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Offshore Wind Market Report: 2022 Edition

Disclaimer

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List of Acronyms

BNEF	BloombergNEF
BOEM	Bureau of Ocean Energy Management
CapEx	capital expenditures
COD	commercial operation date
COP	Construction and Operations Plan
CTV	crew transfer vessel
DOE	U.S. Department of Energy
GE	General Electric
GW	gigawatt
km	kilometer
LCOE	levelized cost of energy
LEEDCo	Lake Erie Energy Development Corporation
m	meter
MW	megawatt
MWh	megawatt-hour
NREL	National Renewable Energy Laboratory
NTP	National Transmission Planning
OCS	Outer Continental Shelf
O&M	operations and maintenance
OEM	original equipment manufacturer
OREC	offshore renewable energy certificate
OWDB	offshore wind database
POI	point of interconnection
PPA	power purchase agreement
ROD	Record of Decision
SAP	site assessment plan
SOV	service operation vessel
TBD	to be determined
WEA	wind energy area
WTIV	wind turbine installation vessel

Executive Summary

The "Offshore Wind Market Report: 2022 Edition" provides detailed information on the U.S. and global offshore wind energy industries to inform policymakers, researchers, and analysts about technology, economic, and market trends. The scope of the report covers the status of more than 257 global operating offshore wind energy projects as well as the broader global pipeline of projects in various stages of development through Dec. 31, 2021. To provide up-to-date data and discussion of this emerging industry in the United States, this report tracks the most significant U.S. domestic industry progress and events from Jan. 1, 2021, through May 31, 2022.

U.S. Offshore Wind Energy Market

By May 2022, the U.S. offshore wind energy project development and operational pipeline grew to a potential generating capacity of 40,083 megawatts (MW). The 40,083 MW in the U.S. offshore wind energy pipeline shows a 13.5% growth over the 35,324 MW reported in the "Offshore Wind Market Report: 2021 Edition" (Musial, Spitsen, et al. 2021). The expansion of the U.S. project pipeline was largely due to the addition of eight new lease areas that were auctioned in the Atlantic and two Call Areas that were converted into wind energy areas (WEAs) in California (U.S. Department of the Interior 2021). Even though three of the existing WEAs were reclassified as "dormant" and removed from the pipeline, the net expansion was 4,759 MW higher than the capacity reported in May 2021. A map of the current pipeline activity and Call Areas is shown in Figure ES-1.

States policies aim to procure at least 39,322 MW of offshore wind energy capacity by 2040. The U.S. offshore wind energy market continues to be driven by state-level offshore wind energy procurement activities and policies. Collectively, offshore wind energy policies in eight states call for deploying at least 39,322 MW of offshore wind energy capacity by 2040, which is approximately the same total amount reported in the "Offshore Wind Market Report: 2021 Edition." These policies provide a pathway to achieving the national offshore wind energy target of 30 gigawatts (GW) by 2030 (The White House 2021a).

BOEM announces plan to develop WEAs in up to seven U.S. regions by 2025. In October 2021, BOEM announced its "Offshore Wind Leasing Path Forward 2021–2025," calling for plans to hold up to seven new offshore WEA lease auctions including the New York Bight, Carolina Long Bay, Central Atlantic, Gulf of Maine, California, Oregon, and the Gulf of Mexico by 2025 (U.S. Department of the Interior 2021). The new lease areas will substantially increase the number of viable offshore wind energy sites in the United States, provide regional diversification beyond the North Atlantic and mid-Atlantic, and enable technology diversification by introducing the first commercial lease opportunities for floating offshore wind projects.

BOEM held lease auctions for six new lease areas in the New York Bight and two lease areas in Carolina Long Bay. In February 2022, BOEM auctioned six lease areas in the New York Bight, which sold for $4.37 billion. The lease area selling prices ranged from a winning bid

of $285 million for OCS-A 0544 ($1,637,931 per square kilometer [km^2]) to a winning bid of $1.1 billion for OCS-A 0539 ($2,380,952/km^2). The auction set records for total revenue generated from an offshore energy lease auction in the United States. In May 2022, the two lease areas in the Carolina Long Bay auction sold for a combined total of $315 million, with an average sale price of $707,894/km^2.

As of May 31, 2022, 24 power purchase agreements[1] for offshore wind energy procurement were signed in the United States. Eight states have unique targets with varying power offtake mechanisms to procure electrical generation from specific offshore wind projects. These state policies have resulted in 24 power purchase (offtake) agreements, adding up to 17,597 MW in offshore wind energy contracts. From the beginning of 2021 through May 31, 2022, 10 new power purchase agreements, totaling 11,874 MW, were signed.

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[1] A contract between one party who generates the electricity (the seller) and another party who is purchasing the electricity (the buyer).

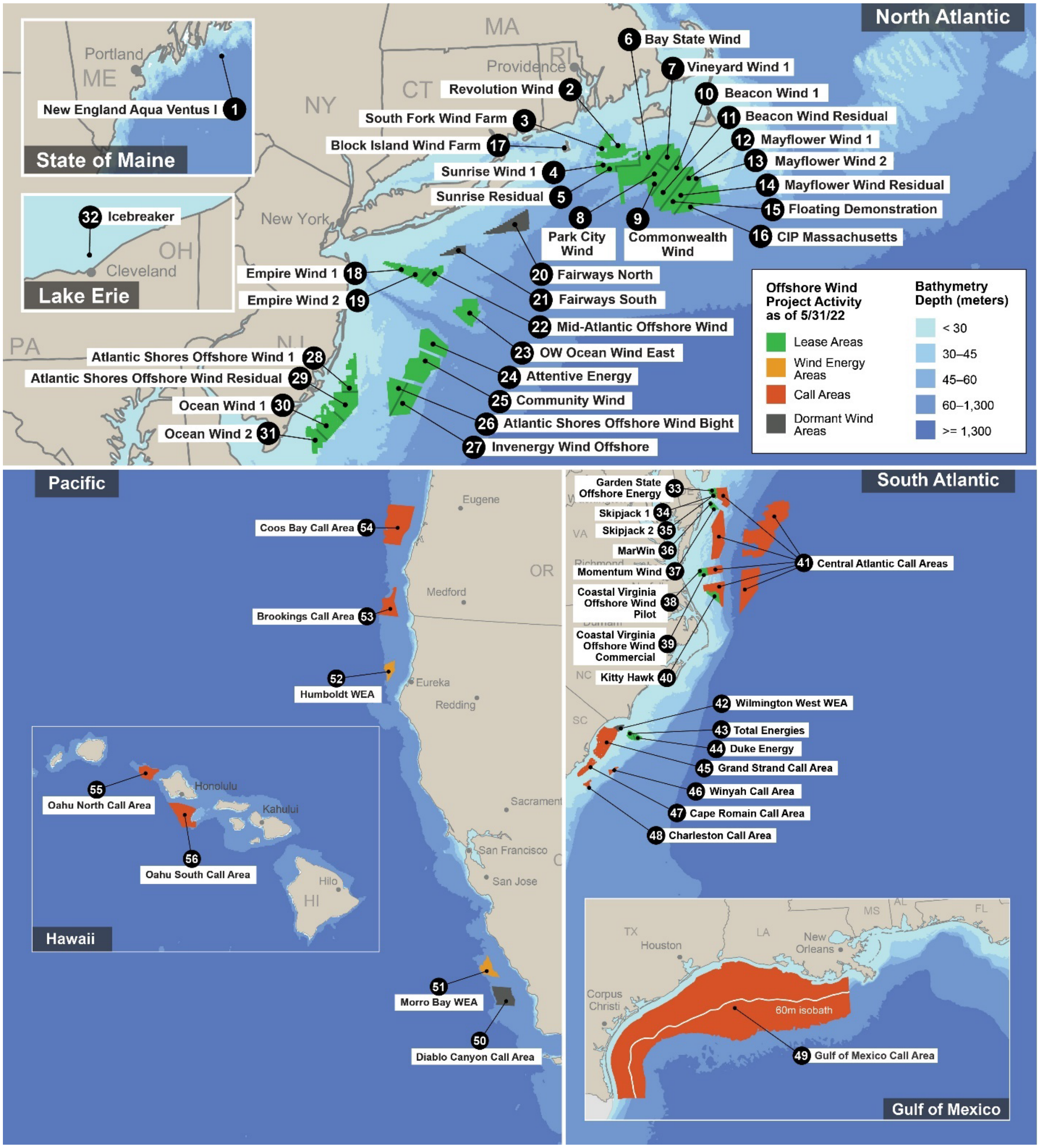

Figure ES-1. Locations of U.S. offshore wind pipeline activity and Call Areas as of May 31, 2022. ***Map created by NREL***

Global Offshore Wind Energy Market

Global offshore wind energy in 2021 had a record year for deployment with 17,398 MW of new projects commissioned. The surge in offshore wind energy deployment this year pushed global installed capacity past 50 GW. This growth was largely attributed to China, which commissioned 13,790 MW—more capacity in 1 year than the entire world has installed in any single previous year. The United Kingdom had the next largest annual deployment (1,855 MW), followed by Vietnam (643 MW), Denmark (604 MW), the Netherlands (402 MW), and Taiwan (109 MW) (National Renewable Energy Laboratory 2021). By the end of 2021, cumulative global offshore wind installed capacity grew to 50,623 MW from 257 operating projects. Projections indicate that annual global capacity additions may fall below the 2021 pace in 2022, but overall, new deployments will likely accelerate up to 2025 and beyond.

The global generating capacity potential of the project pipeline for all offshore wind energy projects reached 368 GW in 2021. As of December 31, 2021, the global pipeline (includes all projects from the planning stage through those already installed) for offshore wind energy development capacity was assessed to be 368,170 MW, up nearly 20% over the 308 GW reported in 2020. The uptick is primarily attributed to multiple new Asian-based projects announced this year that are entering the planning phase.

Macroeconomic and geopolitical events have raised the level of market uncertainty in 2022. The extended impact of monetary policy, the COVID-19 pandemic, and the ongoing conflict in Ukraine have created macroeconomic volatility, supply chain disruptions, and inflationary pressures. These complex external drivers are having both positive and negative impacts on offshore wind and broader energy industries. Increased fossil-fuel prices have led nations around the world to accelerate the development of renewable energy to mitigate rising consumer electricity costs and strengthen their energy security. On the other hand, increased commodity prices and continued supply chain disruptions threaten to slow offshore wind energy cost declines or potentially increase costs, which could dampen offshore wind deployment in the near term (Vestas 2022).

The global pipeline for floating offshore wind energy more than doubled in 2021. Overall, the 2021 global floating offshore wind energy pipeline grew from 26,529 MW to 60,746 MW, representing 34,217 MW of growth since the "Offshore Wind Market Report: 2021 Edition." This growth is attributed to several new projects in South Korea, the United Kingdom, Brazil, and Australia entering the pipeline and beginning their planning phase during 2021.

Three floating offshore wind energy projects came online in 2021, totaling 57.1 MW of new capacity. The largest floating offshore wind project built to date (50 MW total—2 MW of which moved from Portugal in 2021), Kincardine Offshore Wind Farm, came online in Scotland (Principle Power, Inc. 2021). A 5.5-MW floating offshore wind energy demonstration project came online in China, which was developed by China Three Gorges Group (Russell 2021). Additionally, the 3.6-MW TetraSpar Demonstration Project was installed in Norway at a water depth of 200 meters (Stiesdal A/S 2021). With these additions, the total global floating offshore wind energy capacity is now 123.4 MW.

Offshore Wind Energy Technology Trends

Offshore wind turbines in the 15-MW class are advancing toward commercial production. After the three leading wind turbine manufacturers announced their plans to develop wind turbines in the 15-MW class last year, a leading Chinese manufacturer, MingYang, announced its plans to deliver a 16-MW wind turbine for the commercial market by 2024. These 15-MW-class wind turbines are under full development at Siemens Gamesa, Vestas, and General Electric, with intentions to have them available for purchase by 2024 or sooner. Industry announcements indicate that developers will be depending on these turbines for most U.S. projects.

Offshore Wind Energy Cost and Price Trends

The levelized cost of energy estimated for U.S. fixed-bottom offshore wind energy projects in 2021 has declined to $84/megawatt-hour (MWh) on average, with a range of $61/MWh to $116/MWh globally. This cost decline in fixed-bottom offshore wind farms (i.e., wind turbines connected rigidly to the seafloor) represents a reduction of 13% on average compared to 2020 U.S. estimates, bringing the total cost reduction to more than 50% since 2014 (Wiser et al. 2021). For representative market scenarios, leading research entities and consultancies estimate that levelized cost of fixed-bottom offshore wind energy will be $60/MWh on average by 2030.

Record-setting lease auction prices in the New York Bight were followed by auction format changes to benefit states and local stakeholders. The $4.37 billion paid for leases in the New York Bight was unprecedented. While signaling strong confidence in the offshore wind energy market, those high lease prices translate to about $763/kilowatt and raise concerns about higher electricity costs from offshore wind energy. In May 2022, the BOEM auction rules were modified for the Carolina Long Bay auction using multifactor bidding criteria that allow bidding credits to be allocated for local supply chain commitments. A multifactor approach is also planned in the next upcoming lease auction in California scheduled for late 2022 that will allow bidding credits for local benefits.

Future Outlook

Although still at the beginning stages in the United States, offshore wind is now recognized globally as one of the principal energy sources to combat climate change. Offshore wind energy deployment is forecast by 4C Offshore and BloombergNEF to increase globally to about 260 GW or more by 2030 (4C Offshore 2022a; BloombergNEF 2021a), and the number of countries currently generating power from offshore wind energy is expected to double over the next decade (Ferris 2022).

U.S. domestic offshore wind energy deployment is expected to follow global growth trends, driven by robust state-level procurement targets, and a national target of 30 GW of offshore wind energy by 2030, set in March 2021. Following BOEM's October 2021 announcement to ramp up offshore leasing in Federal waters, and the record-setting lease prices observed in the New York Bight auction in February 2022, the U.S. industry is signaling rapid growth, and expanding to regions outside the North Atlantic and mid-Atlantic. In the coming years, national leasing plans call for new offshore wind energy lease area auctions in the Gulf of Mexico, Pacific, South Atlantic, and the Gulf of Maine by 2024, which would allow commercial development in these regions as early as 2030.

As these regions integrate offshore wind energy into their electricity markets, the industry will need to tackle new technical challenges, such as hurricane survival, anchoring in deeper water, and lower average wind speeds, but through continued industry research the solutions appear to be attainable (National Offshore Wind Research and Development Consortium 2021; U.S. Department of Energy 2022c). In particular, the development of floating wind turbine technology is likely to continue to gain momentum as the industry works to lower costs to levels approximately equal to fixed-bottom wind turbine technology through the benefits of greater production volume and global market experience. Beyond the near-term leasing plans, the United States could also see offshore wind energy move forward by the end of the decade in regions like Hawaii, Puerto Rico, and the Great Lakes, where technical feasibility, wind resources, and renewable energy demand requirements are already being investigated.

The domestic and global push for clean, carbon-free electricity and complete decarbonization of all energy sectors is likely to remain a primary driver in the United States for offshore wind energy, but caution should be taken as the path to developing large-scale offshore wind energy is not free from obstacles. Uncertain and fluctuating policy support, stakeholder concerns, constrained global supply chains, inflation, restrictive legislation for ocean development, land-based grid limitations, and geopolitical conflicts will pose challenges that could potentially impact the industry’s progress.

The Biden administration’s 30-GW-by-2030 goal suggests a strong pace of development and establishes a pathway to deploy 110 GW or more of offshore wind energy in the United States by 2050 (The White House 2021a). Further research is needed to determine the extent of offshore wind energy’s role in a decarbonized energy future, but offshore wind energy market indicators suggest it will be a substantial part of a comprehensive U.S. decarbonization strategy.

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1 Introduction

In the United States, commercial-scale offshore wind energy deployment is at an early stage with only 42 megawatts (MW) generating power; however, the domestic industry is poised for an exponential increase in new installations after the first large commercial projects advanced to the construction phase in 2021–2022. Over the past 20 years, offshore wind energy got a head start outside the United States with the help of coordinated European offshore wind energy incentives. In the coming years, however, market trends suggest a shift away from European market dominance and toward more global diversity. The industry is experiencing greater geographic expansion driven by a broader demand for clean energy and an expectation of continued cost declines. More countries around the world are actively including offshore wind energy in their long-range planning and some have recently announced new offshore wind targets. In 2022, industry-leading countries like Denmark, the United Kingdom, and Germany have announced increases in their offshore wind targets to gain more energy independence from Russian fossil-fuel imports (Durakovic 2022b; European Commission 2022; Ferris 2022; German Federal Ministry of Economics and Technology 2022; Government of Belgium 2022; Government of France 2022; Government of the Netherlands 2022).

In the United States, offshore wind energy is valued in many coastal states for social and economic benefits that extend beyond simple cost-of-energy measures. Large, utility-scale electric-generating projects can be built offshore, adjacent to populated load centers, and minimally interfering with other ocean activities. These projects can access more energetic wind resources than those found on land, avoid high real estate costs that would be incurred as a result of siting projects on inhabited land, and create thousands of high-paying jobs. U.S. offshore wind energy adoption has been primarily incentivized through state policies in the Northeast and mid-Atlantic regions to help individual states meet renewable energy targets while reaping these economic benefits and is strongly backed by the Biden administration’s goal to meet 30 gigawatts (GW) of offshore wind energy by 2030 (The White House 2021a). Today, this coordinated U.S. policy at the state and federal levels has strengthened private commercial investment, signaling sustained offshore wind market growth in the near-term.

While the long-term market outlook is positive, global economic and geopolitical factors are creating new market uncertainty. The extended impact of the COVID-19 pandemic, central bank policies, and the ongoing conflict in Ukraine have created macroeconomic volatility, supply chain disruptions, and inflationary pressures on key commodities used in the offshore wind sector. These developments have mixed impacts on the sector and the energy industry as a whole. On one hand, increased fossil-fuel prices have led nations around the world to accelerate the development of renewable energy projects and increase energy security measures. For example, Belgium, Denmark, Germany, and the Netherlands announced a joint goal to develop 65 GW of offshore wind by 2030 and 150 GW by 2050 (German Federal Ministry of Economics and Technology 2022). This announcement supports the broader European Union REPowerEU Plan to end dependence on Russian fossil fuels while addressing the ongoing climate crisis

(European Commission 2022). On the other hand, higher commodity prices and continued supply chain disruptions could hinder deployment and result in potential cost increases in the near to medium term (Vestas 2022).

This "Offshore Wind Market Report: 2022 Edition" was researched and written by the National Renewable Energy Laboratory (NREL) for the U.S. Department of Energy (DOE) to provide offshore wind energy policymakers, regulators, developers, researchers, engineers, financiers, and supply chain participants with up-to-date quantitative information about the offshore wind energy market, technology, and cost trends in the United States and worldwide. This report includes detailed information on the domestic offshore wind energy industry, providing context to help navigate technical and market barriers and opportunities. It also covers the status of 257 operating offshore wind power plants in the global fleet through Dec. 31, 2021, and provides the details and analysis on a broader global pipeline of projects at varying stages of development. In addition, this report provides information on U.S. offshore industry developments and events through May 31, 2022.

This report includes data obtained from a wide variety of sources about offshore wind energy projects that are both operating and under development to offer past, current, and forward-looking perspectives. These projects are also used as key inputs to the annual "Cost of Wind Energy Review" report, which provides an updated summary of the cost of land-based and offshore wind energy in the United States to support DOE's programmatic reporting on the cost of wind energy (Stehly and Duffy 2022). This report is also a companion to the "Land-Based Wind Market Report: 2022 Edition" and "Distributed Wind Market Report: 2022 Edition," which are funded by DOE and authored by the Lawrence Berkeley National Laboratory (Wiser et al. 2022) and the Pacific Northwest National Laboratory (Orrell et al. 2022), respectively. These companion reports cover the status of utility-scale and distributed, land-based wind energy located primarily in the United States and provide quantitative data and context for use by the wind industry and its stakeholders.

Global offshore wind energy deployment in 2021 was a record year for deployment, with 17,398 MW of new offshore wind energy commissioned globally and future projections indicating continued growth both globally and nationally. Long-term projections predict more than 260 GW by 2030 and more than 1,000 GW by 2050 (BloombergNEF [BNEF] 2021a; 4C Offshore 2022a).

1.1 Approach and Method

1.1.1 NREL Offshore Wind Database

This "Offshore Wind Market Report: 2022 Edition" uses NREL's internal offshore wind database (OWDB), which contains information on more than 2,079 offshore wind energy projects located in 49 countries and totaling 831,991 MW of announced project capacity (both active and dormant) (NREL 2022a). The database includes both fully operational projects dating back to 1990 and anticipated future deployment that may or may not have announced their commercial operation date (COD).

The OWDB contains information on project characteristics (e.g., water depth, wind speed, distance to shore), economic attributes (e.g., project- and component-level costs and performance), and technical specifications (e.g., component size and weight). The database also contains information on installation and transportation vessels, as well as ports that support the construction and maintenance of offshore wind energy projects.

The database is built from internal research using a wide variety of data sources including press releases, industry news reports, manufacturer specification sheets, subscription-based industry databases, global offshore wind energy project announcements, and peer-reviewed literature. Unless stated otherwise, the data analysis in this report—both global and domestic—is derived by NREL from the OWDB and reflects the best judgment of the authors and industry subject matter experts that were consulted. To ensure accuracy, NREL verified the OWDB against the following sources:

- 4C Offshore Wind Database (4C Offshore 2021a)
- Bureau of Ocean Energy Management (BOEM) online published data
- BNEF's Renewable Energy Project Database (BNEF 2021a).

Although we validated and harmonized the data with these other sources, minor differences in their definitions and methodology may cause the data in this report to vary from data in other published reports. For example, the method for counting annual capacity additions often varies among different sources, because terms such as "installed" or "operational," and "first power" or "commercial operation date" are often defined differently. NREL considers a project to be commercially operational when all wind turbines are fully operational and transmitting power to a land-based electric grid (see Table 1). Data may also vary in quality and are subject to high levels of uncertainty, especially those used for future projects that are subject to change based on developer and regulatory requirements. Despite annual variability and potential future project-level uncertainty, trends reported elsewhere are consistent with long-term market trends in the OWDB.

Cost and pricing data gathered for the OWDB span many years and are reported in different currencies. To analyze and compare these data, we normalized all information in this report into 2021 U.S. dollars (USD) by:

- Converting costs and prices to USD, using the exchange rate for the year in which the latest data were reported (Bureau of the Fiscal Service 2022)
- Inflating the values, which are in nominal USD after the exchange rate conversion, to 2021 USD using the U.S. Consumer Price Index (U.S. Bureau of Labor Statistics 2022).

1.1.2 Classification of Project Status

The "pipeline" in this report is an offshore wind energy development and operating project tracking process that provides the ability to follow the status of a project from early-stage planning through decommissioning. We aligned the primary tracking method with the U.S.

offshore wind regulatory process, but the methodology generally applies for tracking global projects as well. All offshore wind projects in federal waters must navigate through the regulatory process that formally begins when a regulator initiates the leasing process to designate a wind energy area (WEA), which typically leads to a competitive lease auction.[2] This classification system is also used in non-federal waters of the United States where the regulatory process is overseen by state governments (e.g., the Great Lakes).

In parallel with the regulatory process are the developer's private efforts to demonstrate the economic viability of the project and obtain financing. Regulatory and financing pathways often happen at the same time and have several interdependencies. Because financial negotiations are usually confidential, this report primarily tracks projects by their regulatory achievements, which are largely in the public domain. As a result, the "pipeline" is defined as the set of all offshore WEAs and projects, including potential generating capacity of WEAs that are waiting to be auctioned,[3] potential generating capacity of sites where developers hold offshore wind leases, and nameplate capacity of projects under development, operational projects, and decommissioned projects. If known, we report in this document information on a project's power offtake agreements and financial contracts as well.

In general, the first mandatory step in BOEM's competitive leasing process is to issue a Call for Nominations that solicits input from offshore wind energy developers and stakeholders who indicate their interest in a proposed Call Area. Call Areas are the precursors to establishing a WEA in a particular region. There are now many Call Areas across the United States' Outer Continental Shelf (OCS), but because their boundaries are likely to change, no portion is counted in the pipeline totals until the Call Area is designated as a WEA.

In the early stages of a project, the exact footprints and generating capacities are not always known, but NREL assumes that all lease areas will eventually be fully developed with an array power density of at least 3 MW/square kilometer (km^2). In the absence of more detailed information, NREL uses 3 MW/km^2 as the default for calculating the potential capacity of a lease area or WEA, which is a conservative estimate of eventual installed capacity for many cases (Musial et al. 2013, 2016). However, remaining conservative in this estimation allows for possible reductions to the developable area that may be necessary to accommodate navigation lanes, geohazards, technology setbacks, prescribed turbine spacing, and other easements without overstating the generating potential (Musial et al. 2013). As projects become more precisely defined, developers often achieve higher array densities. The pipeline capacity totals are adjusted when those decisions are publicly announced.

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[2] A Call Area is the precursor to a wind energy area (WEA), which is designated after significant public review of the original Call Area. After the WEA is designated, it is subdivided into individual lease areas prior to a competitive auction. It is possible that the Bureau of Ocean Energy Management (BOEM) may reduce the size of a designated WEA before the final lease areas are announced.

[3] Note that this year, the classification of some WEAs was changed to "dormant," which means they are no longer being actively reviewed or developed by BOEM. Dormant WEAs are not counted in the pipeline.

Table 1 describes the classification criteria used in this report for tracking the development of offshore wind energy projects in the United States, but these criteria are also applied to the global project classification. However, some differences between the domestic and global regulatory processes may not allow for direct comparisons, especially during the earlier stages of planning because some countries have different methods of establishing "site control."

Table 1. Offshore Wind Project Pipeline Classification Criteria

Step	Phase Name	Start Criteria	End Criteria
1	Planning	Starts when a developer or regulatory agency initiates the formal site control process (e.g., designation of a WEA)	Ends when a developer obtains control of a site (e.g., through competitive auction or a determination of no competitive interest in an unsolicited lease area (United States only)
2	Site Control	Begins when a developer obtains site control (e.g., a lease or other contract)	Ends when the developer files major permit applications (e.g., a Construction and Operations Plan [COP] for projects in the United States)
3	Permitting = Site Control + Offtake Pathway	Starts when the developer files major permit applications (e.g., a COP or an offtake agreement for electricity sales)	Ends when regulatory entities authorize the project to proceed with construction and certify its offtake agreement
4	Approved	Starts when a project receives regulatory approval for construction activities and offtake agreement certification	Ends when sponsor announces a "financial investment decision" and has signed contracts for construction work packages
5	Financial Close	Starts when sponsor announces a financial investment decision and has signed contracts for major construction work packages	Ends when the project begins major construction work
6	Under Construction	Starts when construction is initiated[4]	Ends when all wind turbines have been installed and the project is connected and generating power to an electrical grid
7	Operating	Starts when all wind turbines are installed and transmitting power to the grid; COD marks the official transition from construction to operation	Ends when the project has begun a formal process to decommission and stops feeding power to the grid
8	Decommis-sioned	Starts when the project has begun the formal process to decommission and stops transmitting power to the grid	Ends when the site has been fully restored and lease payments are no longer being made

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[4] Note that some developers may elect to start construction at an onshore landing area to secure certain subsidies or tax incentives.

1.2 Report Structure

The remainder of this report is divided into four sections:

- Section 2 summarizes the status of the offshore wind energy industry in the United States, providing in-depth coverage on the project development pipeline, regulatory activity, offtake mechanisms, infrastructure and vessel trends, and regional developments.
- Section 3 provides an overview of the global offshore wind energy market. Operational and proposed future projects are tracked by country, status, COD, and capacity. Developments on international floating offshore wind energy projects are also covered in detail.
- Section 4 describes offshore wind energy siting and technology trends focusing on wind turbine technologies, turbine manufacturers, project performance, fixed-bottom substructures, electrical power systems, and floating technologies.
- Section 5 provides insight into global and domestic offshore wind capital and operating costs, procurement prices, and financing trends for both fixed-bottom and floating technologies.

2 U.S. Offshore Wind Market Assessment

2.1 U.S. Offshore Wind Industry Overview

The U.S. offshore wind energy pipeline grew by 13.5% between May 31, 2021, and May 31, 2022.[5] In addition to this continued global market expansion, in the United States multiple projects advanced within the project development pipeline. The U.S. pipeline expansion was driven primarily by two new BOEM WEA lease auctions, the announcement of new WEAs in California, and the initiation of construction activities for the first two commercial projects. In addition, there were 10 new power offtake awards and a continued swell of industry supply chain, port, vessel, and infrastructure investments. Some of the U.S. highlights in this 2022 report edition include:

- In October 2021, BOEM announced the "Offshore Wind Leasing Path Forward 2021–2025," which calls for up to seven new offshore wind lease auctions in various U.S. regions, including the New York Bight, Carolina Long Bay, California, Gulf of Mexico, Central Atlantic, Oregon, and the Gulf of Maine. In February 2022, the first of these auctions was held for six lease areas in the New York Bight, which can support at least 5,600 MW of new capacity. This auction netted a record $4.37 billion from lease sales. In May 2022, the second auction was held for two lease areas in Carolina Long Bay that netted $315 million in lease fees and can support at least 1,337 MW of new capacity.
- In November 2021, Avangrid and Copenhagen Infrastructure Partners initiated construction on the 800-MW Vineyard Wind 1 project, with a groundbreaking held at the cable landing site at Covell's Beach in Barnstable, Massachusetts. The project is expected to be fully operational in 2024. Additionally, in February 2022, Ørsted and Eversource broke ground on their 132-MW South Fork Wind Farm project in East Hampton, New York, which is expected to become fully operational at the end of 2023.
- In December 2021, five new offtake agreements were awarded: two in Maryland for the Skipjack 2 project (808 MW) and the Momentum Wind project (848 MW), and three in Massachusetts (two for the Commonwealth Wind project [1,232 MW] and one for the Mayflower Wind 2 project [400 MW]), for a total increase in contracted capacity of 3,288 MW.
- BOEM has published a Record of Decision (ROD) for Vineyard Wind 1 and South Fork Wind Farms and announced that by 2025, it would complete the review of at least 16 Construction and Operations Plans (COPs).

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[5] Note: This Offshore Wind Market Report covers U.S. offshore wind energy development through May 31, 2022. International developments are only tracked through Dec. 31, 2021.

2.2 U.S. Offshore Wind Energy Market Potential and Project Pipeline Assessment

2.2.1 U.S. Offshore Wind Energy Pipeline

As of May 31, 2022, NREL estimates the U.S. offshore wind energy pipeline to have 40,083 MW of capacity, which is the sum of current installed projects, approved projects, projects in the permitting process, existing lease areas, and unleased WEAs. Table 2 shows the U.S. market divided into seven segments by capacity.

Table 2. U.S. Offshore Wind Energy Pipeline Categories

Status	Description	Total (MW)
Operating	The project is fully operational with all wind turbines generating power to the grid.	42
Under Construction	All permitting processes completed. Wind turbines, substructures, and cables are in the process of being installed. Onshore upgrades are underway.	932
Financial Close	All permitting processes completed. Begins when sponsor announces final investment decision and has signed contracts.	0
Approved	BOEM and other federal agencies reviewed and approved a project's COP. The project has received all necessary state and local permits as well as acquiring an interconnection agreement to inject power to the grid.	0
Permitting	The developer has site control of a lease area, has submitted a COP to BOEM, and BOEM has published a Notice of Intent to prepare an Environmental Impact Statement on the project's COP. If project development occurs in state waters, permitting is initiated with relevant state agencies.	18,581
Site Control	The developer has acquired the right to develop a lease area and has begun surveying the lease area.	15,996
Unleased Wind Energy Area	The rights to a lease area have yet to be auctioned to offshore wind energy developers. Capacity is estimated using a 3 MW/km^2 wind turbine density assumption.	4,532

We used developer-specified project capacity values for the most advanced projects in the pipeline, which include operating projects (42 MW), projects under construction (932 MW), approved projects (0 MW), and projects working through the permitting and offtake process (18,581 MW). These projects have announced project plans, a specified site boundary, and specified design details related to wind turbine size, array density, and nameplate capacity, among other things.

The most impactful changes in the U.S. pipeline from the "Offshore Wind Market Report: 2021 Edition" are as follows:

- The advancement of Vineyard Wind 1 (800 MW) from “approved” to “under construction” in November 2021
- The advancement of South Fork Wind Farm (132 MW) from “permitting” to “under construction” in February 2022
- Redefining the “permitting” category definition to require a submittal of a COP and BOEM issuing a Notice of Intent that the COP is under review
- The February 2022 sale of six lease areas in the New York Bight, adding at least 5,600 MW of new capacity to the “site control” category
- The designation of the Humboldt Bay (1,607 MW) and Morro Bay (2,925 MW) WEAs in California in November 2021[6]
- The May 2022 sale of two lease areas in Carolina Long Bay, adding at least 1,337 MW of new capacity to the “site control” category
- Recategorizing Fairways North, Fairways South, and Wilmington West WEAs as “dormant” and removing their capacities from the pipeline.

Figure 1 shows the U.S. pipeline activity as of May 31, 2022, for all categories in Table 2 by project status and state. The U.S. pipeline by project status includes:

- 2 operating projects (42 MW)
- 2 under construction (Vineyard Wind 1 [800 MW] and South Fork Wind Farm [132 MW])
- 18 (18,581 MW)[7] with site control, submitted a COP with BOEM issuing a Notice of Intent to prepare an Environmental Impact Statement of the COP, and are in the process of securing a power offtake contract
- 17 lease areas that developers have the rights to possibly develop (a technical potential of at least 15,996 MW)
- 2 active, unleased WEAs (with the potential to support at least 4,532 MW).

Note that in Figure 1, we enlarged the vertical scale for operating projects to show the two U.S. projects at a higher resolution.

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[6] Note: BOEM issued a proposed sale notice on May 26, 2022, that recommends these California WEAs be subdivided into five new lease areas.

[7] Note: most developers are submitting one COP for a design envelope for the entire lease area, in which the developer may build multiple or phased projects. Therefore, we counted Sunrise Wind 1 and Sunrise Wind Residual as one project.

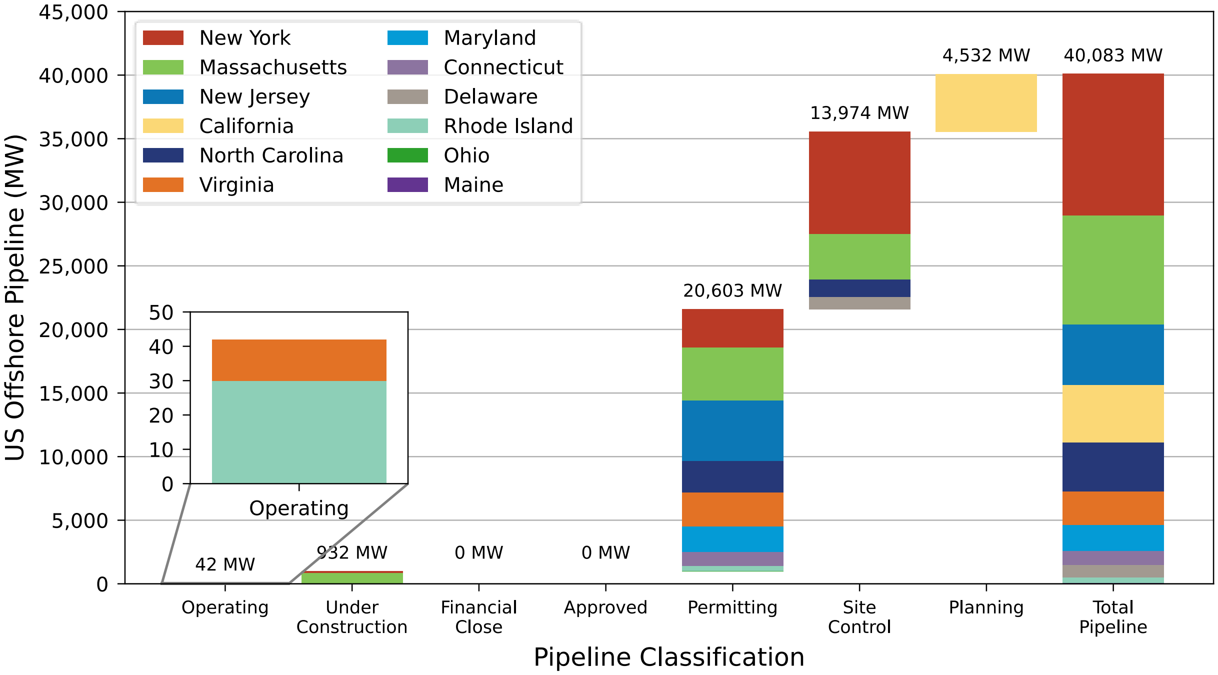

Figure 1. U.S. project pipeline classification by status

Projects progressing through offtake and permitting approval processes are primarily located in the Northeastern United States. The availability of new lease areas, the emergence of new Call Areas, and the presence or absence of state-level procurement policies currently impact project development. Recent regulatory activity outside the North Atlantic region of the United States indicates a trend toward increased geographic diversification for offshore wind. The creation of WEAs in California and new Call Areas are described in Section 2.3.3.

Figure 2 shows the same pipeline data but sorted by state. Note, Figure 2 allocates capacities to states based on power offtake contracts, not geographic location.[8] With the six new lease areas in the New York Bight, New York and New Jersey now have a combined estimated pipeline potential of more than 15,915 MW. Massachusetts has an estimated pipeline capacity of 8,553 MW.

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[8] For example, Revolution Wind is subdivided such that 304 MW is allocated to Connecticut and 400 MW is allocated to Rhode Island. Sunrise Wind Residual is allocated to Massachusetts and Beacon Wind is allocated to New York. Since neither of the “residual sites” have offtake contracts, offtake location was assigned based on state offshore wind procurement goals. It is likely that future procurement actions will impact the size of these projects and which state they ultimately sell power to.

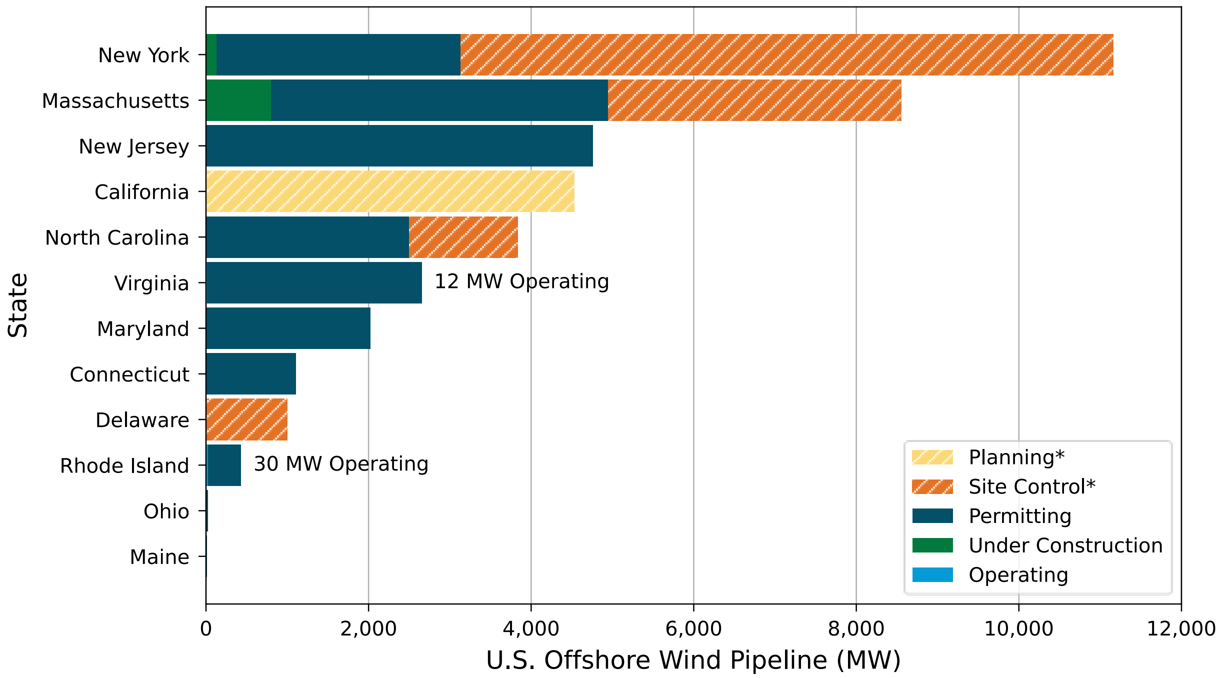

Figure 2. U.S. project pipeline by state

*Note: Offtake contracts may not always be with the state where the project is built. Projects in the "Planning" and "Site Control" phases are assigned to the state where the WEA is geographically located.

All 40,083 MW that make up the U.S. offshore wind energy pipeline are listed as individual projects or project opportunities in Table 3, Table 4, and Table 5 as well as maps shown in Figure 3, Figure 4, and Figure 5, each corresponding to the North Atlantic and Great Lakes, South Atlantic and Gulf of Mexico, and West Coast and Hawaii, respectively.[9]

Table 3, Table 4, and Table 5 include 11 Call Areas located in three regions, but the potential generating capacities of the Call Areas are not calculated or counted in the total pipeline capacity because these areas are considered preliminary and are likely to change in size and location. In total, there are 56 sites in the United States where there is offshore wind energy development activity (as shown on the three maps, compared to 39 sites in the "Offshore Wind Market Report: 2021 Edition"). Among this activity are three projects in state waters, including the operating Block Island Wind Farm in Rhode Island, New England Aqua Ventus I in Maine, and the Lake Erie Energy Development Corporation (LEEDCo) Icebreaker project located just north of Cleveland. Both Aqua Ventus and Icebreaker are funded under the DOE Advanced Technology Demonstration Project program, which began in 2012 (DOE undated [a]).

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[9] Note that the first column in Table 3, Table 4, and Table 5 corresponds to the project number(s) on the maps. Please also note that project capacities (where announced by developers) are subject to change as permitting and project development processes mature.

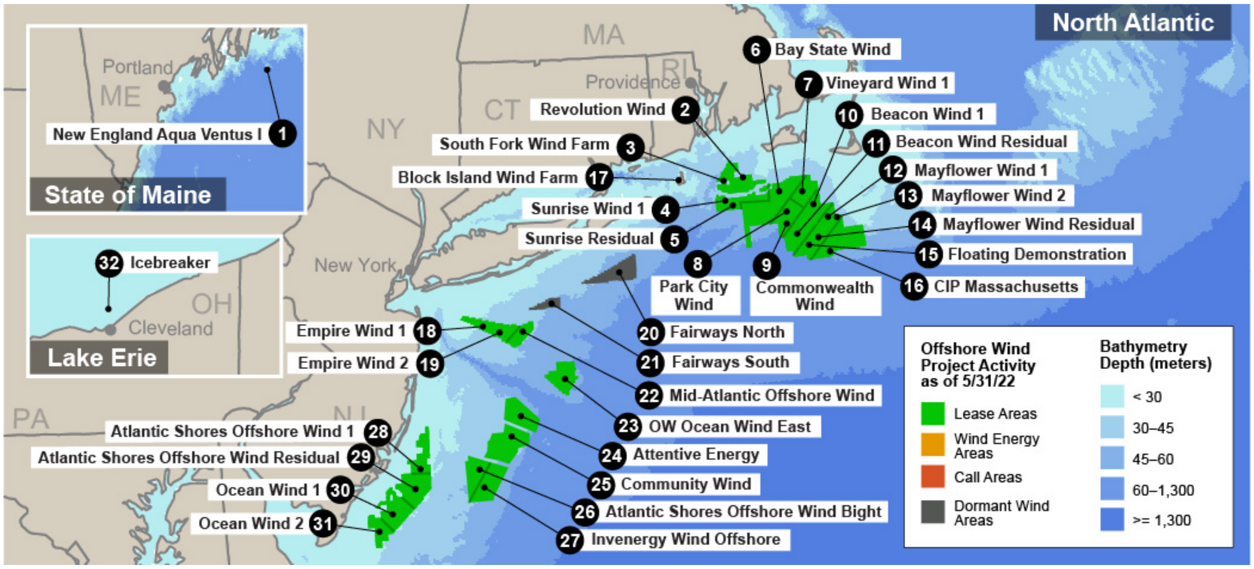

Figure 3. U.S. North Atlantic and Great Lakes offshore wind energy pipeline and Call Areas as of May 31, 2022. ***Map created by NREL***

Table 3. U.S. Offshore Wind Energy Pipeline (North Atlantic and Great Lakes)

No.	Geographic Location	Project Name	Developer	Lease Area	Offtake Agreement	Estimated Commercial Operation Date	Installed (MW)	Under Construction (MW)	Permitting (MW)	Site Control (MW)	Planning (MW)
1	ME	New England Aqua Ventus I	Univ. of Maine/ Diamond Offshore/ RWE	State Lease	Power purchase agreement PPA (ME)	2024			12		
2	MA/RI	Revolution Wind	Ørsted and Eversourc	OCS-A 0486	PPA (RI) PPA (CT)	2024			704		
3	MA/RI	South Fork Wind Farm	Ørsted and Eversource	OCS-A 0517	PPA (NY)	2023		132			
4	MA/RI	Sunrise Wind 1	Ørsted and Eversource	OCS-A 0487	PPA (NY)	2025			924		
5	MA/RI	Sunrise Residual	Ørsted and Eversource	OCS-A 0487	To be determined (TBD)	TBD			900		
6	MA	Bay State Wind	Ørsted and Eversource	OCS-A 0500	TBD	TBD				2,000	
7	MA	Vineyard Wind 1	Avangrid and CIP	OCS-A 0501	PPA (MA)	2024		800			
8	MA	Park City Wind	Avangrid	OCS-A 0534	PPA (CT)	2025			800		
9	MA	Commonwealth Wind	Avangrid	OCS-A 0534	PPA (MA)	2027			1,232		
10	MA	Beacon Wind 1	Equinor and BP	OCS-A 0520	Offshore renewable energy credit (OREC) (NY)	2028				1,230	
11	MA	Beacon Wind Residual	Equinor and BP	OCS-A 0520	TBD	TBD				1,200	
12	MA	Mayflower Wind 1	Ocean Winds and Shell	OCS-A 0521	PPA (MA)	2025			804		
13	MA	Mayflower Wind 2	Ocean Winds and Shell	OCS-A 0521	PPA (MA)	2025			400		

No.	Geographic Location	Project Name	Developer	Lease Area	Offtake Agreement	Estimated Commercial Operation Date	Installed (MW)	Under Construction (MW)	Permitting (MW)	Site Control (MW)	Planning (MW)
14	MA	Mayflower Wind Residual	Ocean Winds and Shell	OCS-A 0521	TBD	TBD			800		
15	MA	Floating Demonstration	Shell/ Kent Houston Offshore Engineering/Ocergy	OCS-A 0521	TBD	TBD			10		
16	MA	CIP Massachusetts	CIP	OCS-A 0522	TBD	TBD				1,607	
17	RI	Block Island Wind Farm	Ørsted and Eversource	State Lease	PPA (RI)	2016	30				
18	NY	Empire Wind 1	Equinor and BP	OCS-A 0512	OREC (NY)	2026			816		
19	NY	Empire Wind 2	Equinor and BP	OCS-A 0512	OREC (NY)	2027			1,260		
20	NY	Fairways North	-	WEA	-	-					Dormant
21	NY	Fairways South	-	WEA	-	-					Dormant
22	NY/NJ	Mid-Atlantic Offshore Wind	CIP	OCS-A 0544	TBD	TBD				523	
23	NY/NJ	OW Ocean Winds East	EDPR and Engie	OCS-A 0537	TBD	TBD				868	
24	NY/NJ	Attentive Energy	Total Energies	OCS-A 0538	TBD	TBD				964	
25	NY/NJ	Community Wind	RWE and National Grid	OCS-A 0539	TBD	TBD				1,387	
26	NY/NJ	Atlantic Shores Offshore Wind Bight	Shell and EDF	OCS-A 0541	TBD	TBD				924	
27	NY/NJ	Invenergy Wind Offshore	Invenergy and Lighthouse Energy	OCS-A 0542	TBD	TBD				934	
28	NJ	Atlantic Shores Offshore Wind 1	Shell and EDF	OCS-A 0499	OREC (NJ)	2027			1,510		
29	NJ	Atlantic Shores Offshore Wind Residual	Shell and EDF	OCS-A 0499	TBD	TBD			1,000		

No.	Geographic Location	Project Name	Developer	Lease Area	Offtake Agreement	Estimated Commercial Operation Date	Installed (MW)	Under Construction (MW)	Permitting (MW)	Site Control (MW)	Planning (MW)
30	NJ	Ocean Wind 1	Ørsted and PSEG	OCS-A 0498	OREC (NJ)	2025			1,100		
31	NJ	Ocean Wind 2	Ørsted and PSEG	OCS-A 0532	OREC (NJ)	2028			1,148		
32	OH	Icebreaker	LEEDCo	State Lease	PPA (OH)	2042			21		
Regional Totals							**30**	**932**	**13,441**	**11,637**	**0**

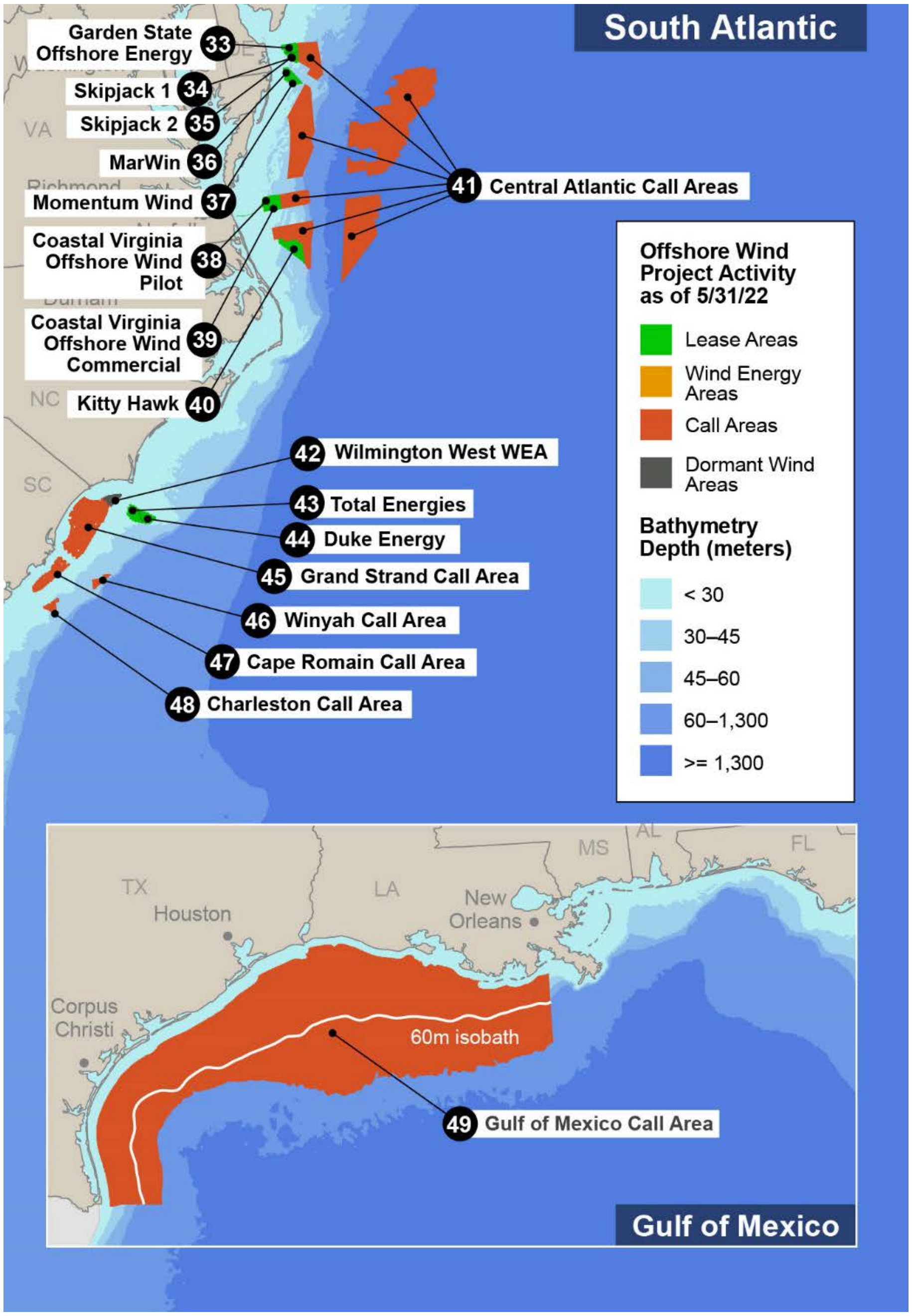

Figure 4. South Atlantic and Gulf of Mexico offshore wind pipeline and Call Areas as of May 31, 2022. *Map created by NREL*

Table 4. U.S. Offshore Wind Pipeline (South Atlantic and Gulf of Mexico)

No.	Geographic Location	Project Name	Developer	Lease Area	Offtake Agreement	Estimated Commercial Operation Date	Installed (MW)	Under Construction (MW)	Permitting (MW)	Site Control (MW)	Planning (MW)
33	DE	Garden State Offshore Energy	Ørsted	OCS-A 0482	TBD	TBD				1,000	
34	DE	Skipjack 1	Ørsted	OCS-A 0519	OREC (MD)	2026				120	
35	DE	Skipjack 2	Ørsted	OCS-A 0519 and OCS-A 0482	OREC (MD)	2026				808	
36	MD	MarWin	U.S. Wind	OCS-A 0499	OREC (MD)	2024				248	
37	MD	Momentum Wind	U.S. Wind	OCS-A 0499	OREC (MD)	2026				846	
38	VA	Coastal Virginia Offshore Wind–Pilot	Dominion Energy	OCS-A 0483	Utility Owned	2020	12				
39	VA	Coastal Virginia Offshore Wind – Commercial	Dominion Energy	OCS-A 0487	Utility Owned	2026			2,640		
40	NC	Kitty Hawk	Avangrid	OCS-A 0508	TBD	2027			2,500		
41	DE/MD/ VA/NC	Central Atlantic Call Areas	-	Call Areas	-	-					
42	NC	Wilmington West WEA	-	-	-	-					Dormant
43	NC	Total Energies	Total Energies Renewables USA	OCS-A 0545	-	-				667	
44	NC	Duke Energy	Duke Energy Renewables Wind	OCS-A 0546	-	-				670	
45	SC	Grand Strand Call Area	-	Call Area	-	-					
46	SC	Winyah Call Area	-	Call Area	-	-					
47	SC	Cape Romain Call Area	-	Call Area	-	-					
48	SC	Charleston Call Area	-	Call Area	-	-					
49	LA/TX/ AL/MS	Gulf of Mexico Call Area	-	Call Area	-	-					
Regional Totals							**12**	**0**	**5,140**	**4,359**	**0**

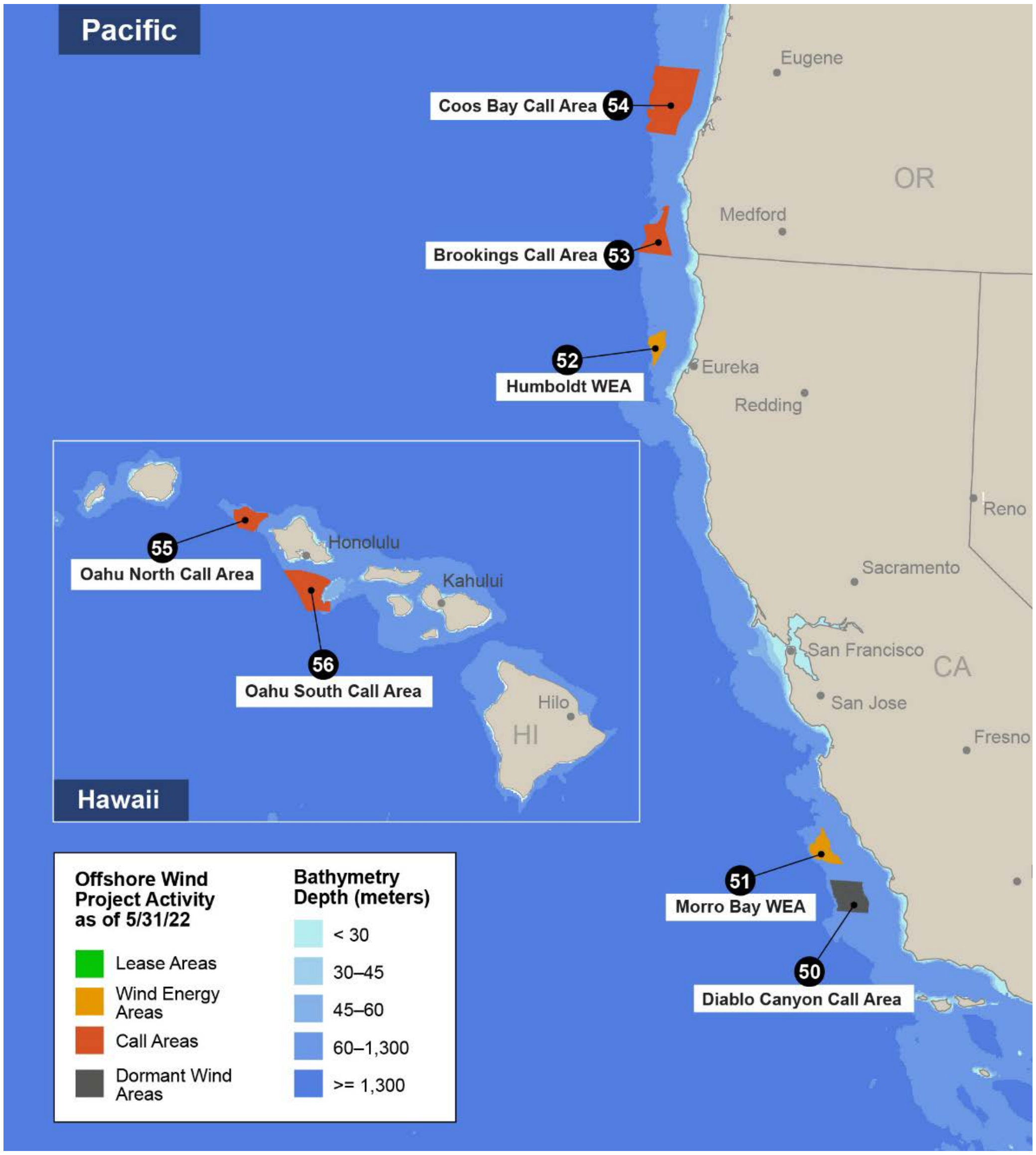

Figure 5. Pacific offshore wind energy pipeline and Call Areas as of May 31, 2022. *Map created by NREL*

Table 5. U.S. Offshore Wind Pipeline (Pacific)

No.	Geographic Location	Project Name	Developer	Lease Area	Offtake Agreement	Estimated Commercial Operation Date	Installed (MW)	Under Construction (MW)	Permitting (MW)	Site Control (MW)	Planning (MW)
50	CA	Diablo Canyon Call Area	-	Call Area	-	-					dormant
51	CA	Morro Bay WEA	-	WEA	-	-					2,925
52	CA	Humboldt WEA	-	WEA	-	-					1,607
53	OR	Brookings Call Area	-	Call Area	-	-					
54	OR	Coos Bay Call Area	-	Call Area	-	-					
55	HI	Oahu North Call Area	-	Call Area	-	-					
56	HI	Oahu South Call Area	-	Call Area	-	-					
Regional Totals											**4,532**

2.2.2 U.S. Offshore Wind Market Forecasts to 2030

Figure 6 shows two independent forecasts for offshore wind energy deployment in the United States through 2031. The chart illustrates the degree of expected market growth and the possible variability associated with the year, size, and location of future projects.

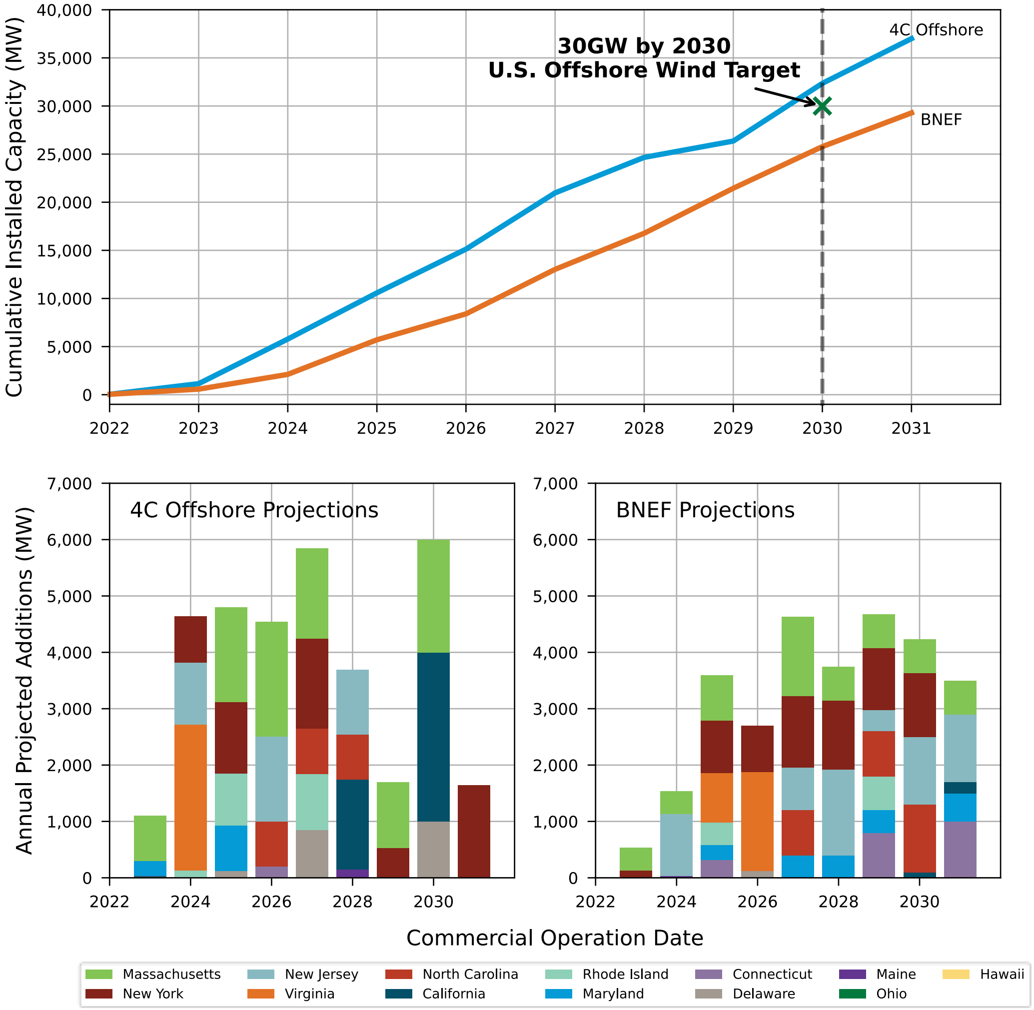

Figure 6. Industry offshore wind U.S. deployment projections to 2031

The forecasts in Figure 6 were developed by BNEF (2021a) and 4C Offshore (2022a), which estimate that offshore wind energy deployments in the U.S. market will cumulatively reach 26 GW and 32 GW by 2030, respectively. Note that both projections cited in the "Offshore Wind Market Report: 2021 Edition" estimated deployment numbers below the administration's 30-GW-by-2030 target. This year, the 4C Offshore forecast of 32 GW suggests that these industry forecasters predict that the administration's deployment goal is becoming more achievable, although continued support from individual states, industry, and the federal government will likely be needed. The actual size and speed of U.S. offshore wind buildout will depend on continued regulatory efficiency, the availability of installation vessels and port infrastructure, proactive onshore and offshore grid planning and upgrades, the successful commercialization of the 15-MW wind turbine platforms,[10] and sustained market demand.

These forecasts predict that most of the future offshore wind energy deployment out to 2031 will occur on the East Coast in states with existing offshore wind energy procurement goals. Only 4C Offshore's forecast includes U.S. floating projects before 2030, which are presumed to be in California and Maine.

2.3 Regulatory Activity

2.3.1 Regulatory Overview

Acquiring exclusive rights to develop a lease area is necessary for building an offshore wind energy project in the United States. The United States experienced a significant uptick in regulatory activity in 2021 and early 2022 because of BOEM's "Offshore Wind Leasing Path Forward 2021–2025," a plan announced in October 2021 to open new offshore wind development in up to seven regions (Figure 7). The first two auctions were held so far: one for six lease areas in the New York Bight, and another for two lease areas in Carolina Long Bay. In addition, two new WEAs were designated in California, and four new Call Areas were created.

Federal permitting in the United States involves several major steps after a lease area is acquired. First, BOEM reviews and issues permits for a site assessment plan (SAP) that enables the developer to begin collecting data on the lease area. The developer will later submit a COP, which is a comprehensive project plan that is reviewed by BOEM. If successful, BOEM will approve the COP and issue a ROD that enables the developer to start construction. Table 6 describes the current federal permitting status for projects in each lease area in the order that the leases were issued.

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[10] Wind turbine manufacturers typically design new turbines around a range of generator and rotor sizes that all perform within the design limits of a basic structural frame referred to here as the "platform." Recently, most of the offshore wind industry turbine manufacturers have moved to a nominal 15-MW "platform," which may have nameplate ratings that are incrementally greater or less than 15 MW.

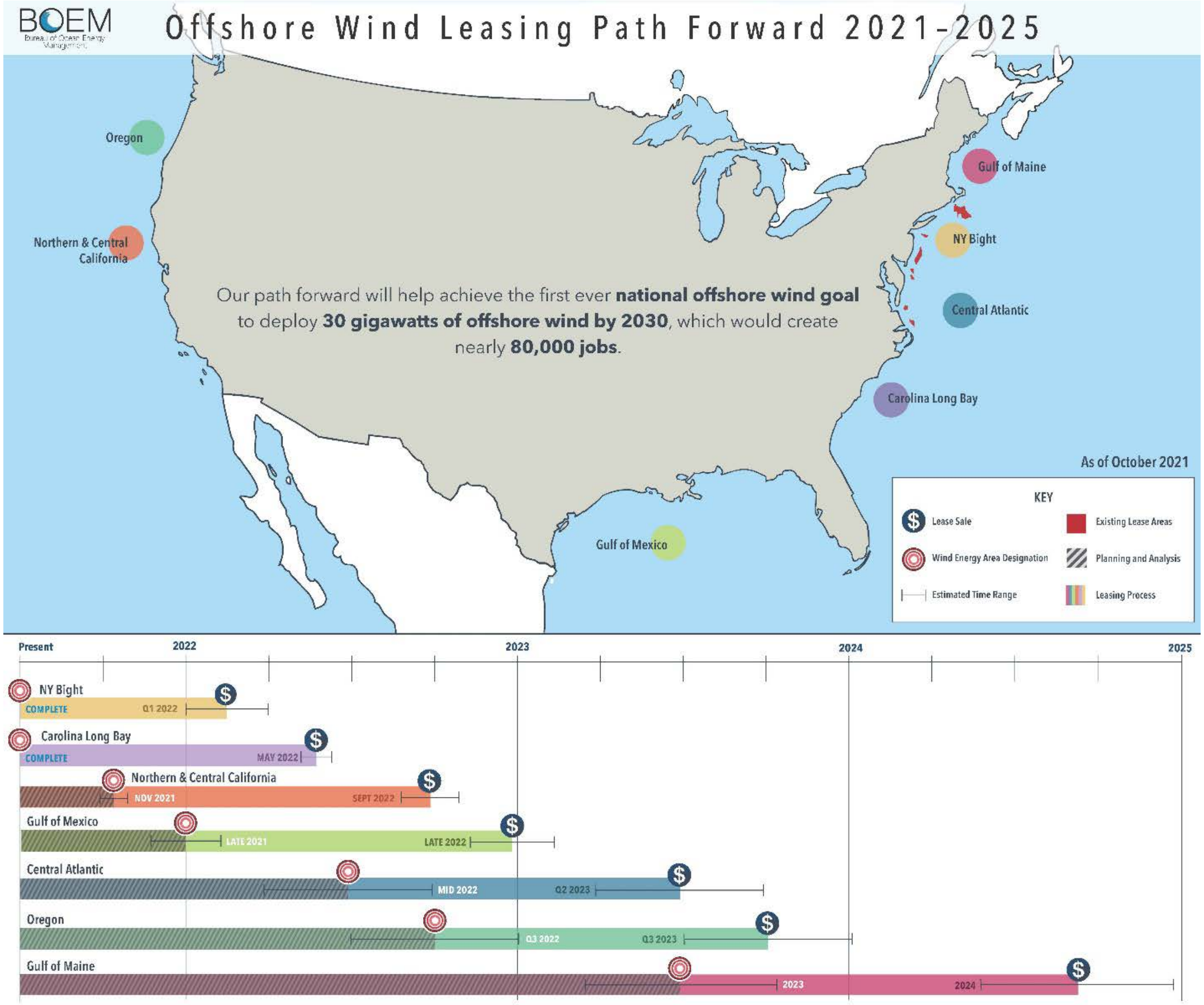

Figure 7. BOEM's "Offshore Wind Leasing Path Forward 2021–2025." *Image created by BOEM*

Table 6. U.S. Federal Offshore Wind Lease Permitting Status as of May 31, 2022

Geographic Location	Lease Number	Area (km²)	Date Issued	Project(s) Being Developed in Lease Area	Status
Delaware	OCS-A 0482	284	2012	Garden State Offshore Energy Skipjack 2	SAP Approved (COP Not Submitted)
Virginia	OCS-A 0483	456	2013	Coastal Virginia Offshore Wind – Commercial	COP Submitted – Notice of Intent (NOI) for Environmental Impact Statement (EIS)
Massachusetts/Rhode Island	OCS-A 0486	339	2013	Revolution Wind	COP Submitted – NOI for EIS
Massachusetts/Rhode Island	OCS-A 0517	55	2013	South Fork	ROD Approved – Under Construction
Massachusetts/Rhode Island	OCS-A 0487	445	2013	Sunrise Wind 1	COP Submitted – NOI for EIS
Maryland	OCS-A 0490	323	2014	MarWin	SAP Approved (COP Not Submitted)
Massachusetts	OCS-A 0500	586	2015	Bay State Wind	COP Submitted
Massachusetts	OCS-A 0501	264	2015	Vineyard Wind 1	ROD Approved – Under Construction
Massachusetts	OCS-A 0534	411	2015	Park City Wind Commonwealth Wind	COP Submitted – NOI for EIS
New Jersey	OCS-A 0498	306	2016	Ocean Wind 1	COP Submitted – NOI for EIS
New Jersey	OCS-A 0532	344	2016	Ocean Wind 2	COP Submitted – NOI for EIS
New Jersey	OCS-A 0499	742	2016	Atlantic Shores Offshore Wind	COP Submitted – NOI for EIS
North Carolina	OCS-A 0508	495	2017	Kitty Hawk	COP Submitted – NOI for EIS
New York	OCS-A 0512	321	2017	Empire Wind 1 & 2	COP Submitted – NOI for EIS
Delaware	OCS-A 0519	107	2018	Skipjack 1& 2	SAP Approved (COP Not Submitted)
Massachusetts	OCS-A 0520	521	2018	Beacon Wind	SAP Approved (COP Not Submitted)
Massachusetts	OCS-A 0521	516	2018	Mayflower Wind 1 & 2 Shell/Kent HOE/Ocergy Demonstration	COP Submitted – NOI for EIS
Massachusetts	OCS-A 0522	536	2018	CIP Massachusetts	SAP Approved (COP Not Submitted)
New York/New Jersey	OCS-A 0544	174	2022	Mid-Atlantic Offshore Wind	Provisional Auction Winner
New York/New Jersey	OCS-A 0537	289	2022	OW Ocean Winds East	Provisional Auction Winner
New York/New Jersey	OCS-A 0538	321	2022	Attentive Energy	Provisional Auction Winner
New York/New Jersey	OCS-A 0539	462	2022	Community Wind	Provisional Auction Winner
New York/New Jersey	OCS-A 0541	308	2022	Atlantic Shores Offshore Wind Bight	Provisional Auction Winner
New York/New Jersey	OCS-A 0542	311	2022	Invenergy Wind Offshore	Provisional Auction Winner
North Carolina	OCS-A 0545	222	2022	Total Energies	Provisional Auction Winner
North Carolina	OCS-A 0546	223	2022	Duke Energy	Provisional Auction Winner

2.3.2 Lease Activity

In February 2022, BOEM auctioned six lease areas in the New York Bight (see Table 7 and Figure 8 for the auction results) (Bureau of Ocean Energy Management 2022b). This auction was the first held in the United States since three lease areas in the Massachusetts WEA were auctioned in 2018 for about $154 million each. Lease areas in the New York Bight auction ranged from $285 million to $1.1 billion, for a total of $4.37 billion for all six lease areas, which increased the pipeline capacity by at least 5,600 MW. The New York Bight winning bids set new records for offshore wind lease prices. The new leases also added several new developers, including Engie, Total Energies, RWE, and Invenergy. When developed, electricity from these new lease areas is likely to be sold to either New York or New Jersey, which have made policy procurement mandates of 9,000 MW and 7,500 MW, respectively.

Table 7. New York Bight Lease Area Auction Results

Lease Number	Purchaser	Developer	Area (km^2)	Capacity (MW)	Price	Price per km^2
OCS-A 0544	Mid-Atlantic Offshore Wind LLC	CIP	174	523	$285,000,000	$1,637,931
OCS-A 0537	OW Ocean Winds East LLC	EDPR and Engie	289	868	$765,000,000	$2,647,059
OCS-A 0538	Attentive Energy LLC	Total Energies	321	964	$795,000,000	$2,476,636
OCS-A 0539	Bight Wind Holdings LLC	RWE and National Grid	462	1,387	$1,100,000,000	$2,380,952
OCS-A 0541	Atlantic Shores Offshore Wind Bight LLC	Shell and EDF	308	924	$780,000,000	$2,532,468
OCS-A 0542	Invenergy Wind Offshore Wind LCC	Invenergy and EnergyRE	311	934	$645,000,000	$2,073,955

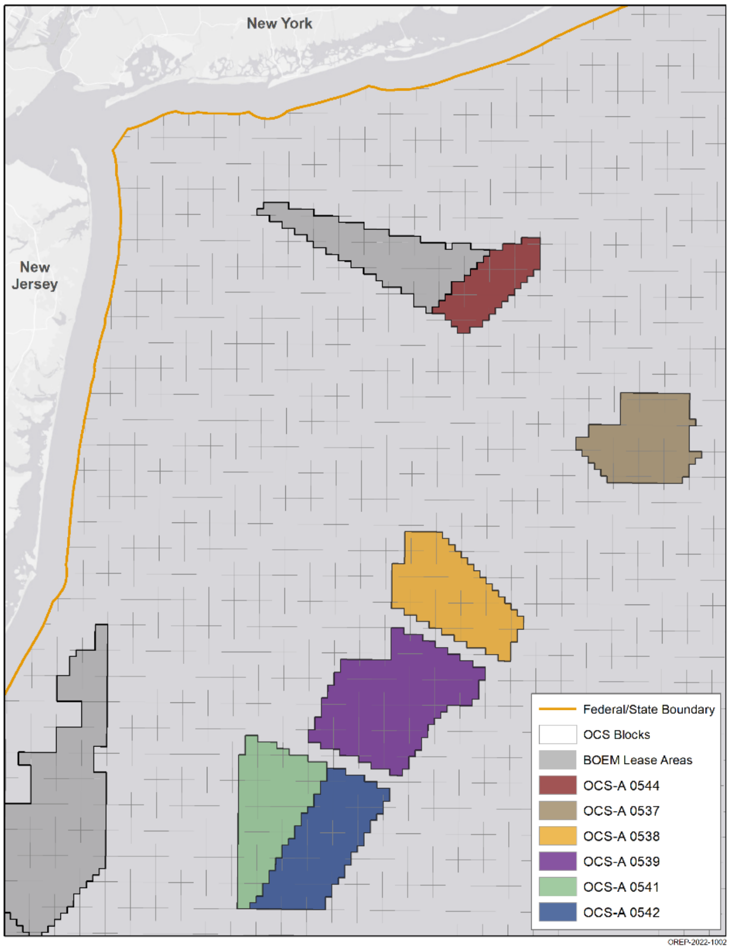

Figure 8. New York Bight leasing area map. ***Map created by BOEM***

In May 2022, BOEM auctioned two lease areas in the Carolina Long Bay (see Table 8 and Figure 9 regarding the auction results). The two lease areas have a combined capacity of at least 1,337 MW based on the conservative 3 MW/km^2 metric. Following the New York Bight auction by less than 3 months, the Carolina Long Bay auction final sale prices were significantly lower, with a combined total sale of $315 million. The two lease areas are near the North Carolina and South Carolina border and comprise 445 km^2. Further, the new tenants include Duke Energies Renewable Wind as a new player to the U.S. industry. When developed, electricity from these new lease areas is likely to be sold to either North Carolina or South Carolina. Through Executive Order 218, the state of North Carolina has a policy to develop 8,000 MW of offshore wind energy by 2040.

Before the Carolina Long Bay auction, all revenue generated from offshore wind lease sales was required to be returned to the United States Department of the Treasury. For Carolina Long Bay, BOEM changed its offshore wind auction format from a single factor (monetary) to multifactor bidding. The new format accounts for the highest cash bid coupled with nonmonetary factors, such as workforce development, supply chain, or community benefits. The auction format change enables some of the proposed investments that benefit the states and the local communities to be considered in the auction process.

Table 8. Carolina Long Bay Lease Area Auction Results

Lease Number	Purchaser	Area (km²)	Capacity (MW)	Price	Price per km²
OCS-A 0545	Total Energies Renewables USA LLC	222	667	$160,000,000	$720,721
OCS-A 0546	Duke Energies Renewable Wind LLC	223	670	$155,000,000	$695,067

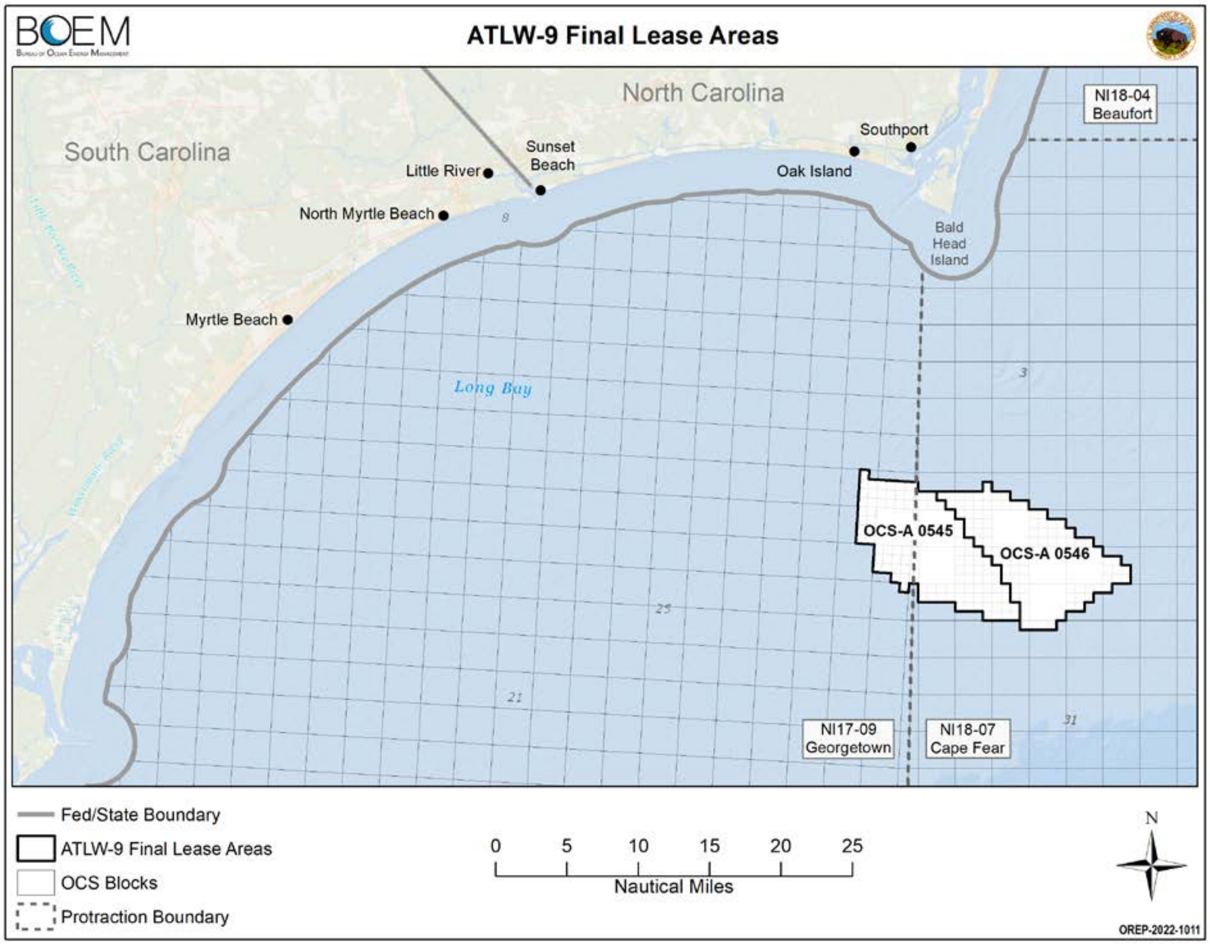

Figure 9. Carolina Long Bay wind energy auction. ***Map created by BOEM***

Figure 10 and Table 9 illustrate how winning bid prices for U.S. offshore wind lease areas have increased exponentially over time, from initial noncompetitive leases that sold at a very low cost in 2015, to the New York Bight leases in February 2022, wherein the winning bid for OCS-A 0539 was $1.1 billion. Figure 10 (with price per square kilometer plotted on a log scale) shows that high sale prices are strongly correlated with their proximity to states with aggressive procurement goals and contracted offtake mechanisms. These state policies give developers increased certainty regarding the demand for an offshore wind project's power, and adequate compensation via a power purchase agreement (PPA) or offshore renewable energy certificate (OREC). The absence of a robust state offshore wind policy may have reduced final lease prices in the Carolina Long Bay auction (May 2022), where lease areas that are roughly the same size as those in the New York Bight auction (February 2022) garnered lower bids. Other factors that may have also contributed to lower auction prices in Carolina Long Bay include lower wind speeds, limited port, supply chain, and grid infrastructure, as well as greater hurricane risk.

Conversely, factors that may be driving up bid prices in general include increased market confidence resulting from the recent issuance of RODs for two commercial projects, the announcement of BOEM's goal to complete 16 COP reviews by 2025, the March 2021 announcement of the administration's 30-GW-by-2030 goal, the scarcity of new lease areas, and more competition resulting from new offshore wind companies entering the market.

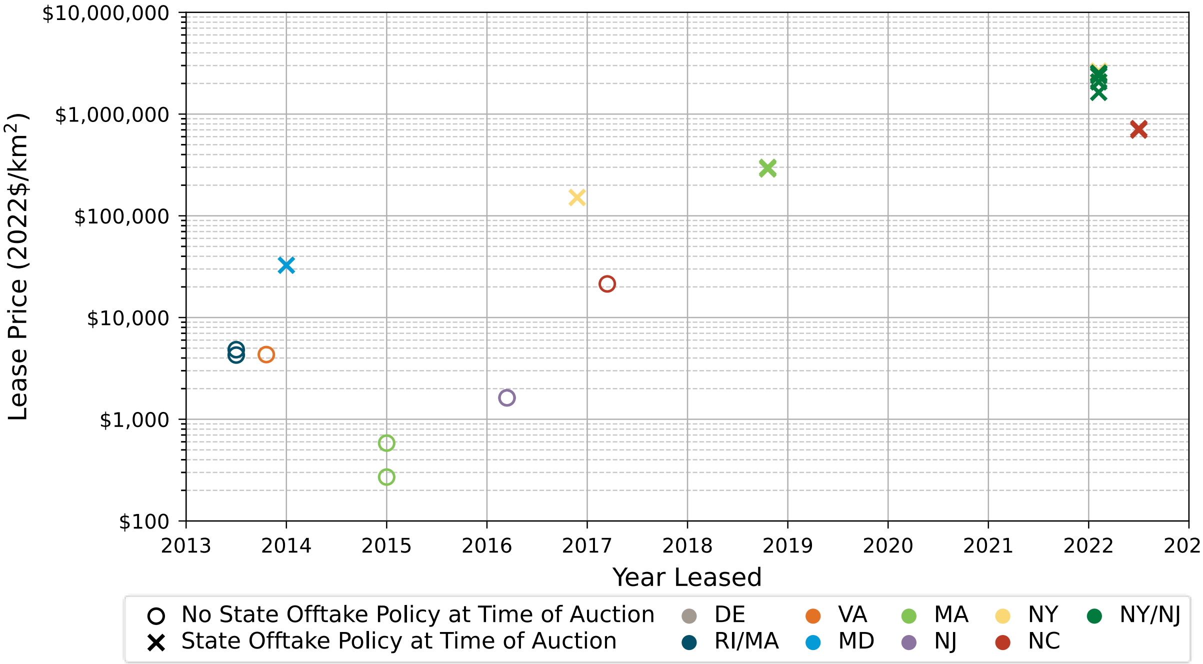

Figure 10. U.S. offshore wind lease price per square kilometer by year leased

Table 9. U.S. Offshore Wind Lease Prices (in Order Sold)

Lease	Lease Location	Year	Lease Price (2022$)	Price per km² (2022$)
OCS-A 0482/OCS-A 0519	Delaware	2012	N/A	N/A
OCS-A 0483/OCS-A 0497	Virginia	2013	$1,971,276	$4,323
OCS-A 0486/OCS-A 0517	Massachusetts/Rhode Island	2013	$1,903,181	$4,803
OCS-A 0487	Massachusetts/Rhode Island	2013	$1,903,181	$4,277
OCS-A 0490	Maryland[11]	2014	$10,553,535	$32,673
OCS-A 0498/OCA-A 0532	New Jersey	2016	$1,054,690	$1,625
OCS-A 0499	New Jersey	2016	$1,205,011	$1,624
OCS-A 0500	Massachusetts	2015	$341,474	$583
OCS-A 0501/OCS-A 0534	Massachusetts	2015	$182,336	$270
OCS-A 0512	New York	2016	$48,611,290	$151,437
OCS-A 0508	North Carolina	2017	$10,592,835	$21,400
OCS-A 0520	Massachusetts	2018	$154,525,000	$296,593
OCS-A 0521	Massachusetts	2018	$154,525,000	$299,467
OCS-A 0522	Massachusetts	2018	$154,639,500	$288,057
OCS-A 0537	New York/New Jersey	2022	$765,000,000	$2,643,039
OCS-A 0538	New York/New Jersey	2022	$795,000,000	$2,472,980
OCS-A 0539	New York/New Jersey	2022	$1,100,000,000	$2,378,569
OCS-A 0541	New York/New Jersey	2022	$780,000,000	$2,531,449
OCS-A 0542	New York/New Jersey	2022	$645,000,000	$2,072,760
OCS-A 0544	New York/New Jersey	2022	$285,000,000	$1,635,660
OCS-A 0545	North Carolina	2022	$160,000,000	$720,721
OCS-A 0546	North Carolina	2022	$155,000,000	$695,067

Based on progress made to date and BOEM announcements, the bureau will likely hold its next lease auction in California for the Morro Bay and Humboldt WEAs (Figure 11) following the leasing plan (BOEM 2022c).

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[11] Note that the 2014 Maryland offshore wind auction originally comprised two lease areas (OCS-A 0489 and OCS-A 0490) that were later combined; the listed price is the total for both original areas.

Figure 11. California WEAs at Humboldt Bay and Morro Bay. *Map courtesy of BOEM (2022)*

This will be the first commercial lease sale in the United States requiring the deployment of floating wind technology. In 2021, California State Legislature passed AB 525, which directs the California Energy Commission and other relevant agencies to evaluate and quantify the maximum feasible capacity of offshore wind energy to achieve reliability, ratepayer, employment, and decarbonization benefits, and to establish offshore wind energy planning goals for 2030 and 2045 (California Legislature 2021). California state agencies, with assistance from BOEM and NREL, updated their integrated resource planning methodology and models to include offshore wind scenarios. The Public Utilities Commission also directed the California Independent System Operator to analyze the transmission requirements for an 8,000-MW and 21,000-MW offshore wind scenario (California Independent System Operator 2022). On May 17, 2022, the California Energy Commission announced preliminary offshore wind energy goals of 3,000 MW by 2030, and between 10,000 and 15,000 MW by 2045 (California Energy Commission 2022), but these goals are still subject to revision as of this report writing. On May 26, 2022, BOEM released the Proposed Sales Notice for the Humboldt Bay and Morro Bay WEAs. The proposed sales notice comment period closes August 1, with the auction expected in fall 2022 (BOEM 2022d). This auction will likely result in the sale of two lease areas in the Humboldt WEA and three lease areas in the Morro Bay WEA (U.S. Department of the Interior 2022).

2.3.3 New Area Identification

BOEM publishes Calls for Information and Nominations to initiate the commercial competitive leasing process and assess commercial competitive interest for offshore wind energy development on specific parcels of ocean acreage in federal waters. The information gathered during these calls is used by BOEM in conjunction with other stakeholder input to identify future WEAs and subsequent lease area auctions. A Call Area is a precursor to a defined WEA, but not all Call Areas become WEAs, and they are typically modified (e.g., reduced in size or augmented) to address stakeholder input. Since May 2021, there have been several new areas identified for possible future development.

Following the creation of a regional intergovernmental taskforce including Louisiana, Alabama, Mississippi, and Texas, BOEM published a Call for Information and Nominations in 2021 for potential offshore wind areas in the Gulf of Mexico (BOEM 2021). The Call Area (Figure 12) comprises almost 30 million acres just west of the Mississippi River to the Texas/Mexico border, from the state/federal water boundary out to the 400-meter (m) isobath. On Jan. 11, 2022, BOEM announced it is preparing a draft environmental assessment to consider potential offshore wind leasing in federal waters of the Gulf of Mexico (BOEM 2022a). In February 2022, the Louisiana Climate Action Plan recommended the state develop a procurement goal of 5,000 MW of offshore wind energy by 2035 (State of Louisiana 2022). Offshore wind lease auctions are planned for 2023 in the Gulf of Mexico.

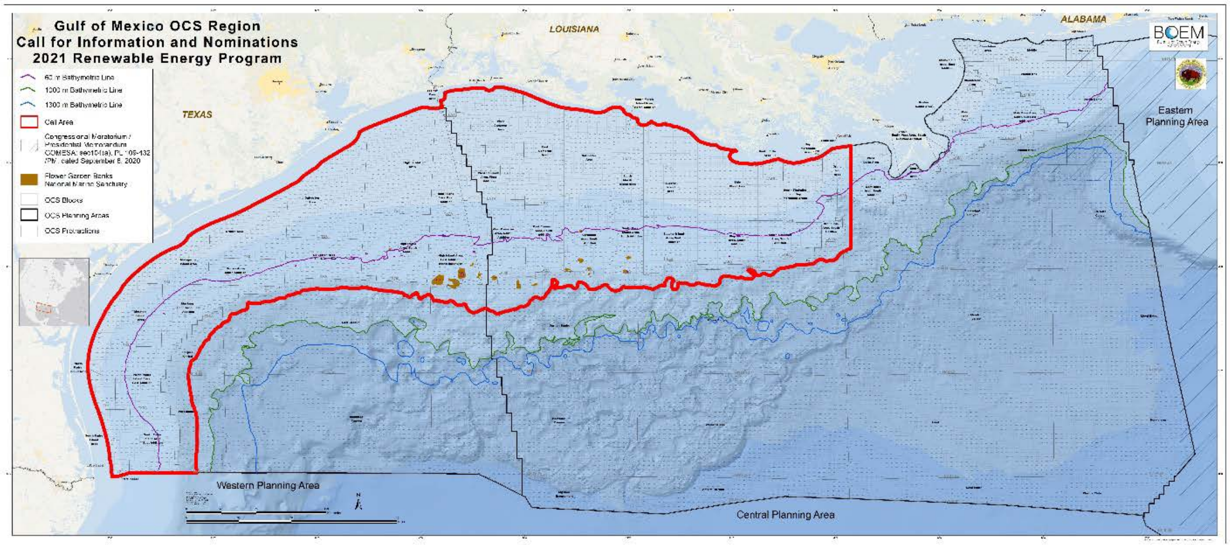

Figure 12. Gulf of Mexico Call Area. ***Map created by BOEM***

In September 2021, the State of Oregon passed HB 3375, setting a planning goal for the development of up to three gigawatts of floating offshore wind energy in the federal waters off the Oregon coast by 2030 (Oregon State Legislature 2021). This law coincides with BOEM’s Intergovernmental Task Force developing two Call Areas off the Oregon coast, announced by BOEM in April 2022. The proposed Oregon Call Areas are shown in Figure 13.

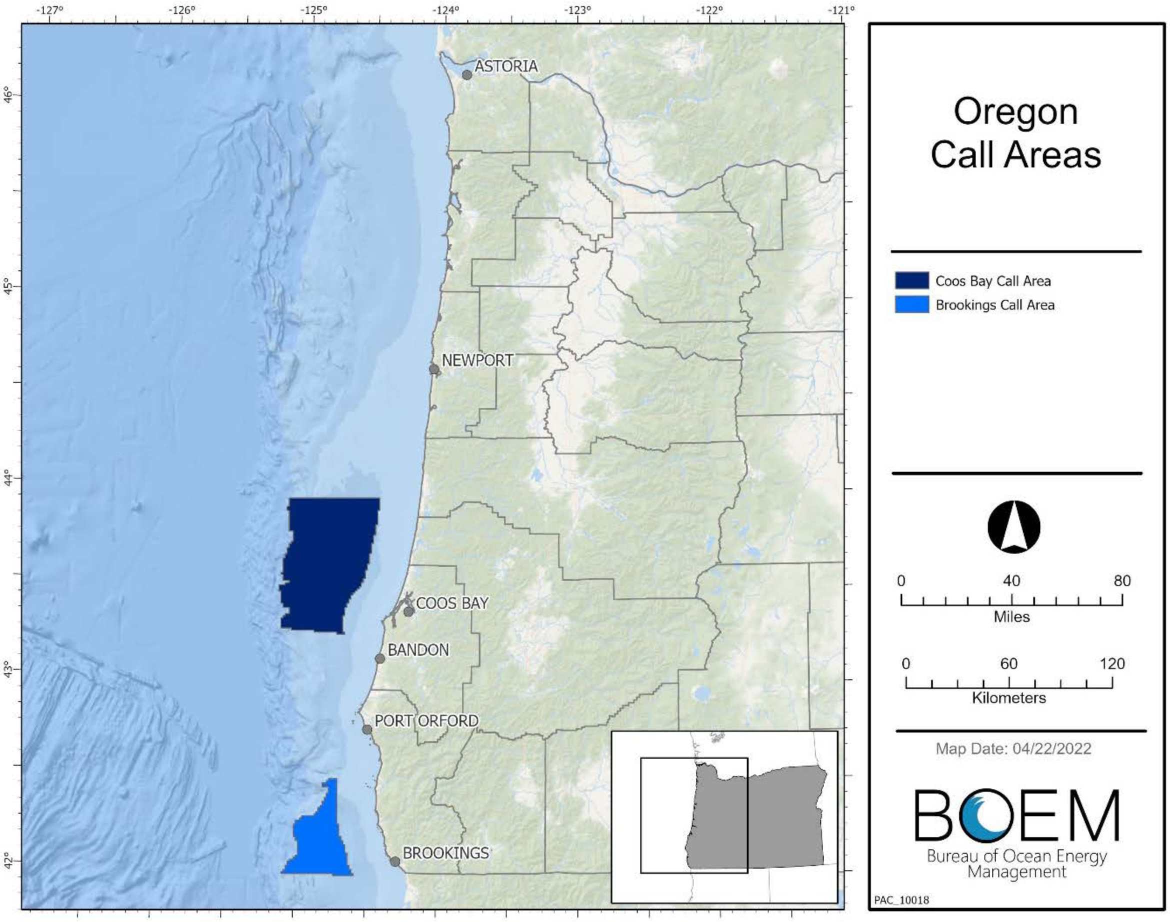

Figure 13. Proposed Call Areas for the state of Oregon. ***Map courtesy of BOEM***

In April 2022, BOEM also announced it is seeking public input on a newly released BOEM Central Atlantic draft Call for Information and Nominations Area (BOEM 2022e). The proposed areas (Figure 14), totaling 3,897,388 acres, could enable the development of roughly 30,000 MW of generating capacity, and support the deployment of both fixed-bottom and floating wind turbines. It is likely that these six new Call Areas will be significantly reduced in size following public comment. One unique aspect of these Call Areas is that the Zone E and F Call Areas are in water depths up to 2,600 m, which is over twice as deep as the California and Oregon Call Areas. As a result, these depths may be technically challenging for developers and may require significant adaptation to the current mooring system technology.

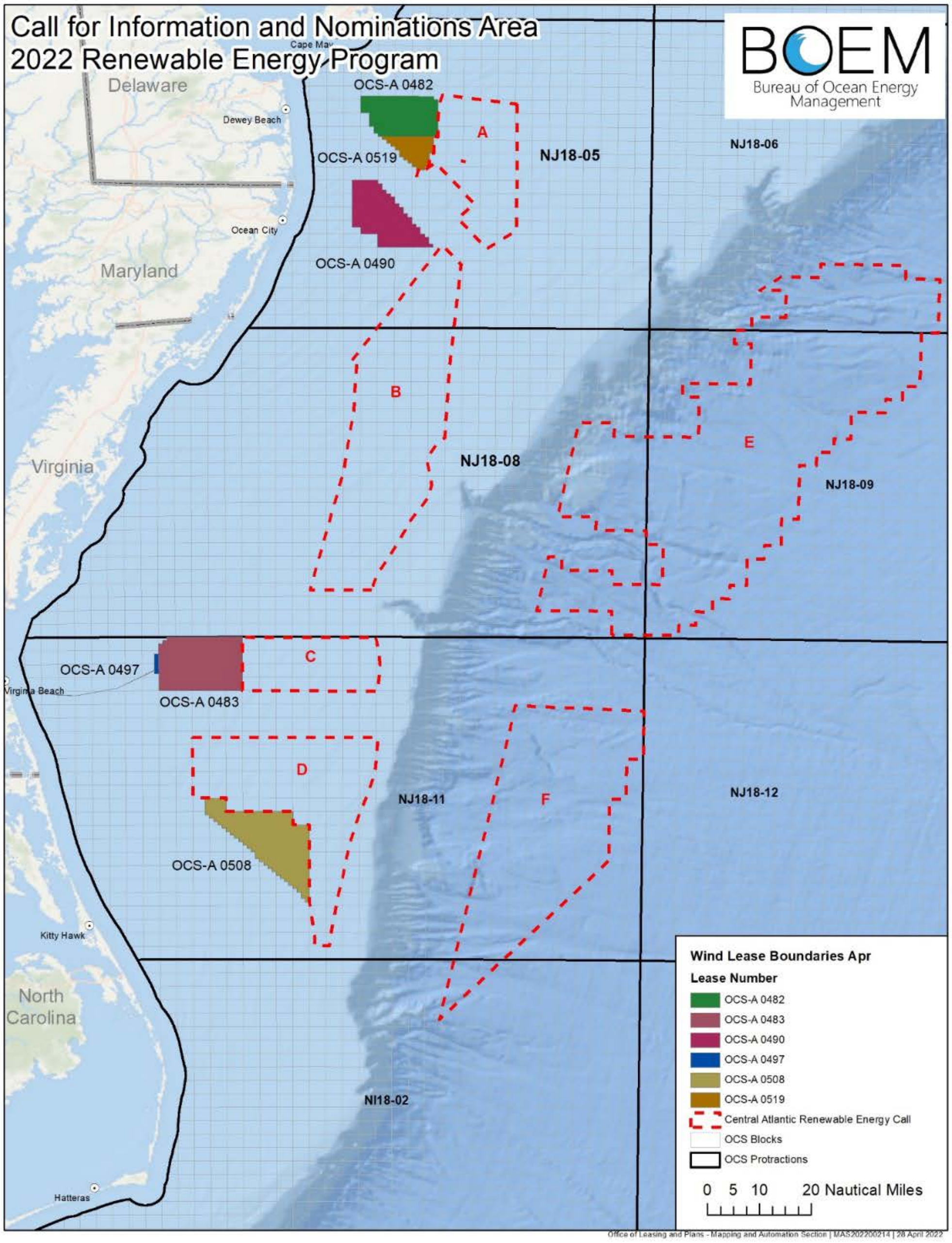

Figure 14. Proposed Call Areas for the Central Atlantic. ***Map courtesy of BOEM***

As of May 2022, there are 11 Call Areas for offshore wind energy in the United States (listed in Table 10), with the six new Central Atlantic Call Areas counted as one single area. They can also be found in Figure 3, Figure 4, and Figure 5 and in Table 3, Table 4, and Table 5.

Table 10. Call Areas As of May 31, 2022

State	Name	Year Designated	Area (km²)	Likely Substructure Type[12]
South Carolina[13]	Grand Strand Call Area	2016	2,541	Fixed bottom
South Carolina	Winyah Call Area	2016	141	Fixed bottom
South Carolina	Cape Romain Call Area	2016	629	Fixed bottom
South Carolina	Charleston Call Area	2016	144	Fixed bottom
Hawaii	O`ahu North Call Area	2016	1,331	Floating
Hawaii	O`ahu South Call Area	2016	626	Floating
California	Diablo Canyon Call Area	2019	1,441	Floating
Louisiana/Texas	Gulf of Mexico Call Area	2021	121,006	Mixed
Delaware, Maryland, Virginia, North Carolina	Central Atlantic Call Areas	2022	15,772	Mixed
Oregon	Brookings Call Area	2022	1,160	Floating
Oregon	Coos Bay Call Area	2022	3,528	Floating

2.4 U.S. Offshore Wind Project Offtake

2.4.1 Project Offtake Agreements

In addition to obtaining site control and regulatory approval, negotiating an offtake agreement to sell the electricity and other clean power attributes (e.g., ORECs) is another necessary step to developing a bankable project. In the United States, eight states have unique procurement targets but use different mechanisms to procure an individual project's electrical generation from a developer. As of May 31, 2022, 24 offtake agreements have been signed, associated with 17,597 MW of contracted capacity. These agreements are detailed in Table 11. From the beginning of May 2021 through May 31, 2022, 10 new offtake agreements were signed for a total capacity of 11,874 MW.

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[12] Substructure type is based on water depth where sites shallower than 60 m are assumed to be fixed bottom and sites greater than 60 m are assumed to be on floating foundations.

[13] Note the status of a federal moratorium on future offshore energy leasing for South Carolina, Georgia, and Florida creates uncertainty around the South Carolina Call Areas.

Table 11. U.S. Offshore Wind Offtake Agreements As of May 31, 2022

Project	Year Signed	Size (MW)	Duration (Years)	Offtake Type	Regulator Approved	Levelized Nominal Price ($/megawatt-hour)	Power Delivery Year	Power Purchaser
Block Island Wind Farm	2010	30	20	PPA	Yes	244	2016	National Grid
South Fork Wind Farm	2017	132	20	PPA	Yes	163	2024	Long Island Power Authority
MarWin	2017	248	20	MD OREC	Yes	131.9		Exelon
Skipjack 1	2017	120	20	MD OREC	Yes	131.9	2026	Exelon
Vineyard Wind 1	2018	400	20	PPA	Yes	74	2024	National Grid, Eversource, Unitil
Vineyard Wind 1	2018	400	20	PPA	Yes	65	2024	National Grid, Eversource, Unitil
Coastal Virginia Offshore Wind – Pilot	2018	12	20	Utility Owned	Yes	780	2020	Dominion Energy
Revolution Wind	2018	400	20	PPA	Yes	99.5	2024	Eversource, UIL
Revolution Wind	2018	200	20	PPA	Yes	98.4	2024	Eversource, UIL
Revolution Wind	2019	104	20	PPA	Yes	98.4	2024	Eversource, UIL
Ocean Wind 1	2019	1,100	20	NJ OREC	Yes	116.8	2024	PSEG, Rockland Electric Cooperative, Jersey City Power & Light, Atlantic City Electric
Empire Wind 1	2019	816	25	NY OREC	Yes	83.3	2026	New York utilities
Sunrise Wind	2019	924	25	NY OREC	Yes	83.3	2025	New York utilities
New England Aqua Ventus I	2019	12	20	PPA	Yes	Undisclosed	2024	Central Maine Power
Mayflower Wind 1	2020	400	20	PPA	Yes	58.4	2025	National Grid, Eversource, Unitil
Mayflower Wind 1	2020	404	20	PPA	Yes	58.4	2025	National Grid, Eversource, Unitil
Icebreaker	2020	21	20	PPA	Yes	Undisclosed	2024	Local Municipalities
Park City Wind	2021	800	20	PPA	Yes	79.8	2025	Eversource, UIL
Empire Wind 2	2021	1,260	25	NY OREC	Yes	107.5	2027	New York Utilities
Beacon Wind 1	2021	1,230	25	NY OREC	Yes	118	2028	New York Utilities
Ocean Wind 2	2021	1,148	20	NJ OREC	Yes	42.3	2027	PSEG, Rockland Electric Cooperative, Jersey City Power & Light, Atlantic City Electric
Atlantic Shore Offshore Wind 1	2021	1,510	20	NJ OREC	Yes	58.8	2028	PSEG, Rockland Electric Cooperative, Jersey City Power

Project	Year Signed	Size (MW)	Duration (Years)	Offtake Type	Regulator Approved	Levelized Nominal Price ($/megawatt-hour)	Power Delivery Year	Power Purchaser
								& Light, Atlantic City Electric
Skipjack 2	2021	846	20	MD OREC	Yes	71.6	2026	Exelon
Momentum Wind	2021	808	20	MD OREC	Yes	71.6	2026	Exelon
Mayflower Wind 2	2021	400	20	PPA	Yes	77	2025	National Grid, Eversource, Unitil
Commonwealth Wind	2021	1,232	20	PPA	Yes	72	2027	National Grid, Eversource, Unitil
Coastal Virginia Offshore Wind - Commercial	2021	2,640	TBD	Utility Owned	TBD	Undisclosed	TBD	Dominion Energy
Total		**17,597**						

2.4.2 State Procurement Policies

The U.S. offshore wind energy market continues to be driven by an increasing amount of state-level offshore wind procurement activities and policies. In aggregate, as of May 31, 2022, these activities call for deploying at least 39,322 MW of offshore wind capacity by 2040. States with offshore wind energy policies are listed in Table 12. Note that several other states have adopted policies that support offshore wind energy development but have not quantified procurement targets or created procurement requirements (e.g., California [California Air Resources Board undated], Oregon [Oregon State Legislature 2021], Louisiana [State of Louisiana 2022]).

Table 12. Current U.S. Offshore Wind Procurement Policies As of May 31, 2022

State	Offshore Target (MW)	Goal Year	Amount Procured (MW)	Authorities	Year Implemented
Maine	-	-	12	None	
Ohio	-	-	21	None	
Massachusetts	5,600	2035	3,236	An Act to Promote Energy Diversity An Act to Advance Clean Energy An Act Creating a Next Generation Roadmap for Massachusetts Climate Policy	2016 2018 2021
Rhode Island	-	-	430	None	-
Connecticut	2,000	2030	1,104	Public Act No. 19-71	2019
New York	9,000	2035	4,362	Case 18E-0071 Climate Leadership & Community Protection Act	2018 2019
New Jersey	7,500	2035	3,758	Offshore Economic Development Act Executive Order 8/AB 3723 Executive Order 92	2010 2018 2019
Maryland	2,022	2030	2,022	Maryland Offshore Wind Energy Act Clean Energy Jobs Act	2013 2019
Virginia	5,200	2034	2,652	Virginia Clean Economy Act	2021
North Carolina	8,000	2040	-	Executive Order 218	2021
Total	**39,322**		**17,597**		

Offshore wind energy projects developed in federal waters are not required to sell their power to the state adjacent to where their project is located. Developers compete for the most favorable offtake options, generally in states where the anticipated value of offshore wind energy is highest and the most favorable PPAs can be negotiated. Several projects, including Revolution Wind, Skipjack, South Fork Wind, and Sunrise Wind have signed contracts to offtake power with neighboring states.

2.5 U.S. Infrastructure Trends

2.5.1 Vessels and Logistics

One of the key logistical challenges for installing fixed-bottom offshore wind turbines in the United States is the uncertainty regarding the availability of Jones-Act-compliant wind turbine installation vessels (WTIVs). The Jones Act is a U.S. law that requires vessels that ship merchandise and passengers between two U.S. points to be U.S. built and registered (flagged), as well as owned and crewed by U.S. citizens or residents (Papavizas 2022a). As of 2022, no U.S.-flagged WTIVs exist that can lift the new 15-MW-class wind turbines. To date, there is only one U.S.-flagged WTIV under construction[14]—the Charybdis—with a target completion of late 2023 (Dominion Energy 2021b). As a result, the rapid commissioning of additional WTIVs could be important. Based on projected offshore wind energy deployment, the United States will require between four and seven WTIVs to meet the 30-GW-by-2030 deployment target (Bocklet et al. 2021; Eneti 2021b; Lantz et al. 2021; Shields et al. 2022).

To avoid supply chain bottlenecks stemming from a lack of WTIVs, developers must either commission the construction of new U.S.-flagged WTIVs or advance alternative Jones-Act-compliant installation strategies that integrate foreign-flagged WTIVs and U.S.-flagged feeder vessels.[15] It costs approximately $500 million and takes 3 years to build a WTIV capable of installing 12- to 20-MW offshore wind turbines in the United States, compared to roughly $330 million and 2 years to construct the same vessel (GustoMSC NG-16000X) in Asia (Dominion Energy 2021b; United States Government Accountability Office 2020; Eneti 2021a; Craik 2021). In an April 2022 ruling on the Jones Act, U.S. Customs and Border Protection confirmed that a foreign-flagged WTIV can install wind turbine foundations and tower components (heavy-lift actions) if the vessel did not transport those items from a U.S. point (Papavizas 2022b). The ruling also clarified that foreign-flagged vessels can move crew and work materials.

At least two companies are developing feeder barge installation strategies in which U.S.-flagged barges work together with foreign-flagged WTIVs to access U.S. ports without violating the Jones Act. Maersk Supply Service announced they would build a foreign-flagged WTIV (which will be constructed in Singapore) along with U.S.-flagged tugs and barges to support the construction of Equinor's Empire 1 and 2 projects (Maersk Supply Service 2022a). Friede &

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[14] Eneti, which acquired Seajacks in August, 2021, announced that they have discontinued discussions with a U.S. shipyard around building a Jones-Act-compliant WTIV (Eneti 2022).

[15] Feeder vessels move goods from a marshaling port to the installation site where they are offloaded by a larger vessel.

Goldman have developed designs for a “BargeRack” system, which allows a WTIV to lift feeder barges out of the water to reduce risks during installation (Friede & Goldman 2021). The design has Approval in Principle from the American Bureau of Shipping, and Friede & Goldman has entered into an agreement with Cosco Shipping (Qidong) Offshore Co. to develop a foreign-flagged WTIV based on the “BargeRack” system, which could serve the U.S. market (Ylhe 2022; Buljan 2022c). Ampelmann and C-Job Naval Architects are also developing a feeder strategy with motion compensation technology to support U.S. offshore wind construction operations (Ampelmann 2022).

Table 13. U.S.-Flagged Vessels To Serve Offshore Wind Energy Industry

Vessel Category (Vessel Name)	Companies Backing	Project Contracts	Commissioning	Source(s)
Wind Turbine Installation Vessel (Charybdis)	Dominion Energy, GustoMSC, Keppel AmFELS	Coastal Virginia Offshore Wind, Revolution Wind, and Sunrise Wind	Expected 2023	Dominion Energy (2021b)
Service Operations Vessel (ECO EDISON)	Edison Chouest Offshore, Ørsted, and Eversource	Revolution Wind, South Fork Wind, and Sunrise Wind	Expected 2024	Memija (2022a)
Service Operations Vessel	Crowley Maritime Corporation, ESVAGT	(Empire Wind Possible)	Not Listed	Haun (2022)
Service Operations Vessel (Plug-in Hybrid)	Equinor, BP, Edison Chouest Offshore	Empire Wind	Mid-2020s	Empire Wind (2022)
Crew Transfer Vessel x2 (Atlantic Pioneer, Atlantic Endeavor)	Atlantic Wind Transfers, Blount Boats Inc., Chartwell Marine Ltd.	Block Island Wind Farm and Coastal Virginia Offshore Wind	Vessels Delivered in 2016 and 2021	Atlantic Wind Transfers (undated)
Crew Transfer Vessel x2 (WindServe Odyssey, Unnamed)	WindServe Marine, Senesco	Block Island Wind Farm, Coastal Virginia Offshore Wind, Revolution Wind	First Vessel Delivered 2020	Ørsted (2019c); Skopljak (2020)
Crew Transfer Vessel	Gladding-Hearn Shipbuilding, Duclos Corporation	Mayflower Wind	Expected Mid-2020s	Mayflower Wind (2021)
Crew Transfer Vessel x4	American Offshore Services, Blount Boats	Four Wind Farms on U.S. East Coast	Expected 2023	Durakovic (2021c)
Rock Installation (With Option To Contract a Second Vessel)	Great Lakes Dredge & Dock, Ulstein Group, Philly Shipyard, Inc.	Not Listed	Expected 2024 (Second Vessel Expected 2025, if Awarded)	Ulstein Group (2020); Durakovic (2021b)
Multipurpose Feeder (Eleanor)	Moran Iron Works Shipyard, Green Shipping Line, Keystone Shipping Company, DEKC Maritime	Not Listed	Expected Mid-2023	DEKC Maritime (2021)
Walk-to-Work (Paul Candies)	Siemens Gamesa, U.S. Otto Candies, LLC	South Fork, Revolution Wind	2018	Moore (2021)
(2) Tugs and Barges	Maersk Supply Service, BP, Equinor, Kirby Offshore Wind	Empire 1 and 2	Not Listed	Maersk Supply Service (2022a)

A dependence on foreign-flagged WTIVs may present a risk to U.S. developers as the global pipeline of projects grows, because increasing foreign competition may constrain the availability of these vessels. Global WTIV demand (excluding China[16]) is expected to increase by a factor of 7 between 2021 and 2030 (Lysne and Busby 2022). Most of this demand will be for vessels capable of installing wind turbines larger than 12-MW. The turbine upsizing trend to 15-MW-class turbines (see Figure 36) poses an additional risk for wind installation vessel owners, because many ships built prior to this decade were designed for 6-MW wind turbines or smaller and may become obsolete before they are profitable, and additional turbine upscaling may continue this trend (Lysne and Busby 2022).

Table 13 provides a full list of U.S.-flagged vessels (completed or under construction) slated to serve the offshore wind energy industry. The challenges for procuring U.S.-flagged crew transfer vessels (CTVs), service operation vessels (SOVs), survey vessels, and support vessels for the construction and operation of U.S. offshore wind energy projects appear to be smaller because of greater availability and lower vessel construction costs. In the short term, existing oil and gas platform service vessels may be adapted or repurposed as U.S.-flagged SOVs (Buljan 2022a). Foreign-flagged cable-lay vessels can conduct cable-lay operations because they are compliant with the Jones Act on the basis that they are "paying out" cable rather than transporting it between U.S. points, including if they load cable at a U.S. port (Papavizas 2022a). Table 14 provides a list of foreign-flagged vessels with U.S. contracts.

Table 14. Foreign-Flagged Vessels and Vessel Operators With U.S. Contracts

Vessel/Operator	Projects Served	Sponsor	Source(s)
Unspecified/DEME Offshore	Vineyard 1 (Wind Turbine and Foundation Installation)	Vineyard/Foss Maritime	Vineyard Wind (2021a); Offshore Engineer (2021)
Aeolus/Van Oord	Unnamed U.S. East Coast Project (Wind Turbine Transportation and Installation)	Unnamed	renews.biz (2022b)
Newbuild WTIV/Maersk Supply Service	Empire Offshore Wind - Empire 1 & 2 (Installation)	Equinor/BP	Maersk Supply Service (2022a)
Leonardo da Vinci and Ulisse/Prysmian Group	Park City and Commonwealth Wind (Cable Installation)	Vineyard Wind	Prysmian Group (2021)
Nexans Aurora/Nexans	Revolution Wind Farm	Ørsted/Eversource	Nexans (2022)
Stril Explorer/MMT U.S. Inc.	Equinor's New England Lease Area (Cable Installation)	Equinor	MMT (2020)
Unspecified/Heerema Marine Contractors	Empire Wind and Beacon Wind (Foundation and Substation Transport and Installation)	Equinor/BP	Heerema (2022)

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[16] China is excluded because reliable data are difficult to obtain.

2.5.2 Ports Investments

The Biden administration announced several programs that provide federal investments in ports. Specifically, the U.S. Department of Transportation's Maritime Administration's Funding Opportunity Announcement via the Port Infrastructure Development Program makes $230 million available for port upgrades, including offshore-wind-energy-related efforts (U.S. Department of Transportation Maritime Administration 2021; The White House 2021b). Under this program, the Port of Albany in New York received $29.5 million to develop a vacant industrial area into a tower manufacturing facility, the South Brooklyn Marine Terminal in New York received $25 million to add a barge berth and an additional crane pad, and the Portsmouth Marine Terminal in Virginia received $20 million to create storage and staging areas for wind turbines, monopiles, and other project components (U.S. Department of Transportation Maritime Administration 2021). The Biden administration's Bipartisan Infrastructure Law allocated $17 billion to be invested in modernizing port infrastructure and waterways (The White House 2021c). The proposed investments are in addition to approximately $3 billion in existing guaranteed loans announced by DOE's Loan Programs Office to support innovative renewable energy technologies (The White House 2021b).

Even if enough vessels are available to support the U.S. offshore wind energy deployment pipeline, the development and timing of port infrastructure could also become a significant bottleneck for the industry. The suitability of port infrastructure development may be impacted as wind turbines and project sizes continue to grow (American Bureau of Shipping 2021). Approximately five marshaling ports will be required to meet the needs of the first 10 GW of offshore wind energy projects on the Atlantic Coast alone (Lefevre-Marton et al. 2019). Floating wind technologies will face additional challenges, as no U.S. ports currently exist that can support a commercial-scale floating wind project. Developers and state bodies are making investments in port infrastructure to ensure they can accommodate the requirements of large-scale commercial projects that intend to use the new 15-MW turbine platform. A summary of recent major infrastructure investments is provided in Table 15.

Table 15. Port Infrastructure Investments To Support Offshore Wind Energy

Location	Details	Sponsor(s)	Amount ($ million)	Source(s)
New London, CT	Public-private investment to upgrade State Pier's infrastructure (deepwater port) and heavy-lift capabilities. Construction is expected to begin in early 2021 and completed by August 2022. Ørsted agrees to sign a 10-year lease at that facility.	Ørsted and Eversource, CT Port Authority	157	Ørsted (undated [a]), Ørsted (undated [b]
Bridgeport, CT	As part of the Park City Wind winning proposal, Vineyard Wind will make Bridgeport home to Park City Wind's operations and maintenance (O&M) hub for the life of the project.	Vineyard Wind	Up to 26.5	Park City Wind (2019)
Bridgeport, CT	Redevelop 18.3-acre waterfront industrial property. Barnum Landing property to do critical foundation transition piece steel fabrication and final outfitting.	Vineyard Wind	Unspecified	Park City Wind (2019)
Sparrows Point, MD	Tradepoint Atlantic will create a 3,300-acre global logistics and staging center for laydown and assembly of components for Skipjack Wind offshore wind farm. Improvements will include strengthening ground-bearing capacity.	Ørsted	13.2	Ørsted (2019d)
New Bedford, MA	Investment to develop the first offshore wind port in the United States (originally intended to support the failed Cape Wind project in 2014)	State of Massachusetts	113	WBUR (2014, 2015)
New Bedford, MA	A $50,000 grant to the New Bedford Port Authority for developing publicly owned port facilities that can support offshore wind construction, O&M, and other activities.	Vineyard Wind	0.05	Vineyard Wind (2019)
New Bedford, MA	Cannon Street Power Station will be demolished, and the surrounding area cleared to develop a 30-acre site for offshore wind.	Cannon Street Holdings	Unspecified	Sennott (2021)
New Bedford, MA	Vineyard Wind signed a $6-million annual lease to use the New Bedford Marine Commerce Terminal for 18 months (total $9 million).	Vineyard Wind	9	Serreze (2018)

Location	Details	Sponsor(s)	Amount ($ million)	Source(s)
New Bedford, MA	Adding base of operations and terminal logistics facility including storage and laydown yards, berth facilities for tug and barge operations, and host CTV and SOV support services.	Foss, Cannon Street Holdings, LLC	Unspecified	Foss (2022)
New Bedford, MA	A grant to extend the port bulkhead, allowing room for additional vessels and an offshore wind staging site.	U.S. Department of Transportation	15.4	Senator Ed Markey's Office (2018)
Salem, MA	Vineyard Wind and Crowley agreed to develop a deepwater offshore wind port for wind turbine assembly and staging activities.	Vineyard Wind, Crowley, City of Salem	Unspecified	Crowley (2021)
Atlantic City, NJ	Ørsted plans to locate its construction logistics base, foundation and transition-piece staging port, and O&M port in New Jersey.	Ørsted	Unspecified	Ørsted (2018)
Brooklyn, NY	Equinor will invest over $60 million in port upgrades throughout New York for part of its Empire Wind project. Empire Wind proposed to invest $60 million in port upgrades statewide, including the Port of Coeymans, Homeport Pier on Staten Island, and South Brooklyn Marine Terminal.	Equinor	60	Equinor (2019)
Brooklyn, NY	Upgrade South Brooklyn Marine Terminal as an offshore wind hub.	Equinor, BP	200–250	Klinge (2022)
Brooklyn, NY	A grant to add a berth for 400-foot long barges and an additional crane pad at the South Brooklyn Marine Terminal.	U.S. Department of Transportation Maritime Administration	25	U.S. Department of Transportation Maritime Administration (2021)
Albany, NY	A grant to develop an 81-acre vacant space into a suitable location for an offshore wind tower manufacturing port at the Port of Albany.	U.S. Department of Transportation Maritime Administration	29.5	U.S. Department of Transportation Maritime Administration (2021)
New York State	Establish a NY Ports Infrastructure Development Fund, thereby ensuring port facilities can serve as staging areas.	Ørsted, Eversource	11	Ørsted (2019b)
Port Jefferson, NY	New O&M Hub including dockage for a 250-foot service operation vessel, a warehouse, and office facility.	Ørsted, Eversource	Unspecified	Ørsted (2019a)

Location	Details	Sponsor(s)	Amount ($ million)	Source(s)
New Jersey Wind Port, NJ	Purpose-built marshaling, manufacturing, and assembly port including heavy lift wharfs.	New Jersey Economic Development Agency	400	Johnson (2021)
Providence, RI	Port improvements for the Port of Providence, Quonset Business Park, and potentially additional ports in the state.	Ørsted, Eversource	40	Ørsted (undated [a])
Bridgeport, CT	Vineyard Wind has signed a lease at Barnum Landing to use as a construction and staging location. Downtown Bridgeport to serve as the Connecticut headquarters for the company's offshore wind energy project.	Vineyard Wind	Unspecified	Vineyard Wind (2021b)
Portsmouth, VA	A grant to fund the creation of two staging areas for wind turbine generators, monopiles, and other project components at the Portsmouth Marine Terminal	U.S. Department of Transportation Maritime Administration	20	U.S. Department of Transportation Maritime Administration (2021)
	Total Announced 2021–2022	**($ million)**	**675–725+**	
	Cumulative Total Announced	**($ million)**	**1,120–1,170+**	

In 2020, the New Jersey Economic Development Authority announced that it would construct a custom offshore wind energy port (State of New Jersey 2020). The port is expected to cost between $300 million and $400 million and will be located on the Delaware River. The first phase will develop a 30-acre marshaling site and a 25-acre manufacturing site, and the second phase will add another 150 acres for further marshaling and manufacturing activities. Construction began in September 2021.

In addition, the state of Connecticut reached a final agreement with Gateway Terminal, Ørsted, and Eversource for a public-private partnership worth $157 million to develop the State Pier in New London into an offshore wind energy center (State of Connecticut 2020). In April 2021, Ocean Wind (Ørsted and PSEG) announced that it, along with German steel manufacturer EEW, broke ground on a dedicated monopile manufacturing facility located at the Port of Paulsboro Marine Terminal in New Jersey. One of the upgrades includes substantial reinforcement of the quay to bear the weight of 2,500-ton monopiles that will be manufactured on-site. Additional welding and painting facilities are also under construction, with a goal of producing the first monopiles at the facility by 2023 (Ocean Wind 1 2021).

2.5.3 U.S. Supply Chain Development

The U.S. offshore wind energy supply chain for major components saw significant growth in 2021 and 2022 with 10 new major domestic manufacturing facilities announced at ports along the East Coast. Table 16 (Shields et al. 2022) lists major supply chain announcements made recently; all "Announced" supply chain facilities listed here were made in 2021 except for the Brayton Point cable facility, which was announced in 2022. The investment costs for these factories range from $40 million (Eversource and Ørsted's intent to produce foundation platforms at the Port of Providence in Rhode Island) to $350 million (Marmen Welcon and Smulders' tower and transition piece facility at the Port of Albany).

The total announced investment from the beginning of 2021 through May 2022 was about $1.2 billion, although not all facilities disclosed their anticipated development costs. Major investors include original equipment manufacturers (OEMs) and project developers; in some cases, state governments have also contributed funds to site development to encourage local economic development and local offshore wind farm content (State of New Jersey 2020). Finally, the EEW monopile facility at the Port of Paulsboro in New Jersey broke ground in April 2021 to begin quayside reinforcement and build two buildings that will support circumferential welding, sandblasting, and painting (Ocean Wind 1 2021). The EEW monopile facility has been contracted to supply monopiles to the Ocean Wind 1 and Atlantic Shores projects off the coast of New Jersey.

Although European offshore wind energy supply chains are more mature than in the United States, they may not have enough capacity to serve all the demand on both continents (Shields et al. 2022). The U.S. supply chain is anticipated to grow and mature as more projects begin construction. As a result, this maturation could provide significant economic benefits to the U.S. economy while working toward the national offshore wind target of 30 GW by 2030 (Shields et al. 2022). A U.S supply chain that can manufacture all major components domestically (including, but not limited to, the components in Table 16) could create between 12,300 and 49,000 annual, full-time-equivalent manufacturing jobs and could inject $1,600 million to $6,200 million of added value into the economy every year (Shields et al. 2022). This domestic supply chain will need to expand to meet a demand of more than 2,000 wind turbines and foundations, 8,000–11,000 km of array and export cables, and over 50 offshore substations expected in the coming years (Shields et al. 2022; The Special Initiative on Offshore Wind 2021). In addition, transitioning the production of critical-path-supporting components, such as permanent magnets, bearings, flanges, steel plates, large castings, offshore substation electrical systems, and mooring chains, to the U.S. supply chains presents further domestic opportunities. These subcomponents are vital to fabricating some of the major components (e.g., generators, mooring systems, nacelles) and associated economic benefits are realized in U.S. factories (Shields et al. 2022). The total capital expenditures (CapEx) to achieve the national offshore wind target are expected to total around $100 billion by 2030 (The Special Initiative on Offshore Wind 2021).

Table 16. Major Supply Chain Announcements in the United States Through May 31, 2022

Component	Location	Investors	Status	Announced Investment ($ million)
Blades	Portsmouth Marine Terminal (Virginia)	Siemens Gamesa	Announced	200
Nacelles (Final Assembly Only)	New Jersey Wind Port (New Jersey)	Vestas, Atlantic Shores	Announced	Not Announced
	New Jersey Wind Port (New Jersey)	GE, Ørsted	Announced	Not Announced
Towers	Port of Albany (New York)	Marmen Welcon, Equinor	Announced	350
Monopiles	Paulsboro Marine Terminal (New Jersey)	EEW, Ørsted	Under Construction	250
	Tradepoint Atlantic (Maryland)	U.S. Wind	Announced	150
Foundation Platforms	Port of Providence (Rhode Island)	Eversource, Ørsted	Announced	40
Secondary Steel	Port of Coeymans (New York)	Eversource, Ørsted	Announced	86
Transition Pieces	Port of Albany (New York)	Marmen Welcon, Smulders	Announced	Not Announced
Array and Export Cables	Nexans High-Voltage Cable Facility (South Carolina)	Nexans	Operational	200
	Kerite (Connecticut)	Kerite, Marmon Group, Vineyard Wind	Operational	4
	Tradepoint Atlantic (Maryland)	Ørsted, Hellenic Cables	Announced	140
	Brayton Point (Massachusetts)	Prysmian, Avangrid	Announced	200
Offshore Substations	Ingleside (Texas)	Kiewit, Eversource, Ørsted	Operational	Not Announced[17]
Total Announced Investments Made in 2021–2022 ($ million)				**1,166**

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[17] Offshore substations can be fabricated at existing shipyards with minimal investment.

Figure 15 shows a map of the locations for major ports and infrastructure projects from Table 15 and Table 16.

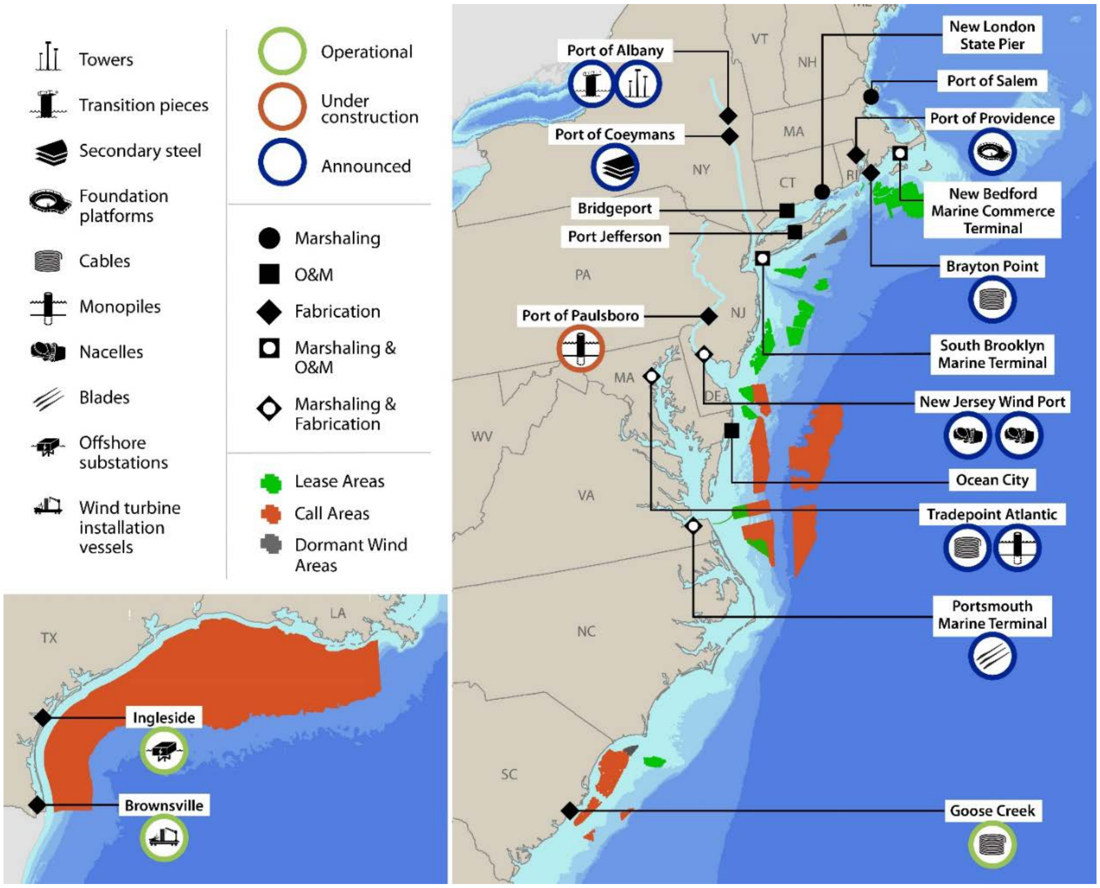

Figure 15. Locations of major offshore wind ports and infrastructure investments. *Images created by NREL*

2.5.4 Electric Grid

Based on developer-announced plans, the current approach for transmitting electricity from offshore wind power plants to the onshore grid in the United States is through high-voltage radial spurs (generator lead lines) from each plant to an onshore point of interconnection (POI) on a project-by-project basis. However, existing POIs may not have sufficient capacity available to connect every planned project individually through generator lead lines. A better solution may be for multiple projects to share transmission to shore. This shared transmission would reduce the number of cables and beach landings, provide improved reliability, and have fewer impacts on the marine environment and coastal communities. Although shared transmission may be the preferred solution, the level of planning and coordination at the state, federal, and utility levels presents a significant challenge with respect to maintaining project timelines and early projects will likely default to the generator-lead-line approach.

A recent literature review and gaps analysis of more than 20 Atlantic offshore wind transmission studies was published by DOE in October 2021, which pointed to several industry research and infrastructure needs including the following (Bothwell et al. 2021):

- Onshore transmission upgrades and expansion will be required to transmit electricity from offshore wind power plants to onshore load. For example, the New York Independent System Operator can integrate 9 GW of offshore wind energy if it expands Long Island bulk transmission and upgrades transmission in New York City. Cable routing limitations in New York Harbor, space constraints in Manhattan's substations, and permitting complexities in New York Harbor and Long Island are among the system operator's challenges. The study also found that ISO-New England can integrate 5.8 GW of offshore wind energy if it makes minimal onshore transmission upgrades, but capacities beyond 5.8 GW will require substantial upgrades.
- Careful planning of offshore wind energy within lease areas, onshore and offshore cable routes, transmission cable landfalls, and onshore POIs is required.
- Independent researchers found that planned, shared offshore transmission topologies are cheaper, increase reliability, and reduce impacts to coastal communities and the environment. However, these results have not been fully validated and may not account for all the risks, costs, and timing of offshore wind energy projects relative to the development of shared transmission infrastructure.

To address key gaps identified by Bothwell et al. (2021), DOE's Wind Energy Technologies Office is sponsoring the Atlantic Offshore Wind Transmission study to evaluate planned, coordinated transmission solutions, including interregional ones, along the Atlantic coast from Maine to South Carolina. The study includes multiple scenarios of offshore wind generation and transmission configurations, including radial spurs, a meshed grid, and backbones, for 2030 and 2050. The study includes capacity expansion, product cost, resource adequacy, dynamic contingency, electromagnetic transient stability, and resilience modeling.

In November 2020, the New Jersey Board of Public Utilities asked PJM to competitively solicit proposals for offshore wind transmission and include the state's public policy goal of 7,500 MW of offshore wind energy by 2035 into PJM's transmission planning processes under the "State Agreement Approach" established by the Federal Energy Regulatory Commission's Order No. 1000. In April 2021, PJM opened a competitive solicitation for transmission options to help meet New Jersey's offshore wind energy goals. PJM received about 80 proposals that cover multiple options to accommodate coastal states' offshore wind goals and PJM states' request for proposals requirements (Figure 16). The commission accepted the executed State Agreement Approach in April 2022 (PJM 2022).

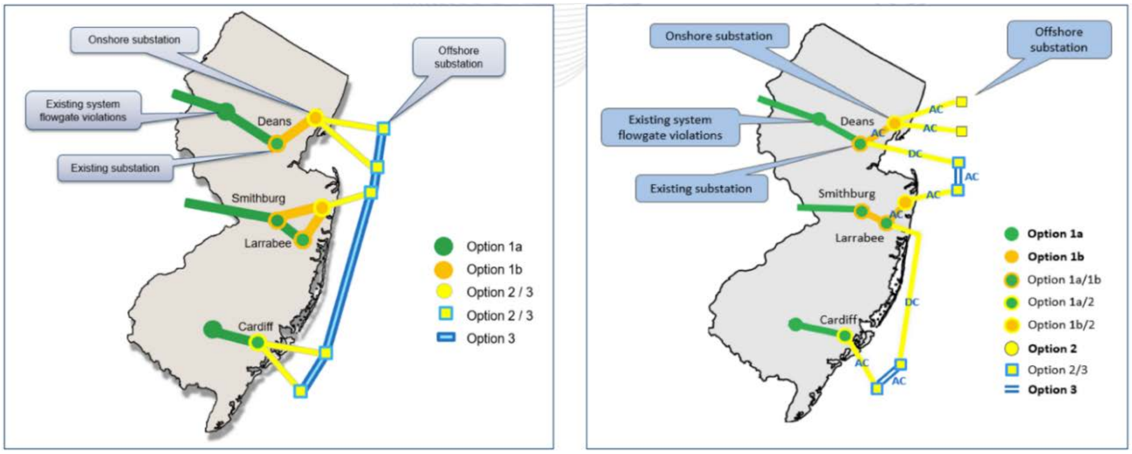

Figure 16. Potential transmission options in the New Jersey 2021 State Agreement Approach

Proposed costs of these transmission options range from $627 million for 2027 offshore wind expansion scenarios to $3.2 billion for 2035 scenarios. Proposed offshore wind injections range from 6,416 MW to 17,016 MW (PJM 2021).

In January 2020, the New York Public Service Commission unanimously voted to require offshore wind developers to provide "mesh-ready" transmission plans when making bids to state solicitations.[18]

In January 2022, DOE launched the "Building a Better Grid" initiative to accelerate upgrading and expanding the nation's transmission lines and planning efforts, especially for high-capacity and interregional transmission. This initiative includes coordination and planning on a broad scale with community stakeholders and industry transmission organizations to assess the nation's transmission needs in support of the transition to 100% clean electricity by 2035 and a zero-emissions economy by 2050 (DOE 2022a).

One of the first steps in the "Building a Better Grid" initiative is the National Transmission Planning (NTP) study, which aims to support the administration's goals for a decarbonized power sector by 2035 and a net-zero emissions economy by 2050 while ensuring grid reliability. Achieving these goals will require substantial growth of wind and solar power, which in turn require significant transmission expansion to deliver electricity to load. NTP objectives include:

- Identifying regional, interregional, and national strategies to accelerate grid decarbonization while enhancing system resilience and maintaining reliability
- Informing regional and interregional transmission planning processes, particularly engaging stakeholders about their priorities
- Determining viable, efficient transmission options that will provide broad-scale benefits to electric customers.

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[18] Mesh-ready topologies enable individual offshore wind farms to aggregate power before delivering it to shore and provide redundant transmission pathways to increase grid reliability.

NTP study results will help prioritize future DOE funding for transmission infrastructure support and help fill gaps in existing interregional transmission planning to facilitate the nation's transition to carbon-free energy. The NTP study kicked off in March 2022 and will continue into the second half of 2023 (DOE undated [b]).

2.6 Other Regional Developments

Over 2021 and early 2022, several other notable offshore wind energy activities occurred, as described in the following subsections.

2.6.1 North Atlantic Region

Maine. While the New England Aqua Ventus I Floating Demonstration Project progresses, in October 2021, Maine Governor Mills submitted a research lease application to BOEM to develop a floating research array made of 12 or fewer turbines in the Gulf of Maine (State of Maine 2021). BOEM is evaluating this research lease application and has identified a planning area for potential commercial offshore Call Areas in the Gulf of Maine.

Rhode Island. In early 2022, the Rhode Island legislature, with the support of Governor McKee, introduced legislation that would require local utilities to issue a request for proposals (no later than August 2022) to procure up to 600 MW of offshore wind capacity to advance the state's clean energy goals (State of Rhode Island 2022). The bill is still under consideration in the legislature.

Connecticut. As discussed earlier, the Revolution Wind and Park City Wind projects are progressing through federal and state permitting processes. At the same time, the state government and industry continue to make port and supply chain investments and look for new opportunities to deploy additional offshore wind capacity in accordance with the state's procurement goal.

2.6.2 South Atlantic Region

South Carolina. H4831 was introduced in the South Carolina General Assembly in February 2022, directing the state Department of Commerce to analyze the state's business advantages, economic climate, workforce readiness, and any other relevant state assets. The goal of this analysis is to create a road map for South Carolina to effectively attract offshore wind energy supply chain industries to the state (South Carolina General Assembly 2022).

2.6.3 Gulf of Mexico Region

Louisiana. See Section 2.3.3.

2.6.4 Great Lakes Region

The New York Department of Public Service issued Order 15-01168, directing the New York State Energy Research and Development Authority to complete a Great Lakes Offshore Wind Feasibility Study for the New York portions of Lake Erie and Lake Ontario. (New York State Energy Research and Development Authority 2022). The agency also held four public webinars over the course of 2021 to elicit stakeholder feedback. The final report is expected in July 2022.

2.6.5 Pacific Region

For California see Section 2.3.2, and for Oregon, see Section 2.3.3.

Washington. Offshore wind energy developer, Trident Winds, submitted a 2,000-MW unsolicited lease application to BOEM to develop a floating offshore wind project called Olympic Wind off Washington State (Trident Winds 2021).

Hawaii. The state of Hawaii and BOEM continue to engage stakeholders regarding the optimal way to potentially develop offshore wind energy off the Hawaiian Islands. In October 2021, NREL published a study examining the cost and feasibility of offshore wind energy at multiple sites off Oahu (Shields, Duffy, et al. 2021).

2.6.6 U.S. Territories

Puerto Rico. Commissioner González-Colón of Puerto Rico introduced the Offshore Wind for U.S. Territories Act to the House, which aims to establish processes for offshore wind leasing in federal waters off U.S. territories including Puerto Rico, Guam, American Samoa, the United States Virgin Islands, and the Commonwealth of the Northern Mariana Islands (H.R. 1689; U.S. House of Representatives 2021). The Build Back Better Act has similar language clarifying the federal leasing process in federal waters offshore Puerto Rico. In addition, DOE is managing post-Hurricane-Maria energy recovery efforts on behalf of the Federal Emergency Management Agency. In 2022, DOE (in partnership with NREL and other national labs) launched a 2-year study to investigate how to transition Puerto Rico to 100% renewable energy as part of the post-Hurricane-Maria recovery efforts (NREL 2022b). This effort will inform LUMA Energy's (Puerto Rico's main utility) grid planning processes in Puerto Rico.

3 Global Offshore Wind Energy Development

3.1 Current Status of Global Offshore Wind Energy Industry

The offshore wind energy industry is growing worldwide, with more countries entering the market, many projects advancing in the pipeline, and more offshore wind capacity being deployed in total. This section captures this global expansion in the key markets of Europe, Asia, and the rest of the world, as well as the distinct technology markets of fixed bottom and floating wind. This section has four parts. The first is a summary of current global offshore wind deployment, covering a closer look at the emerging floating offshore wind market. Next, the near-term pipeline of projects from the NREL OWDB through 2027 is examined for all offshore wind energy, as well as projections for floating offshore wind energy. The third section looks at independent industry forecasts for deployment to 2031. The final section examines offshore wind deployment goals by country.

3.1.1 Aggregate Global Deployment Summary

For global offshore wind energy deployment, 2021 was a record year, with 17,399 MW of new capacity commissioned, as shown in Figure 17.

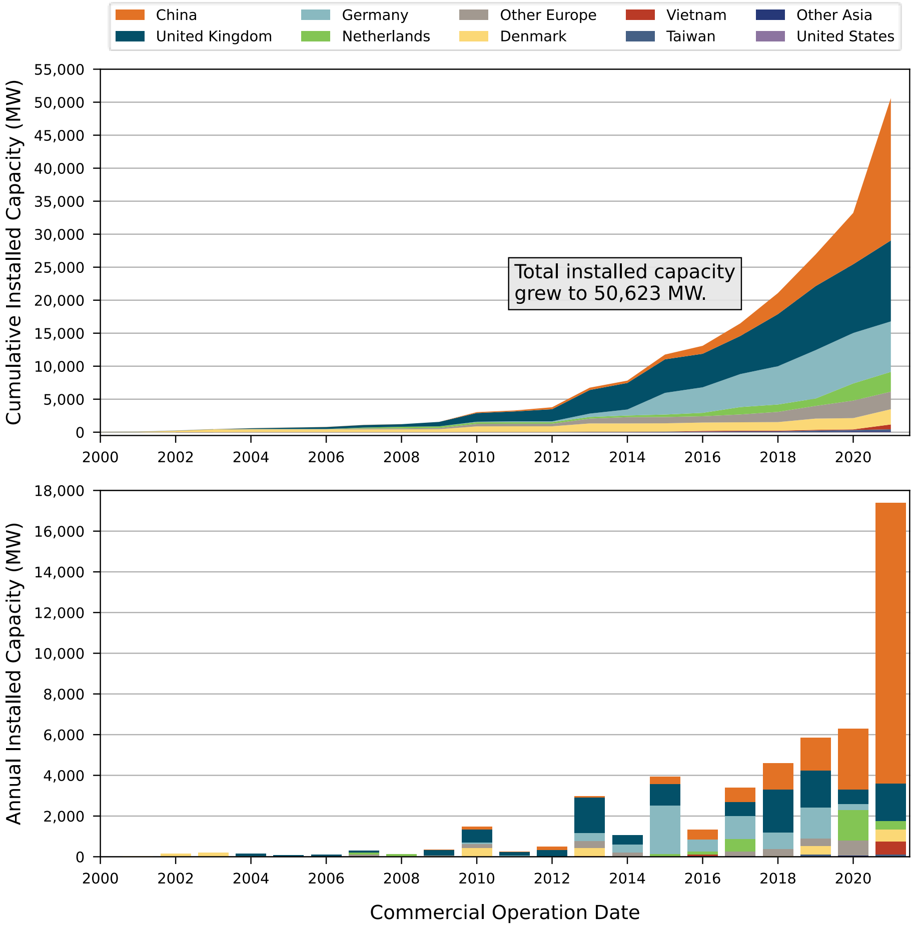

Figure 17. Global cumulative offshore wind energy deployment (top) and annual capacity additions (bottom) through 2021

In 2021, China commissioned 13,790 MW—more capacity in 1 year than the entire world installed in any single previous year. The United Kingdom had the next largest annual deployment, with 1,855 MW, followed by Vietnam (634 MW), Denmark (605 MW), the Netherlands (402 MW), and Taiwan (109 MW). By the end of 2021, the total offshore wind capacity grew to 50,623 MW from 254 operating projects.

China's rapid rise has substantially shifted the distribution of global offshore wind deployments between the European and Asian markets. Europe still has most of the cumulative installed offshore wind capacity, with approximately 27,881 MW, representing 55.1% of the global total. However, Asia's market share sharply increased to 44.8% (22,701 MW) in 2021. North America's nascent market is the third largest, with only 42 MW of installed capacity. As shown in Figure 18, the top three countries contributing to offshore wind capacity growth in 2021 were China, the United Kingdom, and Vietnam.

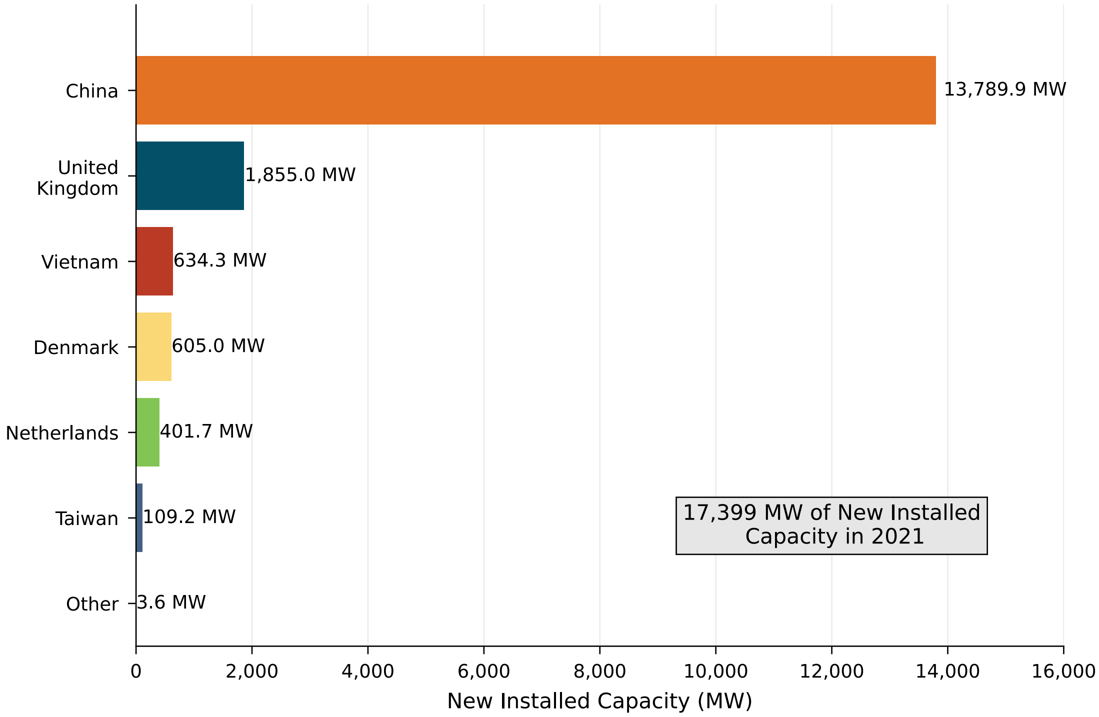

Figure 18. Global offshore wind energy installations in 2021

Of the 50,623 MW of cumulative offshore wind energy deployment recorded by the end of 2021, Figure 19 shows the historic trajectory of offshore wind growth among all countries individually. China's massive deployment in 2021 enabled it to rapidly surpass the United Kingdom and Germany to lead the world in terms of total offshore wind energy capacity with 44.8% market share. China is followed by the United Kingdom (24.2%), Germany (15.1%), the Netherlands (5.9%), and Denmark (4.6%).

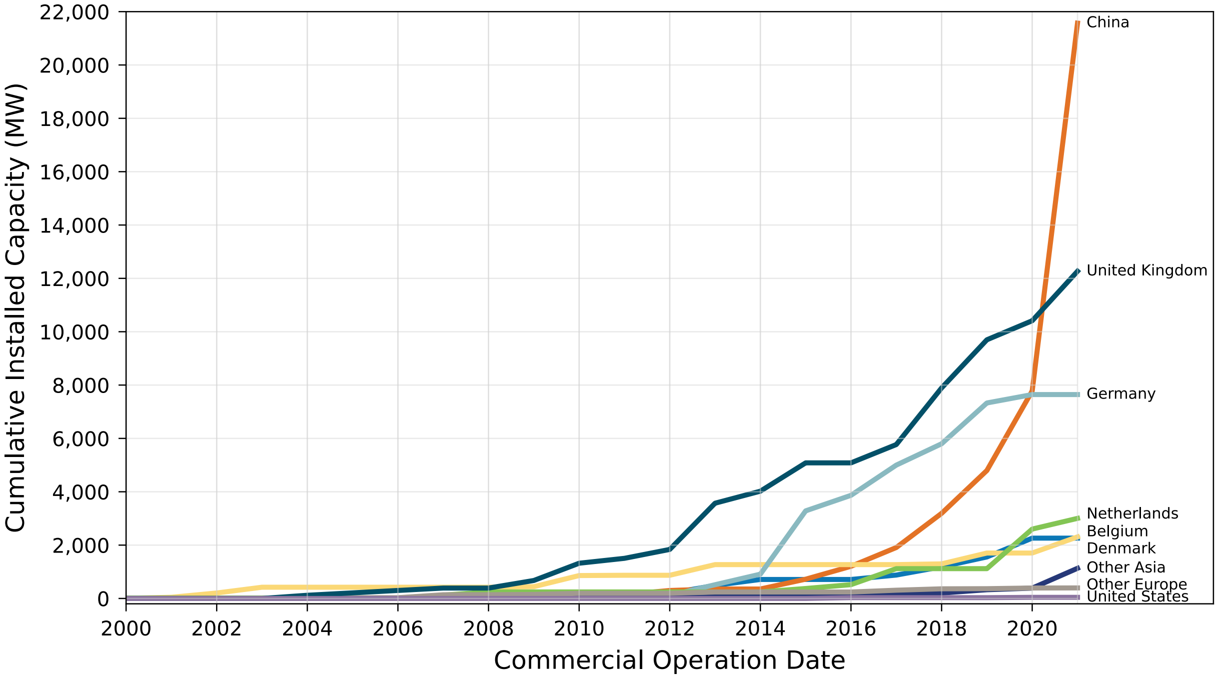

Figure 19. Cumulative installed offshore wind capacity by country

From 2010 through 2020, the United Kingdom had the largest share of total offshore wind deployment. Germany began its transition to offshore wind energy around 2010 and has sustained deployment through 2020 but added no capacity in 2021.

3.1.2 Global Floating Offshore Wind Energy Deployment Summary

Floating offshore wind represents an opportunity to access a much larger ocean area with high-quality wind resources in waters that are deeper (greater than 60 m) than where fixed-bottom foundations are feasible. In the United States, the majority of the total technical offshore wind resource lies over water depths greater than 60 m, and in Europe that number is estimated to be 80% (Musial et al. 2016; Komusanac, Fraile, and Brindley 2019). Globally, the development trajectory of a floating offshore wind energy market continues at the pilot scale (10 MW to 100 MW) in Europe, Asia, and North America. This pilot and demonstration phase, which includes most projects anticipated to begin operations between 2022 and 2024, is expected to provide data and experience that inform the development of cost-effective, commercial-scale projects that may be installed as early as 2025. At the end of 2021, there were 10 floating offshore wind energy projects operating globally,[19] totaling 123.4 MW. Seven of those 10 projects (112.9 MW) are in Europe and three (10.5 MW) are in Asia.

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[19] Only projects with capacities greater than 1 MW were counted. Smaller projects are considered experimental and do not contribute to commercial market totals.

Three floating offshore wind projects came online in 2021, totaling 56.5 MW of new capacity. The largest floating offshore wind project to date is Scotland's new 47.5-MW Kincardine Offshore Wind Farm, shown in Figure 20, which came online in 2021 (Principle Power, Inc. 2021). A 5.5-MW floating demonstration project also began operations in China, developed by the China Three Gorges Group (Russell 2021). Additionally, the Stiesdal Offshore Wind 3.6-MW TetraSpar demonstration project began operations in Norway at a water depth of 200 m (Stiesdal A/S 2021).

Figure 20. Kincardine 47.5-MW floating offshore wind plant. ***Photo courtesy of Principle Power, Inc.***

Note that the pipeline of international projects is based on projects up to Dec. 31, 2021. In early 2022, there have been two other notable projects. Maersk Supply Service completed the mooring pre-lay installation for the 2-MW DemoSATH floating offshore wind demonstration project in Spain, and the first floating wind turbine for the 88-MW Hywind Tampen project in Norway was assembled later in 2022 (Maersk Supply Service 2022b; MarineLink 2022). Neither of these projects are counted in the floating pipeline for this report but are expected to be completed in 2022. The Tampen project, when complete, will be the largest floating wind project globally.

3.2 Market Projections

We determined the near-term (through 2027) and medium-term (through 2031) projections for the global offshore wind energy market using NREL's OWDB. These projections can help illuminate broad market trends and identify different national and regional deployment trajectories.

3.2.1 Aggregate Project Pipeline Through 2027

The near-term projections to 2027 are based on available data for projects under construction. Figure 21 shows that there are 25,403 MW of new offshore wind energy projects under construction globally.

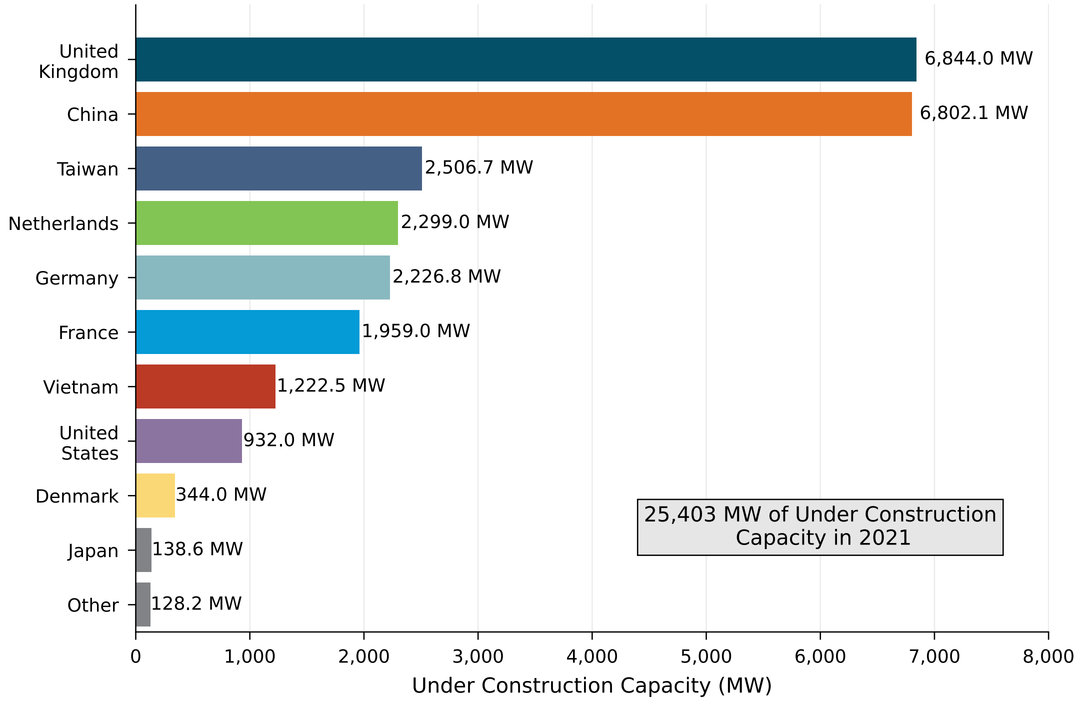

Figure 21. Offshore wind capacity under construction by country as of 2021

Projects that have advanced past financial close and are being built have a much higher probability of reaching COD and a much lower uncertainty about when they will begin operations. Categorized by country, the data indicate that all markets will continue to grow over the next 5 years. Although the European market is currently the largest, it is likely that the Asian offshore wind energy market will soon surpass it in terms of total capacity, driven primarily by China.

By the end of 2021, 53 projects in Asia were under construction, representing 10,670 MW of new capacity. Most construction (27 projects [6,802 MW]) is occurring in China, followed by Taiwan (7 projects [2,507 MW]), and Vietnam (16 projects [1,223 MW]). The large amount of construction in Asian offshore wind energy markets is expected to grow in the coming years. In Europe, 26 projects, with a combined capacity of 13,801 MW, are currently under construction. Of the projects under construction, there are six each in the United Kingdom (6,844 MW), the Netherlands (2,299 MW), and France (1,959 MW). Based on these projects currently under construction, projections for 2022 indicate that an increase in new global capacity is possible, similar to this year's 17,399 MW, if a significant portion of the 25,403 MW under construction gets completed. The U.S. market is a distant third in size globally, with only 42 MW operating, but with 932 MW under construction and over 40 GW in the project pipeline, the data indicate accelerated growth.

Figure 22 provides a yearly estimate of projected new deployment based solely on the developers' estimation of when they expect their project to be commissioned. Although a project developer may not always be at liberty to disclose detailed updates or provide public information related to its exact deployment schedule, the developer COD data provide a good estimate of near-term deployment.

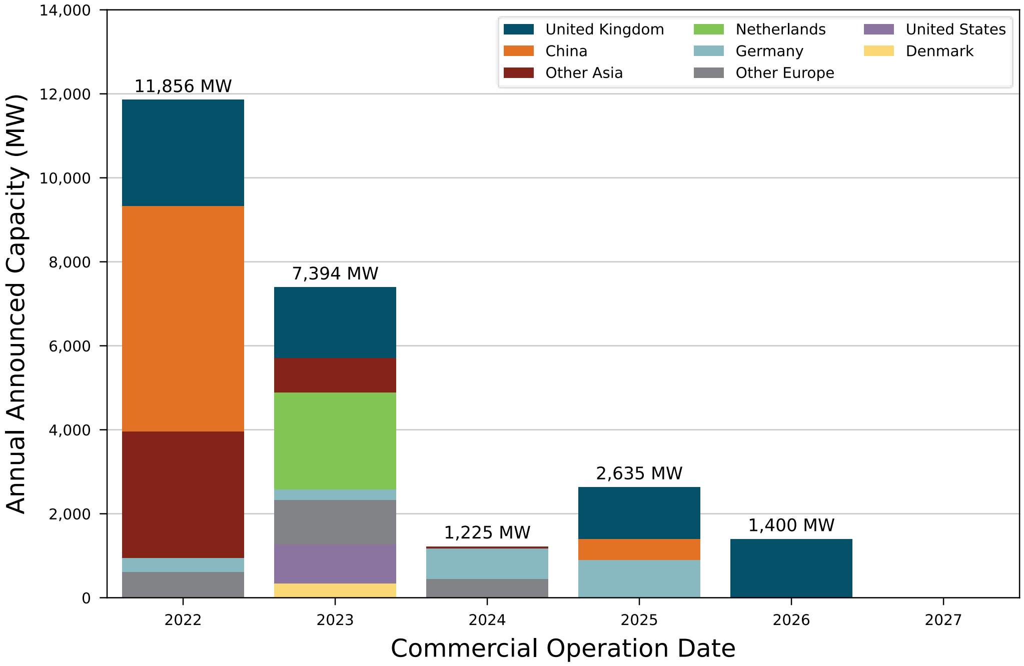

Figure 22. Developer-announced offshore wind capacity through 2027 for projects with announced COD

Based on only the projects reporting COD dates between 2022 and 2023, annual capacity additions are expected to be dominated by the United Kingdom, China, Taiwan, and the Netherlands. China's pace of new project deployment is expected to decrease relative to 2021 as feed-in tariffs are being phased out in 2022, but the country is still expected to continue as a major deployment leader at least through 2025 (Barla 2021). After 2024, developments in other Asian markets, the United States, and other European countries, such as Poland, may diversify the market, as well as the expected commercialization of the floating wind market. These new additions could result in approximately 24.5 GW of new capacity from 2022 through 2027 based on developer announcements. As shown in Figure 23, the cumulative offshore wind energy deployment by 2027 could reach approximately 177 GW.

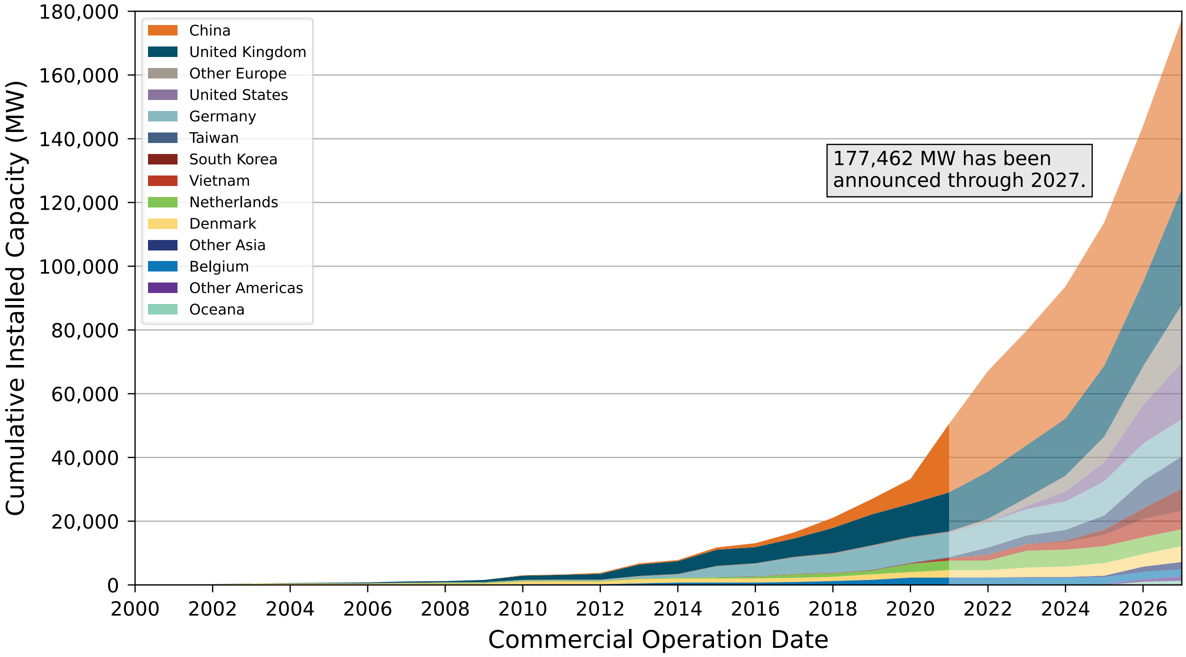

Figure 23. Estimated cumulative offshore wind capacity by country based on developer-announced CODs (the darker areas signify deployed capacity and lighter areas represent projected deployments)

3.2.2 Floating Offshore Wind Through 2027

Based on NREL's OWDB for all projects that have announced a COD, the data in Figure 24 show estimated cumulative deployment of floating offshore wind by country through 2027.

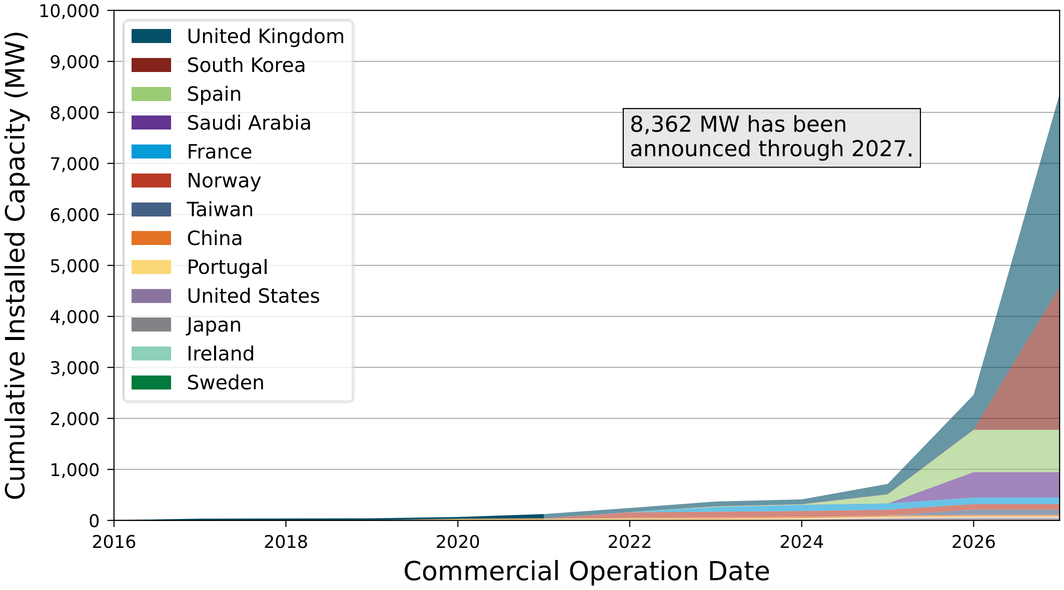

Figure 24. Cumulative floating offshore wind capacity by country based on announced CODs through 2027

The near-term floating offshore wind projections increased in 2022 to 8,362 MW, more than doubling the 5-year-ahead near-term estimate of 3,688 MW reported last year. However, because most of the large commercial projects that make up this new estimate are still in the planning phase, there is a high degree of uncertainty about their timing and likelihood of completion. Most of the developer-announced deployment is in the United Kingdom (3,780 MW), South Korea (2,806 MW), Spain (828 MW), and Saudi Arabia (500 MW). Most other near-term floating offshore wind deployment estimates are evenly spread throughout multiple countries in Europe.

3.2.3 Total Global Offshore Wind Pipeline

Figure 25 shows the global capacity of the operating and announced development pipeline for all offshore wind energy projects by region at the end of 2021 to be 369 GW, compared to approximately 308 GW that was reported at the end of 2020. The uptick is primarily attributed to more Asian projects entering the planning phase. This figure does not provide information about the likely timing or probability of developments within the long-term pipeline but provides overall announced capacity for all active projects recorded in the OWDB. Generally, projects that are more advanced within the pipeline are likely to reach COD, maintain their announced capacity, and be installed sooner than those at an earlier stage; however, international differences in regulatory structure can result in a wide range of development timelines. The global project pipeline data indicate that most of the installed projects and those under advanced development are in Europe; however, a large portion of potential future capacity is in Asia.

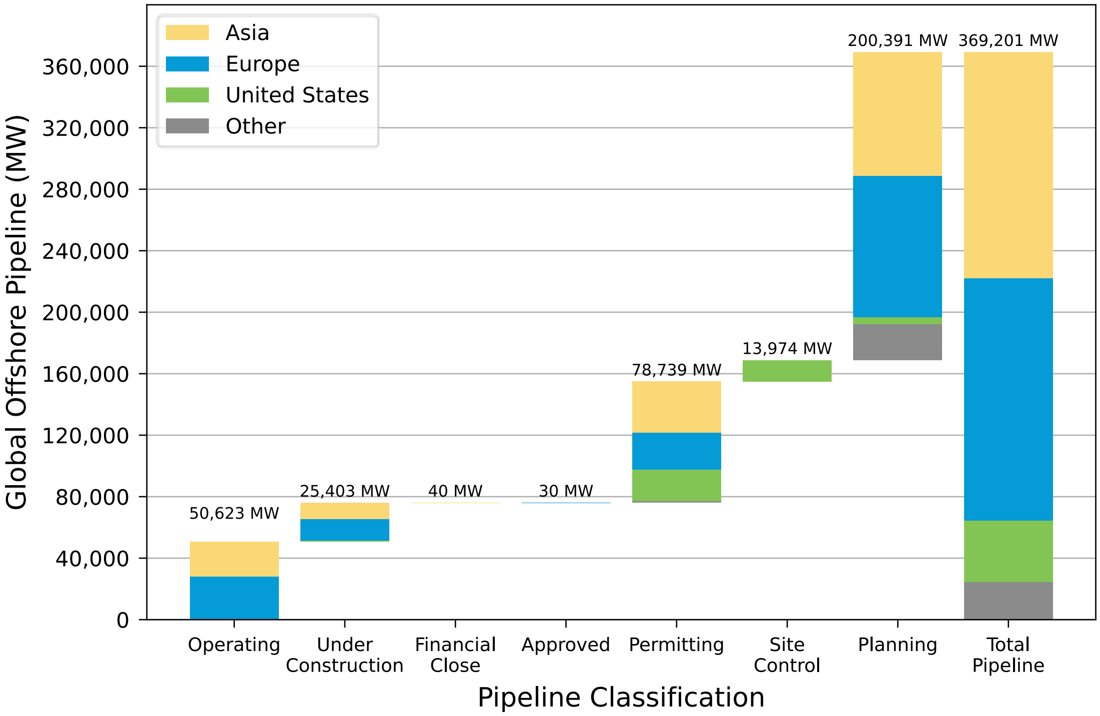

Figure 25. Total global pipeline by regulatory status

Looking at project status, there are approximately 79 GW of projects in the “permitting” stage in the global pipeline—approximately equal to the amount of capacity currently installed and under construction combined. If all the permitting capacity is built, this would be a dramatic expansion of the global market that would require increased development of global supply chains and manufacturing capabilities, and a larger, more robust installation and support vessel fleet.

3.2.4 Global Floating Offshore Wind Pipeline

Overall, the total capacity in the 2021 global floating offshore wind energy pipeline is 60,746 GW, as shown in Figure 26 (note that the *y*-axis has two scales to help identify the advanced early-stage projects). This capacity represents growth of about 27 GW relative to last year’s “Offshore Wind Market Report: 2021 Edition.” The floating pipeline growth was primarily driven by new project announcements in South Korea, the United Kingdom, Brazil, and Australia.

In the near-term floating pipeline (through 2027), there are four projects representing approximately 125 MW that are currently under construction. Four other projects (70 MW) have reached financial close or have all regulatory approvals. Ten projects (221 MW) have advanced to the permitting phase. Most of the pipeline is in the planning stage (including projects with a COD beyond 2027), which comprises 60,206 MW of floating projects. Table 17 includes the total global offshore wind energy floating pipeline and breaks it down by country.

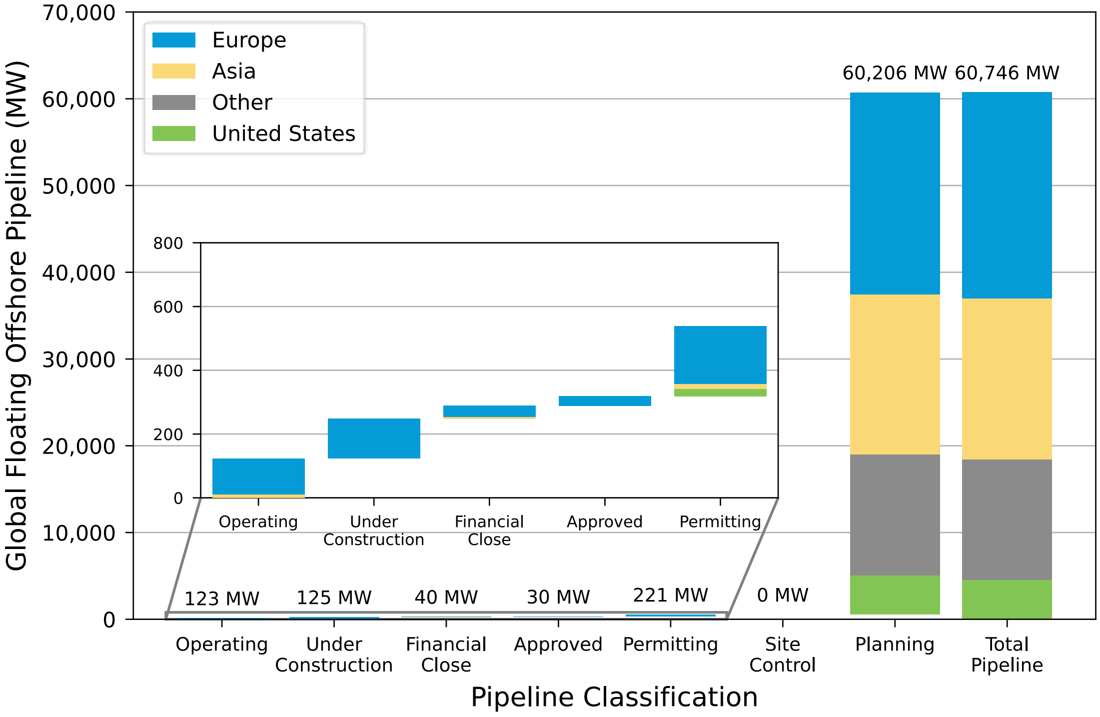

Figure 26. Total global floating offshore wind energy pipeline

Table 17. Global Floating Offshore Wind Energy Pipeline

Country	Operating (MW)	Under Construction (MW)	Financial Close (MW)	Approved (MW)	Permitting (MW)	Planning (MW)	Total (MW)
China	5.5					25	31
France	2	35	25.2	30	28.5	506	627
Japan	5				16.8	2,500	2,522
Norway	5.9	88	10			6	110
Portugal	25						25
United Kingdom	80				110	8,891	9,081
Spain		2			33	2,332	2,367
South Korea			5			9,664	9,669
Ireland					10	6,550	6,560
United States					22	4,532	4,554
Australia						7,400	7,400
Brazil						6,507	6,507
Italy						2,793	2,793
Saudi Arabia						500	500
Sweden						2,200	2,200
Taiwan						5,800	5,800
Total	**123**	**125**	**40**	**30**	**221**	**60,206**	**60,746**

3.3 Forecasted Projections to 2031

3.3.1 Forecasted Global Offshore Wind Deployment

In Figure 27, two independent forecasts are shown: BNEF (2021a) and 4C Offshore (2022a), which estimate the future growth of the global offshore wind energy industry. BNEF forecasts offshore wind energy will reach more than 261 GW by 2031, whereas 4C Offshore estimates a projected deployment level of more than 286 GW by 2031. Together, the forecasts illustrate some variability associated with longer-range deployment estimates, but both indicate strong global market growth with over a fivefold increase in offshore wind energy deployment projected over the next decade.

Like the 2027 near-term projections, the most prominent shift in the offshore wind market in the 2031 forecast is the estimated growth of the Chinese market. Both forecasts expect China will cumulatively deploy between 65 and 77 GW by 2031. The forecasts also predict European developers will build projects at an increasing rate relative to today, with Europe holding roughly 45%–50% of the total installed global offshore wind capacity by 2031. China is expected to represent 22%–30% of the total 2031 installed capacity, with the remaining other Asian countries (e.g., Taiwan, Korea, Japan, and Vietnam) accounting for 15%. Depending on the forecast scenario (4C Offshore or BNEF), the U.S. portion of installed capacity is forecast to be about 10% to 11% of the global total by 2031.

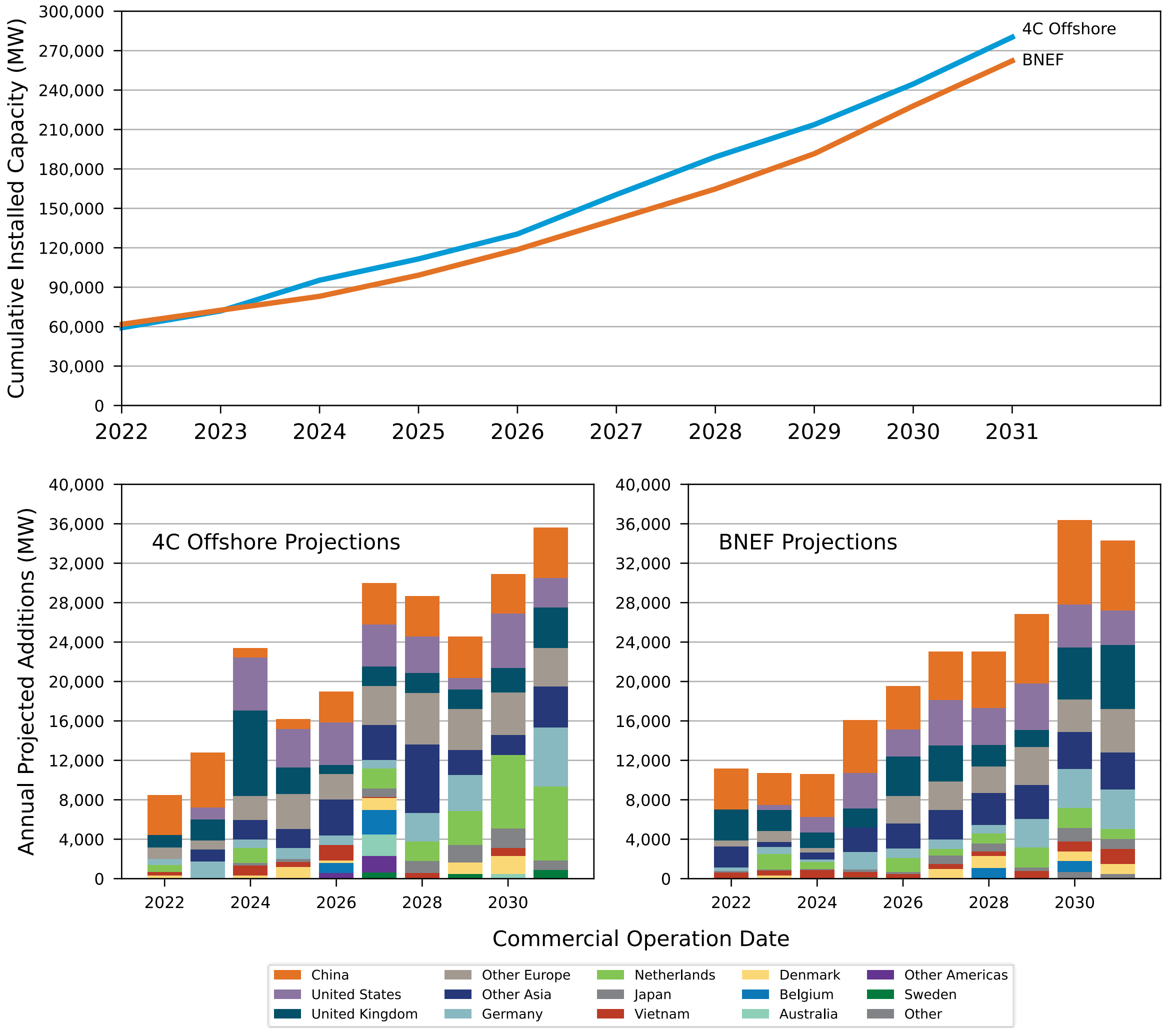

Figure 27. Industry forecasts for global offshore wind energy deployment to 2031

3.3.2 Forecasted Floating Offshore Wind Deployment

Figure 28 shows forecasted floating offshore wind deployment by five independent groups from 2025 out to 2050. The projections show various estimates at about 10 GW by 2030 to as much as 264 GW by 2050, as forecast by DNV (Snieckus 2022a). Factors that may contribute to this predicted growth in floating offshore wind are declining costs due to industry commercialization and supply chain maturity, growing scarcity of shallow, fixed-bottom sites, floating-specific technical innovation, and interest from new markets where only deepwater sites are available (e.g., U.S. Pacific).

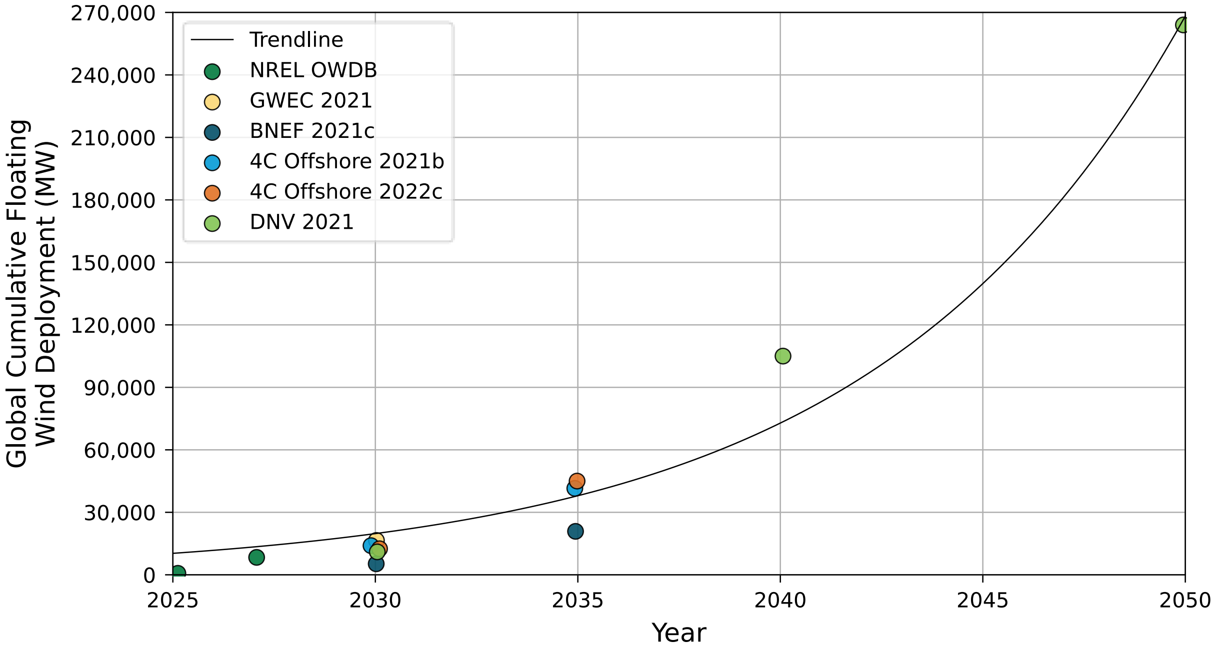

Figure 28. Long-term cumulative floating offshore wind deployment projections

GWEC = Global Wind Energy Council

3.4 Country-Specific Offshore Wind Energy Goals

Future offshore wind energy development is often driven by government leadership at the country level, such as through implementing established national offshore wind targets and wind leasing plans. National offshore wind capacity targets define the size of the future demand, and leasing schedules can help determine how fast the supply will grow to meet that demand. A major trend seen globally is the geographic expansion of the industry. Currently, there are 18 countries with operating offshore wind projects, but that number is expected to nearly double by 2030 (Ferris 2022).

Tables 18, 19, and 20 show national deployment goals and procurement targets for Europe, Asia, and the rest of the world, respectively. Sections 3.4.1 through 3.4.3 provide country-specific offshore wind energy market developments for each of those regions.

3.4.1 European Market Activities

Table 18 presents national goals and developments for European countries. A major advance for floating offshore wind in 2021 was the Scotwind leasing announcement in the United Kingdom, which added a total of 25 GW of offshore wind energy to the country’s planning process, including about 15 GW of floating offshore wind lease area (The Crown Estate 2022). Germany and the Netherlands both outlined plans to increase offshore wind goals to accelerate their planned energy transitions. France, Norway, and Portugal also announced plans to lease offshore wind areas.

In the spring of 2022, many European countries—in response to the Russian invasion of Ukraine—have announced plans to accelerate renewable energy development, including offshore wind, to reduce dependence on Russian fossil fuels.

Table 18. European National Offshore Wind Targets

Country	National Offshore Wind Targets	Key Developments or Procurements	Source(s)
Belgium	5.8 GW by 2030		Government of Belgium (2022)
Denmark	10 GW by 2030 35 GW by 2050	Proposal to increase target to 12.9 GW by 2030 to decrease dependence on Russia	Brooks (2021) renews.biz (2022d)
France	40 GW by 2050	Narbonnaise and Gulf of Fos bidding timelines	Government of France (2022) Russell (2022)
Germany	30 GW by 2030	New government was discussing a plan for 70 GW by 2045. Fast-tracked energy transition to reduce reliance on Russian gas in response to the conflict between Russia and Ukraine. Draft Wind Energy at Sea Act (WindSeeG).	Radowitz (2021) Reuters (2022a) renews.biz (2022a)
Ireland	5 GW by 2030	Maritime Area Planning Bill 2021	Smyth (2022)
Italy	No official policy yet	The government is working on incentives to reduce dependence on Russian gas.	Reuters (2022b)
The Netherlands	21 GW by 2030		Government of the Netherlands (2022) Durakovic (2022b)
Norway	30 GW by 2040	First auction planned in 2022	WindEurope (2022) renews.biz (2022c)
Poland	5.9 GW by 2030 11 GW by 2040	These may go up to 20 GW	Radowitz (2022)
Portugal	3–4 GW by 2026	Planned 2022 auction for 3–4 GW of floating offshore wind operational by 2026	Evwind (2022) Lee (2022)
Spain	1–3 GW of floating wind by 2030		Durakovic (2021e)
United Kingdom	40 GW of fixed-bottom wind by 2030; 1 GW of floating wind by 2030	Scotwind leasing about 15 GW of floating wind	4C Offshore (2022b) Global Wind Energy Council (2021); The Crown Estate (2022)

3.4.2 Asian Market Activities

Table 19 presents national offshore wind energy goals and developments for countries in Asia.

Table 19. Asian Market Activities and National Targets

Country	National Target	Key Developments	Source(s)
Azerbaijan	No official policy yet	World Bank Offshore Wind Roadmap outlines a possibility for 7 GW by 2040	Snieckus (2022b)
China	Over 150 GW in provincial-level goals	Offshore wind subsidies scheduled to phase out by 2022	Barla (2021)
India	30 GW by 2030		Energy World (2018)
Japan	10 GW by 2030; 30–45 GW by 2040		Frangoul (2022)
South Korea	12 GW by 2030		
Oman	No official policy yet	16 GW of wind by 2040—offshore wind not specified	McQue (2021)
Philippines	No official policy yet	The road map released in April 2022 indicates 3 GW to 21 GW by 2040 possible.	World Bank (2022)
Taiwan	15.5 GW by 2035		Ferry (2021)
Vietnam	1 GW by 2030	Draft National Power Development Plan VIII would increase this to 4 GW by 2030	VietnamPlus (2021)

3.4.3 Activities in Other World Markets

Outside of Europe and Asia, Australia, Brazil, and Colombia all took steps toward developing their first offshore wind farms.

Table 20. Rest of the Word Market Activities and National Targets

Country	National Target	Key Developments	Source(s)
Australia	2 GW by 2032 4 GW by 2035 9 GW by 2040	Offshore Electricity Infrastructure Bill 2021 provides a legal framework for electricity infrastructure projects	State of Victoria (2022); Shrestha (2021)
Brazil	No official policy yet	Decree # 10,946 allows Brazil's Ministry of Mines and Energy to select offshore zones for offshore wind energy development. BlueFloat has almost 15 GW and Shell has 17 GW in planning stages.	Durakovic (2022a); Buljan (2022d, 2022e)
Colombia	9 GW by 2050	The Offshore Wind Roadmap for Colombia outlines a path for development.	RCG (2022); Quigley (2022); Buljan (2022d)

4 Offshore Wind Energy Technology Trends

This section details trends for offshore wind energy project siting, substructures, wind turbines, blade recycling, and renewable hydrogen production. Some of these technology trends that are enabling further cost reductions for offshore wind energy include larger wind turbines, advanced controls, supply chain development, increased competition, and systemwide design optimization. Novel floating offshore wind technologies are also enabling new regional markets to evolve and other markets to expand. Overlapping supply chains and shared components mean that some of the same cost reduction drivers for fixed-bottom offshore wind translate directly to the floating offshore wind market. As a result, floating wind energy may soon be commercially feasible in several new offshore wind regions. These recent cost reductions have allowed fixed-bottom offshore wind systems to compete with existing electricity generation technologies in some energy markets without subsidies, and these same cost trends may soon apply to floating wind.

4.1 Global Offshore Wind Siting Trends

Figure 29 summarizes offshore wind energy project deployment trends for four parameters—depth, distance, project status, and project size—and shows these trends for global offshore wind energy projects that have advanced to at least the site-control phase.

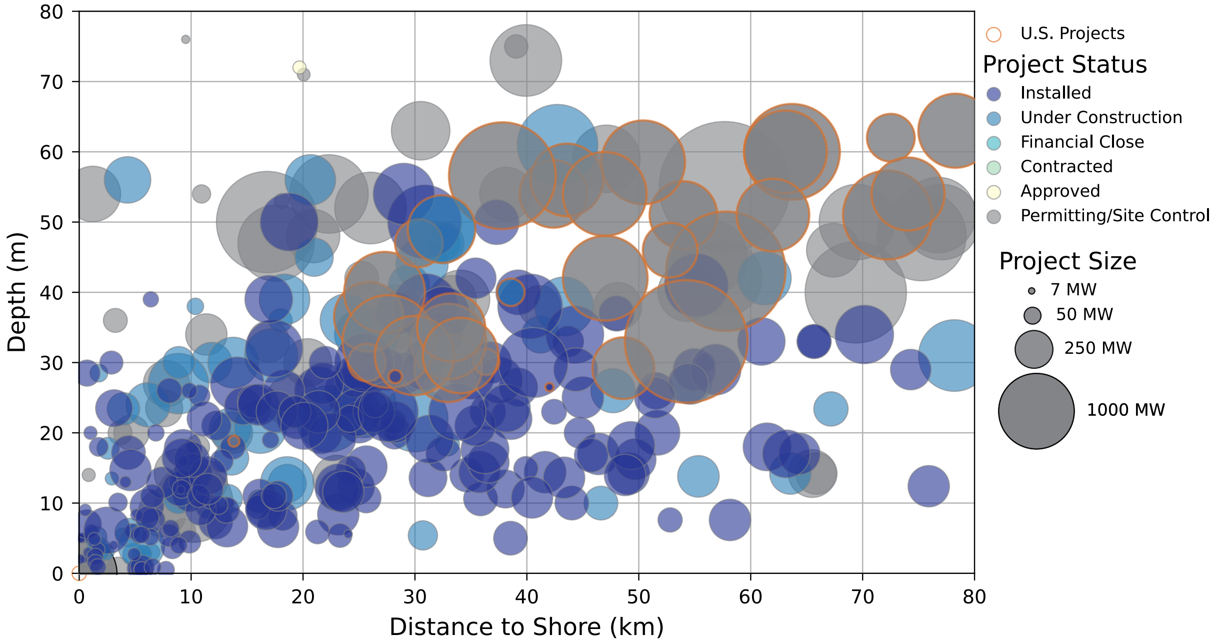

Figure 29. Global fixed-bottom offshore wind energy project depths and distances to shore

In Figure 29, global projects are color-coded by their respective project status in the pipeline. The 22 U.S. projects (indicated with an orange border) that have advanced to the permitting phase in the regulatory process are also included. The figure highlights the general trend that projects in an earlier stage of development tend to be larger, farther from shore, and located in deeper water. Larger project size has been shown to lower projects cost (Shields, Beiter, et al.

2021). The trends toward increased distance from shore and water depth can be attributed to incremental technology improvements in support structures, a better understanding of project risks, and near-shore site scarcity caused by increasing demand. More remote siting has also been enabled by technology advancements in electrical grid infrastructure, such as high-voltage direct-current technology, which avoids the higher losses of a long-distance, alternating-current transmission system. Some of these trends may not be fully apparent from the plot shown in Figure 29 because the large quantity of project data and the lack of a temporal reference.

Figure 30 and Figure 31 show distance to shore and water depth by COD year for the same global project data. These plots may help clarify the historical and projected trends. Asian projects are depicted with an “X” to illuminate the unique Asian market trends from the rest of the world.

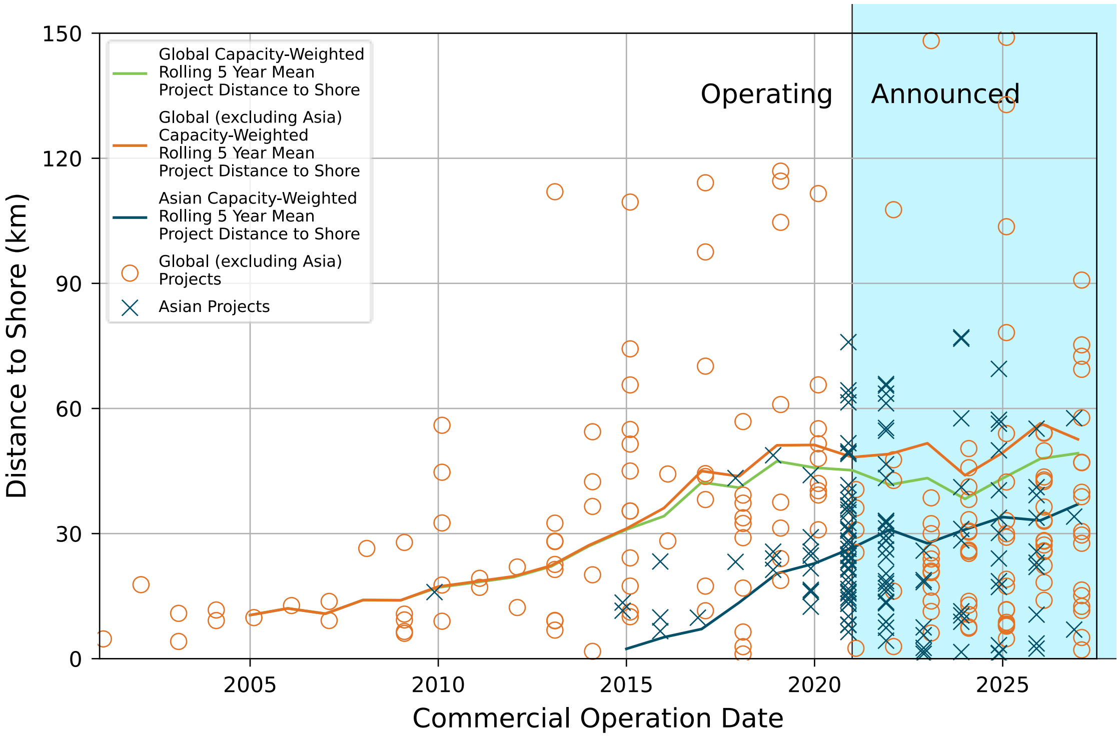

Figure 30. Distance to shore for global operating and future fixed-bottom offshore wind energy projects

In Figure 30, global average distance to shore increases but appears to peak around 2019 and is projected to level out through 2024. This trend can be partially explained by the rapid expansion of offshore wind energy into new Asian markets, and China in particular, where different regulatory environments have enabled projects to be built closer to shore than in Europe. However, the average distance to shore for projects built in Asia has been increasing since 2015 and is trending toward the global average. Although there is less certainty about projects further into the future, the data indicate that the decrease in the global average over time, shown in Figure 30, may be temporary, although the average distance from shore for projects in the rest of the world also seems to be leveling off.

The average water depth over time for global offshore wind projects is presented in Figure 31. The historic trend of increasing water depth levels off slightly in 2021, but the data indicate the trend toward deeper-water, fixed-bottom projects will continue with some annual fluctuations through 2027. As in the case of distance to shore, the slight decrease in global average water depth expected in the near future is attributed to the large quantity of early Asian projects (largely in China) that are located closer to the shore in shallower waters. Interestingly, there was also a slight decrease in the average water depth for projects that came online in Europe in 2021; however, this anomaly does not change the overall trend. The data indicate that the Asian and global trends will converge in 2027.

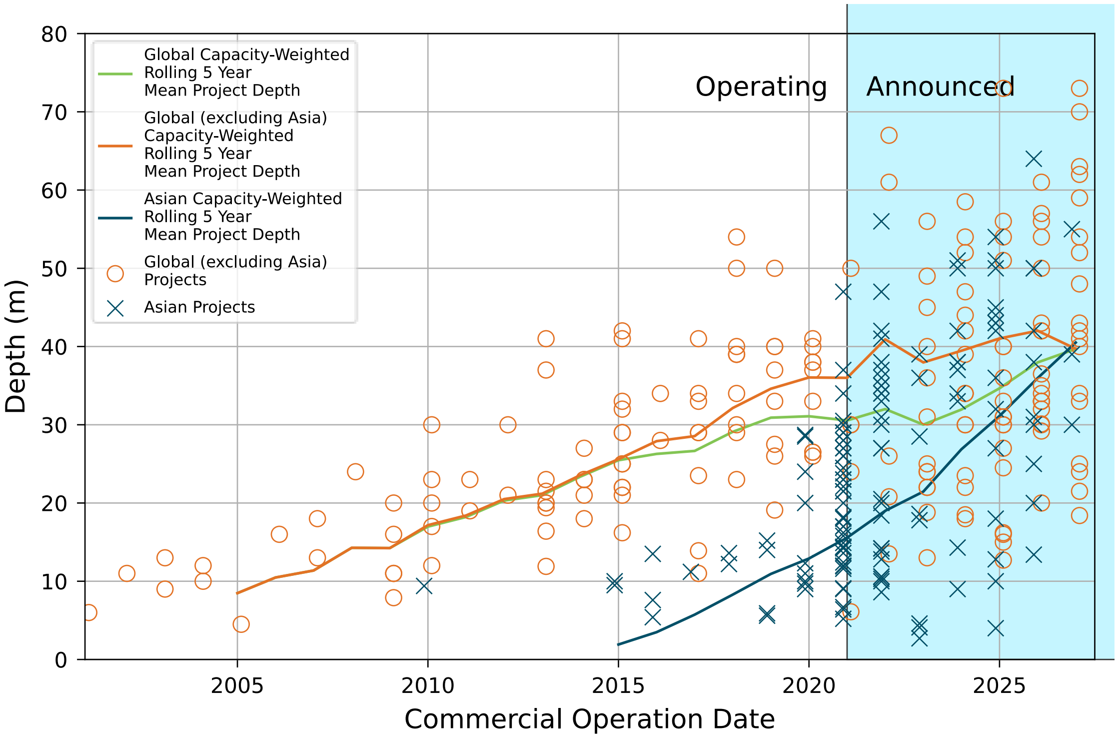

Figure 31. Water depth for global operating and future fixed-bottom projects

4.2 Offshore Wind Energy Substructures

Nearly all operating offshore wind energy projects have used fixed-bottom foundations. Figure 32 shows the current substructure technology mix for offshore wind energy projects operating at the end of 2021, totaling 50,623 MW. Monopiles remain the dominant foundation type, representing 64.4% of the total offshore wind foundation market for installed projects. Jacket substructures are the next most common foundation type, with 11.6% of operating substructures.

Figure 33 shows data for future offshore wind projects that have announced their intended substructure technology. The data show that the share of monopiles drops to 56.5% of the announced market, but because monopile production is a mature process that has been industrialized, monopiles generally have a cost advantage and are expected to remain dominant.

As floating offshore wind projects enter the commercialization phase, the data in Figure 33 also show that projects that have announced their substructure type favor semisubmersibles, and that there is enough capacity in the floating pipeline now for these foundation types to gain the second largest market share, representing 16.2% based on announced projects. As fixed-bottom projects are planned in deeper waters and manufacturing options for jackets increase, jackets are expected to account for 13.4% of the future market, and gravity-base foundations are also likely to increase their market share. Gravity-base foundations might be the most suitable in rocky soils where pile driving may be difficult, or when underwater pile driving noise needs to be avoided to protect wildlife.

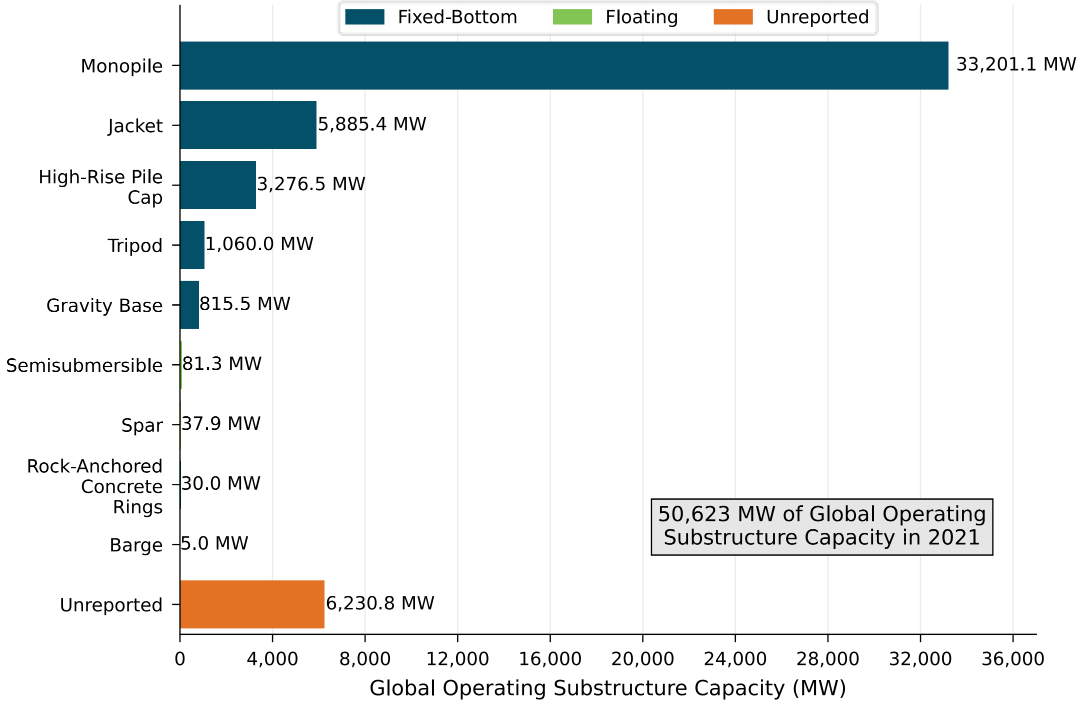

Figure 32. Offshore wind substructure technology used in operating projects

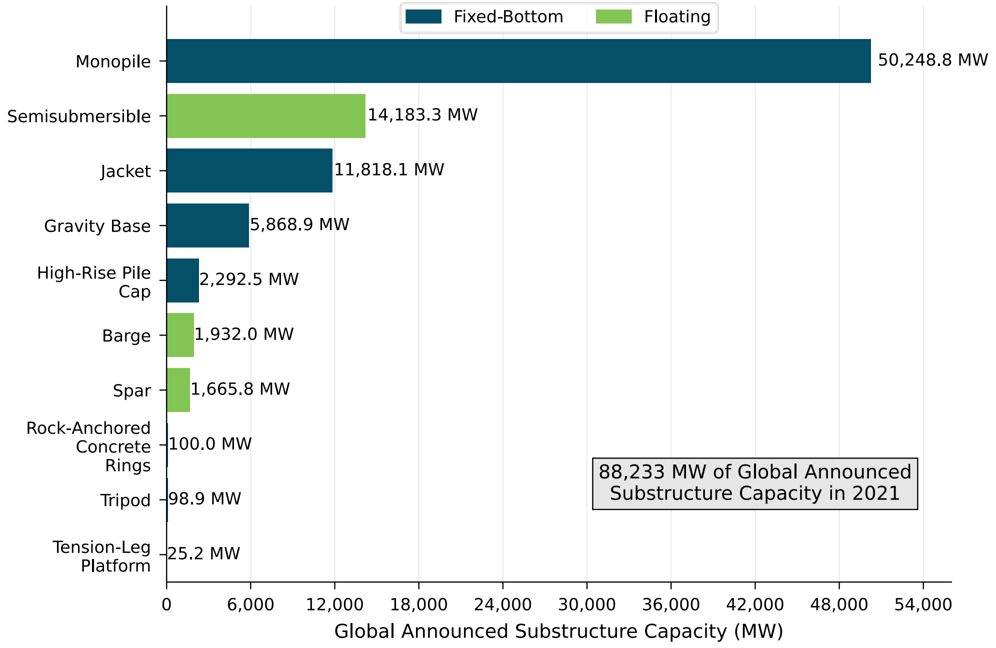

Figure 33. Announced offshore wind substructure technology for future projects

The following wind companies have deployed floating technology at the megawatt scale (or greater):

- China Three Gorges Group (semisubmersible floating substructure)
- Principle Power, Inc. (WindFloat semisubmersible floating substructure)
- Equinor Hywind (spar floating substructure)
- Stiesdal Tetraspar (hybrid floating substructure)
- Toda (spar hybrid floating substructure)
- BW Ideol (Damping Pool barge floating substructure).

Figure 34 shows the installed and announced floating substructure capacity combined, broken down by technology type. Most floating projects in the pipeline (79.6%) plan to use semisubmersible substructures. We attribute the preference for semisubmersibles to their relatively shallow draft and hydrodynamic stability after wind turbine installation. As a result, the turbines can be assembled, installed, and commissioned at quayside, and towed out to the site without using heavy-lift installation vessels. Additional innovations like rapid disconnect cables may help facilitate tow-to-port operations and maintenance (O&M) strategies.

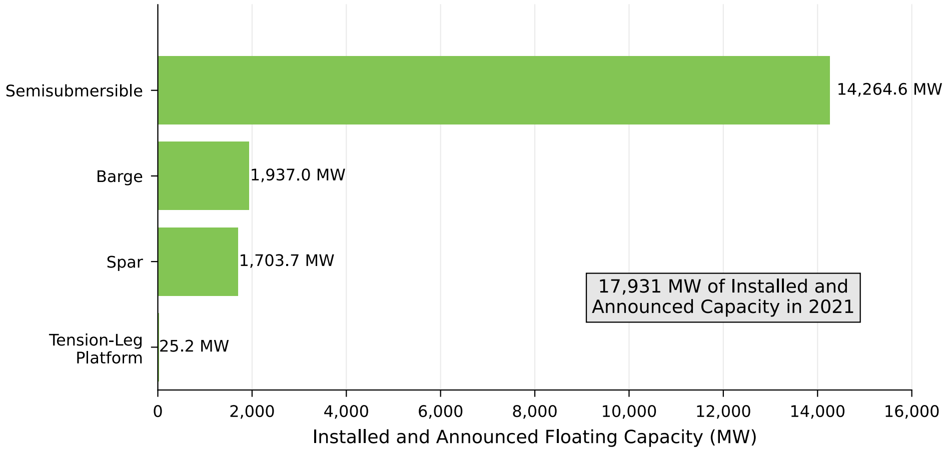

Figure 34. Global floating substructure market share (installed and announced)

Floating substructure technology is evolving rapidly as different providers compete to provide cost-effective solutions for the first generation of commercial floating projects. Two emerging themes are the rise of hybrid substructures (novel substructures that merge the shallow draft of semisubmersibles with the favorable attributes of other substructure types) and industrialization (innovations that simplify design and manufacturing to enable mass production) of the floating supply chain; both have the potential to dramatically lower system costs. Additional information about the development status of most of the current floating substructure technologies competing to supply the emerging floating offshore wind industry can be accessed in “Floating Offshore Wind Turbine Development Assessment” (ABS Group 2021).

The floating offshore wind industry has been gaining commercial interest over the past few years. Since 2019, the project pipeline expanded by nearly fourfold, mostly because of new projects entering the planning phase. However, one of the primary barriers to cost reduction is that the market volume is not yet large enough for investors and developers to reap the benefits of large-scale production or establish an organized industrialized supply chain. Factories and ports for floating offshore wind will likely be different than for fixed-bottom foundations and it is not clear yet what the scale of deployment is needed for such infrastructure investment (Umoh and Lemon 2020).

4.3 Offshore Wind Turbines

The dominant trend in offshore wind turbines is the industry’s continued push for increased generating capacity to lower project costs. All the major OEMs continue to compete to deliver ever-increasing generating capacity in response to market demand. In late 2021, MingYang Smart Energy joined the ranks of GE, Siemens, and Vestas, which have all announced plans for wind turbines at the 15-MW scale. The MingYang announcement was for a 16-MW offshore wind turbine, which they claim will be in serial production by 2024 (MingYang Smart Energy 2021). Not only is this the largest announced turbine capacity to date, but if MingYang can deliver on the promised timeline, it represents a rapid acceleration of turbine growth in Asia and a significant move toward the convergence of Asian and European markets.

Figure 35 shows the historical trend of offshore wind turbine upsizing based on market averages. The figure presents data for the global-weighted-average offshore wind turbine capacities, hub heights, and rotor diameters over time, with the 2021 values indicated in the gray box in the plot area.[20]

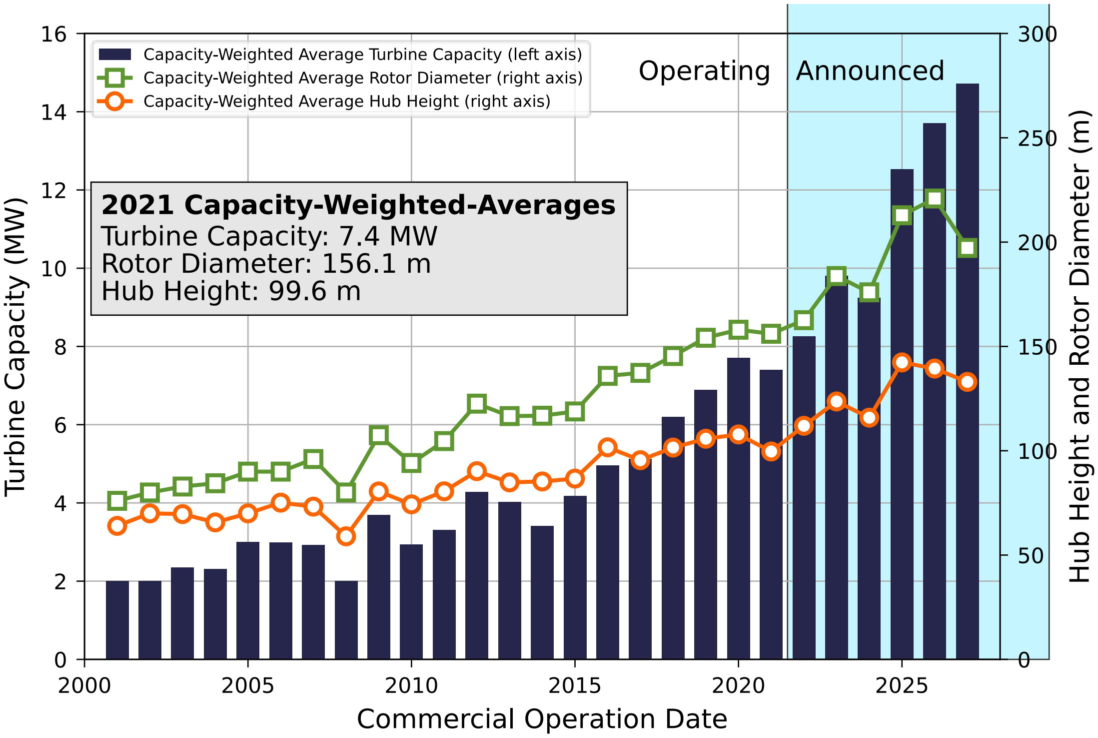

Figure 35. Global average offshore wind turbine capacity, hub heights, and rotor diameters

Figure 35 indicates the general trend of the industry will be to adopt 15-MW-class wind turbines by 2027. Increased wind turbine nameplate capacity has been one of the main drivers behind lower offshore wind energy costs. The average offshore wind turbine capacity installed in 2021 was 7.4 MW, slightly down from 7.6 MW in 2020, but a small departure from the broader trend that is expected to be upward. The average rotor diameter in 2021 was 158 m, with an average tower height of 108 m.

Developers generally prefer to use the largest wind turbine available for a given project because fewer are needed for the same plant capacity, which reduces balance-of-system and O&M costs on a per-kilowatt basis. Offshore turbine upscaling is more feasible than on land because transportation and installation barriers are not as limiting (Shields, Beiter, et al. 2021). Turbine upscaling is generally focused on the rotor diameter and generator power rating. Composite manufacturing, design, and material innovations, as well as load-reducing advancements in wind turbine controls, have facilitated the upscaling of wind turbine rotors, as shown in Figure 35. Wind

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[20] The slight dip in the average installed turbine capacity in 2021 is likely caused by the massive quantity of projects coming online in China in 2021 with lower turbine ratings (a 5.7-MW average in China compared to an 8.3-MW average in the rest of the world).

turbine hub heights tend to increase directly with rotor radius to maintain a 25- to 30-m clearance between the blade tip and the still water surface. This increase in hub height also results in incremental performance improvements because of better winds at higher altitudes, but those performance benefits are offset to varying degrees by increased tower and support structure costs.

Figure 36 shows offshore wind turbine growth trends by depicting the power-generating capacity relationship between the average installed offshore turbine capacity (from Figure 35) and the capacity of new wind turbine prototypes over time.

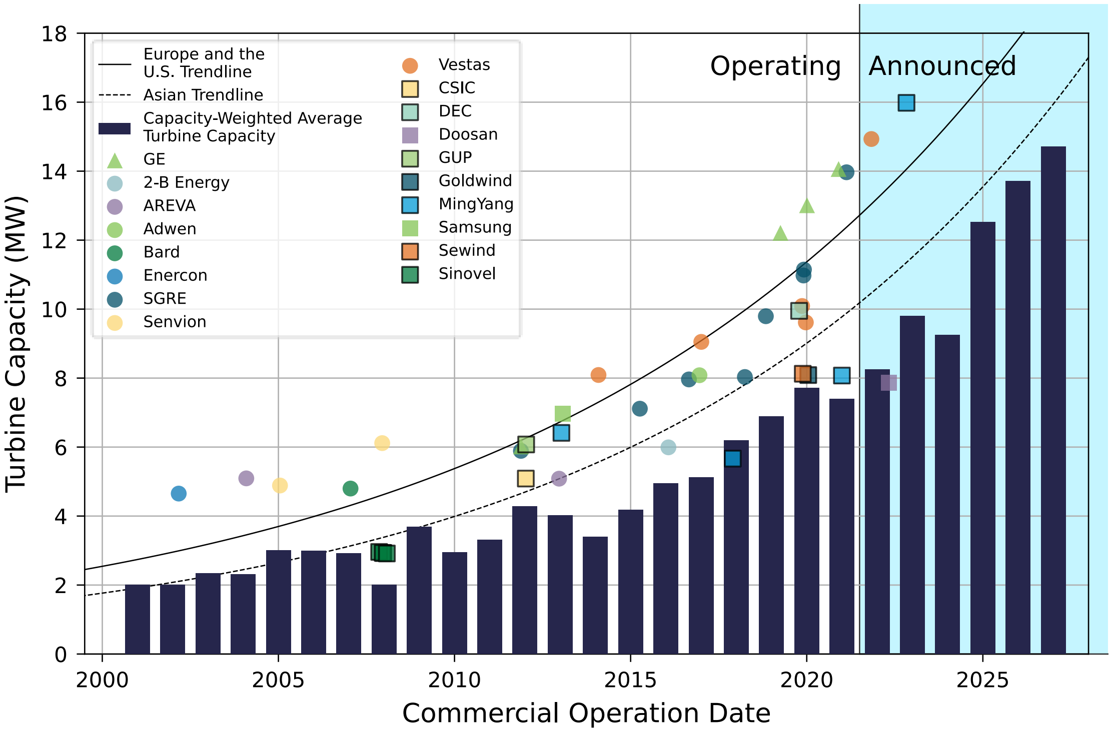

Figure 36. Comparison of offshore wind turbine prototypes with commercial offshore turbine growth.

Note: In the figure, GE is General Electric, SGRE is Siemens Gamesa Renewable Energy, CSIC is China Shipbuilding Industry Company, DEC is Dongfang Electric Corp., and GUP is Guodian United Power Technology Co., Ltd.

There is usually a lag of several years between the time operational prototypes are installed and demonstrated, and when they reach serial production and are fully adopted by the commercial market. “Operating” prototypes are verified to determine that they have been installed and are operating, although performance details are not often shared by the OEM. Future wind turbine prototypes that are “announced” are plotted based on public information regarding their target installation dates. These data are more uncertain because they rely on the OEM’s intended schedule but do not account for potential delays or technical setbacks. In the figure, data symbols representing Chinese wind turbine prototypes are outlined in black to distinguish them from European trends. Exponential curve fits of historical and future announced prototypes show that growth in wind turbine capacity is increasing among both Asian and European/United States (western) OEMs.

We caution extrapolating the curves in Figure 36 very far beyond the existing prototypes, however, because the returns on the industry's investments in these new 15-MW wind turbine prototypes have not yet been realized. None of these turbines are in serial production yet; therefore, the industry may decide that capturing the potential cost reductions from efficiencies resulting from mass production, industry learning, infrastructure amortization, and industrialization may be more profitable than further upscaling. Historically, the market dynamics of turbine upscaling have been challenging to predict and ultimately, a combination of economic, technological, and regulatory considerations determine future turbine sizes (Beiter et al. 2022).

In 2021, China installed a record-breaking amount of offshore wind capacity (see Section 3). As a result, the emerging Asian market is increasingly influencing the global wind turbine growth trends shown in Figure 36. Currently, installed turbine ratings in Asia lag the rest of the world (largely Europe). The difference between the wind turbine prototype trendline for western turbines (rest of the world) and the trendline for Asian turbines indicates that Asian prototypes are currently 20%–25% lower in capacity than their western counterparts in 2021. Both western and Asian trendlines are increasing at about the same rate and the chart shows that the upscaling of turbines prototyped by Asian manufacturers lags western prototypes by about 4 years.

The largest wind turbine operating in Asia is the Dongfang Electric Corp. 10-MW prototype installed in 2020 (Buljan 2020). Other Asian OEMs have announced development of prototypes between 10 MW and 13 MW but have not listed timelines for prototype installation or serial production, so they are not included in Figure 36 (Dongfang Electric Corp. 2021; Yahoo! Finance 2021).

In Europe, Siemens Gamesa's SG 14-222 DD prototype was installed in October 2021 and is now operational in Østerild, Denmark (renews.biz 2021, Durakovic 2021a). The 14-MW Siemens prototype matches the capacity of GE's Haliade-X, which is now operating in the Netherlands at 14 MW, making these two machines the largest operating offshore wind turbines in the world (General Electric 2021). However, Vestas plans to install the V236-15 MW prototype at the Østerild test stand in 2022 (Vestas 2021a).

Generally, the OEMs design new turbine platforms with enough margin to increase the generator nameplate rating with the same rotor. GE has demonstrated this twice already with their Haliade X, by moving the prototype from a 12-MW to a 13-MW rating, and to a 14-MW rating in just 2 years (GE 2019, 2020a, 2021). This strategy enables higher power output and energy production on the same nacelle frame without needing to retool blade production. It also allows for rapid upgrades to higher capacity but must be carefully engineered to avoid increased risk from higher fatigue loading and potential decreases in the turbine's design life.

Historically, it takes OEMs longer than 2 years to deploy operational prototypes after public announcements, and Figure 36 indicates a lag of approximately 6–8 years between installing a prototype and the year in which the global market average reflects the adoption of these turbines. Generally, current OEM timelines are more optimistic than these historical trends, with serial production promised in less than 4 years following the installation of their respective prototypes.[21]

Figure 37 and Figure 38 illustrate wind turbine OEM market share for operating and announced projects, respectively.

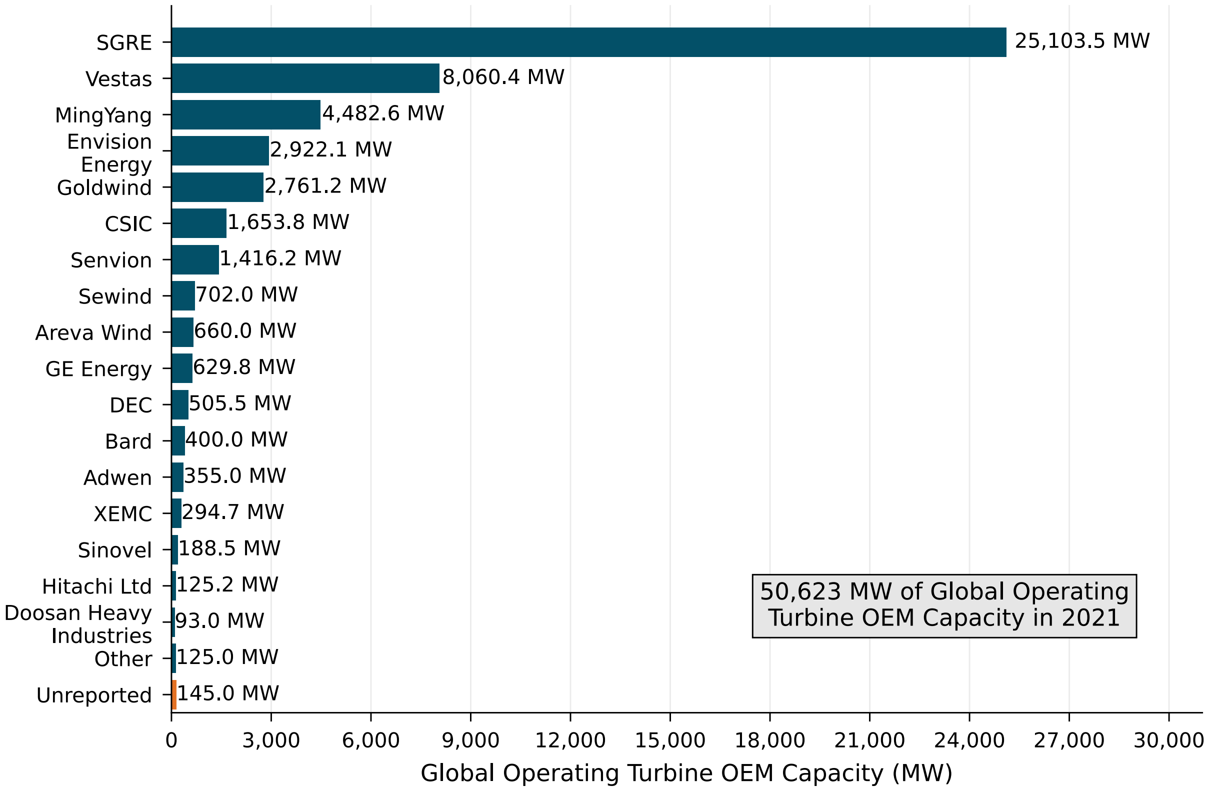

Figure 37. Offshore wind turbine manufacturer market share for operating projects.

Note: In the figure, SGRE is Siemens Gamesa Renewable Energy, CSIC is China Shipbuilding Industry Company, GE is General Electric (Energy), and DEC is Dongfang Electric Corp.

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[21] Note that market averages also lag serial production to some degree.

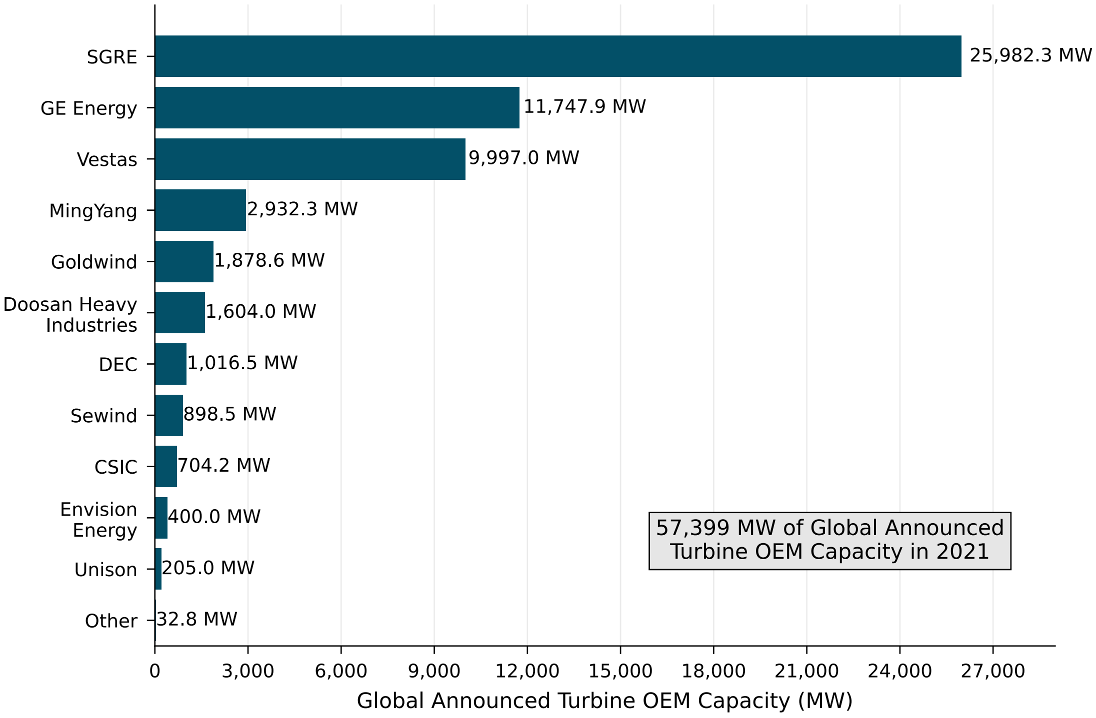

Figure 38. Offshore wind turbine manufacturer market share for announced projects

Siemens Gamesa is the dominant offshore wind turbine manufacturer, with approximately 50% market share of all turbines installed today, but data from announced projects indicate this market share will decrease to 45% as GE, Vestas, and Asian OEMs gain market share. Vestas (including MHI Vestas) is the second-largest OEM in terms of market share of existing capacity. GE Energy, which was largely focused on the land-based market until 2015, was the first of the major OEMs to scale up to 12 MW with its Haliade-X turbine (now at 14 MW) and its market share is projected to increase to about 20%, based on announced projects that have reported their turbine.

Figure 38 indicates MingYang and Goldwind will be the dominant Chinese OEMs based on announced project commitments. In parallel with its efforts to develop larger wind turbines, MingYang is also expanding its global market presence as the supplier for two projects in Europe, representing a possible globalizing trend for the Chinese turbine manufacturer (Buljan 2021b, 2021c; Memija 2022b).

To date, no OEMs have announced plans to develop bespoke floating offshore wind turbines, although some adaptive features that can be implemented without major design changes will be needed. These features include stiffer towers and advanced controls to mitigate tower motion. It is likely that OEMs will wait until there is a larger and more advanced pipeline of floating offshore wind energy projects before committing to investments in custom floating wind turbines.

Similarly, wind turbines built to operate in low-wind climates with high extreme conditions (like hurricanes in the Gulf of Mexico) are not yet available. However, trends seen in the Asian offshore wind market indicate that International Electrotechnical Commission typhoon-class turbines are already available but not yet customized for low average wind speeds (Barla 2021). More research into reducing the uncertainty for hurricane survival may still be needed (Musial and Greco 2020).

4.4 Wind Turbine Blade Recycling

Most of the material used to manufacture a wind turbine is recyclable—85%–90% by weight (metal, fiberglass, and resin components). Historically, the materials in thermoset composites used to make turbine blades have been challenging to separate (Vestas 2021b). The offshore wind energy industry is addressing sustainability considerations for decommissioning wind power plants by developing fully recyclable wind turbine blades. All three of the major western OEMs—Siemens Gamesa, Vestas, and GE (LM Wind Power)—are members of the DecomBlades consortium announced in 2021, with the aim of developing recyclable wind turbine blades (Siemens Gamesa 2021a). Both Siemens Gamesa and Vestas intend to produce zero-waste wind turbines by 2040 (Siemens Gamesa 2021a; Vestas 2021b). Ørsted is also a member of DecomBlades and has committed to reusing, recycling, or recovering all decommissioned blades from its wind power plants (Ørsted 2021).

In September 2021, Siemens Gamesa launched their “RecyclableBlade,” the world’s first recyclable offshore wind turbine blade (Siemens Gamesa 2021b). The first six RecyclableBlades have been manufactured and are being deployed in 2022 on the Kaskasi offshore wind farm in Germany. The Zero wastE Blade ReseArch (ZEBRA) consortium, including GE subsidiary LM Wind Power, announced the production of its first prototype recyclable wind turbine blade in March 2022 (GE 2022; LM Wind Power 2021). This is a step beyond a previous effort by LM Wind Power’s parent company, GE, and Veolia to process blades into raw materials for cement (GE 2020b).

In the United States, the Bipartisan Infrastructure Law (Infrastructure Investment and Jobs Act) includes $40 million for facilitating wind energy recycling research (DOE undated [c]).

A United Kingdom project between Aker Offshore Wind and University of Strathclyde’s Advanced Composites Group and Lightweight Manufacturing Center was granted $2 million GBP ($2.54 million) for the country’s first blade recycling project (University of Nottingham 2021). The focus of the project is to commercialize a fiber-recovery method used to separate glass fibers from resin components in composites and reprocess them.

In the United States, the Carbon Rivers project, funded by the U.S. Department of Energy in collaboration with the University of Tennessee, Knoxville, successfully scaled up a recovery process for wind turbine blade recycling that has the capability to divert thousands of tons of fiberglass from landfills. Carbon Rivers has upcycled a few thousand metric tons and is building capacity in their new facility to take in over 50,000 metric tons annually (U.S. Department of Energy 2022d).

4.5 Green Hydrogen Production From Offshore Wind

Governments, energy companies, and industrial end users (chemical companies and steel producers, for example) are increasingly looking at offshore wind as a power source to produce green hydrogen that can be used in other sectors of the economy (e.g., transportation, heating, industry/manufacturing, grid storage) as a zero-emission fuel. Several global projects have either been proposed or are in early stages of development including:

- Shell, RWE, Gasunie, Gascade, Equinor, Ørsted, Boskalis, and a growing consortium of over 90 members signed a declaration of intent to continue collaborating on the AquaSector initiative (RWE 2021; AquaVentus 2022). This initiative includes the AquaVentus and AquaDuctus projects in Germany with the aim of using 10 GW of offshore wind energy to produce up to 1 million tonnes of hydrogen and pipe it to Europe from 2035 onward (RWE 2022a).
- Ørsted and POSCO formed a South Korean Hydrogen Pact. POSCO, one of South Korea's largest industrial and steel conglomerates, plans to use 1.6 GW of Ørsted's offshore wind capacity off the coast of Incheon to power its hydrogen production requirements.
- Neptune Energy's PosHydon project announced that it brought on Emerson (a U.S. manufacturing firm) to develop the software and systems for integrating offshore-wind-based hydrogen production with offshore gas, and offshore hydrogen for Dutch utilities Eneco, Gasunie, Noordgastransport, and Northern Offshore Gas Transfer (J. Burgess 2021; M. Burgess 2022).
- Ørsted's H2RES project is expected to start operation in 2022 (Buljan 2022b). The wind-to-hydrogen project at Avedøre Holme in Denmark aims to produce 1,000 kilograms of hydrogen per day and power zero-emission road transport in the greater Copenhagen area (Buljan 2021a).
- The American Bureau of Shipping is developing technical guidance for hydrogen production on offshore platforms (The Maritime Executive 2022).
- The Shell-led Flexible Offshore Wind Hydrogen Power Plant Module (FlexH2) 4-year research project to accelerate the scale-up of offshore wind to green hydrogen production and its integration in the energy system started in April 2022 (Durakovic 2021d; Windpowernl 2022).
- The first floating green hydrogen project, Dolphyn, is skipping plans for a prototype phase and is planning to make a final investment decision on the 10-MW unit by the end of 2022 (Thomas 2021).
- A new partnership emerged between Marine Power Systems and Marine2o (Gluon) to develop solutions for transporting green hydrogen with marine vessels (Marine Power Systems 2022).

- RWE and Neptune Energy agreed to develop an offshore-wind-to-green-hydrogen project in the Dutch North Sea with an electrolyzer capacity of 300–500 MW and an existing pipeline to shore (RWE 2022b).
- A U.S. bipartisan infrastructure law includes $9.5 billion for clean hydrogen, which can be used to explore offshore-wind-to-hydrogen projects and other applications (DOE 2022b).
- SJI has a partnership with Atlantic Shores Offshore Wind to examine a pilot program to blend green hydrogen[22] with natural gas in New Jersey (SJI 2021).
- A multiagency consortium that includes New York, Connecticut, Massachusetts, and New Jersey announced a partnership together with 40 hydrogen ecosystem partners to develop one of four clean energy hydrogen hubs as part of the Bipartisan Infrastructure Investment and Jobs Act (New York State Governor's Office 2022).

4.6 Offshore Wind Technology Summary

The trend toward wind turbine upsizing in the offshore wind industry pervades most other technology trends in 2021 because the industry relies on the rapid success of the 15-MW platform and the expectation that all OEMs will follow suit to remain competitive (Shields, Beiter, et al. 2021). As such, turbine upscaling is driving trends in substructures and infrastructure development, such as ports and vessels. All three major European manufacturers of offshore wind turbines are working on developing 15-MW-class wind turbines with rotor diameters spanning up to 236 m, with the potential for commercial production between 2022 and 2024. As such, the associated support structures, installation vessels, fabrication facilities, and operational strategies are also being upsized.

In contrast, the industry is also calling for the industrialization of the technology, especially with respect to floating offshore wind, to reduce cost through experience and economies of scale. The two competing trends, upscaling versus industrialization, will need to be balanced. The National Offshore Wind Research and Development Consortium's "Offshore Wind Roadmap 3.0" goes into further detail regarding the research needs to advance offshore wind technology (National Offshore Wind Research and Development Consortium 2021).

The average nameplate capacity of offshore wind turbines installed in 2021 was not higher than 2020, but the long-term upward trend is still very evident. Monopile substructures remain the dominant foundation type, although future project announcements indicate that the market share for monopiles will drop from 64% in installed projects to about 56% in announced projects, yielding some share to floating substructures, jackets, and gravity-base foundations.

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[22] Generally, green hydrogen refers to the production of hydrogen from a renewable energy or low-carbon source.

Floating offshore wind technology is still maturing but the industry is pushing toward large-scale commercialization using lessons learned from upscaling fixed-bottom technology. Floating offshore wind continues to use the same turbines as fixed-bottom wind, with minor adaptations. The industry is pushing to accelerate commercialization of floating technology with the expectation that increased market commitments and industrialization of floating systems will lower costs and inspire investors to commit to develop large-scale production facilities.

5 Cost and Price Trends

Offshore wind energy continued an 8-year cost reduction trend and realized incremental cost declines in 2021 globally, despite supply chain constraints and inflation. Further cost reductions are estimated for the decades ahead. This section presents cost trends from empirical project data and estimates from leading research organizations, both for fixed-bottom and floating offshore wind technologies. The data sources report cost trends on a regular basis and serve as references for many industry and research stakeholders. The cost data presented in this section are complemented by price data from recent competitive tenders for U.S., European, and Asian fixed-bottom projects. Prices and costs are conceptually different but considered together they provide a more robust perspective on the economics of offshore wind energy. Costs are often derived from bottom-up modeling or project market reporting; price data are sourced from public tenders. The project sample size varies across the cost and price metrics featured in this section.

5.1 Fixed-Bottom Technologies

5.1.1 Levelized Cost of Energy Trends

The estimated levelized cost of energy (LCOE) for commercial-scale offshore wind projects in the U.S. declined to $84/megawatt-hour (MWh) on average, with a range of $61/MWh to $116/MWh (Figure 39). The sources depicted in Figure 39 are from leading research organizations and consultancies that have published LCOE estimates and projections during 2021. This decline represents a reduction of 13% on average compared to 2020 U.S. estimates, bringing the total cost reduction to more than 50% since 2014 (Wiser et al. 2021).

For their midcase scenario, leading research entities and consultancies estimate that LCOE will be $60/MWh on average by 2030.

Variation in the estimated LCOE within any given year is caused by many factors, including:

- Differences in site characteristics (e.g., wind speed)
- The regulatory and market environment
- Calculation methods
- Assumptions about financing
- Technology and market maturity.

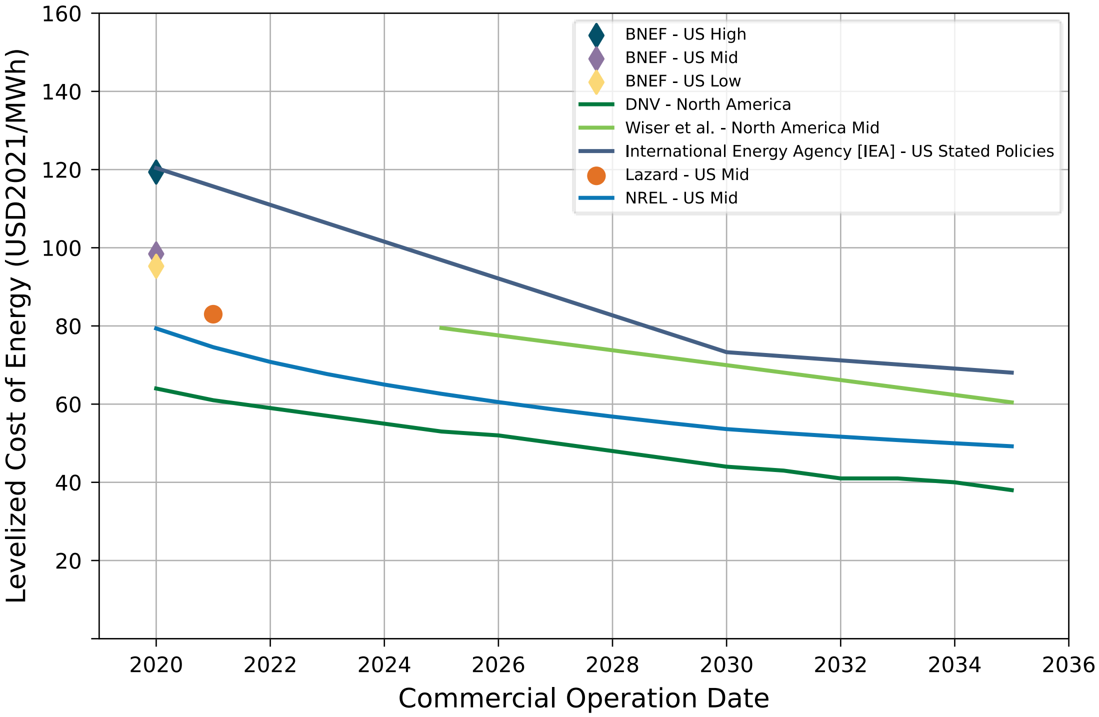

Figure 39. LCOE estimates for fixed-bottom offshore wind energy in the United States.

Sources: BNEF (2021b); Wiser et al. (2021); NREL (2021); DNV (2021), International Energy Agency (2021); Lazard (2021).

Some U.S. developers indicated that disrupted global supply chains and inflationary pressures from high demand for commodities (e.g., steel) and offshore goods and services (e.g., offshore wind foundations, WTIVs and logistics, and offshore substations) caused price increases in 2021–2022 (Eversource Energy 2021; Ørsted 2022). This, in turn could result in higher costs and prices for energy generation, including from offshore wind energy. At this point, the extent of the cost increases caused by inflation is uncertain because some developers might have finalized procurement terms before inflationary pressures took hold or they indexed their assets for inflation (i.e., to hedge their procurement against inflation risk) (Eversource Energy 2021).

While cost data have only been available through inference from European project data in the past, a first U.S. data point has been made public by Dominion Energy for its Coastal Virginia Offshore Wind project (Table 21). These project data show a cost level comparable to European projects.

Table 21. Publicly Reported Costs for the Dominion Offshore Wind Energy Project

Component	Value	Units
CapEx	3,788	$/kW
Transmission	299	$/kW
Substation	145	$/kW
Contingency and hedging	193	$/kW
Balance of plant	425	$/kW
Onshore facilities	444	$/kW
Offshore work	580	$/kW
O&M costs	50	$/kW-yr
Gross capacity factor	43.3	%
Availability	97	%
Lifetime	30	years
Investment tax credit eligibility	83.27	%
LCOE (including 30% investment tax credit)	77	$/MWh
Return on equity	9.2	%
Project size	2,587	MW
Wind turbine rating	14.7	MW
Wind turbines	176	-
Commercial operation date	2026	-
Distance from shore	44.4	km

Source: Dominion Energy (2021a)

Note: Dollar-year adjustments from $2027 to $2021 were used assuming an annual inflation rate of 2.0%, which is consistent with the rate used by Dominion Energy (2021a). Values were converted from $ to $/kW and $/kW-year.

Cost projections adopting a learning-curve approach can offer a complementary method for forecasting future cost reductions. For each doubling of industrywide installed capacity, a learning curve indicates a rate at which LCOE declines based on empirical project data. Learning rate estimates of offshore wind energy vary considerably, from 14% to 33% (Junginger and Louwen 2019; Wiser et al. 2021; Beiter, Cooperman, et al. 2021). Global offshore wind energy capacity is projected to grow to about 273 GW by 2031 (Section 3)—over fivefold the currently installed capacity of 50.6 GW. Assuming these deployment levels, an average learning rate of 14% (the lower end of the range mentioned earlier) and an LCOE of $84/MWh in 2021 would yield a possible LCOE of approximately $59/MWh by 2031.

5.1.2 Capital Expenditure Trends

CapEx is the single largest contributor to the life cycle costs of offshore wind power plants and include all expenditures incurred prior to the start of commercial operation.

In this section, we show the reported CapEx over time for operational projects as well as for those in various stages of the near-term project pipeline globally (Figure 40). After a period of increasing CapEx (Musial et al. 2017), since 2015 the capacity-weighted average CapEx for offshore wind projects has decreased, reaching approximately $3,700/kW in 2021 (COD) globally and just below $4,000/kW in European and U.S. markets. Reported CapEx tend to be higher in Europe and the United States than in Asia, but the two markets have been converging since 2015, with Europe and the United States CapEx projected to reach similar levels to those in Asia by 2026.

Reported global project data suggest a decline of the 5-year rolling capacity-weighted mean CapEx globally from $3,700 in 2021 to about $3,100/kW by the mid to late 2020s. The underlying data for Figure 40 include considerable variation of CapEx within a given year. For projects with a COD in 2021 and capacities greater than 100 MW, CapEx falls into a range of approximately $1,990/kW (Kriegers Flak, Denmark [605 MW]) to $6,380/kW (Moray East, United Kingdom [950 MW]).[23] Several factors may possibly explain the variations in CapEx within a given year and over time (Smith, Stehly, and Musial 2015), including:

- Varying spatial conditions (e.g., water depth, distance to port, point of interconnection, and wave height of sites that affect technical requirements of installing and operating a wind farm)
- Project size
- Different levels of supply chain shortages (e.g., components, vessels, and skilled labor)
- Changing prices for commodities and energy
- Macroeconomic trends, such as fluctuating exchange rates
- A change in the appreciation of the costs and risks associated with offshore wind energy project implementation.

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[23] Demonstration projects are excluded from this range.

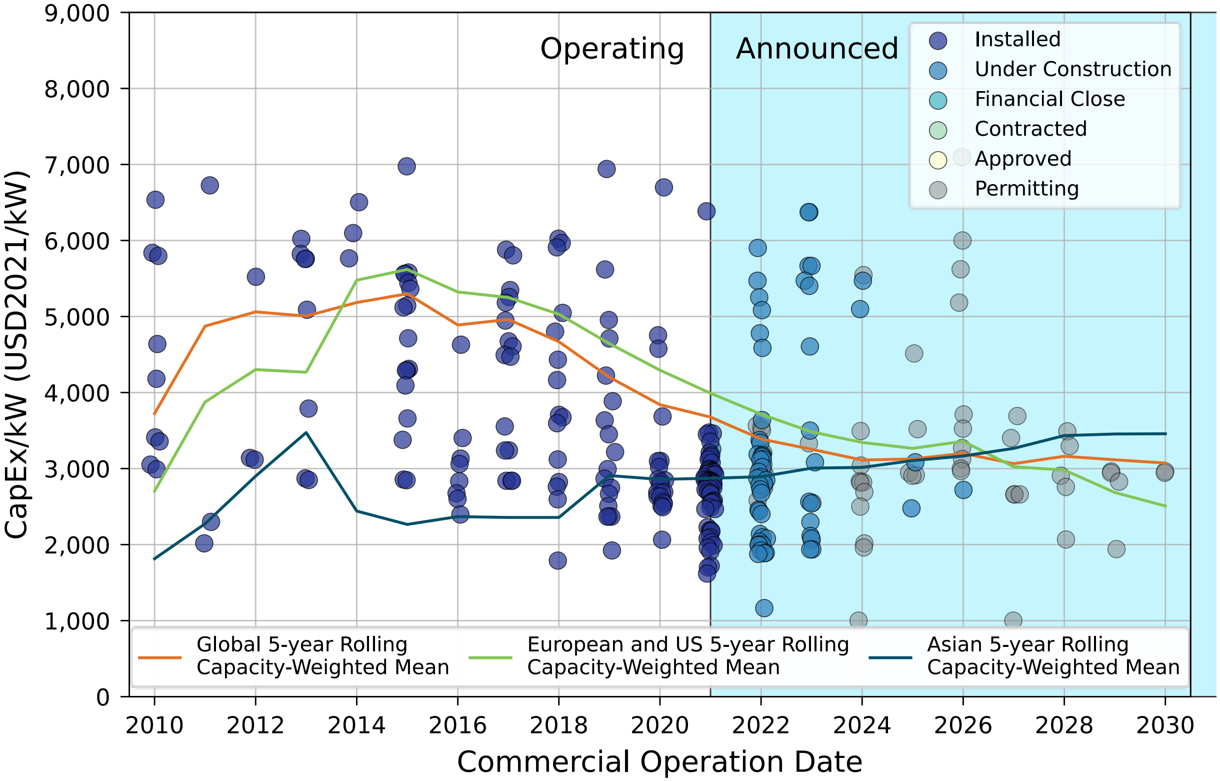

Figure 40. Capital expenditures for global offshore wind energy projects

CapEx has been reported for 155,586 MW of global offshore wind energy projects (Figure 40). The announced cost is shown for 145 installed projects (44,693 MW), with 42 projects (19,327 MW) that have started construction, 61 projects (46,857 MW) in the permitting process, and 64 projects (44,709 MW) that are still in the planning phase. The uncertainty related to these CapEx data varies between projects and over time (Musial, Spitsen, et al. 2021).

A growing trend within the offshore wind energy industry is the escalation of lease sale prices, especially in recent U.S. auctions. The six lease areas in the New York Bight auctioned by BOEM on February 23, 2022, were awarded at sales prices that far exceeded those of previous BOEM lease area auctions (Section 2). The average lease price of $728 million ($763/kW) is equivalent to approximately 22% of the average CapEx of $3,400/kW from U.S. projects with disclosed CapEx data (Figure 41). In the previous BOEM auction that was held for three leases in the Massachusetts WEA in 2018, the lease sale price was only about 2% of the total CapEx.

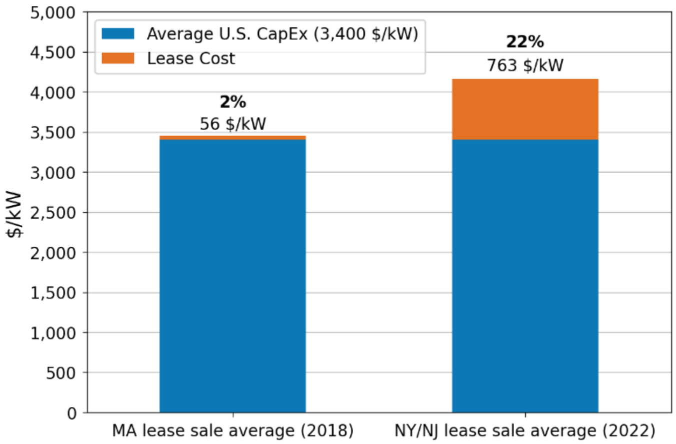

Figure 41. Relative share of lease costs from total CapEx of the two most recent BOEM lease sales.

Note: Average U.S. CapEx includes those projects that have disclosed cost data and are greater than 500 MW in plant size. The $/kW value of the lease prices was calculated using the estimated "installation capacity" from BOEM (2022a).

The lease price of $763/kW is based on a general conservative assumption that lease area capacity will be 3 MW/km^2.

5.1.3 Operational Expenditures

Data on operational expenditures are not publicly available for the only two U.S. operating projects—the Block Island Wind Farm (30 MW) and Coastal Virginia Offshore Wind pilot projects (12 MW). Using industry research based on European experience, OpEx is estimated to range from $59/kW-year to $89/kW-year for U.S. projects with a COD between 2021 and 2030 (Figure 42). This estimated range is above the reported OpEx of $50/kW-year by Dominion Energy (announced 2026 COD) (Section 5.1.1), although Dominion might be able to realize lower OpEx cost through economies of scale from its relatively large project size of 2,587 MW.

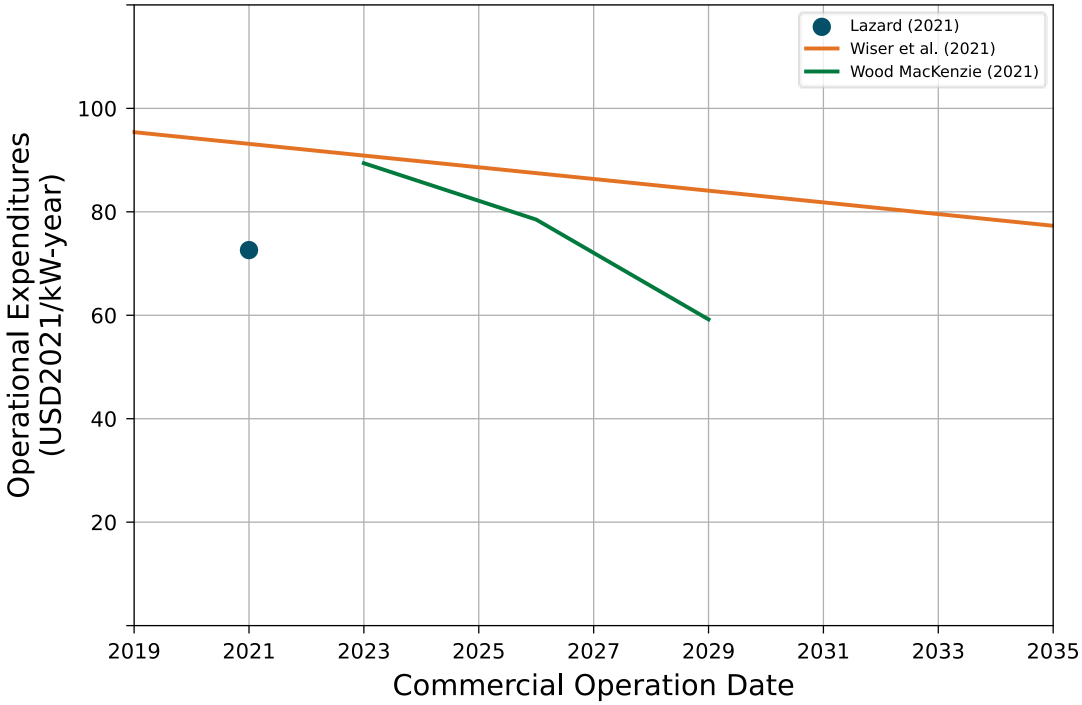

Figure 42. U.S. offshore wind power plant operational expenditures.

Note: Only the midcase scenario is depicted in this figure for simplicity. Lazard (2021) and Wood MacKenzie (2021) provide the estimates for U.S. projects, whereas Wiser et al. (2021) represents a global average. Additional data points (including scenario ranges) are available from the sources.

5.1.4 Price Trends

The electricity sales prices from the competitive procurement of offshore wind energy provide insight into the economics of offshore wind. The prices are often revealed as part of publicly held auctions or PPA awards. Prices are influenced by a variety of factors, including costs, competition, and the awarded support and contract regime (e.g., a contract for difference or PPA). Price data can be indicative of generation costs (Junginger and Louwen 2019; Beiter, Cooperman, et al. 2021) after making some adjustments. These adjustments to enable direct comparisons between generation costs and prices typically include contract length, export cable expenses, the monetized value of tax incentives, and converting to the same currency year (Beiter, Kitzing, et al. 2021). The projects depicted in Figure 43 represent the adjusted strike prices and all-in prices (e.g., export cable costs are included). Between 2020 and 2025 (COD), the average global trendline suggests a decrease in procurement price from approximately $150/MWh to $88/MWh (or more than 41%) with a considerable price spread in any single year. In the United States, the levelized PPA and OREC prices range between $103/MWh (Vineyard Wind 1, 400 MW) and $75/MWh (Mayflower Wind, 804 MW) between 2022 and 2025 (COD), based on a total of nearly 5.5 GW of signed agreements. The Skipjack and U.S. Wind projects have a considerably higher price of $149/MWh than the other U.S. projects, perhaps because of their smaller project sizes of 120 MW and 248 MW, respectively. With an adjusted levelized PPA price of $75/MWh, the Mayflower Wind project is among the lowest-priced, announced offshore wind energy projects globally.

It remains to be seen what the impact from the latest BOEM lease area sales in New York and New Jersey will have on OREC pricing. The lease price of $727 million on average in the New York Bight makes up a 22% share of the average CapEx (Figure 41), which could result in higher OREC pricing. Other efforts to reduce project costs and competition among offtake bidders might mitigate some of this upward pressure on prices.

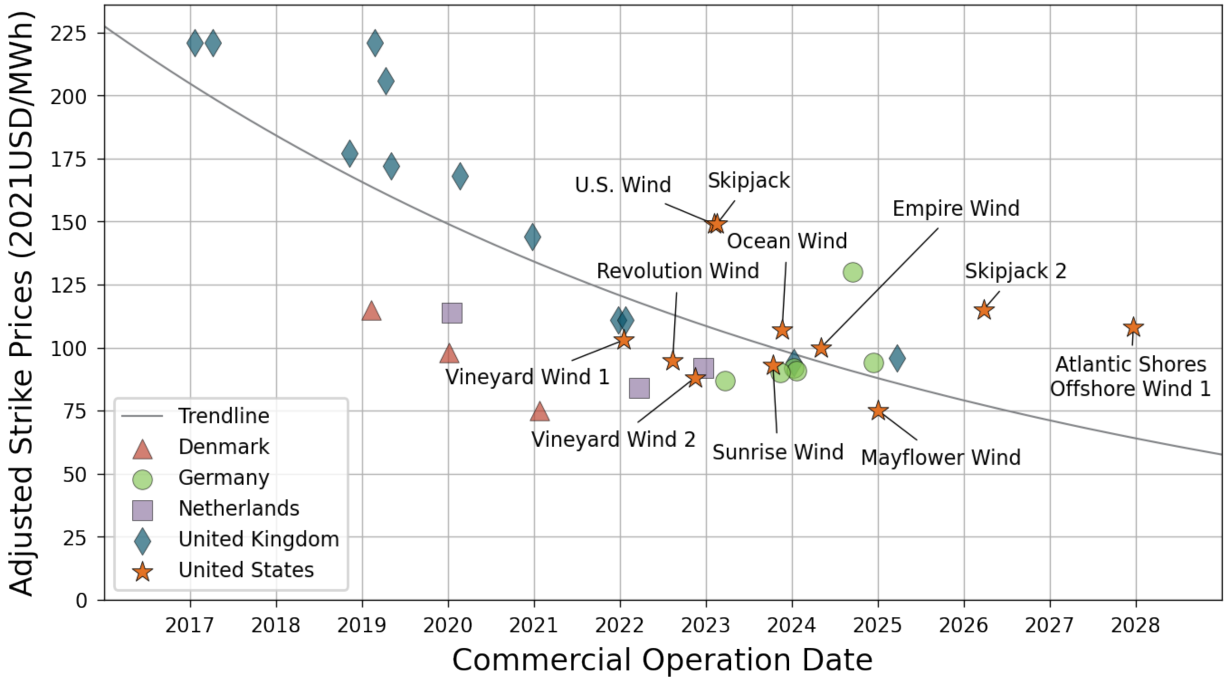

Figure 43. Adjusted strike prices from U.S. and European offshore wind procurements.

Note: Method adapted from Beiter, Kitzing, et al. (2021)

5.2 Floating Offshore Wind Energy Cost Trends

The LCOE for U.S. floating offshore wind projects is estimated to decline from approximately $200/MWh (2021) to $58–$120/MWh (2030) by various research organizations (Figure 44). These estimates assume commercial-scale floating wind power plants and learning-curve benefits commensurate with a mature industry. The cost of floating offshore wind technology is currently based on a small set of data from the first phase of demonstration projects. Generally, the potential for floating offshore wind cost reduction is high (Wiser et al. 2021) because early-stage technology advances usually result in significant cost reductions. In addition, technological and commercial developments from fixed-bottom offshore wind systems might translate to floating offshore wind systems. Cost estimates from technology-specific cost reduction potential come from a range of factors, including (but not limited to) the ability of floating offshore wind systems to:

- Leverage cost reductions, innovations, and experience from fixed-bottom systems
- Use existing supply chains

- Optimize floating structures using lighter components and increased modularity
- Reduce the number and complexity of construction steps at sea (e.g., by assembling the wind turbine and substructure at quayside)
- Automate production and fabrication of the floating substructures
- Access higher wind speeds through remote siting that are enough to offset the higher O&M and installation costs associated with greater distances to shore and harsher meteorological conditions.

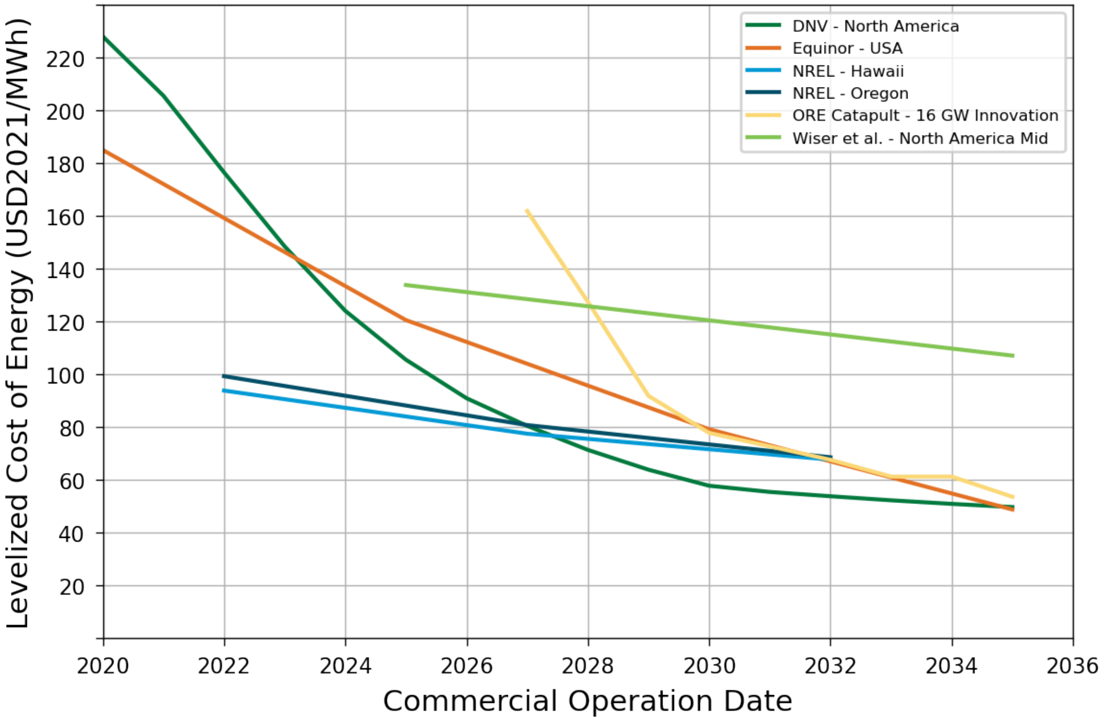

Figure 44. U.S. LCOE estimates for floating offshore wind technologies.

Sources: ORE Catapult (2021); Shields, Duffy, et al. 2021 (Hawaii), Musial, Duffy, et al. 2021 (Oregon); Wiser et al. (2021); Equinor (2021); DNV (2021)

5.3 Financing Trends

In contrast to fossil-fueled power plants (e.g., natural gas or coal), variable costs of offshore wind power plants are relatively small, and most lifetime costs are incurred up-front through CapEx for the development and construction of a project. These upfront expenditures generally require investments of more than $1 billion for utility-scale projects. The financing rate of a project, commonly expressed in terms of the weighted-average cost of capital (WACC), has considerable impact on lifetime project costs (i.e., LCOE) because it determines the annual debt service and equity repayment for the initial (CapEx) investment.

Financing structures for U.S. projects have been reported to be in the range of 50%–80% (debt share) and 20%–50% (equity share), with the equity portion being split between sponsor and tax equity (Table 22). A recent elicitation of global experts estimates a WACC of 5.2% (nominal) for U.S. projects anticipated for commercial operation in the mid-2020s (Beiter et al. forthcoming). This represents a cost of financing that is slightly higher than the WACC in established offshore wind markets, such as the United Kingdom (4.0%), Germany (3.2%), and Denmark (4.8%).

Table 22. Typical Financing Conditions for U.S. and European Offshore Wind Energy Projects

Year	Coverage	Debt/Sponsor Equity/Tax Equity (%)	Pricing[24] (Basis Points)	Source
2006–2007	Europe	60/40/0	150–200	Guillet (2018)
2009–2011	Europe	65/35/0	300–350	
2012–2013	Europe	70/30/0	200–250	
2014–2015	Europe	70/30/0	200–250	
2016–2017	Europe	75/25/0	150–225	
2018	Europe	70/30/0	120–175	
2019	United States	50/20/30	150–175	Martin (2019)
2020	United States	80/20 (combined)[25]	170	Martin (2020)
2021	United States	55/45	n/a	Martin (2021)

Note: Year 2008 not available from sources.

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[24] Basis points are indicated as being above the London Interbank Offered Rate. One basis point is equal to 1/100 of a percent and 100 basis points equals 1%.

[25] The split between sponsor and tax equity is not clear from the source (Martin 2020) and is reported here as an aggregate.

References

4C Offshore. 2021a. Global Offshore Windfarms Intelligence. https://subscribers.4coffshore.com/dashboard/. Accessed through subscription.

___. 2021b. “Global Floating Wind Progress Update: 2021.” September 3, 2021. Accessed through subscription.

___. 2022a. Global Offshore Wind Farm Intelligence (Online Database). February 2022. https://www.4coffshore.com/windfarms/.

___. 2022b. “Scotwind Market Focus Webinar.” February 4. Accessed through subscription.

___. 2022c. “Global Market Overview Q1 2022.” March 16, 2022. Accessed through subscription.

ABS Group. 2021. *Floating Offshore Wind Turbine Development Assessment*. Technical Report for BOEM 2021-030. Arlington, VA. https://www.boem.gov/sites/default/files/documents/renewable-energy/studies/Study-Number-Deliverable-4-Final-Report-Technical-Summary.pdf.

American Bureau of Shipping. 2021. *Positioning for U.S. Expansion: U.S. Ports and Vessels Innovation*. https://absinfo.eagle.org/acton/media/16130/offshore-wind-report-positioning-for-us-expansion-us-ports-and-vessels-innovation.

Ampelmann. 2022. “Offshore wind feeder vessel design reveal by Ampelmann and C-Job Naval Architects.” April 21, 2022. https://www.ampelmann.nl/news/offshore-wind-feeder-vessel-design-press-release.

AquaVentus. 2022. “AquaVentus Förderverein e.V.” March 10, 2022. https://aquaventus.org/foerderverein/mitgliederliste/.

Atlantic Wind Transfers. Undated. “Our Vessels.” Accessed March 29, 2022. https://www.atlanticwindtransfers.com/our-vessels.

Barla, Sashi. 2021. *Global wind turbine technology trends and database 2021*. Market Report. Wood Mackenzie. https://www.woodmac.com/reports/power-markets-global-wind-turbine-technology-trends-and-database-2021-478735.

Beiter, Philipp, Joseph T. Rand, Joachim Seel, Eric Lantz, Patrick Gilman, and Ryan Wiser. 2022. “Expert Perspectives on the Wind Plant of the Future.” *Wind Energy* 25 (8): 1363–78. https://doi.org/10.1002/we.2735.

Beiter, Philipp, Lena Kitzing, Paul Spitsen, Miriam Noonan, Volker Berkhout, and Yuka Kikuchi. 2021. "Toward Global Comparability in Renewable Energy Procurement." *Joule* 5 (6): 1485–1500. https://doi.org/10.1016/j.joule.2021.04.017.

Beiter, Philipp, Aubryn Cooperman, Eric Lantz, Tyler Stehly, Matt Shields, Ryan Wiser, Thomas Telsnig, Lena Kitzing, Volker Berkhout, and Yuka Kikuchi. 2021. "Wind Power Costs Driven by Innovation and Experience with Further Reductions on the Horizon." *WIREs Energy and Environment* n/a (n/a): e398. https://doi.org/10.1002/wene.398.

Beiter, Philipp, Florian Egli, and Michael Taylor. Forthcoming. "The Cost of Financing for Renewables." International Renewable Energy Agency (IRENA).

BloombergNEF (BNEF). 2021a. Renewable Energy Project Database. https://about.bnef.com/.

___. 2021b. "Global LCOE Benchmarks for Select Low Carbon Technologies - 1H 2020." Access through subscription.

___. 2021c. "2H 2021 Offshore Wind Market Outlook." Accessed through subscription.

Bocklet, Charles, Christian Herbosa, Gregory Loweth, Matthew Griswold, Lauren Quickel, Roan Gideon, Jay Borkland, Rockford Weitz, Barbara Kates-Garnick, and Eric M. Hines. 2021. *Wind Turbine Installation Vessels: Global Supply Chain Impacts on the U.S. Offshore Wind Market*. OSPRE-2021-02. OSPRE Reports. Medford, Massachusetts: Tufts University. http://hdl.handle.net/10427/RN301F830.

Bothwell, C., M. Marquis, J. Fu, and J. Lau. 2021. *Atlantic Offshore Wind Transmission Literature Review and Gaps Analysis*. U.S. Department of Energy Office of Energy Efficiency and Renewable Energy. Washington, D.C. https://www.energy.gov/sites/default/files/2021-10/atlantic-offshore-wind-transmission-literature-review-gaps-analysis.pdf.

Brooks, Cristina. 2021. "Denmark's offshore wind tender continues 'negative subsidy' trend." December 3, 2021. https://cleanenergynews.ihsmarkit.com/research-analysis/denmarks-tender-continues-negative-subsidy-offshore-wind-trend.html.

Buljan, Adrijana. 2020. "Largest wind turbine in China now grid-connected." July 13, 2020. https://www.offshore-energy.biz/largest-wind-turbine-in-china-now-grid-connected/.

___. 2021a. "Construction Starts on Ørsted's First Green Hydrogen Project." May 17, 2021. https://www.offshorewind.biz/2021/05/17/construction-starts-on-orsteds-first-green-hydrogen-project/.

___. 2021b. "MingYang Secures Second Offshore Wind Turbine Order in Europe." October 29, 2021. https://www.offshorewind.biz/2021/10/29/mingyang-secures-second-offshore-wind-turbine-order-in-europe/.

___. 2021c. "MingYang Enters UK Offshore Wind Market with Major Investment Plans and MoU with Government." December 17, 2021. https://www.offshorewind.biz/2021/12/17/mingyang-enters-uk-offshore-wind-market-with-major-investment-plans-and-mou-with-government/.

___. 2022a. "Norwegian Shipowner to Convert Another Oil & Gas Vessel for Offshore Wind Ops." January 19, 2022. https://www.offshorewind.biz/2022/01/19/norwegian-shipowner-to-convert-another-oil-gas-vessel-for-offshore-wind-ops/.

___. 2022b. "Ørsted to Put Its First Green Hydrogen Project Into Operation in Next Six Months." February 2, 2022. https://www.offshorewind.biz/2022/02/02/orsted-to-put-its-first-green-hydrogen-project-into-operation-in-next-six-months/.

___. 2022c. "Cosco Taps Friede & Goldman's Solution for New Jones Act-Compliant WTIV." March 25, 2022. https://www.offshorewind.biz/2022/03/25/cosco-taps-friede-goldmans-solution-for-new-jones-act-compliant-wtiv/.

___. 2022d. "BlueFloat Energy Has 14 Offshore Wind Projects in South America." May 4, 2022. https://www.offshorewind.biz/2022/05/04/bluefloat-energy-has-14-offshore-wind-projects-in-south-america/.

___. 2022e. "Shell Unveils 17 GW Offshore Wind Plans in Brazil." March 21, 2022. https://www.offshorewind.biz/2022/03/21/breaking-shell-unveils-17-gw-offshore-wind-plans-in-brazil/.

Bureau of the Fiscal Service. 2022. "Treasury Reporting Rates of Exchange." https://fiscaldata.treasury.gov/datasets/treasury-reporting-rates-exchange/treasury-reporting-rates-of-exchange.

Bureau of Ocean Energy Management (BOEM). 2021. "Call for Information and Nominations-Commercial Leasing for Wind Power Development on the Outer Continental Shelf in the Gulf of Mexico." *Federal Register* 86 FR 60283 (Docket No. BOEM-2021-0077): 60283–87. https://www.federalregister.gov/documents/2021/11/01/2021-23800/call-for-information-and-nominations-commercial-leasing-for-wind-power-development-on-the-outer.

___. 2022a. "BOEM Initiates Environmental Assessment for Offshore Wind in the Gulf of Mexico." January 11, 2022. https://www.boem.gov/newsroom/press-releases/boem-initiates-environmental-assessment-offshore-wind-gulf-mexico.

___.2022b. "New York Bight Wind Energy Auction." Accessed May 27, 2022. https://www.boem.gov/renewable-energy/state-activities/new-york-bight.

___. 2022c. “Offshore Wind Leasing Path Forward 2021-2025.” Accessed May 27, 2022. https://www.boem.gov/sites/default/files/documents/renewable-energy/state-activities/OSW-Proposed-Leasing-Schedule.pdf.

___. 2022d. “Pacific Wind Lease Sale 1 (PACW–1) for Commercial Leasing for Wind Power on the Outer Continental Shelf in California—Proposed Sale Notice.” https://www.boem.gov/sites/default/files/documents/renewable-energy/state-activities/california/2022-11537.pdf.

___. 2022e. “Request for Information: Commercial Leasing for Wind Power Development on the Central Atlantic Outer Continental Shelf.” https://www.regulations.gov/search?filter=BOEM-2022-0023.

Burgess, James. 2021. “Neptune Energy progresses blue, green hydrogen projects in UK and Netherlands.” May 13, 2021. https://www.spglobal.com/commodity-insights/en/market-insights/latest-news/electric-power/051321-neptune-energy-progresses-blue-green-hydrogen-projects-in-uk-and-netherlands.

Burgess, Molly. 2022. “Emerson supports PosHYdon hydrogen project with automation technologies.” January 11, 2022. https://www.gasworld.com/emerson-supports-poshydon-hydrogen-project-with-automation-technologies/2022481.article.

California Air Resources Board. Undated. “2021 – Assembly Bill 525 (Chiu, David), Offshore Wind Generation (Chaptered).” CA.gov. https://ww2.arb.ca.gov/2021-assembly-bill-525-chiu-david-offshore-wind-generation-chaptered.

California Legislature. 2021. *AB-525 Energy: Offshore Wind Generation*. https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=202120220AB525.

California Energy Commission. 2022. “Presentation - Workshop for AB 525 Wind Energy Goals.” https://efiling.energy.ca.gov/Lists/DocketLog.aspx?docketnumber=17-MISC-01.

California Independent System Operator. 2022. *2021-2022 Transmission Plan*. http://www.caiso.com/InitiativeDocuments/ISOBoardApproved-2021-2022TransmissionPlan.pdf.

Craik, David. 2021. “US offshore pricing stand-off raises vessel sourcing risks.” Reuters Events. October 21, 2021. https://www.reutersevents.com/renewables/wind/us-offshore-pricing-stand-raises-vessel-sourcing-risks.

Crowley. 2021. “Vineyard Wind Announces Partnership with the City of Salem and Crowley to Transform Salem Harbor into Offshore Wind Port.” September 30, 2021. https://www.crowley.com/news-and-media/press-releases/vineyard-wind-crowley-salem/.

DEKC Maritime. 2021. “DEKC Signs Jones Act Partnership with US Based Green Shipping Line.” June 10, 2021. https://www.dekc-maritime.com/news2/dekc-signs-jones-act-partnership-with-us-based-green-shipping-line.

DNV. 2021. “Energy Transition Outlook 2021: A Global and Regional Forecast to 2050.” https://eto.dnv.com/2021.

Dominion Energy. 2021a. “Application, Direct Testimony, Appendices, and Schedules of Virginia Electric and Power Company.” PUR-2021-00142. https://coastalvawind.com/resources/pdf/public-application-volume-01-2021-cvow.pdf.

___. 2021b. “Dominion Energy, Ørsted and Eversource Reach Deal on Contract to Charter Offshore Wind Turbine Installation Vessel.” June 1, 2021. https://news.dominionenergy.com/2021-06-01-Dominion-Energy,-rsted-and-Eversource-Reach-Deal-on-Contract-to-Charter-Offshore-Wind-Turbine-Installation-Vessel.

Dongfang Electric Corp. 2021. “DEC Releases Design of 13-MW Offshore Wind Turbine.” October 25, 2021. http://www.dongfang.com.cn/index.php?s=/Home/Article/detail/id/1290.html.

Durakovic, Adnan. 2021a. “Siemens Gamesa Sends Off 14 MW Wind Turbine Nacelle Prototype.” October 12, 2021. https://www.offshorewind.biz/2021/10/12/siemens-gamesa-sends-off-14-mw-wind-turbine-nacelle-prototype/.

___. 2021b. “Shipbuilder Selected for First US Subsea Rock Installation Vessel.” November 16, 2021. https://www.offshorewind.biz/2021/11/16/shipbuilder-selected-for-first-us-subsea-rock-installation-vessel/.

___. 2021c. “New US Offshore Wind Player Orders Crew Transfer Vessel Fleet.” November 17, 2021. https://www.offshorewind.biz/2021/11/17/new-us-offshore-wind-player-orders-crew-transfer-vessel-fleet/.

___. 2021d. “Dutch Offshore Wind-to-Hydrogen Project Ready to Take Off.” December 14, 2021. https://www.offshorewind.biz/2021/12/14/dutch-offshore-wind-to-hydrogen-project-ready-to-take-off/.

___. 2021e. “Spain Approves Offshore Wind Roadmap.” December 13th, 2021. https://www.offshorewind.biz/2021/12/13/spain-approves-offshore-wind-roadmap/

___. 2022a. “Brazil Takes Major Step Towards Developing Offshore Wind Potential.” January 27, 2022. https://www.offshorewind.biz/2022/01/27/brazil-takes-major-step-towards-developing-offshore-wind-potential/.

___. 2022b. “The Netherlands Designates Areas for 10.7 GW of New Offshore Wind.” March 21, 2022. https://www.offshorewind.biz/2022/03/21/the-netherlands-designates-areas-for-10-7-gw-of-new-offshore-wind/.

Empire Wind. 2022. “Empire Wind Selects Edison Chouest Offshore To Provide Plug-in Hybrid Service Operations Vessel.” May 12, 2022. https://www.empirewind.com/2022/05/12/empire-wind-selects-edison-chouest-offshore-to-provide-plug-in-hybrid-service-operations-vessel/.

Energy World. 2018. “India Announces 30-GW Offshore Wind Target by 2030.” June 2018. https://energy.economictimes.indiatimes.com/news/renewable/india-announces-30-gigawatt-offshore-wind-energy-target-by-2030/64651102.

Eneti Inc. 2021a. “Eneti Inc. Company Presentation.” November. https://www.eneti-inc.com/wp-content/uploads/Eneti-Inc.-November-Company-Presentation.pdf.

___. 2021b. “Eneti Inc. Third Quarter 2021 Earnings Presentation.” December 8. https://www.eneti-inc.com/wp-content/uploads/Eneti-Q3-21-Earning-Presentation_vf.pdf.

___. 2022. “Eneti Inc. Announces It Has Discontinued Its Discussions With a U.S. Shipyard and Announces New Contract Awards for Seajacks.” February 1, 2022. https://www.eneti-inc.com/eneti-inc-announces-it-has-discontinued-its-discussions-with-a-u-s-shipyard-and-announces-new-contract-awards-for-seajacks/.

Equinor. 2019. “Equinor offshore wind bid wins in New York State.” Last modified February 17, 2020. https://www.equinor.com/news/archive/2019-new-york-offshore-wind-bid

___. 2021. “The Future of Offshore Wind Is Afloat.” https://www.equinor.com/en/what-we-do/floating-wind.html.

European Commission. 2022. “REPowerEU: A plan to rapidly reduce dependence on Russian fossil fuels and fast forward the green transition.” https://ec.europa.eu/commission/presscorner/detail/en/IP_22_3131.

Eversource Energy. 2021. “Q4 2021 Eversource Energy Earnings Call. Edited Transcript.” https://www.eversource.com/content/docs/default-source/investors/q4-2021-earnings-call-transcript.pdf?sfvrsn=80938f62_2.

Evwind. 2022. “Portugal will auction between 3 and 4 GW of floating offshore wind energy.” March 16, 2022. https://www.evwind.es/2022/03/16/portugal-will-auction-between-3-and-4-gw-of-floating-offshore-wind-energy/85155.

Ferris, Nick. 2022. “The number of countries generating offshore wind power is set to double.” April 18, 2022. Energy Monitor. https://www.energymonitor.ai/sectors/power/weekly-data-the-number-of-countries-generating-offshore-wind-power-is-set-to-double.

Ferry, T. 2021. “Good job: upsized offshore wind bonanza a triumph for Taiwan but challenges loom.” RECHARGE, updated May 24, 2021. https://www.rechargenews.com/wind/good-job-upsized-offshore-wind-bonanza-a-triumph-for-taiwan-but-challenges-loom/2-1-1010200.

Foss. 2022. “New Bedford Foss Terminal Opening to Support Offshore Wind.” March 23, 2022. https://www.foss.com/press-releases/new-bedford-foss-terminal-opening-to-support-offshore-wind/.

Frangoul, Anmar. 2022. “BP establishes partnership focused on offshore wind in Japan.” March 25, 2022. https://www.cnbc.com/2022/03/25/bp-establishes-partnership-focused-on-offshore-wind-in-japan-.html.

Friede & Goldman. 2021. “BargeRack - Offshore Feeder Solution Made Safe & Simple.” https://www.fng.com/bargerack/.

General Electric. 2019. “GE’s Haliade-X 12 MW, the World’s Most Powerful Offshore Wind Turbine, Produces Its First KWh.” November 7, 2019. https://www.ge.com/news/press-releases/ges-haliade-x-12-mw-worlds-most-powerful-offshore-wind-turbine-produces-first-kwh.

___. 2020a. “GE’s Haliade-X offshore wind turbine prototype operating at 13 MW.” October 22, 2020. https://www.ge.com/news/press-releases/ge-haliade-x-offshore-wind-turbine-prototype-operating-at-13-mw.

___. 2020b. “GE Renewable Energy Announces US Blade Recycling Contract with Veolia.” December 8, 2020. https://www.ge.com/news/press-releases/ge-renewable-energy-announces-us-blade-recycling-contract-with-veolia.

___. 2021. “GE Renewable Energy’s Haliade-X prototype starts operating at 14 MW.” October 5, 2021. https://www.ge.com/news/press-releases/ge-renewable-energy-haliade-x-prototype-starts-operating-at-14-mw.

___. 2022. “ZEBRA project achieves key milestone with production of the first prototype of its recyclable wind turbine blade.” March 17, 2022. https://www.ge.com/news/press-releases/zebra-project-achieves-key-milestone-with-production-of-first-prototype-of-recyclable-wind-turbine-blade.

German Federal Ministry of Economics and Technology. 2022. “The Declaration of Energy Ministers on the North Sea as a Green Power Plant of Europe.” https://www.bmwk.de/Redaktion/DE/Downloads/Energie/20220518-declaration-of-energy-ministers.pdf?__blob=publicationFile&v=10.

Global Wind Energy Council. 2021. *Global Wind Report 2021*. https://gwec.net/wp-content/uploads/2021/03/GWEC-Global-Wind-Report-2021.pdf.

Government of Belgium. 2022. “Belgian offshore wind energy -5.4-5.8 GW by 2030.” March 29, 2022. https://economie.fgov.be/en/themes/energy/belgian-offshore-wind-energy.

Government of France. 2022. “Le Premier ministre lance l’éolien en mer en Méditerranée et annonce des mesures de France 2030 pour renforcer notre souveraineté energétique.” March 14, 2022. https://www.ecologie.gouv.fr/premier-ministre-lance-leolien-en-mer-en-mediterranee-et-annonce-des-mesures-france-2030-renforcer.

Government of the Netherlands. 2022. “Offshore wind energy.” https://www.government.nl/topics/renewable-energy/offshore-wind-energy.

Guillet, Jerome. 2018. “Who Will Fund U.S. OSW - and on What Terms?” Presented at the Offshore Wind Implementation Summit, Teaneck, New Jersey (U.S.). Green Giraffe. https://green-giraffe.eu/publication/presentation/who-will-fund-us-offshore-wind-and-on-what-terms/.

Haun, Eric. 2022. “Crowley Takes Large & Leading Role In U.S. Offshore Wind.” March 3, 2022. https://www.marinelink.com/news/crowley-takes-large-leading-role-us-494748.

Heerema. 2022. “Heerema selected for Strategic Supplier Agreement with Equinor and bp for the US East Coast.” May 9, 2022. https://www.heerema.com/news/heerema-selected-for-a-strategic-supplier-agreement-with-equinor-and-bp-for-the-us-east-coast.

International Energy Agency. 2021. *World Energy Outlook 2021*. https://iea.blob.core.windows.net/assets/4ed140c1-c3f3-4fd9-acae-789a4e14a23c/WorldEnergyOutlook2021.pdf.

Johnson, Tom. 2021. “Two big steps made in push for NJ offshore wind industry.” March 26, 2021. https://www.njspotlightnews.org/2021/03/new-jersey-bpu-orsted-pseg-offshore-wind-farm-wind-port-delaware-bay-development-millions/.

Junginger, Martin, and Atse Louwen. 2019. *Technological Learning in the Transition to a Low-Carbon Energy System: Conceptual Issues, Empirical Findings, and Use, in Energy Modeling*. Academic Press. https://www.elsevier.com/books/technological-learning-in-the-transition-to-a-low-carbon-energy-system/junginger/978-0-12-818762-3.

Klinge, Naomi. 2022. “Equinor, BP to Turn New York City Port into offshore wind hub.” March 9, 2022. https://www.upstreamonline.com/energy-transition/equinor-bp-to-turn-new-york-city-port-into-offshore-wind-hub/2-1-1178727.

Komusanac, Ivan, Daniel Fraile, and Guy Brindley. 2019. “Wind Energy in Europe in 2018: Trends and Statistics.” WindEurope. https://windeurope.org/about-wind/statistics/european/wind-energy-in-europe-in-2018/.

Lantz, Eric, Garrett Barter, Patrick Gilman, David Keyser, Trieu Mai, Melinda Marquis, Matthew Mowers, Matt Shields, Paul Spitsen, and Jeremy Stefek. 2021. *Power Sector, Supply Chain, Jobs, and Emissions Implications of 30 Gigawatts of Offshore Wind Power by 2030*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5000-80031. https://www.nrel.gov/docs/fy21osti/80031.pdf.

Lazard. 2021. *Levelized Cost of Energy Analysis, Version 15.0*. http://www.lazard.com/perspective/levelized-cost-of-energy-levelized-cost-of-storage-and-levelized-cost-of-hydrogen/.

Lee, Andrew. 2022. "Portugal plans multi-gigawatt floating auction as Ukraine crisis spurs offshore wind push." March 18, 2022. https://www.upstreamonline.com/energy-transition/portugal-plans-multi-gigawatt-floating-auction-as-ukraine-crisis-spurs-offshore-wind-push/2-1-1187359.

Lefevre-Marton et al. 2019. "Scaling the US East Coast offshore wind industry to 20 gigawatts and beyond." McKinsey and Company, April 11, 2019. https://www.mckinsey.com/industries/electric-power-and-natural-gas/our-insights/scaling-the-us-east-coast-offshore-wind-industry-to-20-gigawatts-and-beyond#.

LM Wind Power. 2021. "'ZEBRA project' launched to develop first 100% recyclable wind turbine blades." September 23, 2021. https://www.lmwindpower.com/en/stories-and-press/stories/news-from-lm-places/zebra-project-launched.

Lysne, Martin, and Elliot Busby. 2022. "Super-sized offshore wind installations could suffer bottlenecks from 2024 as vessels remain lightweight." February 2, 2022. https://www.rystadenergy.com/newsevents/news/press-releases/Super-sized-offshore-wind-installations-could-suffer-bottlenecks-from-2024-as-vessels-remain-lightweight/.

Maersk Supply Service. 2022a. "Maersk Supply Service to construct pioneering wind installation vessel for Equinor and bp to operate in the U.S. market." March 29, 2022. https://www.maersksupplyservice.com/2022/03/29/maersk-supply-service-to-construct-pioneering-wind-installation-vessel/.

___. 2022b. "DemoSATH floating wind project successfully completes the offshore mooring installation." May 17, 2022. https://www.maersksupplyservice.com/2022/05/17/demosath-floating-wind-mooring/.

MarineLink. 2022. "First Floating Wind Turbine for Equinor's Hywind Tampen Project Assembled in Norway." May 2, 2022. https://www.marinelink.com/news/first-floating-wind-turbine-equinors-496207.

Marine Power Systems. 2022. “Marine Power Systems and Marine2o Join Forces to Produce Green Hydrogen.” https://www.marinepowersystems.co.uk/marine-power-systems-and-marine2o-join-forces-to-produce-green-hydrogen/.

Martin, Keith. 2019. “US offshore wind: Current financing conditions.” Norton Rose Fulbright. https://www.projectfinance.law/publications/us-offshore-wind-current-financing-conditions.

Martin, Keith. 2020. “Financing US offshore wind projects.” Norton Rose Fulbright. https://www.projectfinance.law/publications/2020/december/financing-us-offshore-wind-projects/.

___. 2021. “US offshore wind financing update.” Norton Rose Fulbright. https://www.projectfinance.law/publications/2021/december/us-offshore-wind-financing-update/.

Mayflower Wind. 2021. “Mayflower Wind Signs Agreement with Gladding-Hearn for Design/Build of Industry-Leading Hybrid Electric Offshore Wind Crew Transfer Vessel.” October 14, 2021. https://mayflowerwind.com/mayflower-wind-signs-agreement-with-gladding-hearn-for-design-build-of-industry-leading-hybrid-electric-offshore-wind-crew-transfer-vessel/.

McQue, Katie. 2021. “Oman's OQ aims to replace 40% of its 3 GW of power consumption with renewables.” June 17, 2021. S&P Global Commodity Insights. https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/electric-power/061721-omans-oq-aims-to-replace-40-of-its-3-gw-of-power-consumption-with-renewables.

Memija, Adnan. 2022a. “Construction Starts on First-Ever Jones Act SOV.” March 4, 2022. https://www.offshorewind.biz/2022/03/04/construction-starts-on-first-ever-jones-act-sov/.

____. 2022b. “Three Turbines to Go at Italy’s First Offshore Wind Farm.” April 14, 2022. https://www.offshorewind.biz/2022/04/14/three-turbines-to-go-at-italys-first-offshore-wind-farm/.

MingYang Smart Energy. 2021. “Leading innovation: MingYang Smart Energy launches MySE 16.0-242, the world’s largest offshore Hybrid Drive wind turbine.” August 20, 2021. http://www.myse.com.cn/en/jtxw/info.aspx?itemid=825.

MMT. 2020. “MMT and EQUINOR to Perform Innovative Surveys in the US.” April 30, 2020. https://www.mmt.se/news-media/news/mmt-and-equinor-to-perform-innovative-surveys-in-the-us/.

Moore, Kirk. 2021. “Siemens Gamesa to contract Gulf of Mexico IMR vessel for turbine project.” December 2, 2021. https://www.workboat.com/wind/siemens-gamesa-to-contract-gulf-of-mexico-imr-vessel-for-turbine-installation.

Musial, W., Z. Parker, J. Fields, G. Scott, and C. Draxl. 2013. *Assessment of Offshore Wind Energy Leasing Areas for the BOEM Massachusetts Wind Energy Area*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5000-60942. http://www.nrel.gov/docs/fy14osti/60942.pdf.

Musial, W., D. Heimiller, P. Beiter, G. Scott, and C. Draxl. 2016. *2016 Offshore Wind Energy Resource Assessment for the United States*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5000-66599. http://www.nrel.gov/docs/fy16osti/66599.pdf.

Musial, W., P. Beiter, P. Schwabe, T. Tian, T. Stehly, P. Spitsen. 2017. *2016 Offshore Wind Technologies Market Report*. U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy. https://energy.gov/sites/prod/files/2017/08/f35/2016%20Offshore%20Wind%20Technologies%20Market%20Report.pdf.

Musial, W. and Greco, T. 2020. "Feasibility of Ocean-Based Renewable Energy in the Gulf of Mexico." Marine Technology Society Journal; Volume 54 No.6. November/December 2020. https://doi.org/10.4031/MTSJ.54.6.3.

Musial, Walter, Paul Spitsen, Philipp Beiter, Patrick Duffy, Melinda Marquis, Aubryn Cooperman, Rob Hammond, and Matt Shields. 2021. "Offshore Wind Market Report: 2021 Edition." DOE/GO-102021-5614. U.S. Department of Energy Office of Energy Efficiency and Renewable Energy. Washington, D.C. https://www.energy.gov/sites/default/files/2021-08/Offshore%20Wind%20Market%20Report%202021%20Edition_Final.pdf.

Musial, Walt, Patrick Duffy, Donna Heimiller, and Philipp Beiter. 2021. "Updated Oregon Floating Offshore Wind Cost Modeling." Golden, Co: National Renewable Energy Laboratory (NREL). NREL/PR-5000-80908. https://www.nrel.gov/docs/fy22osti/80908.pdf.

National Offshore Wind Research and Development Consortium. 2021. "Research and Development Roadmap 3.0." https://nationaloffshorewind.org/wp-content/uploads/Roadmap-3.0-June-30-2021.pdf.

National Renewable Energy Laboratory (NREL). 2021. "2021 Annual Technology Baseline." https://atb.nrel.gov/.

___. 2022a. Offshore Wind Database. Internal database.

___. 2022b. "DOE Launches Study To Consider Equitable Pathways To Power Puerto Rico With 100% Renewable Energy." March 23, 2022. https://www.nrel.gov/news/program/2022/doe-launches-study-to-consider-equitable-pathways-to-power-puerto-rico-with-100-renewable-energy.html.

New York State Energy Research and Development Authority. 2022. “Great Lakes Wind Feasibility Study.” Accessed April 15, 2022. https://www.nyserda.ny.gov/great-lakes-wind-feasibility-study.

New York State Governor’s Office. 2022. “Governor Hochul Announces Multi-State Agreement Signed with Major Hydrogen Ecosystem Partners to Propose a Regional Clean Energy Hydrogen Hub.” March 24, 2022. https://www.governor.ny.gov/news/governor-hochul-announces-multi-state-agreement-signed-major-hydrogen-ecosystem-partners.

Nexans. 2022. “Nexans wins US offshore wind export cables installation contract.” March 10, 2022. https://www.nexans.com/newsroom/news/details/2022/03/2022-10-03-pr-nexans-wins-US-offshore-wind-export-cables-installation-contract.html.

Ocean Wind 1. 2021. “Ocean Wind and EEW Announce Signing of Project Labor Agreement, Beginning Construction of Monopile Manufacturing Facility at the Port of Paulsboro.” https://oceanwind.com/news-archive/2021/04/signing-of-project-labor-agreement---beginning-construction-of-monopile-manufacturing-facility.

Offshore Engineer. 2021. “DEME Offshore to Install Foundations at Vineyard Wind 1 Offshore Wind Farm in U.S.” October 11, 2021. https://www.oedigital.com/news/491191-deme-offshore-to-install-foundations-at-vineyard-wind-1-offshore-wind-farm-in-u-s.

ORE Catapult. 2021. *Floating Offshore Wind: Cost Reduction Pathways to Subsidy Free*. https://ore.catapult.org.uk/wp-content/uploads/2021/01/FOW-Cost-Reduction-Pathways-to-Subsidy-Free-report-.pdf.

Oregon State Legislature. 2021. “HB 3375 - Relating to floating offshore wind energy; and prescribing an effective date.” https://olis.oregonlegislature.gov/liz/2021R1/Measures/Overview/HB3375.

Orrell, Alice, Kamila Kazimierczuk, and Lindsay Sheridan. 2022. *Distributed Wind Market Report: 2022 Edition*. PNNL-31729. U.S. Department of Energy Office of Energy Efficiency and Renewable Energy. Washington, D.C. https://www.energy.gov/eere/wind/articles/distributed-wind-market-report-2022-edition.

Ørsted. 2019a. “Sunrise Wind Announces Plan to Create 100 Jobs, Construct Offshore Wind “Hub” in Port Jefferson.” April 4, 2019. https://us.orsted.com/news-archive/2019/04/sunrise-port-jefferson.

___. 2019b. “Sunrise Wind Announces Major Investments In New York Ports & Plan To Use Capital Region Union Labor For Construction.” April 24, 2019. https://us.orsted.com/news-archive/2019/04/sunrise-wind-ny-port-investments.

___. 2019c. “Ørsted Awards WindServe Marine First U.S. Offshore Wind Vessel Contract.” May 8, 2019. https://us.orsted.com/news-archive/2019/05/windserve.

___. 2019d. “Ørsted U.S. Offshore Wind, Tradepoint Atlantic Partner on Maryland’s First Offshore Wind Energy Center.” July 23, 2019. https://us.orsted.com/news-archive/2019/07/tradepoint-atlantic-partnership.

___. 2021. “Ørsted commits to sustainable recycling of wind turbine blades.” March 6, 2021. https://orsted.com/en/media/newsroom/news/2021/06/702084352457649.

___. 2022. “Ørsted Q4 2021 Earnings Call. Transcript.” https://orsted.com/en/investors/ir-material/financial-reports-and-presentations#A1.

___. Undated (a) “FACT SHEET - Revolution Wind.” Accessed March 30, 2022. https://orstedcdn.azureedge.net/-/media/www/docs/corp/jv/revolution-wind-fact-sheet.ashx?la=en&rev=d2816f5fb6c54be1b0bb5790f1fbd022&hash=826E7885CB2E1FF2FEC561F9D81D5C61;%20https://orstedcdn.azureedge.net/-/media/www/docs/corp/jv/new-london-state-pier-had overview.ashx?la=en&rev=4e752d221f6446399146848fd40ff2e3&hash=A8C011611BD4AF013ED6925E97CC3013.

___. Undated (b) “The Transformation of the New London State Pier: Harbor Development Agreement Overview.” Accessed March 30, 2022. https://orstedcdn.azureedge.net/-/media/www/docs/corp/jv/new-london-state-pier-hda-overview.ashx?la=en&rev=4e752d221f6446399146848fd40ff2e3&hash=A8C011611BD4AF013ED6925E97CC3013.

Papavizas, Charlie. 2022a. “Jones Act Considerations for the Development of Offshore Wind Farms.” *Benedict’s Maritime Bulletin*, Q1 2022. https://www.winston.com/images/content/2/6/v2/262961/First-Quarter-2022-Benedict-s-Maritime-Bulletin-Papavizas.pdf.

___. 2022b. “Customs Issues Comprehensive Offshore Wind Jones Act Ruling.” April 21, 2022. https://www.winston.com/en/maritime-fedwatch/customs-issues-comprehensive-offshore-wind-jones-act-ruling.html.

Park City Wind. 2019. “Park City Wind Will Transform Bridgeport into Offshore Wind Hub.” October 2019. https://www.parkcitywind.com/press-releases/park-city-wind-will-transform-bridgeport-into-offshore-wind-hub-7njeh.

PJM. 2021. “Offshore Wind Transmission Study: Phase 1 Results.” PJM Interconnection. https://www.pjm.com/-/media/committees-groups/committees/teac/2021/20211102/20211102-informational-report-offshore-wind-transmission-study-phase-1-results.ashx.

____. 2022. "FERC Accepts PJM, NJBPU Agreement To Further Offshore Wind Goals." April 19, 2022. https://insidelines.pjm.com/ferc-accepts-pjm-njbpu-agreement-to-further-offshore-wind-goals/.

Principle Power, Inc. 2021. "KOWL: World's largest floating windfarm fully operational." October 19, 2021. https://www.principlepower.com/news/kowl-worlds-largest-floating-windfarm-fully-operational.

Prysmian Group. 2021. "Prysmian secures new Offshore Wind Farm projects in the USA for approx. $900m.". December 17, 2021. https://www.prysmiangroup.com/en/press-releases/prysmian-secures-new-offshore-wind-farm-project-in-usa-for-900-million.

Quigley, John. 2022. "CIP funds first offshore wind farm in Colombia." March 10, 2022. https://www.latinfinance.com/daily-briefs/2022/3/10/cip-funds-first-offshore-wind-farm-in-colombia.

Radowitz, Bernd. 2021. "New German government plans 70GW offshore wind target under massive renewables boost." November 24, 2021. *RECHARGE*. https://www.rechargenews.com/energy-transition/new-german-government-plans-70gw-offshore-wind-target-under-massive-renewables-boost/2-1-1105020.

___. 2022. "'War-triggered' Warsaw mulling higher offshore wind goal: Siemens Gamesa Poland boss." April 13, 2022. *RECHARGE*. https://www.rechargenews.com/wind/war-triggered-warsaw-mulling-higher-offshore-wind-goal-siemens-gamesa-poland-boss/2-1-1201835.

RCG. 2022. "Offshore Wind Roadmap for Colombia – Draft Report." https://www.minenergia.gov.co/static/ruta-eolica-offshore/src/document/Colombia%20Offshore%20Wind%20Roadmap%20VE.pdf

renews.biz. 2021. "Siemens Gamesa 14MW prototype delivers first power." December 10, 2021. https://renews.biz/74277/siemens-gamesa-14mw-prototype-delivers-first-power/.

____. 2022a. "Germany amends offshore wind draft law." March 17, 2022. https://renews.biz/76453/germany-amends-offshore-wind-draft-law/.

___. 2022b. "Van Oord wins first US contract." March 28, 2022. https://renews.biz/76715/van-oord-wins-first-us-contract/.

___. 2022c. "Norway unveils 30GW offshore wind goal by 2040." May 11, 2022. https://renews.biz/77756/norway-unveils-30gw-offshore-wind-goal-by-2040/#:~:text=Norwegian%20Prime%20Minister%20Jonas%20Gahr,in%20total%20in%20Norway%20today.

____.2022d. "Denmark boosts 2030 offshore wind goal by 4GW." June 13, 2022. https://renews.biz/78407/denmark-to-boost-2030-offshore-wind-goal-by-4gw/.

Reuters. 2022a. “Germany to Speed Renewables Push Due to Ukraine Crisis.” February 28, 2022. https://www.reuters.com/business/energy/germany-hike-onshore-wind-solar-tender-volumes-document-2022-02-28/.

____. 2022b. “Italy working on incentives for offshore wind projects.” May 11, 2022. https://www.reuters.com/business/energy/italy-working-incentives-offshore-wind-projects-2022-05-11/.

Russell, Tom. 2021. “China’s first floating turbine installed.” July 13, 2021. https://www.4coffshore.com/news/china27s-first-floating-turbine-installed-nid23856.html.

____. 2022. “France sets 40 GW by 2050 offshore wind goal.” February 11, 2022. https://www.4coffshore.com/news/france-sets-40-gw-by-2050-offshore-wind-goal-nid24984.html.

RWE. 2021. “AquaSector: Study investigates potential for first large-scale offshore hydrogen park in the German North Sea.” July 23, 2021. https://www.rwe.com/en/press/rwe-renewables/2021-07-23-aquasector-partnership-on-first-large-scale-offshore-park-for-green-hydrogen-in-germany.

____. 2022a. “Hydrogen production in the North Sea; AquaVentus.” https://www.rwe.com/en/our-portfolio/innovation-and-technology/hydrogen/aquaventus.

___. 2022b. “Demonstration project for green hydrogen in the Netherlands; H_2opZee.” https://www.rwe.com/en/our-portfolio/innovation-and-technology/hydrogen/h2opzee.

Senator Ed Markey’s Office. 2018. “Senators Markey and Warren, Rep. Keating announce $15 million of federal investment in the port of New Bedford.” December 7, 2018. https://www.markey.senate.gov/news/press-releases/senators-markey-and-warren-rep-keating-announce-15-million-of-federal-investment-in-the-port-of-new-bedford.

Sennott, Will. 2021. “Offshore wind staging area planned for Eversource site.” July 14, 2021. https://newbedfordlight.org/eversource-property-sold-for-offshore-wind-use-in-new-bedford/.

Serreze, Mary. 2018. “Vineyard Wind signs $9 million Lease at New Bedford commerce pier.” October 23, 2018. https://www.masslive.com/news/2018/10/vineyard_wind_signs_9_million.html.

Shields, Matt, Philipp Beiter, Jake Nunemaker, Aubryn Cooperman, and Patrick Duffy. 2021. “Impacts of turbine and plant upsizing on the levelized cost of energy for offshore wind.” *Applied Energy* 298 (September): 117189. https://doi.org/10.1016/j.apenergy.2021.117189.

Shields, Matt, Patrick Duffy, Walt Musial, Michael Laurienti, Donna Heimiller, Rob Spencer, and Mike Optis. 2021. *The Cost and Feasibility of Floating Offshore Wind Energy in the O`ahu Region*. Golden, CO: National Renewable Energy Laboratory (NREL). NREL/TP-5000-80808. https://www.nrel.gov/docs/fy22osti/80808.pdf.

Shields, Matt, Ruth Marsh, Jeremy Stefek, Frank Oteri, Ross Gould, Noe Rouxel, Katherine Diaz, et al. 2022. *The Demand for a Domestic Offshore Wind Energy Supply Chain*. Golden, CO: National Renewable Energy Laboratory (NREL). NREL/TP-5000-81602. https://www.nrel.gov/docs/fy22osti/81602.pdf.

Shrestha, Priyanka. 2021. "Australia introduces legislation to unlock investment in offshore Energy." September 3, 2021. https://www.energylivenews.com/2021/09/03/australia-introduces-legislation-to-unlock-investment-in-offshore-energy/.

Siemens Gamesa. 2021a. "DecomBlades consortium awarded funding for a large, cross-sector wind turbine blade recycling project." January 25, 2021. https://www.siemensgamesa.com/en-int/newsroom/2021/01/210125-siemens-gamsa-press-release-decomblades-launched.

___. 2021b. "Siemens Gamesa pioneers wind circularity: launch of world's first recyclable wind turbine blade for commercial use offshore." September 2021. https://www.siemensgamesa.com/newsroom/2021/09/launch-world-first-recyclable-wind-turbine-blade.

SJI. 2021. "SJI Congratulates Atlantic Shores Offshore Wind for Winning New Jersey Wind Farm Application that Advances Green Hydrogen Partnership." June 30, 2021. https://www.sjindustries.com/investors/news-events/newsroom/south-jersey-industries/2021/sji-congratulates-atlantic-shores-offshore-wind-fo.

Skopljak, Nadja. 2020. "Ørsted's First US-Made CTV Starts Sea Trials." July 17, 2020. https://www.offshorewind.biz/2020/07/17/orsteds-first-us-made-ctv-starts-sea-trials/.

Smith, Aaron, Tyler Stehly, and Walter Musial. 2015. *2014–2015 Offshore Wind Technologies Market Report*. Golden, CO: National Renewable Energy Laboratory (NREL). NREL/TP-5000-64283. https://www.nrel.gov/docs/fy15osti/64283.pdf.

Smyth, Russell. 2022. "Ireland's offshore wind pipeline." March 14, 2022. https://home.kpmg/ie/en/home/insights/2022/03/irelands-offshore-wind-pipeline-infra-gov.html.

Snieckus, Darius. 2022a. "Floating wind forging 'structural shift' with sights on 15% of new offshore arrays by 2050: DNV." April 5, 2022. *RECHARGE*. https://www.rechargenews.com/wind/floating-wind-forging-structural-shift-with-sights-on-15-of-new-offshore-arrays-by-2050-dnv/2-1-1196722.

____. 2022b. "'Right long-term vision' could see Azerbaijan swing from oil to offshore wind: World Bank." June 3, 2022. *RECHARGE*. https://www.rechargenews.com/wind/right-long-term-vision-could-see-azerbaijan-swing-from-oil-to-offshore-wind-world-bank/2-1-1231353.

South Carolina General Assembly. 2022. *R270, H4831.* https://www.scstatehouse.gov/sess124_2021-2022/bills/4831.htm.

State of Connecticut. 2020. "Governor Lamont Announces Final Harbor Development Agreement for New London State Pier." February 11, 2020. https://portal.ct.gov/Office-of-the-Governor/News/Press-Releases/2020/02-2020/Governor-Lamont-Announces-Final-Harbor-Development-Agreement-for-New-London-State-Pier%20.

State of Louisiana. 2022. *Louisiana Climate Action Plan - Climate Initiatives Task Force Recommendations to the Governor*. https://gov.louisiana.gov/assets/docs/CCI-Task-force/CAP/Climate_Action_Plan_FINAL_3.pdf.

State of Maine. 2021. "Governor's Energy Office Submits Federal Lease Application for Small-Scale Floating Offshore Wind Research Site." October 1, 2021. https://www.maine.gov/governor/mills/news/governors-energy-office-submits-federal-lease-application-small-scale-floating-offshore-wind.

State of New Jersey. 2020. "Governor Murphy Announces $250 Million Total Investment in State-of-the-Art Manufacturing Facility to Build Wind Turbine Components to Serve Entire U.S. Offshore Wind Industry." https://www.nj.gov/governor/news/news/562020/20201222a.shtml.

State of Rhode Island. 2022. *S 2583: Relating to Public Utilities and Carriers - Affordable Clean Energy Security Act*. http://webserver.rilin.state.ri.us/BillText/BillText22/SenateText22/S2583.pdf.

State of Victoria. 2022. "Offshore Wind Policy Directions Paper." Victoria, Australia: The State of Victoria Department of Environment, Land, Water, and Planning. https://www.energy.vic.gov.au/__data/assets/pdf_file/0016/561400/Offshore-Wind-Policy-Directions-Paper.pdf.

Stehly, Tyler, and Patrick Duffy. 2022. "2020 Cost of Wind Energy Review." Golden, CO: National Renewable Energy Laboratory (NREL). NREL/TP-5000-81209. https://www.nrel.gov/docs/fy22osti/81209.pdf.

Stiesdal A/S. 2021. "The TetraSpar full-scale demonstration project." December 2021. https://www.stiesdal.com/offshore-technologies/the-tetraspar-full-scale-demonstration-project/.

The Crown Estate. 2022. "ScotWind offshore wind leasing delivers major boost to Scotland's net zero aspirations." 17 January 2022. https://www.crownestatescotland.com/news/scotwind-offshore-wind-leasing-delivers-major-boost-to-scotlands-net-zero-aspirations

The Maritime Executive. 2022. "ABS: Offshore Wind Could Power the Hydrogen Economy." February 25, 2022. https://www.maritime-executive.com/article/abs-offshore-wind-could-power-the-hydrogen-economy.

The Special Initiative on Offshore Wind. 2021. *Supply Chain Contracting Forecast for U.S. Offshore Wind Power - The Updated and Expanded 2021 Edition*. https://nationaloffshorewind.org/wp-content/uploads/SIOW-supply-chain-report-2021-update-FINAL.pdf.

The White House. 2021a. "FACT SHEET: Biden Administration Jumpstarts Offshore Wind Energy Projects to Create Jobs." Washington, D.C. https://www.whitehouse.gov/briefing-room/statements-releases/2021/03/29/fact-sheet-biden-administration-jumpstarts-offshore-wind-energy-projects-to-create-jobs/.

___. 2021b. "Executive Order on America's Supply Chains." February 24, 2021. Washington, D.C. https://www.whitehouse.gov/briefing-room/presidential-actions/2021/02/24/executive-order-on-americas-supply-chains/.

___. 2021c. "President Biden's Bipartisan Infrastructure Law." Washington, D.C. https://www.whitehouse.gov/bipartisan-infrastructure-law/.

Thomas, Allister. 2021. "Dolphyn green hydrogen project off Aberdeen to skip prototype, moves FID to 2022." June 25, 2021. https://www.energyvoice.com/renewables-energy-transition/332512/dolphyn-green-hydrogen-aberdeen-fid-2022/.

Trident Winds. 2021. "Olympic Wind Project Overview." https://tridentwinds.com/olympic-wind/.

Ulstein Group. 2020. "Rock Installation: Awarded Ship Design Contract for U.S. Offshore Wind Industry." December 14, 2020. https://ulstein.com/news/ulstein-awarded-design-contract-for-first-jones-act-compliant-rock-installation-vessel-to-serve-u-s-offshore-wind.

Umoh, Kubiat, and Mark Lemon. 2020. "Drivers for and Barriers to the Take up of Floating Offshore Wind Technology: A Comparison of Scotland and South Africa." *Energies* 13, no. 21: 5618. https://doi.org/10.3390/en13215618.

United States Government Accountability Office. 2020. "Planned Projects May Lead to Construction of New Vessels in the U.S., but Industry Has Made Few Decisions amid Uncertainties." GAO-21-153. Washington D.C. https://www.gao.gov/assets/gao-21-153.pdf.

University of Nottingham. 2021. "£2m pilot to develop UK's first wind turbine blade recycling solution." November 22, 2021. https://www.nottingham.ac.uk/news/2m-pilot-to-develop-uks-first-wind-turbine-blade-recycling-solution.

U.S. Bureau of Labor Statistics. 2022. "Consumer Price Index." Accessed April 16, 2022. https://www.bls.gov/cpi/.

U.S. Department of Energy (DOE). Undated(a). "Offshore Wind Advanced Technology Demonstration Projects." Accessed April 18, 2021. https://www.energy.gov/eere/wind/offshore-wind-advanced-technology-demonstration-projects.

___. Undated(b). "National Transmission Planning Study." Accessed May 2022. https://www.energy.gov/oe/national-transmission-planning-study.

___. Undated(c). "Wind Energy Tech Recycling Research & Development - Bipartisan Infrastructure Law." Accessed July 12th, 2022. https://www.energy.gov/bil/wind-energy-tech-recycling-research-development.

___. 2022a. "Building a Better Grid Initiative." U.S. Department of Energy Office of Electricity. January 12, 2022. https://www.energy.gov/oe/articles/building-better-grid-initiative.

___. 2022b. "DOE Establishes Bipartisan Infrastructure Law's $9.5 Billion Clean Hydrogen Initiatives." DOE Establishes Bipartisan Infrastructure Law's $9.5 Billion Clean Hydrogen Initiatives. February 15, 2022. https://www.energy.gov/articles/doe-establishes-bipartisan-infrastructure-laws-95-billion-clean-hydrogen-initiatives.

___. 2022c. *Offshore Wind Energy Strategies; Regional and national strategies to accelerate and maximize the effectiveness, reliability, and sustainability of U.S. offshore wind energy deployment and operation*. https://www.energy.gov/sites/default/files/2022-01/offshore-wind-energy-strategies-report-january-2022.pdf.

___. 2022d. "Carbon Rivers Makes Wind Turbine Blade Recycling and Upcycling a Reality With Support from DOE", July 22, 2022. https://www.energy.gov/eere/wind/articles/carbon-rivers-makes-wind-turbine-blade-recycling-and-upcycling-reality-support.

U.S. Department of the Interior. 2021. "Secretary Haaland Outlines Ambitious Offshore Wind Leasing Strategy." Press Release. October 13, 2021. https://www.doi.gov/pressreleases/secretary-haaland-outlines-ambitious-offshore-wind-leasing-strategy.

____. 2022. "Biden-Harris Administration Proposes First-Ever California Offshore Wind Lease Sale." May 26, 2022. https://www.doi.gov/pressreleases/biden-harris-administration-proposes-first-ever-california-offshore-wind-lease-sale.

U.S. Department of Transportation Maritime Administration. 2021. "2021 Port Infrastructure Development Program Grant Awards." Accessed June 17, 2022. https://www.maritime.dot.gov/ports/port-infrastructure-development-program/2021-port-infrastructure-development-program-grant.

U.S. House of Representatives. 2021. *Bill H.R. 1689 – Offshore Wind for Territories Act*. https://www.congress.gov/bill/117th-congress/house-bill/1689?s=1&r=78.

Vestas. 2021a. "Vestas to install V236-15.0 MW prototype turbine at Østerild in Denmark." October 15, 2021. https://www.vestas.com/en/media/company-news?l=22&n=4089955#!.

___. 2021b. "New coalition of industry and academia to commercialise solution for full recyclability of wind turbine blades." May 17, 2021. https://news.cision.com/vestas-wind-systems-a-s/r/new-coalition-of-industry-and-academia-to-commercialise-solution-for-full-recyclability-of-wind-turb,c3347473.

___. 2022. "First Quarter 2022: Vestas Wind Systems A/S." https://www.vestas.com/content/dam/vestas-com/global/en/investor/reports-and-presentations/financial/2022/2022%20Q1%20Investor%20presentation.pdf.

VietnamPlus. 2021. "Vietnam eyes 4 GW offshore wind power capacity by 2030." November 23, 2021. https://en.vietnamplus.vn/vietnam-eyes-4-gw-offshore-wind-power-capacity-by-2030/215946.vnp.

Vineyard Wind. 2019. "Vineyard Wind Announces Grant to New Bedford Port Authority to Advance Offshore Wind Industry." November 25, 2019. https://www.vineyardwind.com/press-releases/2019/11/25/vineyard-wind-announces-grant-to-new-bedford-port-authority-to-advance-offshore-wind-industry.

___. 2021a. "Vineyard Wind Selects DEME Offshore US for Wind Turbine Installation." March 31, 2021. https://www.vineyardwind.com/press-releases/2021/3/31/vineyard-wind-selects-deme-offshore-us-for-wind-turbine-installation.

___. 2021b. "Vineyard Wind Announces Connecticut Headquarters, Signs Lease for Construction and Staging at Barnum Landing." May 19, 2021. https://www.vineyardwind.com/press-releases/2021/5/19/vineyard-wind-announces-connecticut-headquarters-signs-lease-for-construction-and-staging-at-barnum-landing.

WBUR. 2014. "New Bedford To Be Cape Wind Staging Area." September 12, 2014. https://www.wbur.org/news/2014/09/12/cape-wind-new-bedford.

___. 2015. "With Cape Wind Faltering, New Bedford's Future As Offshore Wind Hub Uncertain." Updated April 6, 2015. https://www.wbur.org/news/2015/04/06/new-beford-terminal-cape-wind-future.

Wind Europe. 2022. "Norway announces first offshore wind auction." February 17, 2022. https://windeurope.org/newsroom/news/norway-announces-first-offshore-wind-auction/.

Windpowernl. 2022. "FlexH2 project kicks off". April 1, 2022. https://windpowernl.com/2022/04/01/flexh2-project-kicks-off/

Wiser, Ryan, Joseph Rand, Joachim Seel, Philipp Beiter, Erin Baker, Eric Lantz, Patrick Gilman. 2021. "Expert elicitation survey predicts 37% to 49% declines in wind energy costs by 2050." *Nature Energy*, April 15, 2021, 1–11. https://doi.org/10.1038/s41560-021-00810-z.

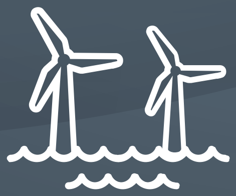
Wiser, Ryan, Mark Bolinger, Ben Hoen, Dev Millstein, Joe Rand, Galen Barbose, Naïm Darghouth, Will Gorman, Seongeun Jeong, Andrew Mills, and Ben Paulos. 2022. "Land-Based Wind Market Report: 2022 Edition." U.S. Department of Energy Office of Energy Efficiency and Renewable Energy. https://www.energy.gov/eere/wind/articles/land-based-wind-market-report-2022-edition.

Wood Mackenzie. 2021. "Global Bottom Fixed Offshore Wind Operations and Maintenance 2021." Accessed through subscription.

World Bank. 2022. "New Roadmap Shows Potential for 21GW of Offshore Wind by 2040 in the Philippines." April 20, 2022. https://www.worldbank.org/en/news/press-release/2022/04/20/new-roadmap-shows-potential-for-21gw-of-offshore-wind-by-2040-in-the-philippines.

Yahoo! finance. 2021. "Shanghai Electric Launches 11 MW Direct-Drive Turbine Petrel Platform SEW11.0-208." October 15, 2021. https://finance.yahoo.com/news/shanghai-electric-launches-11-mw-025100870.html.

Ylhe, Xu. 2022. "Cosco and F&G Develop Jones Act-Compliant WTIV." March 4, 2022. https://www.upstreamonline.com/energy-transition/cosco-and-f-g-develop-jones-act-compliant-wtiv/2-1-1178763.



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*Cover details: Haliade 150-6MW offshore wind turbine at Deepwater
Wind's 30MW Block Island Offshore Wind Farm, USA
Photo courtesy of Deepwater Wind*