



Floating Offshore Wind



CREO | September 2024

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Table of Contents

1	Introduction	1
1.1	The Landscape of Floating Offshore Wind.....	1
1.1.1	The Ecosystem	1
1.1.2	The Pipeline.....	2
1.1.3	The Value Chain	3
1.2	Lessons From Similar Industries in FOW Innovation.....	4
2	Pathways to Commercialization	6
3	Conclusion.....	9
4	Appendix.....	10
4.1	Key Policy Unlocks	10
	References.....	11

List of Figures

Figure 1: FOW Incumbent Industry Categorized by Function	2
Figure 2: FOW Operational and In-Progress Pipeline Map	3
Figure 3: FOW Value Chain	6
Figure 4: FOW Market Map	7

1 Introduction

The offshore wind resource is massive, 71 TW per the World Bank.¹ According to the International Energy Agency (IEA), the global offshore wind resource is 18x the world's current electricity demand and, of this, 80% is floating and 20% is fixed.² In areas with clean energy targets, the onshore wind resource is generally being harvested and the fixed offshore is rapidly approaching saturation as well, leaving floating offshore the only remaining renewable resource to tap in many geographies.

Currently, offshore wind farms predominantly use fixed-bottom turbines anchored to the seabed, utilizing conventional materials adopted from onshore wind and oil and gas (O&G) industries, generally suitable for water depths of up to 50 meters. Floating offshore wind (FOW) features turbines affixed to a floating base up to 1,000 meters or more above the seabed, anchored by extended cables, with underwater cables for transmission. They may be as tall as 900 feet to harvest the high-quality floating offshore wind resource most efficiently; however, there are many competing designs, and bigger may not be better in this case.

For onshore wind in particular, original equipment manufacturers (OEM) of wind turbines to build taller turbines because onshore space is limited, and taller turbines make the best use of the limited space. This, in turn, is because wind energy scales with the cube of the wind speed, and wind speed generally increases with height. Wind speed and direction are also generally more constant with height as well, further increasing the quality of the resource and efficiency of the generation. These factors thus incentivize large, tall towers on land. However, the FOW resource is vast, making space less of an issue, and relatively fungible conditions open the door to modularization. Importantly, assembling such massive structures at sea is logistically extremely challenging due to their size. Local regulations exacerbate this challenge in some geographies such as the US.

Despite the challenges, there is widespread support for the FOW sector, as demonstrated by ambitious deployment goals from countries like the United Kingdom, France, Portugal, Japan, Norway, South Korea, Spain, Italy, Ireland, and the United States. This support provides a secure foundation for the rapid growth of the industry, provided the industry can overcome the aforementioned logistical challenges to deployment and innovate on turbine design and manufacturing to drive down costs.

The remainder of this paper will discuss the emerging opportunities in the FOW sector, with a focus on technological innovations enabling low-cost and rapid deployment.

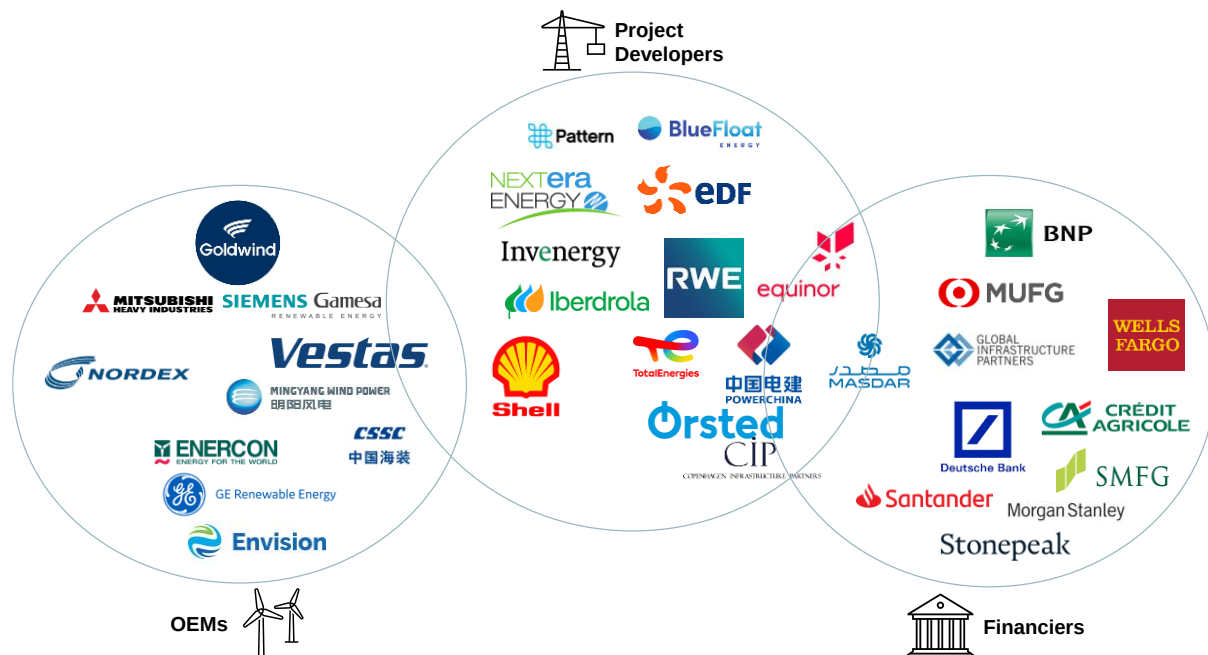
1.1 The Landscape of Floating Offshore Wind

1.1.1 The Ecosystem

The FOW industry is made up of OEMs, project developers, and financiers, as shown in Figure 1. OEMs are responsible for the design and manufacture of wind turbines. Most of these players come from the onshore wind industry, and the landscape is dominated by a few select players in each geography. China is notable for a burgeoning set of new OEMs, but the industry is very different there due to state support. For the most part, OEMs stay away from FOW as it is too small and not yet profitable for these large companies in which to

invest. Thus, startups are currently performing the bulk of the innovation in this space. Project developers perform all of the project-specific tasks, such as siting and permitting, construction, logistics, and more. These tend to be specialized in a given geography, but due in part to the nascent state of the FOW, some players (e.g., BlueFloat) are currently involved globally. O&G major (e.g., Equinor) are also active in this space, which is different from onshore wind, as they seek to leverage experience with their existing offshore floating oil rigs. Rarely, mostly for demonstration projects, some OEMs will take on the developer role as well. Project financiers provide financial support, and often developers can serve in this role as well.

Figure 1: FOW Incumbent Industry Categorized by Function



1.1.2 The Pipeline

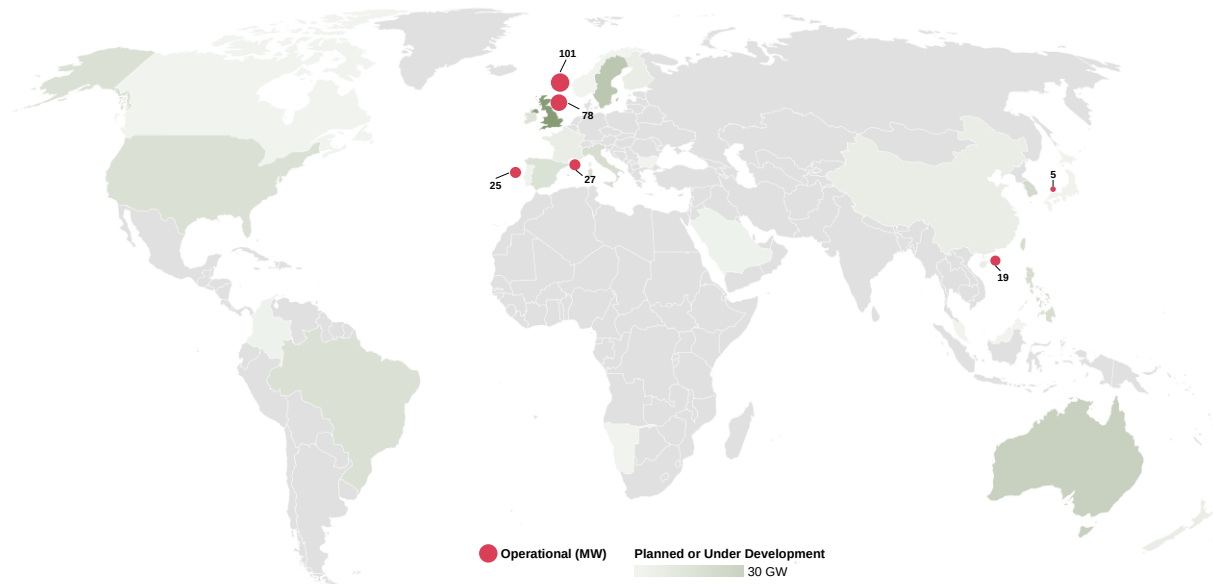
The deployment of floating offshore wind is set to boom, expanding by more than a 150x increase by 2030 and over 900x in total, based on the current pipeline. The current operational floating offshore wind capacity is approximately 261 MW as of H1 2024, and as of 2023, there are almost 40 GW of floating offshore wind scheduled to come online by 2030, and 244 GW in the pipeline overall. However, the large magnitude of the deployment and the aggressive timelines should be viewed with caution, as many of these larger projects are prone to delays and some projects may not make it past the planning stage.

Nevertheless, the pipeline does show the approximate magnitude of the forthcoming floating offshore wind boom. Many large wind farms are expected to come online between 2028 and 2030, and so tracking progress until that period should give a good sense of progress toward the goals. Rapid deployment by countries to meet 2030 goals may represent an inflection point and an opportunity for infrastructure investors in the space.

Geographically, most of the operational and planned FOW capacity is concentrated in Organization for Economic Cooperation and Development (OECD) nations and China, as shown in Figure 2. Hywind Scotland in the UK was the first commercial-scale project and came online in 2017, and Hywind Tampen in Norway is the largest at 88 MW. The UK also leads the world in planned FOW farms with almost 30 GW in the pipeline. Several players

such as the US, Australia, Italy, and China have large pipelines but no operational large commercial FOW farms. China has several smaller farms operational and several larger ones under construction, including the 1 GW Hainan Wanning project started in 2022 and projected for completion in 2027. Potential project investors in the space will likely have a clear perspective on local policy support and grid conditions, especially with respect to the achievability and firmness of renewable targets.

Figure 2: FOW Operational and In-Progress Pipeline Map



1.1.3 The Value Chain

FOW projects are manufactured, installed, and operated using a diverse value chain of fabricators and suppliers, port facilities, and installation assets. Key challenges arise with lack of standardization and differing requirements that influence the capacity of the industry to scale. For this report, we focus on identifying the most critical and demanding parts of the value chain, where we see the greatest potential for technological innovation to accelerate throughput rates and lower production costs. The value chain consists of:

- **Materials** used for component manufacturing
- **Design and Engineering** activities for components: FOW turbines (blade, tower, nacelle), mooring systems, anchors, and cables
- **Installation and Assembly** of assembled, pre-assembled, or partially assembled FOW substructures, using port facilities providing transport, assembly, and storage services
- **Operation and Maintenance** of floating offshore wind turbine projects-at-large, separate components (both exterior and interior), subsea cables, etc.
- **Logistics**, including digitalization, optimization, and efficiency technology, in the form of sensors, Internet of Things (IoT), software, etc.

1.2 Lessons From Similar Industries in FOW Innovation

At first glance, innovation may seem challenging in FOW because even demonstration projects must be relatively large. An at-scale offshore wind farm will typically cost several billion dollars and have a lifetime of over 30 years. While these are real constraints, the rapidly expanding Total Addressable Market (TAM) of FOW due to large, firms' demand not met by existing manufacturing capacity and availability of non-dilutive capital set the stage for innovation and attractive returns for disruptors. This is especially true if modularization can aggressively drive down the cost of FOW. Innovation across some portions of the value chain will take the form of FOW-specific technology (as opposed to borrowing from onshore and O&G) that may require riskier capital, while other areas such as Materials and much of Design and Engineering. Venture-backed companies have driven innovation in industries with many similarities to FOW, such as the space and renewable industries.

Over the past couple of decades, there have been rapid cost declines in onshore wind and solar. Today, they are some of the lowest-cost sources of energy generation. In the early years of solar, cost declines were dominated by technological advances and material costs, but post 2001 were dominated by manufacturing advances.³ These advances drove costs from \$5.56/W in 2010 to approximately \$1/W in 2020.⁴ Onshore wind-cost declines have been driven primarily by engineering technology advancements in turn driven by a desire to maximize use of an often-limited wind resource, which, as previously mentioned, is not necessarily the case for FOW. FOW is both in a nascent stage of development and poised for large advancements in manufacturing and technology. However, continuing the comparison to onshore wind and solar, timing is important, as the bust of cleantech 1.0 is well documented.⁵ Subsequent analysis of that bust has determined the major fundamental cause to be a lack of demand coincident with the investment timeline.⁶ This lack of demand does not seem to be present; but given the early state of the industry, investors may find it prudent to develop an informed perspective on the trajectory of the FOW market prior to committing capital.

Regarding investor returns, due to the commodity-based nature of the energy industry, this is less likely for developers but remains possible for technology providers. That said, for both groups, other liquidity events exist prior to a large Initial Public Offering (IPO), which given the nascent state of the industry may take too long for many funds. Initial commercial demonstration projects could represent liquidation events for early investors, but acquisition by larger players in the industry likely will be the most common exit.

While the FOW industry is nascent, the overall wind industry is mature and dominated by several OEMs, as mentioned regarding Figure 1. OEMs are currently struggling to make a profit in the more mature onshore and fixed offshore spaces, and so increasing manufacturing capacity is difficult,⁷ especially when coupled with the costs of innovation for FOW. If FOW costs come down or even prove profitable, OEMs will likely aggressively enter the sector and be active in the Mergers & Acquisitions (M&A) space.

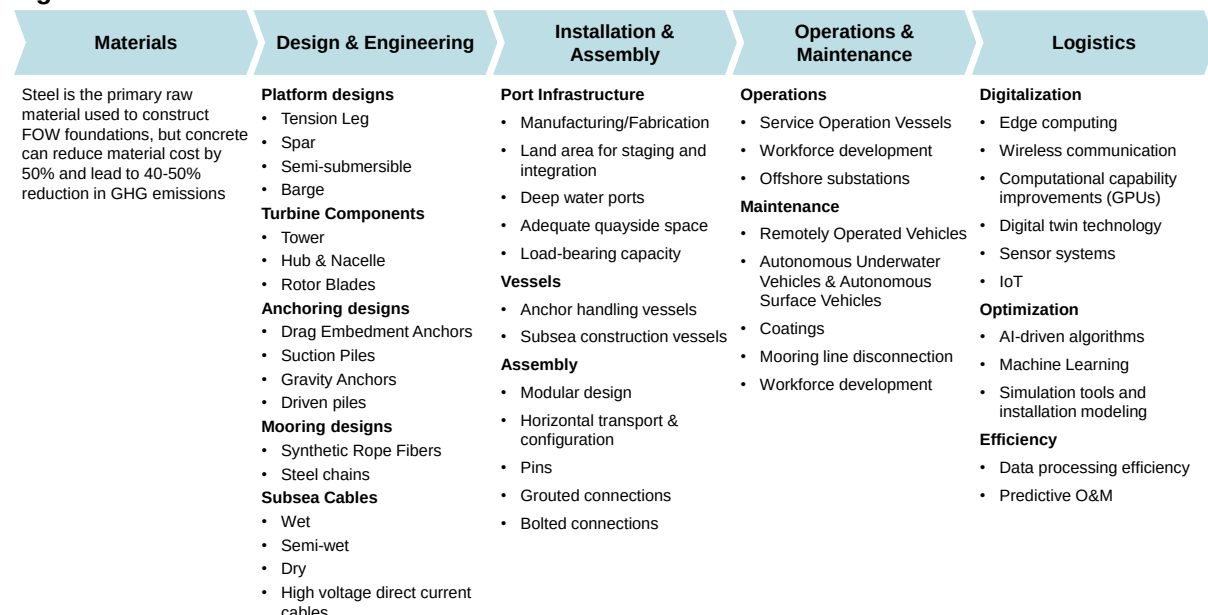
Space is a similarly infrastructure-heavy sector that for most of its history was supported via government funding. That has changed in the last decade as evidenced by the rise of firms like SpaceX, which has received \$9.8 billion in venture funding since its inception and its forthcoming Starship is estimated to cost between \$2 and \$10 billion to develop. Blue Origin, Virgin Galactic, Axiom Space, and Sierra Space are other examples of well-funded infrastructure-heavy startups in the sector. In total, according to data from Space Capital, \$291 billion of private equity is into space in the last decade.⁸ Per McKinsey, leading venture capital firms in the space industry pointed to the expanding TAM as a key reason for space being such a successful investment sector.⁹ FOW's is clearly positioned to grow rapidly as evidenced by announcements from governments around the world, so the expanding TAM sets the stage for similar success.

2 Pathways to Commercialization

Technological advancements can play a crucial role in the development of floating offshore wind energy through cost declines, and is an oft-overlooked opportunity to speed up the deployment process. Improvements in turbine design and the use of new materials may not yield immediate returns for Venture Capital (VC) investors, as they are better suited for long-term investment. Innovations focusing on reducing logistical challenges and enhancing efficiency in the software stack to decrease operation time and maintenance costs for turbines is particularly appealing to venture investors. However, addressing supply-chain issues and achieving standardization where possible is equally as necessary. This requires significant funding from corporations, infrastructure, and government sectors, as these are asset-heavy areas of the value chain. Recent macroeconomic trends indicate that future supply-chain bottlenecks will squeeze wind developers' profitability, necessitating increased government subsidies for manufacturing hubs and port developments for domestic floating offshore wind, especially in the US.¹⁰ Nonetheless, venture investment can drive market signals to encourage the participation of these stakeholders.

The advancement of the floating offshore wind industry depends on reducing production costs and increasing throughput rates through technological innovation. Despite the substantial second-mover advantage and the translation of skills and equipment from O&G and onshore wind industries, FOW is currently not cost competitive, with LCOE exceeding \$200 per megawatt-hour (MWh) (compared to \$50 per MWh for fixed-bottom turbines).¹¹ However, according to a report from DNV, the LCOE of floating wind farms is expected to drop to \$100 per MWh by the middle of this decade and to \$67 per MWh by 2050.¹² This indicates plenty of opportunities for cost-saving technological advancements throughout the value chain, as provided in Figure 3.

Figure 3: FOW Value Chain

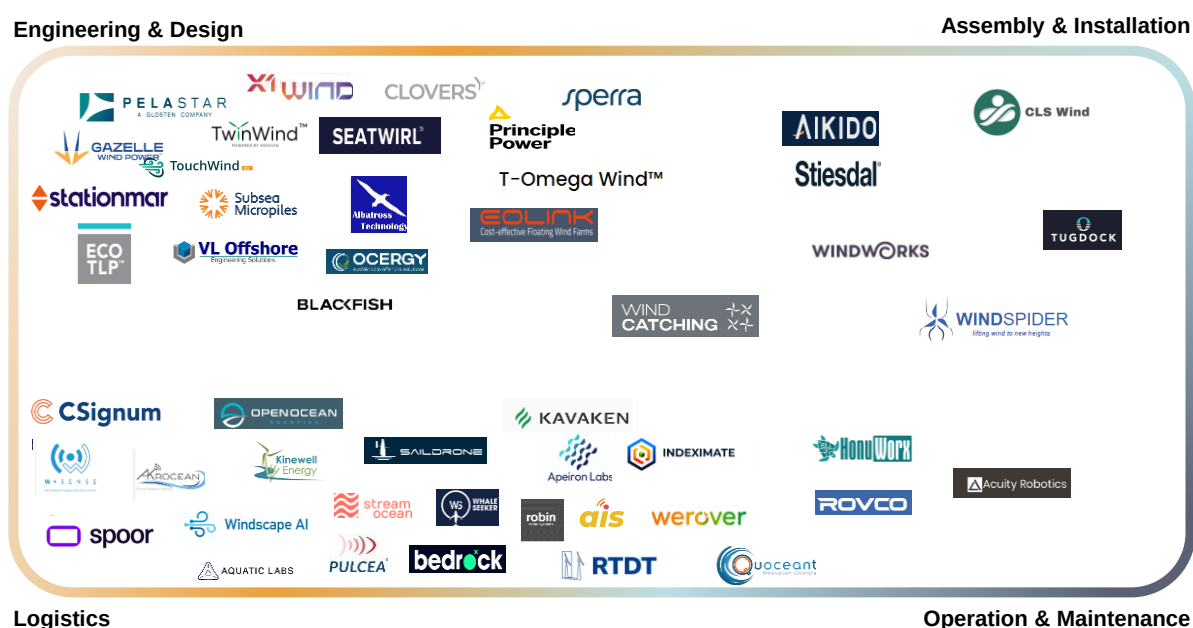


Traditional materials in the supply chain for onshore and fixed-bottom offshore wind face shortages and delays. Floating wind projects require larger turbines that are not yet mass-produced. Logistical challenges include scarcity of deep-water ports and limited availability of specialized vessels, leading to potential delays. Additionally, floating offshore wind

projects lack dedicated component manufacturing, causing capacity constraints for OEMs due to high demand in the fixed-bottom offshore wind industry. Based on data collected from Windar Renovables, a wind turbine OEM, and Navantia, a shipbuilding company that has built most of the full-scale, steel floating-wind foundations to date, using conventional technology, offshore wind throughput rate (both fixed and floating) reaches only 0.3 GW per year.¹³ These numbers also suggest that the FOW industry requires its own dedicated supply chain, inviting technology disruption, rather than forcing the adoption of traditional land-based turbine designs and software from onshore wind, which has largely directed the development of fixed-bottom offshore wind and O&G.

Finally, to make floating offshore wind energy commercially viable, it will be wise to standardize certain components. For example, it would be beneficial to determine the optimal “Goldilocks” size for floating offshore wind turbines — large enough to produce sufficient power and favorable unit economics but still manageable in terms of logistics. Instead of continually increasing the size of these turbines, it may be wise to set a limit of 18 or 20 MW, allowing for better utilization of the abundant offshore wind resources. However, practical considerations will affect the economics of individual units, and it is likely that the LCOE of FOW is still undiscovered given the lack of a dedicated supply chain. Increased government funding is likely necessary to establish a dedicated supply chain before the industry can accurately calculate the predicted LCOE. The innovation in floating offshore wind technology primarily centers on engineering, design, and logistics within the value chain, as shown in Figure 4.

Figure 4: FOW Market Map



Logistics plays critical roles in project development, influencing permitting and site selection. Innovations in logistics technology can significantly expedite the commercialization of floating offshore wind and mitigate associated risks. Monitoring marine wildlife entanglement and its impact on the ecosystem is crucial for offshore wind farms in deep waters.¹⁴ Data collection and Artificial Intelligence (AI) analytical tools include startups such as Spoor, using DeepTech AI to monitor and track birds at wind farms, Kavaken, utilizing analytical AI for predictive maintenance, and Akrocean’s Windseam, a floating LiDAR for wind and metocean measurements. Most logistics startups use significantly less capex than engineering and

design startups and include revenue streams by providing monitoring and AI capabilities for additional ocean-based industries.

Established OEMs or project developers will likely execute operations and maintenance (O&M) internally. However, the lack of innovation in this area suggests that more demonstration projects must be implemented before significant innovation takes shape. To incentivize capable players, such as the shipping industry, to develop the necessary O&M assets, the industry requires a clear pipeline of large-scale projects. Additionally, OEMs and project developers may want to consider leading the development of new FOW O&M tools and solutions. These assets have the potential to disrupt and transform current strategies for Major Component Replacement (MCR) operations. For the long-term strategy of MCR in commercial-scale floating arrays, experts believe that major service providers would handle these assets further offshore, while local facilities closer to shore may be more suitable for dry docks,¹⁵ or would alternatively use motion-compatible and commercially available submersible heavy-lift vessels.

Wind farms are increasingly utilizing Remotely Operated Vehicles (ROV) to lower O&M costs and enhance safety,¹⁶ such as those produced by Acuity Robotics. Nevertheless, investors express uncertainty in the projected costs and benefits of robotics and automation systems. Investors require further industry research to fully understand the economic advantages offered by ROVs, and wind farm operators will need to present a compelling business case to justify implementing the costly technology. Developers face significant obstacles in bringing innovative technology to market due to the substantial time, cost, and risk involved.¹⁷ The leading offshore wind developers (e.g., Orsted, RWE, BlueFloat, Total) are more likely to invest in ROVs once an agreement on standardization of materials, turbine components, etc., is reached.

Investors in engineering and design startups should be prepared for a longer investment horizon and anticipate substantial capital expenditure. Currently, some startups are dependent on prospective projects and, if they are lucky, are awaiting the fulfillment of contracts with demonstration projects. Nevertheless, technological advances in this sector harbor significant potential for disruption across the full value chain. For instance, Wind Catching Systems, based in Norway, has built a mega-array of smaller rotors arranged in a grid to achieve 126 MW, or five times the energy of a 15 MW single-rotor turbine, in North Sea conditions. The startup also claims its wide platform makes for easier installation and maintenance elevators, which run up and down the scaffolding of smaller turbines, behind its generators.

Finally, project developers might want to monitor technology innovation in assembly and installation as the deployment of demonstration projects increases. Although the existing project queue does not support a large ecosystem, developers expect deployment to ramp up per the 2030 projected pipeline, and innovations and technology solutions in assembly and installation are some of the most effective ways to increase the throughput rate of floating offshore wind projects. One such solution is Aikido technology, a floating platform designed for horizontal transport of floating offshore wind turbines, fondly described as an “Ikea flatpack” FOW solution. It uses pin joints that enable the serialized production of the steel components of floating offshore wind turbines. This allows the platform to fold up during assembly and occupies two-thirds less space in a shipyard or quayside port facility.

3 Conclusion

FOW is ripe for innovation. At present, it appears that venture investment is well suited to fund advancements in asset-light software and service, away from the critical parts of the turbine requiring intense engineering. These crucial elements, such as spars, barges, semi-submersibles, tension leg platforms, and mooring systems, are all being developed, but may be harder to execute on. Many of the platform technologies in pilot projects embody next-generation innovations essential for reducing costs for utility-scale floating wind farms.

Investors with a shorter horizon will likely focus on optimization technology, software stacks, and innovations that reduce assembly costs and deployment times. Investors with longer horizons and the appropriate risk profile may find deploying patient capital for technological solutions aimed at standardizing the design and engineering of the industry to be a compelling strategy. Both groups will likely maintain a clear perspective on non-dilutive funding and other governmental support in the regions in which they are active, as this will be key to deployment at scale. Catalytic capital may also be deployed toward ensuring continued FOW support. Initiatives such as the US DoE's Floating Offshore Wind Shot¹⁸ is a prime example of such advanced support even beyond renewable targets. Finally, the largest pool of capital will likely come from infrastructure investors in support of project development. These investors will likely have longer horizons seeking stable returns, working with developers in the near term to scale necessary infrastructure and fund demonstration projects, and in the long term to scale FOW deployment as it booms to meet global clean energy needs in support of the energy transition.

4 Appendix

4.1 Key Policy Unlocks

Policy has a long history of influencing the energy industry, particularly renewables.¹⁹ For FOW, there are many policy levers that could catalyze development in offshore wind and that CREO members interested in this space should be tracking. These fall into 3 areas: market development, streamlining deployment, and accelerating technology development.

Market development can take two main forms, the first is subsidizing renewable energy deployment via tax credits such as the investment tax credit (ITC) and production tax credit (PTC), the second is subsidizing manufacturing. In the US there is a need for both. The Inflation Reduction Act (IRA) has provisions for ITCs to subsidize up to 40% of new FOW if produced domestically; however, the current workforce and manufacturing capacity is not sufficient. Additionally, OEMs are currently not profitable in the fixed-bottom offshore wind industry and therefore are not financially incentivized to invest in the still nascent FOW sector. IRA manufacturing incentives like 45x and 48c were created to address these issues, but these are likely not enough. Most importantly, all of these subsidies are under some degree of political threat; continued support is necessary for FOW deployment in the US, and more likely is necessary if the US is to be a leader in FOW.

Streamlining deployment policies facilitate deployment at either accelerated timelines or lower cost. In terms of specific policies, the Jones Act is perhaps the most frequently cited barrier to deployment. The Jones Act requires that shipping between US ports may only use US-made vessels and crew. This policy, originally signed in 1920, when applied to the FOW industry has disastrous consequences as there are no US-made vessels that can haul the very large components of a typical turbine. Furthermore, shipbuilding is very expensive in the US, approximately 3x that of competitors.²⁰ This presents a huge hurdle for the US FOW industry and reduces competitiveness on a global scale. The first Jones-Act compliant FOW service and operations vessel (SOV) came online as of May 2024,²¹ and more may follow, but at great cost. The policy that exempted FOW from the Jones Act restriction would be much more cost effective for the FOW industry. Additionally, site approval for offshore wind (both transmission and generation) by the National Environmental Protection Agency (NEPA) can take over 11 years.²² This and other similar permitting issues can be addressed both by streamlining regulations and by increasing staffing levels at appropriate offices.

Technology development policy encourages technological development and tech transfer. Unlike fixed-bottom offshore wind, FOW is a nascent space still near the beginning of its learning curve. A key way that CREO members can support this is by supporting research initiatives. The Floating Offshore Wind Shot is a prominent example, launched in 2022 by the US Department of Energy (DOE) as part of its Energy Earthshots Initiative. It has the goal of lowering FOW costs to \$45/MWh by 2035.²³ Achieving this is projected to lead to an additional 19 GW of deployment by 2050, and savings of \$94 billion.²⁴ To aid tech transfer, the US is partnered with Japan and joined the Global Offshore Wind Alliance. Also notable is the DOE's Office of Clean Energy Demonstrations (OCED), which facilitates demonstration projects for novel technologies. Finally, much of this is made possible by expertise in the national labs and DOE, particularly the National Renewable Energy Laboratory (NREL) and the Wind Energy Technologies Office (WETO). Ensuring these and other institutions are well funded can be an extremely cost-effective way to bring down the cost of FOW.

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