Marine Energy Commercialization Review: Evaluation of the Transition From Public to Private Capital

Jenny Wiegele and Courtney Jones

National Renewable Energy Laboratory

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Contract No. DE-AC36-08GO28308

Technical Report
NREL/TP-5700-91213
December 2024

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Suggested Citation
Wiegele, Jenny, and Courtney Jones. 2024. *Marine Energy Commercialization Review: Evaluation of the Transition From Public to Private Capital*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5700-91213. https://www.nrel.gov/docs/fy25osti/91213.pdf.

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National Renewable Energy Laboratory
15013 Denver West Parkway
Golden, CO 80401
303-275-3000 • www.nrel.gov

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This work was authored by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Water Power Technologies Office. The views expressed herein do not necessarily represent the views of the DOE or the U.S. Government.

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Acknowledgements

We would like to thank Anna Yee, Sebastian Grimm, David Oonk, Allison Johnson, David Marchand, and Sam Zhang from the U.S. Department of Energy Water Power Technologies Office, and Tessa Greco, Ben Maurer, Kerry Grantham, Amy Brice, and Scott Jenne from the National Renewable Energy Laboratory for their contributions, review, and feedback during the development process.

Acronyms

BOEM	Bureau of Ocean Energy Management
DOE	U.S. Department of Energy
FERC	Federal Energy Regulatory Commission
GP	general partner
LACI	Los Angeles Incubator Network
LCOE	levelized cost of energy
LP	limited partner
LTI	long-term investors
NEPA	National Environmental Policy Act
NREL	National Renewable Energy Laboratory
OCED	Office of Clean Energy Demonstrations
ORPC	Ocean Renewable Power Company
PE	private equity
PURPA	Public Utility Regulatory Policies Act
R&D	research and development
SBIR	Small Business Innovation Research
TEAMER	Testing Expertise and Access for Marine Energy Research
USACE	U.S. Army Corps of Engineers
VC	venture capital
WPTO	Water Power Technologies Office

Executive Summary

The U.S. Department of Energy's (DOE's) Water Power Technologies Office's (WPTO's) mission is to enable research, development, and testing of new technologies to advance marine energy, and next-generation hydropower and pumped storage systems, for a flexible, reliable grid. Marine energy is a nascent technology that extracts energy from waves, currents, tides, and thermal and gradient differentials (ocean thermal, pressure, and salinity)—resources that are abundantly available in the United States: "In the United States, the total available marine energy resource is equivalent to nearly 60% of U.S. power generation. Even if only a small percentage of that technical resource potential is captured, marine energy technologies would make significant contributions to the nation's energy needs" (WPTO 2019).

The available marine energy resource could help meet a variety of needs, both in the near term by "producing fresh water through desalination or servicing the power demands for aquaculture and ocean sensing," and in the long term by supplementing available energy on the grid (WPTO 2022a). Early research and development efforts, primarily funded by WPTO, are focused on proving the functionality of marine energy devices, identifying opportunities for technical and economic improvement, and generating resource and performance data (WPTO 2019).

Because of its nascency though, professionals in the marine energy sector must navigate a variety of risks and challenges related to in-water testing regulatory authorizations, operation and maintenance difficulties in the ocean, and others that cause associated delays in private capital interest in the technology. Some of these challenges can be overcome with lessons learned from developers[1] in other technology areas while others are unique to marine energy and require new approaches. This paper focuses on identifying the barriers, gaps, and potential solutions to commercializing marine energy technologies through an evaluation of public reports and peer-reviewed literature from government agencies, nongovernmental organizations, academia, and the private sector, along with data gathered from stakeholder and industry feedback and historical investment and programmatic actions taken by WPTO to progress marine energy.

Defining Commercialization

As part of the literature review, initial gaps identified were the lack of targeted goals that would signify successful commercialization of a marine energy technology and the lack of standard metrics for measuring progress toward commercialization. Standard metrics are likely to support the advancement of marine energy by helping to measure progress toward WPTO's goals and by informing developers advancing marine energy and private capital providers currently or prospectively investing in marine energy technologies. Report authors define commercialization of marine energy as the process by which a technology developer advances a device's core functionality, reduces the cost of development and/or testing deployment, or facilitates a

[1] The term "marine energy developers" includes engineering firms, national laboratories, research institutions, small businesses, and service providers supporting developers working in any of the prior organization types. This term is used throughout the report to refer to the comprehensive list of developers working in this industry.

marketable use of a technology. Any of the following considerations could be used to clearly define marine energy's value proposition and measure progress toward commercialization:

- A quantifiable improvement in the resilience, reliability, and/or quality of an energy supply
- A quantifiable reduction in the levelized cost of the energy produced
- The number, breadth, and/or quality of the jobs provided
- The ability to serve a specific end use, either as electricity or some other service
- The ability to sustain technology development and/or company growth after public funding has concluded through private capital, technology transfer, or some other mechanism.

Key Commercialization Challenges and Access to Public Funding and Private Capital

Global and domestic policies and the current public funding landscape have influenced clean energy technology investments. WPTO is the primary funding source for marine energy developers in the United States and supports sector advancement through competitive awards made to technology developers and research institutions. This funding has steadily increased over time. Additional public funding, historically at lower levels, has also been available for marine energy developers from other DOE offices, such as the Advanced Research Projects Agency – Energy and the Office of Indian Energy, and federal agencies like the U.S. Navy, the Bureau of Ocean Energy Management, and the National Oceanographic and Atmospheric Administration. State and local governments also provide support, in addition to international agencies and foreign governments, although funding from non-U.S. governments has fluctuated in levels of interest and investment.

Despite these funding avenues, marine energy developers face substantial barriers, including regulatory authorizations[2] averaging 7.5 years, high costs, system reliability challenges, and competition from other energy sources as developers enter the commercial market to begin selling their product to end users. The regulatory authorization process to install and operate devices is intricate and time-consuming due to the substantial level of regulatory agency and stakeholder consultation involved with renewable energy projects in water bodies. The use of adaptive management strategies has been proposed to address some of these challenges, but such strategies require substantial resources, providing some solutions while increasing the costs associated with the process. Additionally, historical international policies suggest that sustained early government investment and innovative policy frameworks, such as those seen in the UK and the Netherlands, can play a crucial role in advancing marine energy and attracting private capital. The lessons learned from these policies emphasize the need for long-term, demand-side support and targeted funding to bridge gaps and mitigate commercialization risks.

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[2] "Regulatory authorizations" is a comprehensive term used throughout this report to include a reference to the permitting, licensing, and other regulatory considerations a developer must navigate. These authorization requirements are explored in detail in the Public Funding and Policies section.

Public funding and policy are important in the early stages of marine energy development, but the transition to private capital is a critical late-stage step in commercializing technologies. Despite the potential of marine energy, private investment remains limited. Private capital return targets are typically proprietary, but at a high level, generally require a proven prototype, demonstrated long-term performance, and the ability to meet quantitative return on investment targets of 20% or more within a decade. Private capital providers evaluate a number of factors, including the levelized cost of energy, comprehensive risk analyses, and long-term development plans. Intermediaries such as incubators and accelerators offer support to address some of these cost and logistical challenges by coordinating capital sources and supportive resources as well as facilitating connections between developers and investors. Incubators and accelerators enhance coordination between public and private capital. These qualitative and quantitative return expectations for private capital providers are explored in detail in Section 3, Private Capital: Investment Structures and Anticipated Returns.

Venture capital (VC) and private equity (PE) have been pivotal for technology developers navigating the transition from public to private funding for early-stage technologies. However, investments in clean energy, including marine energy, have faced cyclical boom-and-bust funding challenges and private capital provider skepticism, exacerbated by global financial crises that have led to significant losses and a more cautious approach from VC and PE firms. Marine energy's development timelines and capital requirements often clash with the shorter-term, high-return expectations typical of VC and PE investors, and developers have difficulty demonstrating product differentiation as compared to other energy generation technologies and long-term potential. Additionally, debt financing serves as an option for mature technologies but remains inviable for marine energy projects because of high capital costs for developers resulting from stringent requirements (i.e., required minimum revenue or profit, confirmed customers, or commercial availability as examples) on the part of the debt financing providers during the underwriting process, enabling more mature technologies to access debt financing more affordably.

In contrast to the strict quantitative return requirements of VC and PE investors and debt providers, corporate VC, long-term investment funds, and tailored bond programs are driven by varied qualitative and strategic investment goals. Corporate VC investors seek opportunities that are aligned to their strategic corporate goals such as innovation and environmental, social, and governance commitments, and identifying this alignment could be an opportunity for marine energy developers. Long-term investment funds like pension funds and philanthropic organizations could better align with marine energy's longer development horizons as well, but these investors face challenges in identifying promising technologies due to limited awareness of these developers or insufficient capacity to fully evaluate their investment potential. Tailored green and blue bond programs offer innovative debt financing structures, albeit with varying degrees of maturity and effectiveness. Overall, while various private capital mechanisms offer different benefits, the requirements and interests associated with these mechanisms are often not well aligned with the current development stage of most marine energy technologies.

To facilitate a smoother transition to a higher balance of private capital investment in the sector, this report highlights potential programmatic adjustments that may inform future strategies to support marine energy development. Potential strategies include: enhancing public-private sector communication, refining commercialization requirements in funding opportunities, leveraging existing technology transfer programs, fostering interagency and intra-agency partnerships, developing a more robust patent library, providing targeted capacity-building for developers, creating tailored modular support systems, evaluating the impact of funding structures to meeting commercialization goals, and identifying other unique funding mechanisms that could be leveraged for marine energy, such as contracts for difference and blue bonds.

By adopting these strategies and targeting new technology developments to the identified standard metrics for marine energy commercialization, WPTO and marine energy developers could realize measurable progress toward the outlined commercialization goals. The proposed strategies and support mechanisms aim to improve an understanding of the realistic development timelines for marine energy for both public and private actors and enable collaborations and financial structures that can better support the advancement of the marine energy industry.

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1 Introduction

The U.S. Department of Energy's (DOE's) Water Power Technologies Office's (WPTO's) mission is to enable research, development, and testing of new technologies to advance marine energy, and next-generation hydropower and pumped storage systems, for a flexible, reliable grid. Marine energy is a nascent technology that extracts energy from waves, currents, tides, and gradient differentials (ocean thermal, pressure, and salinity)—resources that are abundantly available in the United States: "In the United States, the total available marine energy resource is equivalent to nearly 60% of U.S. power generation. Even if only a small percentage of that technical resource potential is captured, marine energy technologies would make significant contributions to the nation's energy needs" (WPTO 2019).

The available marine energy resource could help meet a variety of needs, both in the near term by "producing fresh water through desalination or servicing the power demands for aquaculture and ocean sensing," and in the long term by supplementing available energy on the grid (WPTO 2022a). Early research and development efforts, primarily funded by WPTO, are focused on proving the functionality of these devices, identifying opportunities for technical and economic improvement, and generating resource and performance data (WPTO 2019).

To achieve the mission to advance marine energy systems, WPTO issues competitive direct funding mechanisms, including Small Business Innovation Research (SBIR) and Small Business Technology Transfer grants; prizes and competitions; Notices of Funding Opportunities; and technical assistance facilitated by DOE's national laboratories. These strategic investments focus on early-stage research and technology design, validation of performance and reliability for new technologies, providing access to necessary testing infrastructure, and disseminating objective information and data for technology developers and decision makers. WPTO-funded programs support the marine energy sector by strategically advancing technologies for various end users and markets, from power grid operations to off-grid, colocated energy users and communities. In support of this mission, the National Renewable Energy Laboratory (NREL) serves as one of the DOE-owned national laboratories enabling these advancements. NREL's marine energy research team leverages more than 40 years of institutional experience designing, evaluating, validating, and demonstrating renewable energy systems and applies that expertise to innovate marine energy technologies. NREL's position as a DOE laboratory enables access to additional resources to advance WPTO's marine energy research and development (R&D) goals.

Because of the nascency of the industry, marine energy developers experience a number of challenges in commercializing these technologies. This report, the Marine Energy Commercialization Review, analyzes the commercialization pathways for technology developers working on renewable energy and outlines the implications and long-term development targets for marine energy R&D to address those challenges. This project was led by NREL and funded by WPTO's Strategic Innovation and Outreach Program.

This report identifies barriers to marine energy technology commercialization that developers may experience, represented in Figure 1, based on an analysis of the commercialization of other renewable energy technologies. The team conducted a literature review that included public reports and peer-reviewed literature from government agencies, nongovernmental organizations, academia, and the private sector and gathered data from stakeholder and industry feedback and historical investment and programmatic actions taken by WPTO to progress marine energy. The review evaluated the barriers to commercialization that other renewable energy technologies have faced, common investment structures that could support the industry transition from public funding to private capital, the historical influence of policy structures impacting investor interest in renewable energy technologies, and potential strategies to address barriers to commercialization.

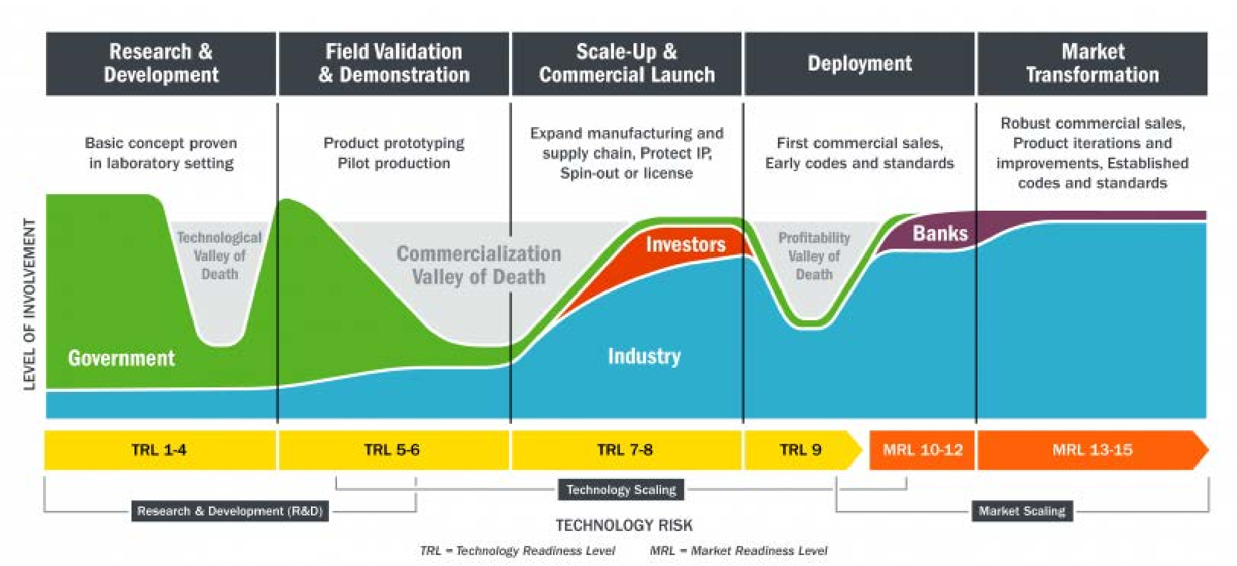

Figure 1. Graphic representing the technology commercialization process and the "valleys of death." This report specifically aims to address marine energy technologies funded by WPTO and enable successful passage across the commercialization valley of death.

Source: Building Technologies Office (n.d.)

Outcomes from this work are intended to support the development and implementation of a commercialization and innovation ecosystem strategy for marine energy technologies. Potential strategies are designed around the most successful models used for other renewable energy technology development strategies. These strategies represent potential pathways to commercialization, qualitative and quantitative indicators and metrics to encourage investment, and targets for support mechanisms to improve the commercialization potential of marine energy. This report is intended to provide guidance for marine energy developers, intermediary organizations, public funders, and private capital providers with a current or potential interest in marine energy technologies; additionally, it may inform funding solicitation development, follow-on support programs, and project administration.

1.1 Defining Commercialization

"Technology commercialization" is a broad term. As part of the literature review, initial gaps identified were the lack of targeted goals that would signify successful commercialization of a marine energy technology, and the lack of standard metrics for measuring progress toward commercialization. To advance the marine energy industry, it is critical to develop these standard metrics to measure progress toward WPTO's goals and to inform developers advancing marine energy and private capital providers currently or prospectively investing in marine energy technologies. For the purposes of this report, the team explored the use of this term in relevant DOE materials.

As part of DOE's Science and Innovation strategy, commercialization is "the process by which technologies and innovations developed in the lab make their way to the market." Commercialization is a dynamic "process" that requires strategic engagement from developers and both public and private actors. Figure 2 shows an example commercialization process for another energy technology (DOE n.d.). The *Pathways to Commercial Liftoff* report (DOE 2023), some benefits of commercializing technologies are identified, including "creating high quality American jobs, strengthening domestic supply chains and global competitiveness, and facilitating an equitable energy transition." This perspective identifies common quantifiable targets that can help a technology be successful in the market.

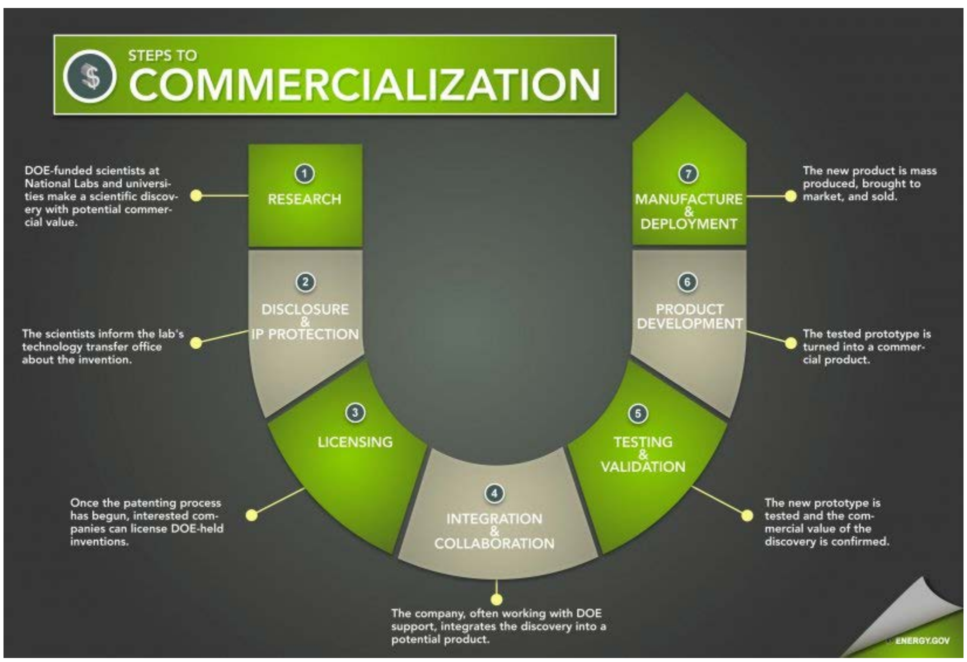

Figure 2. Example commercialization process in the steps to commercialize nickel metal hydride batteries.

Source: DOE (n.d.)

In WPTO's *Multi-Year Program Plan* (WPTO 2022a), the office identified a number of goals and approaches that could help accelerate the commercialization of marine energy. The following do not define what a commercialized technology would look like but rather provide some characteristics to consider in what could qualify as a successfully commercialized technology:

- "Significantly reduced timelines of design iterations for developers and researchers working in the marine energy industry, ultimately accelerating the iterative R&D process."
- "Documented improvements in energy-water system resilience and security for a number of targeted remote communities, enabled by marine energy systems."

In incorporating the various definitions and the elements that may be critical to reaching commercialization goals offered by DOE resources, report authors define the commercialization of marine energy as the process by which a technology developer advances a device's core functionality, reduces the cost of development and/or testing deployment, or facilitates a marketable use of a technology. Any of the following considerations could be used to clearly define marine energy's value proposition and measure progress toward commercialization:

- A quantifiable improvement in the resilience, reliability, and/or quality of an energy supply
- A quantifiable reduction in the levelized cost of the energy produced
- The number, breadth, and/or quality of the jobs provided
- The ability to serve a specific end use, either as electricity or some other service
- The ability to sustain technology development and/or company growth after public funding has concluded through private capital, technology transfer, or some other mechanism.

Because marine energy technologies are still in the early stages of development, it is not clear which of these metrics will have the most impact on long-term success for marine energy. Clearly outlining progress on any one of these points could be used to measure WPTO's success in supporting marine energy commercialization to better support the advancement of the industry.

1.2 Key Commercialization Challenges

Despite its potential to provide abundant clean power from the ocean, marine energy remains largely untapped, and the industry as a whole is still in the precommercial stage. Marine energy systems face a number of technical, social, and regulatory challenges, some of which are discussed below in the context of potential support mechanisms to help developers overcome these challenges.

Designing, installing, operating, maintaining, intervening, and decommissioning marine energy systems hinge on a variety of sensitive and challenging factors driven by the dynamic ocean environment. Operating technologies at sea require resilience to storms and corrosion, requiring the technologies to be accessible by vessel and/or diver. Operating these technologies at sea could also impact dynamic ocean ecosystems if environmental risks are not properly mitigated (WPTO 2019). Before testing their technology in the water, developers must first grapple with the complex science and engineering challenges that govern the technology's performance at sea—novel challenges for which there is often not a marine precedent or land-based systems analogue.

Given these technological challenges, marine energy developers have also experienced some public hesitancy from prior marine energy and other historical renewable energy development practices to work through the development life cycle. As an example, in 2024, the city of Niagara passed a resolution opposing installations of marine energy devices in the Niagara River. Concerns from citizens included issues related to "habitat protection, access to public designated parkland, and environmental impact on avian wildlife" (The City of Buffalo 2024). These hesitations around deployments create challenges in learning from deployments. Castrejon-Campos et al. (2022) found that technology deployments help increase understanding and support for early-stage technologies at a much quicker pace; such deployments provided learning opportunities that benefitted solar and wind technologies during their early stages of development. While this paper suggests pilot test deployments would help to expedite marine energy technology development, pilot deployments are also inherently more public, potentially influencing the perception of their readiness and eroding trust in the technology, marine energy developers and the associated industry, and the supporting government and regulatory bodies. Anecdotally, private investors and communities have expressed hesitations in their willingness to take on a pilot marine energy project due to these public development phases.

Marine energy potentially has a role in supporting both on-grid and off-grid applications, but each application necessitates an evaluation of social, economic, and cultural values and perceptions. Renewable energy must surmount historically entrenched issues of disparate and inconsistent access to funding for energy improvements, maintenance, and R&D from both public funding and private capital (Romero-Lankao et al. 2023). Community pushback on marine energy technologies because of fears around environmental impacts, aesthetic concerns, and associated reductions in tourism revenue has also delayed projects (Bedard 2007). Marine energy is not unique in the need to address these systemic challenges; these barriers have been overcome for other technologies, and lessons can be learned from that work through the inclusion of community representatives as key partners in pilot tests, co-development processes, and environmental analyses. Specific strategies for addressing these barriers directly are beyond the scope of this report but may be explored in future work.

Environmental impact studies and mitigation strategies are costly and require specific expertise: any displacement of marine life and reduction in marine water quality requires significant up-front evaluations, and grid interconnection for any new generation remains a challenge for all renewables—not just marine energy (Vazquez and Iglesias 2015). Specific regulatory barriers are explored more in the following sections, but at a high level, regulatory requirements significantly extend development timelines and increase costs and risk on host communities interested in marine energy. Through programs like Testing Expertise and Access for Marine Energy Research (TEAMER) and the forthcoming test facility PacWave, WPTO offers access to indoor test facilities as well as pre-permitted open-water facilities to validate technologies during the early stage of development. Support also includes conducting these environmental impact studies and navigating regulatory authorizations to help mitigate some regulatory and environmental risks (Strout Grantham 2022; TEAMER n.d.). Such access to shared infrastructure is critical and necessary for technology validation (Noailly and Smeets 2022).

The feasibility and operational challenges associated with marine energy generally translate into high costs, longer-term R&D timelines, and an investment market that has struggled to competitively attract sufficient private interest.

The nascency of the technology also contributes to the difficulty many developers have experienced in transitioning from public to private capital: "Younger firms and for firms in less mature technology areas such as [wave and tidal] ... are particularly affected by financing constraints" (Noailly and Smeets 2021). Even given the recent increases in available public funding and investment tax credits through the Bipartisan Infrastructure Law (Congress.gov 2021) and Inflation Reduction Act (Congress.gov 2022), respectively, outside of a steady increase in publicly available funding through WPTO, state-level policies and incentives and private capital interest are considered fragmented in comparison to frameworks in other countries (Outka 2021).

Marine energy has not reached a state of technical and financial certainty necessary to investors until interest has started to build for those seeking a diversified risk portfolio and long-term gains. There is also a disconnect between WPTO's primary goals, which focus on technology-specific advancements, and private capital providers' focus on the investment potential when evaluating customer and sector interests that are agnostic to a technology. These goals are not necessarily in conflict with one another, but no public or private actor alone can sustainably support these developers: an "absence of a cohesive investing ecosystem contributes to the 'valley of death' by significantly inhibiting critical information flow, investor confidence, and, consequently, consistent capital allocations toward novel clean energy development" (Drover et al. 2017). An effort to better understand benefits and outcomes from investment from public and private actors and how they translate to benefits to other capital providers—along with a clearer identification of the quantitative and qualitative transition points between public and private capital—can enable more strategic support mechanisms to help developers meet those transition points and navigate a complex funding ecosystem. Additional detail on these return expectations is provided in Section 3, Private Capital: Investment Structures and Anticipated Returns.

1.3 Recent Transitions From Public to Private Capital

While the identified commercialization challenges for marine energy are still creating formidable barriers for developers in the transition from public to private capital, there are some successful projects that have leveraged unique opportunities and secured funding beyond WPTO. The developers of these projects had to navigate this complex funding ecosystem and blend multiple funding sources across programs, agencies, and private capital providers to continue to progress their research. They were often required to build capacities in business development, stakeholder engagement, and project management to sustainably continue their research. By leveraging a variety of financing mechanisms, Oneka Technologies and the Ocean Renewable Power Company (ORPC) serve as examples of two potential pathways marine energy developers could take to advance their technologies.

Oneka Technologies was the grand prize winner of WPTO's Waves to Water Prize (WPTO 2023), receiving $966,000 for their participation between 2019 and 2022. The prize was designed to enable the development of an emerging field, and participating developers produced some of the first pilot deployments of wave-powered desalination systems. After the conclusion of the prize, Oneka Technologies received $1.5 million in follow-on funding in partnership with Fort Bragg, California, to pilot a new iteration of their system (Garanovic 2023). They were also selected to receive an additional $3.4 million from WPTO through a Notice of Funding Opportunity to continue refining wave-powered desalination technologies (Office of Energy Efficiency and Renewable Energy 2023). Oneka also secured investments from the Ocean Supercluster at $14.1 million (Canada's Ocean Supercluster 2023) and $4.9 million from Sustainable Development Technology Canada (2023), bringing their total public funding to approximately $25 million. These public investments reduced the risk for private investors, which included the Hoffecker Family, Horizon Capital Holdings, AQC Capital, the Wilson Family, Propulia Capital, and Invest Nova Scotia, enabling Oneka to close a Series A round in equity financing for an additional $12.5 million (Mandel 2023).

ORPC has shifted between public funding and private capital as opportunities arise. In 2014, ORPC developed a partnership with a customer in the community of Igiugig, Alaska, with funding from WPTO to test the RivGen device to refine and co-develop their technology with the community (WPTO 2022a). This project led to installing two grid-connected RivGen devices under a Federal Energy Regulatory Commission (FERC) pilot license, first in 2019 and a follow-on deployment in 2022. Following public outreach on this project, ORPC was able to secure $25 million in private growth capital to continue refining the technology and modifying it for other locations (ORPC 2021). ORPC then secured new opportunities for revenue contracts from the governments of Chile and Canada in 2022 (ORPC 2022), a commitment from Shell to purchase two systems to deploy in the Mississippi River in 2023 (ORPC 2023), and received further support from WPTO to partner with and co-develop an updated iteration of the technology with Millinocket, Maine (WPTO 2024a). ORPC is currently pursuing the opportunity to develop a tidal array that would harness the United States' largest tidal energy resource. In 2024, WPTO selected ORPC as one of two potential projects to receive $3 million each for scoping a project that will transition to a commercial tidal project. If ORPC is chosen to advance to the commercial stage, it will receive an additional $29 million in funding to deploy two tidal energy devices in Alaska's Cook Inlet, the largest tidal energy resource in the country (Office of Energy Efficiency and Renewable Energy 2024).

Both of these companies are still working to refine and improve their technologies, making them examples for WPTO's role in commercializing marine energy by creating sustainable pathways for technology development. The ongoing development and long-term business sustainability for both ORPC and Oneka are well aligned to the proposed metrics to evaluate progress toward commercialization as well as the long-term investment potential sought by private capital providers.

2 Public Funding and Policies

2.1 Public Funders and Mechanisms Supporting Marine Energy

As of this publication, the majority of funding for marine energy from either public or private sources is WPTO (Mazzucato and Semieniuk 2018). In Fiscal Year 2024, WPTO received annual appropriations of $141 million for marine energy R&D (WPTO n.d.[a]), not including any further funding enacted through the Bipartisan Infrastructure Law or the Inflation Reduction Act, enabling the office to act as the primary funder and driver for technology development priorities still in the R&D stage. The office provides funds through a number of competitive solicitations, and additional information on the full investment portfolio (WPTO n.d.[b]) and funding opportunities (WPTO n.d.[c]) are publicly available.

Other offices within DOE also provide support to developers without a focus on a specific technology area. The Advanced Research Projects Agency – Energy provides opportunities for early-stage technologies and has periodically offered opportunities related to marine energy. The Office of Technology Transitions supports the commercialization of technologies built out of the national lab commercialization ecosystem. As technologies advance, the Office of Clean Energy Demonstrations (OCED) provides funding for pilot demonstrations and the Grid Deployment Office enables the deployment of infrastructure projects. The Office of Indian Energy supports the development and deployment of energy solutions that benefit American Indians and Alaska Natives. The Loan Programs Office then offers debt financing with favorable terms to support energy infrastructure deployments as well. A summary of public funding mechanisms both within and outside of DOE is included in Table 1.

Table 1. Summary of Public Funding Providers for Marine Energy

Public Funder	Funding Priorities	Potential Timeline Applied to Marine Energy
DOE		
Advanced Research Projects Agency-Energy	Early-stage technology developments	Near term
Water Power Technologies Office	Research, testing, development, and commercialization of marine energy	Near term
Office of Clean Energy Demonstrations	Pilot demonstrations that enable energy infrastructure	Medium term
Office of Indian Energy	Energy solutions that benefit American Indians and Alaska Natives	Medium term
Office of Technology Transitions	Commercialization of energy technologies	Medium term
Grid Deployment Office	Energy infrastructure deployments	Long term
Loan Programs Office	Debt financing for energy technologies	Long term
Bureau of Ocean Energy Management	Offshore project regulatory authorizations and R&D	Near term

Public Funder	Funding Priorities	Potential Timeline Applied to Marine Energy
National Oceanic and Atmospheric Administration	Complementary R&D for environmental impact and ocean monitoring/modeling	Near term
U.S. Navy Office of Naval Research	Research to support power reliability to meet U.S. Navy mission needs	Medium term
International governments	Alignment to individual national priorities; strategies vary	Medium term
State governments	Alignment to individual state priorities; strategies vary	Medium term

Outside DOE, a number of other federal agencies also provide funding to marine energy developers. The Bureau of Ocean Energy Management (BOEM) manages project leasing and permitting and develops regulations for offshore projects. The National Oceanographic and Atmospheric Administration (n.d.) evaluates environmental impacts, conducts ocean monitoring and modeling, and sustains aquaculture—helping to mitigate many of the challenges marine energy developers face in working in the ocean environment. Both the National Oceanographic and Atmospheric Administration and BOEM fund complementary R&D indirectly related to marine energy The U.S. Navy's Office of Naval Research supports research and technology applications that can help meet their mission-critical power needs at sea, which may or may not directly include marine energy.

Governments at various levels beyond U.S.-based federal agencies can also have a significant role in the development of marine energy technologies. These agencies plan their investments around regional priorities that shift over time. As priorities align with marine energy, these government entities can serve both as a driver for technology development priorities and as a further resource for developers. Non-U.S. governments have provided opportunities—Canada, in particular, with their support for both Oneka and ORPC—but carry varied program requirements and structures. State and local governments have also created unique and niche opportunities for developers. As examples of state policies that have provided opportunities for marine energy developers, Oneka Technologies partnered with the state of California for further pilot deployments, and the state of Oregon offers ongoing incentives to provide funding for communities that choose to pursue early-stage technology pilot deployments, including marine energy (Oregon Department of Energy 2022). A major surge and drop in state utility interest in marine energy between 2005 and 2008 (Figure 3) offered an additional short window of opportunity for marine energy developers (Mazzucato and Semieniuk 2018).

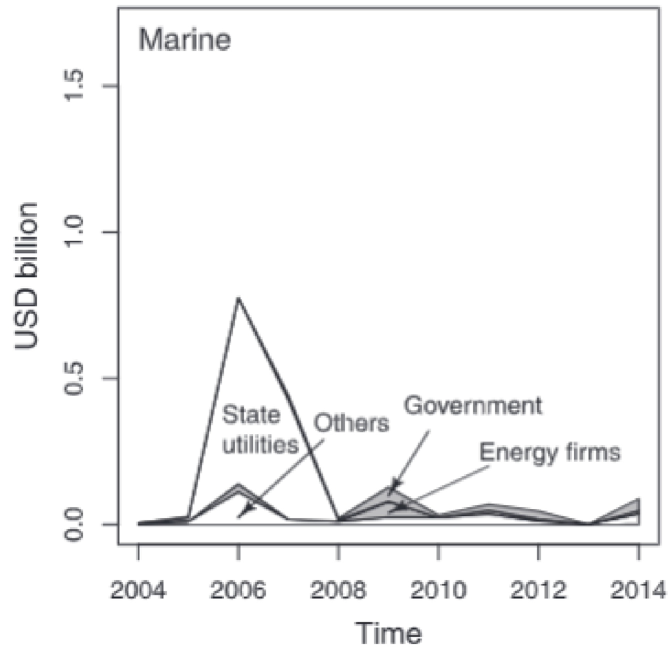

Figure 3. State utility investment peak and decline between 2005 and 2008. Major influxes and retractions of capital such as this one suggest that a further exploration of policy alignment could help to create additional alternative pathways for developers.

Source: Mazzucato and Semieniuk (2018).

WPTO continues to remain the most reliable public funder for marine energy technology developers in the United States, but there are challenges to accessing federal funding. In a report published by the Office of Energy Efficiency and Renewable Energy (Brooks et al. 2022), respondents to an associated request for information offered a number of common issues faced by DOE funding applicants, including "high cost-share requirements ... high administrative burdens and complicated applications ... and narrowly defined scopes for solicitations [that] limit innovation and tend to favor existing approaches, technologies, and research topics that are often dominated by large organizations, national laboratories, or established entities" (Brooks et al. 2022). These challenges were shared by both those new to a technology domain or public funding and those experienced in navigating these resources. Because of the complexity of these opportunities and the lack of certainty and consistency around their timing and size, technology advancement is constrained.

Additionally, WPTO is structured to focus specifically on the early stages of R&D, testing, and demonstrations for marine energy, limiting their ability to support a technology fully through to a commercial product. Although DOE has other funding programs, like OCED, to support larger-scale demonstration, deployment, and commercialization activities for energy technologies that are intended to fill this gap, there are no direct pipelines connecting early-stage R&D programs like WPTO to follow-on funding for scaling demonstrations offered through programs OCED offers. Marine energy companies must compete for funding from programs like OCED alongside applicants with more mature, established technologies.

The effect of shifting priorities; associated capital influxes and retractions; state, local, and international policies around early-stage technology investments; and what can be learned from these trends all have an impact on both developer sustainability and investment interest in a technology.

2.2 Historical Influence of Policies on Investment Behavior

Commercialization barriers create high uncertainty for investors, and a variety of public policy approaches have been implemented for other renewable technologies and in other countries to support sustained investment. The policies have had varied results, but outcomes from these efforts to provide incentives and mitigate investor risk offer some lessons on approaches that could better enable the transition of marine energy projects from public to private capital.

Policy impact that can be measured in long-term economic value rather than short-term benefits will improve investor confidence. As an example, feed-in tariffs have been leveraged internationally for both wind and solar developments early on. These incentives were *not* the primary mechanism for supporting wind in the United States, and their absence resulted in an increase in private sector investment following the conclusion of the program (Karikari Appiah et al. 2022). Solar feed-in tariffs, however, that were present early in commercial solar deployment created a negative association with the technology early on, as fully subsidized development raised questions on whether or not the technology would be economically viable when the policy ended (In, Monk, and Knox-Hayes 2020).

Economic viability and sustainability of a technology in the transition from public to private capital may also be in question if incentives focus on offering a positive impact on externalities alone. This can be mitigated, however, if those policies are correcting an externality and providing an associated economic value to a private capital provider (Gaddy et al. 2017). An incentive provided by the Inflation Reduction Act includes a combination of modified and expanded clean energy investment tax credits, resulting in credits for up to 30% of the cost for clean energy projects that meet specific criteria in hiring qualified employees and meeting wage standards (U.S. Department of the Treasury 2023). This policy has resulted in increased project planning for mature, proven solar, wind, energy storage, and other renewable energy deployments (American Clean Power 2024).

SBIR funding in early-stage technologies also has a complex impact on investor confidence and highlights the importance of how government funding is used by a developer—not just that a developer was selected as a recipient. Receiving Phase 1 funding increases the likelihood of a developer for securing a patent by 30% and the chance of receiving venture capital (VC) funds by another 10%. Funding in Phase 1 is typically used for prototyping and testing, which are the primary successes private capital providers are seeking—further detailed in the following section. Phase 2, however, "has no measurable effect" on a developer's success: "the grant effects on VC and survival decline with age, previous cite-weighted patents, and sector maturity" (Howell 2017). Rather than leveraging this funding as an offramp to other capital sources, Phase 2 recipients often reapply in future years (Howell 2017).

Initial investment in a nascent technology project can help the cost of projects decline over time and increase investor confidence, as seen in the United Kingdom (Whitehead 2014). The British government created the contract for difference scheme through the Energy Act of 2013, which sets a price for electricity that generators receive per unit of power output. Generators either receive a subsidy or pay back the excess so they receive the original price regardless of electricity price changes. These contracts are auctioned to developers where the cheapest projects are chosen first. The fourth round of contracts, which opened in 2021, aimed to increase the total renewable energy capacity from 5.8 GW to 12 GW with an increased focus on marine renewables. Through this mechanism, the UK funded £31 million of funding for offshore wind, matched by £30 million from the private industry. Within a year of this policy's release in 2022, 11 new offshore wind projects were announced (Sutherland et al. 2022). Furthermore, beginning in 2021, the UK committed to allocating £20 million annually to tidal energy with the goal of beginning to lower costs, as was done for the offshore wind industry. These policies have proven effective for other technologies, dropping megawatt-hour costs for offshore wind by 65% from 2015 to 2019 (Hands and Kwarteng 2021). In the Netherlands, the government has also begun including marine energy in marine spatial planning. Interreg North Sea, an organization co-funded by the EU, recommends "de-risking projects through an insurance fund" (Interreg North Sea Region n.d.). One example showed that "public guarantees of around €48m can unlock 55 MW [megawatts] of ocean energy capacity and capital investments of circa €440m" (Interreg North Sea Region n.d.).

In the United States, onshore wind developments also provide lessons in progressive incentives to encourage long-term investments that grow over time. The Public Utility Regulatory Policies Act of 1978 (PURPA) required utilities to buy a set amount of electricity generated from renewable resources, including—but not exclusively—wind. In the 1990s, production tax credits were offered for each kilowatt-hour of electricity generated from wind to offset the cost (Congress.gov 1992). Following these policies, DOE released the National Offshore Wind Strategy in 2011, subsequently making over $100 million in staged funding available to offshore wind demonstration projects. A $12 million demonstration investment from DOE led to a grid-connected floating wind turbine being deployed a few years later (Wind Energy Technologies Office n.d.). These DOE investments were not without challenges though, providing marine energy opportunities to understand some of the social, economic, and cultural barriers the wind industry experienced in its evolution as well.

In evaluating the United States' strategy with wind, early government investment can help mitigate risk assumed by private capital providers investing in a new technology. Over time, more learning about the technology helps drive down prices and could make marine energy a more competitive renewable energy source. However, government spending is not a panacea. Policies like PURPA helped wind energy get off the ground by creating demand for domestic renewable energy, and a long-term positive demand shock is needed for private investors to be consistently successful when funding clean energy startups. Targeted public sector investments to address any remaining funding gaps in cleantech innovation, such as by providing financial support for firms with limited potential for outsized returns, can then be more impactful as a technology advances.

Supply-side economics is based on the idea that an increased supply of goods will grow the economy, whereas demand-side economics attributes growth to consumer demand. Supply-side policies tend to promote production of goods by cutting taxes, and demand-side policies generally involve government spending. Clean energy sectors are most likely to grow with a balance of both supply- and demand-side policies (Caviglia-Harris, Kahn, and Green 2003). When demand-side policies are in place, such as carbon pricing or cap-and-trade policies, clean energy becomes more profitable. Without these supporting demand-side policies, startups may continue to struggle to attract private capital, even if there are other government efforts to fill funding gaps (Surana et al. 2023).

2.3 Project Regulatory Authorization Complexities

Licensing, permitting, and review requirements are primary challenges to marine energy pilot deployments. In addition to being complex, obtaining regulatory authorizations for open-water testing is expensive because of the time and data required, the complex and challenging pilot deployment and maintenance processes, and the system requirements to validate the environmental impact. The average time to obtain construction regulatory authorization is 7.5 years[3] (National Hydropower Association 2021); this report does not evaluate all of the nuances of these processes but instead identifies some considerations for developers to reference as they navigate a path to open-water testing of their technology.

Marine energy projects that are connected to the grid must go through the FERC licensing process. The project proponent must apply for either a hydrokinetic pilot or commercial FERC license from one of the three available licensing processes. The commercial FERC license can take an average of 7.5 years to process and is issued for up to 50 years. FERC has a memorandum of understanding with three additional relevant agencies: the U.S. Army Corps of Engineers (USACE), BOEM (which has leasing authority if the proposed project is situated on the Outer Continental Shelf), and the U.S. Coast Guard. For every pilot deployment, project proponents must first engage in an initial consultation phase with FERC, USACE, BOEM (if applicable), and the Coast Guard. Federal resource agencies, including the U.S. Fish and Wildlife Service and the National Marine Fisheries Service, must be consulted for a National Environmental Policy Act (NEPA) review. These NEPA reviews can take months and, in some cases found in the marine energy industry, years to complete (Freeman et al. 2022). Additionally, the project proponent must consult with state agencies for regulatory authorizations related to submerged land leasing, Clean Water Act and National Historic Preservation Act compliance, and any other relevant regulatory authorizations unique to the state. For projects that are not grid-connected, the lead agencies are either the state and USACE regulating state waters, or BOEM and USACE for projects on the Outer Continental Shelf. Often, grid-connected projects and some non-grid-connected projects also have to permit with state agencies. Processes across these agencies may or may not be aligned, potentially causing further delays. Table 2 summarizes the potential federal, Tribal, state, and local entities that may be involved in authorizing marine energy projects.

[3] 1–8 years (Ocean Energy Systems n.d.)

Table 2. Summary of the Potential Federal, Tribal, State, and Local Entities That May Be Involved in Authorizing Marine Energy Projects

Agency	Statute	Permit or Action	Grid-Connected	Non-Grid-Connected
Federal Energy Regulatory Commission	Federal Power Act Energy Policy Act	License (pilot or commercial)	X	N/A
U.S. Army Corps of Engineers	Rivers and Harbors Act Clean Water Act	General or nationwide permit	X	X
U.S. Coast Guard	Title 33 Navigation and Navigable Waters	Private Aids to Navigation Permit	X	X
National Oceanic and Atmospheric Administration	Endangered Species Act Marine Mammal Protection Act Magnuson-Stevens Act	NEPA review	X	X
U.S. Fish and Wildlife Service	Endangered Species Act Marine Mammal Protection Act Fish and Wildlife Coordination Act Migratory Bird Treaty Act	NEPA Review	X	X
U.S. Customs and Border Control	Jones Act	Waiver if using a foreign vessel for project work	X	X
Tribal government consultation	Executive Order 13175	Federal authorizations require Tribal consultation	X	X
Sovereign Tribes' rules and regulations (on Tribal land)	See specific Tribe for additional authorizations		X	X
State agencies	National Historic Preservation Act Coastal Zone Management Act Clean Water Act Regulations pertaining to state-managed submerged lands	Authorizations and permits to obtain from state agencies; names of agencies vary by state	X	X
County permits	Varies by county		X	X
Municipal permits	Varies by municipality		X	X

Many of these delays in reviews and licensing approvals are generated by the high levels of uncertainty for new marine energy projects—uncertainty that cannot be resolved without testing devices. The Verdant Exception was created to allow developers to test small-scale (<5 MW) facilities for a short period (<18 months) to collect data and support license applications. This was born out of the Roosevelt Island Tidal Energy (RITE) Project, in which FERC decided "to exempt Verdant Power from having to obtain a license to operate its test turbines for the RITE project." (Walsh 2008) While this addresses the need for technology validation, developers cannot sell the energy generated, creating another period of nonprofitability and risking the sustainability of these businesses. Given the lengthy and uncertain time frame to get a FERC license and the inability to generate profit until the FERC license is issued, developers have been unable to fund projects to completion.

Adaptive management is a tool that is often used to help mitigate some of the risks for developers as they navigate public requirements and private expectations. Adaptive management is an approach that allows for "flexible decision-making that can be adjusted in the face of uncertainties as outcomes from management actions and other events become better understood. Careful monitoring of these outcomes both advances scientific understanding and helps adjust policies or operations as part of an iterative learning process" (Williams and Brown 2014). This approach is resource-intensive due to the need for a management team, monitoring requirements, and lengthy operational times. However, it is potentially useful "as a means for proceeding with agency permitting of wave and tidal energy projects in the face of uncertainty" (Johnson and Jansujwicz 2015).

3 Private Capital: Investment Structures and Anticipated Returns

3.1 Private Capital and Mechanisms Enabling Marine Energy Business Growth

Public funding and policy are powerful resources for early-stage developments, but access to private "financial institutions ha[s] a substantial impact on the green energy transition" (Qin et al. 2023). Private capital is needed to successfully support marine energy commercialization and encourage pilot deployments and eventual adoption of marine energy systems. Because of the nascency of the technologies along with the additional barriers to commercialization, private capital providers interested in marine energy are currently relatively limited in both number and size of investments: "Most financial actors are only strongly active in one or two high-risk technologies" (Qin et al. 2023), and many of those private capital portfolios do not yet include marine energy. Renewable energy technologies also require significantly more up-front capital than fossil fuel technologies, increasing the risk for private capital providers: 84%–93% of the cost is needed for a renewable energy project compared to 66%–69% and 24%–37% for coal and gas, respectively (Noailly and Smeets 2022).

Because of the higher financial risk and increased up-front capital required, private funders of marine energy currently include risk-tolerant investment banks, VCs focused on early-stage technologies, angels and other philanthropic organizations, corporate venture arms, and a limited number of utilities. Table 3 outlines a summary of the private capital providers, associated targets as available, and the potential applicability to marine energy. Despite their contributions, the overall availability of private capital is relatively limited (Mazzucato and Semieniuk 2018).

Table 3. Private Capital Provider Targets and Timelines for Marine Energy

Private Capital Provider	Targets	Potential Timeline Applied to Marine Energy*
Venture capital	3–5-year return timelines; 20%+	Long term
Private equity	3–5-year return timelines; 20%+	Long term
Corporate venture capital	Alignment to business goals; strategies vary	Long term
Long-term investment funds	10+ year return timelines; alignment to mission goals; strategies vary	Medium term
Market-based debt financing	Proven, sustainable revenue streams and/or collateral	Long term
Blue bonds	2–20-year return timelines	Medium to long term

*Timelines are estimated at a high level, based on current estimated LCOE for marine energy provided in DOE's Powering the Blue Economy report. Varying actions may be required for the private capital source to become more broadly available for marine energy developers, further detailed in Potential Strategies to Address Commercialization Barriers section.

Quantitative decision-making criteria for individual private capital providers is generally not public information. In the public data review, common themes emerged on the qualitative factors of interest: human and social capital, the availability and ability to protect intellectual property, innovativeness of the technology and/or business model, management structures, and the ability to create a sustainable competitive advantage (Drover et al. 2017; Karikari Appiah et al. 2022). While these are helpful to understand, they are not specific or contextualized enough to provide development targets on their own for marine energy. In parallel with the public data review, the team also collected responses from private sector representatives not yet investing in marine energy. Responses are not reflective of a comprehensive assessment of the private sector landscape, as all respondents were open to investing in a variety of early-stage technologies. They do, however, provide some comments and quantitative drivers that can help inform technology development goals.

First identified was the necessity for a developer to have a proven prototype: "Before even getting to profitability, [i]t is so important to demonstrate steady long-term performance in-water under various wave conditions and develop a strategy for dealing with storms ... a real-world demonstration is the actual evidence needed and is currently lacking." The need for a prototype was shared by all respondents, and another commented that developers "need to validate the tech[nology] in marine environments to demonstrate reliability, consistency[,] and durability" (quotes from survey responses).

Another commonality across the group is that no respondents were open to an anticipated long-term return of less than 10% or an anticipated return timeline longer than 10 years. Historically, many potential marine energy investors have been much stricter on these return timelines as well: "If there is no confidence as to what it will earn in six years' time, you can't get any money. It's as simple as that" (Whitehead 2014). An ability to meet these quantitative return targets and a viable, proven prototype are essential for crossing the technological valley of death and bridging public and private capital.

In evaluating a developer's financial viability, the levelized cost of energy (LCOE) is a commonly used metric to compare technologies. Competing on LCOE with other renewables is currently inviable for marine energy developers to be successful due to the technologies being precommercial, but it is not the only metric evaluated by private sector respondents either. One survey respondent commented "Most of these companies will need some sort of subsidized offtake agreement to get off the ground and compete from an LCOE perspective [with] solar." To reduce risk, respondents expressed strong preferences for funding commitments from other sources, either public or private, and considered these other sources as a component of their evaluation. Long-term considerations for the financial viability of the technology are critical, and a "strong assessment of both [capital expenditure] and [operating expenditure] implications of the technology beyond basic LCOE" provide a more comprehensive picture. The number of responses received for each qualitative factor is included in Figure 4.

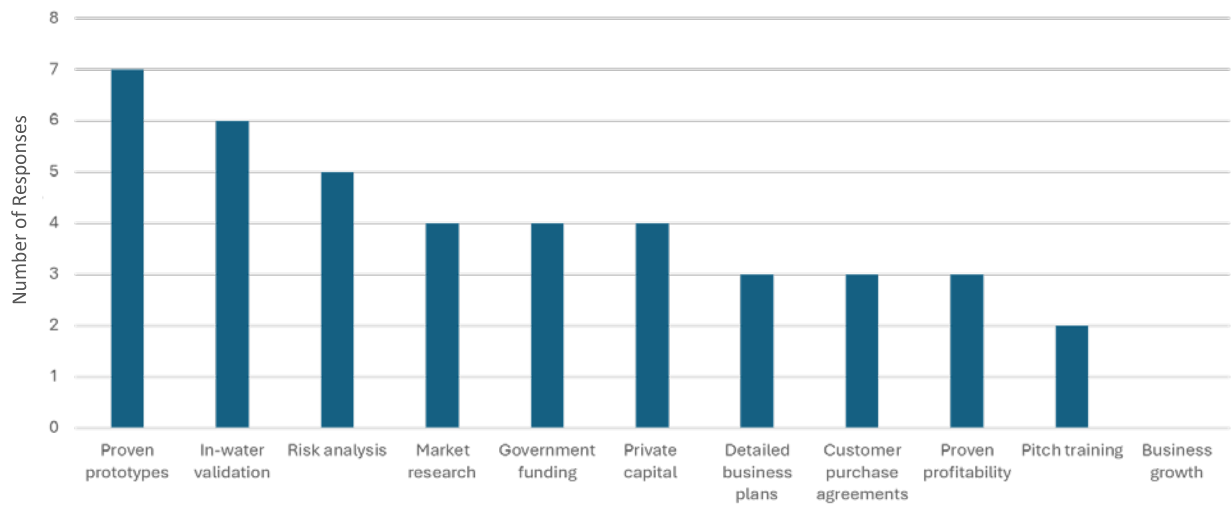

Figure 4. Questionnaire responses on the qualitative factors most likely to influence investment potential of an early-stage technology

Comprehensive risk analyses, a clear understanding of potential growth opportunities and strategy, long-term development plans, and investment return potential were all required. One respondent commented on this nuance and suggested that a "clear identification of potential customers and ... steps to reach commercial purchases is key." Also helpful in building private sector confidence is clearly defining "maintenance and service plans ... alongside full responsibilities of the startup within the value chain." Echoed among respondents as well as other private capital providers, a clear strategy for the technology's value proposition is necessary. As stated by Engel-Cox et al. (2022): "Adoption of new technology occurs only if it presents value that is unavailable elsewhere."

3.2 The Role of Intermediaries

Within the private sector, additional support mechanisms and unique capital structures provided to early-stage developers are also available from intermediaries. These entities are most often structured as incubators or accelerators and support the sustainability of early-stage technologies like marine energy. These intermediaries focus on addressing critical cost and logistics challenges for early-stage technologies through connections to marine energy networks, enabling "a shared use of resources or infrastructure to reduce costs for acquisition or R&D and production" (Qin et al. 2023). Approaches such as the "integrated technology-push and market-pull model" emphasize the necessity of these intermediaries in supporting developers across the technological valley of death with such high development costs in the early stage (Monk and In 2020).

These organizations are crucial for developers as they make a transition from being researchers to entrepreneurs. Private sector respondents expressed the need for developers to possess experience related to their technology and also a proven ability to scale that technology to a relevant industry. This expertise often requires significant capacity expansion on the business side and equivalent expertise from intermediaries to "coordinate different sources of capital and act as brokers between actors (e.g., public and private) during the innovation cycle" (Qin et al.

2023). This coordination requires intermediaries to then have significant awareness of the technology-specific support and available mechanisms on both public and private capital providers—expertise that is much more difficult to replicate—resulting in varying degrees of effectiveness in supporting developers (Monk and In 2020). These intermediaries have seen significant growth in recent years, captured in the chart in Figure 5.

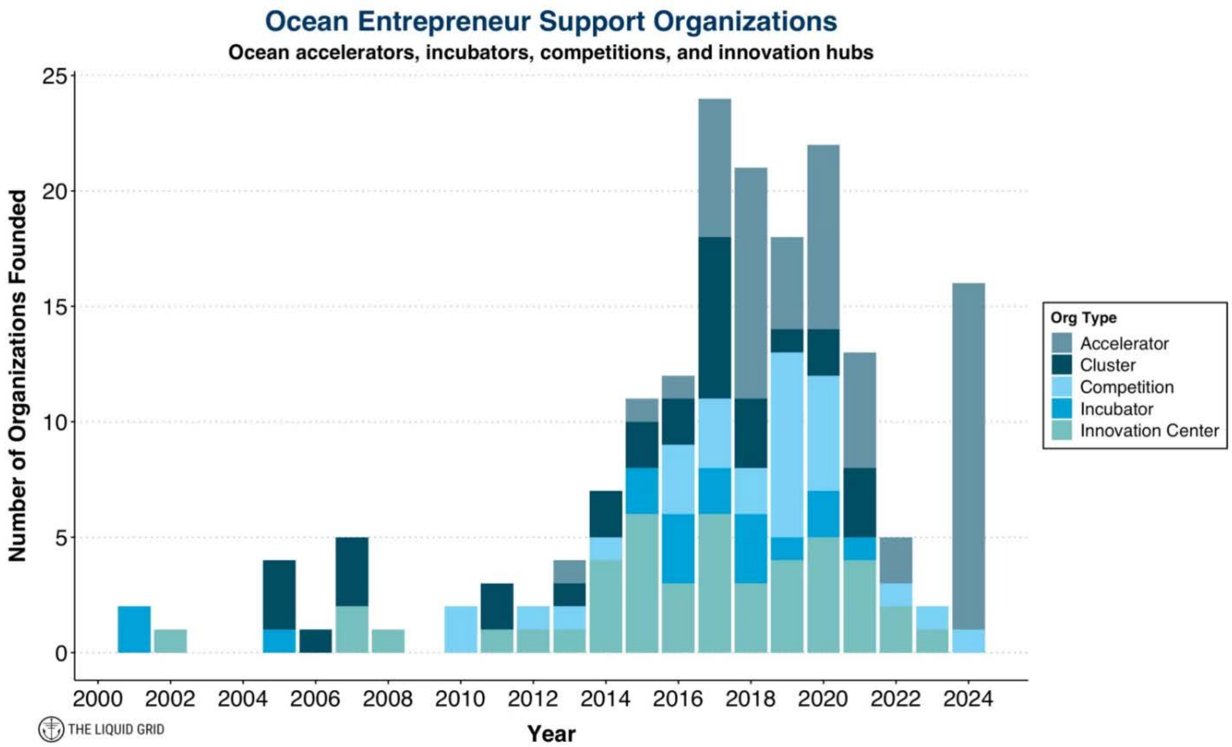

Figure 5. Ocean entrepreneur intermediary growth between 2000 and early 2024 in the United States. Specific organization information serving as the input for this chart is also available.

Source: Hume (2024)

The intermediaries that have supported marine energy developers so far are specifically structured to provide strategic support directly to developers rather than act as an unbiased third party to support evaluations. There is a clear role for financial intermediaries, which has been effectively leveraged for more mature technologies. Financial intermediaries communicate information about early-stage developers as their technology advances, publicize investor preferences, and make connections between companies and capital providers. In a report evaluating the effectiveness of these intermediaries (In, Monk, and Knox-Hayes 2020), their role is described as:

> "(1) An anchor that offers small amounts of early-stage risky capital that can, if needed, take a first-loss position"
>
> "(2) a mechanism that enables companies to raise capital, at-scale from various funding sources and provide equity and debt capital to companies maturing commercially (connecting both sides of the "barbell" of financial innovation)"

> "(3) a boundary spanner that provides reliable and objective information about clean energy companies or projects in a highly transparent and trustworthy manner and helps investors with long-term perspective mobilize their capital into clean energy ventures while also meeting their unique investment criteria."

Financial intermediaries are not currently engaged in marine energy technology development. However, as of the time of writing, WPTO is reviewing applications from a recent Notice of Funding Opportunity to support water power entrepreneurship and innovation that may fund these intermediaries (WPTO 2024b). The role intermediaries have in connecting public and private capital also highlights the disconnect between these two entities.

3.3 Venture Capital and Private Equity

Due to their high risk tolerance, VC and private equity (PE) investments have been critical for technology developers working to transition from public to private capital: "VC/PE investments have been one of the primary sources of capital available to startups that face huge technology risks" (Drover et al. 2017). Relationships between VC investors and developers are structured more closely to partnerships that support developers through challenging periods, making that relationship more attractive for developers as well. Examples of these partnerships working successfully can be found for information and communication technologies and biotechnologies—technologies that tend to have shorter development timelines than marine energy (van den Heuvel and Popp 2023). Successful developers are able to raise multiple rounds of funding from VC investors as their technology matures, represented as pre-seed and seed, and Series A, B, and so on.

The availability of this funding for clean energy has gone through a number of boom-and-bust cycles, influenced by global geopolitical events. Between 2006 and 2011, VCs invested approximately $25 billion in cleantech startups and lost more than half of those original investments. The losses incurred, largely influenced by the parallel global financial crisis, impacted investor confidence in clean energy technologies. VC and PE investors are now more inclined to "write off investments and withhold further funding from potentially successful cleantech companies," especially those that are early stage (Drover et al. 2017).

The quantitative targets of VC and PE firms are not ubiquitous and are typically proprietary, making them challenging to track and prepare marine energy developers for these expectations. There are, however, baseline models available publicly that can be used as a reference to inform the typical financial structures and return expectations implemented for other technologies. For technologies that are more mature, a shorter-term funding model available from PE firms is appropriate. PE financing is enabled by a relationship between limited partners (LPs), the partner providing much of the capital, and the general partner (GP) that creates the investible PE financial product and works directly with the technology developers. PE investors are typically looking for returns and exit opportunities within 3 to 5 years and are willing to invest $10–$15 million in a company for that period. A minimum 20% return on that initial investment is required to repay LPs, incentivizing PE firms to seek opportunities that are likely to outperform that 20% margin to increase the return for the GP (In, Monk, and Knox-Hayes 2020). This shorter-term model is often not viable for clean energy technologies because of both the time horizon and return expectations: "Most clean energy startups require hundreds of millions of dollars to build facilities, which ties up precious capital in illiquid assets" (In, Monk, and Knox-Hayes 2020). There are, however, some longer-term opportunities offered by patient VC investors that are structured more closely to partnerships. The financial support, structured as equity finance, is set on a 10-year horizon with the expectation that the VC investor would exit through a public offering or sale of that equity to another investor. This financial model is also enabled by an LP/GP partnership, and as such, GPs are again incentivized to invest in companies that can show they have the potential to provide a return greater than 20% (Gaddy et al. 2017). The anticipated return timeline aligns with private sector respondents in this report at fewer than 10 years as well.

Applying VC and PE Funding to Marine Energy

For marine energy, the cyclicality and expectations of VC and PE investments are "at odds with the time horizon and capital constraints of clean energy investments" (Drover et al. 2017). This misalignment raises questions about the model itself and its applicability to these technologies. The high risks that are inevitable for VC and PE investors mean that "many of their bets fail," but because of these inevitable losses inherent in risk-tolerant funding structures, VC and PE investors must require higher fees and shorter return timelines (van den Heuvel and Popp 2023). The receipt of public funding also generates mixed results in attracting VC investments for developers as well. Public funding is intended to support early-stage R&D, so the long-term success rate of developers receiving this funding remains small: "Public money might attract Series A investors but ... clean energy startups that receive both public and VC funding fare no better than those that receive only VC funding" (Özdurak 2021).

A related challenge for marine energy developers is their end product. In most cases, marine energy developers are generating a commodity with a set, comparable price: "The inability of many clean energy startups to earn the high margins that VCs look for can, at least partly, be explained by their lack of product differentiation" (van den Heuvel and Popp). Even with a growing demand for energy, differentiation of a product, the public sector's ability to stimulate demand for a product, or a developer's ability to communicate the value that product provides for an end user are critical. Without a change to their strategy, marine energy developers "cannot generate the needed return over the time horizon required" (In, Monk, and Knox-Hayes 2020). Many of the challenges with this model allow for it to function for much more mature technologies that are able to offer a quick return. The timelines and return expectations, however, are not yet well-suited to the development timelines, capital requirements, and risk associated with marine energy technologies.

3.4 Corporate Venture Capital and Acquisitions

As opposed to VC and PE investors who are primarily measuring quantitative returns on short timelines, corporate investors work from a range of quantitative and qualitative motivations.

The quantitative motivations are again not publicly available, but corporate investors are most active in later investment stages when developers begin to scale businesses (e.g., series A, series B, or growth equity) and technologies are closer to market deployment (Surana et al. 2023).

Qualitative motivations may make these investments more accessible, as a number of factors influence corporate investment decisions in a technology. For example, corporations may be driven to invest in early-stage technologies as a factor of expanding existing business models, gaining innovation insights in new areas, undercutting competition through acquisition, pivoting to climate-friendly applications of core expertise, demonstrating climate leadership, and meeting increasing environmental, social, and governance commitments (Surana et al. 2023). In addition to capital, corporations can also provide in-kind advantages to developers through their existing network of resources, such as internal research and design services, access to global markets and supply chains, and manufacturing facilities (Surana et al. 2023).

Because of the growing alignment between clean energy technologies and corporate priorities, corporate investors are emerging as a major financier of new technologies. A small number of corporations are currently operating at scales similar to large public agencies in their volume of investments targeted to clean energy technologies, but that number continues to grow. In 2021, corporations represented 25% of all public and private investment dollars (Surana et al. 2023). Despite historical underinvestment by corporate investors, clean energy technologies have become a huge area of interest—$2.6 trillion of corporate external-facing investments between 2010 to 2019 were in renewable energy (Kolte et al. 2023).

Corporate investment in broad energy technologies spans multiple sectors, ranging from fossil fuel companies to utilities to digital service companies (consumers of power, “big tech”) to transportation, in order of most to least investments (Surana et al. 2023). Interest in certain clean energy technologies also differs by sector. While fossil fuel and utility corporations have shown a particular interest in wind, smart grids, and hydrogen, digital companies have made the most investment deals in geothermal, transportation, and energy efficiency, along with transportation firms focusing on hydrogen, energy storage, and electric vehicles (Surana et al. 2023). As of 2021, hydropower and marine energy combined have seen about 15% of investment deals through corporations across fossil fuel, utility, food, and manufacturing sectors.

Despite the growing opportunity space, there remains a lack of unbiased financial information and data about technology performance for early-stage research for corporate investors to evaluate—a challenge mirrored for long-term investors (In, Monk, and Knox-Hayes 2020). While there is opportunity to reach corporate investors earlier on when a technology supports an organizational priority, corporate investors will still tend to favor modular and scalable technologies with well-defined customers and clearly available data, similar to VC and PE (Surana et al. 2023).

3.5 Long-Term Investment Funds

Long-term investors (LTIs), or the LPs that provide capital better aligned to the development timelines and return expectations associated with marine energy, are available. These investors include a number of funding structures: pension funds, sovereign wealth funds, family offices, philanthropic organizations, and foundations. LTIs have also “pledged to identify promising start-ups and technologies in which to invest multiple billions of dollars of ‘patient’ capital that will not require returns for a decade or more” (Gaddy et al. 2017). The accessibility of this funding, however, remains limited. Due to significant information gaps, LTIs may struggle to identify promising early-stage technologies, and developers frequently lack awareness of these investors. Bridging this gap is often the role of the GP in the LP/GP partnership, but "most of the support for asset management is in short-term returns" (Drover et al. 2017). This gap underscores the need for novel approaches to leverage long-term investments more effectively, and "LTIs must lead this innovation" (Drover et al. 2017).

Quantitative LTI targets are also proprietary, as with VC and PE investors, and are often layered within the LP/GP partnership structure. At a high level, they have a much longer-term view, reducing the return expectation and time horizon limitations for developers, making LTIs "more comfortable integrating long-term risks in investment decision-making, such as those posed by climate change … As a result, they tend to be better suited to scale up innovation and realize appropriate returns over the required timeframe" (Drover et al. 2017). This longer-term approach contrasts the short-term return expectations of VC and PE investors and provides a different perspective on performance goals more closely aligned with their organizational missions and realistic development timelines for marine energy (Özdurak 2021). Working with LTIs may enable more sustainable capital sources and more impactful partnerships.

While the quantitative targets are more achievable for marine energy developers, the qualitative requirements vary significantly with organizational priorities, as with corporate investors, highlighting a different set of challenges and opportunities. Foundations and philanthropic organizations seek technologies and projects that deliver tangible benefits aligned with their missions. An LTI mission could include making a measurable impact in a sustainable development goal, supporting the development of replicable or scalable solutions, public recognition, or measurable community benefits, as examples. An understanding of the unique priorities of an individual foundation or philanthropic organization is a critical metric for an LTI, as are clearly communicating how a technology development project ties into that mission, what the funding supports, and how it is meaningful to the life of the project (Li and Okur 2023).

As an example from the National Community Solar Partnership, a number of philanthropic organizations provided follow-on financial support for awardees because of the impact community solar had in "reduc[ing] energy bills for low-income households, creat[ing] jobs in disadvantaged communities, and shut[ting] down a polluting power plant" (Li and Okur 2023). This project serves as just one example of how developers were able to align project goals with a broader organizational mission and identify and measure specific metrics that were of value to these organizations. While qualitative targets vary by organization, marine energy developers have an opportunity to align with the unique priorities of a foundation or philanthropic organization to propose how their technology could support the end use that organization is working to support. Projects that clearly define who will benefit, how they will benefit, and how those benefits align to a mission are more likely to secure support from LTIs rather than technology advancement goals alone—even with long-term return timelines (Li and Okur 2023).

3.6 Debt Financing

While private capital investments in clean energy have predominantly focused on equity financing, it is also critical to consider the role of debt. Long-term financial planning must include both equity and debt for more mature technologies, so debt will eventually have a role in shaping the development of marine energy. Debt financing offers a different approach with its own set of benefits and challenges and an altered risk profile for both the private capital provider and the developer. In this structure, developers borrow a loan from a lender to be repaid to pay for the implementation of their clean energy projects.

As a technology matures and supporting policies are developed, the cost of debt financing is shown to decrease. As a reference, the cost of capital including both debt and equity for utility-scale solar and land-based wind is between 3%–6% and 4%–7%, respectively (International Energy Agency 2021). The lack of financial incentives, though, and the associated technology risk for marine energy still keeps these costs high—market-based lenders typically require terms that are difficult for early-stage companies to meet, including an adequate debt-to-equity ratio and acceptable debt service coverage ratio.

Globally, regional trends emerge in the use of debt financing to support technology developers: "The share of debt spending is particularly low in the Middle East and Eurasia, at 38%, mainly due to the higher share of equity financing and a greater share of fossil fuels in the energy mix. In China, Japan, Korea and other Asian countries, the share of debt is higher, at around 50%." For comparison, in Europe, the share of debt financing is at approximately 43% (Tam et al. 2024). Debt financing is more common for technologies with lower risks and predictable long-term revenues. This again suggests that debt financing will not be a major driver for investment in marine energy in the near future (Tam et al. 2024).

There are debt financing models that exist for early-stage technology developers in the United States that aim to help fill financing gaps without significantly increasing the cost of capital. Lengthy contracting periods are mentioned as a major challenge that developers experience when working to receive public funding and have resulted in the failure of a number of technologies (Brooks et al. 2022). To fill this gap, the Los Angeles Cleantech Incubator (LACI) has developed a debt financing structure designed to address delayed negotiation cycles in public funding opportunities. LACI's model provides loans to early-stage clean energy developers, with a special focus on those managed by underrepresented founders. Models like this are not common, especially for debt financing that is typically much more expensive. DOE does offer debt financing for developers through the Loan Programs Office, but these loans are specifically designed to support commercial deployment of large-scale energy projects, primarily available for technologies that are more mature than marine energy.

At present, the cost of debt financing is much too high for early-stage technologies to address long-term risks and development timelines that are still needed for companies to navigate the needed R&D. External debt financing is more expensive than equity due to the need for collateral and lack of shared benefits in company value at the end of the loan (Michelfelder et al. 2022). Since the funds needed are directed to R&D, which is primarily composed of labor costs, there is limited collateral that banks would be seeking in exchange for debt financing (Noailly and Smeets 2021).

3.7 Tailored Bond Programs

While traditional market-based debt financing is currently too expensive for marine energy developers, the bond market offers a unique perspective on how debt financing may be leveraged for early-stage technologies. Conventional bonds are structured as fixed-income debt products with very low risk for the investor and enable much longer-term return timelines. Tailored bond programs aligned with a mission have also begun to evolve, beginning with green bonds, “first launched in 2007 by the European Investment Bank (EIB) to finance green projects” (Arfaoui et al. 2023). Green bonds were created specifically to support clean energy technologies and can provide both investment opportunities with reduced risk for private investors, as well as more flexible capital to developers.

The risk mitigation offered by green bonds is critical, with a diverse portfolio of both early-stage and more mature clean energy technologies. The green bond structure has been shown to provide “diversification benefits against stock and energy markets,” and offer numerous other benefits as “dynamic hedges against dirty energy assets” (Arfaoui et al. 2023). During the COVID-19 pandemic, green bonds were “found to be the only asset that serve[d] as a safe haven against large stock market fluctuations” (Yousaf, Suleman, and Demirer 2022). The broad portfolio included in these structures enables a “risk mitigation capacity [to be] maintained during times of market stress” (Kuang 2021). Green bonds are relatively common in the market now as well: One report suggests that at the end of 2023, the lifetime value of all issued green bonds was $2.5 trillion (Climate Bonds Initiative 2023).

The effectiveness of green bonds can be limited by the enabling policy environment. Green bonds have been shown to improve environmental performance and generate a positive stock market response, but only when the bonds were certified by independent third parties. They have also been shown to help corporations pay for carbon reductions when those reductions are incentivized by relevant policies. Without these enabling supportive policy structures, though, green bond financing “does not lead to measurable benefits for the environment,” limiting their growth potential and ultimately their availability for early-stage developers (Flammer 2020).

Blue bonds are very similar to green bonds in their structure but are specifically focused on supporting technologies both for and in the ocean. The market supporting the development of blue bonds and the impact they can have on ocean-focused technologies is much earlier as well: blue bonds are “where green bonds were 15 years ago” (Audino 2023). As of 2023, $500 million in blue bonds have been issued (Murdoch 2023). The World Bank defines blue bonds as a “debt instrument issued by governments, development banks or others to raise capital from impact investors to finance marine and ocean-based projects that have positive environmental, economic and climate benefits” (World Bank Group 2018). The median size of blue bonds issued globally between 2018 and 2022 was $123 million, with maturities ranging from 2 to 20 years.

An issue with blue bonds is that the scope, while focused on the ocean, is still broad and blue bonds may be used for “the entire scope of the blue economy,” including for deep-sea mining and fossil fuel extraction (Thompson 2022). Additionally, the language referencing how bonds are repaid is often vague, and early blue bonds have had financial institutions as guarantors. This, combined with the nascency of blue bonds and a lack of understanding of how they produce returns, may negatively impact their long-term viability as a funding mechanism. Financial stability fluctuates frequently, but tools such as tailored bond programs can provide a unique supplementary mechanism to encourage investment in early-stage technologies despite economic ebbs and flows (Yousaf, Suleman, and Demirer 2022).

4 Potential Strategies To Address Commercialization Barriers

This report outlines a number of challenges that marine energy developers face: lengthy development timelines and risks, “high costs, lengthy permitting and licensing processes, and barriers to testing” (WPTO 2022b). These all contribute to a high dependence on public funding for these early-stage technologies before a transition to private capital can be possible (Clemente, Rosa-Santos, and Taveira-Pinto 2021).

Through this analysis of available public funding and support and private capital, the following strategies may better enable technology developers to leverage both public funding and private capital. While the strategies outlined will not guarantee the success of a single developer or necessarily resolve the technical challenges developers are still working through in their effort to commercialize their technologies, the intent is to highlight existing support mechanisms and identify opportunities to inform future strategies for commercializing marine energy technologies.

4.1 Relationships and Partnerships

4.1.1 Leverage Existing Technology Transfer Programs

Mature renewable energy technologies have provided examples of leveraging technology transfer mechanisms that marine energy developers may be able to emulate. As an example for innovative solar technologies, Antora Energy and 7AC Technologies both leveraged patent licensing opportunities for solar, received technology development support provided by a variety of programs to mitigate perceived risk about their technology, and successfully raised both grant and seed funding prior to their acquisition by a larger company (Wolf 2024). The successes these companies experienced are examples of identifying existing technology transfer mechanisms that could be more effectively leveraged for marine energy.

A critical first step is the need for a more robust and navigable patent library. National laboratories and academic research institutions, primary sources of available patents (Figure 6), typically offer free licensing agreements for developers interested in further advancing a technology, but these resources are often fragmented and incomplete. A dedicated effort is required to further develop the available patent libraries within national laboratories and academic research institutions and clearly communicate these opportunities for developers both in terms of an easily accessible platform and the variety of available agreements. A number of technology transfer agreements that enable developers to leverage these technologies exist and are commonly used for developers to gain access to this intellectual property, including Cooperative Research and Development Agreements, Strategic Partnership Project agreements, and the Agreement for Commercializing Technology—each with their own structure and complexity to support the needs of developers. Improving the availability of patents during the early stages of technology development and offering guidance for how developers can leverage this intellectual property and build a business around it may also “incentivize partnerships between large corporations, startups, and incubators, and offer favorable technology transfer terms from the national laboratories” (Gaddy et al. 2017). This approach could potentially serve as a further pathway for the transition of marine energy technologies from the laboratory and into the marine energy industry.

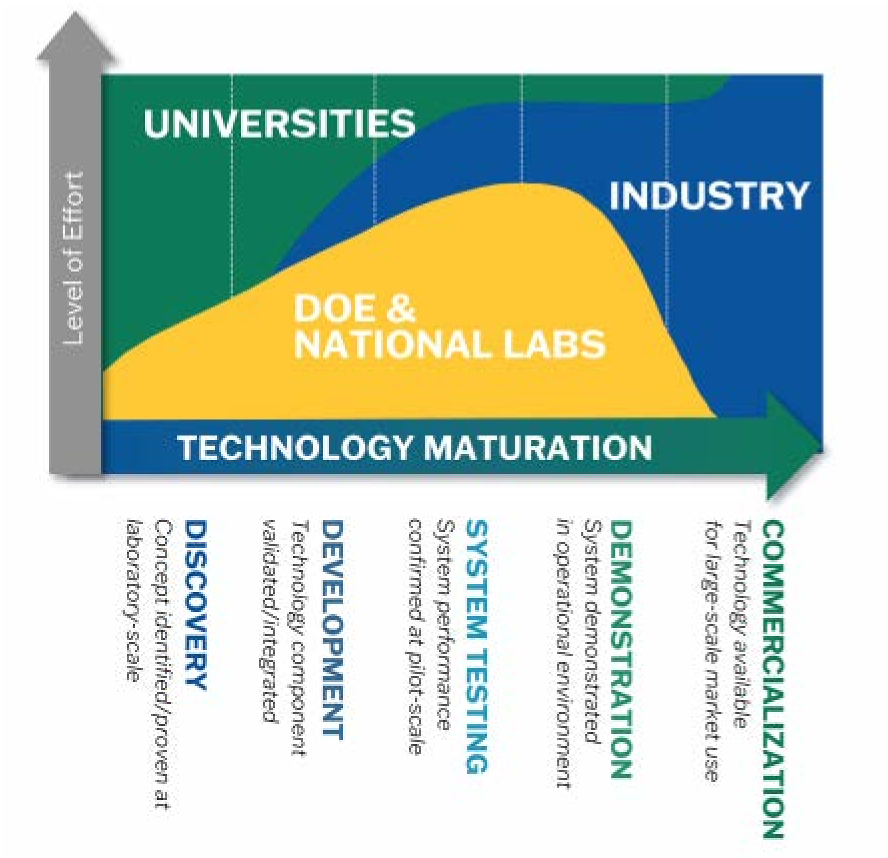

Figure 6. Organizational types typically responsible for each stage of the technology development life cycle.

Source: DOE (2020)

The Laboratory Embedded Entrepreneurship Program, funded by DOE's crosscutting Advanced Materials and Manufacturing Technologies Office (n.d.) supported developers Antora and 7AC as well as developers in other technology areas. There are additional opportunities to support technology-specific work and connect marine energy developers with national laboratory researchers and facilities (DOE 2024). Programs provided under the Laboratory Embedded Entrepreneurship Program "support entrepreneurship at the national laboratories by building on the success of the Cyclotron Road program" (Berkely Lab n.d.; Gaddy et al. 2017), managed by Lawrence Berkeley National Laboratory, and West Gate (NREL n.d.), managed by NREL. These programs situate developers alongside national laboratory researchers and enable DOE's goals to integrate the "importance of entrepreneurship and entrepreneurial thinking to DOE mission accomplishment" with resources and individuals supported by DOE funding (DOE 2024).

Developers also express issues with limited capacity, given the challenges in navigating the funding environment (Brooks et al. 2022). A number of capacity support models exist already but are largely offered from a technology-agnostic perspective. DOE offers the Clean Energy

Innovator Fellowship (Office of Energy Efficiency and Renewable Energy n.d.) to supplement governmental capacity, and nonprofit organizations provide community-based programs like the Island Institute Fellows (Island Institute n.d.) to better support capacity at the local level. This model could be leveraged to fill in some of these identified gaps for developers, leveraging the infrastructure of organizations such as Activate (Activate n.d.). This program is designed to enable business sustainability and cover funding shortages and capacity limitations aligned with technology-specific priorities.

4.1.2 Inter- and Intra-Agency Coordination

Because offices and agencies typically focus on achieving their own goals, some opportunities to partner within and across agencies may not be leveraged. Publicly available data suggest that historically, aside from WPTO's investments, state-level marine energy interest has been significantly greater than any other source of capital. A better understanding of these state-level priorities and how marine energy could support state goals could help reveal how and why funding for marine energy at the state level has decreased. This additional engagement with state energy offices and state investment banks may help identify an alignment of technology priorities. Reopening these conversations and, as possible, partnering with these entities could be opportunities for an offramp for marine energy developers aligned with both state-level and WPTO priorities (Mazzucato and Semieniuk 2018).

Agency and DOE office missions are structured around specific technology goals, but that is disconnected from how private capital providers evaluate potential investments: through a market opportunity and sector-based lens. A number of agencies and other offices within DOE support the development of a range of complementary technologies that could benefit the advancement of multiple agency and office goals. A reconsideration of how complementary and supportive technologies that may already be under development in another agency or office and how each side could benefit from potential inter- and intra-agency partnerships could provide new opportunities for advancements more closely aligned to private capital providers. Developments in artificial intelligence, communications technologies, sensors, and the reliability of any complementary technologies in the challenging ocean environment, are all potential areas that would be of interest to other agencies and offices.

Additionally, offices across DOE are authorized with a unique technology development mission at different stages of commercialization. Specific office priorities and their applicability to marine energy are noted in "Public Funders and Mechanisms Supporting Marine Energy." There are no restrictions preventing intra-agency collaboration, but there also are not yet any pipelines between WPTO—focused on early-stage R&D, testing, and demonstration—and the offices that support larger-scale demonstration, deployment, and commercialization activities that are intended to address the gap between early-stage research and engagement with private capital providers. Marine energy companies must compete for funding from these later-stage programs alongside applicants with more mature, established technologies, similar to a developer's experience in competing for private capital. Additional collaboration and the establishment of an early-stage research pipeline could help address these challenges and keep these businesses more sustainable as they seek other offramps for further funding.

The lengthy and expensive authorization timelines for marine energy developers remain a challenge, resulting in delayed proof-of-concept prototypes that are crucial to improving investor confidence. These marine energy deployment delays create risks not only for the cost and timeline of authorization cycles, but also in the viability of the projects after their pilot deployment. Adaptive management has the potential to reduce these timelines and better enable quicker early-stage deployments to validate technologies: "To elevate the [marine energy] industry to commercialization, it is vital that scaling from a single device to an array is conducted using adaptive management frameworks" (Barr et al. 2021). Further exploration on the structure of a cost-effective adaptive management process for marine energy, the potential required collaborations among multiple agencies on a state and federal level, and how this expedited approval process may influence investor confidence would all be valuable. Implementing a new adaptive management framework, though, could be an opportunity to further derisk marine energy technologies for private capital providers.

4.1.3 Public-Private Partnerships

Financial institutions are bolstered by governmental policies, and it is critical that public and private actors work together: "Government assistance has considerably aided investor confidence, including carbon pricing systems, tax incentives, and subsidies for renewable energy sources" (Li 2023). Public support influences private capital interest by providing "regulatory stability [and] technological developments" (Li 2023). This stability acts as a major driver of clean energy transitions and increased investment in clean energy technologies (Qin et al. 2023). The mutual benefit of technology advancement for public and private actors highlights the opportunity for more formalized public-private partnerships.

Further work is needed to determine appropriate partners, but the identification of private capital providers that are interested in the early stages of marine energy technology development can continue to inform the gaps between public funding and private capital. A formalized relationship focused on information could create better compatibility between the anticipated returns and developments timelines required for R&D and eventually product development (Engel-Cox et al. 2022). These relationships can also be strengthened by leveraging research and existing technology transfer mechanisms: "A venture fund or partnerships with existing funds, which have patient capital, should be established to invest in commercializing technology derived from research" (DOE 2024).

4.2 Funding and Direct Support

4.2.1 Evaluate SBIR Impacts To Maximize Effectiveness

According to a study performed by Howell (2017), "grants are a significant funding source for high-tech entrepreneurs [and] the largest single provider in the United States is the SBIR grant program." Through this research evaluating the effectiveness of the program overall, SBIR proved to "enable new technologies to go forward, [and] transform some awardees into privately profitable investment opportunities" (Howell 2017). This research included 7,436 small companies representing over $884 million in awards between 1983 and 2013. Projects included in this analysis were exclusive to companies supported by offices in DOE, representing both early-stage and mature technologies.

In evaluating these data, Howell identified a repeated trend that Phase 1 was particularly effective for nascent technologies in building awareness of technology development cycles and expertise in the base of entrepreneurs working on these technology areas. Receiving Phase 1 funding increases the likelihood of a developer for securing a patent by 30% and the chance of receiving VC funds by another 10%. In the research performed on Phase 2, however, SBIR was shown to have "no measurable effect" on a developer's success: "the grant effects on VC and survival decline with age, previous cite-weighted patents, and sector maturity" (Howell 2017). Rather than leveraging this funding as an offramp to other capital sources, Phase 2 recipients must often reapply in future years. Trends in repeated use of the mechanism potentially reduce investor confidence in a technology and limit the transitional impact of the program—in a report evaluating the perception of SBIR recipients, PwC noted that "a business model predicated on getting money from the government is not a business model" (2023).

As Howell's research was done with a sample of SBIR awards across the agency, it is not clear whether these trends are mirrored for marine energy developers. Because of the potential varied impact of these awards between phases 1 and 2 that Howell's research identified, an evaluation of the applicability of this trend to marine energy awardees could be helpful and allow WPTO to identify the most appropriate stages at which additional support from the office could be the most impactful in supporting the intended transitional nature of the program.

4.2.2 Unique Funding Mechanisms

While marine energy's nascency may make some unique funding mechanisms an approach to be employed further in the future, two de-risking mechanisms identified in this report are potentially promising with further evaluation. Modeling a contract for difference scheme similar to that employed in the United Kingdom could allow for consistent revenue for marine energy, following grid interconnection. The contract for difference scheme "gives greater certainty and stability of revenues to electricity generators by reducing their exposure to volatile wholesale prices, whilst protecting consumers from paying for higher support costs when electricity prices are high" (Gov.uk 2017). Balancing high generation costs will be crucial for marine energy: In 2019, DOE "forecasted LCOE for the first commercial-scale project was in the range of $120–470/MWh [megawatt-hour] for wave energy and $130–$280/MWh for tidal energy" (WPTO 2019). Implementing a contract for difference would require a partnership with another federal program, perhaps OCED, and energy producers to set a strike price, where OCED and the generator would exchange funds depending on whether the actual energy cost is greater or less than the strike price. Guaranteeing a revenue stream for electricity generators could help de-risk investor returns. Additionally, though not yet implemented, a marine energy insurance fund such as the model offered in the European Union could provide another approach to de-risking investments. Further study on the effectiveness of this model in the European Union and examples in the United States on similar insurance models that are publicly funded are needed to understand the viability of this approach as an option.

Marine spatial plans are tools "to manage the use of our seas and oceans coherently and to ensure that human activities take place in an efficient, safe and sustainable way" (European Commission n.d.). These tools have the potential to incentivize further marine energy pilot test deployments and have already been implemented by the European Union as well. The United States does not have federal-level marine spatial planning legislation, but it is not unheard of in the United

States. Washington has a Marine Spatial Plan that was adopted in 2018 and applies to new ocean energy projects, providing economic, administrative, and ecological benefits, including “greater certainty for long-term investment decision[s]” (Ehler 2008). Still, greater study on the impact of marine spatial planning in the United States and an exploration on how DOE can participate in the development or adoption of such plans is needed.

Blue bonds are a potentially useful, comparatively inexpensive funding mechanism that can lead to increased attention on oceanic challenges, including energy generation (e.g., offshore wind and marine energy). They are not yet common, though—as of 2022, only nine blue bonds were issued for renewable energy projects globally. Presently, the lack of a clear definition for what blue bonds can be used for and ambiguity caused by private actors self-regulating blue bonds creates barriers to their more widespread use. Standardizing blue bonds can allow more funding vessels to enter the investment space, while also helping to avoid the pitfalls of bluewashing and legitimizing blue bonds as a whole. Additionally, impacts of blue bonds should be reported through clear and standard metrics (e.g., megawatts of capacity installed). Investors may be more attracted to investing in blue bonds with clearly defined benchmarks and third-party certifications.

Blue bonds are particularly attractive for marine energy because of the length of time for the bond to reach maturity. While on average this is nearly 9 years, one Belizean bond has a maturity of 20 years. In the United States, long regulatory windows and the need for testing and validation for marine energy lend themselves well to this framework. Currently, international banks, corporations, governments, and environmental organizations have issued blue bonds. This includes collaborative approaches, such as The Nature Conservancy partnering with the Inter-American Development Bank to issue a $150 million bond to issue a bond through Barbados, in which The Nature Conservancy raised investor capital for funding the blue bond (KPMG 2023). Given the similarities between blue and green bonds, it may be most useful to align the bond with International Capital Markets Association standards and to follow similar procedures as with blue bonds (United Nations Global Compact n.d.). In the United States, states and local governments have issued green bonds in the past, and it may be a fruitful endeavor to further research how DOE could support future creation and funding of blue bonds (U.S. Environmental Protection Agency 2024).

Finally, debt financing models that could be applied to early-stage technologies may be worth exploring as well. The LACI debt financing structure to fill in funding gaps that are created by delayed negotiation cycles could provide a mutually beneficial partnership to enable business sustainability and address funding delays experienced by developers. Further discussions with LACI or another organization offering a similar debt financing mechanism are warranted to evaluate the alignment of early-stage marine energy technologies with debt fund priorities to determine if this could serve as a viable pathway for developers (LACI n.d.).

4.2.3 Breadth and Depth of Intermediary Support

Throughout much of the literature, intermediaries that support early-stage clean energy technology developers are repeatedly mentioned as a critical support mechanism. The transitional support offered can be made more successful by focusing support on advancing the capacity and expertise of high-quality intermediaries that are structured to respond to the niche requirements of marine energy development and respond flexibly to the tailored needs of individuals. This approach would enable a network that can be applied in a modular and targeted way.

The background information collected for this and similar reports can strategically inform those efforts as well. Clearly communicating industry commercialization targets and providing a roadmap of the funding landscape would also help intermediaries align with, track progress toward, and meet quantitative targets informed by private capital providers (In, Monk, and Knox-Hayes 2020). Efforts undertaken to better understand the commonalities around developer gaps in their commercialization strategy requirements would help direct this effort as well. In addition to navigating the complex and unique challenges of marine energy commercialization, some specific needs identified that intermediaries could support include strategic guidance in business formation and management structure around a business model instead of just R&D (Monk and In 2020) and building and testing prototypes to validate technology and improve investor confidence (Howell 2017; Qin et al. 2023). These intermediaries are likely the organizations that are structured flexibly to respond to tailored needs in a modular support ecosystem.

The financial intermediary model that has been employed for other renewable energy technologies is not yet a focus of intermediary support. The role of a financial intermediary is to provide unbiased information on early-stage technologies that could help to bridge knowledge gaps identified between LTIs and marine energy developers. For other early-stage technologies, financial intermediaries have tracked progress and information about all companies developing a particular technology or competing in a sector, publicize investor preferences to clarify pathways to reaching private capital, and make connections between developers and those capital providers (Drover et al. 2017). Further evaluation of this structure and the appropriate mechanism for supporting these types of intermediaries would be needed to implement this approach.

4.3 Language and Outreach

4.3.1 Public-Facing Materials

A distinctive difference in the literature describing public funding as compared to the materials describing private capital highlight the differences in language used—and needed—at these different stages of development. The language used in government funding opportunities, the outreach approaches used to incentivize applicants, and the long list of acronyms employed create barriers for new applicants to become part of the public funding ecosystem. Successes and advancements are also represented in the context of technology-specific developments and how those developments meet agency technology and externality goals.

These successes are not problematic on their own, but do not clearly connect to what private capital providers are looking for: quantifiable returns, the role of marine energy in balancing a risk portfolio through diversification, or how some funding gaps may be resolved with policies that already exist (Reboredo and Ugolini 2018). This disconnect is also present in the reverse: "Efforts by incumbents in the energy sector to invest in renewable technologies ... tend to be perceived as attempts to greenwash rather than substantive efforts to find alternative energy sources to replace or complement their core activities" (Kanger 2021), disincentivizing public-private partnerships. This disconnect becomes a challenge for developers to navigate, and feeds into the ecosystem fragmentation between public and private capital for marine energy developers (Kanger 2021).

These communication challenges can be addressed in the near term. Rather than leaving developers to navigate the funding ecosystem individually, a roadmap of public and private opportunities and priorities could be developed to better support developers in understanding when and how to leverage each of these mechanisms (Willis et al. 2023). An intentional effort by developers to tie their technology to a consumer-focused sector and a probable end user for each opportunity would help developers communicate that value proposition to private capital providers in parallel with the technology advancements that help meet agency goals (Noailly and Smeets 2021). An outreach and engagement strategy can also be developed to better communicate marine energy's risk level and its role in diversifying investment portfolios to increase awareness in parallel with other early-stage technologies communicating what is of value to private capital providers (Ellwood, Williams, and Egan 2020).

4.3.2 Resetting Funding Expectations

Public funding opportunities may require developers to include a commercialization strategy as a part of those applications. Because there were no previously published metrics to define commercialization and what success means within the WPTO portfolio, and because marine energy is early-stage, standard metrics were not previously identified to assess the effectiveness of these strategies. To resolve this misalignment, clearly setting expectations for transitioning to private funding within the commercialization strategy requirement of public funding opportunities would help developers create clearer, more realistic strategies that can communicate success. This would help developers set and meet realistic, meaningful targets that will both support WPTO's R&D goals and bring developers closer to long-term private capital expectation targets.

Adjusting these expectations within the commercialization strategy requirement also creates an opportunity for tracking commonalities in developer needs and creating a modular support ecosystem that fills those identified gaps. Applications to funding opportunities with the commercialization strategy requirement and requests for technical support through the TEAMER program could provide indicators for the type of support that would be most beneficial. The modularity of this support is critical, as there may be opportunities for group trainings to fill in long-term support needs, but developers have also expressed challenges in finding support that is specific to their work and technologies (Willis et al. 2023). Developing associated trainings and offering individualized support in meeting both near-term and long-term goals could also benefit developers.

5 Conclusion

WPTO has played a critical role in advancing early-stage marine energy, but the path to commercial technologies and transitioning developers from public funding to private capital has not always been clear. This report highlights key opportunities that could enhance the commercialization of marine energy sector-wide, but these potential improvements are not all actions WPTO could take and would require active collaboration with other public and private sector partners. Initially, establishing a standard metric for measuring progress toward commercialization that is informed by public technology development goals, developer challenges, and private capital requirements is critical. These considerations could help expedite commercialization as they offer informed targets designed to keep marine energy developers, and eventually businesses, sustainable.

Marine energy developers have struggled to connect public funding with sustainable private capital because of extended development timelines, high early-stage R&D costs, complex permitting processes, and strong competition from other energy sources. The current public funding landscape is led by WPTO, with a number of other funding sources, including other federal agencies, state governments, and international bodies, providing opportunities for marine energy developers. Despite this support, marine energy developers face substantial barriers, notably in licensing and permitting, which can delay progress and increase costs. Historical and international examples underscore the importance of sustained government investment and innovative policy frameworks to overcome these challenges.

To address the identified barriers and enhance commercialization efforts, several strategies are identified. First, improving communication and outreach strategies would be valuable. The current language and presentation of public funding opportunities often do not align with the expectations of private capital providers. Connecting the language both in reference to the successes of technology advancements and in the requirements of new funding opportunities offered by WPTO may make it easier for developers to navigate the funding ecosystem and effectively convey the value of their technologies to potential investors. Recalibrating funding expectations and commercialization strategies within public funding mechanisms may enable developers to set realistic, measurable targets as well. This adjustment will help align public funding efforts with the needs of private investors and facilitate a smoother transition from government support to private capital.

Leveraging existing technology transfer programs and enhancing patent libraries can offer significant support to marine energy developers. By improving access to technology transfer mechanisms and fostering partnerships with established programs, marine energy developers can benefit from proven strategies employed by other renewable energy technologies. Exploring and implementing innovative funding mechanisms, such as contracts for difference, marine energy insurance funds, and blue bonds, could provide new avenues for de-risking investments and stabilizing revenue streams. These mechanisms, alongside efforts to streamline permitting processes through adaptive management frameworks, could enhance investor confidence and accelerate the commercialization of marine energy technologies. Strengthening relationships between public and private actors and supporting intermediary organizations will be crucial. Building formalized partnerships and improving the capacity of intermediaries to address the specific needs of marine energy developers will provide valuable support and guidance throughout the commercialization process.

This report provides an analysis of the challenges facing marine energy technology developers and offers actionable strategies that may help to bridge the gap between public funding and private capital. While the strategies presented do not guarantee the success of individual technologies, they can help to create a more supportive and cohesive ecosystem for marine energy development. By implementing these strategies, WPTO and marine energy developers can better align efforts and resources, ultimately facilitating a more successful transition from public funding to sustainable private investment, accelerate pathways to commercialization, and contribute to a more sustainable energy future.

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