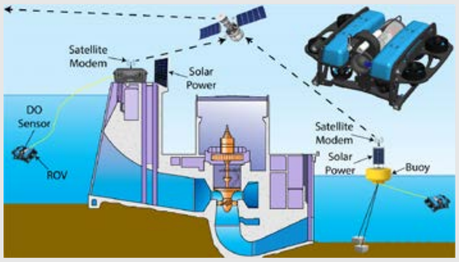

Figure 12. The autonomous water quality monitoring system increases the reliability of water quality data collection around hydropower facilities. The data are collected via a robot, to be retrieved anywhere with an internet connection.

Courtesy of PNNL

Currently, water quality monitoring at hydropower facilities is limited by a lack of mobility. Most methods rely on a stationary buoy and sensor or a human worker to take measurements. This not only limits the selection of sampling sites but can pose safety risks during data retrieval and equipment maintenance. Additionally, reliance on a single point source measurement of water quality at a specified depth fails to provide data that present a complete picture of water quality throughout a water column at multiple locations.

Although many hydropower projects perform monthly dissolved oxygen sampling or retrieve hourly logged data during equipment maintenance visits, PNNL's autonomous water quality monitoring system is based on a remotely operated vehicle that can travel to multiple depths and locations and features software that allows users to access real-time and historical sensor data. The data are displayed on a dashboard, so power plant operators can provide dissolved oxygen data in real time as needed to optimally operate aeration equipment for mitigating low dissolved oxygen levels.

The platform features two deployment schemes, allowing it to accommodate flow conditions from upstream and downstream dams:

- **Dam structure-based deployment:** The remotely operated vehicle is tethered from a station at the top of the dam—without using a buoy—with locations and depths along the face of the dam near the intake.
- **Buoy-based deployment**: The remotely operated vehicle uses a buoy as a docking station at a downstream location—at or very near the tailrace—to take measurements at any location not limited by the length of the vehicle's tether and local flow conditions.

In late 2019, the technology was put into practice at Eagle Creek's High Rock Hydroelectric Facility outside Charlotte, North Carolina. Situated on the Yadkin River, the High Rock facility had experienced difficulties in maintaining minimum levels of dissolved oxygen during seasons of drought or when the facility was passing water through its turbines for generation. To mitigate during periods of low dissolved oxygen, Eagle Creek implemented two measures: 1) adapting an existing spill gate to aerate spill and 2) installing GE's new aerating turbine. The project team deployed PNNL's water quality monitoring system to demonstrate how it can be used to assess the performance of these systems, allowing High Rock to more effectively monitor the dissolved oxygen and use the data to optimize turbine operations through digitalization. Data from the effort will also help GE to accurately assess the performance of its new aerating turbine to inform any future design changes.

Looking ahead, the team will conduct outreach to hydropower owners, operators, and other interested stakeholders to share advances and gather feedback on the prototype and present the resulting research findings. In 2021, PNNL, working in partnership with Southern Company, will also deploy the water quality monitoring system in the tailrace at Logan Martin Dam in Alabama.

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Fleet Modernization, Maintenance, and Cybersecurity

WPTO's Hydropower Program supports the existing hydropower fleet through research and development into advanced instrumentation and data evaluation to improve equipment longevity and condition-based repair. In addition, the portfolio focuses on creating cybersecurity tools and studies to enhance the security of critical dam infrastructure by articulating the cybersecurity structure, risk, and recovery landscape, as well as developing cross-cutting digitalization systems and advanced sensor suites to empower data-driven decisions on operations, maintenance, and asset management. Work was also initiated in hydropower digitalization to document the value opportunities and trends in the sector.

New Techniques Demonstrate Significant Reductions in Cavitation, Critical for Extending the Service Life of Hydropower Components

In 2019, PNNL's Solid-State Processing (SSP) project completed a series of laboratory tests and successfully identified a number of techniques with potential to reduce cavitation erosion, a critical step toward enhancing the performance and service life of new and repaired hydropower components. The recipient of a 2017 R&D 100 Award—which recognizes the top 100 most innovative technological breakthroughs in the world—PNNL's SSP work presents a novel approach for producing a wide range of high-performing materials with efficient manufacturing methods to lower operation and maintenance costs, reduce the duration and frequency of outages, and extend the life of hydropower components. Testing results have thus far proved promising, with SSP outperforming more conventional techniques of component repair following a series of experiments.

Cavitation is a phenomenon affecting many hydropower metal components where vapor bubbles form and collapse as a result of rapid pressure changes in the water. When the vapor bubbles collapse, they generate small but powerful shock waves that create "pits," or small cavities on metal surfaces. As the number and size of pits increases, wear rates and intensity of cavitation accelerate. Cavitation damage is usually the costliest maintenance item for hydropower facilities because of unexpected shutdowns and unplanned maintenance. Mitigation of material loss resulting from cavitation is key to the cost-effective long-term operation of hydraulic machines.

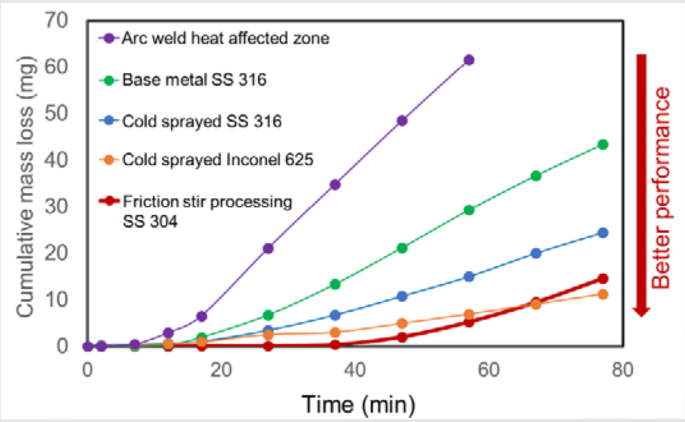

Figure 13. Friction stir processing and cold spray are both types of solid-state processing that dramatically outperform arc welding and base metal by demonstrating better cavitation erosion resistance.

Courtesy of PNNL

Although a variety of techniques are used for repairing cavitation, the most common is arc-welding filler material onto a component to replace eroded material. One of the major drawbacks of this technique is that arc welding can degrade the microstructure of the component and original metal, causing high heat input and melting, which can result in additional costs. Unlike arc welding, SSP technologies can produce repairs that match or exceed the performance of the parent material of existing turbines. In addition, they also have the potential to produce new components with improved mechanical properties and cavitation resistance, a differentiating quality that can aid in long-term maintenance strategies.

To demonstrate the feasibility of SSP to reduce cavitation damage in hydropower components, PNNL performed a series of tests by applying two promising SSP techniques—cold spray and friction stir processing—to base metal samples commonly used in hydropower components. Cavitation testing was successfully performed on the samples, and the results were benchmarked against commercially available, unprocessed materials and arc-welded counterparts. The results demonstrated SSP can lead to significant improvements in cavitation erosion resistance compared to that of the unprocessed base metal and conventionally repaired counterpart. This improved performance provides a stepping stone for further adoption of SSP to enhance U.S. hydropower infrastructure.

Commencing in 2020, the next stage of the project focused on advancing cold-sprayed technologies, which were identified as the best method for on-site cavitation repair. Cold spray is a metal powder deposition process in which material coatings are built up by supersonic impingement of metal powders upon a base metal. Innovations in tooling equipment have made it possible to execute cold-spray repairs in areas with clearances as small as 1.5 inches, making this technology ideal for performing repairs in tight spaces, which are characteristic of typical hydropower plants. PNNL is currently optimizing the chemistry for hydropower applications, establishing processes and parameters for portable equipment, and exploring the feasibility of combining cold-sprayed technologies with robotic repair in anticipation of a forthcoming field demonstration. This technology is expected to dramatically improve the service life of hydropower components, resulting in maintenance cost savings, improved plant reliability, and reduced frequency of outages—all important for grid reliability and resilience.

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Data Access and Analytics

The Hydropower Program's Data Access and Analytics portfolio was developed to help the hydropower industry and stakeholders manage large and disparate, data sets necessary for resource assessment and project siting, plant and unit performance, operations, costs, maintenance, permitting, and environmental mitigation. This includes efforts to support the comprehensive historical review of regulatory process drivers and outcomes as well as identify mechanisms for increasing access to information and coordination among permitting agencies. This area of work also includes the office's efforts to make all of the data and information collected and produced in the course of funded research publicly available and easily accessible.

Constructing a Complete Picture: DOE Publishes Timely and Valuable Data on U.S. and Global Hydropower and Pumped-Storage

In January 2021, WPTO will publish the third complete edition of the "U.S. Hydropower Market Report." Previous surveys and feedback from readers shows the information about U.S. hydropower and industry trends is useful to a broad range of stakeholders and decision makers. Combining data from public and commercial sources, as well as DOE R&D projects, the seminal report provides the most comprehensive picture of developments in U.S. hydropower and PSH alongside national and global industry trends and future projections.

The publication is the third complete edition of the "U.S. Hydropower Market Report," preceded by the 2014 and 2017 editions. This edition picks up where the 2017 report left off, covering the updated 2017–2019 data and contextualizing this information with high-level trends spanning the past 10–20 years. The publication was evaluated by 34 external reviewers from 24 organizations, ranging from turbine manufacturers and owners and operators of hydropower systems to federal agencies, consultancies, labs, and other associations and organizations.

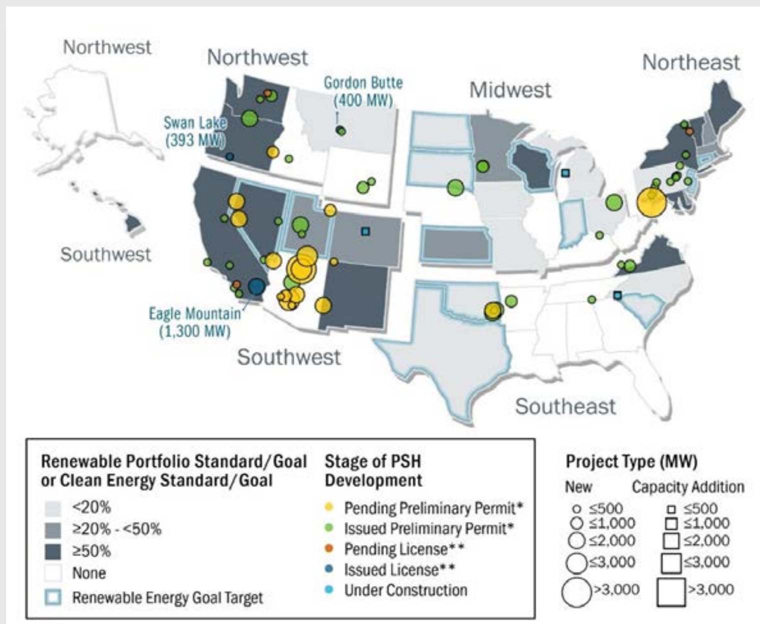

Figure 14. Pumped-storage hydropower project development pipeline by region and status in relation to state-level renewable energy targets (as of December 31, 2019).

Courtesy of ORNL

Breaking trends down by region, plant size, owner type, and other attributes, the report also communicates updated information about the U.S. and global hydropower and PSH development pipeline and hydropower prices, and offers performance metrics for the period following the "2017 Hydropower Market Report." The 2019 report discusses hydropower and PSH's contributions to flexibility services and grid reliability, summarizing findings from DOE's HydroWIRES Initiative.

Organized into seven chapters, the report includes a chapter looking back at changes across the U.S. hydropower and PSH fleet, as well as a chapter looking ahead to the future U.S. hydropower and PSH development pipeline. Chapters 3–7 examine U.S. hydropower in the global context, U.S. hydropower price trends, U.S. hydropower cost and performance metrics, trends in the U.S. hydropower supply chain, and policy and market drivers, respectively.

The report draws several important conclusions:

- Almost as much PSH capacity was added from 2010 to 2019 (1,400 MW)—mostly from upgrades to existing plants—as the combined installed capacity of all other forms of energy storage in the United States (1,675 MW).
- Interest in PSH in the United States continues to grow significantly, as evidenced by the doubling of the numbers of projects in the development pipeline over the past 5 years.
- Geographic interest in U.S. PSH has expanded as well, with new projects under exploration in Pennsylvania, Virginia, Wyoming, Oklahoma, Ohio, and New York.
- Internationally, there has been a significant and growing interest in PSH. At the end of 2019, 50 PSH projects under construction equated to 53 GW of capacity globally, with an additional 226 GW of PSH in development, essentially doubling the global fleet.
- Hydropower provides a plethora of ancillary services, punching well above its weight when compared to percent of installed capacity in nearly every region and by every metric analyzed, including black start, 1-hour ramps, frequency regulation, and reserves.
- At the end of 2019, a total of 128 projects constituting 669 MW of hydropower had been issued a FERC license, though construction had not yet been initiated; more than half of the projects had been in this state of limbo for 3 years or more.
- FERC relicensing activity is expected to more than double in the coming decade, with an estimated 4.7 GW of hydropower capacity and 9.1 GW of PSH capacity to be added.

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Innovations for Low-Impact Hydropower Growth

DOE's Hydropower Program supports new, low-impact hydropower development by advancing design and testing of new standard modular hydropower technologies for existing water infrastructure and new stream-reach developments. This new, philosophically different approach to systems design for hydropower projects incorporates ecological and social objectives for rivers throughout the design processes. Work in this area also seeks to leverage new advancements in manufacturing and materials to dramatically lower costs of standard modular hydropower components and modular system designs to reduce costs of custom-engineering and construction and timelines. Another key objective is the scoping and development of testing infrastructure for new technologies.

Hydropower Manufacturing Prize Winners Conceive Strategies To Lower Costs and Improve Performance of Hydropower Components

On December 18, 2020, 11 winners were announced for the Innovations in Advanced Manufacturing for Hydropower (I AM Hydro) Prize, a competition designed to award ideas that have the potential to dramatically lower costs and increase performance of hydropower components and system designs by leveraging advanced manufacturing principles and practices. Each winner, out of a prize pool of $175,000, received a cash prize to further evolve and develop their concept throughout 2021. Ideas were scored based on innovation, impact, and feasibility. 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 nonpowered dams using 3D concrete printing, additive manufacturing technology paired with modern advances in robotics to enable superior repair, antifouling coating for hydropower cost reductions, and more.

Over the last decade, advanced manufacturing has helped revolutionize the energy sector, offering a boost to the U.S. manufacturing industry and opening pathways to increase American competitiveness. Novel applications of advanced manufacturing have ushered in benefits in other energy sectors such as wind and solar and helped industries reach economies of scale and mass production; however, the potential applications for hydropower remain largely unexplored, and thus the benefits remain untapped.

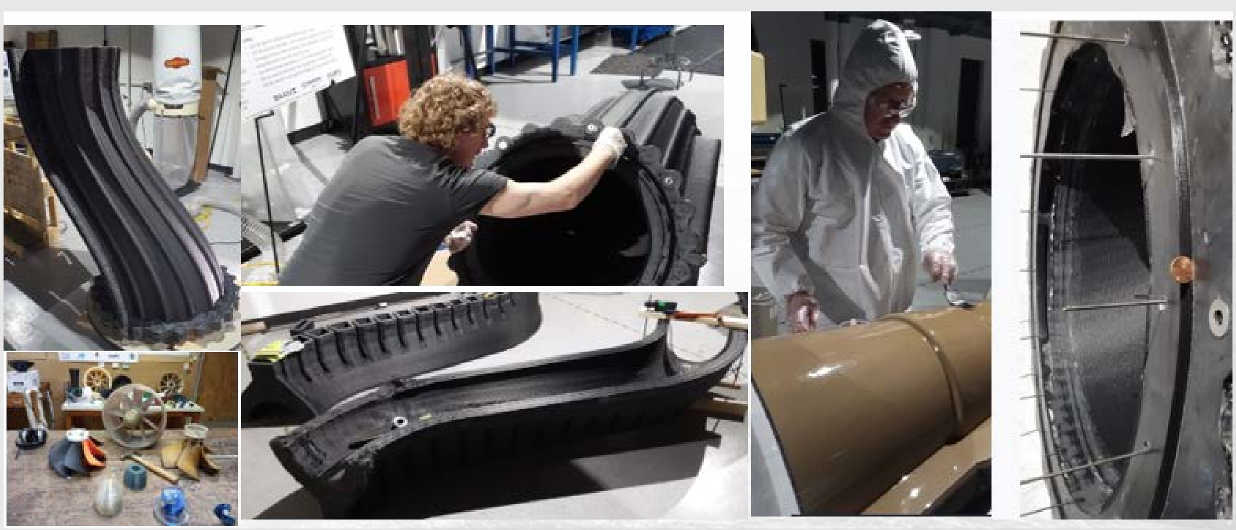

Figure 15. To link automated design to additive manufacturing, the grand prize winner of the I AM Hydro Prize, Team Cadens Hydro, completes post-print processing, fabrication, fit, and finishing steps. Their winning concept may radically reduce costs for micro/small hydro parts and tools and increase annual energy production.

Courtesy of Randal J. Mueller, Team Cadens Hydro, I AM Hydro Prize

WPTO designed this single-stage competition, part of the American-Made Challenges series, as a means of identifying high-impact opportunities to apply advanced manufacturing processes and materials to improve conventional hydropower manufacturing—enhancing design flexibility, decreasing energy consumption, lowering costs, and reducing time to market. The prize solicited ideas for advanced manufacturing applications with specific interest in the following categories: joining, coating, and repair; additive and composite manufacturing; casting, forming, and machining; and advanced materials.

The I AM Hydro Prize was designed to:

- Catalyze the use of advanced manufacturing to drive down levelized costs of hydropower by seeking solutions that can dramatically lower initial capital costs and/or increase annual energy production
- Inform WPTO's future investments by identifying targeted, high-impact opportunities to apply advances in manufacturing to address hydropower's critical challenges, which may be used to inform future funding opportunities
- Bring new innovators into the hydropower sector and help form partnerships and collaborations between industry, academia, and government to accelerate innovative advanced manufacturing technologies for hydropower.

Funded by WPTO and administered by NREL and ORNL, the I AM Hydro Prize launched in June 2020 and accepted submissions through October. For a full list of winning concepts, prize teams, and next steps, visit the American-Made Challenges I AM Hydro Prize page.

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Penn State Demonstrates Modular, Scalable, and Rapidly Deployable Hydropower Turbine and Generator System Appropriate for a Variety of Sites

After four years of comprehensive analysis and testing, Pennsylvania State University (Penn State) successfully manufactured and tested a rapidly deployable, high-efficiency hydropower turbine-generator system prototype. This modular and scalable turbine-generator was developed for energy generation at a variety of low-head sites and has the potential to significantly reduce levelized cost of energy. The university's design uses a condition-based health monitoring system to reduce the cost of O&M and to enable advanced control of the turbine-generator system performance. A combination of condition-based maintenance and optimized control could potentially result in increased reliability and operational availability across a fleet of hydropower units.

Figure 16. Products of advanced manufacturing and validation testing.

Courtesy of Pennsylvania State University

Supported by WPTO, PSU's project focused on producing a device that could be flexibly deployed at reduced costs. The 0.2-meter-diameter prototype was designed for scalability across a wide number of low-head hydropower applications, ranging from 10–30 meters of head, with a power output between 100 kilowatts (kW) and 1 MW. Low-head hydropower sites tend to display higher variability of flow rates than higher-head locations, and Penn State developed its variable-speed permanent-magnet generator system to allow for high efficiencies over wide operating ranges. Using conventional and additive manufacturing techniques, Penn State produced several blades before opting for 316L—a type of stainless steel—as the prototype blade alloy due to its material strength, corrosion resistance, weldability, and cost.

The turbine prototype was fabricated and tested at the university's Applied Research Laboratory water tunnel. The team simulated representative fault conditions during the tunnel testing to generate realistic fault data and verify the system's ability to identify issues. Results demonstrated the initial capital costs for Penn State's design were competitive with existing commercial solutions, with hydraulic efficiencies approaching 90% over a broad range of flows. The team was also able to demonstrate the key advantages of additive manufacturing—such as additional design freedom, minimization of initial material purchase, minimal postprocess machining, and elimination of fixed tooling. Future work will focus primarily on commercializing the device for wider applications.

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The 21st Century Archimedes Screw: New Materials and Manufacturing Techniques Enable the Turbine's Highest-Ever Measured Efficiency

In July 2019, Percheron Power, with support from PNNL and Utah State University's Water Research Lab, developed and tested a next-generation Archimedes hydrodynamic screw turbine constructed from composite materials and leveraging advanced manufacturing methods. While the Archimedes screw has been primarily used as an irrigation tool for several millennia, the past 15 years have seen exciting new applications of the device in the form of hydroelectric power. The project explored a new approach to manufacturing with potential to lower costs and increase efficiencies of future turbine blade development across the industry and demonstrated record efficiency for an Archimedes hydrodynamic screw turbine to date.

Figure 17. Percheron Power's composite Archimedes hydrodynamic screw.

Courtesy of Utah State University

Though reliable, efficient, and fish-friendly, the technology has faced barriers to production, transportation, and installation that have resulted in higher project costs and slowed industry adoption of the design in the United States. The current Archimedes hydrodynamic screw manufacturing process requires bending of large steel plates that must be welded together, ground smooth and prepped for painting, then completely finished at a factory. This means a turbine assembly up to 16 feet in diameter and up to 80 feet long must be shipped fully constructed to the installation site, which is both costly and logistically challenging. Producing the turbines from composite materials, however, offers an attractive alternative on several fronts. The research team evaluated four optimized composite turbine designs developed and 3D printed by Percheron Power. The researchers generated more than 900 data sets and published a paper in the *Journal of Hydraulic Engineering* before selecting the best design for a larger prototype.

In Phase 1 of the project, researchers investigated various methods of blade fabrication before deciding upon Light Resin Transfer Molding, which offers lower production costs, as well as reduced waste and emissions relative to conventional steel. Though they can provide the same structural properties as steel, composite turbines are 25%–30% lighter in weight. Because the composite blades are gel-coated while in the mold, they require no primer or corrosion-resistant paints as a steel blade would. Moreover, the smooth, gel-coated blades reduce corrosion—as well as friction—which reduces hydraulic losses.

Light Resin Transfer Molding produces identical, highly reproducible blades from molds that can be used more than 1,000 times each, ultimately resulting in reduced production costs per each turbine. Turbines produced through this method also eliminate oversize shipping costs and logistics, as the blades can be mounted on the shaft at the turbine installation site instead of the factory. The composite blades can be replaced individually, unlike a traditional steel turbine blade. The team also filed a patent on the design and methodology for producing this removable-blade turbine.

In Phase 2, the screw-turbine prototype was successfully tested at full scale. The Utah Water Research Lab completed more than 70 successful water test runs of the first prototype, achieving the highest measured efficiency of any Archimedes hydrodynamic screw to date, with power outputs of 39 kW, tested flows from 10 to 50 cubic feet per second, and turbine speeds from 10 to 40 revolutions per minute. The Composite Archimedes Hydrodynamic Screw Project effectively developed a new, optimized composite Archimedes hydrodynamic turbine, demonstrating it can be effectively and efficiently produced via advanced manufacturing methods. Percheron Power is believed to be the first company in the world to manufacture replaceable composite blades for an Archimedes hydrodynamic screw turbine or pump employing the Light Resin Transfer Molding process. The resulting composite blade turbines are durable, efficient, and cost-effective energy generators that are expected to positively impact future turbine assemblies and low-head hydropower applications.

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U.S. DEPARTMENT OF
ENERGY

Office of
ENERGY EFFICIENCY &
RENEWABLE ENERGY

Marine and Hydrokinetics Program

A recently launched 35-kilowatt water power system in Alaska used the Kvichak River as a renewable energy source to provide approximately half of the Native Village of Igiugig's electricity. *Courtesy of ORPC.*

2. Marine and Hydrokinetics Program Overview

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. These challenges are intensified by high costs and lengthy permitting processes associated with in-water testing.

The vision of the WPTO Marine and Hydrokinetics (MHK) Program is a U.S. marine and hydrokinetic industry that expands and diversifies the nation's energy portfolio by responsibly delivering power from ocean and river resources. To help realize the vision, the MHK Program conducts transformative early-stage research that advances the development of reliable, cost-competitive MHK technologies and reduces barriers to deployment. The MHK Program comprises four core R&D activity areas and one initiative that represent the program's strategic approach to addressing the challenges faced by U.S. marine and hydrokinetic stakeholders.

Success stories within this year's publication are presented within these areas:

1. Powering the Blue Economy
2. Reducing Barriers to Testing
3. Foundational R&D
4. Technology-Specific System Design and Validation
5. Data Access and Analytics.

Readers can learn more about the MHK Program and its projects by visiting the WPTO website, following the Office's Water Wire e-newsletter, or exploring the WPTO Projects Map.

Powering the Blue Economy

WPTO formally launched the Powering the Blue Economy™ initiative in 2019 following an analytically driven process focused on near-term end-user needs to understand the potential for using marine energy within the blue economy. The program is strategically growing a portfolio of investments to accelerate development and deployment of marine energy technologies, which includes supporting foundational research; providing access and upgrades to testing assets; developing an entrepreneurial ecosystem; and fostering partnerships with government and private sector end users.

New WPTO-Led Initiative Drives Marine Energy as a Future Enabler of Growth in the Blue Economy, New Scientific Discovery, and Resilient Communities

Within a year of announcing the Powering the Blue Economy initiative, WPTO launched several new competitive solicitations, including prizes and competitions like the Waves to Water Prize, the Ocean Observing Prize, and the Marine Energy Collegiate Competition; formalized partnerships with other agencies and offices within DOE; and released publications detailing preliminary national laboratory–led research on customer demand for energy resources for ocean observing. In 2020, WPTO made more than 85 awards to partners outside of the labs to catalyze innovation in marine energy, including 60 selected projects through its prizes and competitions, 13 new projects under the Small Business Innovation Research/Small Business Technology Transfer Program, and 12 new grants and subcontracts in coordination with other agencies and DOE offices. The initiative is applying an array of funding platforms to more closely connect with customers and end users in the blue economy; to better understand the power requirements of emerging coastal and maritime markets; and to advance marine renewable energy technologies to relieve power constraints and promote economic growth.

From a purely economic perspective, the "blue economy" is a rapidly growing sector of the world economy. The Organization for Economic Cooperation and Development predicts the global economic value attributable to ocean-related activities will double from $1.5 trillion in 2015 to $3 trillion by 2030, which is twice the rate of growth as the rest of the global economy.[1]According to the White House 2020 Proclamation on National Ocean Month, developing and advancing the blue economy is a federal government priority.[2] There is a growing recognition of the importance of new technologies to support the blue economy. Some sectors and opportunities—such as aquaculture, ocean observing, and mineral extraction—are expanding further offshore, but moving farther from the shore requires systems that allow for access to consistent, reliable power and are untethered to land-based power grids. These opportunities are not limited to the offshore environment, as coastal communities are also increasingly looking to the ocean to develop resilient energy, food, and water systems.

However, growth in many blue economy sectors is constrained by lack of energy, or these sectors are reliant on sources that require frequent refueling or battery recharging or changing, limiting the growth potential. Existing energy solutions are often unfit for purpose, limited in capacity, damaging to the environment, and expensive, so there are is a real need and opportunity for energy innovation. There is significant potential to develop technologies to serve both deep offshore and nearshore energy solutions. Technology breakthroughs in the blue economy are possible but will require new ways of thinking about energy development, including interdisciplinary approaches, co-development of energy solutions embedded within or tied to blue economy platforms, and innovation across multiple technology domains.

To better understand possible applications for marine energy in the blue economy, WPTO, NREL, and PNNL investigated potential opportunities for the resource to provide services within different blue economy sectors. From 2017 through early

[1] "Organization for Economic Cooperation and Development, The Ocean Economy in 2030," 2016, https://www.oecd.org/environment/the-ocean-economy-in-2030-9789264251724-en.htm.

[2] "Whitehouse, Proclamation on National Ocean Month, 2020," 2020, https://www.whitehouse.gov/presidential-actions/proclamation-national-ocean-month-2020/.

2019, the team conducted extensive analysis and stakeholder engagement as part of this effort. In April 2019, the results of this effort were released in "Powering the Blue Economy: Exploring Opportunities for Marine Renewable Energy in Maritime Markets." The report identified eight key markets, ranging from aquaculture to coastal resiliency, that are likely to benefit from marine renewable energy.

Figure 24. Through its Powering the Blue Economy initiative, WPTO is exploring opportunities for marine energy to provide power at sea and enable resilient coastal communities.

Courtesy of NREL

Providing reliable marine renewable energy to these markets will require new technologies, programs, and partnerships across the marine energy sector, which WPTO aims to foster through interagency agreements and funding opportunities. To support growth in this area, the program invested in key projects at the national laboratories in FY 2019 and FY 2020, which included expanding the use of prizes to support entrepreneurial growth, funding blue economy innovation ecosystem growth in partnership with the U.S Department of Commerce Economic Development Administration, and launching a program in partnership with four national laboratories and three DOE offices to explore the benefits of marine energy to energy resiliency.

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WPTO Prize Unveils 17 Promising Wave-Powered Desalination Designs

WPTO's Waves to Water Prize—the first prize to launch under the Powering the Blue Economy initiative—is a five-stage, $3.3-million competition to accelerate the development of small, modular, wave-powered desalination systems capable of providing potable drinking water in disaster-relief scenarios and to remote coastal locations. Since its launch in 2019, the prize has attracted more than 120 submissions from teams across the nation, with partners across the globe, spanning academia, large corporations, small start-ups, and individuals.

More than 1.1 billion people lack access to potable water. In disaster-relief scenarios and remote coastal locations, accessing fresh drinking water can be particularly challenging. The Waves to Water Prize was initiated to help address this challenge. In 2020, WPTO announced a new stage, ADAPT, to provide competitors more time to adapt their novel designs to the selected site of the final, DRINK stage of the competition. This final stage is set to take place at Jennette's Pier in North Carolina in 2022.

Figure 19. The Waves to Water Prize consists of five stages and culminates with finalists testing their devices in the open ocean.

Courtesy of NREL

In 2019, more than 60 teams submitted their wave-powered desalination system ideas during the CONCEPT stage of the competition. CONCEPT stage winners featured a range of technologies, incorporating novel materials like inflatable materials and collapsible systems, and included devices such as easily deployable wave attenuators, point absorbers, and oscillating wave surge converters. Following the CONCEPT stage, WPTO launched the DESIGN stage. More than 40 competitors participated in this stage, developing technical plans and supporting analyses to demonstrate their concept for a wave-powered desalination system, including its design feasibility and performance.

In June 2020, 17 DESIGN stage winners received a total of $800,000 in prizes. The third stage—ADAPT—opened shortly thereafter. During the summer and autumn of 2020, teams optimized their desalination system designs to meet site conditions at Jennette's Pier in anticipation of the final two prize stages, CREATE and DRINK, which will open in 2021. Teams will build functional prototypes of their systems in the CREATE stage, and the selected final competitors will test their devices in the open water at Jennette's Pier, competing for $1 million.

The Waves to Water Prize has the potential to advance solutions that meet the needs of several blue economy sectors, including seawater desalination, as well as coastal resiliency and disaster recovery. While the focus of this prize is specific to meeting the needs of remote communities and improving disaster response, WPTO also encourages innovative ideas that can advance marine energy technology readiness for cost-competitive applications of both small-scale and municipal-scale water production. In supporting competitors to demonstrate initial viability through this prize, WPTO aims to lay the groundwork for additional research and attract other capital to support the development and deployment of wave-energy-powered desalination.

Learn more about the Waves to Water Prize.

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First Round of WPTO-NOAA Prize Engages Over 60 Teams, Challenges Competitors To Improve Hurricane Monitoring Technology

WPTO's Powering the Blue Economy: Ocean Observing Prize is a multistage competition run in partnership with the National Oceanographic Atmospheric Administration (NOAA) that challenges innovators to integrate marine renewable energy with ocean observation platforms, potentially unlocking the ability to map, understand, and monitor the ocean. By removing the need for the system to be brought back to shore or to a research vessel for recharging, marine energy could revolutionize the ability to observe the ocean. In 2019, WPTO launched the DISCOVER Competition, engaging more than 60 teams representing a range of competitors, such as universities and marine energy companies and corporations. WPTO used ideas put forward in the competition to help inform the subsequent DEVELOP stage of the prize.

More than 80% of the ocean is unmapped, unobserved, and unexplored. And ocean-observing systems and missions are increasingly constrained by energy limitations that impede data transmission and limit time spent at sea. Through the Ocean Observing Prize, WPTO seeks to change that by challenging innovators to integrate ocean-observing sensors and platforms with marine renewable energy technologies.

Figure 20. By encouraging innovative designs for tomorrow's storm tracking technologies, the Ocean Observing Prize is improving the ability to forecast storms and provide an invaluable service to coastal communities. Receiving renewable energy funding for the first time, one of the DISCOVER Competition winners, Team Navatek, proposed to integrate a rapidly installed breakwater structure into an attenuating wave energy converter, like the one pictured here, to generate power for unmanned underwater vehicles.

Courtesy of Team Navatek

The multiyear, multiphase Ocean Observing Prize combines a series of competitions with up to $3 million in cash prizes to encourage innovation in the fields of marine energy and ocean observations. The first phase, the DISCOVER Competition, commenced in November 2019. Competitors submitted novel concepts that integrate ocean-observing technologies with marine energy systems to address end-user needs across five broad themes: (1) unmanned vehicles; (2) communications and underwater navigation; (3) extreme environments; (4) buoys, floats, and tags; and (5) blue sea ideas (i.e., other). The ideas proposed in this competition—ranging from autonomous underwater vehicles to weather buoys to electronic tags for marine animals—encompassed mobile and stationary technologies. Competitors were evaluated on the impact of their innovation, end-user market potential, and technical feasibility. Eleven winners were selected and awarded a total of $125,000.

The prize's second phase, the DEVELOP Competition, focuses on hurricane monitoring and challenges contestants to develop their ideas into a functioning prototype through three contests: the DESIGN Contest, BUILD Contest, and SPLASH Contest. Through spring 2022, competitors will design, test (in tanks), and deploy systems in an open-water environment, ultimately building systems that demonstrate the viability of charging the systems needed to detect and monitor hurricanes. Hurricane monitoring is just the beginning for the

Figure 21. The Ocean Observing Prize's first DEVELOP competition, focused on self-charging AUVs for hurricane monitoring, includes three stages.

Courtesy of NREL

competition. Subsequent iterations of the prize will focus on different ocean monitoring applications, which could include tracking critical fish stocks or even alerting coastal areas of impending deadly tsunamis.

The prize is a joint effort between WPTO and NOAA's Integrated Ocean Observing System program, with additional support from NREL and PNNL. The competition creates new opportunities for building partnerships between the marine energy and ocean-observing communities to address energy challenges and boost the resilience of coastal communities by extending the range of observation equipment, reducing operational costs, and enabling new data streams.

The Ocean Observing Prize is the second competition to be launched under WPTO's Powering the Blue Economy initiative. Solutions that emerge from this effort will address energy challenges in the blue economy, further advancing ocean energy production and providing an invaluable service to coastal areas. Innovators can tap into NOAA and DOE's network of national laboratories, technology developers, subject matter experts, and other resources to build novel technologies critical for future ocean exploration.

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First-Ever Marine Energy Collegiate Competition Engaged 100+ Students Across Diverse Disciplines

In its inaugural year, DOE's 2020 Marine Energy Collegiate Competition (MECC) challenged university students to propose technical solutions and business cases for marine energy to serve the blue economy, with the potential for real-world applications in the not-so-distant future. Sponsored by WPTO and administered by NREL, the MECC is the first nationwide marine-energy-focused competition designed for students in the United States.

The MECC provided unparalleled professional development and networking opportunities to a large and diverse group of students, many with little to no prior experience in marine energy, helping them understand potential markets for marine energy while preparing them for future careers in the field. Designed to be interdisciplinary, the competition acknowledged the diverse skills needed to enter the marine energy field, whether in research, technology development, project management, marketing, or education.

Figure 22. Photo of the Juracan Energy team from the Universidad Ana G. Mendez in Puerto Rico, one of two teams that tied for third place in the 2020 MECC.

Courtesy of Team Juracan Energy

For this competition, 14 teams developed a market-research-supported business plan and technical design of a marine energy device, created a poster defending the feasibility of the design and business plan, and pitched their ideas to a panel of expert judges. Proposals could address maritime-based industries and communities including—but not limited to—those identified in WPTO's Powering the Blue Economy report. Each pitch included the team presentation and a question-and-answer session, as well as a networking event, giving students the opportunity to seek career advice from marine energy experts.

Participating teams represented universities from 11 states and one territory, Puerto Rico, highlighting all corners of the country. The competition also attracted international interest, welcoming universities from two foreign countries. Notably, the MECC administration moved the in-person event, originally scheduled to take place at the International Conference on Ocean Energy, to a virtual format and adjusted the deliverables, rules, and structure of the competition to meet the new setup. Despite having to finish the competition virtually, the students demonstrated their determination, flexibility, and resilience—three qualities critical to a career in marine energy.

In July 2020, DOE announced the winners of the inaugural MECC. Winning ideas focused on a variety of blue economy applications, including:

- The University of Hawaii's Hālona mobile wave energy converter-powered platform, a self-charging ocean-observing platform that charges autonomous underwater vehicles while simultaneously collecting ocean data

- The University of Massachusetts Dartmouth's Maximal Asymmetric Drag Power Wave Energy Converter that charges batteries in remote or deep-ocean locations
- A resilient and sustainable aquaculture with advanced wave energy converter proposed by Columbia University with Virginia Polytechnic Institute and State University
- The Universidad Ana G. Mendez's buoy pump for water desalination, which aims to provide clean drinking water for disaster-relief areas and isolated communities, inspired by the students' own experiences living through tropical storms in Puerto Rico.

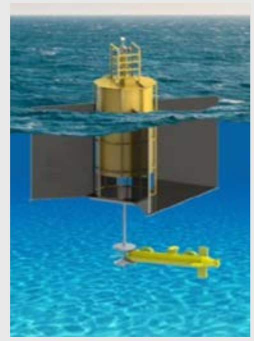

Figure 23. The University of Hawaii Hālona WEC team's proposal focused on a mobile, wave energy-powered, self-charging ocean-observing platform.

Courtesy of the Hālona WEC team

Through the competition, WPTO targeted two important goals. First, WPTO sought to leverage the creativity of students to gather ideas for practical applications for marine energy in the blue economy. Second, the office aimed to engage a diverse set of students and develop the next generation of marine energy experts and entrepreneurs.

The 2020 MECC proved successful in meeting WPTO's goals for the student competition. The second iteration of the competition will launch in 2021, challenging student competitors again to unlock the power of the ocean to support the growth of the blue economy. Building off the 2020 competition, the 2021 MECC enables students to not only formulate and pitch their ideas but also produce a prototype of their device in spring 2021. Teams are encouraged to propose a marketable device powering any marine energy sector of the blue economy.

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Reducing Barriers to Testing

Testing marine energy devices can be particularly challenging, time-consuming, and expensive because of the need to operate in open-water settings. Access to testing infrastructure is limited, while permitting processes can be complex with extensive requirements for environmental monitoring and limited transferability of information. WPTO strives to reduce barriers to testing for the marine energy industry by providing access to world-class testing facilities, focusing research on reducing cost and complexity of permitting and environmental monitoring, and ensuring that existing data are accessible and used by regulators. Scientific research is also directed toward reducing uncertainty about potential environmental risks.

First-Ever U.S.-Accredited, Grid-Connected Wave Energy Test Site Makes Critical Advances Toward 2022 Commissioning

Oregon State University (OSU) has completed the design phase of PacWave South, the first accredited, grid-connected, prepermitted wave energy test facility in the United States, and will soon initiate procurement and construction. Funded by WPTO, OSU submitted a Final License Application and an Applicant Prepared Environmental Assessment to FERC in May 2019 to secure a 25-year license authorizing construction and operation of the 20-MW wave energy test facility.

In April 2020, FERC published a notice of an environmental assessment and a Finding of No Significant Impact for PacWave South, which was finalized following a 45-day public comment period. This was a major milestone in the licensing process, as it provided confirmation that the test site's planned construction, installation, and eventual operations would bear as little environmental effect as possible. OSU also completed the final engineering design requirements for the test site, which includes technical specifications for key components such as the subsea cable system, grid interconnection, and utility connection and monitoring facility (UCMF), which will transmit wave-energy-produced power to the local utility grid. These accomplishments establish the framework for site construction to begin in 2021, with operations expected to commence in 2022.

To connect the power generated by future developers at PacWave with the local land-based utility system and to analyze the performance of each wave energy device, the OSU team will lead the installation and maintenance of subsea power and data cables running from the test site 7 miles off the coast of Newport, Oregon. However, it will be the test clients' responsibility to connect their wave energy devices to the subsea cables via umbilical cables. Although conventional umbilical cables often do not meet the needs of wave energy technologies, work led by NREL and PNNL in partnership with Delmar Systems Inc. and the University of Southampton aims to advance the design of cost-effective umbilical cables for wave energy converters (WECs) that can better meet needed strength and design life requirements. This work will advance designs and tools for power and communication umbilicals that connect floating WECs to subsea transmission cables, which should help developers connect to the grid more effectively.

The PacWave South subsea cable system design, which was developed by engineering consultants 3U Technologies LLC, includes a dedicated subsea cable for each of the four WEC test berths rated for power transmission of up to 5 MW each. The cables will provide data connectivity between developers' WEC systems and the UCMF via 12 fiber-optic elements per cable. An auxiliary, fifth subsea cable will provide power and fiber-optic data connectivity from the UCMF to support the research and development of associated marine energy technology, ocean and environmental research, and activities that support the Powering the Blue Economy initiative. The cables will run below the seafloor for 9–12 miles from depths of 260 feet at the offshore test berth to a shore landing site at Driftwood Beach State Recreation Site. Splice vaults, or beach manholes, will serve to connect the subsea cables to terrestrial cables for onward transmission to the UCMF.

As the future base for test site operators and visiting developers, designs for the UCMF were also completed in 2019. OSU worked alongside project partners, such as Williwaw Engineering, David Evans & Associates, and HGE Inc., to develop and finalize the surveying, engineering, planning, and architectural work needed to enable construction. Following purchase of the UCMF property in March 2019, plans for 2021 include the construction of a 1.2-acre facility designed to accommodate three buildings: a power conditioning building; a switch gear building; and a data, control, and communications center.

Within the power conditioning building, each of four developer bays will be able to accommodate two 40-foot shipping containers for proprietary equipment and other materials. Conditioned power will then run through the switch gear building and into the Central Lincoln People's Utility District power grid.

In addition, the data, control, and communications center will provide site operators and developers with control rooms, communications equipment, data storage capabilities, and other support facilities. A Request for Proposals was issued in early 2020 seeking firms to provide construction and engineering services for terrestrial and marine horizontal directional drill bores and underground construction at this location and the shore landing. Construction will commence once the final FERC license is officially granted.

Once completed, the UCMF site will serve as a base for operations and monitoring of device testing. The four PacWave test berths will have a combined peak capacity of 20 MW. As the test site gears up for construction, the PacWave team is reaching out to developers to secure spots before the site opens for business.

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Figure 24. Aerial view of PacWave's future location and connections to shore.

Courtesy of OSU

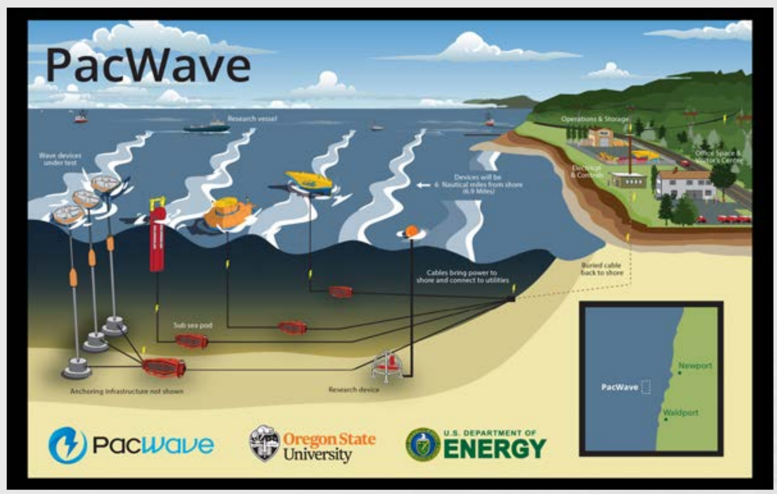

Figure 25. Illustration showing the PacWave South wave energy test facility.

Courtesy of OSU

Critical Field Tests Demonstrate Performance of Newly Developed Environmental Monitoring Technologies

The PNNL-led Triton initiative, designed to support the development and testing of more precise and cost-effective environmental monitoring technologies for marine energy, provided the technical support needed to finalize various stages of testing for several competitively selected WPTO projects, including the University of Washington's Drifting Acoustic Instrumentation SYstem (DAISY), the third-generation Adaptable Monitoring Package (3G-AMP), and Integral Consulting's Benthic Monitoring Study. Between FY 2019 and FY 2020, these projects leveraged PNNL's Marine and Coastal Research Laboratory (MCRL) to gather important environmental data and demonstrate performance prior to deploying in higher energy environments. FY 2020 also saw substantial progress in the Triton Field Trials project, which is designed to advance marine energy environmental monitoring by developing recommended guidelines for data collection and analysis.

Often, the permits to operate a marine energy project require documenting the effects of underwater noise on marine life. While a recent International Electrotechnical Commission (IEC) technical specification (IEC TS 62600-40) helps standardize this process, it can still be challenging to identify the noise produced from marine energy converters against the backdrop of natural underwater sounds. This uncertainty can lead to inaccuracies in determining the environmental risks associated with deploying and operating converters. DAISY addresses these challenges through a rapidly deployable, modular system optimized for high-energy marine environments. The DAISY device is equipped with a hydrophone that records ocean sounds (while minimizing motion between itself and surrounding water), a global positioning system for position information, and meteorological equipment to characterize wind conditions—all integrated using low-cost electronics. There are two DAISY variants: one for measuring current environments (C-DAISY), and another for wave environments (W-DAISY).

In FY 2019, MCRL and several other locations, including the Clallam Bay in Washington and the Wave Energy Test Site in Hawaii, served as testing locations for the DAISY device, which successfully demonstrated system functionality, ease of deployment and recovery, and integration of all sensors. Additionally, PNNL and the University of Washington have developed an application that allows researchers to track DAISY devices in real time and check their status, allowing for ease of use and reliability.

MCRL was also leveraged to advance the 3G-AMP, a system equipped with an integrated set of sensors designed to collect environmental data to support detection and classification of marine animals. Building off of previous tests supported by WPTO, the 3G-AMP includes multibeam sonars, an acoustic Doppler current profiler, an array of hydrophones, a stereo-optical camera, antibiofouling systems, and more. With logistical and field support from the Triton team, the University of Washington was able to test the efficacy of these tools during a 5-month deployment at MCRL in FY 2019, signifying the first deployment of a system with this level of complexity and controllability at a marine energy site.

To reduce the costs and risks of deploying in high-energy environments, the project team redesigned the 3G-AMP system around a modular architecture, allowing the device's sensor head to be more easily deployed and/or integrated with a range of systems, such as wave energy converters and stand-alone landers, than previous models. The 3G-AMP package performed well throughout testing, with 97% operational uptime during an additional 4-month deployment in the Sequim Bay channel, and it accomplished a significant milestone in automatically classifying fish schools, diving birds, and seals with high accuracy rates. An additional open-water, long-term test deployment is anticipated, as the 3G-AMP moves toward commercialization.

Also concluded in FY 2020 is the Triton-supported Integral PacWave Benthic monitoring project. Initiated in 2016, the project developed a new broad-scale seafloor habitat mapping approach, which is based on established acoustic and imaging survey methods. The approach is cost-effective, repeatable, and generates high-resolution benthic habitat maps for environmental monitoring at marine energy sites. Over a number of years, researchers conducted a series of surveys at various locations, including the PacWave South Energy Test Site. The results provided a detailed and contiguous mosaic of physical and biological habitat conditions at the future PacWave site while also demonstrating a process that can detect whether a marine energy device alters seafloor physical or biological conditions.

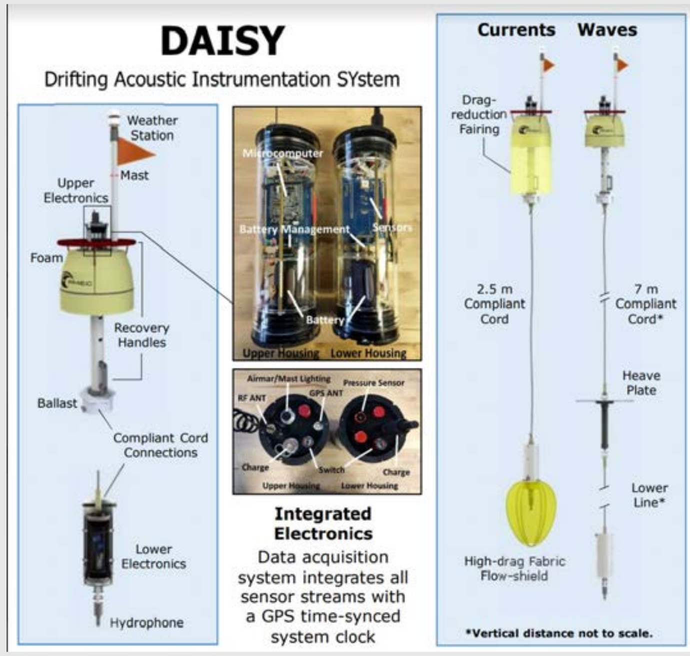

Figure 32. Schematic depicting the DAISY device instrumentation and components.

Courtesy of University of Washington

Finally, Triton made foundational advancements within the Triton Field Trials project in FY 2020, completing a literature review that evaluated existing models and their limitations for collision risk, electromagnetic fields, underwater noise, changes to habitat, displacement of marine species, and changes to physical systems. This review resulted in a report to DOE and has been submitted for publication in a special issue of the *Journal of Marine Science and Engineering*. While field testing has been delayed because of COVID-19, in FY 2020, the project team finalized the locations that will be used for field testing and determined the methodologies that will be evaluated for collision risk, underwater noise, changes in habitat, and electromagnetic fields. Looking ahead, the Triton project team hopes to commence field testing in 2021.

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U.S. Leads Development of the Third International State of the Science Report, Providing the Latest Information on Potential Environmental Impacts of Marine Energy

In September 2020, on behalf of the International Energy Agency's Ocean Energy Systems collaborative, PNNL released the "2020 State of the Science Report: Environmental Effects of Marine Renewable Energy Development Around the World," summarizing scientific progress to date on marine renewable energy devices and their potential interactions with the marine environment, including the animals that live there and the habitats that support them. The report can help inform project siting, engineering design, operational strategies, and monitoring program design, and is targeted for use by many different types of stakeholders, such as regulators, engineers, researchers, policymakers, and more. Prior to releasing the final report, PNNL researchers and other authors released a draft report in June, conducted public webinars, and elicited stakeholder feedback.

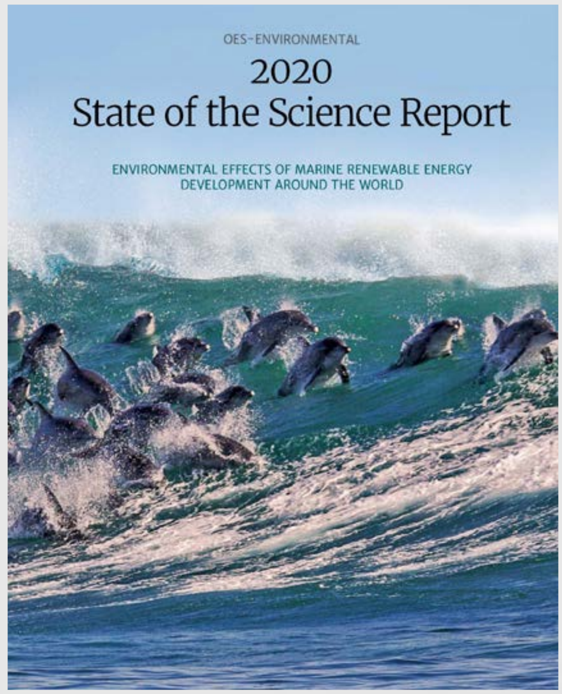

Figure 33. To better understand the impact marine renewable energy devices have on the marine environment, 30 marine scientists from around the globe spent the past 4 years reviewing existing data and research, resulting in the "2020 State of the Science Report."

Courtesy of Andrea Copping and Lenaig Hemery

Although marine energy technologies have the potential to provide a suite of societal benefits—from marine debris cleanup to new drinking water sources—they could also pose some risks if not well-studied and documented. Therefore, monitoring potential interactions between devices and marine animals, habitats, and the environment is vital. Over the past decade, the understanding of potential environmental effects across multiple scales has significantly increased, thanks to environmental monitoring. The "2020 State of the Science Report" represents the most up-to-date knowledge on environmental effects of marine renewable energy, based on studies and monitoring from publicly available, peer-reviewed scientific literature and reports. The study focused on analyzing key potential stressors, including:

- Underwater noise
- Electromagnetic fields
- Changes in oceanographic processes, including circulation, sediment transport, and water quality
- Encounters with moorings and cables
- The risk of a marine mammal or fish colliding with a device.

Funded by WPTO and Ocean Energy Systems, more than a dozen PNNL researchers served as authors, in addition to more than a dozen other authors from around the world. After synthesizing four years of global research, the report found the potential impact to marine life is likely small or undetectable. However, uncertainty still exists around some issues, which will continue to be monitored and studied.

Key report findings include the following:

1. To date, no marine mammals, fish, or seabirds have been observed colliding with a marine renewable energy device.
2. There was no evidence that underwater noise emitted from marine renewable energy devices will significantly alter the behavior or cause physical harm to marine animals.
3. The ecological impacts of electromagnetic fields emitted from power cables from single marine renewable energy devices or small arrays are likely to be limited, and marine animals living in the vicinity of these devices and export cables are not likely to be harmed by emitted electromagnetic fields.
4. Overall, changes in habitat caused by marine renewable energy devices and arrays are likely to pose a low risk to animals and habitats if projects are sited to avoid rare or fragile habitats.
5. Marine renewable energy cables and lines do not have loose ends or sufficient slack to create an entangling loop, so the risk of entanglement is considered very low.
6. The growth of marine renewable energy will result in the increasing use of marine space and the potential for conflict with existing ocean uses, which can be partially addressed through implementation of marine spatial planning.

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Sandia National Laboratories Develops Sophisticated, Accurate Method for Quantifying Marine Energy Noise in Complex Environments

New open-source, publicly available modeling tools have been released by Sandia National Laboratories (Sandia) and a number of partners to help quantify marine renewable energy interactions and noise in marine environments. The Hydrodynamic and Acoustic Models for Quantitative Environmental Assessment project has published several model-based reports, open-source codes, and various training materials that regulators, project developers, environmental consultants, and other scientists can use to evaluate potential environmental effects. As the first-ever underwater acoustic modeling tools to include uncertainty quantification, Sandia's Paracousti and Paracousti Uncertainty Quantification models predict how noise from a marine energy device array spreads through water and sediment, and they provide a promising application for evaluating the random variation in those sound levels.

Sandia worked closely with Montana State University and Integral Consulting to develop Paracousti—an underwater sound propagation tool publicly released as open-source code in 2019 for developers and regulators to characterize sound levels within complex, variable marine environments. Underwater acoustic propagation for marine renewable energy devices is challenging to model, especially as many future deployments are envisioned as arrays with complex sound signatures. A single model run from Paracousti can capture the interaction between multiple, complex sound sources at specific times while accounting for the full 3D variation in sound speed and density—details needed to quantify the effects of marine renewable energy on the environments in which they operate.

For less certain applications, where the characteristics of a given environment may only be known through statistical data, Sandia also developed the Paracousti Uncertainty Quantification tool, which computes probability density functions of the propagated sound within a given setting at a fraction of the costs that might be derived from alternative computational methods. While not yet publicly available, a report Sandia recently produced on upgrades to Paracousti Uncertainty Quantification will inform further tool advancements.

With support from WPTO, 2019–2020 presented several opportunities for connecting these tools to industry. In 2019, Sandia produced and uploaded a series of Paracousti tutorials and guides on the open-source GitHub website for the marine renewable energy industry. As these resources expanded, Sandia also developed easy-to-use tools to assist in the visualization and analysis of the results and their integration into other tools. Part of the value proposition of the Paracousti tool is that is enables export of 2D and 3D pressure and particle velocity fields to allow for species-specific investigations when coupled with response information for marine mammal, fish, and other species of concern. Combining these auditory spatial maps with assessments from hydrodynamic, sediment transport, and other tools gives industry a means to weigh and visually screen all relevant risks, significantly easing communication with regulators and supporting the permitting and compliance process.

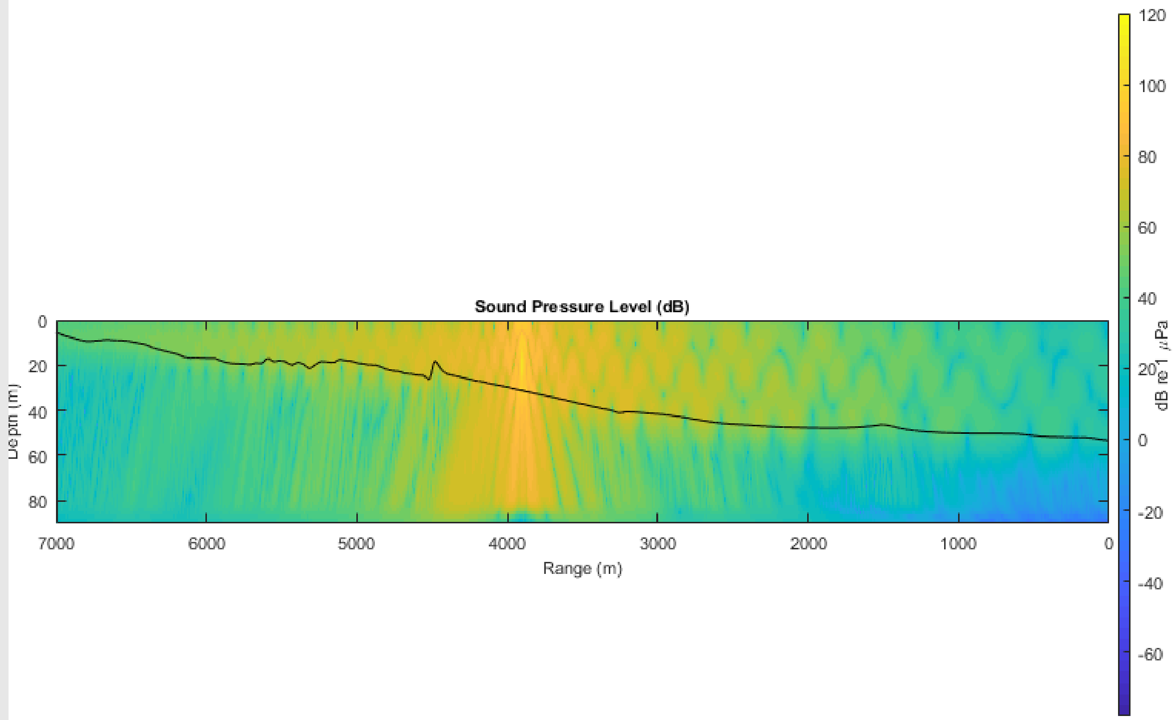

Figure 28. An example file using the Paracousti tool that shows the sound pressure level for a continuous source off a coastline.

Courtesy of Sandia

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Foundational Research and Development

A key part of the MHK Program is the early-stage, foundational research and development to advance the state of components, controls, manufacturing, and materials that can have wide applicability and broad benefit across the marine energy industry. Development and validation of numerical modeling tools as well as improvement of resource assessments and characterizations are also core activities within the portfolio. WPTO works with a wide range of stakeholders to collaboratively develop and apply quantitative metrics to identify and advance technologies with high techno-economic potential.

Co-Design Is Key: Different Approaches to System Controls Research Arrive at Similar Conclusions on the Future of Wave Energy System Design

Through recent research, scientists have confirmed that using advanced controls can result in massive increases (up to 200%) in energy capture for wave energy devices; however, to realize maximum benefits, the controls, power-take-off (PTO) system, and basic structure of the device must all be co-designed from early stages of technology development. From 2014–2020, WPTO supported both Re Vision Consulting and Sandia in conducting controls system research focused on increasing the amount of energy captured from different types of waves to ultimately reduce the costs of power. Re Vision focused on prediction-based methodologies, which assume sensors will be deployed to monitor incoming waves, and Sandia took a broad approach to research but eventually came to favor “predictionless” techniques. Both projects arrived at similar conclusions: co-design for next-generation WECs will likely be important, and additional research and tools to support those processes are necessary.

A consistent challenge with creating energy from waves is ensuring the WEC has an optimized controls framework, which collects information from the device and feeds it back into the system so it operates as efficiently as possible. Re Vision’s favored approach used sensors to take field measurements to anticipate waves off in the distance to model and predict future wave propagation. Broadly referred to as model predictive control, the company found this approach not only enhanced WEC performance but also was the most suitable framework for handling the widest range of device-related controls challenges. Model predictive control typically relies on a forecast of wave forces over a sufficiently long prediction horizon, which Re Vision found to be strongly associated with a WEC’s specific topology and configuration. To investigate how WEC device topology affects controls design processes, Re Vision worked with several developers with different styles of designs to capture the range of challenges encountered in optimal design. This was an especially relevant exercise, as the marine energy industry has not yet settled on a generally accepted archetype, unlike what has occurred with the wind industry and the three-bladed wind turbine. Re Vision’s process involved high-fidelity modeling, wave tank testing, hardware-in-the-loop testing, and open-ocean deployments. One of the company’s conclusions was that WEC performance improvements will be limited by how effective systems-level optimization processes are executed, with the PTO system (mechanism transforming absorbed mechanical energy into usable electricity) and its ability to modulate forces and torques cost effectively in real time being a key component of this. It is therefore important that controls design be deeply integrated into any WEC development effort, beginning with conceptual designs.

Sandia’s perspective on controls arrived at a similar conclusion, where control design should draw on and influence all aspects of WEC design, though an important distinction was their support for “predictionless” control. Throughout the course of the multiyear controls program, Sandia sought to provide developers with a guide for appropriate control strategy relative to their device and PTO system. Sandia ultimately produced a roadmap to WEC control, with a comparison broken down by metrics on control performance as well as on the requirements of implementing different strategies. Lab researchers followed an engineering approach throughout this process, in which any potential research pathway had to be justified with a cost-benefit analysis. A key takeaway from this exercise was that while Sandia found some control methods may provide more power, it found they may also require expensive design changes and/or decrease system reliability and therefore outweigh their benefit. Similarly, if one approach could provide 90% of the optimal result for 10% of the effort of other methods, the first method would be preferred. These insights led to a focus on control system approaches that do not require previous knowledge of incoming waves (i.e., “predictionless control”) through wave measurement and prediction, which can be complex and expensive. A significant benefit of these approaches is that they provide the system insights needed to execute a co-design approach.

Figure 29. A significant component of Re Vision’s controls testing with developers involved open-ocean deployments, such as the one shown here, captured off the shore of Santa Cruz, California.

Courtesy of Re Vision

The findings of this work inspired follow-on work led by Sandia on WEC co-design processes. Initiated in FY 2020, Sandia’s Next Generation WEC PTO Co-Design project was established to apply control design within larger device design processes (incorporating PTO systems, hulls, mooring systems, power electronics, and so on) and leveraging predictionless WEC controls as part of the framework. Using device-agnostic methodologies, the project’s goal is to allow industry developers and researchers to apply controls insights to their own devices and produce better-performing WECs. To further encourage public use of any updates and recent publicly viewable uploads, Sandia researchers regularly use presentations, workshops, and webinars to share information about the project and receive industry input.

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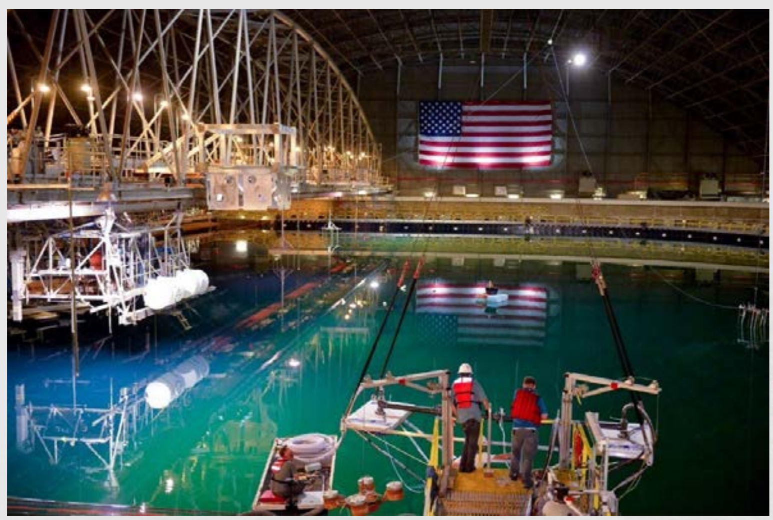

Figure 30. Sandia researchers have been able to expand connections with the U.S. Navy through many rounds of controls testing at the Naval Surface Warfare Center’s Maneuvering and Seakeeping Basin in Bethesda, Maryland

Courtesy of Sandia

Resource Mapping Greatly Expands U.S. Wave Energy Estimates, Charts the Course for Industry Technology Development

At the end of 2020, DOE developed a methodology and released new models and characterization data on the U.S. wave energy resource, including the highest resolution, most comprehensive wave data set publicly available to date. The new methodology, created by the multilab resource characterization project, supports a more complete accounting of how wave energy totals are estimated, resulting in a 30% increase in the estimate of the U.S. wave energy resource potential. With funding from WPTO and led by NREL with support from PNNL and Sandia, the project developed the refined wave resource assessment methodology, enabling an accounting of the effect of local winds blowing on the ocean surface within the U.S. Exclusive Economic Zone, as well as the waves that arrive at U.S. coastlines from the open ocean.

Previous wave resource estimates were at roughly 2,600 terawatt-hours per year, and current estimates, thanks to this improved resource accounting, total 3,500 terawatt-hours per year. The exhibited increase in available wave resources is largely because of this change in the calculation methodology. The project team also developed publicly available, high-resolution wave resource models to cover the entire U.S. Exclusive Economic Zone, spanning 200 nautical miles from shore (including island territories), and covering a 32-year time frame. The refined wave resource assessment methodology will be published in early 2021.

Part of marine energy's value proposition is its predictability, especially in the case of tidal energy, which can be projected with great accuracy over several decades. While tide patterns are entirely predictable, waves have greater predictability on daily and weekly scales compared to other renewable technologies such as wind and solar. The improved resource assessment methodology, coupled with this longer record of wave history, equips the marine energy industry with needed data to identify exactly where marine energy projects could prove most viable, which can have implications for optimal technology design.

The high-resolution nature of the data set is especially valuable because it allows project developers to pinpoint specific sites with the most promising wave energy potential and enables them to identify technologies and tailor array layouts in ways that previous data sets did not support. For example, it can capture the ways in which waves refract in shallower waters—the physics behind how wave crests align with a coastline—and focuses energy at points. The longtime frame of the data record also allows project developers to evaluate risk by comparing the statistics of large waves over periods of time that are similar to the life span of wave energy projects.

The data set could prove valuable to any organization with marine operations inside the U.S. Exclusive Economic Zone, such as the oil and gas industry for offshore platform engineering, the offshore wind industry for turbine and array design, offshore aquaculture production, coastal communities for extreme hazard mitigation, or global shipping companies and fishermen, for a better understanding of weather windows and seasonal wave climate patterns. To successfully disseminate data of such immense volume—currently around 5 terabytes but expected to grow to approximately 100 terabytes—the project team partnered with cloud services companies to host the data set.

In 2021, the project team hopes to render the tool—groundbreaking in terms of the spatial coverage of the data set as well as the cloud-based delivery mechanism—even more user-friendly by making the data available within the MHK Atlas, an interactive tool that maps U.S. wave, tidal, ocean, ocean thermal, and riverine current resources. The three-lab team also plans to complete high-resolution wave models for the Gulf of Mexico, Hawaii, and all U.S. island territories, and host the data from these models publicly, giving industry and researchers access to drive new research and innovation.

Figure 31. NREL researcher Levi Kilcher, wearing the white hard hat, works with a team to deploy tidal energy resource characterization instruments. Resource characterization work like this lays the groundwork for industry to design and develop systems capable of efficiently extracting marine energy resources and delivering power to communities.

Courtesy of NREL

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Technology-Specific System Design and Validation

WPTO's work in technology-specific system design and validation focuses on conducting various types of tests (including those in laboratories, tanks, flumes, and in open water) on industry-designed prototypes while improving cost-effective methods for installation, operations, and maintenance. Development and adoption of international standards for device performance and insurance certification are also critical priorities within the portfolio.

River Hydrokinetics Reduce Dependence on Diesel in Alaska

Like many remote communities, the tiny Alaskan village of Igiugig depends on diesel fuel to power its homes and businesses. To help mitigate this dependence, in July 2019, Igiugig—located on the banks of the Kvichak River—worked with marine energy developer Ocean Renewable Power Company (ORPC) to deploy the RivGen Power System, a submerged 35-kW power system that utilizes the current of the river as a renewable energy source. After a full year of operation, more than 8 MWh of power were transmitted into the small Igiugig grid, at many points providing more than half of the village's peak electricity needs. Additionally, after rigorous monitoring of the RivGen device, the team observed no negative interactions with migrating local salmon populations, an indispensable economic and cultural resource for the community.

Supported by WPTO, the Igiugig Hydrokinetic Project is a collaboration between the Igiugig Village Council and Maine-based ORPC, which has been exploring several different opportunities in the State of Alaska in recent years. Contributing to the overall success of the effort are the experience and training local Igiugig community members are gaining in the implementation of the project. The Igiugig community has the capabilities to deploy and retrieve the device with little help from outside contractors—a valuable component of a successful and sustainable renewable energy system operating in a remote community. The local workforce is also able to deploy and retrieve the device for inspections and maintenance, which contributes to the system's cost effectiveness and long-term community resilience.

In 2019, after the Village of Igiugig became the first U.S. tribal entity to receive a FERC permit for a water-powered project not involving a dam, the project's trial year commenced to study potential impacts on young salmon migrating to the ocean and whether the device would be affected by Igiugig's icy winter conditions. Following its 1-year deployment anniversary, the project team reported that there was no sign of negative effects on the salmon, indicating no impedance to passage or direct interactions with the device. Additionally, the project team reported no impedance to vessels that passed the device, and that it was able to survive a midwinter frazil ice occurrence and quickly return to operational status—increasing confidence in the submerged system's durability.

ORPC's deployment and testing is particularly important for industry because more data are needed on overall marine energy systems, the interaction of underwater turbines with fish, and what kinds of applications may exist for providing stable power for local microgrids. WPTO provides funding for early-market systems in rivers that do not require the installation of structures that impede the flow of the river or impact the environment.

Figure 32. The ORPC RivGen Power System prior to installation on the Kvichak River in Igiugig, Alaska.

Courtesy of ORPC

In addition, the project can demonstrate to other communities that are potentially interested in similar systems that marine energy technologies can be environmentally friendly and operate continuously throughout the year. With support from DOE's Office of Indian Energy Policy and Programs, plans are under way in Igiugig to install a second 35-kW RivGen device in conjunction with smart microgrid electronics and energy storage. When completed, the system will reduce Igiugig Village diesel use by an estimated 90%.

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 (NREL, PNNL) and universities (University of Alaska Fairbanks, University of Washington, University of Maine). It is just the latest in a series of successes resulting from the partnership between WPTO, Igiugig, and ORPC.

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Innovative, Economical Test of a Wave Energy Converter Using Land-Based Lab System Provides Promising Results

A multiyear component design and validation project between NREL and wave energy developer Columbia Power Technologies (C-Power) focused on the development and testing of the company's WEC generator, and demonstrated the feasibility of safely conducting low-speed reciprocating tests of the generator using a traditional wind turbine dynamometer. Leveraging the capabilities of the lab's 5-MW dynamometer, which is located far from the ocean in Colorado, NREL was able to validate that C-Power's generator operated as designed, that no unexpected flaws existed in the mechanical, electrical, or control systems, and that the generator was ready for future tests in open waters.

NREL's work supported C-Power's efforts to build and test a novel, direct-drive PTO module, referred to as the "LandRAY" in a land-based test that simulated open-ocean operating conditions. A successful PTO module—essentially, the generator—is a key component to delivering cost-competitive wave energy. The LandRAY combined a large-diameter permanent-magnet generator with a patent-pending prototype localized airgap-reduction system. The project covered 12 stages of design, assembly, and testing, engineered to thoroughly characterize the PTO components by using overlapping data sets to isolate test results.

At the National Wind Technology Center on NREL's Flatirons Campus, the testing and validation of C-Power's device included mechanical system characterization, generator performance testing, real-seas simulations, energy storage performance validation, design and fault analysis, extreme-event testing, and noise monitoring. Overall, the LandRAY generator produced high-quality power that was smoothed by C-Power's energy storage system—a critical performance landmark needed prior to open-ocean deployment and before connecting to the grid. Additional findings and outputs from the project, including applied methodologies, verification and validation techniques, and links to additional resources can be found in the final report.

Figure 39. Columbia Power Technologies' wave energy converter is installed at NREL's 5-MW dynamometer at its Flatirons Campus.

Photo by Mark McDade, NREL 44103

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Tidal Testing Underway in New York's East River

In October 2020, Verdant Power of New York installed three tidal power turbines with its new TriFrame mount at its Roosevelt Island Tidal Energy site in New York's East River. With support from WPTO, NREL, and the New York State Energy Research and Development Authority (NYSERDA), Verdant is scheduled to test throughout 2021. The project aims to demonstrate a streamlined installation and maintenance approach as well as long-term system reliability that will help inform future deployments for Verdant and others in the marine renewable energy industry.

Verdant's mounting system, a single triangular frame mount that holds three fifth-generation Free Flow System turbines, was designed to simplify deployment and retrieval during installation and maintenance. The mount allows all three turbines to be deployed and retrieved at once, which reduces the timeline and costs of installation and maintenance. Verdant's Free Flow System turbine is a three-bladed, horizontal-axis unit that rotates underwater to convert the hydrokinetic energy of fast-moving water currents into electrical and mechanical energy. While the company's latest test for the TriFrame is estimated to provide 100 kW of power to the grid, future projections show a potential power output of 1,050 kW if deployed at full scale—enough to provide power to 1,000 New York homes. Verdant designed the mount as well as the turbines to be modular and scalable.

Because of the strong water currents that change direction between flood and ebb tides about four times each day, the East River is an ideal site for tidal power generation. Since 2002, Verdant has tested multiple generations of turbines at the site for varying amounts of time. In 2012, the Roosevelt Island Tidal Energy project became the first tidal turbine project to receive a FERC hydrokinetic pilot project license. This license was developed by FERC specifically for marine renewable energy technologies that integrate with the grid. The license was issued in January 2012 for a period of 10 years, and in 2014 Verdant installed the world's first array of grid-connected tidal turbines in the East River.

Also, as part of the 2020 test at Roosevelt Island Tidal Energy, Verdant is working with the European Marine Energy Centre to conduct an off-site power performance assessment using international technical specifications. This will be the first time the European Marine Energy Centre has carried out an off-site performance assessment, and the first report issued through the IEC System for Certification to standards relating to equipment for use in marine renewable energy applications.

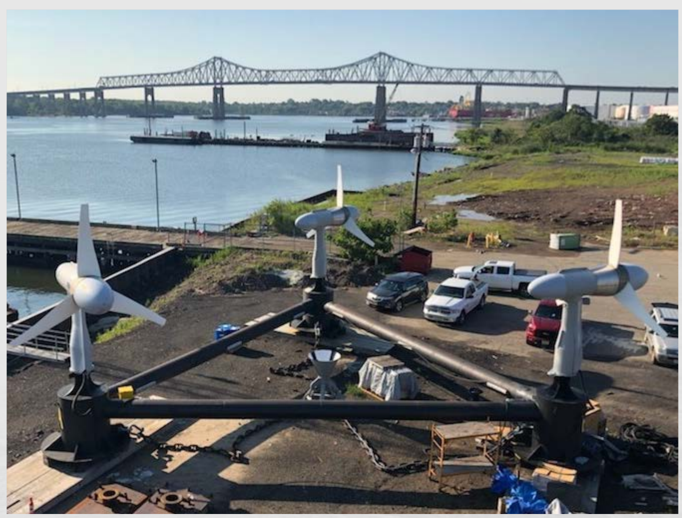

Figure 34. Verdant's Free Flow System turbines positioned on the TriFrame mount.

Courtesy of Verdant Power

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Data Access and Analytics

As the marine energy industry matures, public access to recently produced data on costs, performance, environmental studies, resource characterizations, and a host of other information is critical to many different types of stakeholders to accelerate learning and target future R&D. As such, aggregation, effective storage and management, analysis, and dissemination of relevant marine energy technical and scientific data are core objectives within WPTO’s MHK Program. The Office also conducts and publishes analyses of new potential market opportunities, the state of the science regarding potential environmental impacts from marine energy, and technology cost and performance trends. Improved access to data from around the world also benefits the continual updating and refinement of WPTO’s long-term MHK strategy.

Multilab Partnership Launches New, Centralized Portal for Marine Energy Information Sharing

In 2019, WPTO supported the creation of a central portal for U.S. marine renewable energy data, and in 2020 an integrated search capability was added so that users can now access information via a single search function. Given the early stage of many marine energy technologies, there is limited publicly available data and information from commercial marine renewable energy projects, and data produced under different research efforts reside in many diverse locations and formats, and are often not catalogued or easily accessible. The Portal and Repository for Information on Marine Renewable Energy (PRIMRE) provides centralized access, standardization, community building, and integration of federally funded Knowledge Hubs, tools and codes, and other resources covering a range of marine renewable energy subject matter.

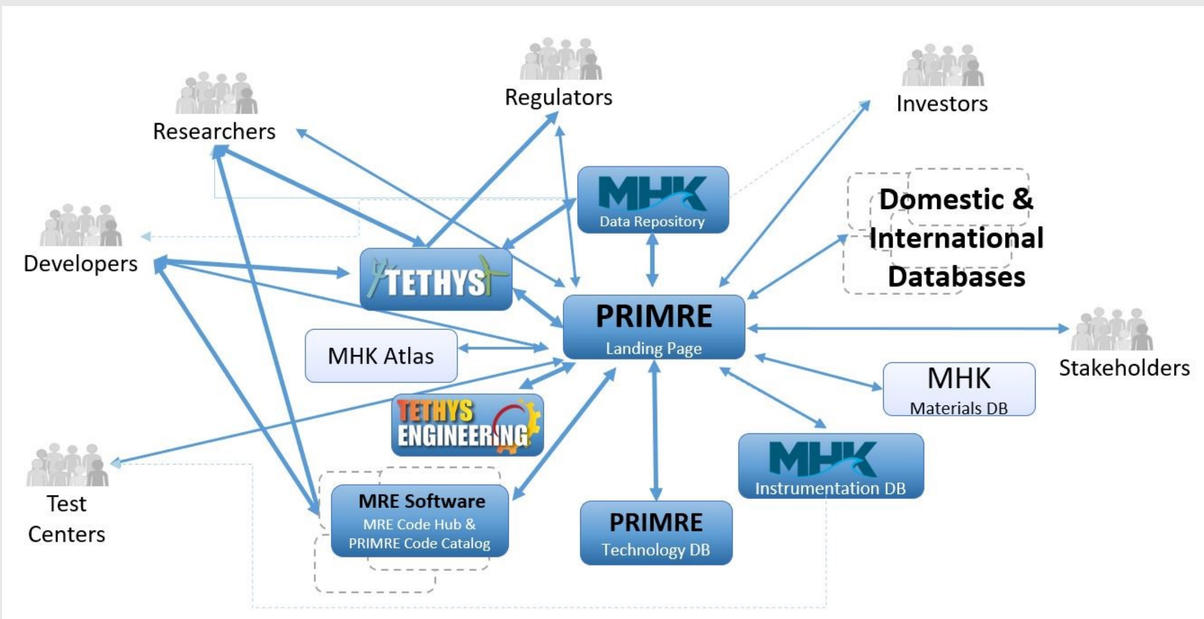

Figure 41. Schema representing connections between the PRIMRE Knowledge Hubs and related resources.

Courtesy of PNNL, NREL, and Sandia

Following the launch of the PRIMRE site in 2019, the multilab PRIMRE team—Sandia, PNNL, and NREL—focused on the development, maintenance, and integration of both new and existing Knowledge Hubs:

- The Marine and Hydrokinetic Data Repository houses data collected by WPTO-funded research and development, including device testing data, resource characterization data, and more.
- Tethys hosts more than 3,200 documents on the environmental effects of marine renewable energy development and supports an international community through the Ocean Energy Systems' Environmental initiative.
- Launched in 2019, Tethys Engineering hosts more than 4,700 documents on the engineering and technical aspects of marine renewable energy development, as well as a library of marine renewable energy photos for free third-party use.

- Released in 2020, the PRIMRE Technology Database contains information on marine renewable energy devices, points to companies active in the marine renewable energy field and traces the development of projects around the world.
- Opened in 2020, MRE Software is a collection of software relevant to marine renewable energy development, including the MRE Code Hub and PRIMRE Code Catalog.
- Launched in 2020, Telesto is a collection of information and guidance for testing, measurement, and data analysis for marine renewable energy research, development, and demonstration.

To improve the connectivity of these Knowledge Hubs, a common metadata schema was created to support information exchange between the sites in a manner that can also be scaled to incorporate new sites in the future (e.g., international databases). In accordance with the schema, an aggregate search capability was then implemented for the PRIMRE site, as well as for the Marine and Hydrokinetic Data Repository, Tethys, and Tethys Engineering, enabling users to find data and information from each site using a single entry point. Finally, the web presence for several signature projects was created in 2020, bringing focus to a number of WPTO projects and enhancing the discoverability of their reports, data sets, and associated papers. Future work will focus on enhancing integration (particularly with international sites) and documenting lessons learned from marine renewable energy researchers and developers.

PRIMRE contributes to WPTO's priority to ensure broad access to information on marine renewable energy so that stakeholders can build upon existing knowledge and lessons learned. With efforts like PRIMRE, WPTO hopes to ensure that researchers and technology developers have easy access to federally funded tools, research, and analysis that can be used to advance marine renewable energy technologies now and in the future.

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WPTO Creates New STEM Hub to Inspire the Future Workforce, Reaches Visitors to the Northeast's Largest Aquarium

In 2020, NREL released new Science, Technology, Engineering, and Math (STEM) and workforce development portals for marine energy and hydropower. These new sites offer a centralized platform for students, educators, and the general public to learn about water power technologies, gather information about careers and training programs, and find resources to use in the classroom or in self-directed learning. Some of the resources featured in the marine energy hub are already being put to use, including as part of a public energy exhibit at Mystic Aquarium in Connecticut.

The hubs feature NREL-aggregated resources from a number of industry and academic partners, as well as new content commissioned by WPTO, such as workforce data, opportunities for site tours, information on training programs, and materials for educators such as animations, games, and lesson plans. While materials developed by WPTO are targeted to college and graduate school students, many of the available resources can be adapted for K–12 audiences or even the general public. Mystic Aquarium turned out to be a natural partner for WPTO, and the two were able to collaborate on a shared interest to inspire the future blue economy workforce.

The partnership began when Mystic Aquarium leadership informed WPTO that they were interested in developing an offshore renewable energy exhibit. WPTO saw this as an opportunity to disseminate new marine energy educational content to the general public and target ocean-loving kids to consider a career in marine energy or the blue economy more broadly. After two years of coordination with WPTO, NREL, and industry partner Ocean Power Technologies, the aquarium unveiled the new Renewable Ocean Energy exhibit in autumn 2020. The exhibit includes a display that spans 400 square feet on the mezzanine level of Mystic Aquarium's main gallery and features interactive mechanical models that allow visitors to manipulate underwater surge flaps and crank offshore wind turbines, simulating the process of renewable power generation. Guests can learn from a diverse group of scientists and engineers working in ocean energy, play games, and test their renewable energy knowledge at informational kiosks. All this takes place around a large screen at the center of the exhibit that displays a marine energy animation—created with strong input from NREL on behalf of WPTO—showing seven different marine energy technologies. NREL technical researchers and communications staff provided guidance to the aquarium on all content created for this exhibit.

NREL's development and centralization of educational materials support WPTO's goal to provide objective and accurate information about marine renewable energy technologies. Given the early stage of marine renewable energy, there are few publicly available resources to help students and those interested in pursuing possible clean energy careers gain familiarity with these technologies. This workforce challenge is exacerbated by infrequent testing and demonstration of new technologies, meaning students, and the marine energy community overall, rarely have opportunities to gain real-world experience. The STEM hub helps to address these challenges by connecting interested educators and students with informational resources about marine energy and making students aware of opportunities to develop skills needed to enter the marine energy workforce. The information provided includes relevant data from adjacent marine-related industries.

In 2021, NREL will continue to incorporate existing resources into the portal and focus content creation tasks where gaps currently exist. The lab will elicit feedback from portal users—including students, educators, and marine energy employers—to inform future development. This effort aims to support the future use of marine energy curricula in the classroom and inspire the next generation of marine energy innovators.

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Figure 36. Renewable Ocean Energy exhibit at the Mystic Aquarium in Connecticut.

Courtesy of Mystic Aquarium

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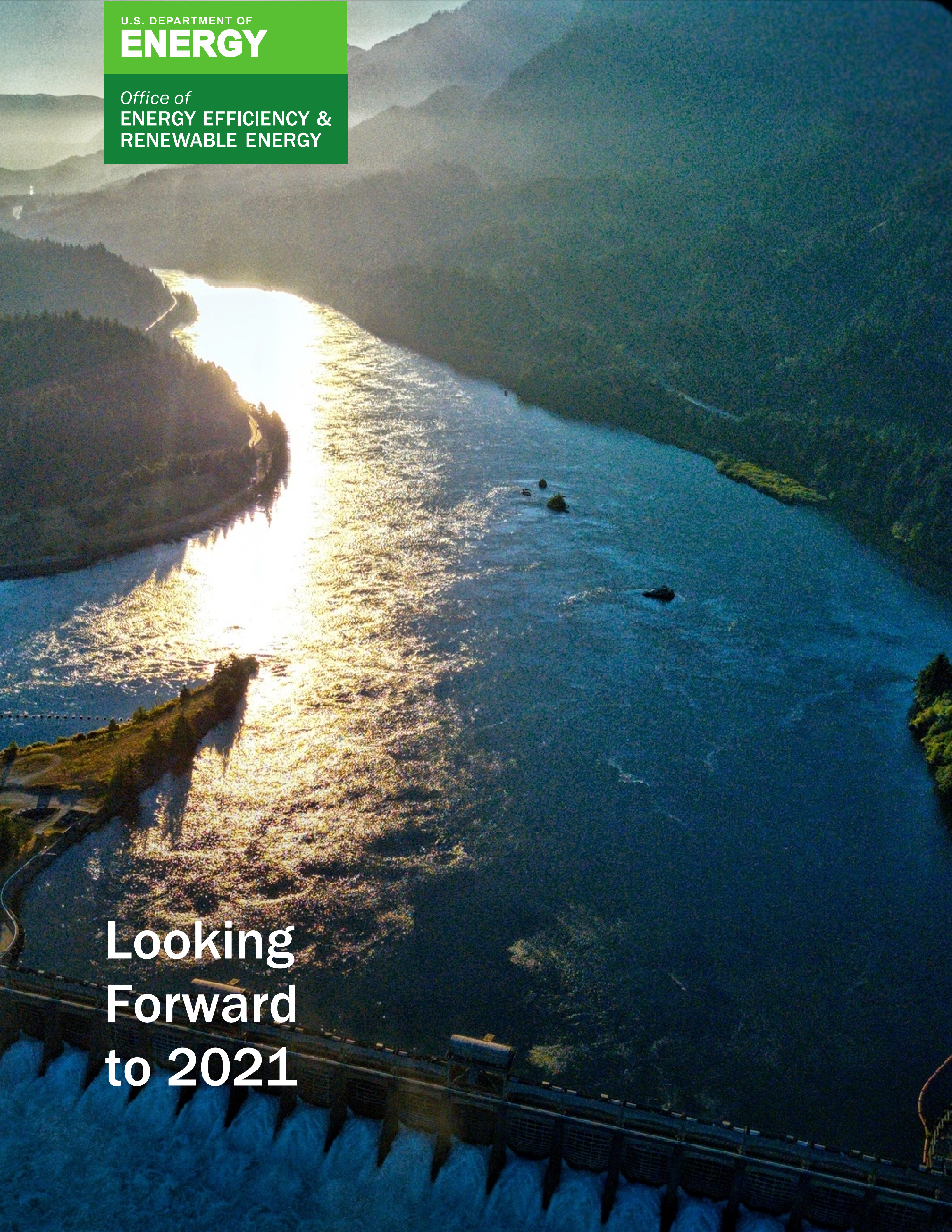

Looking Forward to 2021

3. Looking Forward to 2021

WPTO is continuing its efforts to advance science and cutting-edge research across the Hydropower and MHK Programs in 2021, and there are a number of projects that are expecting significant milestones and results. Many of the projects highlighted in the main body of this report will continue work into 2021, and readers can learn more about the status of those projects by visiting the WPTO website, following the Office's Water Wire e-newsletter, or exploring the WPTO Projects Map. Additionally, WPTO will continue to report on the results of R&D in future accomplishments reports, including the projects mentioned below, which are anticipated to have significant updates in 2021.

Hydropower Research

Case Studies to Highlight the Important Role of Hydropower in Integrating Renewables Across the United States

In early 2021, WPTO will release landmark case studies detailing the current landscape and prospective role and influence of hydropower operations on the nation's electric grid. HVS, a cornerstone project of the HydroWIRES initiative, provides a comprehensive understanding of current hydropower operations and resulting value across the country. Led by PNNL with support from Argonne, INL, ORNL, and NREL along with extensive collaboration from industry, HVS comprises a series of studies developed to support two primary objectives:

1. **Review of current hydropower operations landscape:** This task illustrated recent trends in provision of grid services by hydropower resources based on a comprehensive, data-driven analysis of operations in various markets across the country. These trends show the impacts of further changes on the horizon for hydropower operations and value. The work also identified and estimated the value of grid services provided by hydropower that are not presently monetized, such as inertia.
2. **Hydropower capabilities and operations in future grid states:** The ability of hydropower to provide value to the power system will require understanding the related resources' capabilities, costs, and constraints. Hydropower's capabilities to provide grid services, and the factors influencing how these capabilities vary unit to unit and plant to plant are qualitatively and quantitatively different. This task analyzed the capabilities and constraints that affect a hydropower facility's ability to provide various grid services, both now and in the future.

Findings within each case study, as well as approaches, methodologies, partners, and next steps, will become publicly available in 2021 and will be located on the HydroWIRES web page.

PSH Techno-Economic Valuation Guidebook and Case Studies To Be Released

A valuation guidebook containing a step-by-step methodology for developers, plant owners and operators, and other stakeholders to assess the economic value of existing or planned PSH projects will be published in early 2021. To support validation of the guidebook with real-world applications, a NOTA was issued and technical assistance awarded in FY 2019 for the valuation methodology to be applied at two developing PSH sites in Absaroka Energy's Banner Mountain project as well as GridAmerica's Goldendale site. A national laboratory team led by Argonne engaged with the technical assistance awardees and performed almost a dozen techno-economic studies for the two PSH sites to assess various services and contributions these projects may be able to provide to the grid and to estimate the value of those services.

The key techno-economic studies carried out at the two sites included assessing the value of bulk power capacity, energy arbitrage, and ancillary services, as well as power system stability benefits, impacts on reducing system cycling and ramping costs, reduction of system production costs and other portfolio effects, transmission benefits, and nonenergy benefits. Publication of the guidebook is expected to be accompanied by release of two case studies covering this application of the methodology at the two NOTA sites. Additionally, an online tool will be developed throughout 2021 that will enable greater accessibility of the framework by industry and stakeholders and will include all relevant details covered within the guidebook's application.

Geomechanical Pumped-Storage Developer Gains Series B Funding, Long-Term Contract with NYSERDA

In FY 2020, WPTO awardee Quidnet Energy secured $10 million in funding from a group of investors that included the Bill Gates-backed Breakthrough Energy Ventures, as well as Evok Innovations, Trafigura, and the Jeremy and Hannelore Grantham Environmental Trust. Quidnet plans to use these Series B funds to further develop its team and support deployment of an upcoming 2-MW demonstration project with NYSERDA. The company's concept is centered on geomechanical pumped-storage, wherein energy is stored by pumping water at high pressure to create and pressurize rock fractures and release it to generate power through a reversible unit. This design configuration is particularly important, as it allows for deployment on flat surfaces, easing civil works processes and potentially increasing the amount of viable locations for pumped-storage installation. Currently in the process of completing design and analysis of a 1.5-MW generator prototype under the award with WPTO, the company's envisioned deployment with NYSERDA is part of the High Performing Grid Program, which promotes R&D to develop an advanced and dynamically managed electric grid.

A FlexPower Future—Validating Hybrid Renewable Energy and Storage Systems

In 2021, NREL, Sandia, and INL will develop and demonstrate the FlexPower hybrid plant concept, which combines multiple generation—solar photovoltaic, wind, and hydropower—and energy storage technologies—such as lithium-ion battery energy storage systems, hydrogen storage, and pumped-storage hydropower—to provide energy and reliability services. In collaboration with GE Global Research and First Solar, the multilab team will develop a multimegawatt FlexPower plant validation platform at NREL's Flatirons Campus to demonstrate the main benefits of hybrid photovoltaic-wind-storage-hydropower plants. The FlexPower hybrid plant is a pioneering approach to show how technology hybridization can fully leverage variable utility-scale wind and photovoltaic generation with flexible hydropower generation to provide greater flexibility, ancillary services, and value to the bulk power system.

The project will ultimately result in a grid-scale hybrid system test bed that can be used by industry and the research community for validating and demonstrating new control concepts and future standardization of hybrid technologies. The final year of the project will include a regional integration study, as well as a hydropower-specific regional study, to identify the benefits and operational impacts of hybrid renewable energy and storage systems.

Novel and Superflexible Pumped-Storage System Designs—Industry, Academia, and Lab Collaboration Confirms the Potential To Provide Critical Grid Services

NREL, with support from partners at GE Renewables, Absaroka Energy, and Auburn University, will release new research findings in the coming year that quantify how novel, fast-acting ternary pumped-storage hydropower (T-PSH) can support U.S. grid integration and flexibility needs. Increasing levels of variable renewable energy, such as wind and solar power, have driven the need for complementary technologies like PSH that can quickly support changing power system demands. Leveraging technical performance data of various PSH configurations from the developer Absaroka Energy, NREL created new dynamic modeling tools to more accurately describe the capabilities of ternary technology in providing flexibility, energy storage, and ancillary services to the grid.

Additionally, Absaroka's data enabled an updated comparison of T-PSH with other forms of advanced PSH, including quaternary PSH (Q-PSH). Findings underscore the superior ability T-PSH and Q-PSH have in providing flexible, rapid-response grid services, such as energy imbalance support and voltage and frequency support, especially during scenarios with high variable renewable energy contribution. Results and methodologies are captured in a forthcoming report with quantitative and qualitative information for utilities, policymakers, developers, and other stakeholders seeking to understand this technology's value to the grid.

RADIANCE: Using Hydropower and Other Smart-Grid Solutions To Increase Alaskan Community Energy Resilience

Part of DOE's Grid Modernization Lab Consortium, the Resilient Alaskan Distribution System Improvements using Automation, Network Analysis, Control, and Energy Storage (RADIANCE) project aims to enhance the resilience of the distribution grid in Cordova, Alaska, to prepare for and protect against low-probability, high-impact events (e.g., avalanches, earthquakes, and other natural disasters, as well as manmade threats, such as cyberattacks). The Cordova Electric Cooperative operates as an islanded microgrid, without any electrical connection to the Alaskan Interconnection power transmission system, making the city of Cordova an ideal test bed for validating resilience enhancement technologies in islanded microgrids. Funded by WPTO and DOE's Office of Electricity, the project is led by NREL in collaboration with INL, Sandia, and PNNL, as well as several university partners and industry collaborators.

Two run-of-river hydropower plants—Power Creek and Humpback Creek—provide roughly 60%–70% of electricity generation in Cordova. The project team will assess the technical and economic feasibility of maximizing Cordova's hydropower resources via energy storage and demand response technologies. Employing a real-time simulation of the city's existing microgrid, the team will model and test the design and operation of resilient grid infrastructure at the DOE national laboratories. Actual networked microgrids, combined with storage and other early-stage grid technologies, will then be deployed and validated in Cordova throughout 2021. The RADIANCE team plans to achieve several outcomes: a more resilient, secure grid featuring enhanced energy storage, which will reduce diesel fuel demand for the City of Cordova; a knowledge base and technology transfer to link village communities to microgrids; and improved planning and resilience for coastal communities across Alaska. Additionally, as the project concludes, the National Rural Electric Cooperative Association will disseminate lessons learned to more than 800 electric cooperatives across the United States.

Coming Soon: Roadmap for U.S. Hydro To Respond to and Recover from a Cyberattack

In 2021, a team of national lab researchers led by PNNL and supported by NREL and Argonne will publish a comprehensive U.S. response and recovery framework specifically designed for hydropower facilities to improve their ability to quickly and safely navigate back to normal operations following a security breach. Though U.S. hydropower facilities incorporate security measures to minimize risks of cybersecurity incidents, it is vital that all plants have easily understood contingency plans should one of these instances occur.

The Hydropower Response and Recovery Framework project will provide such a plan, knitting together existing guidance from a range of stakeholders, including the National Institute of Standards and Technology, the North American Electric Reliability Corporation, and the Federal Emergency Management Agency, into a cohesive and easily accessible recovery framework. Once released, the framework will be a living document and will continue to evolve based on user feedback as it is applied in real-world operations.

New Analytical Capability To Enable Improved Value and Reliability of Hydro Assets

After engaging with industry groups and hydropower plant owners and operators, ORNL developed a new, reproducible approach to understand the costs of operating hydropower more flexibly in response to higher amounts of wind and solar on the power system. The methodology, to be published in 2021, will provide plant operators with better insight into their facilities' performance and maintenance, and greater ability to optimize dispatch patterns under increasing grid penetration of variable renewables.

Though various hydropower utilities currently collect a broad swath of data on the cost, condition, and reliability of their plants, these data are not widely disseminated. ORNL's methodology represents a key output of the Hydropower Fleet

Intelligence (HFI) project, which is designed to develop, share, and improve data-driven decision-making practices for the entire U.S. hydropower fleet with a focus on increasing assets' value and reliability.

WPTO Establishes New Research Effort To Unlock Hydropower's Nonenergy Benefits for Communities

Although the dynamics of the energy and water sectors are shifting, a growing effort initiated by WPTO in 2020 took a first step in analyzing the potential opportunity space created by these changes, with initial findings compiled into a forthcoming report entitled "Alternative Opportunities for Hydropower." In striving to not just minimize impacts and costs of new hydropower development but also expand its value beyond energy generation, the project was initiated to investigate how hydropower can provide renewable energy while simultaneously addressing economic and social challenges, such as accelerating drought conditions, rising river temperatures, and aging infrastructure.

Led by PNNL and INL, the project examines opportunities for hydropower to address core issues at the nexus of energy and water that can improve livelihoods while extending hydropower's value far beyond power generation.

Five opportunity classes for smaller-scale hydropower (less than 10 MW) have thus far emerged following a robust stakeholder engagement process. These opportunities were viewed through the lens of the non-hydropower system:

- **Water supply and treatment:** modernization of water delivery infrastructure and operations
- **Source water recharge:** hydropower-enabled groundwater storage for better integrated water resource management
- Irrigation modernization**:** retrofitting agricultural infrastructure for improved energy, water, and growing efficiency
- **Environmental restoration and cleanup:** returning rivers to their pre-anthropogenic state and removing contaminants from river systems
- **Deferrable loads**: using excess generation to produce nonenergy commodities rather than traditional means of balancing loads.

More information about each opportunity area, initial findings, and next steps are catalogued in the full report, expected to be released in 2021.

Irrigation Modernization Visualization Tool

Much of American infrastructure needs reinvestment and modernization, and irrigation canals are no exception. Stakeholder engagement has identified the initial design planning stages as the first large and cost-intensive hurdle in the modernization process, given the specialized knowledge it requires and the diversity of perspectives that must be addressed. INL is leading the development of an irrigation modernization visualization tool to ease this burden; it allows users to quantify the benefits of reinvestment, such as reduced water loss and pumping loads, increased energy production and crop yield, and more within users' unique systems. The outputs of the tool also provide a common starting point for robust discussion amongst the diverse interests around modernization pathways. INL is working closely with PNNL on development of the tool, which is anticipated to offer publicly available demos in summer 2021.

Standard Modular Hydropower Projects Apply Advanced Manufacturing Techniques, Deployments and Field Testing Expected in 2021

Since its inception in 2016, ORNL's Standard Modular Hydropower project has been executing an R&D strategy to incorporate standardization, modularity, and environmental compatibility into the design of hydropower facilities and components. In FY 2020, WPTO selected four awardees for a funding opportunity focused on new module development using advanced manufacturing. These awards will help catalyze the development of standard modular technologies and help industry stakeholders apply related principles in practice. Anticipated project updates for 2021 include:

- Percheron Power will develop an innovative, helical fish passage module with the ability to pass fish species both upstream and downstream of a low-head hydropower plant
- Natel Energy will advance the design of a generation module that can achieve high fish passage survival rates without compromising performance and cost-competitiveness, as demonstrated in a recent field trial
- Littoral Power Systems, in partnership with Whooshh Innovations and EPRI, will design a fish passage module that can provide upstream passage to multiple species simultaneously
- The University of Minnesota will design a sediment passage module based on an approach called "hydrosuction," which uses siphon flow to continually pass sediment through a dam structure.

MHK Research

TEAMER Program Support for Industry Ramps Up

Execution of the new U.S. Testing Expertise and Access for Marine Energy Research (TEAMER) program is underway. DOE announced in September 2019 that the Pacific Ocean Energy Trust (POET) was selected as the network director for TEAMER, which is a 3-year, $16-million program supporting testing and research for marine energy technologies. POET has been working with its network partners, DOE, and the TEAMER technical board, which comprises representatives from the national laboratories and National Marine Renewable Energy Centers, to establish program technical requirements and structure periodic Requests for Technical Support (RFTS) that will be open for developers and researchers to apply for.

POET is also responsible for establishing the TEAMER Test Facility Network and putting agreements in place to facilitate expedited access to facilities and expertise in the TEAMER network. In 2020, POET established the initial TEAMER Test Facility Network to include 14 organizations with more than 35 facilities and capabilities (e.g., numerical modeling, bench testing labs, and tanks/flumes) and opened the first RFTS call in May 2020. Selections were announced at the end of September 2020, and assistance activities will run through May 2021. The second RFTS call opened in November 2020, and POET anticipates releasing three additional RFTS calls in 2021. Additional information is available on the TEAMER website.

CalWave—2020 Open-Water Wave Energy Test in San Diego

One of the finalists of WPTO's 2016 Wave Energy Prize, CalWave, is set to complete construction, installation, and onshore testing of a 1:5-scale demonstration WEC in preparation for a 6-month testing campaign scheduled for early 2021 at the Scripps Institution of Oceanography in San Diego, California. CalWave's design combines novel control methods enabled by submerged WEC architecture, similar to how pitch control is applied in the wind energy industry. In order to directly control the energy input into the WEC, CalWave is developing load management capabilities and intends to validate these methods throughout the course of the open-ocean test while focusing on overall performance and long-term deployment durability. Simultaneously, the company is working on developing a commercial-scale PTO subsystem as well as preliminary designs for a larger-scale WEC for an eventual deployment at PacWave South in the near future.

Upcoming TRITON Initiative Instrumentation Tests—Integral and Biosonics

Integral Consulting of Seattle, Washington, anticipates deploying its NoiseSpotter device at Scripps during 2021 as part of the aforementioned 6-month testing campaign with CalWave. Part of the Triton initiative, the NoiseSpotter comprises an array of sensors that measure and detect sound sources in near real time. With support from several project partners such as PNNL, the device will be co-located with CalWave's demonstration WEC to measure the sounds and controlled acoustic transmissions emitted from the device. It is anticipated that the testing will also be performed in conjunction with other DOE awardees to enable cross-comparisons between technical and cost performance. As the marine energy industry advances, devices like the NoiseSpotter can make critical contributions toward more sustainable development by helping to distinguish noise emitted by WECs from surrounding ocean sounds.

BioSonics, also out of Seattle, Washington, will continue testing its acoustic long-range target detection and classification system for marine animals at the U.S. Navy's Wave Energy Test Site in Hawaii during late 2021. Intended to deliver a cost-effective environmental monitoring system, BioSonics's technology first uses a 360-degree long-range sonar to automatically sense marine life at distances of up to 300 meters. This device is then combined with a more localized directed classification sonar, which tracks targets and provides high-resolution data on the location, depth, and general type of identified marine life along with their behavior.

Deployment at the site will primarily concentrate on mounting the acoustic system on the seafloor, conducting a series of target detection tests at various distances, and then using the collected data sets to develop target detection range maps for selected sea-state conditions. BioSonics will then aim to finalize commercialization, pricing, marketing, and distribution channel planning for the system, which is ultimately intended to provide developers with a tool for detecting marine life, conducting baseline assessments, and monitoring any possible interactions with deployed devices.

Oscilla Power To Conduct Critical Open-Ocean Testing in Hawaii

As one of the final steps within a 5-year project awarded by WPTO in 2016, Oscilla Power Inc. (OPI) of Seattle, Washington, will deploy its community-scale WEC, known as the Triton-C device, at the U.S. Navy's Wave Energy Test Site in early 2021 for a year-long testing campaign. The Triton-C is a 100-kW-rated power system comprising a ring-shaped reaction structure that hangs below a surface float via three tethers. Wave action on the float generates relative motion between these two bodies, which can then be converted to electrical power by drivetrains. Unlike most conventional WECs, Triton-C's surface float is excited by waves in multiple types of motion—heave, pitch, surge, and roll—allowing for increased energy capture across a wide range of ocean conditions. Open-ocean testing of OPI's WEC is expected to increase understanding of system dynamics and parameters that drive the power of the device while helping confirm and improve the numerical models used to support the development of OPI's technology. Through its research, OPI hopes to open immediate market opportunities for the device worldwide and put it on a path to realize some utility-scale opportunities by 2030.

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