Marine Energy Program Peer Review

Marine Energy Program Overview

To help realize the Marine Energy Program's vision, WPTO conducts research, development, demonstration, and commercial activities that advance the development of reliable, cost-competitive marine energy technologies and reduce barriers to deployment. This work is concentrated in four activity areas and one initiative: Foundational R&D; Technology-Specific System Design and Validation; Reducing Barriers to Testing; Data Access, Analytics, and Workforce Development; and the Powering the Blue Economy™ (PBE) Initiative.

As defined in the Energy Act of 2020 (Title 3, Subtitle A, Sec. 3001) the term "marine energy" means 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.
- Differentials in water temperature, including ocean thermal energy conversion.

Utility-scale marine energy technologies are at an early stage of development compared to other renewable energy technologies due to the fundamental challenges of generating power from dynamic, low-velocity, and high-density waves and currents, while surviving in corrosive marine environments. These challenges are intensified by high costs and lengthy permitting processes associated with in-water testing. Addressing these challenges is a key part of WPTO's portfolio.

These challenges are worth overcoming as marine energy has the potential to contribute to an electric grid primarily powered by renewable energy while also addressing the need for climate change mitigation. The program is working to ensure this potential is unlocked while avoiding an undue burden on the environment surrounding deployed marine energy technologies. Current research shows that marine energy's potential environmental impacts are low compared to other energy sources, particularly fossil fuels, with minimal drilling-associated noise pollution and low to non-existing risks of oil spills leading to ecosystem damage, and WPTO is dedicated to ensuring these technologies are developed in a way that keeps this statement true.

In addition to marine energy's potential contribution to the grid, WPTO also sees the value this resource could have in advancing many of the United Nations Sustainable Development Goals by providing power at sea for activities from ocean observation to aquaculture. With all these areas of use, WPTO is working to accelerate the maturity of marine energy technologies according to international standards and specifications, ultimately leading to system accreditation. The program also recognizes marine energy's potential to enhance resilience and power electric microgrids in coastal, remote, and islanded communities. Marine energy technologies can, importantly, help make these communities more resilient in the face of extreme events such as tsunamis, hurricanes, floods, or droughts.

Organization of Tracks and Review Panels

The Marine Energy Program, activity areas, and individual projects were reviewed and scored during WPTO's 2022 Peer Review. Additionally, the reviewers scored and provided specific feedback on the PBE Initiative—an effort that seeks to understand the power requirements of emerging coastal and maritime markets and advance technologies that could integrate marine renewable energy to relieve these power constraints and promote economic growth. Program and activity area overview presentations detailed the goals and objectives, as outlined in the MYPP. For information about the structure, strategy, and implementation of the program and its relation to WPTO's overall mission, please refer to the corresponding program overview and PBE overview slide decks presented during the review.

Four panels of reviewers reviewed these program elements, as well as individual projects across all the Marine Energy Program's activity areas. There were also two reviewers who focused solely on the cross-programmatic prize portfolio and one who did the same for the STEM and workforce work. Figure 13 depicts the total number of marine energy presentations reviewed by program and activity area.

Figure 13. Number of Marine Energy Projects Reviewed by Review Panel

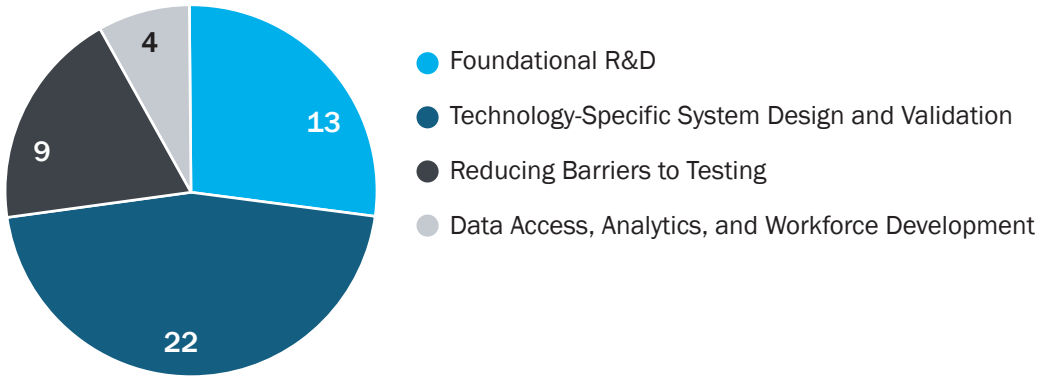


Table 6 summarizes the role, review panel, and affiliation of the external experts who served as reviewers for the Marine Energy Program during WPTO's 2022 Peer Review.

Table 6. Marine Energy Program Reviewers

MARINE ENERGY PROGRAM			
Name	**Role**	**Review Panel**	**Affiliation**
Henry Jeffrey	Review Chair and Panel Lead	Technology-Specific System Design and Validation	University of Edinburgh
David Ingram	Panel Lead	Foundational R&D	University of Edinburgh
Deborah Greaves	Reviewer	Foundational R&D	Supergen Offshore Renewable Energy Hub (University of Plymouth)
Jessie Carman	Reviewer	Foundational R&D	National Oceanic and Atmospheric Administration
Umesh Korde*	Reviewer	Foundational R&D	Johns Hopkins University
Beth Dickens	Reviewer	Technology-Specific System Design and Validation	Quoceant Ltd.
Claudio Bittencourt Ferreira	Reviewer	Technology-Specific System Design and Validation	DNV Renewables
Sue Molloy*	Reviewer	Technology-Specific System Design and Validation	Glas Ocean Electric

MARINE ENERGY PROGRAM			
Name	**Role**	**Review Panel**	**Affiliation**
Sue Barr	Panel Lead	Reducing Barriers to Testing	Cambrian Offshore
Denis Nault	Reviewer	Reducing Barriers to Testing	Maine Department of Marine Resources
Louise McGarry	Reviewer	Reducing Barriers to Testing	Fundy Ocean Research Centre for Energy
Phil Vitale	Reviewer	Reducing Barriers to Testing	Retired (formerly Naval Facilities Engineering Systems Command)
Michael Atkinson	Panel Lead	Data Access, Analytics, and Workforce Development	North Carolina A&T State University
Ana Couto*	Reviewer	Data Access, Analytics, and Workforce Development	European Marine Energy Center
Dan Hasselman*	Reviewer	Data Access, Analytics, and Workforce Development	Fundy Ocean Research Centre for Energy
Linda Silverman*	STEM/Workforce Reviewer	Data Access, Analytics, and Workforce Development	Potential Energy DC
Donna Vincent Roa	Prize Reviewer	Prizes	U.S. Agency for International Development's Partnerships Incubator, The Kaizen Company
Sally Gutierrez	Prize Reviewer	Prizes	Environmental Protection Agency

*Selected to also review the crosscutting Marine Energy STEM and Workforce project.

Marine Energy Program Scores

Reviewers were asked to evaluate WPTO's R&D programs, activity areas, and initiatives at a strategic level, both numerically and with specific, concise comments to support each evaluation. Reviewers evaluated each program on the following equally weighted criteria: strategy and implementation and progress. Figure 14 summarizes reviewers' quantitative assessment of how the Marine Energy Program is performing overall. While all PBE projects fell into other marine energy activity areas and were scored within those panels, it was critical to solicit reviewer feedback on the overall strategy. Figure 15 shows the quantitative assessment of the PBE Initiative. Figure 16 shows the average weighted score for the Marine Energy Program's activity areas, including PBE, with reference lines indicating the average project score and program score. The aggregated reviewer comments justifying these quantitative scores can be found in Volume II.

Figure 14. Marine Energy Program Average Weighted Score by Evaluation Criterion

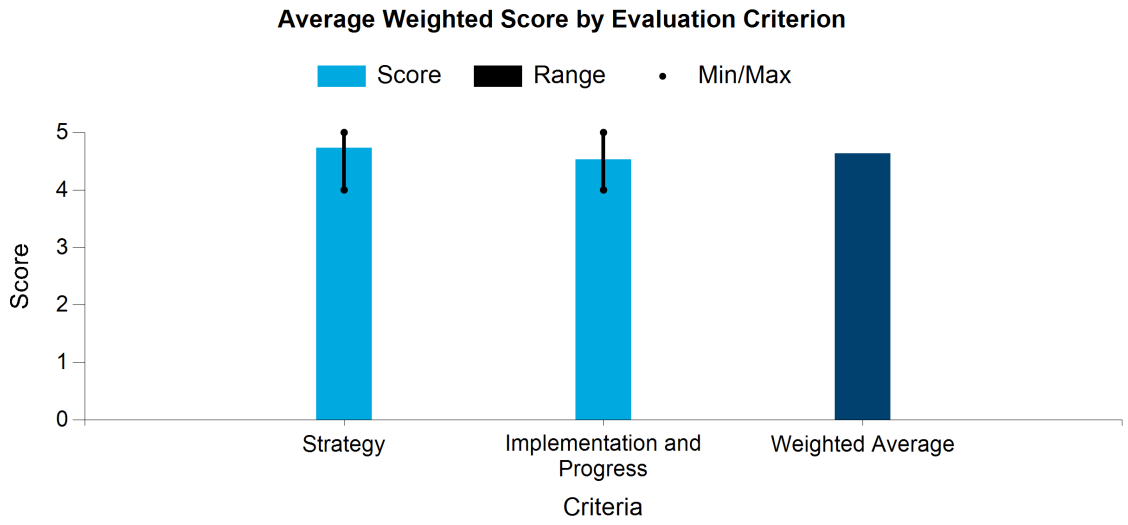


Figure 15. PBE Initiative Average Weighted Score by Evaluation Criterion

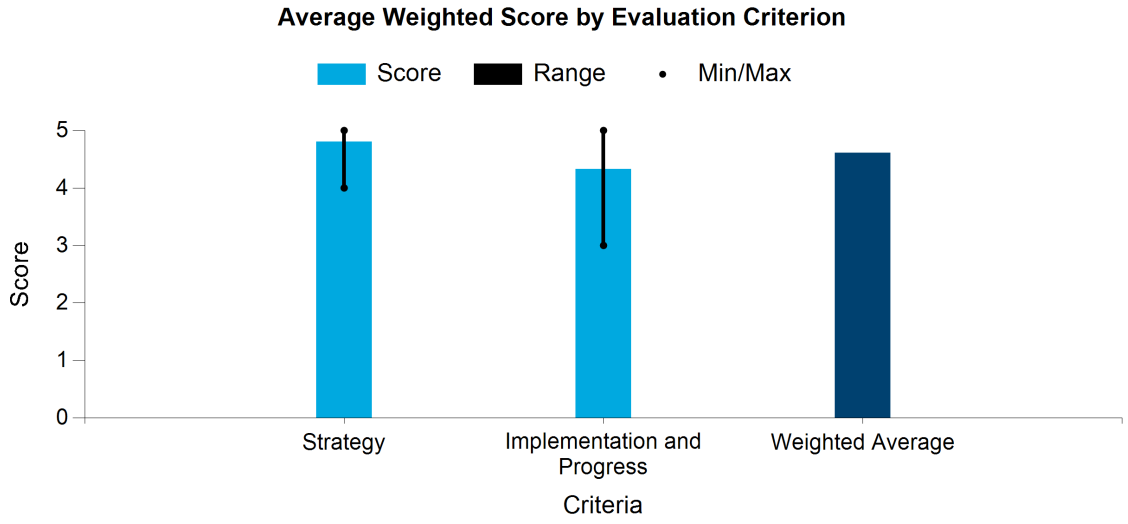
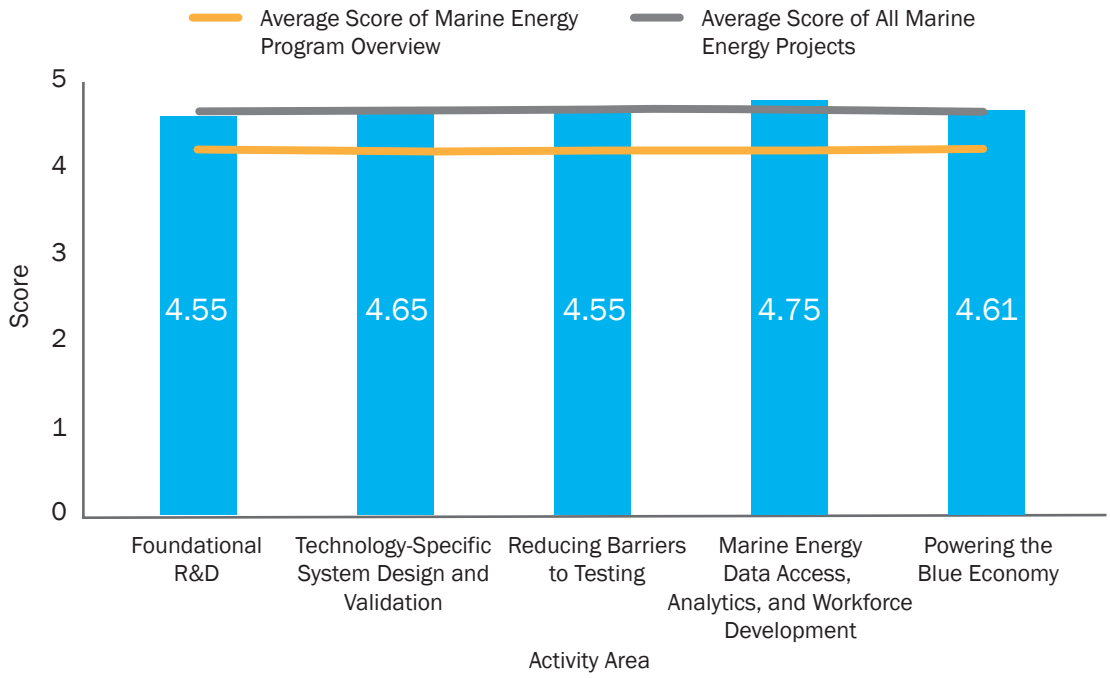


Figure 16. Average Weighted Score by Marine Energy Program Activity Area



Organization of the Results

The quantitative and qualitative results are summarized at the program, activity area, and project levels. Information in this section has been compiled based on the following sources and is organized as follows:

- Marine Energy Program Evaluation Summary: A summary of all marine energy reviewers' comments that provides insight into the program's strengths and weaknesses or potential issues and specific recommendations. The program review chair was responsible for drafting the program summary in consultation with each review panel lead and all marine energy reviewers. Consensus among the reviewers was not required, and the review chair was asked to include differences of opinion and dissenting views within the report.
- Marine Energy Program Response: The WPTO program manager's official response to the recommendations provided in the review chair's program evaluation summary.
- Marine Energy Program Activity Area Results: The results of the reviewers' quantitative scores on the program. Activity area results follow the program results and begin with a summary chart that depicts the average score for each project in each activity area. Each activity area subsection includes the following components:
  - *Activity Area Evaluation Summary*: This consists of a summary of the review panel's comments that provides insight into each activity area's strengths and weaknesses or potential issues and specific recommendations. Review panel leads were responsible for drafting activity area evaluation summaries in consultation with the full review panel and program review chair. Consensus among the reviewers was not required, and the review panel leads were asked to include differences of opinion and dissenting views within the report.
  - *Activity Area Response*: The WPTO activity area lead's official response to the recommendations provided in the review panel lead's activity area evaluation summary.

Marine Energy Program Evaluation Summary

Submitted by Henry Jeffrey, Chair

Key Takeaways

WPTO's Marine Energy Program has moved from strength to strength, ensuring the activity areas are well integrated and leading to the marine energy sector's continued progression. The program laid extensive groundwork related to research capabilities and has ensured there is cohesive coordination between industry and national labs, ranging from the development of full-scale devices to the innovation of supporting components and specialist software.

Pending future budgetary constraints, the scaling of technologies in size, and development and deployment costs, it may now be time to focus the many different research strands to maximize the program's potential to deliver returns consistent with the level of support it has provided. This approach will prevent assets, research themes, and future projects from becoming stranded and ensure the program grows in line with its research commitments moving forward.

Over the medium and long terms, it will be important to fully consider how funding and management environments will need to adapt as projects scale and advance through multiple technology readiness levels (TRLs). It is important to question whether WPTO will have the requisite funding for innovation, as well as the staffing levels for continued sector progress and to continue to run an effective, well-coordinated, and adequately staffed program. If the program is going to continue to grow, it will be critical to ensure the necessary support mechanisms are in place.

Value can be added to WPTO's already effective program in a few ways. The most pressing issues include prioritizing effective knowledge transfer, initiating clear processes to ensure projects can learn from previous successes, tracking long-term project awardees' progress, and ensuring WPTO scales accordingly. However, it is important to highlight the Marine Energy Program's and the staff's progress and laude the impact the program has on an organizational level at accelerating the sector's development and helping to shape the much-needed net-zero transition.

Feedback from the Review Chair to WPTO

The program's breadth and depth are impressive, and its expansive nature ensures multiple key research areas are being targeted and their objectives achieved. It is important to question if this will remain sustainable as technologies achieve higher TRLs. Depending on future funding levels, it may be necessary to focus the program's scope to ensure its continued success and impact.

Value could be bolstered with stronger user engagement, ensuring customer needs, whether in a niche or utility market setting, are well understood. DOE could deliver this centrally, removing the onus from technology developers that may not be uniquely equipped to deliver strong end-user engagement.

Program breadth can also be addressed by assessing the progress of technology developers that have enjoyed sustained exposure to the WPTO support system and received numerous project awards. This will safeguard the long-term validity and effectiveness of the program, and the use of IEA Task 12, Stage Gate Metrics may be an effective tool for this process. Projects' abilities to transition to commercial business models following funding from WPTO is also a key concern and an area that should be explored further.

Prizes remain an effective tool to attract innovation in a new project area. However, they need to be analyzed to ensure they remain cost effective and have a traceable pathway to serve the sector's innovation needs. It is also important to capture each prize program's lessons learned regarding program structure and the technological developments they helped to underpin. Prizes should have a clear pathway for successful developers to continue their journey forward to remove the risk of stranding innovation.

The process of technology transfer is important to ensure that, in the case where any individual project might not meet its long-term goals, there is a mechanism to extract specific, successful technological developments or procedural lessons that might be of benefit to the wider sector.

While there is a strong drive to develop sea-ready, full-scale devices such as wave energy converters (WECs), more needs to be invested into projects conducting fundamental research to better characterize realistic ocean conditions. This can be accomplished by increased funding at the university level where publishing fundamental research is key, and peer-reviewed articles add credibility to new technologies. Additionally, in instances where technologies are being developed by other companies or nations, knowledge transfer will help to limit wasteful duplication and replication of research. Where possible, it would also be beneficial to ensure projects are aligned with other funding such as that from the Department of Defense.

The overwhelming consensus from reviewers is that there needs to be an increased effort in recognizing and mitigating possible negative environmental impacts. While this may be a result of many projects being in the early stages of development, funding projects that genuinely explore eco-friendly solutions should be prioritized. Reviewers also recommend foundational technology and component development projects be required to consider the impact of the real ocean environment (i.e., multidirectional waves, wind driven, ocean and tidal currents, and turbulence) as part of a co-design approach. Finally, reviewers advise that a fair approach is taken to compensate for the adverse effects of COVID-19 and its impact on the flexibility and security of supply chains, working conditions, and internal timelines.

Summary of Reviewer Feedback on the Program

Overall Impressions

WPTO needs to be supplied with both the innovation funding and staff resources to ensure the depth and breadth of the program continues to be effectively managed. There may be a need to focus the program to ensure key projects do not become underfunded and investments do not become stranded. Further, a comprehensive cost-benefit analysis of the prize program approach will ensure it continues to be an effective tool and delivers continued innovation.

It is advisable to ensure there are synergies between technologies underpinning both the blue economy and utility-scale devices with common goals and areas of overlapping research expertise highlighted. WPTO should also ensure all strands of the program have full pathways and funding to commercialization, ensuring broader sector uptake. Sector engagement should be delivered centrally as there are instances where certain projects are heavily focused on single devices with limited potential for outreach and dissemination, ultimately limiting their usefulness to the broader sector.

Program Strategy

The program benefits from having a well-defined strategy in full alignment with the MYPP, including clear objectives and defined research priorities. Although the overall program deals well with short- and mid-term challenges, it is less clear how it will evolve to deal with the longer-term challenges of the sector, whether this is at scale or for new and emerging technologies. Without attempts to refine the scope or expand WPTO's resources, it may be difficult to scale up to comprehensively cover all current areas of development and deployment. Scaling should also involve increased levels of international collaboration, drawing on the expertise and testing capabilities of international leaders in the sector.

With respect to industry and stakeholder needs, the overall strategy is well considered. However, this should be monitored in line with the sector's evolution and with consideration to technologies' scales and the expected differences between niche blue economy and utility-scale technologies. It would also be advantageous to ensure projects are not just aimed at specific end users but, where possible, expanded to take into consideration varied industry and stakeholder requirements. Ensuring strong, diversified attempts at stakeholder engagement are made will only benefit a sector that has global appeal and reach.

Currently, there is a good rationale to support the organization of the sub-activity research areas and priorities. However, this might need to be reconsidered if the program chooses to refocus its priorities or as technologies scale to higher TRLs and introduce different challenges. There is a good mixture of funding mechanisms across the program for academia, labs, and industry, supported by a comprehensive range of prizes and competitions. Ensuring complementary and collaborative links between DOE and the Department of Defense will help to foster accelerated technological development and ensure end users in both sectors have the opportunity to fund or engage with complementary projects.

WPTO funding is additive in its ability to raise additional funding to support projects without compromising overall program deliverables.

Implementation and Progress

The current program is in full alignment with WPTO's stated objectives. Reviewers unanimously agree the program is funding the most relevant technologies, tools, and studies. However, in all instances, whether a project has been deemed successful or not, it is important to retrospectively examine milestones and deliverables that will allow WPTO to highlight isolated instances of technological development that can be utilized or lessons that can be learned and applied across the sector. There should be clear processes in place to ensure future projects can learn from previous projects, limiting the scope for duplication and replication of research aims and challenges.

Companies that receive long-term or consecutive project awards should be monitored to ensure they remain on track to deliver strong results throughout the duration of the project lifetime. This should be supplemented by the inclusion of a go/no-go decision at the halfway point of any project. This will help ensure projects in danger of not achieving their milestones do not continue to accept funding that could be allocated to other projects.

Across the program, activity areas include diverse and complementary R&D projects that are closely tied to the program's strategic direction. This can be safeguarded by enacting a robust evaluation process that can determine risk profiles of projects as they progress. Additionally, it is important to fully understand the context and subsequent consequences of not progressing a project, especially in the later stages of development.

The peer review is a robust and transparent process, reinforced by ensuring outcomes are made publicly available to the wider marine energy sector. However, there should be greater sector and public awareness of the process with effective advertisement and dissemination of the process and its outcomes.

Despite the level of collaboration and knowledge exchange that exists within the WPTO community, the panel feels there could be stronger attempts to coordinate additional dissemination and sharing of results with the wider marine energy sector (in addition to the peer review process). At an individual project level, the program could benefit from greater communication between domestic and international bodies, projects, and industry stakeholders.

Additional Comments on the PBE Initiative

Using WPTO's research capabilities to help power the blue economy has the added advantage of providing an additional route to industrial-scale commercialization of devices in the sector. However, the blue economy is a market in its own right, and any funds directed to it need to be examined to ensure they are an appropriate use of public funds that contributes to the net-zero challenge. Funds should not be diluted, subsidizing both the blue economy and low-carbon utilities, especially in instances when technological development will produce devices with end-user qualities that are not designed for use in low-carbon utilities. This reinforces earlier suggestions that efforts should be made to continually focus the program to ensure it remains a good value for money invested and future research interests are aligned.

Marine Energy Program Response

Submitted by Tim Ramsey, Program Manager

Response to the Review Chair's Key Takeaways

The Marine Energy Program would like to thank the reviewers for the significant time and effort they contributed to this review. The program was honored to work with each of the reviewers and grateful they shared their expertise, and the U.S. marine energy community will benefit for years to come thanks to the reviewers' hard work and dedication. WPTO gained invaluable insights and has already started to incorporate some of the recommendations into the program strategy.

The Marine Energy Program thanks the reviewers for their many positive comments on the quality of WPTO staff. The program is very proud of the team and acknowledges that its success reflects their hard work and professionalism.

Overall, reviewers outlined several areas for improvement to (1) focus and evaluate funding and maximize impact in later stages, (2) improve fundamental research and technology transfer, (3) mitigate possible negative environmental impacts, (4) strengthen supply chain engagement, and (5) further integrate end-user requirements in the PBE Initiative. The following sections outline the program's response to the reviewers' key recommendations.

Recommendation 1: Focus and Evaluate Funding and Maximize Impact in Later Stages

The Marine Energy Program agrees with the reviewers' feedback regarding later-stage technologies and recognizes the challenge ahead. The program has supported a wide breadth of technologies across many resource types and end-use applications, and costs inherently increase as systems advance in TRL. Within current funding levels, the program may be forced to down-select as technologies continue to mature. Selecting the most impactful technologies and projects will be crucial for the industry's advancement. The program will gather as much information as possible to inform these decisions, including feedback on the MYPP and from subject-matter experts across the industry, the National Marine Renewable Energy Centers (NMRECs), and the national labs. The program will also apply IEA-Ocean Energy Systems (OES) Task 12, Stage Gate Metrics, to assist in measuring technology development progress and success. Furthermore, a robust project management plan for later-stage projects will be critical to maximize program funding and support the entire industry's advancement.

The program must also better capture and disseminate information from all projects funded, though particularly for higher-stage and higher-cost projects. It is important to retrospectively examine milestones and deliverables that will allow WPTO to highlight isolated instances of technological development that can be utilized or lessons that can be learned and applied across the sector. The program will strengthen its dissemination plan around the peer review process and look to expand efforts to disseminate and share results with the wider ocean energy sector.

The program will require stronger end-user engagement at the beginning of projects, ensuring customer needs are well understood and projects transition to commercial business models. The program will consider additional mechanisms to foster end-user engagement, including centralizing this effort at WPTO, thereby reducing the onus on technology developers.

In addition to evaluation of the stage of projects being funded, WPTO is actively tracking, evaluating, and monitoring the effectiveness of these programs, including prizes across the portfolio. In addition to the need to fund later stage solutions, the program also views it as critical to continue to invest in new ideas, people, and approaches to ensure a portfolio that has a forward-looking approach and includes reducing risk by investing in new approaches.

WPTO uses a range of financing mechanisms, including prize competitions to spur innovation in new areas and/or from new and under-resourced entrants, SBIR grants to provide non-dilutive grants for commercialization-focused R&D, and larger cooperative agreements for sustained R&D. In addition to financial assistance, WPTO also works with the American-Made Network's Power Connectors and other organizations to provide commercialization support to prize and SBIR awardees, and provides funding to a network of blue economy incubators and accelerators to provide business development support. And the program is committed to tracking and evaluating and disseminating information on the effectiveness of this approach.

Recommendation 2: Improve Fundamental Research and Technology Transfer

The Marine Energy Program appreciates the reviewers' feedback to invest more into projects conducting fundamental research to better characterize realistic ocean conditions. The program has invested heavily in the Foundational R&D Activity Area, notably in controls, modeling, and resource characterization, though more can be done. The program will continue to assess industry's foundational and crosscutting requirements and prioritize those research areas of greatest need and impact. The program also plans to bolster engagement with the NMRECs and affiliated universities to broaden its foundational research impact. The Bipartisan Infrastructure Law included $40 million to support the NMRECs, and the program will leverage this funding to support foundational research. In addition, the recently established University Marine Energy Research Community (UMERC) Program will foster collaboration within the marine energy research community and amplify the impacts of foundational research. The program will look to UMERC to help increase transparency and awareness of marine energy research, inform areas to enhance marine energy research activities, and improve overall research coordination and collaboration.

Recommendation 3: Mitigate Possible Negative Environmental Impacts

The Marine Energy Program thanks the reviewers' feedback regarding environmental impacts. The program will continue to support OES-Environmental (Task 4), led by PNNL, which synthesizes into collaborative reports and documents information and scientific research about marine renewable energy and the environment on a global scale. OES-Environmental hosts workshops and webinars to bring researchers together around environmental effects research and supports environmental effects tracks at international conferences. The program will also continue to engage with regulators and permitters, including the continued use and refinement of the Marine Energy Environmental Toolkit developed by Kearns & West. Additionally, the program agrees with reviewers' recommendation that foundational technology and component development projects should consider the impact of the real ocean environment as part of a co-design approach and will look to strengthen this connection and prioritize projects that genuinely explore eco-friendly solutions.

Recommendation 4: Strengthen Supply Chain Engagement

The Marine Energy Program agrees with reviewers' feedback regarding supply chain engagement. The industry is at a critical stage of development and supply chain engagement is paramount to ensure adoption and commercial success. The program will put more emphasis on the challenges developers face with electrical cables, access to marine vessels, and/or specific device handling and mooring designs, as well as integrate lessons learned from other renewable energy industries, like offshore wind. The program will aim to foster site-specific supply chain development, including at PacWave, to support marine energy developers.

Recommendation 5: Further Integrate End-User Requirements in the PBE Initiative

The PBE Initiative recognizes current challenges in deploying grid-scale marine energy systems, and therefore identifies near-term markets and end users for marine energy to enable technology deployment, prototyping, and testing to accelerate the development and maturity of marine energy technologies. This program is also aimed at commercializing non-grid marine energy systems and applications in the near term.

Because developers are in the concept phase of technology development, PBE recognizes end-user requirements are key to contribute to the concept design, particularly for those non-grid applications. The program will work to engage more with the U.S. Navy, Department of Defense, and the National Oceanic and Atmospheric Administration (NOAA) on system requirements (as they are key end users for the technologies under development) and ensure requirements are considered at the design phase. The Marine Energy Program will facilitate end-user engagement and identification of end-user needs. And as previously mentioned, WPTO is committed to supporting entrepreneurs, industry, and academia connections to end users through mechanisms like the American Made Challenge platform and through other support.

Marine Energy Program Activity Area Results

Foundational R&D

The Foundational R&D Activity Area aims to drive early-stage R&D on components, controls, manufacturing, and materials; develop and validate numerical modeling tools; improve resource assessments and characterizations; and develop quantitative metrics to evaluate devices' potential. Through this activity area, WPTO is working to:

- Drive early-stage R&D on components, controls, manufacturing, and materials.
- Develop and validate numerical modeling tools and methodologies for improved understanding of important fluid-structure interactions.
- Improve marine energy resource assessments and characterizations needed to optimize devices and arrays and understand extreme conditions.
- Develop and apply quantitative metrics to identify and evaluate technologies with high ultimate techno-economic potential.

The review panel was impressed by the focus of the work and the overall deliverables produced but did suggest there be a larger focus on stakeholder engagement to help increase the pool of applicants, recipients, and partners. Figure 17 summarizes the reviewers' quantitative assessment of how the activity area is performing overall, and Figure 18 provides an overview of the scoring of all projects within the Foundational R&D Activity Area.

Figure 17. Foundational R&D Activity Area Average Weighted Score by Evaluation Criterion

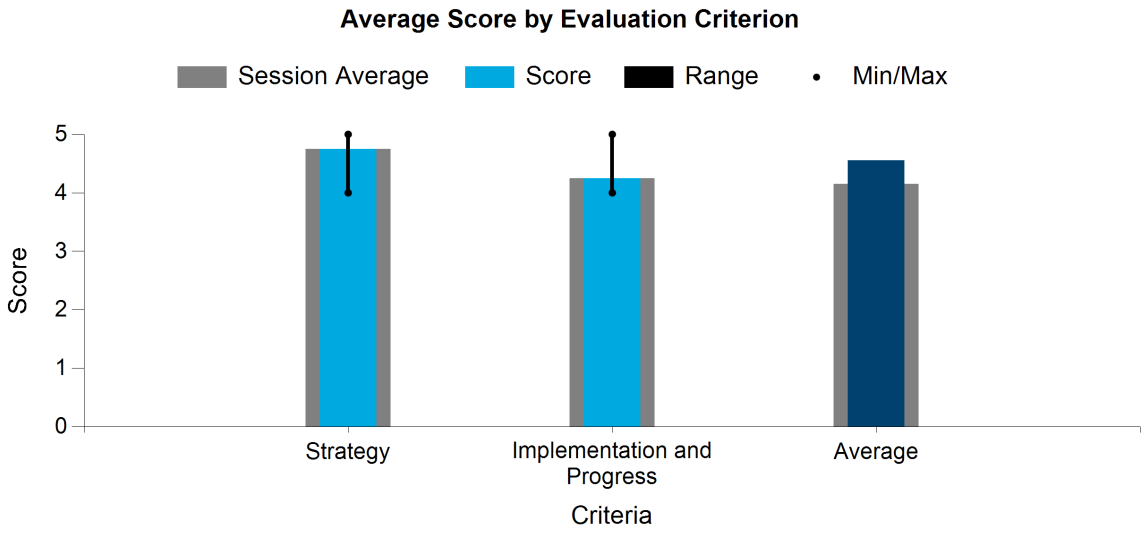
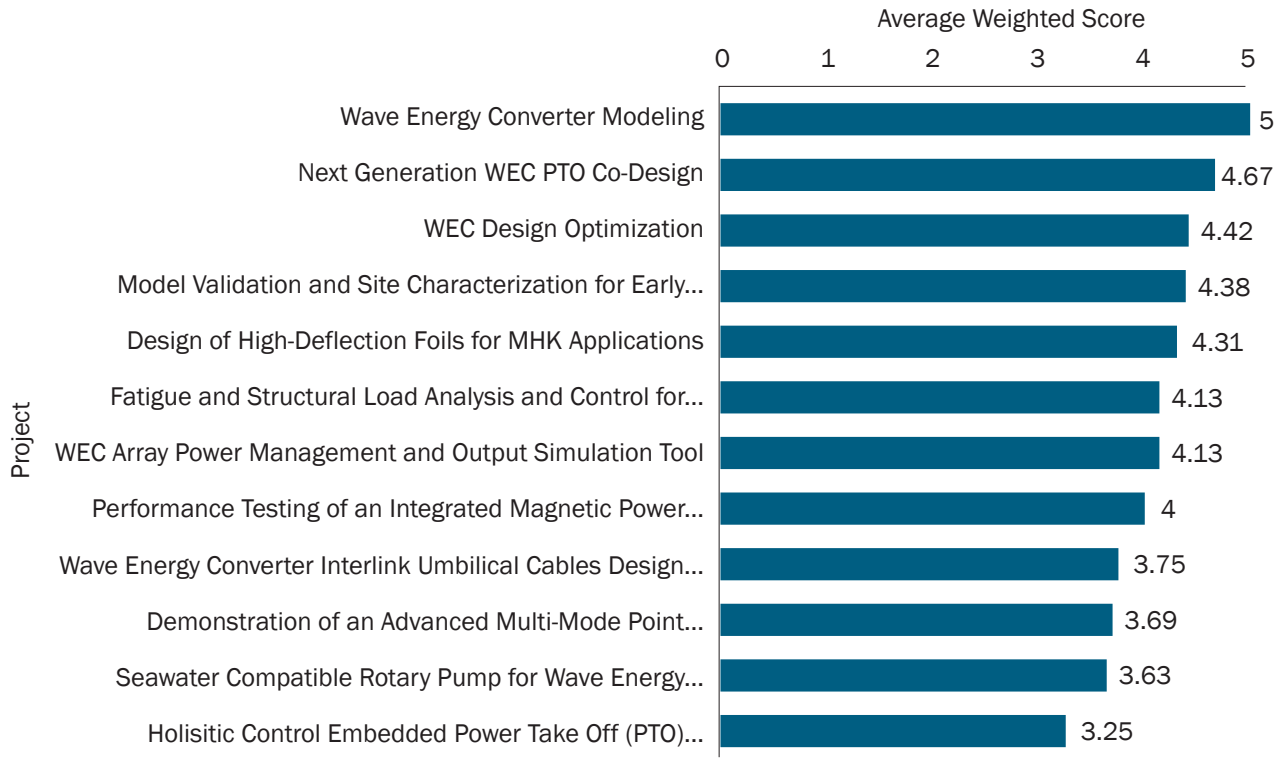


Figure 18. Foundational R&D Activity Area Weighted Average Score by Project



The following subsections include the review panel lead's summary of reviewer comments and the WPTO activity area lead's response to reviewer feedback. The full evaluation results for the activity area and the portfolio of projects can be found in Volume II of this report. For more information about the activity area's structure, strategy, and R&D priorities, please refer to the MYPP or the corresponding activity area overview slide deck presented during the review.

Activity Area Evaluation Summary

Submitted by Professor David M Ingram

Feedback from the Review Panel to WPTO

The Foundational R&D portfolio has delivered some very significant work, particularly in the development of software tools, and WPTO and DOE should be proud of this achievement. The activity area is focused and addresses many of the key challenges facing the sector with a strong focus on co-design.

One concern is that only three wave energy companies and one marine and hydrokinetic (MHK) energy company are involved in foundational R&D, and these companies are often the only stakeholders represented in a project. Wider stakeholder engagement is critical, so lessons learned are shared widely, enabling the overall development of the sector. Another concern is that there are clear linkages and synergies between projects with the risk that work is duplicated, or opportunities are missed due to teams working in silos.

Reviewers recommend much broader stakeholder engagement. Project teams should engage with the international community to leverage learning, accelerate development, and consider a broader range of options/decision needs. Linkages to green hydrogen and floating offshore wind activities within other DOE offices should be explored with the potential for projects to be jointly funded and commissioned.

The development, maintenance, and dissemination (including promotion and training) of the open-source software tools should be continued. In particular, the Wave Energy Converter SIMulator (WEC-Sim) is widely used and has a significant global impact. Furthermore, development of the Marine Energy Atlas should continue with the addition of deployment constraints to deliver a multicriteria site selection tool that includes wind and MHK energy resources. Reviewers consider the development of sea state classifications premature.

Foundational technology and component development projects should be required to consider the impact of the real ocean environment (i.e., multidirectional waves, wind driven, ocean and tidal currents, and turbulence) as part of a co-design approach. Testing should be conducted on the bench or in the laboratory wherever possible. A stage-gated approach should be taken to ensure risks are minimized when devices are deployed in the marine environment and to subject them to a set of standard but representative sea conditions. Access to laboratories should continue to be facilitated through an extended portfolio through the Testing Expertise and Access for Marine Energy Research (TEAMER) program that provides access to large-scale international facilities where domestic capabilities (e.g., multidirectional waves or wave and current testing) are not available.

At-sea testing at specific test sites should only be mandated when the test site is ready and fully able to accept devices for test. DOE should work with test sites and local ports and harbor facilities to ensure there are adequate berth and laying down areas available to accommodate devices during test portfolios. DOE should also encourage the development of local supply chains to support developers coming to test.

Summary of Reviewer Feedback on the Activity Area

Overall Impressions

The Foundational R&D portfolio has delivered some very significant work. The design of the MYPP is based on a careful and competent analysis of the sector's needs. Strengths include the open-source software tools, the Marine Energy Atlas, and the Seedling and Sapling projects that support the investigation of "blue sky" ideas.

In many cases, stakeholder groups are very limited, and projects would benefit from wider engagement. Some projects are not foundational and have limited outreach and dissemination. These are heavily focused on single devices and do not support the broader sector.

Activity Area Strategy

Reviewers agree the Foundational R&D activity area has a clearly defined strategy outlined in the MYPP, which includes clear performance goals, objectives, and research priorities. The reviewers also agree the activity area's strategy reflects an understanding of the near- and long-term challenges facing industry and other stakeholders. In addition, the activity area's strategy effectively communicates the rationale for and organization of the sub-activity areas and research priorities. Finally, reviewers agree the activity area leverages appropriate funding mechanisms to achieve its intended goals and objectives.

While the strategy considers the needs of industry and wider stakeholders, many of the projects have limited stakeholder representation (often drawing on the same stakeholders). This limits the impact of the work and leads to poor dissemination of results. It would be beneficial to include wider, international stakeholder groups and to share learnings more widely with the community. This is a global grand challenge with so many opportunities that technology developers do not need to worry about competition.

Reviewers are concerned that funding models drive developers to test at the U.S. Navy's Wave Energy Test Site (WETS) when it is not ready. WPTO must ensure WETS and the necessary port facilities are ready to accept developers. Another concern is that funding models drive projects to work with WEC designers when other industrial companies (e.g., cable manufacturers) would be more appropriate.

Finally, projects should bench and laboratory test as much as possible. Tests must consider the forces due to multidirectional waves, turbulence, shear, etc. This is critical to de-risking field deployment and will maximize benefits. Projects should have access to international facilities in cases where domestic capabilities do not exist.

Implementation and Progress

Reviewers agree the activity area has selected diverse and complementary R&D projects that are closely tied to the program's strategic direction. The activity area is funding the most relevant technologies, tools, and studies to achieve the MYPP's stated goals and objectives and is likely to meet performance goals and objectives based on the current portfolio of projects.

Many of the projects are clearly foundational and have broad applicability. The open-source software tools and the Marine Energy Atlas and associated resource data are strengths of which WPTO and DOE should be particularly proud.

The umbilical project has struggled because it is working directly with a WEC developer rather than a cable manufacturer. As with the Marine Energy Atlas, its findings are critical for many other sectors, including floating offshore wind.

In several projects, dissemination and engagement activities are very limited, impacting the portfolio's ability to meet its overall performance goals.

Activity Area Response

Submitted by Bill McShane, Technology Manager

The Foundational R&D Activity Area would like to thank the reviewers for their attention during the peer review and for their diligent comments and insights. The breadth and depth of the Foundational R&D portfolio is significant, and WPTO acknowledges that a complete review of the activity area was no easy task. The Foundational R&D Activity Area will take reviewers' comments and evaluate them thoughtfully. The activity area aims for a high performing and focused cohort of research projects and topics. Reviewers' expert and independent comments will help improve WPTO's strategic direction and program management. To sum up, the activity area thanks reviewers for their engagement, which will help the Foundational R&D Activity Area accelerate R&D, enabling a thriving U.S. marine energy industry.

Overall, reviewers outlined several recommendations to (1) ensure test sites are ready and prepared for at-sea testing, (2) explore linkages to green hydrogen and floating offshore wind R&D, (3) engage with the international community to leverage lessons learned and accelerate development, (4) continue to develop, maintain, and disseminate open-source software tools, and (5) consider real ocean environments in Foundational R&D projects. The following sections outline the activity area's response to the reviewers' key recommendations.

Recommendation 1: Ensure Test Sites Are Ready and Prepared for At-Sea Testing

There were several comments on Oscilla's project deployment at WETS, noting that delays were due to WPTO not having control of the test site. In the simplest sense, the activity area agrees. However, there are several factors to consider. First, the award was made in 2016, and this test birth availability delay could not have been foreseen six years ago. WPTO has great communication with the Navy's WETS team, and the two have been working on this issue together. The U.S. Navy needs to be able to maintain its facility as the need arises. Second, the delay was a function of weather windows affecting both Navy maintenance and Oscilla installation. Weather delays will affect other open ocean test sites like PacWave as well.

To anticipate and mitigate future installation delays, WPTO considers the statistical probabilities of relevant weather windows at different open-water test sites. It will also examine weather window probability trends in El Niño and La Niña years, as well as the transition years in between. WPTO has already begun examining the statistical probabilities and trends for weather windows for WETS with Naval Facilities Engineering Systems Command and Hawai'i Natural Energy Institute, which manage the site. WPTO recognizes the current trend for weather windows is significantly scarcer in the past two years than the average of the past 20 years.

Recommendation 2: Explore Linkages to Green Hydrogen and Floating Offshore Wind R&D

Reviewers commented on the potential benefits of co-locating marine energy with other renewable technologies, specifically offshore wind. The reviewers noted that capital and one-time costs—such as cabling, anchoring, and permitting—can potentially be reduced in a larger project, improving levelized cost of electricity and market competitiveness. The Foundational R&D team agrees this is an interesting area to examine to see if there are savings or advantages with co-location. As such, WPTO selected Tufts University to conduct a wave energy technology assessment for optimal grid integration and blue economy advancement, which will be reviewed in a future peer review.

Recommendation 3: Engage with the International Community to Leverage Lessons Learned and Accelerate Development

There were several thoughtful peer review comments urging international connections to avoid duplication of effort and accelerate knowledge transfer and progress for the marine energy sector. WPTO agrees and will continue to encourage international connection and learning by participating in the IEA's Technology Collaboration Programme on OES, the International Electrotechnical Commission's (IEC) Technical Committee 114 on international standards for marine energy, and conferences like the International Conference on Ocean Energy, European Wave and Tidal Energy Conference, Asian Wave and Tidal Energy Conference, and Pan American Marine Energy Conference. WPTO will also continue to approve international subcontract arrangements on its industry and lab projects and engage the international community to serve as independent reviewers for proposal evaluations and public peer reviews. In the future, the activity area will examine if there is a way to have newly awarded projects perform thorough literature searches that include international research, so that early in a project's performance, the PIs are aware of related existing international opportunities for collaboration.

Recommendation 4: Continue to Develop, Maintain, and Disseminate Open-Source Software Tools

Reviewers provided several positive comments on software and modeling. First, the reviewers noted the open-source modeling nature of the Foundational R&D portfolio is a good investment, and the GitHub dissemination is a strength of the portfolio. WPTO will continue to utilize this open-source software model to the extent practical.

Reviewers also commented on long-term maintenance and compatibility of WPTO's software investments. This is a goal for WPTO, but it must be balanced against funding constraints. All the software WPTO has funded will not be maintained at the level WEC-Sim has been funded. The Portal and Repository for Information on Marine Renewable Energy (PRIMRE) contains more than 40 software items, and it would be expensive to maintain all of them. WPTO will need to think more strategically to determine the long-term plan for each software investment. More funding into software support means less funding for future R&D projects, including new software capabilities.

The need for validation of models also came up. The Foundational R&D portfolio wholeheartedly agrees with this comment. This highlights the need for high quality, open-source datasets to validate and calibrate models and numerical tools. Without datasets for validation, software investments' impact is reduced. However, open-source validation data has proven to be expensive and slow to become available. The Foundational R&D portfolio needs to identify a cost-effective, systematic way to quickly generate open-source data to validate and calibrate many software tools and analytical models year over year.

Recommendation 5: Consider Real Ocean Environments in Foundational R&D Projects

Reviewers noted projects should consider the impact of real ocean environments outside the controlled and groomed environments of numerical analysis, tanks, and flumes and recommended additional lab and bench testing wherever possible. WPTO agrees the more realistic the test, the more will be learned. Additionally, more risk is reduced as more computer simulations are tested on the bench or in the lab before going to the tank or sea, where issues are significantly more costly. WPTO's co-design research, and the foundational projects broadly, do move in the direction of realistic testing. However, funding constrains the hardware and test aspects of research projects. WPTO will need to think more strategically about when to make additional hardware and test investments. Sometimes, it may be preferable to see how the foundational R&D project matures before committing additional funding. More funding into hardware and tests may mean less funding for future R&D projects, including projects focusing on real ocean conditions.

Technology-Specific System Design and Validation

The Technology-Specific System Design and Validation Activity Area aims to validate performance and reliability of marine energy systems through prototype testing, including in-water testing, for grid-scale, power-at-sea, and resilient coastal community markets. Through this activity area, WPTO is working to:

- Validate performance and reliability of systems through prototype testing, including in-water testing, at multiple scales.
- Improve cost-effective methods for installation, operations, and maintenance (IO&M).
- Support the development and adoption of international standards for device performance and insurance certification.
- Expand opportunities to realize the unique value proposition of marine energy systems for community resilience and ocean-based scientific and commercial power applications.
- Evaluate existing and potential future needs for marine energy-specific IO&M infrastructure (e.g., vessels, port facilities, etc.).

The review panel was impressed by the breadth and depth of the work that had been achieved within the activity area, though reviewers pointed to the need for further end-user engagement. Figure 19 summarizes the reviewers' quantitative assessment of how the activity area is performing overall, and Figure 20 provides an overview of the scoring of all projects within the Technology-Specific System Design and Validation Activity Area.

Figure 19. Technology-Specific System Design and Validation Activity Area Average Weighted Score by Evaluation Criterion

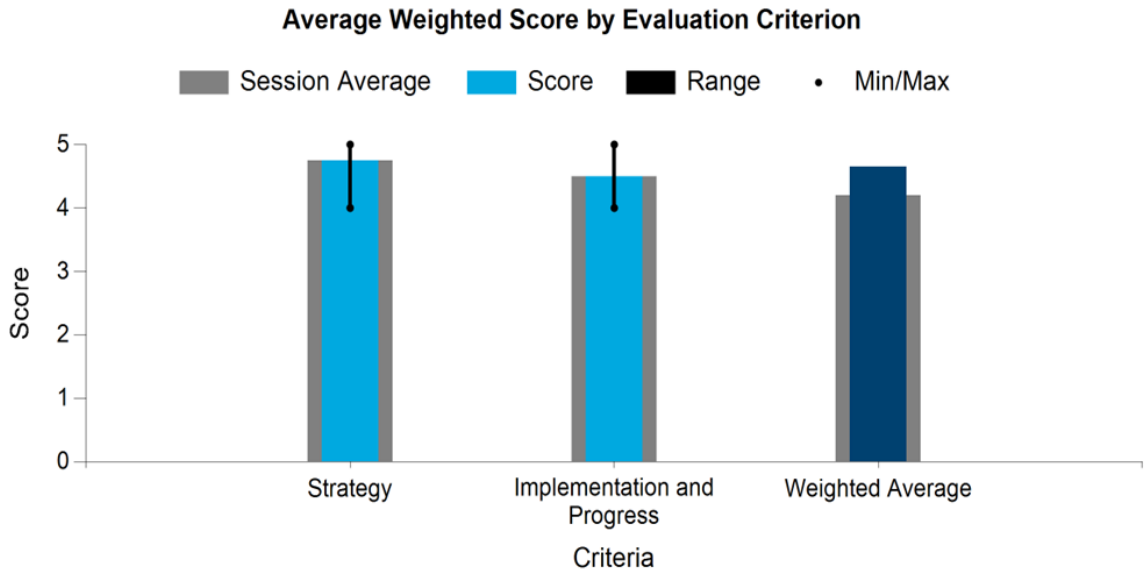
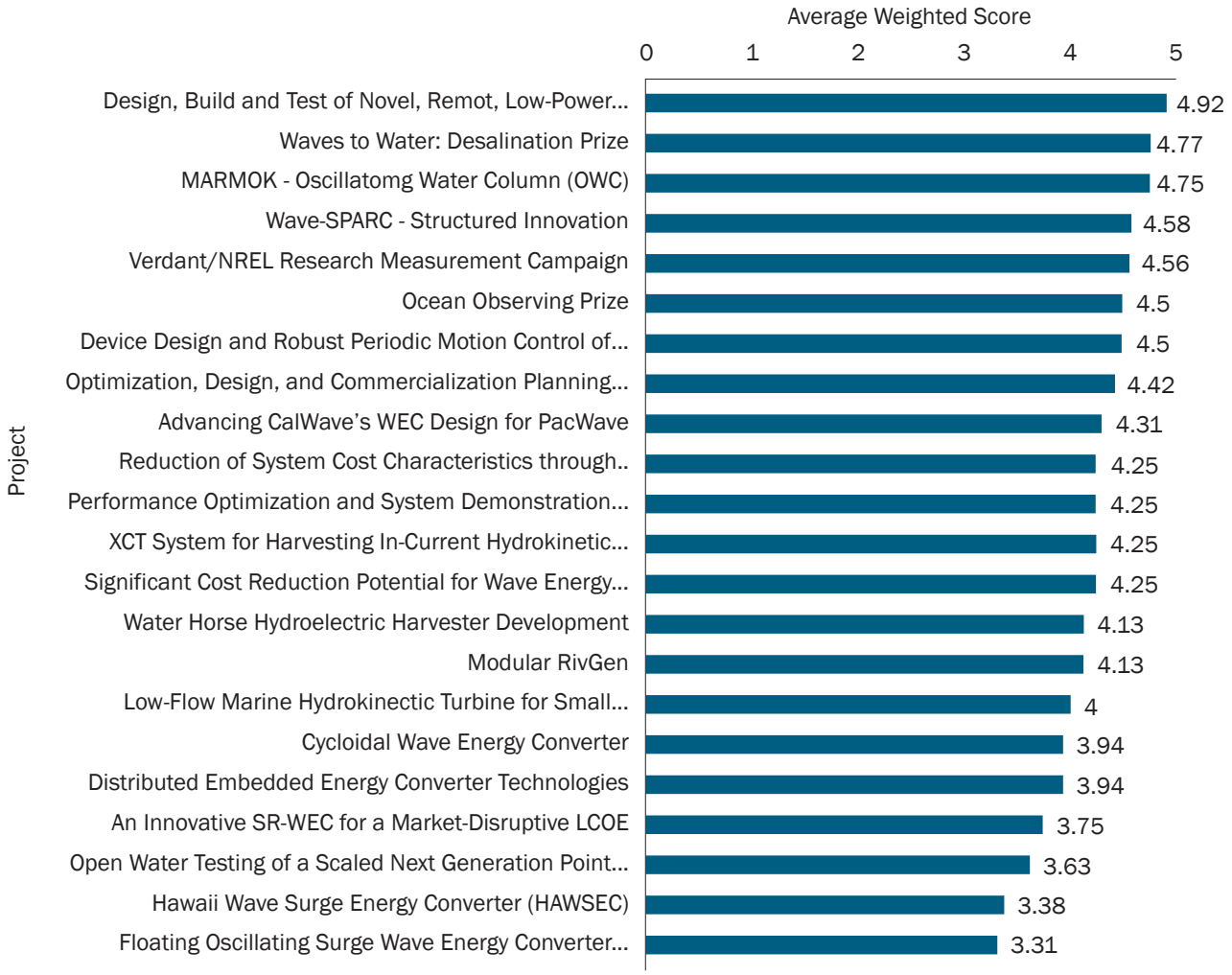


Figure 20. Technology-Specific System Design and Validation Activity Area Weighted Average Score by Project



The following subsections include the review panel lead's summary of reviewer comments and the WPTO activity area lead's response to reviewer feedback. The full evaluation results for the activity area and the portfolio of projects can be found in Volume II of this report. For more information about the activity area's structure, strategy, and R&D priorities, please refer to the MYPP or the corresponding activity area overview slide deck presented during the review.

Activity Area Evaluation Summary

Submitted by Henry Jeffrey

Feedback from the Review Panel to WPTO

Progress has been made in the Technology-Specific System Design and Validation Activity Area, and reviewers note the key role it plays in WPTO's continued success. However, opportunities exist to add value to the activity area.

The breadth and depth of the portfolio are impressive, and its expansive nature ensures multiple key research areas are targeted and objectives are achieved. It is important to question if this will remain sustainable as technologies achieve higher TRLs. Depending on future funding levels, it may be necessary to focus the portfolio's scope to ensure its continued success and impact.

Value could be bolstered with stronger user engagement, which goes beyond the dissemination of research milestones via publications and conferences. By ensuring that customer needs—whether in a niche or utility-market setting—are well understood, the activity area will be able to support the sector's continued progress. This is an activity DOE could achieve centrally through initiatives or workshops and would have multiple benefits. It would remove the onus from technology developers, which may not be uniquely equipped to deliver strong end-user engagement. It would also ensure end users do not suffer from fatigue or have to reiterate their technological needs and preferences multiple times to different developers.

It is important to ensure a fair approach is taken to compensate for the adverse effects of COVID-19 and its impact on the flexibility and security of supply chains, working conditions, and internal timelines. WPTO will need to ensure that whatever measures taken fairly reflect the challenges faced by all technology developers but are consistent with the understood limitations of COVID-19. This is critical so maximum value is still extracted from the projects.

The national labs' LCOE tool used to underpin predictions and targets must ensure the input values and the values distilled from its calculations are cross referenced to ensure it provides an accurate and substantiated point of reference from which energy costs can be responsibly estimated.

The process of technology transfer is important to ensure that, in the case where any individual project might not meet its long-term goals, there is a mechanism to extract specific successful technological developments or procedural lessons that might be of benefit to the wider sector. In instances where other companies or nations are developing technologies, knowledge transfer will help to limit wasteful duplication and replication of research. Where possible, it would also be beneficial to ensure projects are aligned with funding from other government agencies, such as the Department of Defense.

Assessing the progress of technology developers that have enjoyed sustained exposure to WPTO's support system and have received numerous project awards will safeguard the portfolio's long-term validity and effectiveness. It will also help ensure they remain on the pathway to continued technological innovation.

Prizes appear to be an effective tool to attract innovation in a new project area. However, they need to be analyzed to ensure they are cost effective and have a traceable pathway to serve the sector's innovation needs. It is also important to capture each prize program's lessons learned, including program structure and the technological developments they helped to underpin. Prizes should have a clear pathway for successful developers to continue their journey forward and remove the risk of stranding innovation.

Developers successfully testing at PacWave should be supported with a clear progression path to ensure devices and any supporting technological developments can move smoothly to higher, successive generations of development and deployment.

Summary of Reviewer Feedback on the Activity Area

Overall Impressions

WPTO needs the innovation funding and staff resources to ensure the office's depth, breadth, and effective management. There may be a need to focus the portfolio to ensure key projects are not underfunded and investments are not stranded. A comprehensive cost-benefit analysis of the prize program approach will help ensure it continues to be an effective tool and delivers continued innovation without functioning at the expense of time or resources. Additionally, it is advisable to ensure synergies between technologies that underpin both the blue economy and utility-scale applications with common goals and an emphasis on areas of overlapping research expertise. It is also important to ensure all strands of the portfolio have full pathways and funding to commercialization.

Activity Area Strategy

The activity area benefits from having a well-defined strategy in full alignment with the MYPP, including clear objectives and defined research priorities. Although the activity area manages short- and mid-term challenges well, it is less clear how it will evolve to manage the sector's longer-term challenges. Without attempts to refine the scope or expand WPTO's resources, it may be difficult to scale up to comprehensively cover all current areas of development and deployment.

With respect to industry and stakeholder needs, the overall activity area strategy is well considered. However, the strategy should be monitored as the sector evolves, considering technology scale and anticipated differences between niche blue economy and utility-scale technologies. Currently, there is a good rationale to support the sub-activity research areas and priorities. However, these might need to be reconsidered if the activity area chooses to refocus its priorities or as technologies achieve higher TRLs and introduce different challenges. There is a good mixture of funding mechanisms for academia, labs, and industry, supported by a comprehensive range of prizes and competitions. Ensuring complementary and collaborative links between DOE and the Department of Defense will help to foster accelerated technological development and ensure end users in both sectors have the opportunity to fund or engage with projects.

Implementation and Progress

The current portfolio is in full alignment with its stated objectives. The activity area is selecting diverse and complementary R&D projects tied closely to the program's direction. The activity area is funding the most relevant technologies, tools, and studies, and is likely to meet its performance goals. However, over the medium and long term, there is an opportunity to reconsider how funding and management environments will adapt as projects scale and advance through multiple TRLs. It is important to question whether WPTO will have the requisite funding for innovation and staffing to support continued progress in the sector. This consideration would allow WPTO to continue to run an effective, well-coordinated, and adequately staffed program.

Activity Area Response

Submitted by Elaine Buck, Technology Manager

The Technology-Specific System Design and Validation Activity Area would like to thank the reviewers for their attention during the peer review and for their diligent comments and insights. The breadth and depth of the portfolio is significant. Undoubtedly, reviewers took the time before and after the peer review to evaluate the projects' materials and generate thoughtful comments. This was no easy task, and the comments are enormously appreciated.

The Technology-Specific System Design and Validation Activity Area will take reviewers' comments and review them thoughtfully. The activity area aims for a high performing and focused cohort of demonstration projects and topics. Reviewers' expert and independent comments will help improve the activity area's strategic direction and program management. It is clear from reviewers' feedback that capturing lessons learned, increasing deployments, and advancing marine operational health and safety (to include developing a methodology for improving the basis of designs in marine energy) is fundamental to the U.S. marine energy industry's success. To sum up, the activity area thanks reviewers for their engagement, which will help the portfolio accelerate demonstrations across all scales of marine energy technologies, enabling a thriving U.S. marine energy industry.

Overall, reviewers outlined several recommendations to (1) improve knowledge sharing, (2) increase in-water testing, (3) focus on health and safety, and (4) emphasize design phase to get back to basics. The following sections outline the activity area's response to the reviewers' key recommendations.

Recommendation 1: Improve Knowledge Sharing

Reviewers commented on some projects running in isolation, where learning from other projects would be of benefit and value. Reviewers recommended stepping up knowledge-sharing opportunities, especially to identify similar risks or issues faced in deployment projects, which could be developed into case studies for industry. These case studies could be presented at conferences and/or highlighted in WPTO or other relevant webinars. Lessons learned for marine operations—including continued support for the development of new standards identified and prioritized for IO&M by Technical Committee 114—will incorporate best practices for U.S. deployments. Establishing deployment debriefs will also ensure lessons learned are captured, and improvements for health, safety, and environment procedures are planned for similar deployments. As future U.S. test sites come online, knowledge-sharing opportunities will organically bring the marine energy industry together to demonstrate best practices. Other lessons learned between the national labs and developers could be better captured and promoted, demonstrating design innovations and new testing methods. The program and project management teams will work together to develop and establish knowledge-sharing tools and habits into existing and future projects.

Recommendation 2: Increase In-Water Testing

Reviewers commented on the value of real-world, at-sea testing as soon as possible. DOE has a clear intent to continue funding for marine energy at-sea testing. The activity area is keenly aware this is where lessons are learned, but it is incredibly important to focus on health and safety in planning. WPTO aims to de-risk all deployments as much as possible, so they fail fast and cheaply onshore in labs and on test benches prior to at-sea deployments. The program is looking to evaluate rapid prototyping projects that focus on repeated wet/dry testing before scaling up and will continue to coordinate closely with the Reducing Barriers to Testing team as appropriate. It is well understood that proving technology performance, reliability, and survivability happens when metal gets wet. The program will continue to de-risk in-water testing through regular assessment of technical progress and disqualification of underperforming technologies, thereby focusing on funding high-performance technologies. The

activity area will improve the defined requirements for in-water demonstrations, including performance testing in the funding opportunities. The program goal is to create a competitive marine energy portfolio that accelerates technology commercialization.

Recommendation 3: Focus on Health and Safety

Reviewers commented on the risk of health, safety, and environmental issues potentially increasing due to tight budgets and underbudgeting for O&M activities. This is a significant priority for the activity area and the Marine Energy Program more broadly. There are health, safety, and environmental activities that will be incorporated into funding opportunity requirements that de-risk offshore deployments through design to IO&M planning. In FY 2023, the activity area plans to develop a U.S.-focused marine energy health, safety, and environmental framework as well as policies, guidance, training, and implementation/audits for before, during, and after deployments to decommissioning.

Recommendation 4: Emphasize Design Phase to Get Back to Basics

Reviewers noted a lack of emphasis on and technical review of the design phase, including connections with standards and lessons learned from the deployments. WPTO recognizes this issue, but there is no common synthesis of design practices used by developers. WPTO has funded the incorporation of assessment tools—like NREL's System Advisor Model for calculating the LCOE and its risk management framework and methodologies for quality control and assurance that will support efforts from concept to design optimization—at key design states. WPTO will continue to improve access to labs and engineering contractors to support preliminary, final design reviews to include factory acceptance criteria prior to at-sea deployments. WPTO will focus on the development of a design framework—such as best practices and the inclusion of key design phase reviews within statements of project objectives to refine and improve go/no-go criteria—to guide developers for wave and tidal devices. There is a lot of work to do to capture, synthesize, and develop a more robust design phase process with marine energy developers. WPTO has seen success through the prize methods that will continue to influence the activity area. Ultimately, the activity area needs to fully understand the methods used with different design-engineering teams, including how they incorporate standards and capture engineering data outputs that influence design decisions and impact their marine energy technology performance.

Reducing Barriers to Testing

The Reducing Barriers to Testing Activity Area aims to enable access to open-water, grid-connected, and non-grid-connected testing facilities and support environmental monitoring technologies, tools, and data collection to understand potential environmental risks and reduce costs. Through this activity area, WPTO is working to:

- Enable access to world-class testing facilities to accelerate technology development.
- Work with agencies and other groups to ensure that existing data is well-utilized and identify potential improvements to regulatory processes and requirements.
- Support additional scientific research on mitigating environmental risks and reducing costs and complexity of environmental monitoring.
- Engage in relevant coastal planning processes to ensure that marine energy development interests are equitably considered.

The review panel was impressed by the breadth and scope of the work being done in this activity area and encouraged the team behind it to consider wider applications of some of the work being produced. Figure 21 summarizes the reviewers' quantitative assessment of how the activity area is performing overall, and Figure 22 provides an overview of the scoring of all projects within the Reducing Barriers to Testing Activity Area.

Figure 21. Reducing Barriers to Testing Activity Area Average Weighted Score by Evaluation Criterion

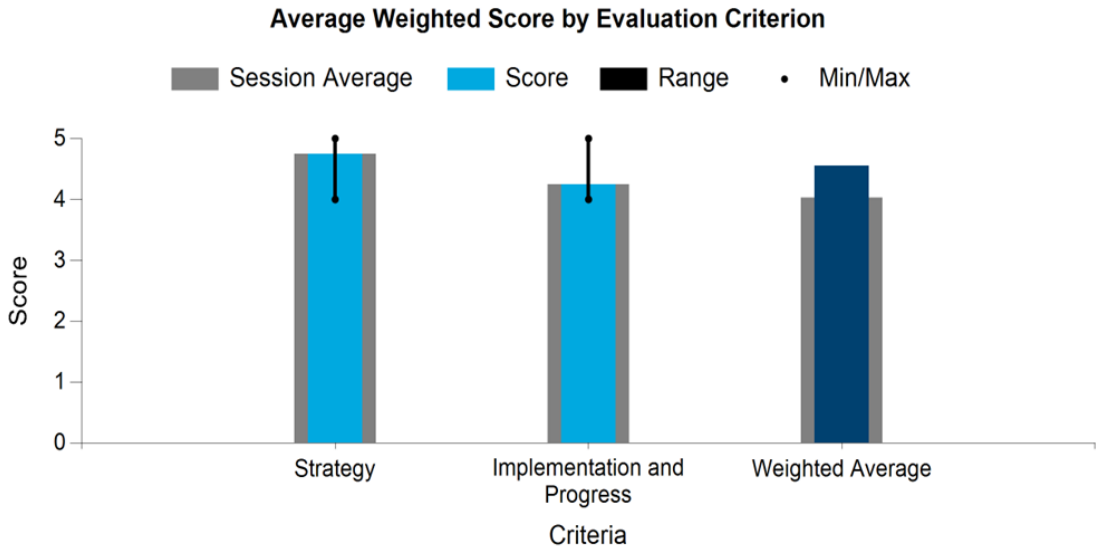
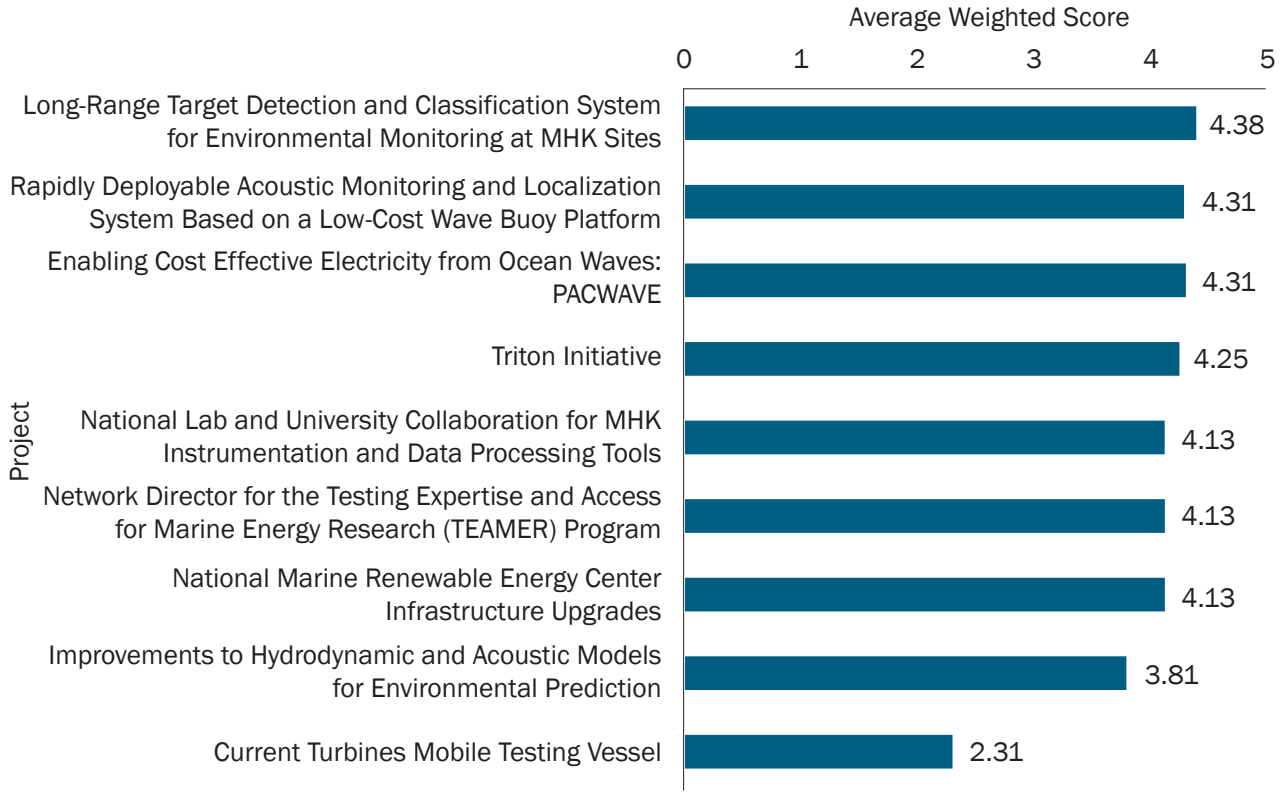


Figure 22. Reducing Barriers to Testing Activity Area Weighted Average Score by Project



The following subsections include the review panel lead's summary of reviewer comments and the WPTO activity area lead's response to reviewer feedback. The full evaluation results for the activity area and the portfolio of projects can be found in Volume II of this report. For more information about the activity area's structure, strategy, and R&D priorities, please refer to the MYPP or the corresponding activity area overview slide deck presented during the review.

Activity Area Evaluation Summary

Submitted by Sue Barr

Feedback from the Review Panel to WPTO

Overall, the panel reviewing the Reducing Barriers to Testing Activity Area is highly impressed with the range and scope of the nine projects presented. In some instances, there is clear alignment and collaboration between projects, which will allow for cumulative successful outcomes. The activity area and program in general are well run and effectively coordinated.

However, it is often challenging to match projects' progress, budgets, and outputs clearly against the assessment criteria, which may be a function of the short time for presentations. Reviewers propose that, alongside the project presentations, project teams provide a short evaluation report to allow for a more effective review process. These projects are highly complex with a range of successful outcomes, and it is challenging to provide a full assessment of all successes and weaknesses in the time provided.

While the activity area appears to focus predominately on wave energy conversion, some of the technology solutions presented could be equally applicable to tidal energy applications. The projects are not explicit on this area, and the panel thinks, in some cases, the technology or solution proposed could have multiple end-user applications or even be a cross-sector solution to several marine research requirements. Providing technology and/or test sites for marine energy could also serve several maritime end users, thus creating additional end-user value. Reviewers recommend WPTO consider how projects will deliver both near- and long-term results for the sector's continued use. This could support future broader uptake. Reviewers are also concerned about projects' abilities to transition to commercial business models, and this is an area WPTO should explore more.

It would be helpful to provide slightly longer for the project presentations and review sessions because it was challenging to fully explore each project in the time provided. Reviewers need more time to focus on project budgets and go/no-go decision processes. In nearly every project, reviewers find stakeholder engagement is often secondary to the delivery of project goals and objectives. In most cases, engagement could be expanded to help achieve project objectives, particularly with regulators (in relation to data use in regulatory decision making) and the marine energy sector itself based on how, when, and why they use research or facilities.

Reviewers recommend projects provide a brief, two-page evaluation report of project progress against program criteria as a supporting document to the project presentation. WPTO should consider the long-term application of technology and facilities and establish criteria to review projects' long-term commercial or business applicability. WPTO should also consider whether the technology, project, or test site being funded has multiple applications, not only in terms of whether it can be transferred between the types of kinetic energy being extracted (wave and tidal), but also whether the technology or site could be applicable or transferable to a broader marine application.

Summary of Reviewer Feedback on the Activity Area

Overall Impressions

Reviewers found several key strengths in the activity area, including the broad spectrum of applicable research and activities covered in the projects and the overarching compatibility between projects (even some co-dependencies). If all the projects are successful, there will be a good suite of monitoring technologies, facilities, and sites for marine energy device testing. This activity area has a broad set of aims to include removing barriers, increasing the availability of testing infrastructure, reducing time for testing cycles, providing testing infrastructure, and supporting data collection and use in a way that supports multiple end-user requirements (including regulatory). The projects show a good range of scope to fulfill the portfolio's aims. General weaknesses include projects' ongoing commercial applicability and a lack of focus on broader sector uptake.

Activity Area Strategy

Reviewers agree the MYPP gives an effective set of research priorities and a means by which to measure performance and objectives. The activity area's strategy is clear and understood.

Reviewers agree there is a strong understanding of the near-term challenges to getting technology in the water and tested. Some reviewers question this activity area's ability to support the sector's long-term challenges related to testing, whether at scale or for new and emerging technologies. To realize and deliver the portfolio's full value, there should be ongoing engagement with the marine energy industry and other marine sectors and stakeholders given opportunities for cross applicability. For example, the measurement of underwater sound is key to marine energy deployment, but the ability to understand more about species' behaviors based on anthropogenic activity in the marine environment is a broad subject. Reviewers are keen to see marine science and this portfolio's outputs be available to a broad range of marine stakeholders.

Reviewers agree the activity area's strategy fully considers industry and stakeholder needs and builds on past work. However, it is unclear to reviewers whether the research will lead to meaningful results for regulators and whether outputs will be taken up by the broader sector and stakeholders. The consideration of industry and stakeholder needs is apparent, but reviewers think projects are often aimed at specific end-user needs that could be expanded to explore additional needs.

Reviewers fully understand and agree with the rationale and organization of the sub-activity areas and research priorities. It is clear why this activity area has been identified and, largely through the project presentations, how it fits among research priorities and broader program aims.

It is clear WPTO funding is additive in terms of the ability to raise additional funds to support a project without compromising program deliverables.

Implementation and Progress

Reviewers are impressed by the range of R&D projects presented—from test site facilities to the development of monitoring equipment that would help remove regulatory barriers. Reviewers could question the value of project outputs in only one case. This relates to the design and build of a vessel for testing of tidal energy devices. It is unclear how the uptake and application of this vessel has been market tested against end users, and reviewers feel it may be highly limited in its application in real-time environments. Many projects complement one another, but reviewers question if there would be overlap between some areas of research, particularly in relation to the establishment of live test sites offshore.

Reviewers primarily represent testing and regulatory fields, so the value of data, time in the water, and dissemination of real-time evidence on these new and emerging technologies are key areas of focus. While reviewers agree the scope of projects funded is excellent, there were some questions on the degree to which projects engage with end users of the technologies, tools, and studies. Reviewers only question one project on its relevance in the program, and this relates to applicability to the end user rather than the overall MYPP. All other projects are highly relevant.

Given the limited time to assess the nine projects presented and the breadth of activity within each project, reviewers take a reasonable view as to projects' likely abilities to deliver performance goals and objectives. There are two areas where this was challenging—in the readiness of wave and tidal technologies to utilize test sites, which is not a risk the projects could have mitigated, and within risks identified in the delivery of cables and subcomponents from suppliers, coupled with offshore risk in methodologies. However, reviewers do not feel the risks to delivery are insurmountable. In fact, these risks are clearly identified in the project risks slides with proposed mitigation efforts. Reviewers believe WPTO should continue to support these projects while fully disclosing the risks of non-delivery.

This is a challenging area in terms of providing technology and test sites in high energy environments, and the risks to timing and delivery should be flexible to meet program needs.

Activity Area Response

Submitted by Lauren Ruedy, Technology Manager

The activity area would like to thank the reviewers for their time and evaluation of the Reducing Barriers to Testing Activity Area. Reviewers asked thoughtful questions and engaged in meaningful dialogue with the presenters, providing the program with significant insight into projects and the portfolio. This feedback will be incorporated into project and program planning moving forward to continue addressing testing and demonstration barriers for the marine energy sector.

The activity area would also like to thank the reviewers for their positive comments on the portfolio's organization and execution. Reviewers observed the strategy was clear and well understood, with an effective set of research priorities, and that the portfolio included an impressive breadth and depth of work that was effectively coordinated. Reviewers further speculated that if all the projects are successful, there would be a good suite of monitoring technologies, facilities, and sites for the testing of marine energy devices, accomplishing the portfolio's aims.

Reviewers noted that while the strategy builds on past work and was informed by industry and stakeholder needs, there were concerns regarding the broader sector's and stakeholders' uptake of project outputs. Reviewers recommended expanded and regular engagement with industry, end users, supply chain providers, and regulators. Furthermore, reviewers recommended considering how research project objectives and deliverables may be applicable to other marine energy resource types (e.g., some technologies, such as environmental monitoring devices and equipment, presented for wave energy could have tidal energy applications as well). The program appreciates the suggestion to consider applying a broader, high-level criterion to evaluate uptake to determine how projects will meet industry and end-user needs over the near and longer term.

In addition to feedback at the activity area level, reviewers also offered a few project-specific recommendations, which the program will address directly with project PIs, including:

- **TEAMER**—One reviewer went above and beyond to identify gaps and offer recommendations on the facility network. This feedback is greatly appreciated and will be discussed with the Network Director to identify opportunities for additional testing access.
- **PacWave**—When the site is operational, reviewers recommended running a lessons learned workshop and evaluating how operational data and experience can be shared more widely with the sector. Additionally, reviewers identified the lack of a universal mooring system as a potential concern to increase costs and delay schedules. These are valuable recommendations that will be discussed with the PacWave team.
- **Triton**—Triton has done a good job disseminating the results of its research, but the key next step is determining whether the recommendations are adopted.

Overall, reviewers outlined several recommendations to (1) consider the long-term application(s) of technologies and facilities, (2) evaluate project applicability across marine energy resources and market applications, (3) increase outreach with stakeholders, (4) critically review needs for test infrastructure investments, and (5) actively manage risk associated with development and utilization of test sites and assets. The following sections outline the activity area's response to the reviewers' key recommendations.

Recommendation 1: Consider the Long-Term Application(s) of Technologies and Facilities

Reviewers observed that many projects within the activity area successfully engaged with industry and potential end users to inform the project and ensure alignment with their needs. However, reviewers also commented that further consideration should be given to the sector's long-term needs and how that would translate to commercial business models for these projects and test sites. The program appreciates this recommendation and will investigate the potential to incorporate a "sectoral uptake" criterion for projects across the program as reviewers suggested.

Recommendation 2: Evaluate Project Applicability Across Marine Energy Resources and Market Applications

Reviewers found the projects presented during this peer review focused predominately on wave energy applications, though some solutions could have equal applicability to tidal energy applications and/or additional end-user applications and markets. The program appreciates this insight and will explore with project researchers whether additional applications and opportunities exist for project outcomes and outputs that would increase the impact or broaden the relevance of the technology or site for additional uses. Furthermore, for newly developed, advanced environmental monitoring technologies specifically, the program will investigate opportunities to expand the range of conditions under which these technologies can be demonstrated.

Recommendation 3: Increase Outreach with Stakeholders

To potentially accelerate uptake and commercial viability, reduce time to permitting, and create a wider understanding of the transferability of the technologies and methodologies tested and developed, reviewers recommended expanded and regular engagement with stakeholders (industry, end users, supply chain providers, and regulators). Reviewers specifically recommended developing a series of workshops to better aggregate and disseminate the portfolio's work to researchers, developers, and regulators domestically and internationally. WPTO currently uses several mechanisms to engage with stakeholders—including webinars, publications, newsletters, requests for information, conferences, and peer review—and to disseminate information, request feedback, and share opportunities. WPTO strives to ensure information is received and not just disseminated. WPTO considers stakeholder feedback to be a critical component of strategy development and will investigate opportunities to increase engagement to ensure investments' relevance and impacts within the Reducing Barriers to Testing portfolio.

Recommendation 4: Critically Review Needs for Test Infrastructure Investments

Reviewers noted that while all test infrastructure investments in the portfolio were clearly intended to address articulated gaps, it was not immediately apparent that all gaps in testing infrastructure were also critical needs for the marine energy industry at this time. WPTO appreciates this insight and will examine both existing and potential future infrastructure investments with this distinction in mind. Additionally, the stakeholder engagement mechanisms described in recommendation 3 can be better used to distinguish the needs from just gaps.

Recommendation 5: Actively Manage Risk Associated with Development and Utilization of Test Sites and Assets

The Reducing Barriers to Testing portfolio contains a high degree of diversity, ranging from developing effective technology to monitor underwater sound and its impact to delivering a full-scale wave technology testing facility offshore. Reviewers acknowledged the challenges of testing and developing test sites in high energy environments and recommended continuing to maximize flexibility to accommodate risks with timing and delivery. WPTO concurs with the reviewers' recommendations and will continue to maintain flexibility with project management to the extent practicable.

Marine Energy Data Access, Analytics, and Workforce Development

The Marine Energy Data Access, Analytics, and Workforce Development Activity Area aims to improve access to and use of data, tools, and STEM resources to increase awareness of marine energy technology advances and lessons learned; reduce cost, time, and uncertainty for marine energy permitting; and develop a skilled marine energy workforce. Through this activity area, WPTO is working to:

- Assess and communicate potential marine energy market opportunities, including those relevant for other maritime markets (e.g., desalination, powering subsea sensors, charging for underwater vehicles).
- Aggregate and analyze data on marine energy performance and technology advances and maintain information-sharing platforms to enable dissemination.
- Leverage expertise, technology, data methods, and lessons from the international marine energy community and other offshore scientific and industrial sectors (e.g., offshore wind, oil, and gas).

The review panel found that the portfolio of projects within this activity area reflected a clear and ambitious strategy. However, they did recommend some additional outreach, especially to regulators. Figure 23 summarizes the reviewers' quantitative assessment of how the activity area is performing overall, and Figure 24 provides an overview of the scoring of all projects within the Reducing Barriers to Testing Activity Area.

Figure 23. Marine Energy Data Access, Analytics, and Workforce Development Activity Area Average Weighted Score by Evaluation Criterion

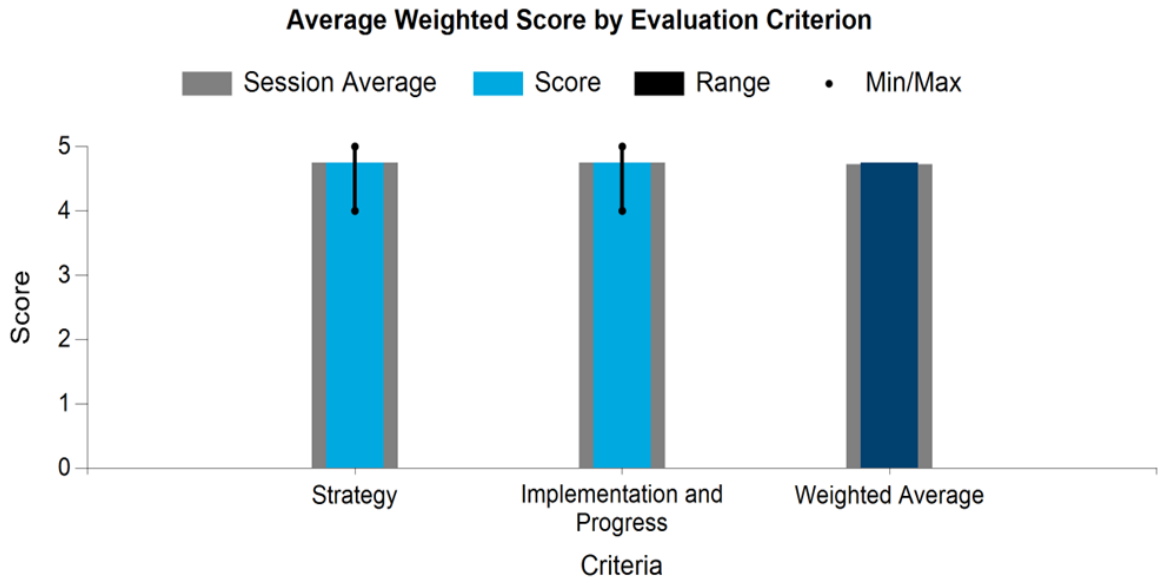
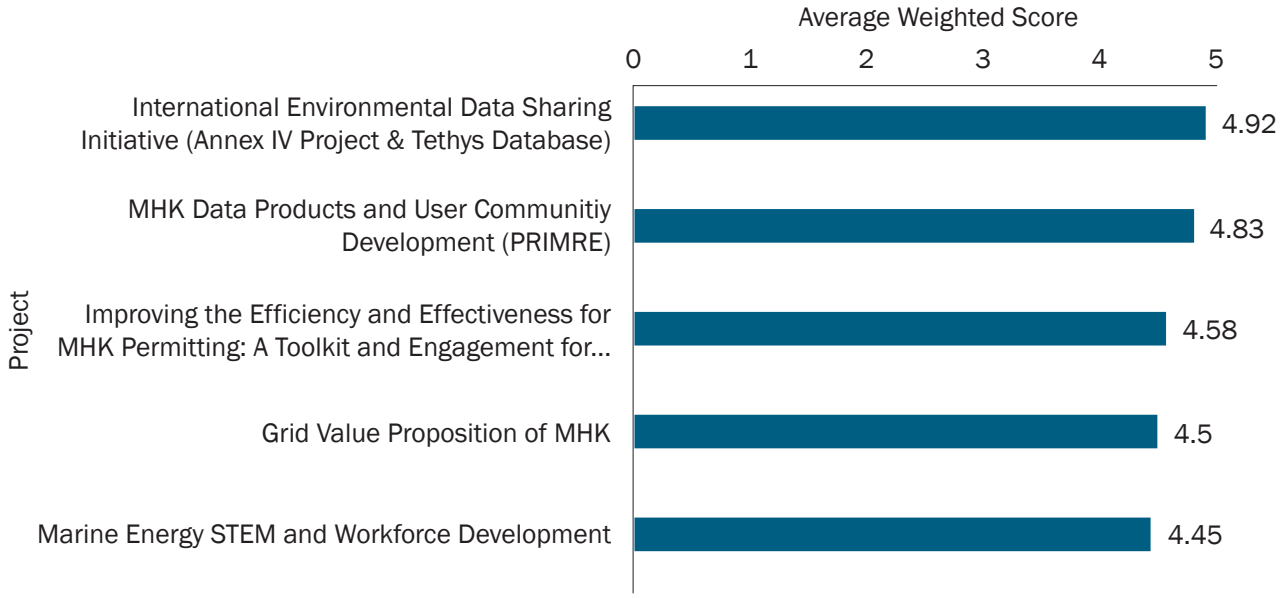


Figure 24. Marine Energy Data Access, Analytics, and Workforce Development Activity Area Weighted Average Score by Project



The following subsections include the review panel lead's summary of reviewer comments and the WPTO activity area lead's response to reviewer feedback. The full evaluation results for the activity area and the portfolio of projects can be found in Volume II of this report. For more information about the activity area's structure, strategy, and R&D priorities, please refer to the MYPP or the corresponding activity area overview slide deck presented during the review.

Activity Area Evaluation Summary

Submitted by Michael Atkinson

Feedback from the Review Panel to WPTO

The activity area's strategy is clear, comprehensive, and ambitious. Given the portfolio's relative novelty, there is a vast amount of work focused on tool and knowledge development to address the marine energy sector's needs and challenges. If funded property, there are diverse activities that will help facilitate and sustain multidisciplinary growth.

While there is a strong drive to develop sea-ready, full-scale devices such as WECs, there is a need for more investments and projects focused on fundamental research to better characterize realistic ocean conditions. This can be accomplished with increased funding at the university level where publishing fundamental research is key, and peer-reviewed articles can add credibility to this new technology. Increased collaboration with academia can also help guide full-scale designs before costly testing at sea.

The improved engagement with regulators is highly encouraged and necessary to reduce barriers to testing. Most reviewers agree an increased effort is needed focused on recognizing and mitigating possible negative environmental impacts. While this may be a result of many projects being in the early stages of development, funding projects that genuinely explore eco-friendly solutions should be prioritized.

Workforce diversification is a stated objective and focus of the portfolio. The Marine Energy Collegiate Competition (MECC) engages international undergraduate and graduate students to design marine energy technologies and develop business plans, and this has led to students starting companies or pursuing careers in the industry after graduation. Furthermore, there is strong evidence of successful diversity, equity, and inclusion (DEI) efforts as demonstrated by the participation of several historically Black colleges and universities and minority-serving institutions in the competition. The outcome of this competition broadens the skillset of recently graduated engineers and entrepreneurs that will hopefully infuse the blue economy with a labor force poised to meet this growing industry's demands. While this effort is beneficial, workforce development should be expanded to increase student engagement. Additionally, there should be more investment in inspiring experts in other fields to enter marine energy.

Summary of Reviewer Feedback on the Activity Area

Overall Impressions

Tools developed through this activity area, such as PRIMRE, provide end users (e.g., researchers, developers, and regulators) with relatively easy access to data and information that would otherwise be difficult to locate and compile. Workforce development in this area involves the creation of MECC and, overall, reflects industry and stakeholder needs and the challenges they face. However, the education and workforce aspects of the program seem very bifurcated. A lot of educational content is being created, but it is unclear how this connects to opportunities for potential employers and employees other than as a resource.

Activity Area Strategy

The strategy outlined in the MYPP includes clear performance goals, objectives, and research priorities. Reviewers agree this activity area has a defined strategy. Two reviewers feel more engagement is needed to attract new people to the field. Mostly, reviewers believe the strategy reflects an understanding of goals. However, two reviewers believe it is not clear all projects' objectives and outcomes lead to opportunities for potential employers and employees. While all reviewers like PRIMRE, one reviewer mentioned it is not clear who is using the data.

Projects consider industry and stakeholder needs and build on past work. There is a consensus that stakeholder feedback is especially helpful, and it is good to see WPTO is attempting to address workforce development and education gaps identified in stakeholder surveys. However, specific to data and tool projects focused on environmental regulations, one reviewer finds there is not yet enough evidence these projects have resulted in improved regulatory efficiencies or reduced uncertainty around environmental impacts from a regulatory perspective.

Overall, the sub-activity areas' direction is good, but one reviewer had concerns focused on being mindful of what educators need at each level. K-12 teachers need to understand the energy system and clean energy's role. It is good marine energy materials are woven into existing curricula rather than created as standalone materials the program would expect individual teachers to grasp. Community college and university professors have their own needs, which often trump what students and potential employees want and need.

The activity area leverages appropriate funding mechanisms (e.g., financial assistance to industry and academia, national lab procurement, and prizes/competitions) to achieve intended goals and objectives. All reviewers like MECC, but two reviewers believe it should be expanded to engage people who do not have an existing interest in the area or knowledge of the field. Furthermore, it would be useful to clarify the audiences the NREL team has shared educational resources with and what types of users are leveraging the marine energy STEM portal.

Implementation and Progress

Reviewers agree diverse and complementary R&D projects are closely tied to the program's strategic direction. There is overwhelming praise for the breadth of projects in this portfolio. The activity area is funding the most relevant technologies, tools, and studies to achieve the goals and objectives stated in the MYPP.

Reviewers agree the projects represent relevant technologies and the tool development is impressive. Reviewers are impressed with the projects' diversity and data generation. However, two reviewers explicitly note the need to develop a metric to better understand who is using this data.

The activity area is likely to meet performance goals and objectives defined in the MYPP based on the current portfolio of projects. Most reviewers agree the goals and objectives defined should meet performance goals. One reviewer recommends connecting information to actual paid work as the best way to advertise marine energy opportunities. Potential employees may visit PRIMRE if a job or internship exists, but they are unlikely to find or visit PRIMRE by itself.

Activity Area Response

Submitted by Allison Johnson, Engagement and Outreach Lead

The program would like to thank the reviewers from the data and workforce panel. They asked great questions and offered important perspectives on WPTO's work. This feedback will help WPTO and its partners in efforts to enable knowledge sharing and develop a skilled workforce for the growing marine energy sector.

The program appreciates the reviewers' praise of the activity area's strategic direction. Reviewers wrote that the strategy for this portfolio is clear, comprehensive, and ambitious, and they believed the activities presented have the potential to support the sector's sustained multidisciplinary growth.

Reviewers noted that informational tools and databases developed, like PRIMRE and the Marine Energy Permitting Toolkit, provide easy access for diverse end users to data and information that would otherwise be difficult to locate and compile. The program agrees with the reviewers' comment that, as good as these tools seem to be, the impact of these projects depends largely on developer and regulator uptake. Reviewers also had positive comments on PNNL's State of the Science report and derivative products as a trusted, respected source on marine energy's environmental impacts. In a similar vein, reviewers commented that PNNL's grid value analysis provides a balanced and novel framework for considering marine energy's value in a holistic way.

Reviewers had positive comments about the MECC, which is one of the main ways WPTO exposes students to marine energy. The panel lead noted the MECC attracts students of different disciplines and backgrounds, resulting in cohorts that are diverse, skilled, and well positioned to enter the marine energy workforce. NREL and WPTO have been thrilled with the competition's ability to attract multidisciplinary, diverse teams and engage educational institutions that previously had limited or no experience working with WPTO or DOE more broadly.

While the reviewers scored projects highly and provided mostly positive comments, they also offered constructive feedback and several useful recommendations, which the program will consider further. Overall, reviewers outlined several recommendations to (1) support more university-led, foundational research, (2) develop clear metrics for success and collect more data on who is using data and tools, (3) consider incorporating broader datasets into PRIMRE, (4) invest more in workforce development activities to reach a broader audience of students and connect youth with job opportunities, (5) be mindful of what educators need at different levels, and (6) increase efforts to understand and mitigate possible negative environmental impacts. The following sections outline the activity area's response to the reviewers' key recommendations.

Recommendation 1: Support More University-Led, Foundational Research

The reviewers noted more foundational research and collaboration between industry and academia are needed to prepare the industry to develop sea-ready, full-scale devices. The activity area agrees universities are invaluable to the marine energy field, and WPTO has plans to deepen and expand investments in universities within the next couple of years. When DOE first started growing its marine energy portfolio more than a decade ago, its first funding opportunity supported academic research and designated new NMRECs. The NMRECS and other universities across the United States are actively supporting university- and industry-led projects and device development through initiatives like the TEAMER network, and WPTO will continue to foster university-led, industry-relevant research through efforts like UMERC. While continuing to invest in UMERC, TEAMER, and the NMRECs' capabilities, WPTO plans within the next year to support new foundational research at universities that are not already members of these networks.

Recommendation 2: Develop Clear Metrics for Success and Collect More Data on Who Is Using Data and Tools

Two reviewers explicitly stated the need to improve metrics to better understand who is using WPTO-funded databases and tools. While it is relatively simple to develop and measure against quantitative metrics for these types of resources (e.g., number of unique visits to a webpage or number of times a dataset was downloaded), qualitative metrics are more challenging. This reality is exacerbated by legal limitations in the federal government regarding tracking detailed user data and personally identifiable information. While these facts make the endeavor challenging, they are not excuses, and the program will work to address this weakness. Some relevant efforts are already underway; for example, the PRIMRE team will soon establish user-driven metrics for the Marine and Hydrokinetic Data Repository by allowing users to provide direct, qualitative feedback on a dataset that other users can also see. In workforce development, NREL is establishing a sub-contract with an objective evaluator who will help develop meaningful metrics and evaluate project outputs. The program hopes to be able to share more meaningful metrics and datapoints to illustrate impact by the next peer review.

Recommendation 3: Consider Incorporating Broader Datasets into PRIMRE

Two reviewers wrote that they believed PRIMRE would be even more valuable if it could host more data and information about projects not funded by WPTO or DOE, including international R&D efforts. WPTO acknowledges the incorporation of international data would make PRIMRE a more comprehensive and, thus, valuable resource. At the same time, the program realizes this would be a big undertaking for one country or government agency to lead on its own, and it is beyond the program's scope as a funder of U.S. marine energy research. However, WPTO welcomes other countries' or funding agencies' collaboration on data sharing and, with financial and in-kind support from international partners, is more than willing to host data produced outside of WPTO-funded projects. The IEA's OES is already making such an investment by co-funding a new international marine energy geographic information system (GIS) tool, which will be built by staff at NREL, PNNL, and Sandia National Laboratories (Sandia) and hosted on PRIMRE. WPTO welcomes further engagement by international partners and would be happy to support additional international data-sharing efforts.

Recommendation 4: Invest More in Workforce Development Activities to Reach a Broader Audience of Students and Connect Youth with Job Opportunities

One reviewer importantly noted the education and workforce development aspects of the portfolio seem bifurcated and more is needed to ensure the work underway results in connections for youth to job opportunities. Two reviewers noted the portfolio should be expanded to engage students who did not have a previous interest in or exposure to marine energy, and reviewers provided useful suggestions for ways the program can expand its reach and support students beyond those in the MECC, such as by providing funding for students to participate in international competitions and conferences, supporting established student organizations, targeting experts in adjacent fields to transition to marine energy, better linking students to job opportunities, and connecting programming to broader efforts across DOE and the federal government. The program appreciates reviewers' specific, tangible suggestions and will pursue all of them.

Recommendation 5: Be Mindful of What Educators Need at Different Levels

One reviewer cautioned WPTO and its partners to consider what educators need at different grade levels when designing and implementing education and workforce development programming. For example, K-12 educators need to teach the energy system as a whole and clean energy's role within it. For this reason, the reviewer noted it is good that educational materials developed by WPTO's partners are woven into existing curricula. WPTO acknowledges this important reminder to always consider the needs of educators at different levels, particularly since the program hopes to have some influence at various levels of the educational spectrum.

Recommendation 6: Increase Efforts to Understand and Mitigate Possible Negative Environmental Impacts

Reviewers agreed the regulatory engagement activities carried out were important and advised WPTO to increase its efforts to recognize and mitigate potential environmental impacts of marine energy technologies. Additionally, one reviewer stated there is not yet enough evidence that WPTO-funded projects in this area have resulted in improved regulatory efficiencies or reduced uncertainty around environmental impacts from a regulatory perspective. The program agrees with the reviewers that there is insufficient evidence these projects have resulted in improved regulatory efficiencies. The program also acknowledges that for WPTO-funded resources, like the permitting toolkit and the State of the Science, to make maximum impact, both regulators and developers must use them. For this reason, WPTO will continue to prioritize regulator engagement and invest in projects that improve scientific understanding of potential environmental impacts. WPTO has a robust portfolio of projects focused on understanding and mitigating potential environmental impacts of marine energy technologies, but those projects were not presented to this panel of reviewers and were instead covered in a different panel.