4 MARINE ENERGY PROGRAM OVERVIEW

Marine energy resources, such as wave, tidal and ocean currents, are abundant, geographically diverse, energy dense, predictable, and complementary to other renewable energy sources. Significant in-water testing and demonstrations have occurred in recent years, both domestically and internationally, to prove performance and reliability for systems that provide utility grid-scale electricity. Marine energy can also serve the needs of many blue economy markets, including producing fresh water through desalination, servicing the power demands for aquaculture and ocean sensing, and supporting coastal resilience through microgrid functionality. Marine energy therefore has the potential to contribute to a carbon pollution-free power sector in an environmentally just and sustainable way.

Basics of Marine Energy

WPTO's Marine Energy Program (formerly the Marine & Hydrokinetics Program) supports research, development, demonstration, and the commercial application of marine renewable energy technologies that expand and diversify the nation's clean energy portfolio by delivering power from ocean and river resources. These firm renewable resources, and the technologies that tap into them, are an integral part of the solution to achieve 100% electricity generation from zero carbon sources by 2035, generating economic opportunity and growth through the deployment of new energy technologies, and supplying clean, reliable power to underserved coastal communities.

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.

Marine Energy Resource Potential

Marine energy resources—such as wave, tidal, and ocean currents—are abundant, geographically diverse, energy dense, predictable, and complementary to other renewable energy sources. More than 50% of the U.S. population lives within 50 miles of coastlines, where there is vast potential to provide clean, renewable electricity to communities and cities using ocean waves, tides, and currents. To understand the full potential for future electricity production that can be harnessed through our nation's water resources, WPTO has conducted resource assessments to assess the potential of marine energy resources.[23]

Marine Energy Technologies and Resources Assessment

Wave energy is the most abundant and geographically diverse marine energy resource in the United States. However, it is also the most complex and expensive resource from which to extract marine energy. The materials and manufacturing costs for devices harnessing energy from waves, along with performance and

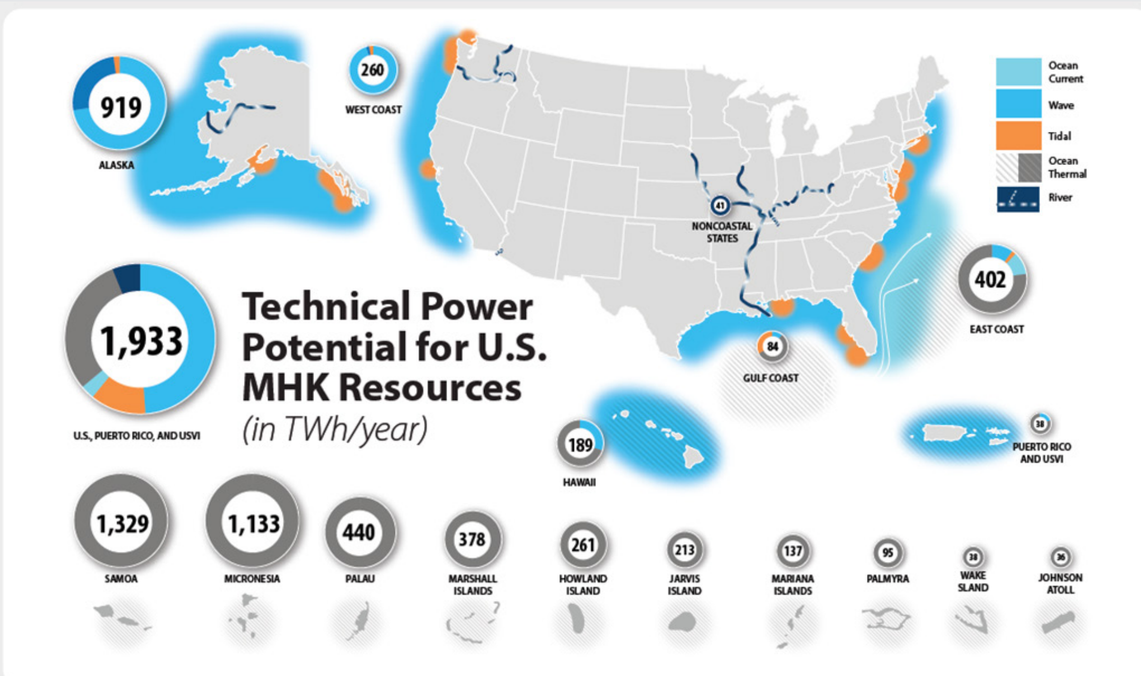
[23] U.S. Department of Energy, "Marine Energy Resource Assessment and Characterization" https://www.energy.gov/eere/water/marine-energy-resource-assessment-and-characterization.

Marine Energy Resource Potential *continued*

reliability improvements yet to be realized for wave energy converters (WEC), result in modeled levelized cost of energy values over $0.50/kWh. This complexity has resulted in a wide range of wave energy converter. archetypes in the industry.[24] While this diversity can enable systems to be optimized for specific markets and locations, it comes at the price of supply chain availability and cost and also complicates workforce training. Tidal and river current energy converter technologies have fewer archetypes[25] and a lower cost compared to wave energy. However, ocean current technologies have a longer-term development timeframe, since the ocean current resource in the United States, specifically in the gulf stream, is more geographically isolated then tidal or river currents, and have challenges with siting optimization. Ocean thermal energy conversion[26] (OTEC) is a technology that extracts energy from temperature differentials in the ocean, and is a significant resource globally, though it is limited to specific U.S. geographic regions such as southern Florida, Hawaii, Puerto Rico, and the Virgin Islands for utility-scale applications.

The technical potential[27] for electric generation from ocean wave, ocean current, tidal current, river current, and ocean thermal resources in the United States in terawatt-hours per year (TWh/yr) are summarized in Figure 10.

Figure 10. Technical Power Potential for U.S. Marine and Hydrokinetic Resources



US States & Territories	MW	TWh/yr	Avg. Homes That Could Be Powered*	Resource as a Percent of U.S. States' Total Electricity Generation (%) ***
Wave (to 10 nm)	112,557	986	92,590,854	
Tidal	25,381	222.34	20,878,727	5.4
Ocean Current	5,594	49	4,601,371	1.2
Ocean Thermal	65,753	576	54,089,586	14.0
River	11,342	99.36	9,330,454	2.4
Total	**220,628**	**1,933**	**181,490,991**	**46.8**

East Coast	MW	TWh/yr	Avg. Homes That Could Be Powered*	Resource as a Percent of Regional Electricity Generation (%) **	Resource as a Percent of U.S. States' Total Electricity Generation (%) ***
Wave (to 10 nm)	0	0	0	0	0.0
Tidal	1,153	10.10	948,431	1	0.2
Ocean Current	5,594	49	4,601,371	5	1.2
Ocean Thermal	39,041	342	32,115,692	37	8.3
River	77	0.67	63,091	0	0.0
Total	**45,864**	**402**	**37,728,585**	**43**	**9.7**

[24] Different wave energy converters (WEC) technologies: https://openei.org/wiki/PRIMRE/MRE_Basics/Wave_Energy.

[25] Different tidal and river current energy current converter technologies: https://openei.org/wiki/PRIMRE/Glossary/Current_Energy.

[26] Further information on Ocean Thermal Energy Conversion (OTEC): https://openei.org/wiki/PRIMRE/MRE_Basics/Ocean_Thermal_Energy_Conversion.

[27] Technical resource potential refers to the portion of a theoretical resource (annual average amount of energy that is contained within the resource) that can be captured by using a specific technology.

Marine Energy Resource Potential *continued*

The most recent marine energy resource assessment[28] calculates the total technical marine energy resource for the continental United States, extending to the Exclusive Economic Zone (EEZ),[29] to be 2,528 TWh/yr, equivalent to the power needs of more than 87 million homes[30] —or 22.5% of the total electricity generation by U.S. states in 2019.[31] When Alaska, Hawaii, Puerto Rico, and the U.S. Virgin Islands are included, the total technical marine renewable energy (MRE) resource increases to 2,777 TWh/yr, equivalent to the power needs of more than 260 million homes, or 67.3% of the total electricity generation by U.S. states in 2019. This increase is largely attributable to the substantial wave and tidal resources in Alaska. Finally, when the immense OTEC resources found within the EEZ of the U.S Pacific territories are included, amounting to 4,060 TWh/yr of the 4,636 TWh/yr available from OTEC in all U.S. states and territories, the total technical MRE resource is 6,837 TWh/yr—equivalent to the power needs of more than 642 million homes, or 166% of the total electricity generation by U.S. states in 2019. If a significant fraction of this potential is realized, marine energy can contribute to a 100% clean energy grid, particularly given the proximity of marine resources to electricity load centers, and the predictability and forecast-ability of electricity generation that complements other daily, seasonal, and annual variable-generation sources.

Marine Energy and Powering the Blue Economy

Even though deploying marine energy to power the electric utility grid remains challenging, there are near-term opportunities for smaller scale marine energy systems to enhance the resilience of coastal communities, including through offsetting a significant amount of fossil fuels,[32] and to power systems in the ocean where other energy sources are challenging to access. Marine energy technologies are persistent, predictable, and renewable sources of energy in the ocean that can serve both deep offshore and nearshore energy solutions. Many remote coastal and islanded communities have significant co-located marine energy resources: Alaskan communities are near rivers and wave energy resources; Hawaiian Islands have wave energy and OTEC resources, and communities on the East Coast and Puerto Rico are located near many kinds of marine energy resources.

To this end, WPTO's Powering the Blue Economy (PBE) initiative addresses the energy needs of the rapidly growing "blue economy"[33] and ocean-based activities with marine renewable energy. Oceans can serve fundamental human needs and drive economic growth; reliable ocean-based energy can enable sustainable aquaculture, observations that expand the understanding of the ocean and track the changing climate, power desalination systems, and more. Additionally, the blue economy is anticipated to double in size to $3 trillion by 2030, but its growth is constrained by a lack of energy due to sources that require frequent refueling or battery changes and are often unfit for purpose, limited in capacity, expensive, and emit greenhouse gases. Deploying marine energy systems in the blue economy requires new approaches in energy development through working with remote communities as partners in assessing energy needs, multidisciplinary collaborations, co-development of energy solutions embedded within or tied to blue economy platforms, and innovation across multiple technology domains.

[28] Resource assessments for wave, tidal currents, ocean currents, OTEC, and river currents have not been completed for all U.S. states and territories; therefore, the technical resources shown underestimate the full MRE resources contained within all U.S. land and EEZ extents.

[29] The EEZ is defined as is a concept adopted at the Third United Nations Conference on the Law of the Sea (1982), whereby a coastal State assumes jurisdiction over the exploration and exploitation of marine resources in its adjacent section of the continental shelf, taken to be a band extending 200 miles from the shore.

[30] In 2019, the average annual electricity consumption for a U.S. residential utility customer was 10,649 kWh, an average of about 877 kWh per month. https://www.eia.gov/tools/faqs/faq.php?id=97&t=3.

[31] U.S. Energy Information Administration. "Net Generation by State by Type of Producer by Energy Source." https://www.eia.gov/electricity/data/state/.

[32] U.S. Department of Energy, 2019. "Energy Department Funding Helps Transform Alaskan River Renewable Energy Resource." https://www.energy.gov/eere/water/articles/energy-department-funding-helps-transform-alaskan-river-renewable-energy-source.

[33] The World Bank defines the blue economy as the sustainable use of ocean resources for economic growth, improved livelihoods, and jobs while preserving the health of ocean ecosystem.

Marine Energy Resource Potential *continued*

WPTO released a report in April 2019 titled *Powering the Blue Economy: Exploring Opportunities for Marine Renewable Energy in Maritime Markets*,[34] demonstrating that marine energy can decarbonize and enable innovation and growth in the blue economy through direct engagements between relevant end-user communities and public and private sector organizations. The report identifies potential opportunities and challenges for marine energy in eight different ocean applications and markets, including some far out at sea—like ocean observation and seawater and mineral mining—and some nearshore, like desalination and coastal resilience. A recent report by The Economist Intelligence Unit,[35] commissioned by the Pacific Northwest National Laboratory, states that "marine energy presents opportunities for renewable, in-situ or local power generation" for maritime transport and tourism, ship building, and fishing and aquaculture, ocean observation and navigation. Further, the International Energy Agency's (IEA) Technology Collaboration Programme on Ocean Energy Systems (OES) recently released a report describing "Blue Economy and its Promising Markets for Ocean Energy."[36] These reports confirm the potential connections between blue economy markets and marine energy is not only multifaceted and nationwide, but global.

Marine Energy: Benefits and Potential Impacts

Mitigating Climate Change and Enabling a 100% Clean Energy Future

Marine energy has the potential to contribute to an electric grid primarily powered by renewable energy[37, 38] while also addressing the need for climate change mitigation.[39, 40] While the manufacturing process and other elements of marine energy technologies' life cycle may generate carbon emissions, these emissions are comparable to those of other renewable technologies. Moreover, marine energy development and deployment can have a significant impact on reducing ocean acidification,[41] ocean warming,[42] and sea level rise,[43, 44] through the permanent reduction

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[34] U.S. Department of Energy, 2019. "Powering the Blue Economy: Exploring Opportunities for Marine Renewable Energy in Maritime Markets." https://www.energy.gov/eere/water/downloads/powering-blue-economy-exploring-opportunities-marine-renewable-energy-maritime.

[35] Economist Intelligence Unit, 2020, "Accelerating Energy Innovation for the Blue Economy." https://www.woi.economist.com/energyinnovation/.

[36] International Energy Agency, "OES releases 'Blue Economy and its Promising Markets for Ocean Energy." https://www.ocean-energy-systems.org/newsletter/oes-releases-a-blue-economy-and-its-promising-markets-for-ocean-energya-/.

[37] Copping, A., LiVecchi, A., Spence, H., Gorton, A., Jenne, S., Preus, R., Gill, G., Robichaud, R., Gore, S., 2018. "Maritime Renewable Energy Markets: Power from the Sea." https://tethys.pnnl.gov/publications/maritime-renewable-energy-markets-power-sea.

[38] Thresher, R., and Musial, W, 2015. "Ocean Renewable Energy's Potential Role in Supplying Future Electrical Energy Needs." https://www.osti.gov/biblio/1251349.

[39] International Renewable Energy Agency, 2019. "Renewable Energy Statistics 2019." https://www.irena.org/publications/2019/Jul/Renewable-energy-statistics-2019.

[40] United Nations General Assembly. 2012. Report on the work of the United Nations Open-ended Informal Consultative Process on Oceans and the Law of the Sea at its thirteenth meeting (A/67/120). https://undocs.org/A/67/120.

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

[42] Cheung, W. W. L., Watson, R., and Pauly, D. 2013. "Signature of ocean warming in global fisheries catch." http://www.ecomarres.com/downloads/warm.pdf.

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

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

of greenhouse gas emissions. Marine renewable energy projects, when sited and scaled in an environmentally responsible manner, can be part of the solution towards decarbonizing the electric grid and overcoming any potential environmental impacts to marine animals and habitats.[45]

Marine renewable energy can also help advance many of the United Nations Sustainable Development Goals. In the near term, marine energy can power ocean observing devices that can enable scientists to collect better and more data than ever before, providing profound insight to the health of the ocean and the effects of climate change, including ocean acidification. In the medium term, marine energy can power offshore aquaculture farms, providing a clean and environmentally sustainable source of protein for billions of food insecure people across the globe, powered by clean, renewable energy. In the long term, marine renewable energy can power the extraction of critical materials that will be integral to the electrification of transportation and other sectors—materials that are currently mined in an economy rife with human rights and sustainability issues.

The oceans and the blue economy face unique challenges due to climate change but can also serve as potential assets for climate change mitigation. The maritime sector and shipping industry are difficult to decarbonize with existing technologies, but ocean-based renewable energy sources can be part of the solution. Ocean-based aquaculture systems can be a source of affordable, plentiful, and nutritious food powered by co-located marine energy resources. Wave-powered desalination can provide clean water in the ocean and to coastal communities, without requiring fossil fuels. Marine energy-powered technologies may even be able to reverse ocean acidification on small scales. Ocean-based energy, powering ocean observing and navigation systems, can aid in measuring the changing climate, monitoring maritime animals, and tracking extreme weather events.

Accomplishing these goals and deploying marine energy on the scale needed to bridge the gap to a 100% clean energy future will require an acceleration of technology maturity and deployment of marine energy development. This can be facilitated using international standards and specifications during design and testing, ultimately leading to system accreditation.

Powering Underserved Communities and Enhancing Coastal Resilience

Marine energy has the potential to enhance resilience and power electric microgrids in coastal, remote, and islanded communities. These technologies can help make communities more resilient in the face of extreme events such as tsunamis, hurricanes, floods, or droughts. Marine energy applications are ideally suited to coastal development through straightforward installation, operation, and maintenance activities, and provide a predictable and uninterrupted energy supply. Marine energy can also power water quality monitoring for harmful algal blooms or pollutants, extreme event observation tools, microgrids for commercial and residential purposes. Finally, marine energy technologies can enhance the coastal resilience of shorelines and be an integrated component of solutions and strategies for long-term coastal change and hazard response.

Marine energy has an important role to play in sustaining marine and ocean ecosystems. The watch circles and operating boundaries around marine energy projects create pseudo-marine reserves that can benefit local ecosystems of fish and other organisms, as stressors associated with human activities like fishing, shipping, waste disposal, shoreline activities, and other disturbances are removed.[46, 47] Furthermore, 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. These stresses,

[45] Copping, A.et al, 2016. "Annex IV 2016 State of the Science Report: Environmental Effects of Marine Renewable Energy Development Around the World. https://tethys.pnnl.gov/sites/default/files/publications/Annex-IV-2016-State-of-the-Science-Report_MR.pdf.

[46] Inger, R. et al, 2009. "Marine renewable energy: potential benefits to biodiversity? An urgent call for research." https://tethys.pnnl.gov/publications/marine-renewable-energy-potential-benefits-biodiversity-urgent-call-research.

[47] Crain, C.M., Halpern, B.S., Beck, M.W. and Kappel, C.V., 2009. "Understanding and Managing Human Threats to the Coastal Marine Environment." https://nyaspubs.onlinelibrary.wiley.com/doi/10.1111/j.1749-6632.2009.04496.x.

their potential risks to the marine environment, and how these risks might be understood, placed in context, managed, and minimized, are described in detail in the OES 2020 State of the Science Report.[48]

Deploying marine energy for coastal and ocean-based applications is also crucial towards accelerating marine energy technology development for the grid. Near-term deployments serving a variety of applications enable marine energy technologies to be quickly demonstrated, while also benefiting coastal communities and the other blue economy markets. With time, these deployments will improve the marinization of marine energy systems to better understand their survival in harsh, highly corrosive, energic environments, and utilize appropriate materials and technologies. In addition, siting marine energy technologies in an environmentally responsible manner through partnerships between coastal communities, the government, private industry, and technical experts can lead to a sustainable and resilient energy technology.

The Future of Marine Energy

Despite the challenges of operating in a harsh, corrosive environment, the marine energy industry has made measurable progress in recent years. Developers in the United States, such as Ocean Power Technologies, Ocean Renewable Power Company, and Verdant Power, have had significant in-water technology demonstrations; developers in Europe, such as Orbital Marine Power, SIMEC Atlantis, and Minesto, are even further along in proving out their technologies. Marine energy is at an inflection point, building off the momentum garnered over the last decade. The industry and DOE's focus, historically, has been on proving performance and reliability for the U.S. grid; as technology performance and operations continue to be vetted, the next opportunity will be focusing on optimization and reducing costs. Technology vetting, cost reduction, and commercial opportunities will also be enabled through applications in entirely new non-grid markets at sea, supporting coastal resilience, and powering ocean sensors and instruments.

Marine energy technologies can ultimately complement an electric grid with high variable renewable energy (like wind and solar) penetration. Community-scale marine energy technologies can be a part of a resilient and sustainable electricity supply. There are emerging RDD&CA pathways to develop entirely new ways to harness the power of the ocean, needs that are currently addressed through fossil fuels. Marine energy is not just about the electric grid, it is about meeting many of our energy needs, including desalination, pumping water and serving as an energy generation asset for secondary markets like green hydrogen, co-locating production with utilization, and decreasing overall energy costs for many needs. The ocean can be a considerable asset in mitigating and reversing climate change, and marine energy can be the key to unlocking this potential.

[48] Copping, A.E. and Hemery, L.G., 2020. "OES-Environmental 2020 State of the Science Report: Environmental Effects of Marine Renewable Energy Development Around the World. Report for Ocean Energy Systems (OES)." https://tethys.pnnl.gov/publications/state-of-the-science-2020.

Marine Energy Program Vision and Mission

VISION

A U.S. marine energy industry that expands and diversifies the nation's energy portfolio by responsibly delivering power from ocean and river resources.

To help realize the vision of the Marine Energy Program, WPTO conducts research, development, demonstration, and commercial activities that advances the development of reliable, cost-competitive marine energy technologies and reduces barriers to deployment. The Marine Energy Program comprises four core R&D activity areas and one initiative that represent the program's strategic approach to addressing the challenges faced by U.S. marine energy stakeholders, as summarized in Table 12.

Table 12. Marine Energy Program Overview

<table>
<tr><th colspan="3">MARINE ENERGY PROGRAM MISSION</th></tr>
<tr><td colspan="3">Conduct research, development, demonstration, and commercial activities that advances the development of reliable, cost-competitive marine energy technologies and reduces barriers to technology deployment.</td></tr>
<tr><th>FOUNDATIONAL R&D</th><th>TECHNOLOGY-SPECIFIC SYSTEM DESIGN AND VALIDATION</th><th>REDUCING BARRIERS TO TESTING</th></tr>
<tr><td>Drive early-stage R&D on components, controls, manufacturing, and materials; develop and validate numerical modeling tools; improve resource assessments and characterizations; develop quantitative metrics to evaluate devices' potential.</td><td>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.</td><td>Enable access to open-water, grid-connected, and non-grid connected testing facilities; support environmental monitoring technologies, tools, and data collection to understand potential environmental risks and reduce costs.</td></tr>
<tr><th colspan="3">DATA ACCESS, ANALYTICS, AND WORKFORCE DEVELOPMENT</th></tr>
<tr><td colspan="3">Improve access to and use of data, tools, and science, technology, engineering, 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.</td></tr>
</table>

Challenges and Marine Energy Program Approaches

With input from numerous stakeholders, the Marine Energy Program has identified several core challenges that must be addressed to achieve its mission and support the ultimate vision for the U.S. marine energy industry. These challenges illustrate the complexities and difficulties that must be overcome to develop commercial marine energy technologies and highlight why high-risk early-stage R&D is necessary to catalyze the transformative innovations capable of addressing them. However, the below challenges are not all-encompassing of every difficulty identified by the marine energy industry and other stakeholders. The challenges highlighted below are ones the program has a direct and government-appropriate role in helping to address. The wide range of specific challenges and high-level approaches to address them have been organized into four corresponding activity areas that the Marine Energy Program aligns its work and efforts to, which is discussed in the following sections and summarized in Table 13.

In addition to addressing these fundamental technical challenges, WPTO is expanding opportunities to realize the unique value proposition for smaller-scale marine energy systems to (1) power microgrids in remote coastal communities including those currently dependent on fossil fuels; (2) power ocean-based scientific and commercial missions currently limited by incumbent energy sources; and (3) integrate with ocean and coastal-based applications like desalination and aquaculture where marine energy can uniquely improve the resilience and economic sustainability of local communities.

Table 13. Challenges and Marine Energy Program Approaches to Overcome Them

Challenges	Approaches
Difficult Engineering to Convert Marine Energy • Fundamental difficulties for designing systems to efficiently capture usable energy, due to the unique physics of the systems. • Open scientific and engineering questions about how devices interact with these complicated resources or with other devices, and efforts to develop validated methods to measure, model, and predict these interactions are ongoing. • Lack of well-developed manufacturing and supply chains for marine energy applications, resulting in long lead times and high costs for materials and components. • Lack of established, commonly-accepted performance metrics to evaluate the wide range of existing technologies.	**Foundational R&D** • 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 e technologies with high ultimate techno-economic potential.
Installing and Operating Reliable Systems • Difficulties in developing effective and efficient methods for installation, testing, operations, and maintenance (O&M) due to the nature of high-energy and corrosive marine/riverine systems. • Limited infrastructure to deploy marine energy devices and support operations in high-energy, deep-water environments where devices will be deployed, and/or infrastructure not optimized for marine energy applications.	**Technology-Specific System Design and Validation** • 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.).

Challenges	Approaches
Prolonged Design and Testing Cycles • Limited access to test infrastructure at various scales for rapid iterative design improvements. • Expensive, time-consuming permitting processes with extensive requirements for environmental monitoring driven by high perceptions of risk. • Limited transferability and utilization of accurate information about siting and deployment of marine energy technologies and complicated coordination with existing users of ocean spaces and waterways.	**Reducing Barriers to Testing** • 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.
Limited Availability of Technology/Market Information • Unclear value opportunities for utilizing marine energy technologies due to the limited availability of information and analysis on the potential of marine energy technologies. • Lack of validated, publicly available data on the performance, costs, and reliability of new marine energy systems. • Lack of STEM-relevant and educational information and opportunities to attract students and early-career professionals to marine energy careers.	**Data Access, Analytics, and Workforce Development** • 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 & industrial sectors (e.g., offshore wind, oil, and gas).

Difficult Engineering to Convert Marine Energy

Marine energy device performance is governed by complex fluid-structure interactions between the devices and the marine environment. Fundamental scientific and engineering challenges remain in understanding how to design the most efficient systems to harness high energy-density and dynamic marine resources. Resource characteristics can vary significantly on very short timescales, such as the passing of an ocean wave or turbulence in water currents, and the ranges of energy intensity that devices experience can vary by several orders of magnitude. Devices must be designed to minimize the cost of energy while still operating reliably for the design life of a project, which can be 20 years or more. Therefore, developing marine energy devices is a multifaceted system design and optimization problem that encompasses many engineering disciplines.

Installing and Operating Reliable Systems

Installing, operating, and maintaining marine energy devices in harsh marine environments in a cost-effective and reliable manner presents significant difficulties that are related to, but also independent of, the fundamental scientific and engineering challenges. The corrosive saltwater environment, deep water, and high pressures at depth, dynamic benthic systems where devices will be anchored, sites that are sometimes located far from shore or port infrastructure, and extreme weather events all combine to create difficult conditions in which marine energy systems must be deployed and maintained. Developing and demonstrating solutions to solve these challenges would significantly reduce reliability concerns and enable greater access to project financing. Additionally, existing ships and port infrastructure have been developed specifically for other offshore commercial and industrial uses, and direct utilization of these ships and infrastructure without adaptation for the unique cost and performance requirements of marine energy technologies often results in suboptimal efficiency and high costs.

Prolonged Design and Testing Cycles

Testing marine energy technologies is inherently more complex and time consuming than for land-based energy generation technologies. The already slow pace of design and in-water testing cycles is further exacerbated by the limited availability of testing infrastructure at various scales, complex and time-consuming permitting processes, and expensive environmental monitoring. These challenges severely limit the ability of technology developers to quickly assess the performance of devices and components, innovate solutions where necessary, and deploy the next generation of devices. Because of the complex physics of the ocean wave and current environments, marine energy prototypes must be tested in real-world environments to fully characterize their performance and reliability. These challenges associated with testing, deploying, and optimizing technologies in a timely and cost-effective manner must be overcome to accelerate the pace of marine energy technology development.

Limited Availability of Technology, Market and STEM Information

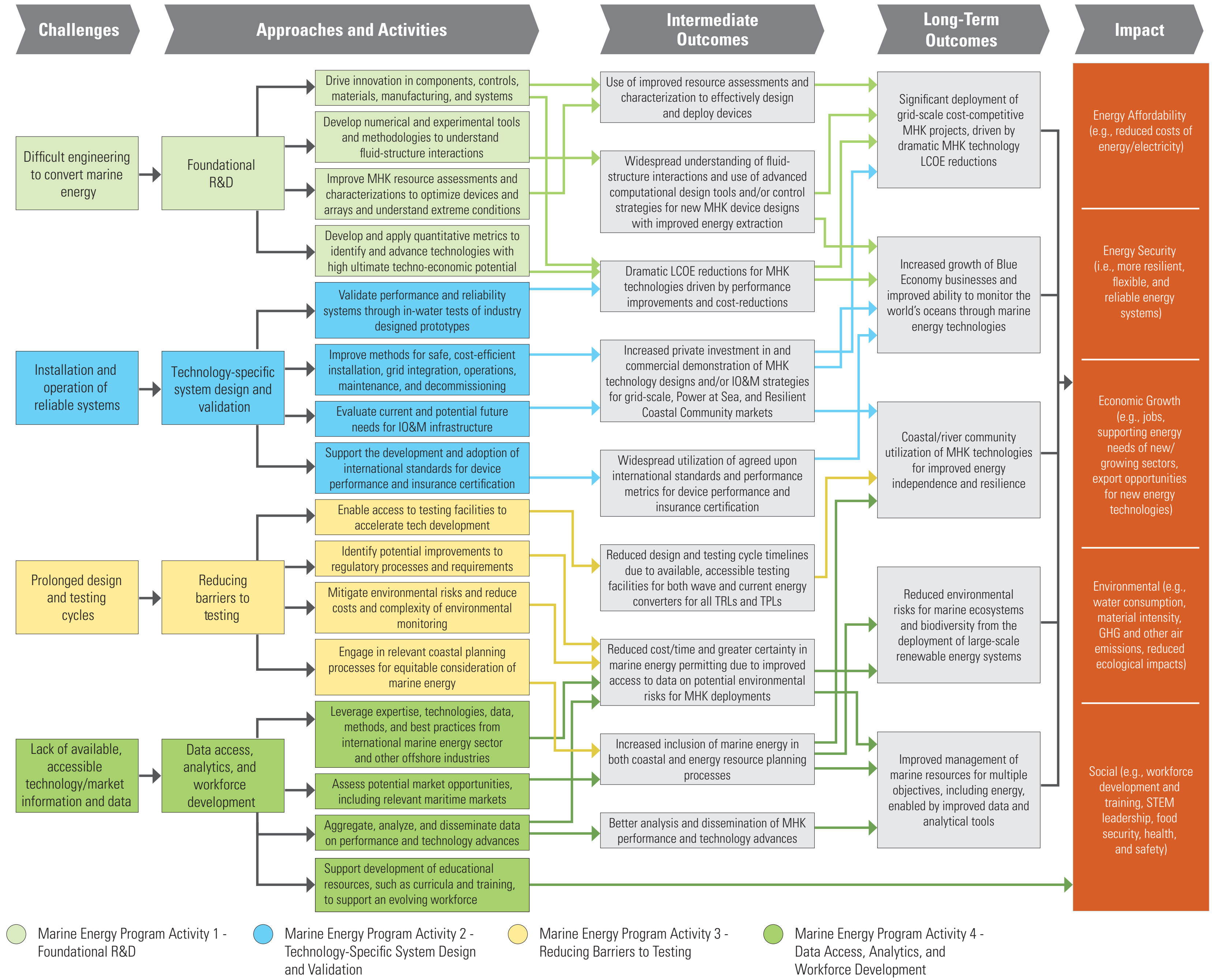
There are a number of challenges associated with the fact that the marine energy industry is in the nascent stages of development. Technologies are largely in the research, development, and demonstration phases, and have not yet been validated as commercially ready. Information and lessons learned from tests and in-water demonstrations that have occurred are often inaccessible or protected. Lack of awareness of different market opportunities and the potential benefits of marine energy technologies, compounded by limited familiarity with the technologies themselves, lead to perceptions of high technical risk. Limited experience in manufacturing devices and designing systems that can be efficiently manufactured at scale add to existing challenges but are capable of being addressed. Finally, access to STEM-relevant data, educational materials, and opportunities for students and other early career professionals to learn more about opportunities in marine energy are critical to supporting long-term workforce needs.

Marine Energy Program Goals and Objectives

Marine Energy Program Logic Model

Figure 9 illustrates the portfolio-wide logic for the Marine Energy Program. The challenges and approaches to addressing those challenges are those identified in the previous section and in Table 13. WPTO's Key Results and Performance Goals for the FY 2021–2025 timeframe are the significant outputs or products that are being targeted within the next five years. Those results and performance goals are critical to achieving the program's 2026-2030 objectives, which are short-term outcomes that are intended to lead directly to one or more of the intermediate outcomes identified in Figure 11. Those intermediate outcomes then hopefully influence the identified long-term outcomes, and the ultimate society or economy-wide impacts.

Figure 11. Marine Energy Program Logic Model



Assessing Performance

The ultimate vision for a successful and dynamic U.S. marine energy industry cannot be realized without intense dedication to technology improvement and ambitious cost-reduction activities. Historically, DOE has targeted roughly 80% reductions in the modeled cost of energy for wave, tidal, and river energy technologies from reference 2015 baselines to the year 2035. These are seen as aggressive, yet feasible, targets.[49] These goals were established several years prior to the publication of this document using the best-available data from literature at the time, along with programmatic and national laboratory expertise. The utilization of modeled levelized costs of energy (LCOE) is useful because it provides a standardized set of assumptions and a means of evaluating the effect of particular device or component R&D improvements over time. One drawback, however, is that the baseline or modeled LCOE values at any particular time may not accurately represent costs for any individual real-world technology because modeled LCOE assumes manufacturing and deployment efficiencies that cannot be realized with prototype devices. LCOE assumptions are also geared toward utility-scale generation technologies and projects and are less directly-applicable for evaluating marine energy devices that are targeted for other types of markets, such as those discussed in the Powering the Blue Economy Initiative Section.

[49] Note: the baseline and goal LCOE values are for generic technology archetypes and not directly attributable to any specific device.