# Executive Summary

This Multi-Year Program Plan (MYPP) is published as a response to the requirement for a Water Power Technologies Office (WPTO) Strategic Plan as directed under the Energy Act of 2020 (Title 3, Subtitle A, Sec. 3001).

WPTO, which is part of the U.S. Department of Energy's (DOE) Office of Energy Efficiency and Renewable Energy (EERE), enables research, testing, development, and commercialization of emerging technologies to advance marine energy[1] as well as next-generation hydropower and pumped storage systems for a flexible, reliable grid. To reduce marine energy costs and fully leverage hydropower's contributions to the grid, WPTO invests in early-stage research and technology design, validates performance and reliability for new technologies, develops and enables access to necessary testing infrastructure, and disseminates objective information and data for technology developers and decision makers. WPTO is also increasing its focus on shorter-term water power technology application and adoption, particularly considering the specific needs of diverse sectors and communities.

People and their communities are deeply reliant on and connected to their water systems as part of their economies and culture. Recognizing and respecting these factors, WPTO has endeavored to build stronger connections to an increasingly diverse set of stakeholders, particularly in remote, tribal, and disadvantaged communities. There is an opportunity to reimagine how to harness water and power by building more resilient infrastructure, producing clean water in new ways, unlocking the full potential of all ocean resources, and better aligning technology development with end users and community needs. WPTO continually strives to leverage evolving innovation ecosystems by incorporating end-user requirements in solicitations and by partnering directly with community-based organizations.

The United States has vast marine energy and hydropower resources, and the continued development of new technologies and modernization of existing assets are critical to furthering the nation's near-term electricity sector decarbonization goals and longer-term, economy-wide objectives. But for those who are not familiar with the specific opportunities these resources hold, the societal and economy-wide benefits that could be unlocked with continued research and innovation may be less obvious. Hydropower is the oldest form of renewable electricity generation in the country; commercially mature systems have been in operation for many decades in some cases. In contrast, marine energy systems are the newest suite of potential technologies, with little more than a decade of significant research having been conducted in the United States and abroad (compared to more than four decades for other renewable technologies) and much work left to do. The following two sections summarize the major benefits and opportunities for continued and sustained investment in water power technologies.

**Hydropower—the oldest form of electricity generation in the United States—remains an important energy resource for the country and is critical to long-term decarbonization goals, warranting additional innovation and research.**

Hydropower has provided clean, low-cost electricity for more than a century as the nation's first renewable source of electricity. Today's evolving power system has created new opportunities for hydropower to play an important role in a 100% clean energy future using existing technologies and infrastructure. In 2020, hydropower provided 7.3% of the electricity on the grid and accounted for 37% of U.S. renewable electricity generation.[2]

[1] The Energy Act of 2020 (Sec 3001) defines marine energy as "energy from waves, tides, and currents in oceans, estuaries, and tidal areas; free flowing water in rivers, lakes, streams, and man-made channels; differentials in salinity and pressure gradients; and differentials in water temperature, including ocean thermal energy conversion."

[2] U.S. Energy Information Administration (EIA), 2021. "Electricity in the U.S." https://www.eia.gov/energyexplained/electricity/electricity-in-the-us.php#:~:text=Hydropower%20plants%20produced%20about%207.3,from%20renewable%20energy%20in%202020.

Numerous recent studies have shown hydropower to be one of the most reliable, predictable, and flexible clean energy generation resources available, and the United States has a sizable existing fleet with more than 80 gigawatts (GW) of generating capacity. While some hydropower plants will reach the end of their useful or economic lives and be retired in coming decades, many others can continue to be valuable energy assets for decades to come. To avoid accelerated or unnecessary losses of U.S. hydropower, which would then need to be replaced by additional low-carbon generation, the existing fleet must be modernized to continue providing clean, flexible power and ensure a 100% clean energy future for the United States.

Firm and flexible hydropower can be expanded by modest amounts by upgrading existing hydropower plants and utilizing other existing infrastructure like non-powered dams and other constructed waterways without building large, new dams and reservoirs. In the past decade in the United States, several dozen new projects of these types have been developed that utilize new technologies and regulatory regimes. For example, the use of new hydropower technologies as part of irrigation modernization projects is an important opportunity to help advance water-system sustainability and agricultural decarbonization goals. As the country continues to upgrade and modernize its water infrastructure, there are also new opportunities for hydropower innovations to be integrated into projects focused on water distribution and groundwater recharge, invasive aquatic species management, and water quality monitoring and improvement. The potential to develop new hydropower from these various opportunities could add another 20 GW of generating capacity.

Pumped storage hydropower (PSH) is the largest contributor to U.S. energy storage with an installed capacity of 21.9 GW or roughly 93% of all commercial energy storage capacity in the United States.[3] PSH could provide tens to hundreds of gigawatts of additional long-duration storage, with projects designed to store energy from days to weeks or months. Many other countries continue to innovate and develop new pumped storage projects, and the global market for pumped storage development is currently larger than it has been in decades. Continued investments to drive down costs, shorten construction timelines, demonstrate and de-risk new types of pumped storage technologies, and reduce market and other deployment barriers for PSH in the United States will ensure that as many low-cost and complementary options for energy storage are available as possible as other energy storage technologies continue to mature.

Work to reduce any existing environmental impacts of hydropower is also important for advancing ecological and environmental justice goals, particularly in the face of greater climate-driven pressures on river systems. As less than 3% of the nation's 90,000+ dams have hydropower, research in this area also has impacts far beyond powered dams for issues like fish passage, recreational access, and water quality improvement. It is important to note that many of the largest and most significant hydropower projects are also multipurpose and serve many other critical societal missions (like flood control, water supply, and navigation) that are unlikely to diminish in importance. Even if hydropower operations ceased, these multipurpose dams will remain, and continuing to innovate new solutions to mitigate environmental impacts is important.

[3] Uría-Martínez, R., Johnson, M., and Shan, R., 2021. "U.S. Hydropower Market Report." https://www.energy.gov/eere/water/downloads/us-hydropower-market-report.

Hydropower can also be utilized and upgraded to directly mitigate some of the effects of climate change and improve the ecological resilience of our river basins. For example, hydropower operations can help to mitigate high water temperature events by increasing the ability to release cold water from deep within reservoirs,[4] monitoring and controlling the spread of invasive species,[5] and mitigating the impacts of more intense floods.[6] Because of the complex and uncertain threats posed by climate change to hydropower and broader dam and water infrastructure, there is also a need for new analytical tools and monitoring technologies to ensure our water systems are adaptable and climate resilient.

Finally, there is a significant domestic workforce and U.S. supply chain that supports the existing hydropower and pumped storage industry, with a diverse footprint across many states and regions. The 2016 Hydropower Vision study showed that the U.S. hydropower and pumped storage industries could add more than 100,000 jobs by 2030 under various scenarios analyzed in addition to continuing to support a workforce of more than 130,000 under business-as-usual cases.[7] Supporting the evolution and growth of this workforce with educational science, technology, engineering, and math (STEM) outreach, training opportunities, and diversity initiatives will be important to ensuring that tens of thousands of good-paying, clean energy jobs continue.

**Marine energy, the newest suite of clean energy technologies, is material to both the nation's short-term and long-term goals for decarbonization, sustainability, and economic growth.**

Given the current maturity of marine energy technologies—with little more than a decade of significant research compared to 40 to 50 years for other renewable technologies—it is true that it will take longer for the industry to realize significant commercial deployment potential. But there are also hundreds of nearer-term opportunities in high-energy-cost remote and distributed communities across the United States and in U.S. territories where there may be limited energy options. These opportunities are real and impactful, and the focus on community-centric needs in the iterative technology development and demonstration cycle is increasingly important.

Marine energy technology development also directly supports and engages blue economy priorities, including building sustainable aquaculture systems and dramatically expanding data collection from our oceans, that will be important for the nation. Oceans themselves can serve as assets for resilience against climate change, and options for marine-powered data collection or renewable fuels production could enable new ways to utilize the oceans as environmentally appropriate sinks for carbon or to decarbonize the maritime transportation sector. Opportunities to apply marine energy technologies include powering desalination systems and ocean observation and providing onsite power to aquaculture production. For example, as water stress likely increases due to climate change, different options for desalination will become increasingly important. Coastal wave-powered desalination systems are already being pursued in some parts of the world. There are near-to-medium-term opportunities for thousands of marine energy systems to be deployed in support of these opportunities.

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4 Duka, M., Shintani, T., and Yokoyama, K, 2021. "Mediating the Effects of Climate on the Temperature and Thermal Structure of a Monomictic Reservoir through Use of Hydraulic Facilities." https://www.mdpi.com/2073-4441/13/8/1128.

5 Milt, A.W., Diebel, M.W., Doran, P.J., Ferris, M.C., Herbert, M., Khoury, M.L., Moody, A.T., Neeson, T.M., Ross, J., Treska, T., O'Hanley, J.R., Walter, L., Wangen, S.R., Yacobson, E. and McIntyre, P.B, 2018. "Minimizing opportunity costs to aquatic connectivity restoration while controlling an invasive species." https://conbio.onlinelibrary.wiley.com/doi/10.1111/cobi.13105.

6 California Legislative Analyst's Office, 2017. Managing Floods in California.

7 U.S. Department of Energy, 2016, "Hydropower Vision Report." https://www.energy.gov/sites/default/files/2018/02/f49/Hydropower-Vision-021518.pdf.

Even though marine energy is not yet a sizable industry with significant numbers of jobs, investments in STEM and foundational research capacity at universities and other research organizations can support broader innovations and growth across important blue economy sectors and lay the groundwork for a robust set of future U.S. industries.

There is also significant deployment potential out to 2050 and beyond, and many reasons why continued investment in marine renewables can be important for long-term U.S. goals. U.S. economy-wide decarbonization targets are ambitious, and even technologies that do not have commercial potential on the scale of other renewables in the next one to two decades can play impactful roles in the long term. Given the trajectory of continuing cost reductions and the historical progress of innovation for other renewable technologies, up to 50 GW of marine energy capacity could be added in the United States by 2050. Modeling efforts also show that to achieve long-term 2050 clean energy goals while also meeting America's growing energy needs, the pace of renewables deployment will need to continue accelerating past 2040, and relatively newer technologies—like marine energy that can utilize other resources—may be well positioned to support ambitious long-term targets. Wind and solar technologies took decades of sustained research to reach their current levels of cost and maturity. For marine energy technologies to be in similar positions a few decades from now, sustained long-term efforts are needed.

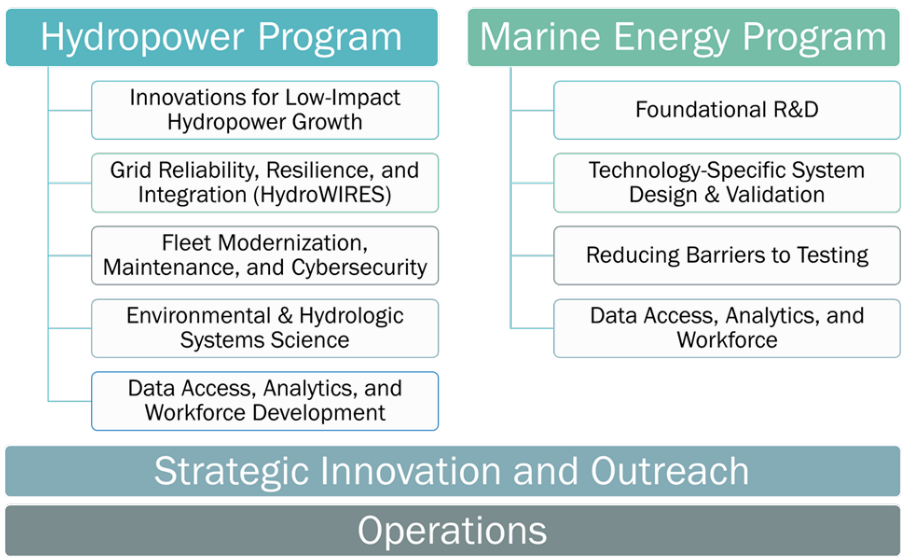
Marine energy technologies hold the potential for significant deployment along densely populated coasts and utilize different materials, manufacturing, and supply chains than other renewables. With huge amounts of wind, solar, and new land-based transmission predicted to be needed, marine energy technologies may be desirable and complementary options if circumstances demand it, especially if there are unforeseen difficulties deploying other renewables to the degree and scales needed. Most marine energy resources are also highly predictable, and in many places, their potential generation profiles are complementary to other renewables in seasonal profiles.

Even if U.S. decarbonization goals are achieved on time, other parts of the world may still have much more work to do to achieve their targets, and marine energy technologies will continue to be highly competitive and desirable options in some places. Other nations are investing significantly in marine energy technology development. Continuing to develop expertise and competitive advantage in the sector will benefit the U.S. economy.

# Water Power Technologies Office Overview

Aligned with the opportunities discussed directly above, WPTO has developed its MYPP for the next decade to broadly address the identified challenges and rapidly innovate new solutions. WPTO supports DOE and EERE objectives of combating the climate crisis, creating new clean energy jobs, and promoting energy and environmental justice. WPTO consists of two R&D programs: the Marine Energy Program and the Hydropower Program. The office also has two teams who work across the programs: the Operations team and the Strategic Innovation and Outreach team (Figure 1). The Multi-Year Program Plan focuses specifically on the Marine Energy and Hydropower Program activities and supporting goals, but these crosscutting teams are critical to implementation of WPTO goals and objectives.

**Figure 1.** WPTO's Organizational Structure




The following sections are summaries of the major activity areas within WPTO's Hydropower and Marine Energy Programs. These summaries also include the key results and performance goals that WPTO is targeting in Fiscal Year (FY) 2021–2025. Accomplishing the 2021–2025 performance goals are critical to achieving longer-term FY 2026–2030 follow-on objectives. These goals are specific to programmatic objectives. Larger, macroeconomic outcomes—like the impact on deployment goals for the United States—are outside the scope of this document but could be included in higher-level DOE or EERE plans. For a discussion of other performance measures and evaluation mechanisms (including Government Performance and Results Act goals), see the Assessing Performance and Evaluating Success section.

# Hydropower Program Overview

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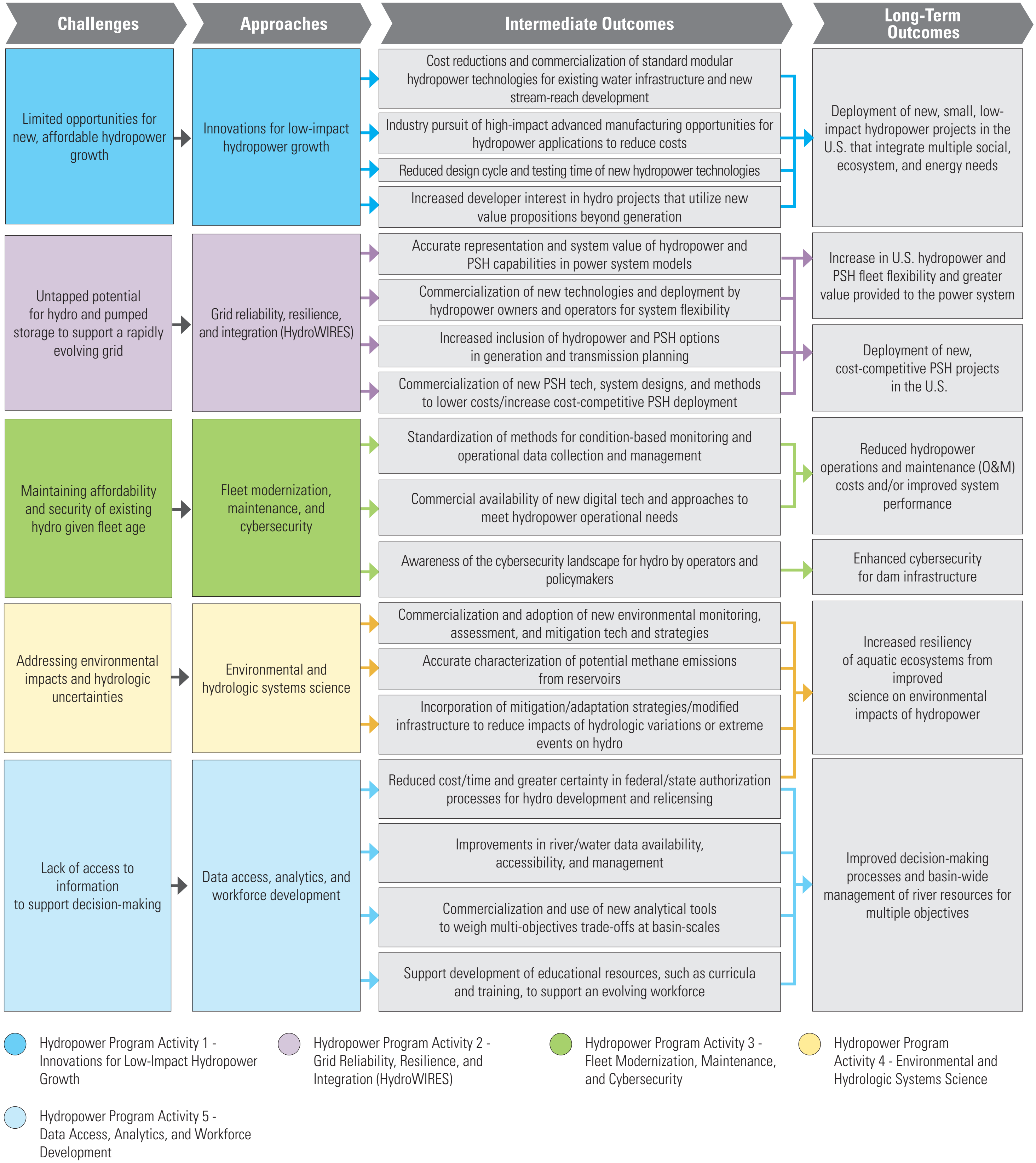
|---|---|
| **VISION** | A U.S. hydropower and pumped storage industry that modernizes and safely maintains existing assets; responsibly develops new low-impact hydropower; promotes environmental sustainability; and supports grid reliability, integration of other energy resources, and energy-water systems resilience. |
| **MISSION** | Conduct research, development, demonstration, and commercial activities to advance transformative, cost-effective, reliable, and environmentally sustainable hydropower and pumped storage technologies; better understand and capitalize upon opportunities for these technologies to support the nation's rapidly evolving grid; and improve energy-water infrastructure and security. |

The Hydropower Program focuses on the following key opportunity areas for potential impact:

- ***Enabling a 100% clean energy future***: Hydropower, including PSH, provides flexibility, inertia, storage, and grid services to support the increased integration of variable renewables like wind and solar energy.
- ***Expanding new value propositions for sustainable hydropower***: Retrofitting existing dams and adding generation at non-powered dams (NPDs) can increase renewable energy production, while rehabilitating dams can address safety problems, increase climate resilience, and mitigate environmental impacts.
- ***Understanding and adapting to climate change impacts on hydropower***: Advances in climate and hydrologic science, coupled with hydropower decision-making tools, can improve hydropower reservoir management by ensuring the continued reliability and climate resilience of our energy-water infrastructure.
- ***Building our hydropower fleet back better***: Modernization of the existing hydropower fleet can restore reliability and improve performance by adding cutting-edge technologies.

The Hydropower Program activities, goals, objectives, and impacts are summarized in Figure 2.

**Figure 2.** Hydropower Program High-Level Logic Model



## Hydropower Program Activity 1 – Innovations for Low-Impact Hydropower Growth

Technology innovation can enable the growth of additional hydropower capacity and generation as an economically competitive source of renewable energy in four resource categories: (1) development in "new stream-reaches" (sometimes referred to as "greenfield" sites); (2) powering of currently non-powered dams; (3) adding generation technology to existing irrigation canals and other water conduits; and (4) upgrades at existing hydropower plants.[8] Different technology pathways addressed in this activity include the major powertrain and civil works components of a hydropower facility—primarily turbine technologies, hydraulic structures, and geotechnical approaches—with an emphasis on standardized, modular designs and approaches centered on environmental performance. Development and adoption of new technologies and strategies could lead to significant U.S. deployment of additional low-impact hydropower that integrates multiple social, environmental, and energy needs, while realizing value and revenue from a variety of sources. Table 1 outlines the key results, performance goals, and follow-on objectives for this activity area.

**Table 1.** Innovations for Low-Impact Hydropower Growth: Performance Goals and Objectives

| Key Results and Performance Goals (2021–2025) |
|---|
| • Develop datasets and interactive geospatial tools to identify development potential and site characteristics of new stream-reaches, NPDs, and conduit resources.<br>• Publish R&D roadmap that identifies high-impact opportunities to leverage advanced manufacturing and materials in hydropower applications.<br>• Complete testing and pre-commercial demonstrations of new cost-competitive technologies across each class of hydropower resource, with validated energy and environmental performance characteristics.<br>• Complete development of a full-scale, federally sponsored hydropower test facility (or network of facilities).<br>• Establish a framework for assessing costs and benefits of new hydropower projects, particularly those that could utilize new value propositions. |
| **Follow-On Objectives (2026–2030)** |
| • Project developers use geospatial tools to site and design new hydropower projects that balance social and ecological considerations, such as recreation, water quality, and biodiversity.<br>• Technology developers actively pursue and apply high-impact advanced manufacturing opportunities for hydropower applications.<br>• Deployment of new technology with revolutionary improvements in technology costs and environmental performance due to adoption of standardization and modularity principles, incorporation of advanced manufacturing and materials, and ability to test prototypes at full scales.<br>• Increased developer interest in exploring hydropower projects that take advantage of new value propositions in addition to energy generation values. |

[8] Increased developer interest in exploring hydropower projects that take advantage of new value propositions in addition to energy generation values.

## Hydropower Program Activity 2 – Grid Reliability, Resilience, and Integration (HydroWIRES)

Rapid changes in the U.S. electricity system, including changes in 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, the HydroWIRES (Water Innovation for a Resilient Electricity System) Initiative seeks to understand, enable, and improve hydropower's contributions to grid reliability, grid resilience, and integration. HydroWIRES investigates 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 lab-led modeling, analysis, tool development, technical assistance, and technology R&D. Table 2 outlines the key results, performance goals, and follow-on objectives for this activity area. Additionally, the HydroWIRES Research Roadmap[9] outlines further areas being pursued by WPTO.

**Table 2.** HydroWIRES: Performance Goals and Objectives

| Key Results and Performance Goals (2021–2025) |
|---|
| • Publish regionally focused roadmaps for maximizing hydropower's value for reliability, resilience, and integration.<br>• Release the first version of an asset-level cost-benefit assessment toolbox for owners and operators of hydropower and PSH plants, which integrates previous model and tool development focused on revenue opportunities, environmental outcomes, and machine impacts to inform asset-level decisions.<br>• Release the first version of a system-level cost-benefit toolbox for system-level decision makers, such as planners and regulators, which integrates system values, system costs, externalities of hydropower, and the abilities of other resources.<br>• Test innovative technology R&D at a small-scale PSH or flexible hydropower demonstration project, potentially including new PSH concepts and/or flexibility enhancement through hybrid controls and advanced operations. |
| **Follow-On Objectives (2026–2030)** |
| • Accurate representations in power system models of hydropower and PSH capabilities, such as the flexibility of modern designs and reservoir constraints, are widely utilized for research, planning, and unit scheduling.<br>• Quantifiable improvement of hydropower plant operations, including coordination or co-location with other resources, to support greater needs for system flexibility.<br>• Commercialization of new technologies for hydropower asset flexibility and deployment by hydropower owners and operators.<br>• New PSH projects that utilize advanced technologies, system designs, and methods to lower costs/increase cost competitive PSH deployment. |

[9] U.S Department of Energy, 2022. "HydroWIRES Research Roadmap." https://www.energy.gov/sites/default/files/2022-02/HydroWIRES%20Roadmap%20FINAL%20%28508%20Compliant%29_0.pdf.

## Hydropower Program Activity 3 – Fleet Modernization, Maintenance, and Cybersecurity

Within this activity, the Hydropower Program supports analysis, research, and development in three areas: (1) modernization; (2) maintenance; and (3) cybersecurity. Modernization refers to upgrading or adding new hydropower system capabilities. While the modernization portfolio is currently expanding to encompass a broader suite of R&D activities, research to date has been primarily focused on hydropower fleet digitalization. Digital transformation refers to the application of digital capabilities to not only solve traditional challenges for hydropower operations but also enable access to a new range of opportunities for the industry. This has been the initial focus of the modernization work because it represents one of the broadest opportunities for improvement in the hydropower sector, with the potential to reduce operation costs, improve system performance through continuous assessment and predictions, and ensure inter-generational knowledge retention. Maintenance research focuses on understanding and improving the specific procedures surrounding the preservation of aging hydropower systems. Maintenance represents the broadest component of asset management, where routine servicing to the system will maximize the remaining useful life of the asset. However, eventually performance degradation or risk of failure will require that the component be refurbished (activities intended to remove operational damage and increase remaining useful life) or replaced. Cybersecurity research focuses on assessing the complex regulatory and risk landscapes and helping asset owners to determine the possible benefits of different cybersecurity investments. Table 3 outlines the key results, performance goals, and follow-on objectives for this activity area.

**Table 3.** Fleet Modernization, Maintenance, Cybersecurity: Performance Goals and Objectives

| Key Results and Performance Goals (2021–2025) |
|---|
| • Develop and make publicly available hydropower digital twin capabilities (e.g., numerical models, computational codes, and underlying physics/engineering data) appropriately scaled for a diverse range of hydropower plant characteristics and operational profiles.<br>• Publish valuation assessment guidance to facilitate right-sized investments into hydropower digitalization, maintenance, and cybersecurity.<br>• Complete initial phases of research on fatigue and wear mechanisms for high-impact hydropower components, including both conventional and advanced materials, which can reduce forced outage instances and help design the next generation of hydropower components.<br>• Develop hydropower plant cyber-surrogate capabilities that can be integrated into existing cybersecurity processes and reduce hydropower plant vulnerabilities. |
| **Follow-On Objectives (2026–2030)** |
| • Asset owners and equipment designers widely utilize new, open-access digital twin capabilities in efforts to improve system/administrative scheduling and condition-based predictive maintenance.<br>• Demonstrated use of new valuation methodologies in hydropower plant capital planning processes as well as the use of these capabilities to identify cost reduction and capability improvement opportunities.<br>• Use of better articulated wear/fatigue mechanisms by asset managers in maintenance scheduling as well as the integration of these insights into plant dispatch strategies.<br>• Integration of cyber-surrogate capabilities into hydropower cybersecurity processes to facilitate the rapid identification cybersecurity intrusions and improve overall system security. |

## Hydropower Program Activity 4 – Environmental and Hydrologic Systems Science

While hydropower has tremendous value to the power system as a flexible, renewable resource, its long-term value is dependent on maintaining a high level of environmental performance across the fleet. The 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. This 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. Table 4 outlines the key results, performance goals, and follow-on objectives for this activity area.

**Table 4.** Environmental and Hydrologic Systems Science: Performance Goals and Objective

| Key Results and Performance Goals (2021–2025) |
|---|
| • Complete field validations of novel and improved fish detection and tracking capabilities relevant for hydropower studies, including demonstration of environmental DNA and prototypes of acoustic telemetry tags for sensitive species and a self-powered acoustic fish tag.<br>• Demonstrate innovative tools and technologies that are benchmarked for cost and performance, including innovative fish passage technologies and sensor systems.<br>• Demonstrate real-time data collection, automation, and visualization to inform decision makers' choices to operate hydropower resources for enhanced environmental performance in water and species management.<br>• Release a nationwide analysis and visualization platform that enables utilities and system operators to evaluate potential long-term water-availability and climate change related risks to existing and new hydropower assets at meaningful local or regional scales.<br>• Validate new technologies to more accurately characterize and model methane emissions from reservoirs and other water bodies. |
| **Follow-On Objectives (2026–2030)** |
| • A suite of demonstrated, cutting-edge tools and technologies for hydropower-specific environmental monitoring, mitigation, and decision-making that enable accurate data collection and predictive outputs with reduced cost and time and can be utilized for community developed standardized processes and Federal Energy Regulatory Commission (FERC) relicensing.<br>• Quantifiable improvements in fish passage performance that can be linked to established fish population and restoration goals.<br>• Documented improvements in real-time data collection and accuracy for species of concern and other environmental variables that inform hydropower operations and management.<br>• Better understanding of the risks of long-term hydrologic variations to hydropower generation and flexibility and documented incorporation into licensing or other planning processes.<br>• Accurate and widely agreed-upon characterization of methane emissions from U.S. reservoirs. |

## Hydropower Program Activity 5 – Data Access, Analytics, and Workforce Development

As a technology-neutral, national research agency with access to some of the most advanced computing, data management, and analytics in the nation, DOE is well-suited to work closely with other agencies and stakeholders to improve the "data landscape" for important hydropower and river-related information. This can help enable the development and commercialization of new crosscutting analytical capabilities to weigh multi-objective tradeoffs and support stakeholder decision-making. Also, as a largely non-regulatory agency, DOE is in a unique position to help provide insights to identify areas with the greatest opportunity for hydropower regulatory process improvements. The Hydropower Program's efforts will focus on extracting lessons learned from the substantial record of development over the last century and will use its convening role to engage other federal agencies, tribes, the hydropower industry, and nongovernmental organizations to share this information and develop ways to enhance stakeholder engagement and benefit regulatory processes. As the nation's energy and water systems become even more complex and intertwined, all of these goals aim to support improved decision-making and basin-wide management of river resources for multiple objectives, including energy, enabled by improved data and analytical tools. Finally, access to STEM-relevant data, educational materials, and opportunities for students and other early career professionals to learn more about opportunities in hydropower are critical to supporting long-term workforce needs across the industry. Table 5 outlines the key results, performance goals, and follow-on objectives for this activity area.

**Table 5.** Data Access, Analytics, and Workforce Development: Performance Goals and Objectives

| Key Results and Performance Goals (2021–2025) |
|---|
| • Launch and improve the new externally oriented HydroSource online data portal with broad use-case capabilities.<br>• Develop a standard suite of application programming interface (API) capabilities that will provide unprecedented access to power market information for the hydropower community.<br>• Leverage machine learning and new big-data access approaches, in collaboration with FERC and other stakeholders, to increase access to information available in FERC's eLibrary.<br>• Publish a report on the key issues on the time, cost, and uncertainty associated with U.S. hydropower regulatory processes.<br>• Release a new hydropower-focused STEM/education portal and initiate new partnered efforts to provide data and informational support for high-priority hydropower workforce training needs.<br>• Launch DOE's first-ever hydropower collegiate competition and hydropower-focused fellowship program, providing students of diverse backgrounds and disciplines the opportunity to develop key skills for a career in hydropower. |
| **Follow-On Objectives (2026–2030)** |
| • Significantly increased use of the HydroSource portal by a diverse set of stakeholders—beyond the current range of application—along with improved ease-of-use metrics and reviews from users.<br>• Power market data are utilized by developers of new hydropower technologies to specifically target the greatest opportunities and approaches for growth, and are incorporated into future technology development and project planning processes.<br>• FERC and other stakeholders leverage eLibrary insights along with interdisciplinary big data approaches to improve licensing and relicensing study efforts while maintaining regulatory effectiveness.<br>• Key issues identified in the U.S. hydropower regulatory process report are utilized by diverse hydropower stakeholders to agree upon and begin to operationalize regulatory process improvements.<br>• Documented increases in hydropower early-career interest/opportunities and improvements in institutional knowledge-transfer landscape. |

# Marine Energy Program Overview

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|---|---|
| VISION | A U.S. marine energy industry that expands and diversifies the nation's energy portfolio by responsibly delivering power from ocean and river resources. |
| MISSION | Conduct research, development, demonstration, and commercial activities that advances the development of reliable, cost-competitive marine energy technologies and reduces barriers to technology deployment. |

The Marine Energy Program focuses on the following key opportunity areas for potential impact:

- ***Mitigating climate change and enabling a 100% clean energy future***: Marine energy development and deployment can reduce ocean acidification,[10] ocean warming,[11] and sea level rise[12, 13] through the reduction of greenhouse gas emissions, while contributing to grid decarbonization.
- ***Powering underserved communities and enhancing coastal resilience***: Marine energy can power electric microgrids in coastal, remote, and islanded communities, enhancing energy and coastal resilience and sustaining marine ecosystems.
- ***Accelerating technology development timescales through deployment***: Marine energy can meet the needs of many blue economy markets by producing fresh water through desalination or servicing the power demands for aquaculture and ocean sensing, and deploying marine energy for coastal and ocean-based applications can accelerate marine energy technology development for the grid.

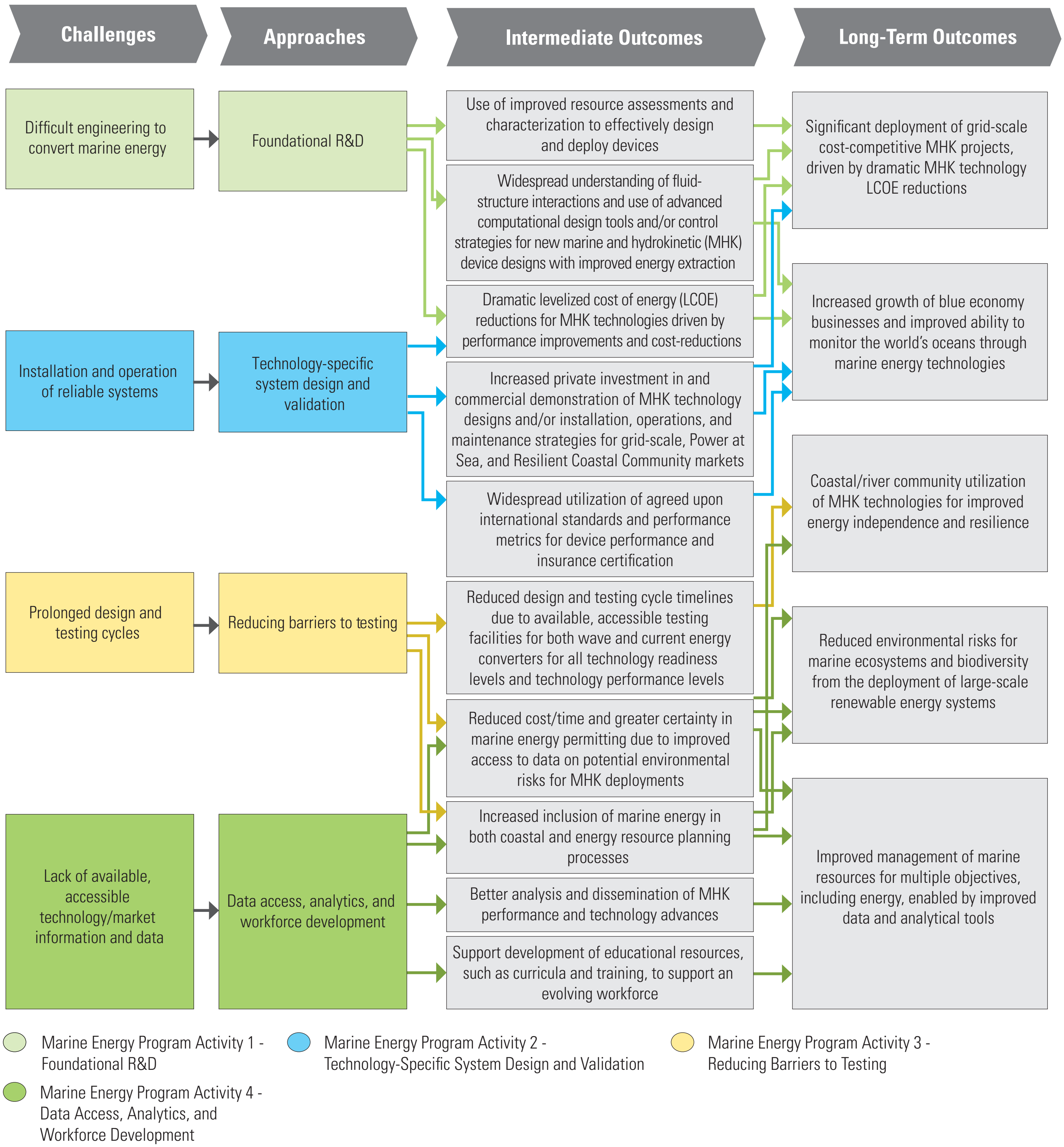
[10] Doney, S. C., Fabry, V. J., Feely, R. A., and Kleypas, J. A. 2009. "Ocean Acidification: The Other $CO_2$ Problem" https://digitalcommons.law.uw.edu/cgi/viewcontent.cgi?article=1055&context=wjelp.

[11] Cheung, W. W. L., Watson, R., and Pauly, D. 2013. "Signature of ocean warming in global fisheries catch." https://www.researchgate.net/publication/236911499_Signature_of_ocean_warming_in_global_fisheries_catch.

[12] Gattuso, JP., Magnan, AK., Bopp, L., Cheung, WWL., Duarte, CM., Hinkel, J., Mcleod, E., Micheli, F., Oschlies, A., Williamson, P., Billé, R., Chalastani, VI., Gates, RD., Irisson, JO., Middelburg, JJ., Pörtner, HO. and Rau, GH., 2018. "Ocean Solutions to Address Climate Change and Its Effects on Marine Ecosystems" https://www.frontiersin.org/articles/10.3389/fmars.2018.00337/full#B48.

[13] Yang, Z., Wang, T., Voisin, N., and Copping, A. 2015. "Estuarine response to river flow and sea-level rise under future climate change and human development." https://www.osti.gov/biblio/1188905-estuarine-response-river-flow-sea-level-rise-under-future-climate-change-human-development.

**Figure 3.** Marine Energy Program High-Level Logic Model



## Marine Energy Program Activity 1 – Foundational R&D

In order to reach cost-competitiveness with other energy resources, marine energy technologies need to see dramatic cost reductions over the next 10-20 years. The Marine Energy Program's Foundational R&D supports research to drive these cost reductions, through improving device performance and reducing costs of existing device designs as well as by developing new capabilities that can allow for entirely new designs and approaches to harnessing the energy in water bodies. These early-stage R&D efforts are typically applicable to a wide range of device archetypes and, in some cases, cut across multiple technology types (e.g., wave, tidal, ocean current). Table 6 outlines the key results, performance goals, and follow-on objectives for this activity area.

**Table 6.** Foundational R&D: Performance Goals and Objectives

| Key Results and Performance Goals (2021–2025) |
|---|
| • Evaluate applicability and performance of composite and other novel materials for marine energy converter systems and subsystems, such as wave energy converter hulls and tidal energy converter blades.<br>• Develop power take-off (PTO)/control system co-design methodologies and partner with technology developers to pilot the use in marine energy converter device design processes.<br>• Validate foundational modeling tools with data from ongoing-water testing projects.<br>• Disseminate high fidelity data sets and models through upgrades of the Marine Energy Atlas and DOE interface to cloud computing services and functional web-based application tools.<br>• Complete resource measurements and assessments in support of marine energy projects to enhance the resilience of specific remote communities.<br>• Test new, important component technologies that support significantly improved installation, operations, & maintenance (IO&M), such as wet-mate connectors and distributed energy conversion technologies.<br>• Advance power electronics technologies that support integration of marine energy devices into power at sea and coastal community microgrid system applications. |
| **Follow-On Objectives (2026–2030)** |
| • Integrated, in-water systems testing completed for new, high-priority materials, power electronics, and other components.<br>• First generation in-water tests completed of device designs documented to have used PTO/control system co-design methodologies and tools.<br>• Early technology readiness levels (TRL) system testing of distributed-energy-conversion technology archetypes.<br>• Widespread utilization (along with positive ease-of-use metrics and value reviews from users) of validated foundational modeling tools. |

## Marine Energy Program Activity 2 – Technology-Specific System Design and Validation

Technology validation is critical to advancing the commercialization of marine energy technologies. This activity area specifically advances systems beyond foundational R&D and focuses specifically on advancing the prototypes necessary to advance marine energy systems across wave, tidal, current, among other energy captures. The R&D in the Technology-Specific System Design and Validation activity area focuses on (1) supporting the design, manufacture and validation of industry-designed prototypes at multiple relevant scales; (2) improving methods for safe and cost-efficient installation, grid integration, operations, monitoring, maintenance, and decommissioning; (3) supporting the development and adoption of international standards for device performance and insurance certification; (4) supporting the early incorporation of manufacturing considerations into device design processes; and (5) leveraging expertise, technology, data, methods, and lessons from the international marine energy community and other offshore scientific and industrial sectors. Table 7 outlines the key results, performance goals, and follow-on objectives for this activity area.

**Table 7.** Technology-Specific System Design and Validation: Performance Goals and Objectives

| Key Results and Performance Goals (2021–2025) |
|---|
| • Complete initial field-testing for modular current energy converter systems that capture hydrokinetic river energy in low-flow environments (less than 2 m/sec) and can incorporate and advance IO&M techniques, which require only limited use of port and deployment vessel infrastructure.<br>• Complete first year-long field tests of wave energy converter device designs in fully energetic wave environments (likely at the PacWave facility).<br>• Complete at-sea, pre-commercial demonstrations of newly developed marine energy-powered ocean observing systems and desalination systems.<br>• Concept refinement, design, and small-scale prototype testing of new wave energy system concepts with high techno-economic potential.<br>• Establish U.S. capabilities for third-party certification of compliance to International Electrotechnical Commission (IEC) technical specifications to include power performance assessment, assessment of mooring systems, electrical power quality requirements, and measurement of mechanical loads at PacWave wave energy test facility, and power performance assessment of current energy converters tested with the Mobile Test Vessel. |
| **Follow-On Objectives (2026–2030)** |
| • New, commercially available marine energy-powered ocean observation systems are deployed for a variety of uses.<br>• Wave powered desalination systems are deployed for the first uses in disaster recovery or international development scenarios.<br>• Documented improvements in energy-water system resilience and security for a number of targeted remote communities, enabled by marine energy systems.<br>• International standards developed for device performance and insurance certification for grid-scale and blue economy market applications. Standards use established as best practice for all device tests and deployments.<br>• First in-water, integrated system tests for newly developed wave energy device concepts.<br>• Design and testing of megawatt (MW) scale current energy converter devices/arrays that incorporates installation, operation, and maintenance lessons. |

## Marine Energy Program Activity 3 – Reducing Barriers to Testing

Testing marine energy technologies is inherently more complex, expensive, and time consuming than for land-based energy generation technologies. The already slow pace of design and in-water testing cycles is further exacerbated by the limited availability of testing infrastructure at various scales, complex and time-consuming permitting processes, and expensive environmental monitoring (again, driven by being in-water). These challenges severely limit the ability of technology developers to quickly assess the performance of devices and components, innovate solutions where necessary, and iteratively test the next generations of devices. Because of the complex physics of the ocean wave and current environments, marine energy prototypes must be tested in real-world environments to fully characterize their performance and reliability. These challenges associated with testing, deploying, and optimizing technologies in a timely and cost-effective manner must be overcome to accelerate the pace of marine energy technology development. The Reducing Barriers to Testing activity area supports national assessments of testing infrastructure and needs, the development of testing facilities (including open-water, grid-connected and non-grid connected facilities) and National Marine Renewable Energy Centers (NMRECs), instrumentation hardware and software dedicated to high resolution data acquisition, as well as environmental data collection. Table 8 outlines the key results, performance goals, and follow-on objectives for this activity area.

**Table 8.** Reducing Barriers to Testing: Performance Goals and Objectives

| Key Results and Performance Goals (2021–2025) |
| --- |
| • Complete a minimum of 100 technical support actions under the Testing Expertise and Access for Marine Energy Research (TEAMER) initiative in collaboration with U.S. universities and national laboratories.<br>• Develop a U.S testing network of at minimum 30 facilities, including a range of capabilities across traditional marine energy research facilities as well as new incumbent facilities with interdisciplinary expertise including non-grid applications.<br>• Identify testing infrastructure gaps, including needs for non-grid applications, at universities and the national laboratories and, as appropriate, address those needs through infrastructure upgrades and development of new capabilities.<br>• Commission, initiate testing, and gain accreditation for the PacWave grid-connected, open-ocean, wave test facility.<br>• Demonstrate the improved technical performance of seven environmental monitoring technologies in relevant marine energy environments while opportunistically collecting data on acoustic outputs, electromagnetic field signatures, benthic habitats, and marine organism interactions with marine energy devices. |
| **Follow-On Objectives (2026–2030)** |
| • Significantly reduced timelines of design iterations for developers and researchers working in the marine energy industry, ultimately accelerating the iterative R&D process.<br>• Validate cost and performance of devices through industry standards, providing confidence to regulatory, investor, and insurance communities.<br>• Adoption of best practices for environmental monitoring technologies resulting in more consistent data collection across projects and greater confidence in the conclusions about the level of risk of specific environmental concerns. |

## Marine Energy Program Activity 4 – Data Access, Analytics, and Workforce Development

As a public research agency and the primary funder of U.S. marine energy R&D, DOE is uniquely capable of aggregating and disseminating objective and accurate information about marine energy. The Marine Energy Program ensures that data and analysis produced are easily accessible and useful to multiple audiences, such as technology developers, researchers, regulators, educators and students. Improved access to and use of data, tools, and STEM resources can lead to: (1) improved awareness of marine energy technology advances and lessons learned; (2) reduced cost, time, and uncertainty around the marine energy permitting processes; and (3) increased opportunities for students and early career professionals to develop skills needed to enter the marine energy workforce. In the long term, these outcomes can support innovation, increase the development and testing of devices at scale, provide a greater understanding of opportunities for marine energy across the blue economy, enhance energy resilience of coastal and river communities, improve marine resource management, and prepare a skilled workforce to advance marine energy into the future. Table 9 outlines the key results, performance goals, and follow-on objectives for this activity area.

**Table 9.** Data Access, Analytics, and Workforce Development: Performance Goals and Objectives

| Key Results and Performance Goals (2021–2025) |
| --- |
| • Publish an assessment of marine energy industry and researcher data needs.<br>• Collect, analyze, and publish data from the existing in-water testing projects to generate new foundational understanding of marine energy devices and identify promising areas for additional research.<br>• Complete integration of publicly available, WPTO-funded marine energy databases with interconnected search functionality.<br>• Launch a new marine energy permitting toolkit to improve regulators' access to and understanding of information about marine energy resources, devices, and potential environmental effects.<br>• Release a new marine energy STEM portal consisting of educator and student resources and curricula.<br>• Improve targeted outreach with the intention of diversifying the pool of students participating in WPTO workforce development programs such as the graduate student research fellowship and Marine Energy Collegiate Competition. |
| **Follow-On Objectives (2026–2030)** |
| • Increased usage of WPTO-developed data, along with supported marine energy databases and toolkits (including the Marine Energy Environmental Toolkit, Marine Energy Permitting Handbook, and State of the Science Report) by a diverse set of stakeholders (along with positive value and ease-of-use metrics collected from users).<br>• Dramatic improvement in regulators' access to useful marine energy data, helping to reduce uncertainty, improve their ability to assess risk, and achieve efficiency gains when permitting projects.<br>• Measurable and significant increases in use of marine energy STEM portal by educators and individuals.<br>• Measured improvement in the diversity of students and student teams participating in WPTO's fellowship programs and Marine Energy Collegiate Competition, including minority students as well as students from minority-serving institutions, such as historically Black colleges and universities, Hispanic-serving institutions, and tribal colleges. |