U.S. DEPARTMENT OF
ENERGY

Office of
ENERGY EFFICIENCY &
RENEWABLE ENERGY

Offshore Wind Market Report: 2023 Edition

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Acknowledgments

The authors would like to extend thanks to Gage Reber, from the U.S. Department of Energy Wind Energy Technologies Office (WETO), for guiding this research. Thanks also to Liz Hartman, Patrick Gilman, Jocelyn Brown-Saracino, Dan Beals, Nate McKenzie, Cynthia Bothwell, and Monica Maher (WETO) for their support, review comments, and strategic guidance.

The authors would also like to thank the following reviewers and contributors from the National Renewable Energy Laboratory (NREL): Brian Smith, Paul Veers, and Eric Lantz.

This report was peer-reviewed by a diverse group of offshore wind energy industry stakeholders including developers; wind turbine manufacturers; state government representatives; internal, NREL management staff; consultants; and regulators. These external peer reviewers include:

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communications coordination by Pardeep Toor. This annual report was produced by NREL for WETO.

List of Acronyms

ACP	American Clean Power
ANSI	American National Standards Institute
BNEF	BloombergNEF
BOEM	Bureau of Ocean Energy Management
BSEE	Bureau of Safety and Environmental Enforcement
CapEx	capital expenditures
COD	commercial operation date
COP	Construction and Operations Plan
CTV	crew transfer vessel
CVOW	Coastal Virginia Offshore Wind
DEIS	Draft Environmental Impact Statement
DOE	U.S. Department of Energy
DOI	U.S. Department of the Interior
EIS	Environmental Impact Statement
GE	General Electric
GW	gigawatt
GWEC	Global Wind Energy Council
HVDC	high-voltage direct current
IRA	Inflation Reduction Act
ITC	investment tax credit
km	kilometer
kW	kilowatt
kV	kilovolt
LCOE	levelized cost of energy
LEEDCo	Lake Erie Energy Development Corporation
m	meter
MassCEC	Massachusetts Clean Energy Center
MW	megawatt
MWh	megawatt-hour
NJBPU	New Jersey Board of Public Utilities
nmi	nautical mile
NREL	National Renewable Energy Laboratory
OCS	Outer Continental Shelf
O&M	operations and maintenance
OpEx	operational expenditures
OREC	offshore renewable energy certificate
OWDB	offshore wind database
POI	point of interconnection
PPA	power purchase agreement

RFCI	Request for Competitive Interest
ROD	Record of Decision
SAP	site assessment plan
SGRE	Siemens Gamesa Renewable Energy
SOV	service operation vessel
TBD	to be determined
USCG	United States Coast Guard
USD	U.S. dollars
WEA	wind energy area
WTIV	wind turbine installation vessel

Executive Summary

The *Offshore Wind Market Report: 2023 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 over 293 global operating offshore wind energy projects as well as the broader global pipeline of projects in various stages of development through December 31, 2022. To provide up-to-date information and discussion on this emerging industry in the United States, this report tracks the significant U.S. domestic industry progress and events from January 1, 2022, through May 31, 2023.

U.S. Offshore Wind Energy Market

By May 31, 2023, the U.S. offshore wind energy project development and operational pipeline reached a potential generating capacity of 52,687 megawatts. The 52,687 megawatts (MW) in the U.S. offshore wind energy pipeline represents 15% growth from the *Offshore Wind Market Report: 2022 Edition*.[1] Most of the 6,915 MW of growth in the U.S. project pipeline capacity was driven by new leasing activity that created three new lease areas in the Gulf of Mexico with an estimated capacity of 4,885 MW. The first two commercial-scale offshore wind power plants in the United States, Vineyard Wind 1 and South Fork Wind, achieved major milestones by entering the wind turbine installation phase of their construction periods.[2] A map of the current pipeline activity and Call Areas is shown in Figure ES-1. Note the potential future offshore wind generating capacity in Call Areas is not included in any of the pipeline estimates in this report.

The Inflation Reduction Act, signed into law in August 2022, provides incentives for investing in offshore wind energy and the domestic supply chain. The Inflation Reduction Act (IRA) effectively extends offshore wind's eligibility for an investment tax credit (ITC) of 30% for at least a decade and makes receipt of the full credit dependent on meeting prevailing wage and apprenticeship requirements. The IRA also includes bonus credits of 10 percentage points each for meeting domestic content thresholds and for locating facilities in fossil-fuel-powered communities or on brownfield sites that can be combined for qualifying projects. The IRA also introduces per-watt manufacturing credits for domestic production of various clean energy technology components. Those components relevant to offshore wind energy include wind turbine blades, nacelles, towers, foundations, and purpose-built offshore wind vessels.

Many U.S. offshore wind energy projects are facing economic headwinds from cost increases. Many projects—particularly those with an expected start of commercial operations between 2025 and 2028—have faced challenges in maintaining economic viability because of

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[1] The pipeline capacity calculated in 2022 was revised to adjust the capacity density of leases areas where specific project dimensions have not been announced from 3 megawatts (MW)/square kilometer (km^2) to 4 MW/km^2. The U.S. offshore wind energy pipeline as of May 31, 2022, was revised to 45,772 MW, from the original reported pipeline of 40,083 MW.

[2] South Fork Wind and Vineyard Wind 1 both began wind turbine installation after May 31, 2023.

rising capital costs and interest rates. As a result, some projects have asked their offtake counterparties or states to renegotiate the terms of their offtake agreements (e.g., Massachusetts Department of Public Utilities 2022). As a buffer to make future offtake agreements more durable, some states have now introduced inflation indexing as part of their forthcoming offshore wind procurements. The IRA may soften the adverse impact of rising inflation, supply chain constraints, and interest rates on offshore wind project costs for early-stage offshore wind projects.

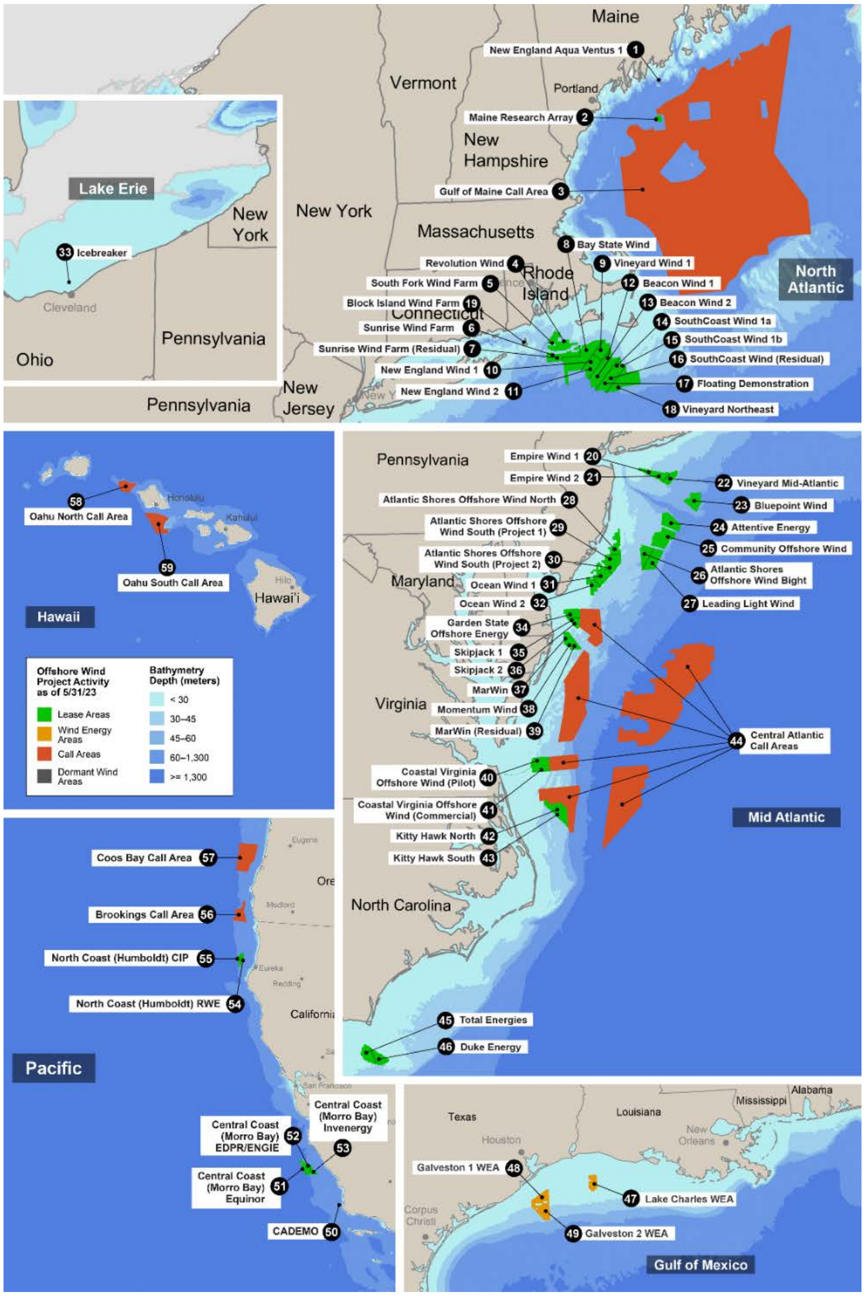

Figure ES-1. Locations of U.S. offshore wind energy pipeline activity and Call Areas as of May 31, 2023. ***Map created by John Frenzl, National Renewable Energy Laboratory***

The U.S. floating offshore wind energy market reached a turning point in 2022. The first-ever commercial floating offshore wind energy lease areas, off the coast of California, were sold in December 2022, for over $750 million. In addition, California announced a planning goal of 25 gigawatts (GW) by 2045. In September 2022, the Biden administration announced the Floating Offshore Wind Shot^{TM}, a nationwide effort to reduce the cost of floating offshore wind by 70% to $45/megawatt-hour (MWh) (U.S. Department of Energy 2022). In concert with the Floating Offshore Wind Shot, the U.S. Department of the Interior announced a deployment target for 15 GW of floating offshore wind capacity to be installed by 2035, with plans for additional commercial leasing for floating wind in the Atlantic and Pacific regions (U.S. Department of the Interior 2022).

Investments in the domestic supply chain continued with $2.7 billion announced in 2022. Since 2014, around $17 billion[3] has been announced or invested in the U.S. offshore wind energy industry according to the Business Network for Offshore Wind. The $2.7 billion invested in 2022 was spread across ports, vessels, supply chain, and transmission, indicating investor confidence in the U.S. offshore wind energy market (Business Network for Offshore Wind 2023). Ports and vessels in particular saw significant investment, with almost $1 billion spread across a total of 12 marshaling, manufacturing, and operations and maintenance ports. The U.S. offshore wind energy industry currently has 8 commissioned vessels and 28 that are announced or under construction.

The Bureau of Ocean Energy Management held three offshore wind lease auctions in 2022, collecting a total of $5.44 billion in sales. The bureau held three of seven lease auctions announced in its “Offshore Wind Leasing Path Forward 2021–2025” in 2022. These auctions sold 13 leases for a total of $5.44 billion, more than $4 billion from the New York Bight alone. The auctions sales included six leases in the New York Bight, two leases off Carolina Long Bay, and five leases off California’s coast (U.S. Department of the Interior 2021). The new lease areas substantially increase the number of viable offshore wind energy sites in the United States, provide regional diversification beyond the north and mid-Atlantic, and enable the U.S. floating offshore wind industry in the United States by introducing the first deep-water commercial leases.

Twenty-seven contracts to purchase 17,567 MW of electricity from offshore wind power plants have been signed, but no new offtake agreements were signed between June 2022 and May 2023. State procurement policies have resulted in 27 offshore wind power offtake agreements, totaling 17,567 MW. Although no new offtake agreements have been signed since May 31, 2022, between January 2021 and May 31, 2022, 10 offtake agreements, totaling 11,874 MW, were signed, and multiple state procurements were open as of May 31, 2023. Several

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[3] The Business Network for Offshore Wind includes revenue from lease sales in this total.

projects have announced they are exploring renegotiation or cancelation of their negotiated power purchase agreements, which could change the current total.

State policies aim to procure 42,730 MW of offshore wind capacity by 2040. The U.S. offshore wind energy market continues to be driven by state-level offshore wind procurement activities and policies. Seven states have durable statutory procurement mandates[4] that total 42,730 MW by 2040; about a 9% increase from the 39,322 MW reported in May 2022. Six other states have set offshore-wind-specific planning targets with varying renewable energy offtake mechanisms to procure electrical generation. In 2023, both New Jersey and Maryland increased their statutory procurement mandates to 11 and 8.5 GW, respectively. In aggregate, 13 coastal states have announced planning targets or procurement mandates for offshore wind energy that combined, add to a total of 112,286 MW of offshore wind capacity by 2050. These policies provide a solid foundation for achieving federal offshore wind energy targets of 30 GW by 2030 and 15 GW of floating offshore wind by 2035 (The White House 2021, 2022a). Figure ES-2 shows the composite timelines for state policy mandates, offtake contracts awarded, and planning targets (which include procurement mandates) as of May 31, 2023.

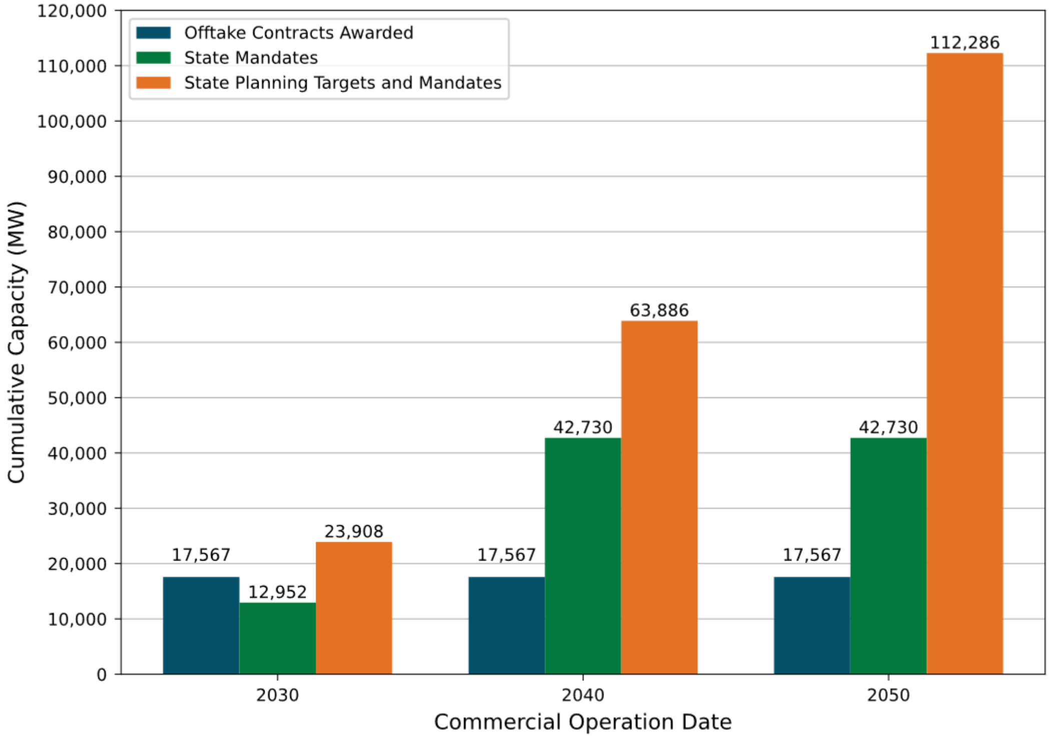

Figure ES-2. U.S. offshore wind energy state planning goals, procurement mandates, and offtake contracts awarded.

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[4] Durable procurement targets are protected by robust legislation rather than based on a single executive order that could potentially be overturned by a change in governance.

Global Offshore Wind Energy Market

Global offshore wind energy in 2022 had its second-best year, commissioning 8,385 MW of new projects. By the end of 2022, the total global capacity reached 59,009 MW from 292 operating projects and over 11,900 operating wind turbines. For the second straight year, most of the growth was attributed to China, which commissioned 5,719.6 MW. The United Kingdom had the next largest annual deployment (1,386 MW), followed by France (480 MW), Germany (342 MW), Vietnam (331 MW), and the rest of the world at (126.5 MW) (National Renewable Energy Laboratory Offshore Wind Database 2021). Projections based on projects under construction indicate that annual global capacity additions may increase slightly in 2023.

The global generating capacity potential in the pipeline for all offshore wind energy projects nearly reached 427 GW in 2022. As of December 31, 2022, the global pipeline for offshore wind energy development capacity was assessed to be 426,789 MW, up nearly 16% over the 368,170 GW reported in 2022. The global uptick is primarily attributed to new European projects entering the planning phase.[5]

Macroeconomic and geopolitical events have raised the level of market uncertainty in 2022. The extended impact of monetary policy to fight inflation and the conflict in Ukraine have created increased market volatility, disrupted the supply chain, and increased project costs. These complex external drivers are having both positive and negative impacts on offshore wind and broader energy industries. Increased fossil-fuel prices and supply uncertainty have increased commitments to renewable energy by Nations around the world to mitigate rising consumer electricity costs and strengthen their energy security. On the other hand, increases in commodity prices and continued supply chain disruptions threaten to increase offshore wind project costs, which could delay offshore wind energy deployment in the near term (Durakovic. 2022c). Higher costs are impacting all renewable and fossil-fueled power generation sources (Henze 2022), though capital-intensive sources like offshore wind energy are relatively more affected.

The global pipeline for floating offshore wind energy increased by nearly 42 GW in 2022. Overall, the 2022 global floating offshore wind pipeline grew from 60,746 MW to 102,529 MW, representing 41,783 MW of growth (approximately 69% increase) since the *Offshore Wind Market Report: 2022 Edition*. This growth is attributed to new commercial project announcements, mostly in the United Kingdom, that entered the pipeline in 2022.

No new global floating offshore wind energy projects came online in 2022, maintaining floating wind global capacity at 123.4 MW. Equinor began construction of their 88-MW Hywind Tampen floating wind plant in 2022 but had not yet fully commissioned all 11 turbines. When it is fully commissioned, likely in 2023, Hywind Tampen will be the largest operating floating offshore wind energy project in the world.

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[5] Note that the capacity density adjustments made to the U.S. pipeline do not affect the rest of the global pipeline.

Offshore Wind Energy Technology Trends

Offshore wind turbines in the 15-MW class are advancing toward commercial production. All three leading wind turbine manufacturers active in Europe and the U.S. market—Siemens Gamesa, Vestas, and General Electric—have announced that their 14-MW and 15-MW wind turbine prototypes have generated power and are moving toward commercial development with the goal of them being available for purchase by 2024. Industry announcements indicate that developers will depend on these turbines for most U.S. projects, and manufacturers such as General Electric have already announced they intend to extend their technology platform beyond 15 MW. Projects outside the United States could possibly use Chinese wind turbines that have also reached a 15-MW scale.

Offshore Wind Energy Cost and Price Trends

Supply chain constraints, high inflation, and rising interest rates have resulted in significant project cost increases of 11%–30% during 2022. These cost increases reported in 2022 may have the greatest impact on the capital expenditures of projects planning commercial operations between 2025 and 2028 with offtake agreements already in place. Although no U.S. offshore wind energy projects were built in 2022, we estimate that a hypothetical fixed-bottom project beginning commercial operations in 2022 would have incurred an increase of 6% in its levelized cost of energy, from $84/MWh to $89/MWh on average. This increase is based on the assumption that supply contracts would have been awarded between 2019 and 2021 for projects with a commercial operation date in 2022. This 6% increase above the reported 2021 U.S. cost estimates still results in a total cost reduction of about 50% since 2014 (Wiser et al. 2021). For representative market scenarios, leading research entities and consultancies now estimate that average levelized cost of offshore wind energy will be $63/MWh by 2030.

Future Outlook

Industry growth in the U.S. market could parallel anticipated global market growth, despite current macroeconomic challenges. Global forecasts from BloombergNEF (2022a) and 4C Offshore (2023) show offshore wind energy could reach between 380 GW and 394 GW, respectively, by 2032, which would represent a sixfold increase in offshore wind capacity over the next decade.

Recent national power sector scenario analysis indicates that some states will need offshore wind to decarbonize their energy supply. A recent National Renewable Energy Laboratory study investigated multiple scenarios to achieve 100% clean electricity generation by 2035 and concluded that given increased electricity demand from electrification, the United States needs roughly two terawatts (2,000 GW) of wind and solar capacity to serve a threefold expansion of electric energy consumption (Denholm et al. 2022). Specifically, between 1,000 GW and 1,200 GW of wind energy (land-based and offshore wind combined) will be needed, with offshore wind contributing a significant portion (Wiser et al. 2023). The study also estimated that the resulting economic and social benefits could potentially exceed the cost of decarbonization.

In the United States, key offshore wind energy market indicators, such as commercial leasing, state energy planning targets, procurement policies, offtake agreements, and federal support for U.S. jobs and supply chain development, point toward sustained market growth when viewed together, but the macroeconomic hurdles facing the first generation of commercial projects could significantly stunt that growth.

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1 Introduction

Offshore wind is a growing sector of the wind energy market with unique characteristics that enable large, utility-scale electric-generating facilities to be built adjacent to populated load centers, with manageable interactions with the environment and other ocean use activities. These projects can access more energy from ocean winds than adjacent projects on land, avoid high real estate costs and numerous siting conflicts in populated areas, and create thousands of high-paying jobs (American Clean Power [ACP] 2023a). In the United States, no new offshore wind energy projects were installed in 2023. Current installed capacity remained at 42 megawatts (MW); however, the 800-MW Vineyard Wind project south of Massachusetts and the 132-MW South Fork Wind project off Rhode Island began construction and are scheduled to start delivering power in 2023. Additionally, more than 20 GW of additional capacity in the permitting phase is moving toward final approval.

However, inflation of commodity prices, global supply chain shortages, higher interest rates from central banks, and uncertainty of wind turbine availability have substantially raised project costs over the past year (for projects with planned commercial operation dates (CODs) of 2025–2028)—threatening the viability of some projects with offtake agreements negotiated before the cost increases began. Several U.S. projects are considering renegotiating or canceling their power purchase agreements based on these rising project costs that may make some projects unviable (Blunt and Hiller 2023; Newburger 2022).

The Inflation Reduction Act (IRA) passed in 2022 at the height of inflation provides a strategically important means of softening the macroeconomic impacts affecting offshore wind project costs. The IRA extends the 30% investment tax credit (ITC) and incentivizes the domestic supply chain to establish a U.S. business base to support the emerging offshore wind industry. The IRA can have a significant positive impact in offsetting the hurdles that threaten this nascent industry from achieving commercial success.

Globally, the offshore wind industry continued a trend toward more geographic diversity with deployment in Asia surpassing European installations for the second straight year. In 2022, the global market expanded into more countries as offshore wind energy continues to be factored into long-range energy planning and policy decisions including deployment targets. This global market growth is motivated by increasing urgency for climate action, energy insecurity exacerbated by Russia's invasion of Ukraine, and the prospect of cost declines from a maturing industry.

Global deployment increased in 2022 with 8,385 MW of new offshore wind energy commissioned. Future projections predict growth globally with long-term projections of more than 290 gigawatts (GW) by 2030 and more than 1,500 GW by 2050 (BloombergNEF [BNEF] 2023; 4C Offshore 2023).

In the United States, offshore wind energy markets received strong policy support from key coastal states in 2022 and early 2023 while federal policies enacted in 2022 have received economic support for projects and their necessary infrastructure, targeting wide-ranging solutions for greenhouse gas reduction; electrification of the energy supply; jobs and economic benefits; and energy justice. Recent federal policies in support of offshore wind energy include the Biden administration's goal to deploy 30 GW of offshore wind energy by 2030, the Bipartisan Infrastructure Law, the IRA, and the Floating Offshore Wind Shot™ announced in September 2022 (The White House 2021; U.S. Department of Transportation Federal Highway Administration 2023; Yarmuth 2022; U.S. Department of Energy [DOE] n.d. [b]) The industry is seeing more coordinated U.S. state and federal offshore wind energy policy that is helping de-risk the market and stimulate private commercial investment.

The long-term market outlook is positive, but these macroeconomic and geopolitical factors are raising concerns that project schedules and electricity-delivery costs may be impacted in the near term (climatenexus.org n.d.).

1.1 About This Report

This *Offshore Wind Market Report: 2023 Edition* was researched and written by the National Renewable Energy Laboratory (NREL) for 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 293 operating offshore wind power plants in the global fleet through December 31, 2022, 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, 2023.

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 future perspectives. These projects are also used as key inputs to the annual *Cost of Wind Energy Review*, 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 those costs (Stehly and Duffy 2022). This report is also a companion to the *Land-Based Wind Market Report: 2023 Edition* and *Distributed Wind Market Report: 2023 Edition*, which are funded by DOE and authored by the Lawrence Berkeley National Laboratory (Wiser et al. 2023) and the Pacific Northwest National Laboratory (Orrell et al. 2023), respectively. These companion reports cover the status of utility-scale and distributed, land-based wind energy in United States, providing quantitative data and context for the wind energy industry and its stakeholders.

1.2 Approach and Method

1.2.1 NREL Offshore Database

This *Offshore Wind Market Report: 2023 Edition* uses NREL's internal offshore wind database (OWDB), which contains information on more than 2,887 offshore wind energy projects located in 49 countries and totaling 1,892,610 MW of announced project capacity (both active and dormant) (NREL 2023). The database includes fully operational projects dating back to 1990, dormant projects, as well as anticipated future deployment that may or may not have announced their 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 NREL 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 2023)
- Bureau of Ocean Energy Management (BOEM) online published data and direct consultations
- BNEF's Renewable Energy Project Database (BNEF 2023).

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 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 operating and transmitting power to their designated end user[6] (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-

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[6] The end user is usually a land-based grid point of interconnect but as the energy sectors become more electrified, the definitions of end use may include converting the electricity directly to storage, renewable fuels, or industrial applications.

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 2022 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 2023)
- Inflating the values, which are in nominal USD after the exchange rate conversion, to 2022 USD using the U.S. Consumer Price Index (U.S. Bureau of Labor Statistics 2023).

1.2.2 Classification of Project Status

The "pipeline" in this report is an offshore wind energy development and operating project tracking process that provides 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 state and federal officials initiate the leasing process to designate a wind energy area (WEA), which may lead to a lease being competitively awarded. This classification system is also used in nonfederal waters of the United States where the regulatory process is overseen by state governments (e.g., the Great Lakes).

In parallel to obtaining state and federal environmental and construction permits, developers also need to demonstrate the economic viability of their project and obtain third-party 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 environmental and construction permitting 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[7] that are waiting to be auctioned, potential generating capacity of sites where developers hold offshore wind leases, nameplate capacity of projects under development, operational project capacity, and capacity of decommissioned projects. If known, we provide 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 prospective offshore wind energy developers and stakeholders who indicate their interest in a proposed Call Area. Call Areas are the precursors to designating a WEA in a particular region. There are now many Call Areas across the United

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[7] This report does not include the generating potential of draft wind energy areas. The estimated generated potential of finalized wind energy areas is included in the U.S. offshore wind energy pipeline.

States' Outer Continental Shelf (OCS), but because their boundaries are likely to change, **no portion of any Call Area is counted in the pipeline totals** until it 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.[8] In previous offshore wind market reports, the capacity of undeveloped WEAs, where project parameters are not known (generally before the Construction and Operations Plan (COP) is submitted), was determined using a capacity density of 3 MW per square kilometer (km^2). This is a conservative estimate of eventual installed capacity in many states (Musial et al. 2013, 2016).

Conservative estimations of capacity density allow for possible reductions to the developable area that may be necessary to accommodate navigation lanes, geohazards, technology setbacks, prescribed wind turbine spacing, and other easements without overstating the generating potential (Musial et al. 2013). However, if the assumptions are too conservative, decision makers who use these data may be misled into thinking more lease area is required to meet state and national targets than necessary.

As projects become more precisely defined, developers can potentially achieve higher capacity densities but there is no simple formula to estimate it.[9] To establish a baseline more accurately for lease area capacity density in the U.S. Atlantic, NREL surveyed detailed publicly available data for 17 U.S. Atlantic-based projects. A detailed assessment is presented in Appendix A that shows how capacity density is expected to vary for proposed projects. Capacity density varies from 2.1 MW/km^2 to 9.07 MW/km^2 for the projects assessed, but the data show an average weighted capacity density of about 4.42 MW/km^2, indicating that previous estimates based on 3 MW/km^2 might underestimate the actual capacity of the leased areas. Therefore, the pipeline calculations for an unspecified lease area in the DOE offshore wind market reports are now based on 4.0 MW/km^2 for both fixed-bottom and floating projects unless project specific data are available. Note that 4.0 MW/km^2 is still conservative to account for the possibility that the built projects may not achieve their intended capacity densities due to a range of potential physical and permitting constraints. This change in how we calculate offshore capacity density caused a significant increase (5,689 MW) in the total capacity we claim in the U.S. offshore wind energy pipeline for 2023. This increase is further described in Section 2.1.

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

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[8] Portions of the lease area may be excluded from commercial development on a site-by-site basis because of seabed geology, unexploded ordinance (e.g., mines), or fisheries considerations.

[9] Note in some states or regions, wind turbine spacing may be shaped by stakeholder engagement and regulatory processes. For example, developers in the Northeast have adopted a 1-nautical-mile-by-1-nautical-mile turbine spacing to accommodate fishing vessel navigation.

planning because some countries have other methods of establishing "site control." Generally, the "site control" step is applied to U.S. projects because they are clearly defined based on the BOEM auction process, but in other countries "site control" is more ambiguous. Therefore, we assign early-stage projects to "planning" unless more information is available.

Table 1. Offshore Wind Energy 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 wind energy area [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	Starts 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 the sponsor announces a "financial investment decision" and has signed contracts for construction work packages
5	Financial Close	Starts when the 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[10]	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; commercial operation date 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	Decommissioned	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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[10] Note that some developers may elect to start construction at an onshore landing area to secure certain subsidies or tax incentives.

1.3 Report Structure

The remainder of this report is structured as follows:

- Section 2 summarizes the status of the offshore wind energy industry in the United States, providing in-depth coverage of 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, and national targets are summarized by country and year.
- Section 4 describes offshore wind energy siting and technology trends focusing on wind turbine technologies, turbine manufacturers, fixed-bottom and floating substructures, and electrical power systems.
- 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.
- Section 6 provides a general outlook and insights for long-term offshore wind development, and trends based on global forecasts.

2 U.S. Offshore Wind Market Assessment

2.1 U.S. Offshore Wind Industry Overview

The *Offshore Wind Market Report: 2023 Edition* updated capacity density assumptions used to calculate the capacities for lease areas where project capacities have not been announced. The capacity density assumption increased from 3 MW/km^2 to 4 MW/km^2. To compare pipeline growth from the previous year accurately, we applied the updated assumptions to the U.S. offshore wind energy pipeline from the *Offshore Wind Market Report: 2022 Edition*. The U.S. offshore wind energy pipeline as of May 31, 2022, was revised to 45,772 MW, from the original reported pipeline of 40,083 MW. U.S. wind energy pipeline growth is calculated based on the revised pipeline. As of May 31, 2023, the U.S. wind energy pipeline grew 15% (6,915 MW), to a total of 52,687 MW. The information in this report is from January 1, 2022, until May 31, 2023, unless otherwise noted.

- Up to 5,089 MW of the 6,915 MW of total pipeline growth came from the proposed 144-MW floating wind research lease in Maine, the proposed 60-MW floating demonstration in California state waters, and the creation of three new WEAs in the Gulf of Mexico, which we estimate will support approximately 4,885 MW of capacity.
- The rest of the pipeline growth came from multiple developers revising their estimated project capacities. Developer revisions increased project capacities by a total of 1,826 MW across the Atlantic Shores Offshore Wind, Garden State Offshore Energy, MarWin, Coastal Virginia Offshore Wind (CVOW) (Commercial), and Kitty Hawk North and South projects.
- Increasing the capacity density assumption added 5,689 MW of capacity to the revised pipeline and increased the capacity assessments of the CIP Massachusetts, Vineyard Mid-Atlantic, Bluepoint Wind, Attentive Energy, Community Offshore Wind, Atlantic Shores Offshore Wind Bight, Leading Light, Garden State Offshore Energy, Total Energy Carolina, Duke Energy Carolina, Equinor-Morro Bay, EDPR/ENGIE – Morro Bay, Invenergy-Morro Bay, RWE-Humboldt, and CIP Humboldt projects.
- The U.S. offshore wind energy industry faced serious challenges in late 2022 and early 2023. Developers who had previously signed offtake agreements and were attempting to bring projects online before 2030 reported significant cost increases driven by inflation and rising interest rates (estimated to be 11%–20%, or more) that potentially rendered their projects financially nonviable (Lloyd-Williams 2023; ACP 2023b).[11]

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[11] In this case, financial nonviability could be driven by a project with a preexisting offtake contract that is expected to yield lower revenues than updated project costs, or a project that still has a positive revenue expectation but with a lower return margin that does not satisfy external financial backers relative to other investment opportunities.

These challenges also prompted some utility partners to sell their joint ownership stakes in offshore wind projects.

- In Massachusetts, New England Wind (owned by Avangrid) and SouthCoast Wind (owned by EDPR/ENGIE/Shell) asked the state regulators to release them from their existing power purchase agreements signed with local utility companies in 2021 (Massachusetts Department of Public Utilities 2022). Both companies cited rising interest rates and continued inflation and commodity price increases driven by global economic volatility and market interruptions connected to the Russian invasion of Ukraine (Massachusetts Department of Public Utilities 2022). While regulators ultimately declined to waive the existing power purchase agreements, the developers, local utilities, regulators, and state legislators are negotiating the option of having developers pay termination fees (estimated to be over $100 million) to break the existing contracts while allowing the projects to rebid into future offshore wind solicitations that would include an inflation adjustment mechanism embedded in the offtake contract (Rubin and Powers 2023; Massachusetts Department of Public Utilities 2022).
- Facing similar cost pressures, Ørsted indicated to investors it was devaluing financial estimates for its Sunrise Wind project in New York because of supply chain bottlenecks, cost inflation, and higher costs of capital (Skydsgaard, Nikolaj. 2023). Equinor/BP and Ørsted petitioned New York regulators to renegotiate their offshore renewable energy certificate (OREC) contracts for Empire Wind 1 and 2, Beacon Wind 1, and Sunrise Wind to adjust the prices to account for inflation (New York Public Service Commission 2023).
- In New Jersey, Ørsted also indicated its Ocean Wind 1 project was facing financial challenges stemming from the lack of an inflation adjustment mechanism in its 2019 OREC contract and would need additional support to reach financial close. In response, the New Jersey legislature implemented a bill that would allow Ørsted to retain any federal tax credit benefits Ocean Wind 1 received instead of passing the tax benefits onto utility ratepayers (New Jersey Legislature 2023). Atlantic Shores Offshore Wind has also indicated to the Governor and New Jersey Board of Public Utilities its Phase 1 project was at risk and needs additional financial support (Parry. 2023).

Despite near-term financial setbacks, the U.S. offshore wind energy market experienced multiple developments that put it on a trajectory for potential long-term growth:

- The IRA includes several tax provisions that apply to offshore wind energy (U.S. Congress 2022; DOE 2023). The Bipartisan Infrastructure Law, passed in November 2021, provides other boosts to offshore wind, such as increased funding for interregional and offshore transmission planning, which can accelerate the interconnection of offshore wind energy projects and funding for federal regulatory agencies to accelerate permitting activities (U.S. Congress 2021, 2022).

- Following respective groundbreakings in late 2021 and early 2022, Vineyard Wind 1 (800 MW) and South Fork Wind (132 MW) are on track to complete onshore and offshore export cable installation and electrical grid infrastructure upgrades in 2023 and began installing offshore wind turbine foundations in the summer of 2023, with the projects expected to become fully operational in 2024. Ocean Wind 1 also received a Record of Decision from BOEM on its COP to construct up to 98 wind turbines and three offshore substations off New Jersey, completing a major permitting milestone and ensuring the project is on track to start construction in fall 2023 (BOEM 2023e).
- Offshore wind energy planning goals and procurement mandates continued to grow. State procurement mandates now total 42.7 GW by 2040. In September 2022, New Jersey Governor Murphy implemented Executive Order 307, which increased the state's procurement mandate from 7.5 GW by 2035 to 11 GW by 2040 (Governor Murphy 2022). In April 2023, Maryland passed the Promoting Offshore Wind Energy Resources Act, increasing the state's procurement mandate from 2 GW by 2030 to 8.5 GW by 2031 (Maryland General Assembly 2023). While these procurement mandates increase market certainty in the near- to midterm, more ambitious state planning targets highlight the potential growth opportunity for offshore wind energy in the long term. New planning targets in California, Oregon, and other regions have grown offshore wind policies (planning targets and mandates) to over 112 GW in the United States by 2050 (California Energy Commission 2022a; Oregon State Legislature 2021).
- Following its "Offshore Wind Leasing Path Forward 2021–2025," BOEM continues to identify and competitively auction offshore WEAs (BOEM 2021). In February 2022, BOEM leased six areas in the New York Bight for a total of $4.37 billion and the potential to support roughly 7.9 GW of offshore capacity (BOEM 2022a). In May 2022, two lease areas were auctioned in the Carolina Long Bay for a total of $315 million and the potential to support approximately 1.8 GW of capacity (BOEM 2022b). In December 2022, five areas were leased off California with the potential to support over 6 GW[12] of floating offshore wind capacity (BOEM 2022c). In January 2023, BOEM published a Determination of No Competitive Interest for a 144-MW floating offshore wind research lease proposed by the state of Maine (BOEM 2023b). In February 2023, the bureau published a Proposed Sales Notice for three WEAs in the Gulf of Mexico that could support roughly 4.9 GW of capacity (BOEM 2023c).
- While no offtake contracts were awarded in 2022, there are five active offshore wind solicitations underway: a 600- to 1,000-MW procurement in Rhode Island, up to 2,000 GW in New York, between 1,200 and 4,000 MW in New Jersey, 1,196 MW in

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[12] Note, the National Renewable Energy Laboratory assumes a 4-megawatt (MW)/square kilometer (km^2) capacity density for all lease areas where developers have not identified a specific capacity. The Bureau of Ocean Energy Management originally assumed the California lease areas could support more than 4.6 gigawatts (GW) of capacity using a 3 MW/km^2 capacity density assumption.

Connecticut, and up to 3,600 MW in Massachusetts (Narragansett Electric Company 2022; New York State Energy and Research Development Authority 2022; New Jersey Board of Public Utilities [NJBPU] 2023a; Connecticut Department of Energy and Environmental Protection 2023; Massachusetts Department of Public Utilities 2023).

2.2 Inflation Reduction Act

The IRA includes several tax provisions that apply to offshore wind energy (DOE 2023). First, it effectively extends offshore wind's eligibility for an ITC of 30% for at least a decade and makes receipt of the full credit dependent on meeting prevailing wage and apprenticeship requirements. The IRA also includes bonus credits of 10 percentage points each for meeting domestic content thresholds and locating facilities in fossil-fuel-powered communities or on brownfield sites that can be combined for qualifying projects. Consequently, a project that meets prevailing wage and apprenticeship requirements and claims one bonus credit would receive a 40% ITC, and a project claiming both bonuses would receive a 50% ITC.

The IRA also introduces per-watt manufacturing credits for domestic production of various clean energy technology components. Eligible wind energy components including wind turbine blades, nacelles, towers, offshore wind foundations, and purpose-built offshore wind vessels. The advanced manufacturing production tax credit is estimated to reduce offshore wind component costs by 27% (blades), 18% (steel towers), 4% (monopiles), and 8% (nacelles)—all resulting in lower costs than if they were imported (Wood MacKenzie 2023). The IRA provides that the ITC will phase out[13] when U.S. electricity sector emissions have declined by 75% compared with 2022 levels, or at the end of 2032, whichever comes last[14].

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

As of May 31, 2023, NREL estimates the U.S. offshore wind energy pipeline to have 52,687 MW of capacity, which is the sum of installed projects, projects under construction, projects approved for construction, projects undergoing various state and federal permitting processes, existing lease areas, and the development potential of yet-to-be-leased WEAs. Table 2 breaks down the U.S. offshore wind energy pipeline by project status.

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[13] The investment tax credit is slated to be replaced with a technology-neutral tax credit in 2025.

[14] For more information on the IRA and other federal incentives see the "Wind Energy Technologies Office Federal Incentives Fact Sheet."

Table 2. U.S. Offshore Wind Energy Pipeline by Classification Status

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	The Bureaus of Ocean Energy Management (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 acquired an interconnection agreement to inject power to the grid.	1,100
Permitting	The developer has site control of a lease area, has received an offtake contract, or 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.	20,978
Site Control	The developer has acquired the right to develop a lease area and has begun surveying the site. If available, developers' announced project capacities are used. If a developer has not announced a specific capacity, it is estimated using a 4-megawatt (MW)/square kilometer (km^2) wind turbine density.	24,596
Planning	The rights to a lease area have yet to be auctioned to offshore wind energy developers. Capacity is estimated using a 4-MW/km^2 wind turbine density assumption.	5,039

We used developer-specified capacity values for operating projects, projects under construction, and projects advancing through the permitting and offtake processes. These projects have announced project plans, a specified site boundary, and definitive design details related to wind turbine size, array density, and nameplate capacity, among other things. For projects in more nascent stages of development (e.g., site control and planning), we use developer-specified capacity where available, or we estimate the potential capacity using a capacity density factor of 4 MW/km^2.

Figure 1 shows the U.S. wind energy pipeline as of May 31, 2023, for all categories in Table 2 by project status and state. The U.S. pipeline by project status includes:

- Two operating projects (Block Island Wind Farm [30 MW] and CVOW Pilot [12 MW])
- Two under construction (Vineyard Wind 1 [800 MW] and South Fork Wind [132 MW])
- One project that has its permits approved, an offtake agreement, and will imminently start construction (Ocean Wind 1 [1,100 MW])
- Nineteen projects (20,978 MW) that have submitted a COP with BOEM and/or secured a power offtake contract.

- Eighteen projects in lease areas where the developers have site control with rights to pursue development (a technical potential of at least 24,596 MW)
- Three active, unleased WEAs in the Gulf of Mexico (4,885 MW), one active, unawarded research lease area in the Gulf of Maine (approximately 144 MW), the proposed floating demonstration in Massachusetts (10 MW), and the proposed floating demonstration in California [60 MW] are in "planning," representing a total of 5,039 MW of capacity.

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

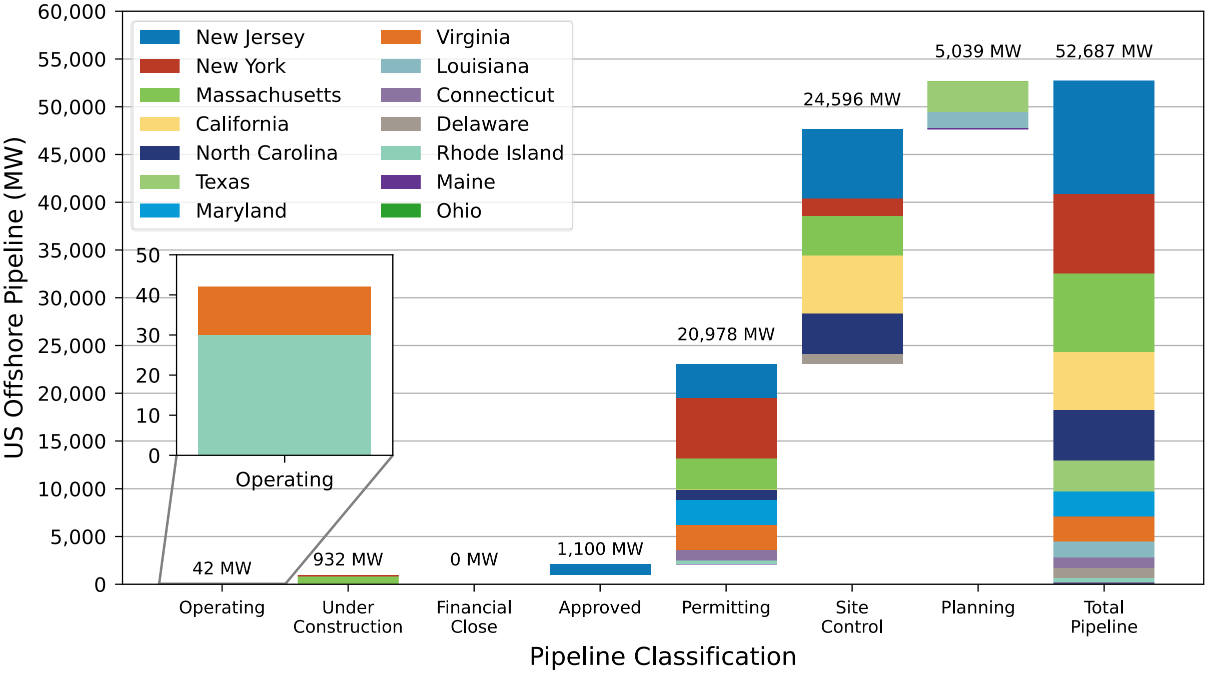

Figure 1. U.S. project pipeline classification by status[15]

All the projects progressing through offtake and permitting approval processes are primarily located in the Northeastern and mid-Atlantic regions of the United States. However, recent regulatory activity in the Pacific (five leases awarded off California) and the Gulf of Mexico (three WEAs identified for future leasing) highlight a trend toward increased geographic diversification and economic viability for offshore wind energy across the country.

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[15] Note the approval of Ocean Wind 1 occurred on July 5, 2023, after the stated cutoff date of May 31, 2023.

Figure 2 shows the same pipeline data but sorted by state. Note, this figure allocates generating capacities to states based on existing power offtake contracts, not geographic location.[16] 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 20,194 MW. Massachusetts has an estimated pipeline capacity of 8,189 MW. Note that projects in planning and site control could ultimately sell their power to a variety of adjacent states.

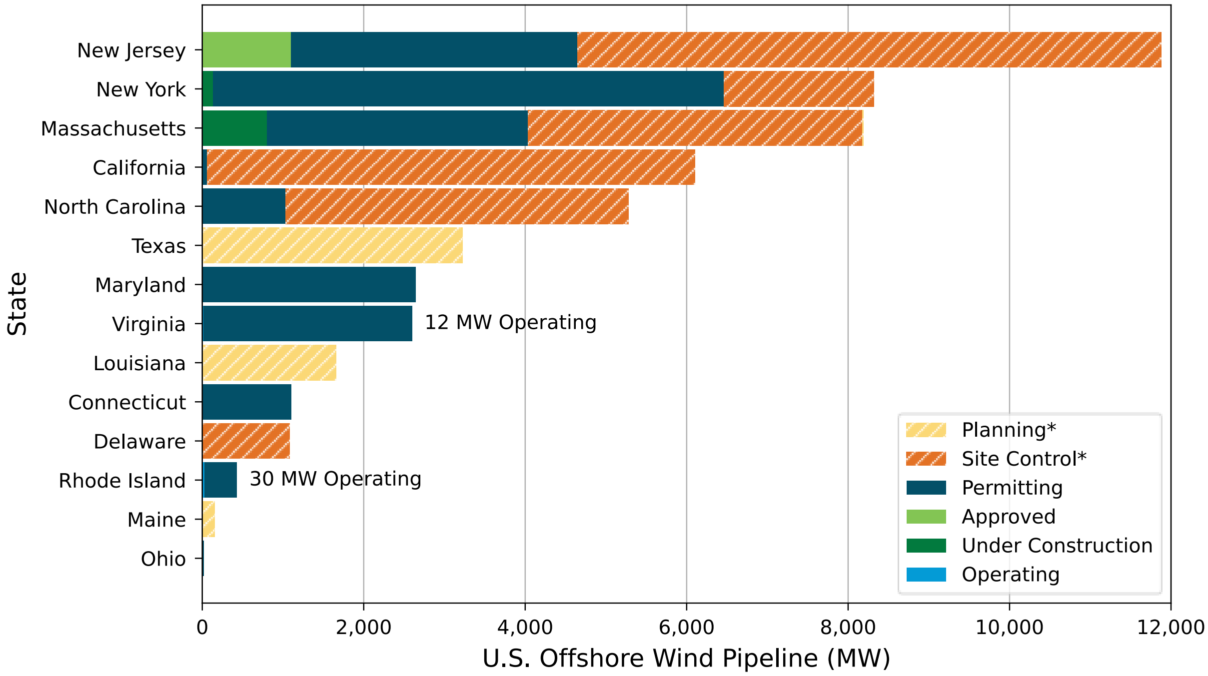

Figure 2. U.S. project pipeline by state

* Planning and site control pipeline capacity is subject to reallocate pipeline capacity to a different state after offtake agreements are negotiated.

2.3.1 U.S. Offshore Wind Energy Pipeline

All 52,687 MW that make up the U.S. offshore wind energy pipeline are listed as individual projects or project opportunities in Table 3, Table 4, Table 5, and Table 6 with corresponding maps shown in Figure 3 through Figure 7. These maps show U.S. leasing activity for the Gulf of Maine and North Atlantic, mid- and South Atlantic, Gulf of Mexico, Pacific Coast, and Hawaii, respectively. The tables and maps also include Call Areas, but the potential generating capacities

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[16] For example, Revolution Wind is subdivided such that 304 MW are allocated to Connecticut and 400 MW are allocated to Rhode Island based on the project’s existing power purchase agreements. Sunrise Wind Residual is allocated to Massachusetts and Beacon Wind is allocated to New York. Because neither of the “residual sites” have offtake contracts, offtake location was assigned based on state offshore wind energy procurement goals. For New York Bight projects, Atlantic Shores Offshore Wind Bight, Attentive Energy, Community Offshore Wind, and Leading Light Wind are allocated to New Jersey. Bluepoint Wind and Vineyard Wind Mid-Atlantic Wind are allocated to New York. It is likely that future procurement actions will impact the size of these projects, and which state they ultimately sell power to.

of those areas are not quantified or counted in the total pipeline capacity because they are considered preliminary and likely to change in size and location as they advance to a designation of WEA.

In total, there are 59 sites in these tables for U.S. offshore wind energy development activity (as shown on the five maps, compared to 56 sites in the *Offshore Wind Market Report: 2022 Edition*). Included in this activity are four projects in state waters: the operating Block Island Wind Farm in Rhode Island, New England Aqua Ventus I in Maine, the Lake Erie Energy Development Corporation (LEEDCo) Icebreaker project located north of Cleveland, Ohio, and the CADEMO project off Vandenburg Space Force Base, California. Both Aqua Ventus and Icebreaker are funded in part through DOE's Advanced Technology Demonstration Project program, which began in 2012 (DOE n.d. [a]).

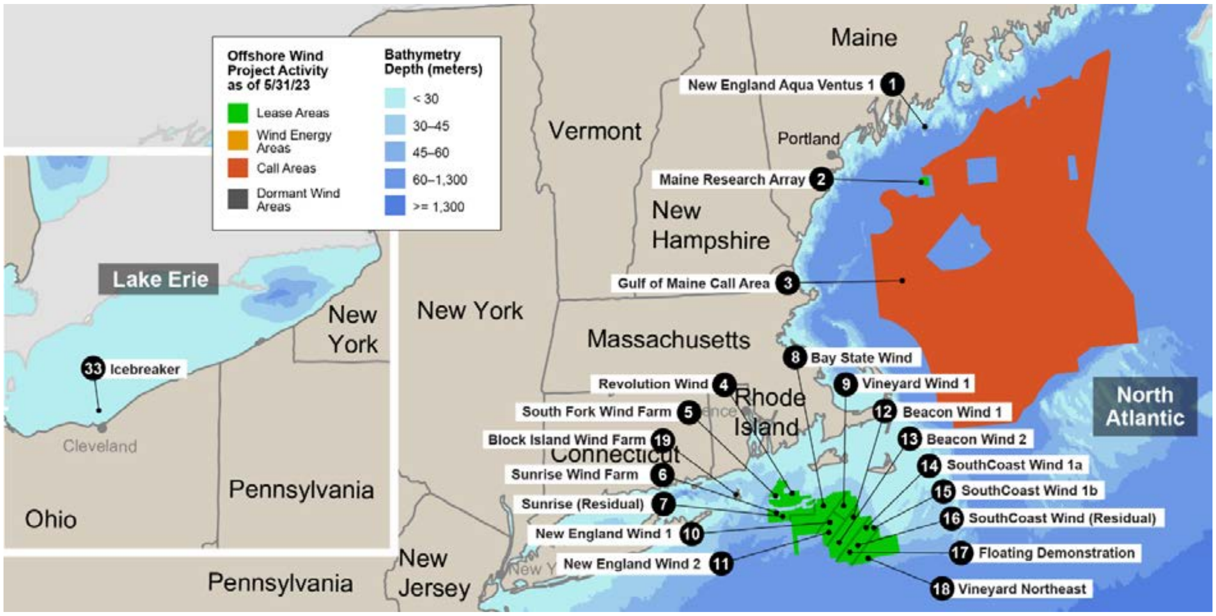

Figure 3. U.S. offshore wind energy pipeline in the North Atlantic, including the Gulf of Maine. ***Image by John Frenzl, National Renewable Energy Laboratory (NREL)***

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

#	Location	Name	Developer	Lease Area	Offtake Agreement	Estimated COD	Current Status	Capacity (MW)	Potential Point of Interconnection (POI) Location
1	Maine (ME)	New England Aqua Ventus 1	Univ. of Maine/Diamond Offshore/RWE	State Lease	Power purchase agreement (PPA)–ME	2024	Permitting	12	To be determined (TBD)
2	ME	Maine Research Array	TBD	TBD	TBD	TBD	Planning	144	TBD
3	ME	Gulf of Maine Call Area	Not applicable (N/A)	N/A	N/A	N/A			N/A
4	Rhode Island (RI)/Massachusetts (MA)	Revolution Wind	Ørsted/Eversource	OCS-A 0486	PPA–RI & Connecticut (CT)	2026	Permitting	704	NG Davisville 115 kilovolts (kV)
5	RI/MA	South Fork Wind Farm	Ørsted/Eversource	OCS-A 0517	PPA–New York (NY)	2024	Under Construction	132	East Hampton (69-kV bus)
6	RI/MA	Sunrise Wind Farm	Ørsted/Eversource	OCS-A 0487	Offshore renewable energy certificate (OREC)–NY	2026	Permitting	924	Holbrook 138 kV
7	RI/MA	Sunrise Wind Farm (Residual)	Ørsted/Eversource	OCS-A 0487	TBD	TBD	Permitting	900	Holbrook 138 kV
8	RI/MA	Bay State Wind	Ørsted	OCS-A 0500	TBD	TBD	Site Control	2,000	TBD
9	MA	Vineyard Wind 1	Avangrid	OCS-A 0501	PPAMA	2024	Under Construction	800	West Barnstable 345 kV
10	MA	New England Wind 1	Avangrid	OCS-A 0534	PPA–CT	2027	Permitting	800	West Barnstable 345 kV
11	MA	New England Wind 2	Avangrid	OCS-A 0534	PPA–MA	2027	Permitting	1,232	West Barnstable 345 kV
12	MA	Beacon Wind 1	Equinor Wind US/BP	OCS-A 0520	OREC–NY	2029	Permitting	1,230	Astoria 138 kV
13	MA	Beacon Wind 2	Equinor Wind US/BP	OCS-A 0520	TBD	TBD	Permitting	1,200	Astoria 138 kV
14	MA	SouthCoast Wind 1a	Shell/EDPR/ENGIE	OCS-A 0521	PPA–MA	2028	Permitting	804	Falmouth, Brayton Point 345 kV
15	MA	SouthCoast Wind 1b	Shell/EDPR/ENGIE	OCS-A 0521	PPA–MA	2029	Permitting	400	Falmouth, Brayton Point 345 kV
16	MA	SouthCoast Wind (Residual)	Shell/EDPR/ENGIE	OCS-A 0521	TBD	TBD	Permitting	800	Falmouth, Brayton Point 345 kV
17	MA	Floating Demonstration	Shell/Kent HOE/Ocergy	N/A	TBD	TBD	Planning	10	TBD

#	Location	Name	Developer	Lease Area	Offtake Agreement	Estimated COD	Current Status	Capacity (MW)	Potential Point of Interconnection (POI) Location
18	MA	Vineyard Northeast	Avangrid	OCS-A 0522	TBD	TBD	Site Control	2,143	TBD
19	RI	Block Island Wind Farm	Ørsted	State Lease	PPA–RI	2016	Installed	30	New Shoreham NG 34.5 kV
33	Ohio (OH)	Icebreaker	LEEDCo	State Lease	PPA–OH	2024	Permitting	21	TBD

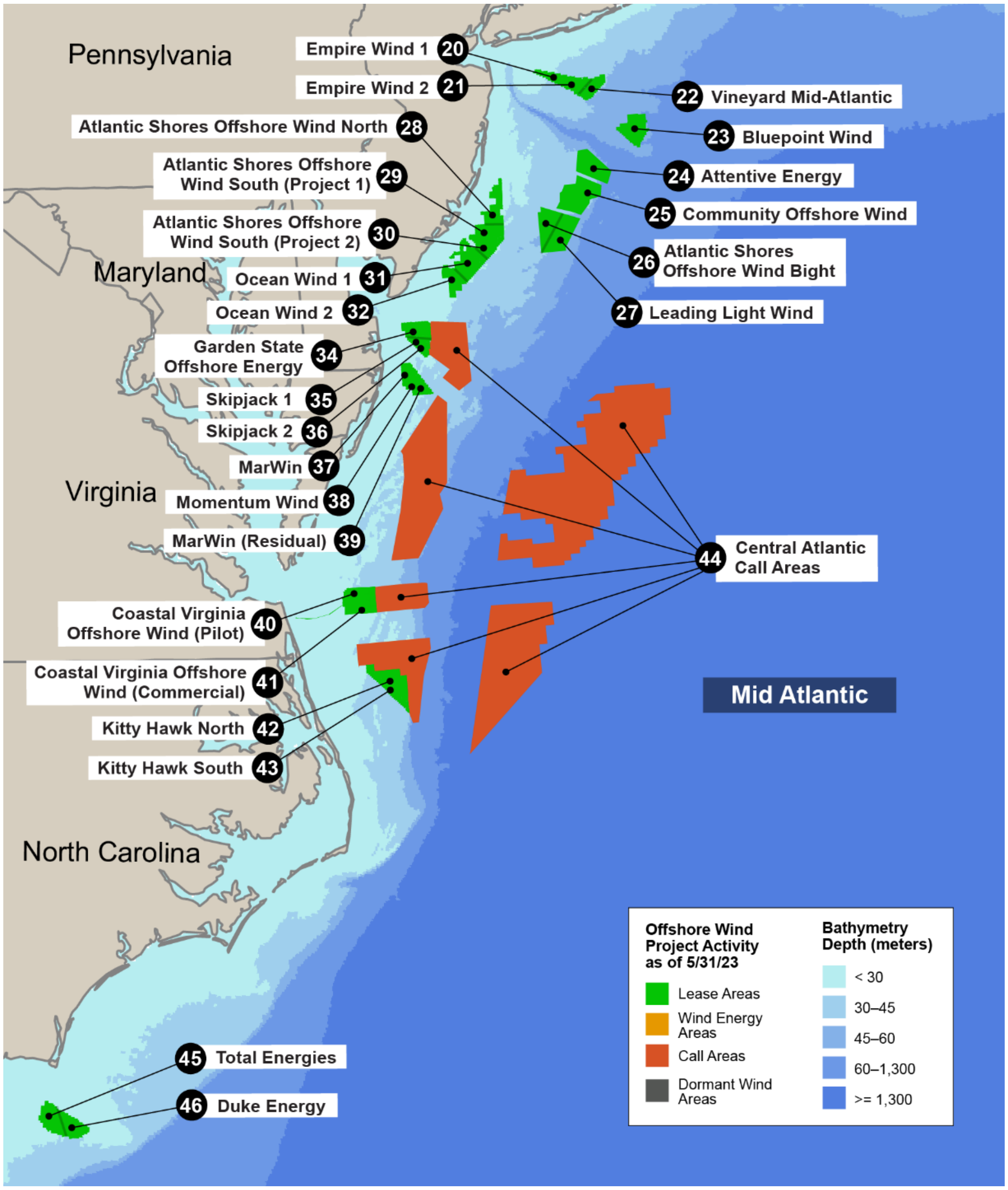

Figure 4. U.S. offshore wind energy pipeline (mid- and South Atlantic). ***Image by John Frenzl, NREL***

Table 4. U.S. Offshore Wind Energy Pipeline for Projects in the Mid- and South Atlantic

#	Location	Name	Developer	Lease Area	Offtake Agreement	Estimated COD	Current Status	Capacity (MW)	Potential POI Location
20	NY	Empire Wind 1	Equinor Wind US/BP	OCS-A 0512	OREC–NY	2026	Permitting	816	ConEd Gowanus
21	NY	Empire Wind 2	Equinor Wind US/BP	OCS-A 0512	OREC–NY	2027	Permitting	1,260	Oceanside
22	NY/New Jersey (NJ)	Vineyard Mid-Atlantic	Avangrid	OCS-A 0544	TBD	TBD	Site Control	697	TBD
23	NY/NJ	Bluepoint Wind	EDPR/ENGIE	OCS-A 0537	TBD	TBD	Site Control	1,158	TBD
24	NY/NJ	Attentive Energy	Total Energies	OCS-A 0538	TBD	TBD	Site Control	1,365	TBD
25	NY/NJ	Community Offshore Wind	RWE/National Grid	OCS-A 0539	TBD	TBD	Site Control	2,039	TBD
26	NY/NJ	Atlantic Shores Offshore Wind Bight	EDF/Shell	OCS-A 0541	TBD	TBD	Site Control	1,284	TBD
27	NY/NJ	Leading Light Wind	Invenergy	OCS-A 0542	TBD	TBD	Site Control	1,359	TBD
28	NJ	Atlantic Shores Offshore Wind North	EDF/Shell	OCS-A 0549	TBD	TBD	Site Control	1,182	TBD
29	NJ	Atlantic Shores Offshore Wind South (Project 1)	EDF/Shell	OCS-A 0499	OREC–NJ	2027	Permitting	1,510	Cardiff Substation, Larrabee Substation
30	NJ	Atlantic Shores Offshore Wind South (Project 2)	EDF/Shell	OCS-A 0499	TBD	TBD	Permitting	890	Cardiff Substation, Larrabee Substation
31	NJ	Ocean Wind 1	Ørsted	OCS-A 0498	OREC–NJ	2025	Approved	1,100	BL England, Oyster Creek Substation
32	NJ	Ocean Wind 2	Ørsted	OCS-A 0532	OREC–NJ	2028	Permitting	1,148	TBD
34	Delaware (DE)	Garden State Offshore Energy	Ørsted	OCS-A 0482	TBD	TBD	Site Control	1,080	TBD
35	DE	Skipjack 1	Ørsted	OCS-A 0519	OREC–Maryland (MD)	2026	Permitting	120	Bethany 138 kV
36	DE	Skipjack 2	Ørsted	OCS-A 0519	OREC–MD	2027	Permitting	846	Indian River 230 kV, Milford-Cartanza 230 kV, Cool Spring 230 kV
37	Maryland (MD)	MarWin	US Wind	OCS-A 0490	OREC–MD	2025	Permitting	270	Indian River 230 kV
38	MD	Momentum Wind	US Wind	OCS-A 0490	OREC–MD	2028	Permitting	809	Indian River 230 kV
39	MD	MarWin (Residual)	US Wind	OCS-A 0490	TBD	TBD	Permitting	600	Indian River 230 kV
40	Virginia (VA)	Coastal Virginia Offshore Wind (CVOW) (Pilot)	Dominion Energy	OCS-A -0497	Utility Owned–VA	2020	Installed	12	Birdneck 34.5 kV

#	Location	Name	Developer	Lease Area	Offtake Agreement	Estimated COD	Current Status	Capacity (MW)	Potential POI Location
41	VA	CVOW (Commercial)	Dominion Energy	OCS-A 0483	Utility Owned–VA	2026	Permitting	2,587	Birdneck-Landstown 230 kV, Oceana 230 kV
42	North Carolina (NC)	Kitty Hawk North	Avangrid	OCS-A 0508	TBD	TBD	Permitting	1,035	Virginia Beach Substation, Birdneck Substation, Corporate Landing Substation Site, Landstown Substation, Fentress Substation
43	NC	Kitty Hawk South	Avangrid	OCS-A 0508	TBD	TBD	Site Control	2,465	TBD
44	DE, MD, VA, NC	Central Atlantic Call Areas	N/A	N/A	N/A	N/A			TBD
45	NC	Total Energies	Total Energies	OCS-A 0545	TBD	TBD	Site Control	889	TBD
46	NC	Duke Energy	Duke Energy	OCS-A 0546	TBD	TBD	Site Control	893	TBD

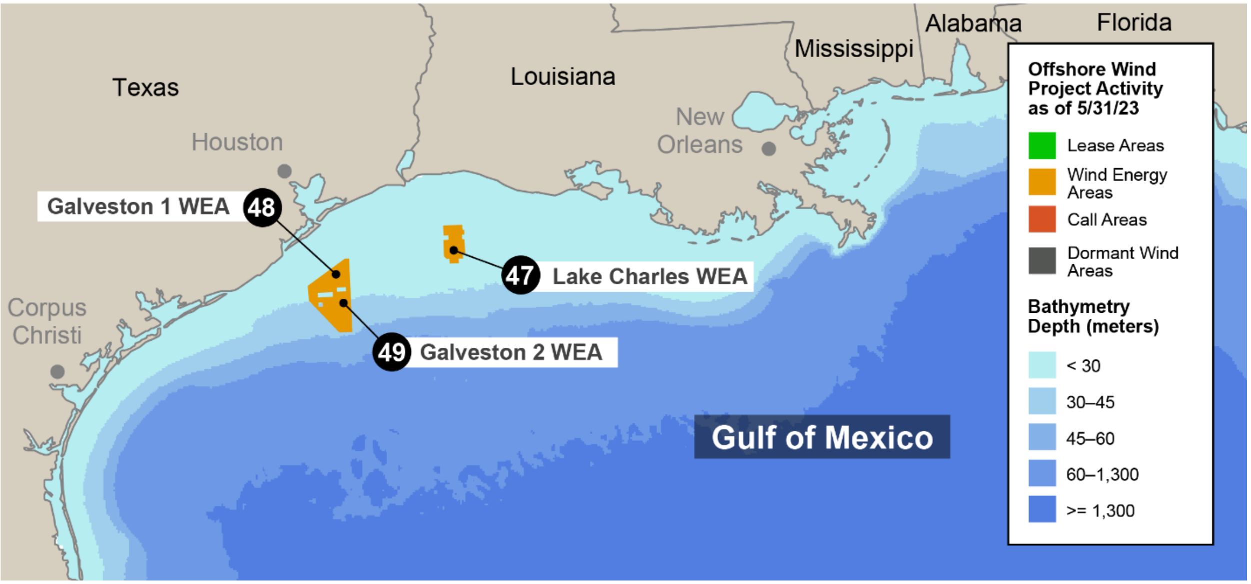

Figure 5. U.S. offshore wind energy pipeline (Gulf of Mexico). ***Image by John Frenzl, NREL***

Table 5. U.S. Offshore Wind Energy Project Pipeline (Gulf of Mexico)

#	Location	Name	Developer	Lease Area	Offtake Agreement	Estimated COD	Current Status	Capacity (MW)	Potential POI Location
47	Louisiana	Lake Charles WEA	TBD	OCS-G 37336	TBD	TBD	Planning	1,659	TBD
48	Texas (TX)	Galveston 1 WEA	TBD	OCS-G 37334	TBD	TBD	Planning	1,659	TBD
49	TX	Galveston 2 WEA	TBD	OCS-G 37335	TBD	TBD	Planning	1,567	TBD

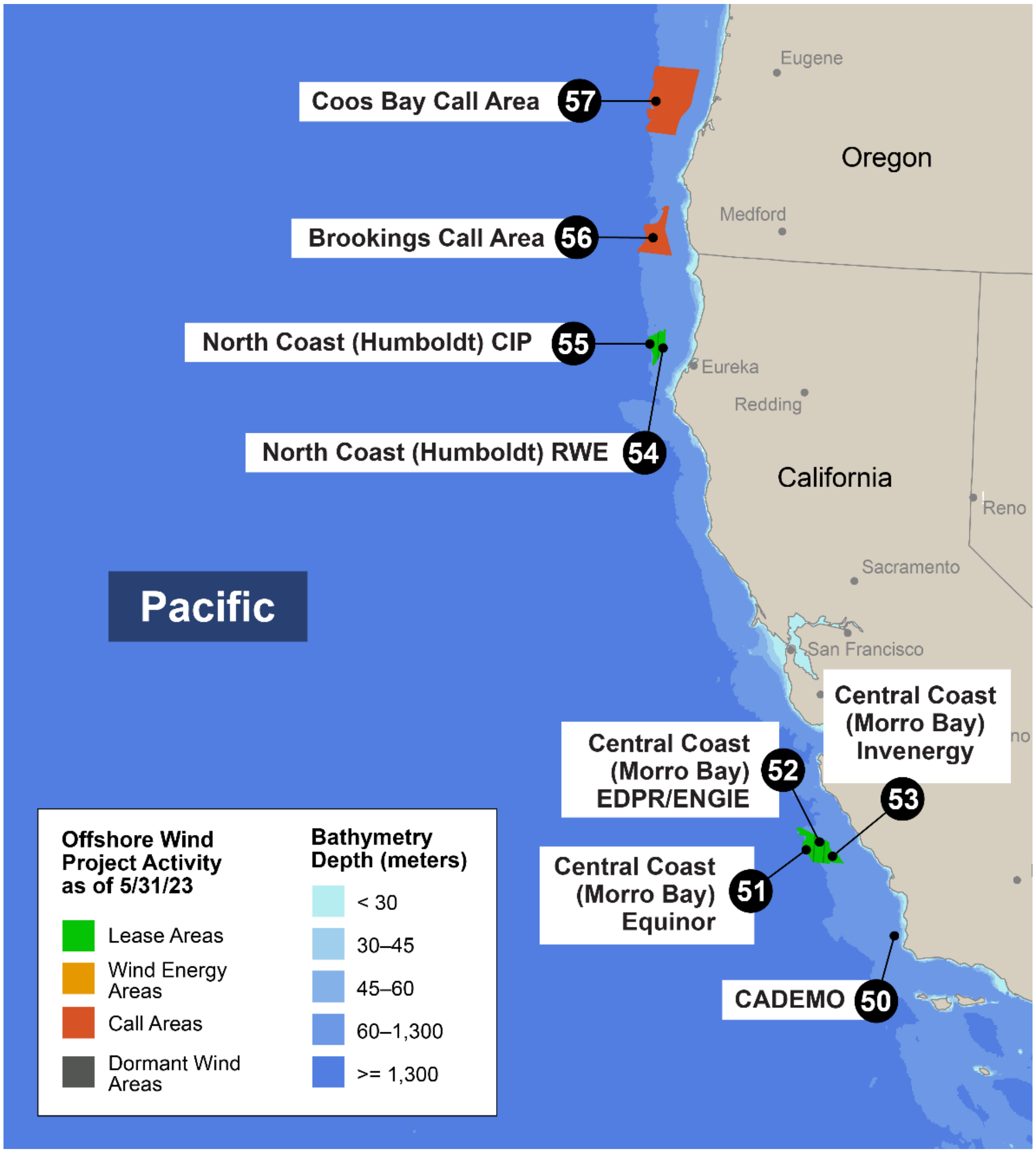

Figure 6. U.S. offshore wind energy pipeline (Pacific). ***Image by John Frenzl, NREL***

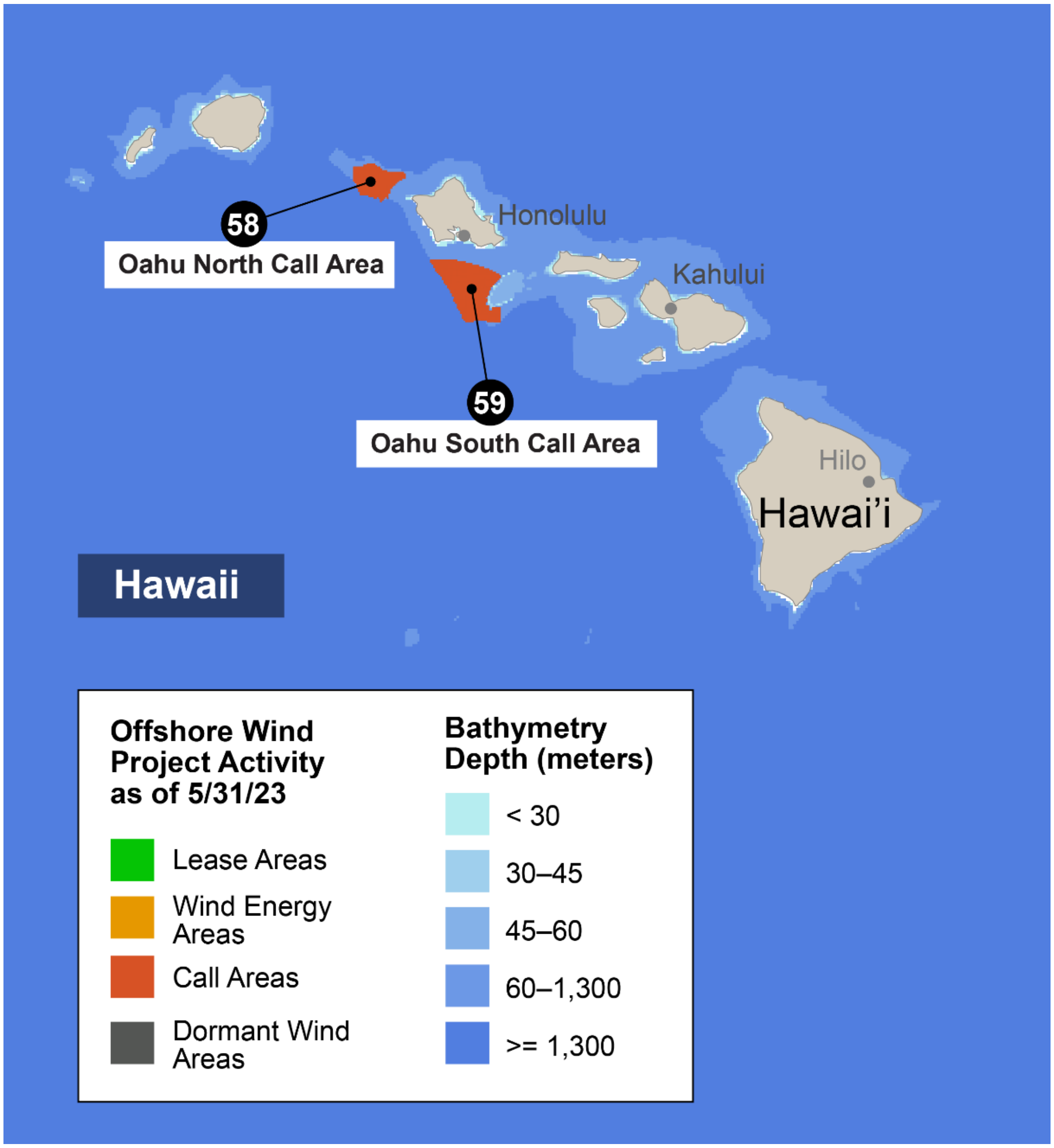

Figure 7. U.S. offshore wind energy pipeline (Hawaii). ***Image by John Frenzl, NREL***

Table 6. U.S. Offshore Wind Energy Project Pipeline (Pacific)

#	Location	Name	Developer	Lease Area	Offtake Agreement	Estimated COD	Current Status	Capacity (MW)	Potential POI Location
50	California (CA)	CADEMO	Floventis (Cierco/SBM)	Proposed State Lease	TBD	TBD	Permitting	60	TBD
51	CA	Central Coast (Morro Bay) Equinor	Equinor	OCS-P 0563	TBD	TBD	Site Control	1,296	TBD
52	CA	Central Coast (Morro Bay) EDPR/ENGIE	EDPR/ENGIE	OCS-P 0564	TBD	TBD	Site Control	1,302	TBD
53	CA	Central Coast (Morro Bay) Invenergy	Invenergy	OCS-P 0565	TBD	TBD	Site Control	1,302	TBD
54	CA	North Coast (Humboldt) RWE	RWE	OCS-P 0561	TBD	TBD	Site Control	1,025	TBD
55	CA	North Coast (Humboldt) CIP	CIP	OCS-P 0562	TBD	TBD	Site Control	1,117	TBD
56	Oregon (OR)	Brookings Call Area	N/A	N/A	N/A	N/A	N/A	N/A	N/A
57	OR	Coos Bay Call Area	N/A	N/A	N/A	N/A	N/A	N/A	N/A
58	Hawaii (HI)	Oahu North Call Area	N/A	N/A	N/A	N/A	N/A	N/A	N/A

2.3.2 U.S. Offshore Wind Energy Market Forecasts to 2032

Figure 8 shows two independent forecasts for offshore wind energy deployment in the United States through 2032. The chart illustrates the degree of expected market growth. Variability between the two forecasts may be associated with interpretations of the year, size, location, and likelihood of future projects.

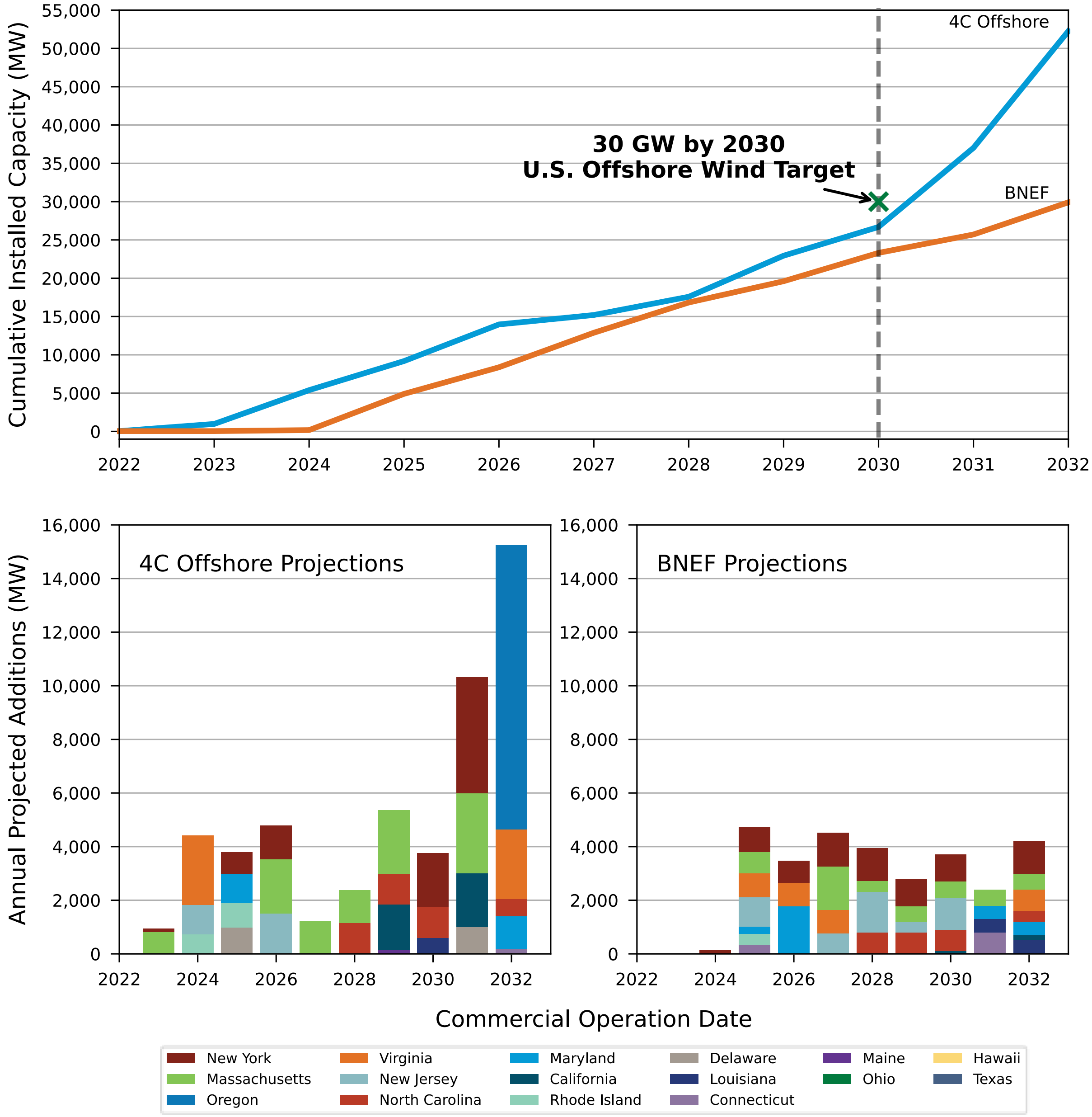

Figure 8. Industry offshore wind energy U.S. development projections through 2032

Figure 8 illustrates forecasts[17] developed by BNEF (2022a) and 4C Offshore (2023), which show U.S. offshore wind energy deployment could cumulatively reach 30 GW or 52 GW by the end of 2032, respectively. Note that the forecasts show lower levels of deployment out to 2030 relative to the *Offshore Wind Market Report: 2022 Edition* forecasts, due to recent project and offtake execution delays as well as potential perceived port, manufacturing, and transmission bottlenecks. However, in 2023, 4C Offshore forecast increases sharply after 2030 to 52 GW by 2032, which reflects guidance from the U.S. Treasury on IRA tax credits, regulatory efficiency, expected maturation of the U.S. supply chain as described in Shields et al. (2023), increased port and transmission infrastructure, and enhanced support from states and the federal government to achieve their ambitious offshore wind targets. The actual size and speed of U.S. offshore wind build-out 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 15-MW-class wind turbines, and sustained market demand.

These forecasts predict that most near-term offshore wind energy deployment will occur on the East Coast in states with existing offshore wind energy procurement goals. However, for the first time, both forecasts assume project development in the Gulf of Mexico and floating offshore wind deployment in Maine and California. 4C also predicts significant floating deployment in Oregon in 2032.

2.4 Regulatory Activity

In 2023, BOEM and the Bureau of Safety and Environmental Enforcement (BSEE), the primary U.S. regulators responsible for renewable energy projects on the OCS, are undergoing significant restructuring and reform activities.

In 2011, after the restructuring of the Minerals Management Service, BOEM was assigned responsibility by the U.S. Department of the Interior (DOI) for regulating offshore wind on the U.S. OCS. In December 2020, DOI determined that offshore wind activity had reached a threshold that justified transferring the inspection and enforcement functions over to BSEE. This split was made final on January 12, 2023, transferring applicable regulations from BOEM to BSEE pertaining to safety, environmental oversight, and enforcement. The results of the split redistributed some of the existing regulations found in 30 CFR part 585 to BSEE under 30 CFR part 285. As a result, the U.S. offshore wind energy industry will see a larger presence from BSEE in the future as projects move into the operational phase. BOEM will retain the primary responsibility for leasing, permitting, and project approvals (BSEE 2023).

In addition, DOI determined that BOEM had acquired enough experience to warrant updates to the 13-year-old regulations. This experience includes conducting 11 auctions resulting in the sale of 27 offshore wind leases, the review of over a dozen COPs, and at least three facility design

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[17] Note that the forecasts are not constrained to U.S. regions or states that have existing lease areas. For example, 4C Offshore includes expected deployments in Oregon where BOEM has only designated Call Areas and has yet to create wind energy areas or propose to hold a competitive auction.

reports and fabrication and installation reports. DOI proposed modifications that modernize the existing 585/285 rules based on feedback obtained from stakeholders that include:

- Proposals for incremental funding of decommissioning accounts
- More flexible requirements for submitting geophysical and geotechnical surveys
- Streamlined approval of meteorological buoys
- Revised project verification procedures
- Reform of BOEM's renewable energy auction process
- Greater clarity regarding safety requirements.

The public comment period for this proposed modification to the offshore wind regulations ended on May 1, 2023 (BOEM 2023d).

Also, in September 2022, new guidance was published by the American National Standards Institute (ANSI) and ACP, in a document titled ANSI/ACP OCRP-1-2022, *ACP Offshore Compliance Recommended Practices (OCRP) Edition 2*, which was written under an industry-based standards initiative to provide primary guidance for the development of offshore wind energy on the OCS. The OCRP-1-2022 document points to more than 200 existing industry standards and guidelines covering all stages of offshore wind plant development—including design, manufacturing, and fabrication; transportation and installation; operations and in-service inspections; and life cycle planning (ANSI/ACP 2022).

In 2022, the industry also saw the continuation of bidding credit schemes applied to the leasing process, which began with Carolina Long Bay in May 2022 but continued with the California lease auctions.

In 2022, BOEM also added a new step to the WEA identification process by issuing draft Call Areas and requesting expressions for commercial interest prior to releasing final Call Areas.

2.4.1 Federal Permitting Status of U.S. Lease Areas

Plans approved by BOEM to develop a lease area are necessary for building an offshore wind energy project in the United States. In alignment with the timeline laid out in the "Offshore Wind Leasing Path Forward 2021–2025," BOEM has advanced its site designation and competitive leasing activities across the United States in 2022.

Federal permitting in the United States involves several major steps after a lease area is acquired. First, BOEM reviews and approves the 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 Record of Decision for the final Environmental Impact Statement. If BOEM does not object to a developer's facility design report and fabrication and installation report that they need to submit after their COP is approved, the developer may begin to fabricate and install the approved facilities. Besides COP approval, developers also need to advance through other independent federal agencies (e.g., National Oceanic and Atmospheric Administration, U.S.

Army Corps of Engineers, Federal Aviation Administration, U.S. Coast Guard [USCG]), state, and local reviews. Table 7 describes the current federal permitting status for projects in each lease area in the order that the leases were issued.

Table 7. U.S. Federal Offshore Wind Energy Permitting Status as of May 31, 2023

Location	Lease Number	Area (km²)	Date Issued	Project(s) Being Developed in Lease Area	Status
DE	OCS-A 0482	284	2012	Garden State Offshore Wind	Site assessment plan (SAP) approved (COP not submitted)
RI/MA	OCS-A 0486		2013	Revolution Wind	COP submitted – Draft Environmental Impact Statement (DEIS)
RI/MA	OCS-A 0 517	55	2013	South Fork Wind Farm	Record of Decision (ROD) approved – under construction
RI/MA	OCS-A 0487	445	2013	Sunrise Wind 1	COP submitted – DEIS
VA	OCS-A 0483	456	2013	CVOW (Commercial)	COP submitted – DEIS
MD	OCS-A 0490	323	2014	MarWin Momentum Wind MarWin (Residual)	COP submitted – Notice of Intent (NOI) for EIS
MA	OCS-A 0500	759	2015	Bay State Wind	COP submitted
MA	OCS-A 0501	264	2015	Vineyard Wind 1	ROD approved – under construction
MA	OCS-A 0534	411	2015	New England Wind (Commonwealth Wind) New England Wind (Park City Wind)	COP submitted – DEIS
NJ	OCS-A 0498	306	2016	Ocean Wind 1	COP submitted – final EIS
NJ	OCS-A 0532	344	2016	Ocean Wind 2	COP not submitted
NJ	OCS-A 0499	348	2016	Atlantic Shores Offshore Wind South (Project 1) Atlantic Shores Offshore Wind South (Project 2)	COP submitted – DEIS
NJ	OCS-A 0549	394	2016	Atlantic Shores Offshore Wind North	COP submitted
NY	OCS-A 0512	321	2017	Empire Wind 1 Empire Wind 2	COP submitted – DEIS
NC	OCS-A 508	495	2017	Kitty Hawk	COP submitted – NOI for EIS
DE	OCS-A 519	107	2018	Skipjack 1 Skipjack 2	COP not submitted
MA	OCS-A 0520	521	2019	Beacon Wind 1 Beacon Wind (Residual)	COP submitted
MA	OCS-A 0521	516	2019	SouthCoast Wind (Mayflower Wind 1) SouthCoast Wind (Mayflower Wind 2) SouthCoast Wind (Residual)	COP submitted – DEIS

Location	Lease Number	Area (km²)	Date Issued	Project(s) Being Developed in Lease Area	Status
MA	OCS-A 0522	536	2019	Vineyard Northeast	SAP approved (COP not submitted)
NY/NJ	OCS-A 0537	289	2022	Bluepoint Wind	SAP or COP not submitted
NY/NJ	OCS-A 0538	341	2022	Attentive Energy	SAP or COP not submitted
NY/NJ	OCS-A 0539	510	2022	Community Offshore Wind	SAP or COP not submitted
NY/NJ	OCS-A 0541	321	2022	Atlantic Shores Offshore Wind Bight	SAP or COP not submitted
NY/NJ	OCS-A 0542	340	2022	Leading Light Wind	SAP or COP not submitted
NY/NJ	OCS-A 0544	174	2022	Vineyard Mid-Atlantic	SAP or COP not submitted
NC	OCS-A 0545	222	2022	Total Energies (Carolina Long Bay)	SAP or COP not submitted
NC	OCS-A 0546	223	2022	Duke Energy (Carolina Long Bay)	SAP or COP not submitted
CA	OCS-P 0561	256	2022	North Coast (Humboldt) RWE	SAP or COP not submitted
CA	OCS-P 0562	279	2022	North Coast (Humboldt) CIP	SAP or COP not submitted
CA	OCS-P 0563	324	2022	Central Coast (Morro Bay) Equinor	SAP or COP not submitted
CA	OCS-P 0564	325	2022	Central Coast (Morro Bay) EDPR/ENGIE	SAP or COP not submitted
CA	OCS-P 0565	325	2022	Central Coast (Morro Bay) Invenergy	SAP or COP not submitted

2.4.2 Lease Activity

BOEM conducted competitive auctions for 13 lease areas in 2022. In March 2022, BOEM awarded six lease areas off the New York Bight for a total price of $4.37 billion, which collectively can support an estimated 7,902 MW of capacity (BOEM 2022a). That auction was covered in the 2022 edition of this report (Musial et al. 2022). In May 2022, BOEM auctioned two lease areas in the Carolina Long Bay (see Table 8) for a total of over $315 million and a combined capacity of 1,782 MW (BOEM 2022b). The two lease areas are near the North and South Carolina border and comprise 445 km^2.

Table 8. Carolina Long Bay Auction Results

Lease Number	Developer	Area (km²)	Capacity (MW)	Price	Price per km²
OCS-A 0545	Total Energies	223	889	$155,000,00	$720,721
OCS-A 0546	Duke Energy	222	893	$160,800,00	$695,067

In December 2022, five lease areas (Figure 9, Table 9) were awarded on the OCS off California that could support an estimated 6,042 MW of capacity (BOEM 2022c). Two lease areas off Humboldt Bay were awarded to RWE Offshore Wind for $157,700,000 and to California North Floating (CIP/RWE) for $173,800,000. In addition, three areas were awarded off Morro Bay to Equinor Wind US for $130,000,000 to Central California Offshore Wind (EDPR/ENGIE) for $150,300,000, and to Invenergy California Offshore for $145,300,000.

Table 9. California Auction Results

Lease Number	Location	Developer	Area (km²)	Capacity (MW)	Price	Price per km²
OCS-A 0561	Humboldt	RWE Offshore Wind	256	1,025	$157,700,000	$616,016
OCS-A 0562	Humboldt	California North Floating (CIP)	279	1,117	$173,800,000	$622,939
OCS-A 0563	Morro Bay	Equinor Wind US	324	1,296	$130,000,000	$401,235
OCS-A 0564	Morro Bay	Central California Offshore Wind (EDPR/ENGIE)	325	1,302	$150,300,000	$461,836
OCS-A 0565	Morro Bay	Invenergy California Offshore	325	1,302	$145,300,000	$447,077

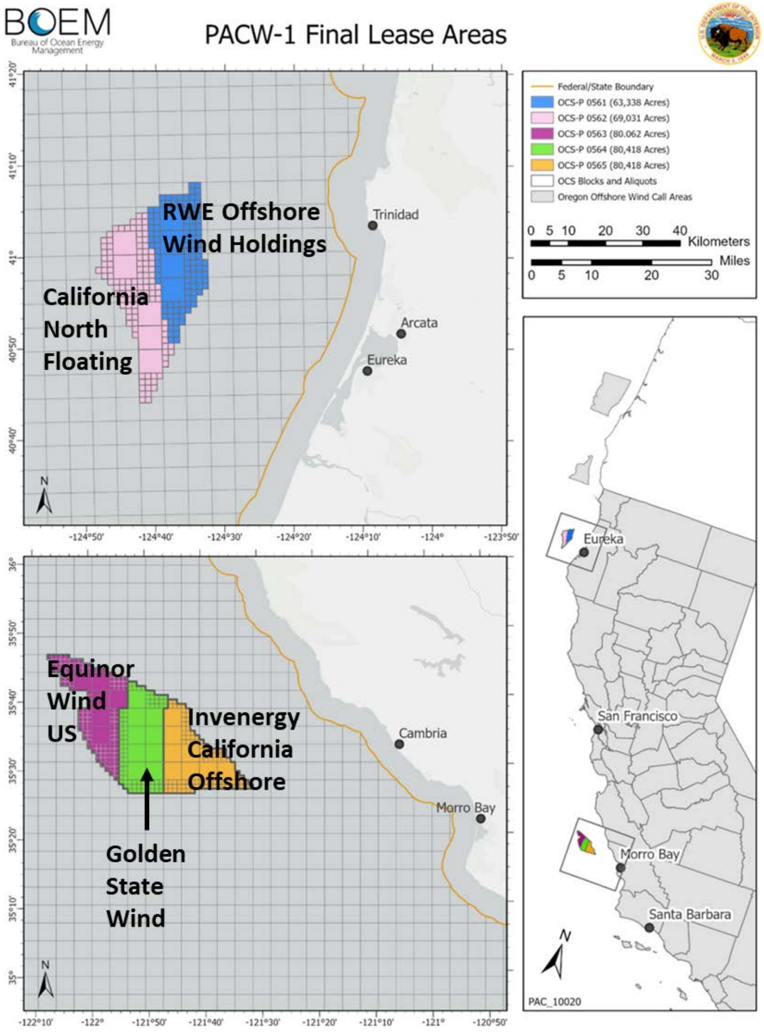

Figure 9. California lease areas. ***Image adapted from BOEM***

Figure 10 and Table 10 illustrate how winning bid prices for U.S. offshore wind lease areas have increased exponentially over time. The data show the escalation of price per square kilometer (plotted on a log scale). They also show a strong correlation of increasing price with the proximity of the lease sale to states with aggressive procurement goals and contracted offtake mechanisms. These state procurement policies give developers increased certainty regarding the demand for an offshore wind energy project's power, and an expectation for reasonable compensation via a power purchase agreement (PPA) or OREC. A detailed analysis of how these higher lease prices would impact PPA prices or consumer electric prices in the states' competitive procurement processes has not yet been done.

The data include the most recent auction prices for the five lease areas in California in December 2022, which were lower than the two previous auctions in the New York Bight and Carolina Long Bay. The lower auction prices were most likely driven by the perceived risk of developing nascent floating offshore wind technology in deep water and the lack of clear offtake or mandated procurement mechanisms, as well as limited port and transmission infrastructure.

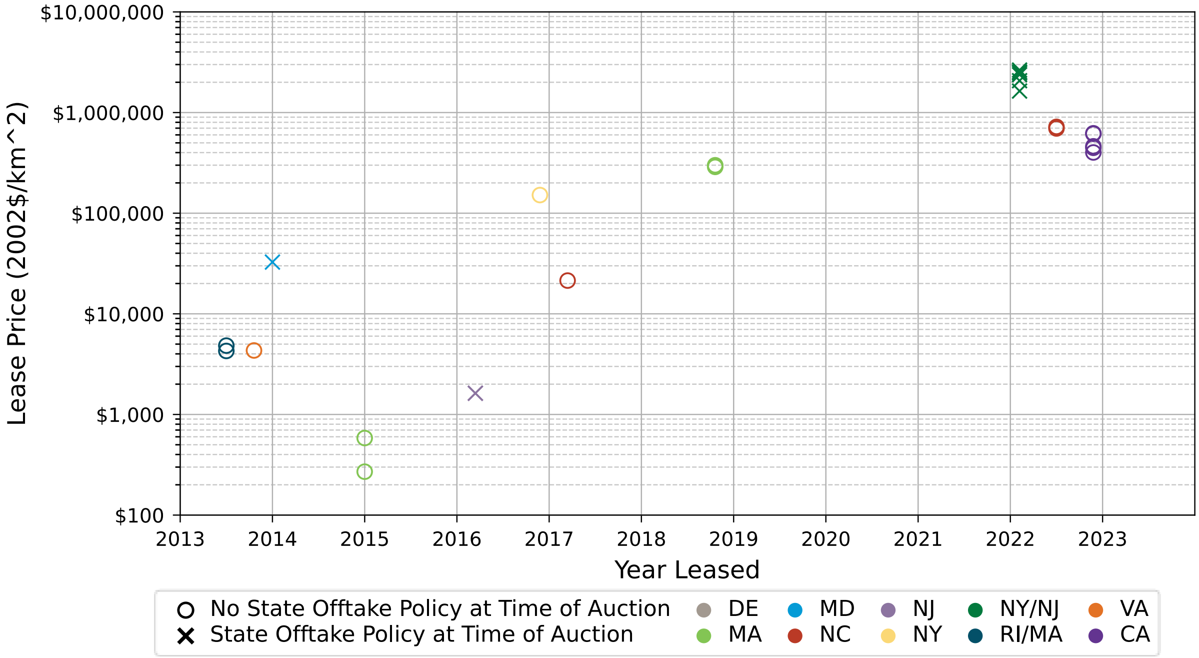

Figure 10. U.S. offshore wind energy lease prices

Table 10. U.S. Offshore Wind Energy Lease Prices in Order Sold

Year	State	Lease	Lease Price 2022$	$/km²	Substructure
2012	DE	OCS-A 0482/OCS-A 0519	$ -	$-	Fixed
2013	RI/MA	OCS-A 0486/OCS-A 0517	$ 1,903,181	$ 4,830	Fixed
2013	RI/MA	OCS-A 0487	$ 1,903,181	$ 4,277	Fixed
2013	VA	OCS-A 0483/OCS-A 0497	$ 1,971,276	$ 4,323	Fixed
2014	MD	OCS-A 0490	$ 10,553,535	$ 32,673	Fixed
2015	MA	OCS-A 0500	$ 341,474	$ 583	Fixed
2015	MA	OCS-A 0501/OCS-A 0534	$ 182,336	$ 270	Fixed
2016	NJ	OCS-A 0498/OCA-A 0532	$ 1,054,690	$ 1,625	Fixed
2016	NJ	OCS-A 0499	$ 1,205,011	$ 1,624	Fixed
2016	NY	OCS-A 0512	$ 48,611,290	$ 151,437	Fixed
2017	NC	OCS-A 0508	$ 10,592,835	$ 21,400	Fixed
2018	MA	OCS-A 0520	$ 154,525,000	$ 296,593	Fixed
2018	MA	OCS-A 0521	$ 154,525,000	$ 299,467	Fixed
2018	MA	OCS-A 0522	$ 154,639,500	$ 288,507	Fixed
2022	NY/NJ	OCS-A 0537	$ 765,000,000	$ 2,643,039	Fixed
2022	NY/NJ	OCS-A 0538	$ 795,000,000	$ 2,472,980	Fixed
2022	NY/NJ	OCS-A 0539	$ 1,100,000,000	$ 2,378,569	Fixed
2022	NY/NJ	OCS-A 0541	$ 780,000,000	$ 2,531,449	Fixed
2022	NY/NJ	OCS-A 0542	$ 645,000,000	$ 2,072,760	Fixed
2022	NY/NJ	OCS-A 0544	$ 285,000,000	$ 1,635,660	Fixed
2022	NC	OCS-A 0545	$ 160,000,000	$ 720,721	Fixed
2022	NC	OCS-A 0546	$ 155,000,000	$ 695,067	Fixed
2022	CA	OCS-P 0561	$ 157,700,000	$ 615,247	Floating
2022	CA	OCS-P 0562	$ 173,800,000	$ 622,139	Floating
2022	CA	OCS-P 0563	$ 130,000,000	$ 401,235	Floating
2022	CA	OCS-P 0564	$ 150,300,000	$ 461,836	Floating
2022	CA	OCS-P 0565	$ 145,300,000	$ 446,472	Floating

On February 4, 2023, BOEM published a Proposed Sales Notice for three WEAs (Figure 11, Table 11) in the Gulf of Mexico that could support 4,885 MW of capacity (BOEM 2023c). One wind energy area, OCS-G 37334 (415 km^2), is located off Lake Charles, Louisiana. The other two are located off Galveston, Texas, OCS-G37335 (415 km^2) and OCS-G 37336 (392 km^2). A final sales notice was announced July 20, 2023, with an associated competitive auction scheduled in August 2023.

Table 11. Gulf of Mexico Lease Areas[18]

Lease Number	Location	Area (km²)	Capacity (MW)
OCS-G 37334	Lake Charles	415	1,659
OCS-G 37335	Galveston 1	415	1,659
OCS-G 37336	Galveston 2	392	1,567

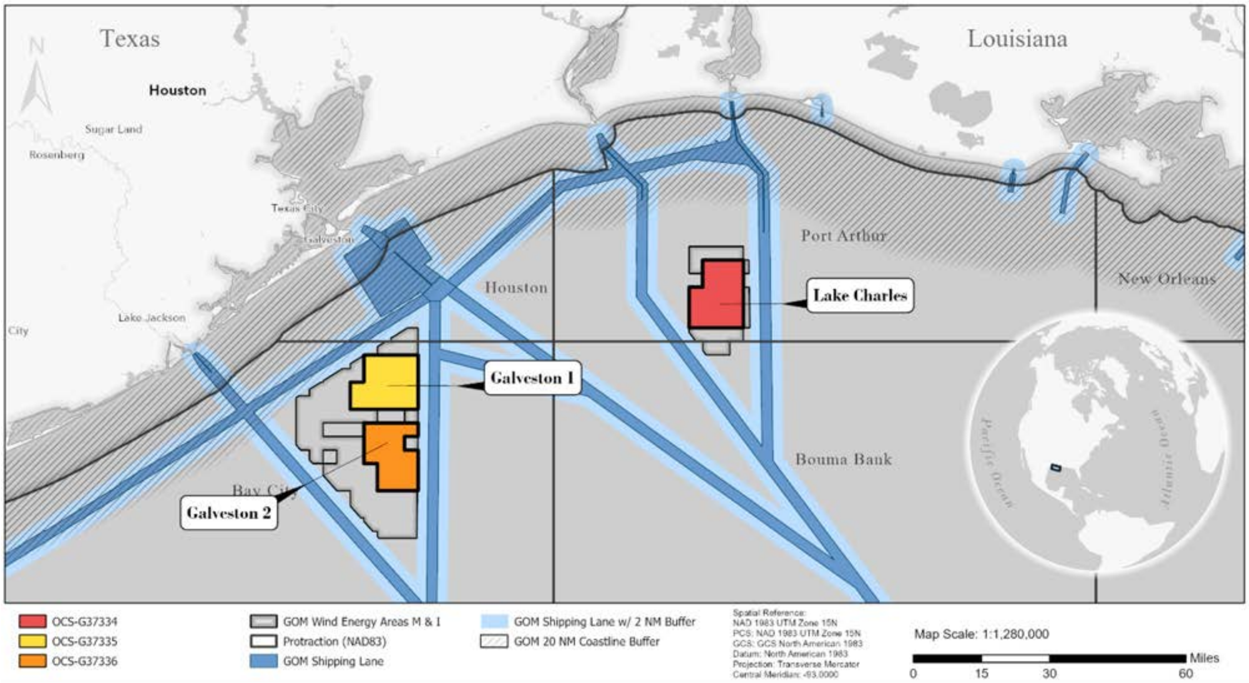

Figure 11. Three Gulf of Mexico lease areas. ***Image from BOEM***

On January19, 2023, BOEM announced its “Determination of No Competitive Interest” for a research lease proposed by the state of Maine. The current boundaries of the research lease are shown in Figure 12, but if approved, the final lease must remain within the larger area (Figure 13) defined by the request for competitive interest (RFCI) (BOEM 2023b). BOEM’s determination means that it will move forward to process the state’s research application, which could be used to inform any future commercial offshore wind energy development in the Gulf of Maine. The determination of no competitive interest in the larger RFCI area does not guarantee that the state of Maine will receive a research lease. The next steps for processing the research application include BOEM publishing their findings in the Federal Register and initiating an environmental review of potential impacts from offshore wind leasing activities associated with the research lease.

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[18] Note that the lease areas are only a portion of the wind energy areas shown in Figure 11.

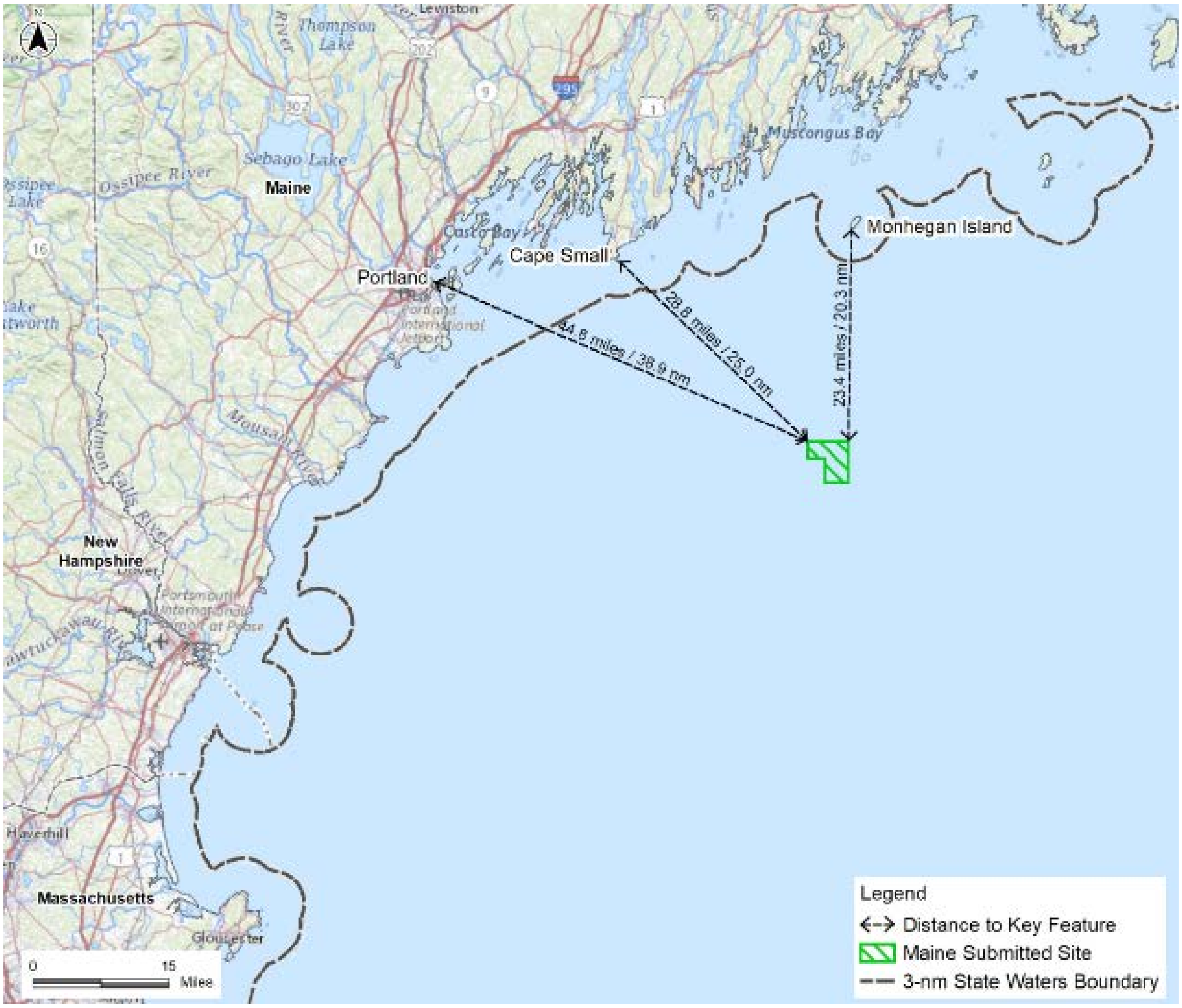

Figure 12. Maine Research Array requested lease area. ***Image from the state of Maine***

2.4.3 New Site Identification

BOEM publishes Calls for Information and Nominations (calls) 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 2021, BOEM has identified new areas, refined existing areas, and/or developed previously identified Call Areas. Table 12 lists all the active offshore wind Call Areas on the OCS.

Table 12. BOEM Call Areas on U.S. Outer Continental Shelf

State	Name	Year Designated	Area (km^2)	Likely Substructure Type
HI	O’ahu North Call Area	2016	1,331	Floating
HI	O’ahu South Call Area	2016	626	Floating
OR	Brookings Call Area	2022	1,160	Floating
OR	Coos Bay Call Area	2022	3,528	Floating
ME	Gulf of Maine Call Area	2022	39,677	Floating
DE/MD/VA/NC	Central Atlantic Draft WEA A	2022	710	Fixed
DE/MD/VA/NC	Central Atlantic Draft WEA B1	2022	128	Fixed
DE/MD/VA/NC	Central Atlantic Draft WEA B2	2022	1,176	Fixed
DE/MD/VA/NC	Central Atlantic Draft WEA C	2022	741	Fixed
DE/MD/VA/NC	Central Atlantic Draft WEA D	2022	849	Fixed
DE/MD/VA/NC	Central Atlantic Draft WEA E1	2022	1,904	Floating
DE/MD/VA/NC	Central Atlantic Draft WEA E2	2022	1,392	Floating
DE/MD/VA/NC	Central Atlantic Draft WEA F	2022	170	Floating

Figure 13 shows the Call Area for the Gulf of Maine issued in April 2023. In August 2022, DOI announced a Request for Interest to determine if there was commercial interest from wind energy developers within a larger area comprising about 13.7 million acres, or about 21,400 square miles. After considering the information gained from public comment, the offshore wind energy industry, and experts at the National Oceanic and Atmospheric Administration’s National Center for Coastal and Ocean Science, the draft Call Area was reduced by about 27% to 9.9 million acres or almost 15,500 square miles. In April 2023, BOEM published the Gulf of Maine Call Area, which comprises 9,804,420 acres (39,677 km^2) (BOEM 2023b; Musial et al. 2023b). This area is shaded green in Figure 13. It extends as far south as Cape Cod and as far from shore as 118 nautical miles (nmi).

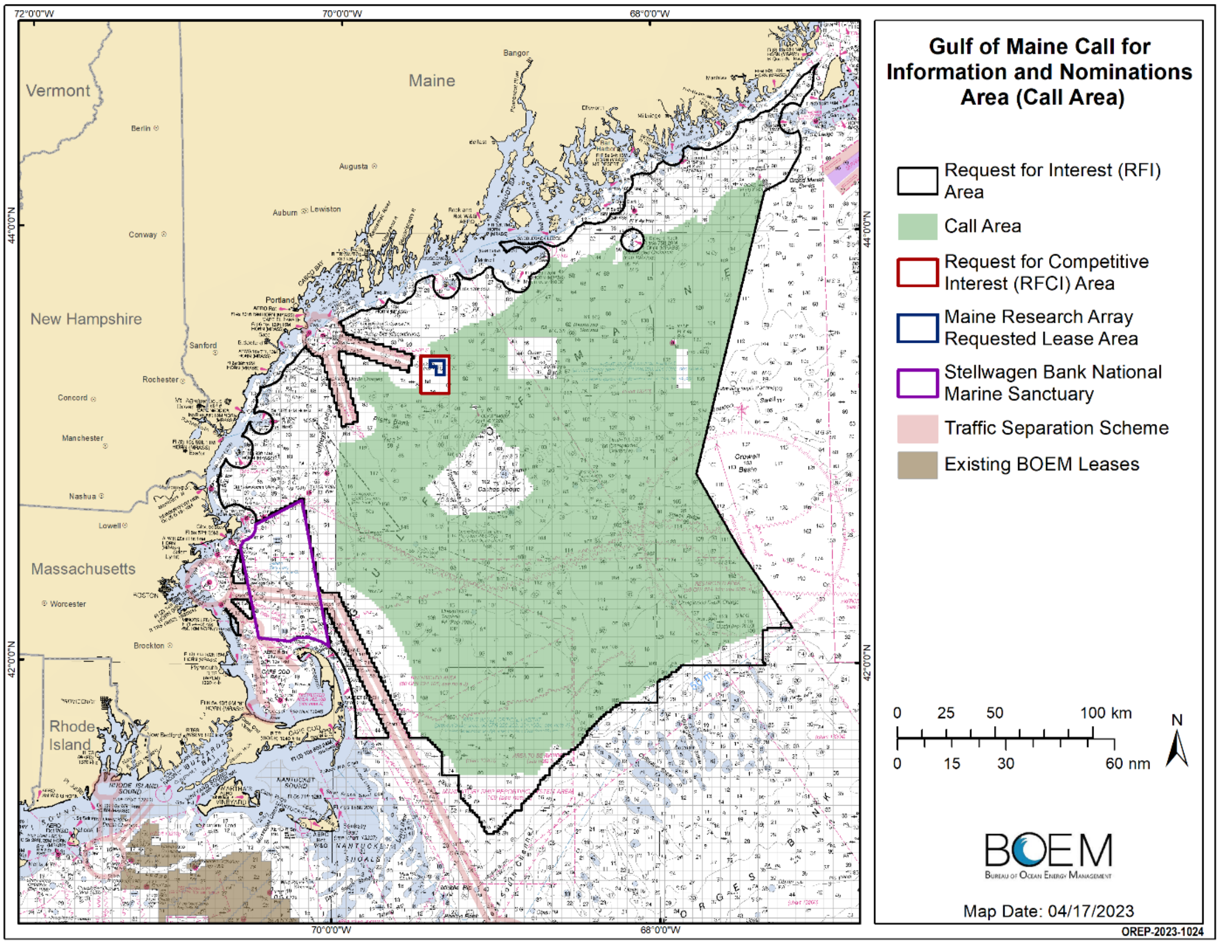

Figure 13. Gulf of Maine Call Area. ***Image from BOEM***

Figure 14 shows the draft WEAs in the central Atlantic that are being considered for near-term leasing. Some of the primary sites shown in blue are where projects are less likely to be conflicted with co-use issues (e.g., recent U.S. Department of Defense and USCG challenges). Secondary sites are shown in yellow and are still being considered. Note that several draft WEAs are farther from shore over ultradeep water near 2,600 meters (m). These sites may have unique technical challenges (water depth) that require further evaluation to lower project risk.

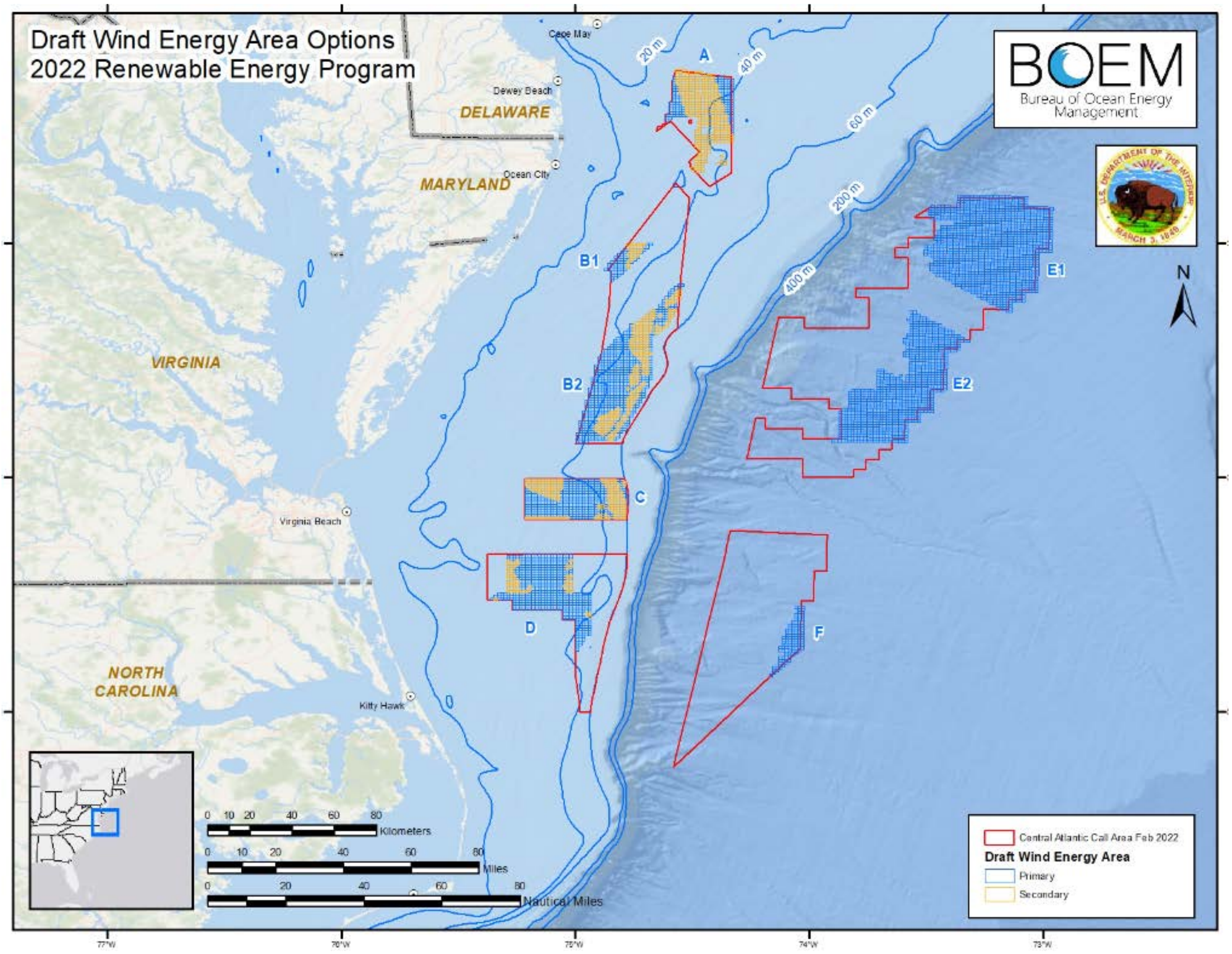

Figure 14. Draft WEAs in the Central Atlantic region. ***Image from BOEM***

2.5 U.S. Offshore Wind Project Power Contracts

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, seven states have unique procurement targets but use different mechanisms to procure an individual project's electrical generation from a developer such as PPAs, ORECs, or direct utility ownership. As of May 31, 2023, 27 offtake agreements have been signed, which are associated with 17,567 MW of contracted capacity. These agreements are detailed in Table 13.

Table 13. Power Offtake Contracts for U.S. Offshore Wind Energy Projects

Project	Year Awarded	Size (MW)	Duration (Years)	Offtake Type	Regulator Approved	Levelized Nominal Price ($/megawatt-hour [MWh])	Inflation-Adjusted Price (2023$/MWh)	Power Delivery Year
Block Island Wind Farm	2010	30	20	PPA	Yes	244	324.5	2016
South Fork Wind Farm	2017	132	20	PPA	Yes	141	159.3	2024
MarWin	2017	270	20	MD OREC	Yes	131.9	153	2026
Skipjack 1	2017	120	20	MD OREC	Yes	131.9	153	2026
Vineyard Wind 1	2018	400	20	PPA	Yes	74	85.8	2024
Vineyard Wind 1	2018	400	20	PPA	Yes	65	75.4	2024
CVOW (Pilot)	2018	12	12	Utility Owned	Yes	780	904.8	2020
Revolution Wind	2018	400	20	PPA	Yes	99.5	115.4	2026
Revolution Wind	2018	200	20	PPA	Yes	98.4	114.1	2026
Revolution Wind	2019	104	20	PPA	Yes	98.4	114.1	2026
Ocean Wind 1	2019	1,100	20	NJ OREC	Yes	116.8	135.5	2025
Empire Wind 1	2019	816	25	NY OREC	Yes	99	114.8	2026
Sunrise Wind 1	2019	924	25	NY OREC	Yes	110	127.6	2026
New England Aqua Ventus I	2019	12	20	PPA	Yes	Undisclosed	N/A	2024
SouthCoast Wind 1a	2020	400	20	PPA	Yes	58.4	63.7	2028
SouthCoast Wind 1a	2020	404	20	PPA	Yes	58.4	63.7	2029
Icebreaker	2020	21	20	PPA	Yes	Undisclosed	N/A	2024
New England Wind 1a	2021	800	20	PPA	Yes	79.8	85.4	2027
Empire Wind 2	2021	1,260	25	NY OREC	Yes	107.5	115	2027
Beacon Wind 1	2021	1,230	25	NY OREC	Yes	118	126.3	2029
Ocean Wind 2	2021	1,148	20	NJ OREC	Yes	42.3	45.3	2028
Atlantic Shores Offshore Wind South Project 1	2021	1,510	20	NJ OREC	Yes	58.8	62.9	2027
Skipjack 2	2021	846	20	MD OREC	Yes	71.6	76.6	2027

Project	Year Awarded	Size (MW)	Duration (Years)	Offtake Type	Regulator Approved	Levelized Nominal Price ($/megawatt-hour [MWh])	Inflation-Adjusted Price (2023$/MWh)	Power Delivery Year
Momentum Wind	2021	809	20	MD OREC	Yes	54.17	57.9	2028
SouthCoast Wind 1b	2021	400	20	PPA	Yes	77	82.4	2027
New England Wind 1b	2021	1,232	20	PPA	Yes	72	77	2027
CVOW (Commercial)	2021	2,587	20	Utility Owned	Yes	87	93.1	2026

2.6 Federal and State Policies Activities

The growth and maturation of the U.S. offshore wind energy industry continues to be driven by policy changes at the state and federal levels. Together, these policies support the growth of the U.S. pipeline, the identification of new lease areas for future development, the pace at which power offtake contracts are awarded, and the tax credits for offshore wind energy projects and other incentives for port, manufacturing, and supply chain investments.

2.6.1 Federal Policy

In 2021, the Biden administration set an ambitious federal goal of deploying 30 GW of offshore wind energy by 2030, which it augmented in fall 2022 with a complementary goal of deploying 15 GW of floating offshore wind by 2035 (DOI 2022). The IRA and Bipartisan Infrastructure Law passed by Congress help support these goals, providing significant incentives to increase the economic attractiveness of offshore wind energy projects, catalyze domestic manufacturing and supply chain investments, and accelerate permitting and project interconnection as well as increase the development of a highly skilled and diversified workforce.

To overcome market volatility, these new federal laws extended long-term tax credits that increase cost certainty and make project financing more likely. The tax credits provide additional bonuses for developers that use domestically produced iron and steel products and manufactured products and/or ensure the project's economic benefits accrue to communities who have historically been negatively impacted by energy production. The IRA also creates a manufacturing tax credit to spur equipment manufacturers to make new investments in manufacturing capacity for wind turbine blades, nacelles, towers, floating foundations, fixed-bottom foundations, and offshore wind vessel substructures. Funds have also been made available to enhance transmission planning, especially focused on offshore wind, to ensure projects maintain high system reliability when they are interconnected to the grid. BOEM and the National Oceanic and Atmospheric Administration received additional federal support to bolster their permitting staff to ensure timely and robust project reviews and safe project implementation. For more information about the IRA tax credits, see Section 2.2.

2.6.2 State Offshore Wind Procurement Policy

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 this 2023 Edition, we differentiate between state planning goals and state procurement mandates. Planning goals are aspirational and do not require agencies to take any direct action. On the other hand, procurement mandates require state agencies or utilities to schedule offshore wind energy solicitations and evaluate developer proposals on a specific timeline. As of May 31, 2023, thirteen states have set planning goals or procurement mandates that total 112,286 MW of offshore wind capacity by 2050. If only the procurement mandates are considered, that total is 42,730 MW by 2040 (Table 14). To date, states have awarded offtake contracts to procure 17,567 MW of offshore wind capacity that is expected to be operational before 2030. Figure 15 illustrates that significant additional deployment is needed to move from the 974 MW of existing projects installed and under construction to the cumulative 2040 state mandate requirement and the 2050 planning goal targets.

Table 14. State Planning Goals, Mandated State Procurements, and Offtake Contracts Awarded by Year

State	Planning Targets		Mandated Procurement		Offtake Contracts Awarded (MW)	Awarded Projects (MW)	Open/Pending Procurement (MW)	Supporting Policies and Documents
	Capacity (MW)	Year	Capacity (MW)	Year				
Maine	156	2030	-	-	12	Aqua Ventus (12)		*Maine Wind Energy Development Assessment* (2012)
Massachusetts	23,000	2050	5,600	2035	3,236	Vineyard Wind 1 (800) SouthCoast Wind 1 (804) SouthCoast Wind 2 (400) New England Wind (1,232)	400–3,600 (closes 1/31/2024)	*Act to Promote Energy Diversity* (2016) *Act to Advance Clean Energy* (2018) *Massachusetts 2050 Decarbonization Roadmap* (2020) *Act Creating a Next Generation Roadmap for Massachusetts Climate Policy* (2021)
Rhode Island	1,430	2030	1,430	2030	430	Block Island Wind Farm (30) Revolution Wind (400)	600–1,000 (closed 3/13/23)	*Request for Proposals for Long-Term Contracts for Offshore Wind Energy* (2022)
Connecticut	2,000	2030	2,000	2030	1,104	Revolution Wind (304) New England Wind (800)	Draft request for proposal for 1,196	*Public Act No. 19-71* (2019)
New York	20,000	2050	9,000	2035	4,362	South Fork Wind (132) Empire Wind 1 (816) Sunrise Wind 1 (924) Empire Wind 2 (1,260) Beacon Wind 1 (1,230)	1,000–2,000 (closed 1/26/2023)	*Case 18-E-0071* (2018) *Climate Leadership & Community Protection Act* (2019) *New York State Climate Action Council Scoping Plan* (2022)
New Jersey	11,000	2040	11,000	2040	3,758	Ocean Wind 1 (1,100) Ocean Wind 2 (1,148) Atlantic Shores Offshore Wind South (Project 1) (1,510)	1,200–4,000 (closes 6/23/23)	*Offshore Wind Economic Development Act* (2010) *Executive Order 8* (2018) *Executive Order 92* (2019) *Executive Order 307* (2022)
Maryland	8,500	2031	8,500	2031	2,045	Skipjack 1 (120) MarWin (270) Momentum Wind (809) Skipjack 2 (846)		*Maryland Offshore Wind Energy Act* (2013) *Clean Energy Jobs Act* (2019) *Promoting Offshore Wind Energy Resource Act* (2023)
Virginia	5,200	2034	5,200	2034	2,599	CVOW (Pilot) (12) CVOW (Commercial) (2,587)		*Virginia Clean Economy Act* (2021)
North Carolina	8,000	2040	-	-	-			*Executive Order 218* (2021)
California	25,000	2045	-	-	-			*AB 525* (2021) *Offshore Wind Energy Development off the California Coast: Maximum Feasible Capacity and Megawatt Planning Goals for 2030 and 2045* (2022)
Ohio	-	-	-	-	21	LEEDCo (21)		*None*
Louisiana	5,000	2035	-	-	-			*Louisiana Action Plan* (2022)
Oregon	3,000	2030	-	-	-			*HB 3375* (2021)
Total	112,286	2050	42,730	2040	17,567			

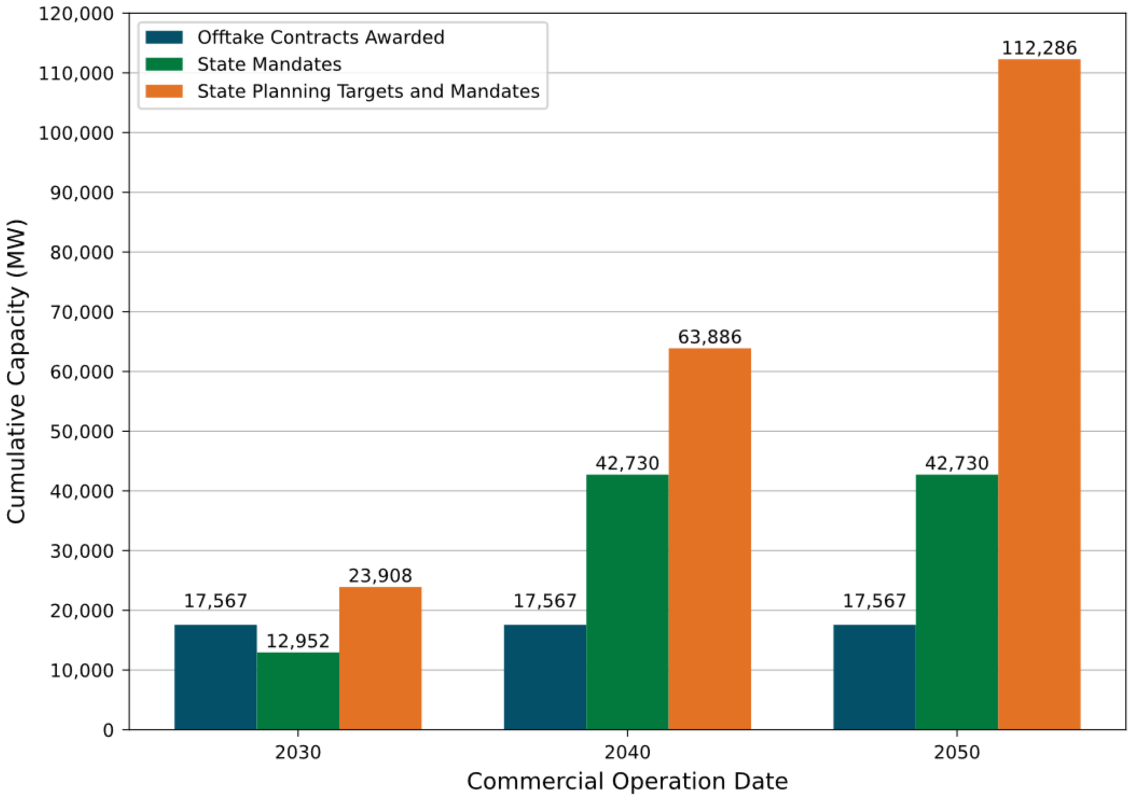

Figure 15. U.S. offshore wind energy state planning goals, procurement mandates, and offtake agreements awarded[19]

2.7 U.S. Offshore Wind Energy Infrastructure Trends

Progress to build the enabling infrastructure needed for offshore wind energy—including ports, vessels, manufacturing, and the electric grid—continued in the United States up until May 31, 2022. Figure 16 shows the announced and active domestic infrastructure projects. The Business Network for Offshore Wind estimates that around $17 billion has been announced or invested in the U.S. offshore wind energy industry since 2014, including $2.7 billion in ports, supply chain, vessels, and transmission in 2022, indicating that investors are gaining confidence in the U.S. offshore wind energy market (Business Network for Offshore Wind 2023).[20] Significantly more investment will likely be required to develop a robust domestic supply chain; for example, NREL estimates at least $22 billion in ports, large installation vessels, and major manufacturing facilities will be needed to achieve the 30-GW-by-2030 target (Shields et al. 2023).

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[19] Note that the state planning targets combines the statuary state procurement mandates with the planning goals that are not binding.

[20] The Business Network for Offshore Wind reports a $4.4-billion investment in 2022, which includes Nucor's $1.7-billion steel plant, which began operation in 2022. Because this investment was announced in 2020, we do not include it in the total for 2022.

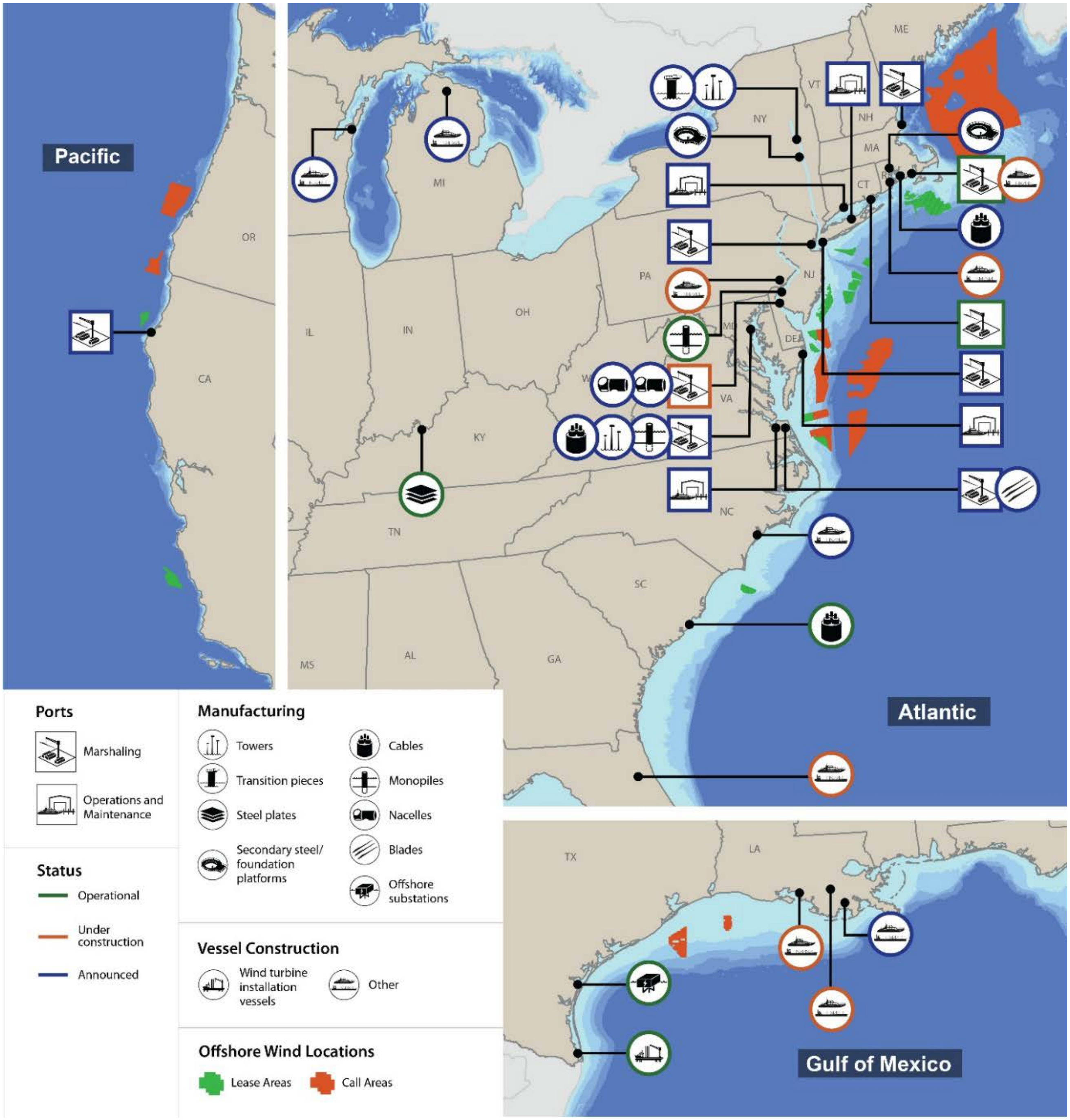

Figure 16. Announced and active port, vessel, and supply chain activity in the United States. Announced facilities that are conditional on winning a power offtake agreement are not shown.
Image created by John Frenzl, NREL

2.7.1 Vessels and Logistics

The United States has begun constructing additional U.S.-flagged vessels[21] to support various phases of the offshore wind energy industry. The Jones Act (or, the Merchant Marine Act of 1920) requires that goods transported between two U.S. points must be carried on vessels that are built, owned, and crewed by U.S. citizens or permanent residents. These Jones-Act-compliant vessels are also referred to as "coastwise qualified vessels" (Papavizas 2022). Dominion Energy is leading a consortium to invest $500 million in the first U.S.-flagged wind turbine installation vessel (WTIV). This vessel is being built in Brownsville, Texas, and is planned to be operational by late 2023 (Dominion Energy n.d.). Ørsted and Eversource have a contract with Edison Chouest in Louisiana to build the ECO Edison, the first U.S.-built, U.S.-flagged service operation vessel (SOV) (Ørsted 2023). The ECO Edison will provide operational support to the Ørsted and Eversource's joint venture offshore wind energy portfolio by 2024. Great Lakes Dredge & Dock is developing the first U.S.-flagged rock installation vessel that will be operational at the earliest in the first quarter of 2024 (Ulstein 2021). NREL tracks the commissioned, announced, and under construction U.S.-flagged offshore-wind-dedicated vessels. Table 15 and Table 16 provide a summary list of the vessels tracked.

Table 15. Commissioned U.S.-Flagged Vessels To Serve the Offshore Wind Energy Industry

Vessel Category (Vessel Name)	Companies Backing	Project Contracts	Commissioning	Source(s)
Crew transfer vessel (CTV) (Gaspee)	McAllister Towing	CVOW (Pilot)	1990	McAllister Towing (n.d.); ACP (2023b); Dominion Energy (2020a)
CTV (Atlantic Pioneer)	Atlantic Wind Transfers, Blount Boats Inc., Chartwell Marine Ltd.	Block Island Wind Farm	2016	Chartwell Marine (n.d.)
CTV (Atlantic Endeavor)	Atlantic Wind Transfers, Blount Boats Inc., Chartwell Marine Ltd.	CVOW	2020	Chartwell Marine (n.d.)
CTV	Atlantic Wind Transfers, Chartwell Marine Ltd.	Not listed	2020	Chartwell Marine (n.d.)
CTV (Odyssey)	Windserve Marine, Ørsted	CVOW	2020	Ørsted (2019)
CTV (Windserve Odyssey)	Senesco Marine, Ørsted	Revolution Wind	Not listed	Ørsted (2019)

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[21] Referring to U.S. vessels as Jones-Act-compliant may be misleading because foreign-flagged vessels can operate in U.S. waters in a Jones-Act-compliant manner. For instance, a foreign wind turbine installation vessel installing wind turbine components transported by a U.S.-built feeder barge. Vessels that transport cargo between U.S. ports need to be built and registered in the United States and owned and crewed by U.S. citizens or permanent residents. In this report, we refer to these as "U.S.-flagged vessels". This definition is similar to the "coastwise qualified" term used in other reports (American Clean Power 2021).

Vessel Category (Vessel Name)	Companies Backing	Project Contracts	Commissioning	Source(s)
CTV	Atlantic Wind Transfers, Dominion Energy	Not listed	Not listed	Power and Energy Solutions (n.d.)
Walk-to-work vessel[22]	US Otto Candies, LLC	South Fork Wind	2018	Blenkey (2021)

Table 16. Announced or Under Construction U.S.-Flagged Vessels To Serve the Offshore Wind Energy Industry

Vessel Category (Vessel Name)	Companies Backing	Project Contracts	Commissioning	Source(s)
Barge	Maersk Supply Service, BP/Equinor	Empire Wind	2030	WorkBoat (2022a)
Barge	Maersk Supply Service, BP/Equinor	Empire Wind	2030	WorkBoat (2022a)
CTV	Patriot Offshore Maritime Services, Vineyard Wind	Vineyard Wind	2023	WorkBoat (2022b)
CTV	Atlantic Wind Transfers, Chartwell Marine, United Kingdom (UK)	Not listed	2023	Memija (2022b)
CTV	WINDEA CTV LLC, GE	Vineyard Wind	2023	WINDEA (2022)
CTV	WINDEA CTV LLC, GE	Vineyard Wind	2023	WINDEA (2022)
CTV	Gladding-Hearn Shipbuilding/Duclos Corporation, Shell New Energies, Ocean Winds	SouthCoast Wind	2023	Professional Mariner (2021)
CTV	WINDEA CTV LLC, GE	Vineyard Wind	2023	WINDEA (2022)
CTV	Blount Boats and Shipyard, American Offshore Services, Ørsted, Eversource	Revolution Wind, South Fork Wind, Sunrise Wind	2023	Ørsted (2022)
CTV	Blount Boats and Shipyard, American Offshore Services	Not listed	2024	Workboat (2021)
CTV	Blount Boats and Shipyard, Vineyard Wind	Vineyard Wind	2024	Vineyard Wind (2022)
CTV	WindServe Marine, LLC, Ørsted, Eversource	Revolution Wind, South Fork Wind, Sunrise Wind	2024	Durakovic (2022a)
CTV	Atlantic Wind Transfers, Chartwell Marine, UK	Not listed	2024	Memija (2022b)

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[22] A walk-to-work vessel is a maintenance vessel with a motion-compensated bridge between the vessel and the wind turbine that allows workers to access the wind turbine in rough sea conditions.

Vessel Category (Vessel Name)	Companies Backing	Project Contracts	Commissioning	Source(s)
CTV	Blount Boats and Shipyard, American Offshore Services, Ørsted, Eversource	Revolution Wind, South Fork Wind, Sunrise Wind	2024	Ørsted (2022)
CTV	WindServe Marine, LLC, Ørsted, Eversource	Revolution Wind, South Fork Wind, Sunrise Wind	2025	Durakovic (2022a)
CTV	WindServe Marine, LLC, Ørsted, Eversource	Revolution Wind, South Fork Wind, Sunrise Wind	2025	Durakovic (2022a)
CTV	Atlantic Wind Transfers, Chartwell Marine, UK	Not listed	2026	Memija (2022b)
CTV	Atlantic Wind Transfers, Chartwell Marine, UK	Not listed	2028	Memija (2022b)
CTV	Atlantic Wind Transfers, Chartwell Marine, UK	Not listed	2030	Memija (2022b)
CTV	Atlantic Wind Transfers, Chartwell Marine, UK	Not listed	2032	Memija (2022b)
Multipurpose (Eleanor)	Moran Ironworks Shipyard, Green Shipping Line, DEKC Maritime, Keystone Shipping Company, DEKC Maritime	Not listed	2023	Durakovic (2021)
Rock Installation (Great Lakes Dredge and Dock Corporation)	Philly Shipyard, Inc., Great Lakes Dredge and Dock Corporation, Ulstein Design & Solutions B.V.	Empire Wind	2024	The Waterways Journal (2020); Ulstein (2020, 2021); Great Lakes Dredge and Dock (2020)
SOV (Eco Edison)	Edison Chouest Offshore, Ørsted, Eversource	Revolution Wind, South Fork Wind, and Sunrise Wind	2024	Schuler (2020)
SOV	Edison Chouest Offshore, Equinor/BP	Empire Wind	2026	Equinor (2022b)
SOV	Crowley, CREST (Crowley/ESVAGT), HAV Design AS	CVOW (Commercial)	2026	Crowley (2023)
Tug	Maersk Supply Service, BP/Equinor	Empire Wind	2030	WorkBoat (2022a)
Tug	Maersk Supply Service, BP/Equinor	Empire Wind	2030	WorkBoat (2022a)

Vessel Category (Vessel Name)	Companies Backing	Project Contracts	Commissioning	Source(s)
WTIV (Charybdis)	Keppel AmFELS, Dominion Energy, GustoMSC	Revolution Wind, Sunrise Wind, CVOW	2023	Dominion Energy (2020b); The Maritime Executive (2020); Skopljak (2020b)

ACP estimates that each project takes 2 to 3 years for its offshore installation, and that at least 25 vessels per project will be needed across all project stages (ACP 2021). Shields et al. (2023) report that, without significant investment in large installation vessels like WTIVs, heavy-lift vessels, and feeder barges, at least half of the pipeline could be at risk of being delayed beyond 2030. To support the investment in offshore wind vessels, the U.S. Department of Transportation's Maritime Administration announced the designation of offshore wind vessels as Vessels of National Interest, making them eligible for financial support through the Title XI Federal Ship Financing Program. This program can provide credit loans at longer terms and lower interest rates than traditional private loans (U.S. Department of Transportation 2022). Funding initiatives of this type may push sponsors closer to agreement for vessel construction contracts.

The vessel that generally requires the highest capital investment is the WTIV. WTIVs are large, highly specialized vessels that could cost at least $500 million to construct, and the United States will likely need 4–6 dedicated WTIVs to meet the national offshore wind energy target (Shields et al. 2023). The shortage of U.S.-built WTIVs has led most projects to plan on using foreign-flagged WTIVs along with U.S.-flagged feeder vessels. These feeder vessels will transport wind turbine components to the sites from U.S. marshalling ports. The partnership between Foss Maritime Company LLC and DEME Offshore US, LLC for the support of Vineyard Wind 1 is one example of a project that selected a feeder vessel strategy for installing its wind turbines. Foss Maritime Company LLC will provide the U.S.-flagged feeder vessels to transport the wind turbine components from New Bedford, Massachusetts, to the specialized DEME Offshore US, LLC's WTIV (Vineyard Wind 2021). Building feeder barges in U.S. shipyards may be more feasible than WTIVs because they are smaller, less expensive, and less specialized (Shields et al. 2023). The feeder barge solution is also being considered in Europe. Maersk Supply Service plans to bring the feeder barge concept to European waters because the solution could result in more efficient installation schedules (The Maritime Executive 2023).

The U.S. offshore wind energy market may be at risk of suffering project delays if the industry keeps depending on foreign-flagged vessels for the construction stages of offshore wind plants. Multiple countries have stated their offshore wind energy deployment targets in Europe and Asia, which means that offshore wind vessel demand is expected to grow globally in the coming years. Therefore, the dependence on the global vessel market with its own increasing demand, along with the specific logistic constraints of the Jones Act, may lead to higher expected costs of

U.S. offshore wind energy projects and compromised construction schedules due to limited vessel availability.

2.7.2 Ports and Supply Chain

The United States saw almost $1 billion of announced investments in marshaling, manufacturing, and operations and maintenance (O&M) ports in 2022 from a variety of federal, state, and private sources. In New York, Equinor and BP announced that they will develop South Brooklyn Marine Terminal into a port with marshaling and O&M capabilities with an investment of $200–$250 million (Equinor 2022a). The upgraded port will support the Empire Wind and Beacon Wind projects. The planning and development of South Brooklyn Marine Terminal are a collaboration between Equinor, BP, the New York City Economic Development Corporation, the New York State Energy Research and Development Authority, and several community-based organizations to prioritize the community's vision for sustainable and equitable use of the existing industrial terminal (Shields et al. 2023).

The Massachusetts Clean Energy Center's (MassCEC) Offshore Wind Ports Infrastructure Investment Challenge awarded $180 million in competitive grants to develop offshore wind port assets in the Commonwealth (Niforos 2022). The Salem Wind Port, a new marshaling facility at the site of a former coal-fired power plant, was awarded $75 million through a public/private partnership between Crowley Wind Services, MassCEC, and the City of Salem. The New Bedford Port Authority and New Bedford Foss Marine Terminal were each awarded $15 million to redevelop and improve existing assets for offshore wind energy activities. Prysmian received $25 million from MassCEC to redevelop a site within the Brayton Point Marine Commerce Center for a subsea cable facility and announced that they would make a $200-million investment in the facility itself (Prysmian Group 2022). Awards were also made to Shoreline Marine Terminals in New Bedford and Gladding Hearn Shipbuilding in Somerset. As part of the offshore wind port investment portfolio, $45 million was allocated for improvements to and expansion of the New Bedford Marine Commerce Terminal.

The U.S. Department of Transportation's Maritime Administration Port Infrastructure Development Program awarded three grants to ports in the North Atlantic (U.S. Department of Transportation Maritime Administration 2022). Arthur Kill Terminal in Staten Island, New York, received $48 million to dredge a ship basin for a staging and assembly facility. The Port of Salem in Salem, Massachusetts, received $34 million (in addition to the $75 million from the State of Massachusetts) to construct a wharf and bulkhead to serve as an assembly and loadout location and to create an upland laydown area for offshore wind components. The Bridgeport Port Authority in Bridgeport, Connecticut, received $10.5 million to build bulkheads, dredge the harbor, and construct crane pads for an O&M facility.

In addition to these new funding announcements, the New London State Pier in New London, Connecticut, completed the construction of a delivery berth to support offshore wind marshaling activities. The berth is part of a $255-million upgrade package that was funded by the State of Connecticut, Ørsted, and Eversource. The entire marine terminal is expected to be completed later in 2023 and will serve as the marshaling port for the South Fork Wind, Revolution Wind, and Sunrise Wind projects.

The Virginia Port Authority selected Skanska to develop the Portsmouth Marine Terminal as an offshore wind marshaling port (Skanska 2022). Skanska will redevelop 72 acres of the port to support the CVOW project, including constructing three heavy-lift berths, dredging the channel and access area, and strengthening the upland area for component laydown. The project is expected to cost $223 million.

Fairwinds Landing, LLC, signed a lease at the Norfolk Southern Lambert's Point Docks property in Norfolk, Virginia, to develop a maritime operations and logistics center to support the offshore wind, defense, and transportation industries (Sidersky 2022). The group plans to spend $100 million to develop buildings and infrastructure.

The Port of Humboldt in Eureka, California, received a $10.5-million grant from the California Energy Commission to conduct preliminary design work for a staging and integration facility to support floating offshore wind energy projects (California Energy Commission 2022b). These funds will also be used to conduct site surveys, prepare environmental impact assessments, and initiate environmental mitigation measures. The Port of Humboldt Bay subsequently signed an agreement with Crowley Wind Services to develop the Humboldt Bay Offshore Wind Heavy Lift Marine Terminal, which will support project developers in the manufacturing, installation, and operation of offshore wind energy projects (Crowley 2022).

The Port of Long Beach released a conceptual study for a 400-acre staging and integration facility known as Pier Wind to support projects in central and northern California (Durakovic 2023c). The Pier Wind facility is estimated to be a $4.7-billion project that could start construction in 2027 and have 200 acres operational by 2031.

Nucor began to manufacture steel plates at its expanded steel mill in Brandenburg, Kentucky, to support offshore wind tower and monopile fabrication (Memija 2023a). The facility cost $1.7 billion to construct and produced its first steel plate at the end of 2022.[23] Nucor can produce 1.2 million tons of steel plate per year using an electric arc furnace manufacturing process. This throughput is approximately equal to the expected annual demand from the U.S. offshore wind industry; however, Nucor is likely to serve heavy plate markets besides offshore wind, and it is not yet known if they will be able to provide the thickest steel plates needed for monopiles (Shields et al. 2023).

A summary of port and supply chain investments from the beginning of 2022 is provided in Table 17.

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[23] Nucor announced the $1.7-billion investment in 2020 and so it is not included in our 2022–2023 supply chain investment total.

Table 17. Investments in Offshore Wind Ports and Tier 1 Manufacturing Facilities From January 1, 2022, to May 2023

PIDP = U.S. Department of Transportation Maritime Administration Port Infrastructure Development Program, CEC = California Energy Commission, MassCEC = Massachusetts Clean Energy Center

Port	State	Type of Investment	Announced Investment ($ million)	Funding Source
New Bedford Marine Commerce Terminal	MA	Marshaling port	45	MassCEC
Salem Wind Port	MA	Marshaling port	108.8	MassCEC, PIDP
New Bedford Foss Marine Terminal	MA	O&M port	15	MassCEC
Prysmian Marine Terminal at Brayton Point	MA	Subsea cable manufacturing	225	Prysmian, MassCEC
Bridgeport	CT	O&M port	10.5	PIDP
South Brooklyn Marine Terminal	NY	Marshaling port	200	Equinor, BP
Arthur Kill Terminal	NY	Marshaling port	48	PIDP
Quonset State Airport	RI	Helicopter operations	1.8	Ørsted, Eversource
Tradepoint Atlantic	MD	Monopile and tower manufacturing	Not disclosed	Not disclosed
Portsmouth Marine Terminal	VA	Marshaling port	223	Virginia Port Authority
Norfolk	VA	Operations and logistics center	100	Fairwinds LLC
Port of Humboldt	CA	Marshaling port	10.5	CEC
Total announced investment in 2022–2023:			**987.6**	

2.7.3 Electric Grid

Stakeholders in the North Atlantic have taken steps toward shared, coordinated transmission for offshore wind energy. In October 2022, the NJBPU selected the Larrabee Tri-Collector Solution project that Mid-Atlantic Offshore Development and Jersey Central Power & Light Company proposed to interconnect the state's goal of 7.5 GW of offshore wind energy by 2035 (NJBPU 2022). NJBPU also awarded onshore upgrade projects. These projects will be the first coordinated offshore wind transmission solution in the United States and NJBPU expects this coordination to save ratepayers up to $900 million. NJBPU has launched a second State Agreement Approach solicitation with PJM to enable transmission for the state's increased goal of 11 GW of offshore wind energy by 2040 (NJBPU 2023b). The board is engaging with other stakeholders to pursue a regional approach to offshore wind energy transmission.

Connecticut, Maine, Massachusetts, Rhode Island, and New Hampshire solicited feedback via a Request for Information in September 2022, on a Modular Offshore Wind Implementation Plan (New England Energy Vision n.d.). New York has mandated "mesh-ready" transmission plans when developers bid for state solicitations. Under this framework, offshore wind energy projects would be required to adapt their designs to connect the power output from their individual wind plants to a series of offshore converter platforms (i.e., ocean-based high-voltage terminals) at sea where the power from multiple projects will potentially be aggregated and transmitted to shore via high-voltage direct current transmission links.

The DOE-sponsored Atlantic Offshore Wind Transmission Study has developed four transmission topologies: radial, intraregional, interregional, and a backbone. The latter three would use multiterminal high-voltage direct current interlinks. This transmission study is evaluating production cost, resource adequacy, dynamic contingency, electromagnetic transient stability, and resilience, as well as quantifying benefits and modeling cost allocation.

The California Independent System Operator analyzed a scenario with 8–21 GW of offshore wind energy by 2030 and found that major transmission build-out in northern California would be required to support offshore wind expansion (California Independent System Operator 2022).

DOE's Wind Energy Technologies Office announced the kickoff of the West Coast Offshore Wind Transmission Study. This study will assess capacity expansion, production cost, resource adequacy, stability, and balancing of supply and demand, as well as conduct contingency modeling to identify transmission options (Wind Energy Technologies Office 2023).

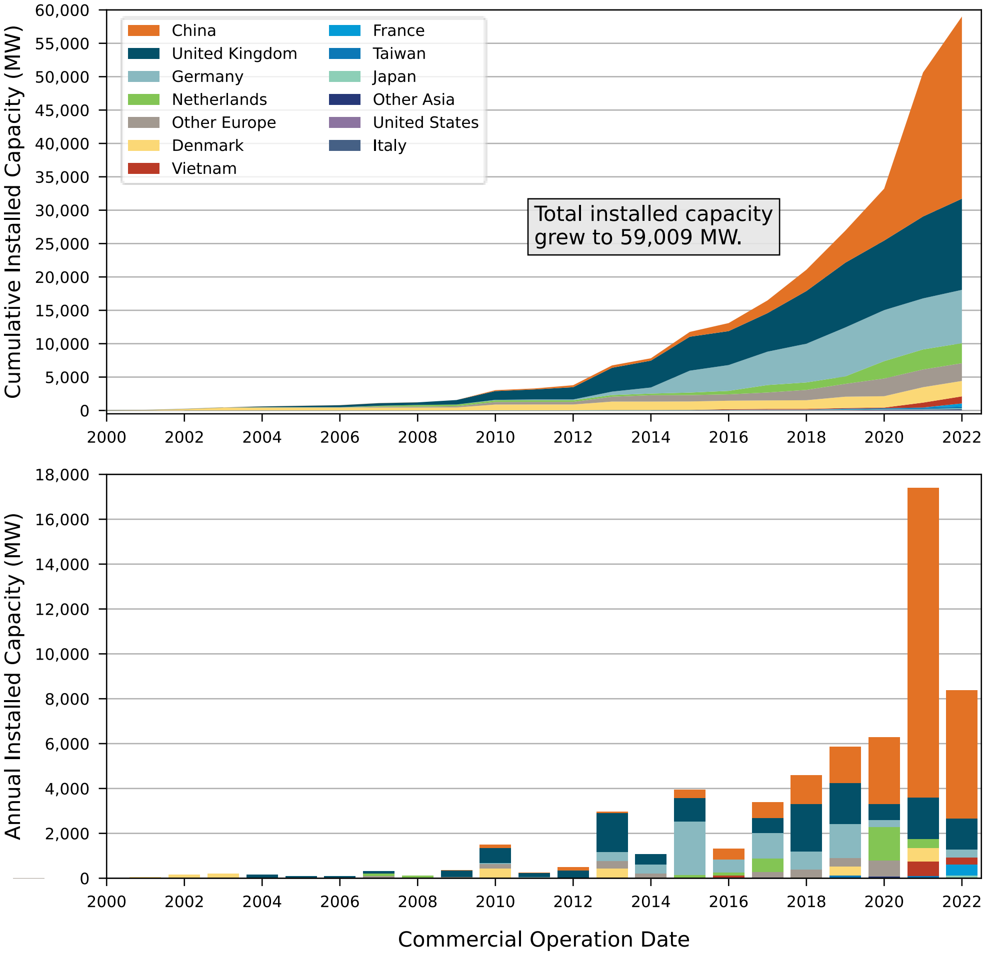
3 Global Offshore Wind Energy Development

This section explores offshore wind energy development for both fixed-bottom and floating technologies in key markets around the world in three parts: a summary of current global offshore wind activity, forecasts for growth, and country-specific offshore wind deployment goals.

3.1 Global Offshore Wind Energy Industry Current Status

3.1.1 Aggregate Global Deployment Summary

In 2022, 8,385 MW of offshore wind energy was deployed, bringing the total global installed capacity to 59,009 MW across 292 operating projects and over 11,900 operating wind turbines (Figure 17). This growth represents an increase of 16.6% in total deployment over the previous year.



Total installed capacity grew to 59,009 MW.

Figure 17. Global cumulative offshore wind energy deployment (top) and annual capacity additions (bottom) through December 31, 2022

The amount of capacity installed in 2022 was lower than the record deployment of 17,399 MW that came online in 2021 but represents the second-largest annual capacity addition ever. The previous year (2021) was exceptional, because a large number of Chinese projects were rushing to qualify for government-sponsored feed-in tariff incentives that expired at the end of 2021 (Barla 2023). Figure 18 shows the new 2022 additions of offshore wind energy by country.

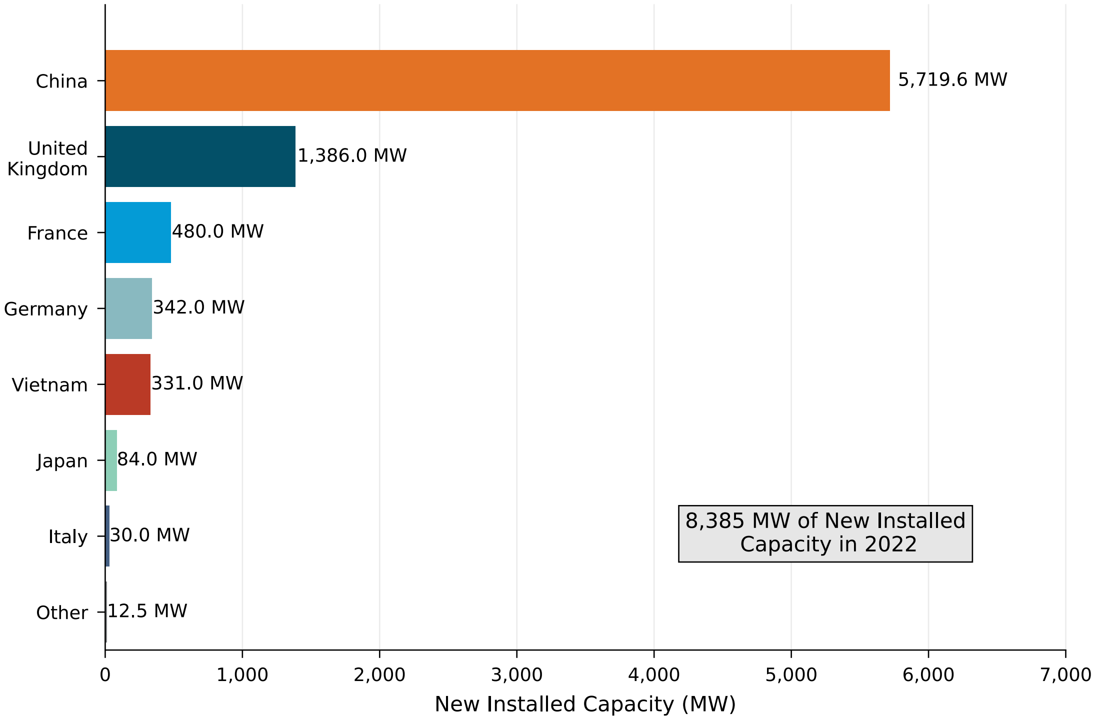


Figure 18. Global offshore wind energy installations in 2022

Of the 8,385 MW new installed capacity in 2022, more than two-thirds (68.2%) was commissioned in China, totaling 5,719.6 MW. The United Kingdom was the next-largest contributor, with 1,386 MW of new installations, followed by France (480 MW), Germany (342 MW), and Vietnam (331 MW). Japan, Italy, and the rest of the world installed 126.5 MW combined in 2022.

Figure 19 presents cumulative offshore wind deployment by country through 2022. China overtook the United Kingdom in 2021 as the world leader in installed offshore wind energy and continued to increase their share of the global offshore wind market in 2022, having 46.2% of the total 59,009 MW deployed globally. The countries with the next-largest shares of installed offshore wind energy include the United Kingdom (23.1%), Germany (13.5%), the Netherlands (5.1%), and Denmark (3.9%), with the remaining 8.2% deployed in the rest of the world. Regionally, most offshore wind capacity operates in Europe (51% across 130 projects), followed by Asia (48.9% across 161 projects), and North America (0.1% across two projects).

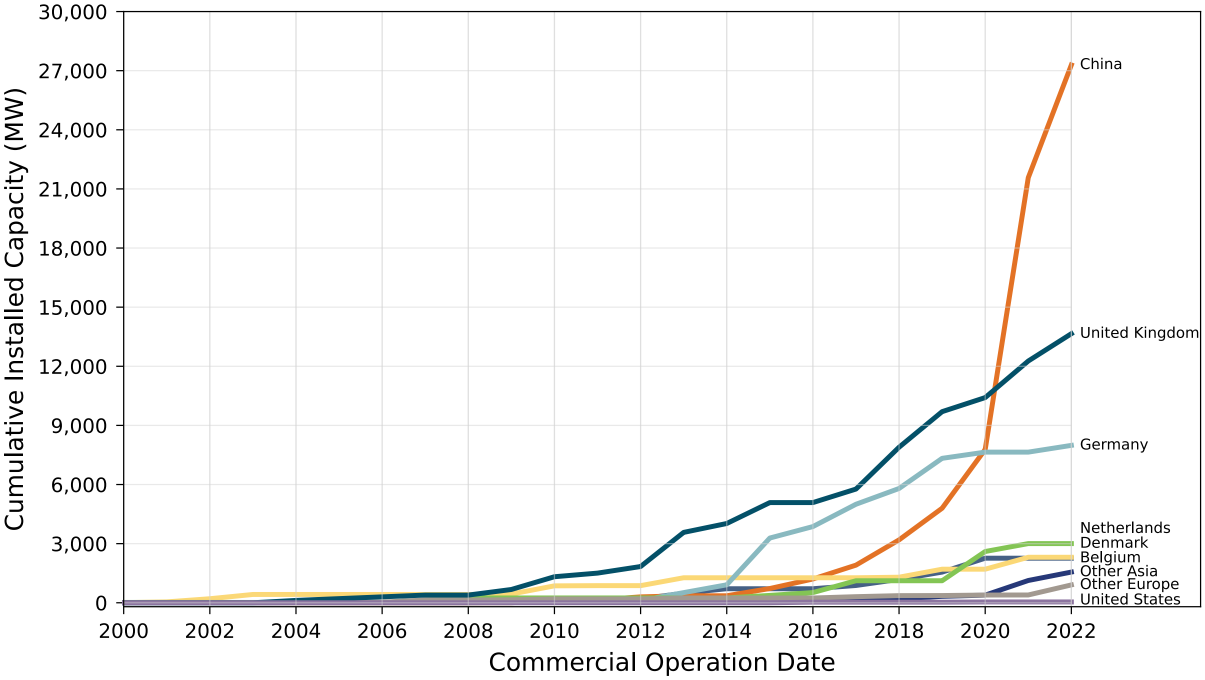


Figure 19. Cumulative installed offshore wind energy capacity by country

Generally, data show a slowdown in European offshore wind deployment with only 2,238 MW commissioned in 2022.

3.1.2 Floating Offshore Wind Technology Deployment Summary

Floating offshore wind technology enables access to areas with higher-quality wind resources in deeper waters (greater than 60 m) and farther from shore than are currently feasible with fixed-bottom technologies. In fact, more than 65% of the total offshore wind resource in the United States lies over these deeper waters (Lopez et al. 2022). In Europe, that number is estimated at 80% (Komusanac, Fraile, and Brindley 2019).

Although no new floating offshore wind energy projects were commissioned in the reporting period from May 2022 through May 2023, the 88-MW, 11-turbine Hywind Tampen project in Norway produced first power for one of Equinor's oil-and-gas platforms in November 2022 (Equinor 2022c). The project is expected to be fully installed in 2023 and will become the largest operating floating offshore wind plant in the world.

In May 2022, the 2-MW DemoSATH demonstration project completed mooring installation at the Biscay Marine Energy Platform test site off the coast of the Spanish Basque Country (Jaén et al. 2022; Saitec Offshore Technologies 2022). As of July 2023, the project teams have not released any news confirming commissioning or first power.

3.2 Announced Deployment Through 2028

To help identify trends in national and regional offshore wind energy markets, we compiled offshore wind deployment projections based on announced project CODs through 2028 using NREL's OWDB.

3.2.1 Announced Projects to 2028

Data for projects under construction[24] provide a reasonable basis for understanding near-term deployment because confidence that a project will achieve its announced COD is significantly higher once it reaches financial close and is actively engaged in construction. Figure 20 shows the distribution of 21,717 MW of projects, by country, that were under construction as of December 31, 2022.

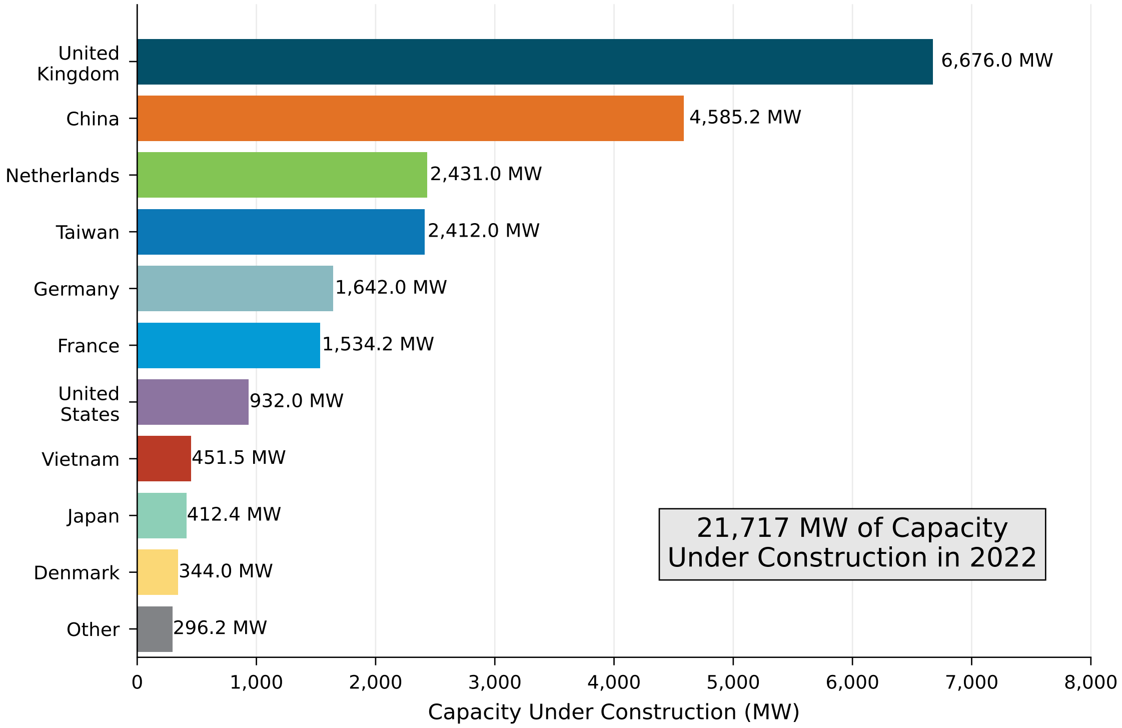


Figure 20. Offshore wind capacity under construction by country as of 2022

The data indicate that all major offshore wind energy markets will continue to grow in the near term, though the total construction capacity is down approximately 14.5% compared with the 25,403 MW reported in 2021. Regionally, Europe has the most capacity under construction with more than 58% totaling nearly12,724 MW across 24 projects. At the end of 2022, 37 projects were under construction in Asia, totaling nearly 8,061 MW. The North American region is the third-largest market for offshore wind energy projects under construction. While this market

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[24] As stated in Table 1, "under construction" means that construction has been initiated. Note that some developers may elect to start construction at an onshore landing area to secure certain subsidies or tax incentives.

significantly lags Europe and Asia with only 932 MW (two projects) under construction, the large pipeline of over 52 GW in the United States signals rapid growth later in this decade and beyond.

At the end of 2022, there were 24 projects under construction in Europe, amounting to 12,724 MW of offshore wind capacity. Of these, six projects are in the United Kingdom (totaling 6,676 MW), four projects are under construction in the Netherlands (2,431 MW), three projects in Germany (1,642 MW), seven projects in France (1,534.2 MW), and one project in Denmark (344 MW).

In Asia, China has the most capacity under construction, with 4,585.2 MW (17 projects), though this is approximately one-third lower than a year earlier. Taiwan has 2,412 MW under construction (six projects), Vietnam has 451.5 MW (seven projects), and Japan has 412.4 MW (five projects).

Figure 21 shows the same data for the projects under construction as Figure 20, but plots the data based on developer-announced CODs. While developers may not make all information about their projects public, these data provide insight into when projects under construction are likely to become operational.

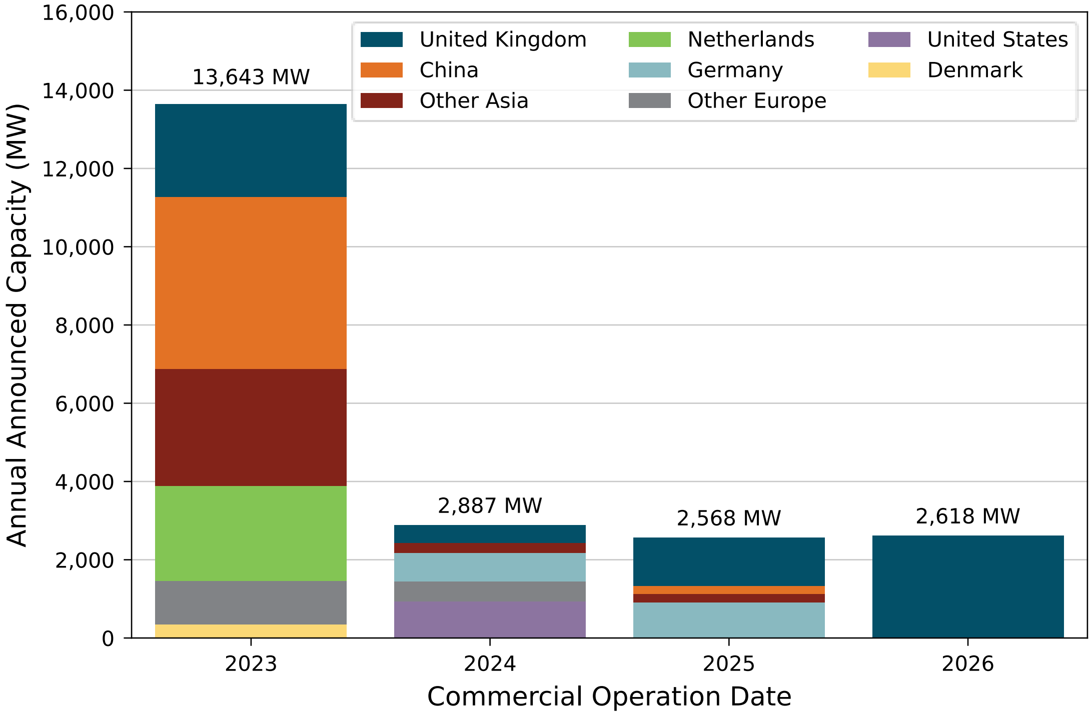

Figure 21. Developer-announced COD for offshore wind energy projects under construction[25]

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[25] Note totals may vary slightly between Figure 20 and 21 due to round-off differences in the databases.

Developer expectations in the figure suggest that the industry is likely to install more capacity in 2023 than in 2022. China, the United Kingdom, the Netherlands, and other parts of Asia are expected to install most of this capacity, signaling sustained or slightly increased deployment levels for the industry in 2023. These data indicate the potential for European deployment to increase in 2023 compared to 2022. The construction data for 2024 and beyond indicate lower deployment but these data may not include all projects that are about to start construction.

Figure 22 shows cumulative offshore wind installations for all projects based on developer-announced CODs. The chart shows that offshore wind energy deployment could reach over 182 GW by 2028.

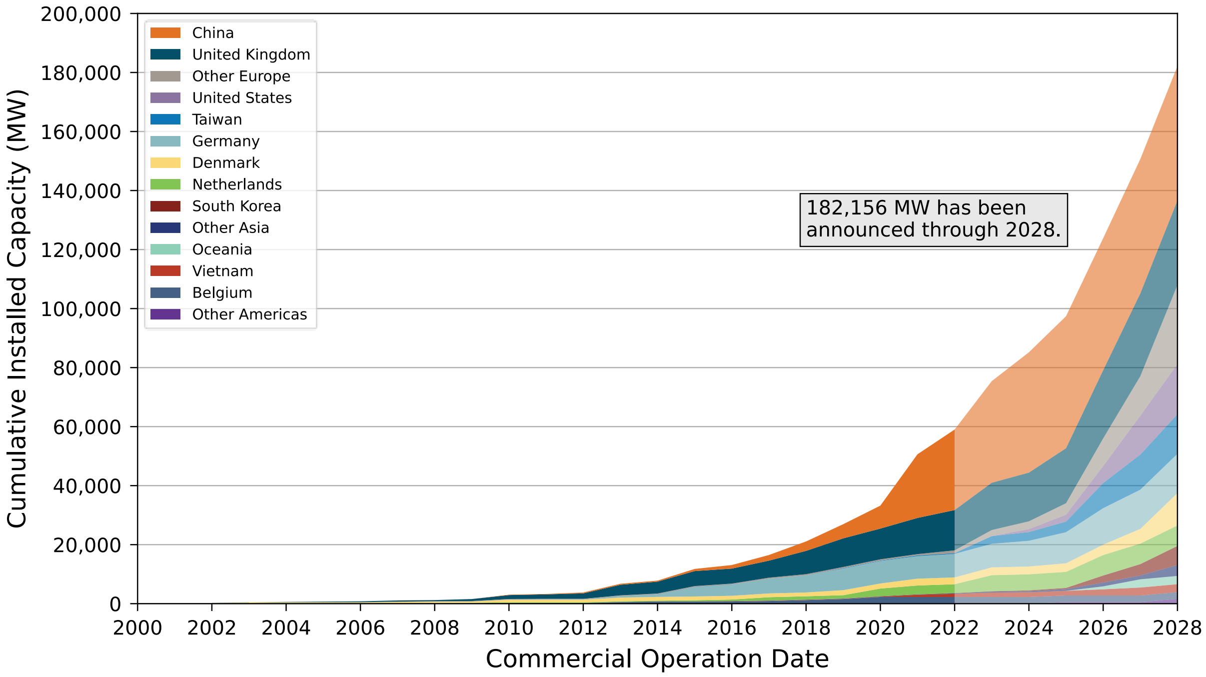

Figure 22. Estimated cumulative offshore wind capacity by country based on developer-announced CODs.

Note: the darker areas represent existing deployed capacity, and the lighter areas represent projected deployments.

3.2.2 Floating Projections to 2030

Based on NREL's OWDB for all projects with an announced COD, the data in Figure 23 show the estimated cumulative deployment of floating offshore wind by country through 2030. Data are displayed through 2030 because floating offshore wind energy deployment is evolving at a different pace than fixed-bottom offshore wind, and the data that extend beyond 2028 are important to illustrate the trend toward commercial scale. The data indicate that 7,957 MW may be installed by 2028 based on developer-announced CODs but by 2030, 39,385 MW of projects have announced they will reach commercial operations. Most of these projects are still in the planning phase; therefore, there is a high degree of uncertainty about their timing and likelihood of completion. However, the potential surge between 2028 and 2030 indicates the transition to commercial-scale projects.

One caution is that most industry forecasts are much lower for the 2030 time frame because developer estimates tend to be more optimistic than impartial analysts (see Figure 27). Most of the developer-announced deployment for 2028 is in Taiwan (1,786 MW), Spain (1,396 MW), the United Kingdom (1,055 MW), China (1,048 MW), and Italy (972 MW). Most other near-term floating offshore wind deployment estimates are more evenly spread throughout multiple countries in Europe.

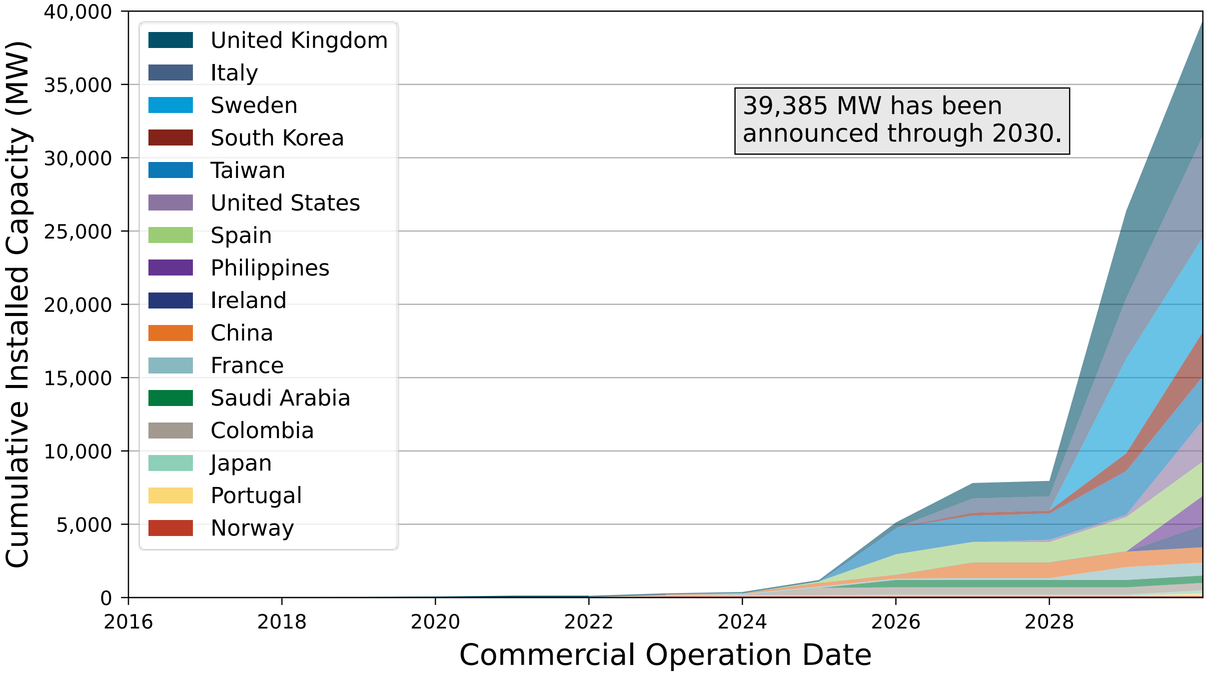

Figure 23. Cumulative floating offshore wind capacity by country based on announced CODs through 2030

3.2.3 Total Global Offshore Wind Energy Pipeline

Figure 24 shows the capacity of the global offshore wind energy pipeline for all operating projects, and projects under development by region at the end of 2022. The total capacity was assessed to be over 426 GW, compared to approximately 369 GW that was reported at the end of 2021. This uptick of about 15.4% over 2022 in total capacity is primarily attributed to about 50 GW of new projects entering the planning phase from around the world. 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 further along in the pipeline are more likely to reach their announced COD and maintain their announced capacity 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 and China; however, a significant portion of potential future capacity is moving forward in the United States. Overall, European projects still dominate the future project pipeline.

By project status, the global pipeline shows there are approximately 25 GW with site control, 68 GW of projects in the "permitting" stage, and almost 22 GW under construction, with over 59 GW in operation.

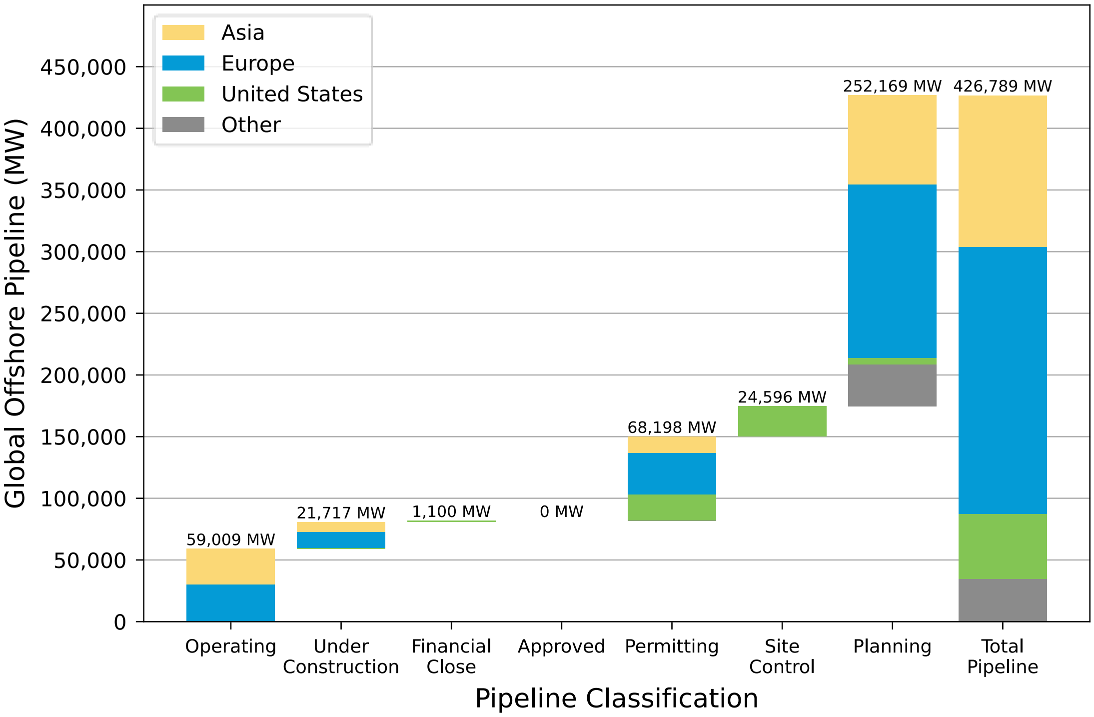

Figure 24. Total global offshore wind energy pipeline by regulatory status

3.2.4 Floating Offshore Wind Energy Pipeline

Overall, the total capacity in the 2022 global floating offshore wind energy pipeline is 102,529 GW, as shown in Figure 25 (note that the y-axis has two scales to help identify the advanced early-stage projects). This capacity represents growth of almost 42 GW (69%) relative to the *Offshore Wind Market Report: 2022 Edition*. The floating pipeline growth was primarily driven by new project announcements in the United Kingdom.

In the near-term floating pipeline (through 2028), there are approximately 447 MW that are currently under construction, which is a threefold increase over 2021. In addition, 218 MW has reached the permitting phase. Most of the pipeline is in the planning stage (including projects with a COD beyond 2028), which comprises 95,698 MW of floating projects. Note that over 6,000 MW in the United States has moved to the site control phase in the pipeline because of the December 2022 lease auction in California. Table 18 provides data by country for how the global floating pipeline is broken down.

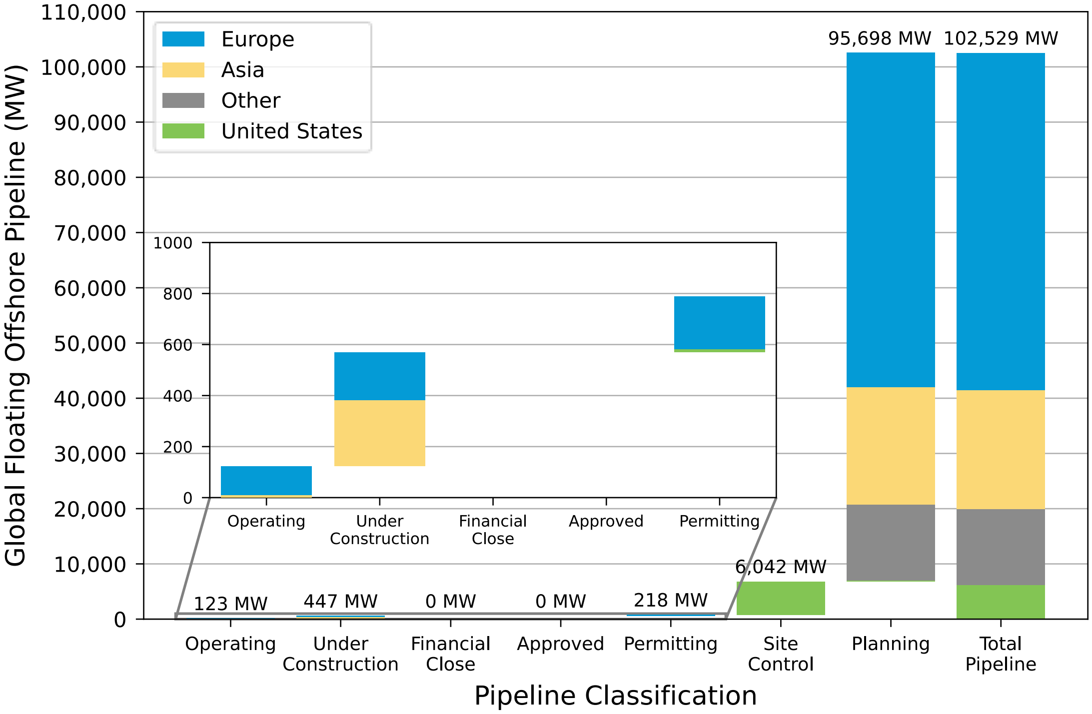

Figure 25. Total global floating offshore wind energy pipeline by regulatory status

Table 18. Global Floating Offshore Wind Energy Pipeline

Country	Operating (MW)	Under Construction (MW)	Permitting (MW)	Site Control (MW)	Planning (MW)	Total (MW)
Australia					11,250	11,250
China	5.5	242.8			1,800	2,048
Colombia					500	500
France	2	90.2			1,790	1,882
Ireland					5,510	5,510
Italy					6,915	6,915
Japan	5	16.8			195	217
New Zealand					2,000	2,000
Norway	5.9	95	1		6	108
Philippines					7,425	7,425
Portugal	25				350	375
Saudi Arabia					500	500
South Korea					3,855	3,855
Spain		2.3			2,341	2,343
Sweden					14,650	14,650
Taiwan					7,486	7,486
United States			12	6,042	144	6,198
United Kingdom	80		205		28,981	29,266
Total	**123**	**447**	**218**	**6,042**	**95,699**	**102,529**

3.2.5 Forecasted Projections for Offshore Wind Energy

In Figure 26, two independent forecasts are shown: BNEF (2022a) and 4C Offshore (2023), which estimate the future growth of the global offshore wind energy industry. BNEF forecasts offshore wind energy will reach 379.5 GW by 2032, whereas 4C Offshore estimates a projected deployment level of 394.4 GW by 2032. 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.

The most prominent trend in the offshore wind energy market in the 2032 forecast is the estimated growth of the Chinese market. Both forecasts expect China will cumulatively deploy between 60.5 GW and 113 GW by 2032. The forecasts also predict European developers will build projects at an increasing rate relative to today, with Europe holding roughly 34%–39% of the total installed global offshore wind capacity by 2032. China is expected to represent 19%–36% of the total 2032 installed capacity, with the remaining other Asian countries (e.g., Taiwan, Korea, Japan, and Vietnam) accounting for 13%–14%. Depending on the forecast scenario (4C Offshore or BNEF), the U.S. portion of installed capacity is forecast to be about 11% to 19% of the global total by 2032.

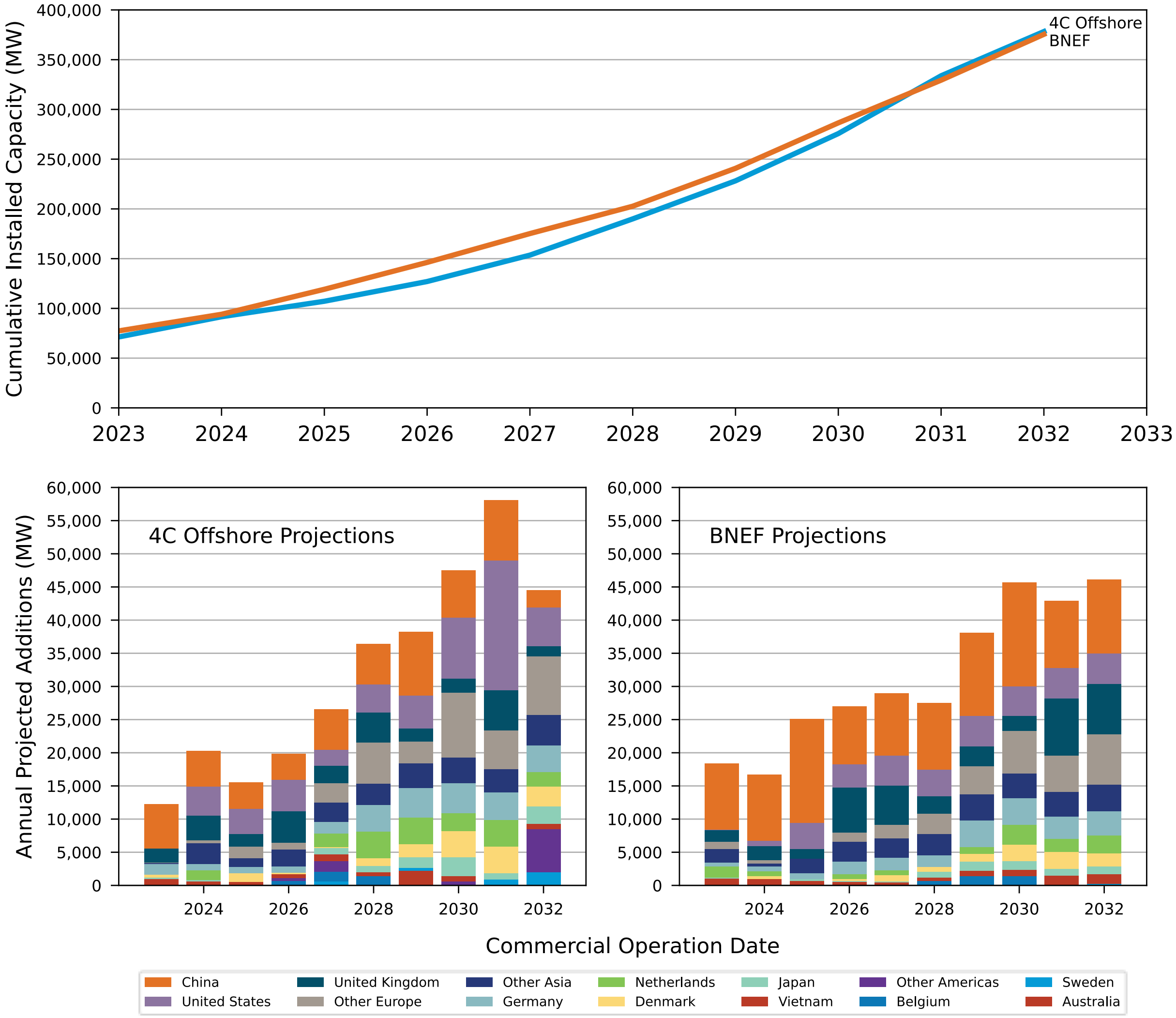

Figure 26. Industry forecasts for global offshore wind energy deployment to 2032

3.2.6 Forecasted Projections for Floating Wind Energy

Figure 27 shows future floating offshore wind energy deployment forecasts for 2025–2050 from multiple independent groups. The projections show various estimates at about 10 GW by 2030 to as much as 300 GW by 2050 (DNV 2022a, 2022b). 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 deep-water sites are available (e.g., U.S. Pacific).

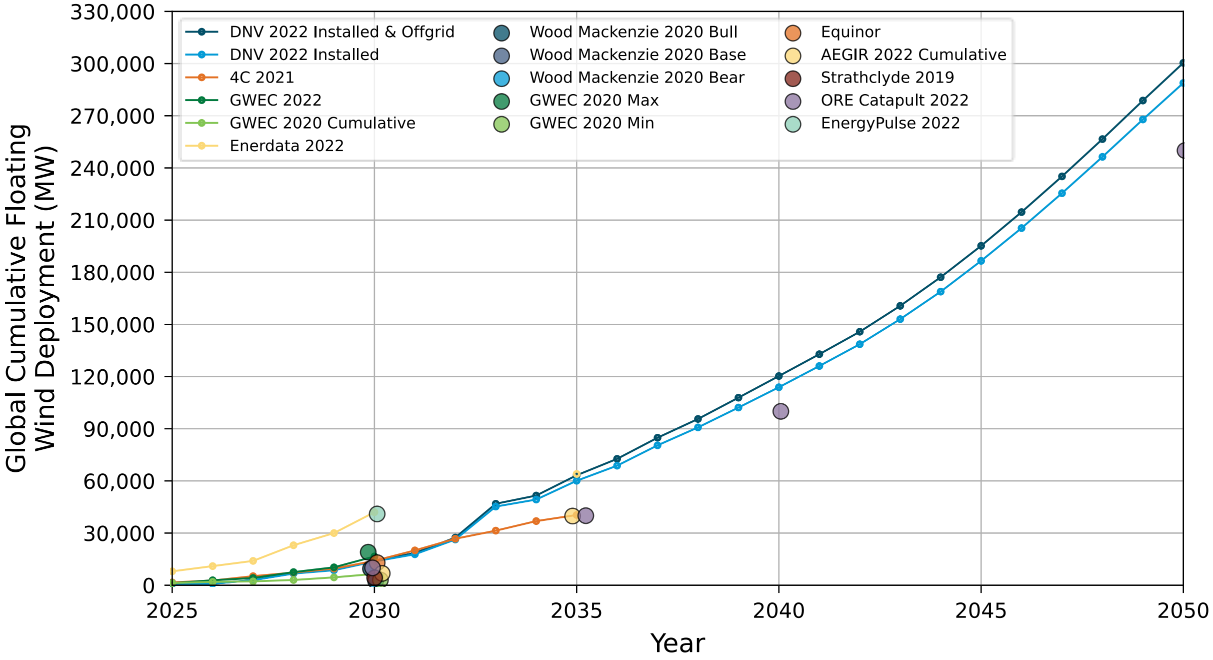

Figure 27. Long-term cumulative floating offshore wind energy deployment projections.

GWEC: Global Wind Energy Council

3.3 Country-Specific Offshore Wind Energy Markets

Government renewable energy targets play a crucial role in advancing offshore wind energy deployment. These targets increase public awareness and support, facilitate planning and coordination among different stakeholders, encourage investment and innovation to drive the costs down, and provide clear direction and long-term stability. In this section, we compiled a diverse array of offshore wind energy targets, ranging from those rooted in law, such as the Greek target, to others, like the U.S. target, which currently lack legal status. We illustrate the offshore wind energy targets worldwide in Figure 28. Table 19, Table 20, and Table 21 show national deployment goals and procurement targets for Europe, Asia, and the rest of the world, respectively. Sections 3.3.1 through 3.3.3 provide country-specific offshore wind energy market developments for each of those regions.

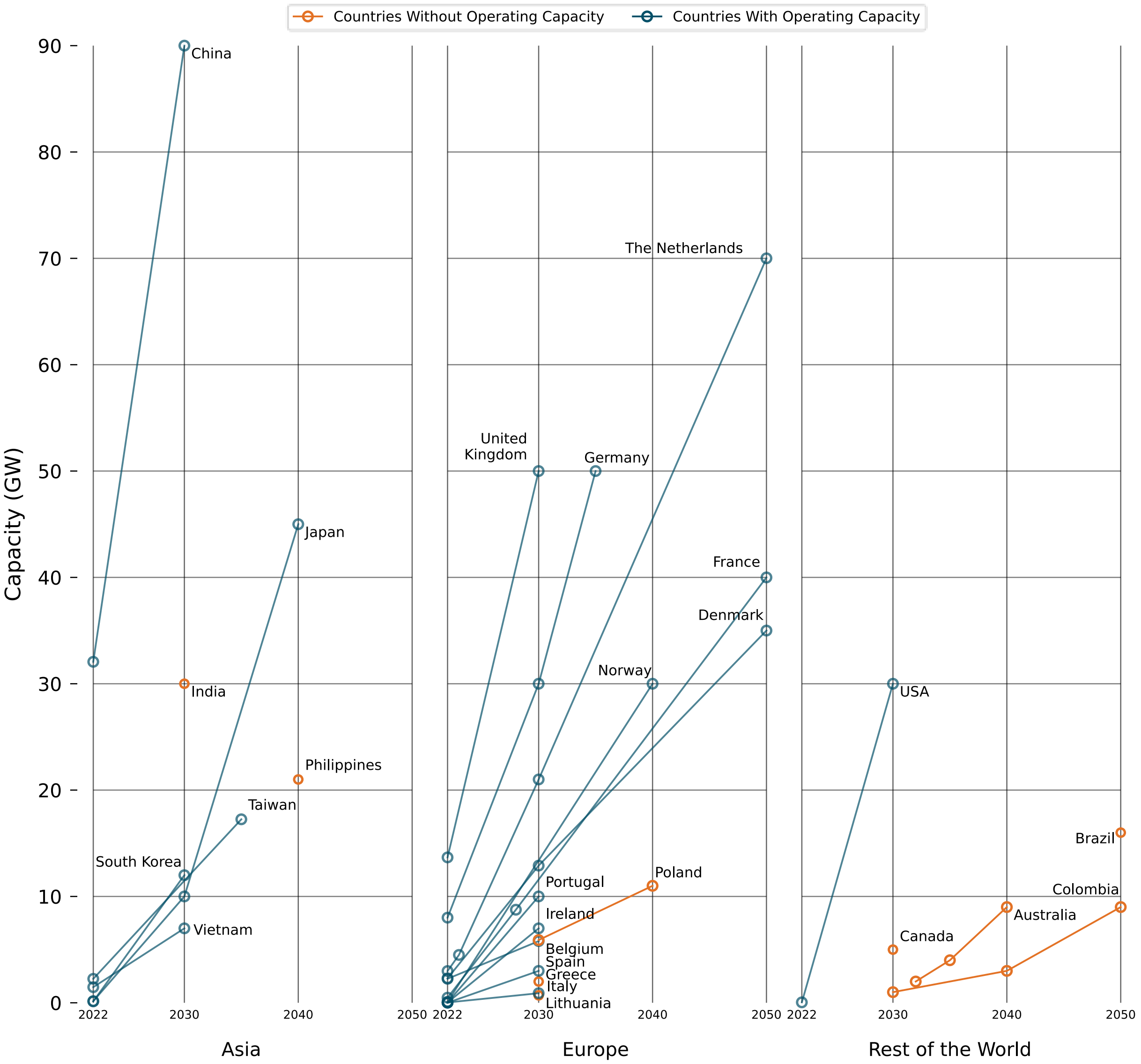

Figure 28. Country-specific offshore wind energy targets

3.3.1 European Market Activities

Table 19. European National Offshore Wind Energy Targets

Country	Installed Capacity in 2022 (GW)	Target(s)	Key Developments or Procurements	Source(s)
Belgium	2.26	5.4–5.8 GW by 2030	The objective is to realize an additional production of 3.15–3.5 GW in the Princess Elisabeth Zone. The Minister of Energy has stated a desire for a future potential target of 8 GW by 2030.	FPS Economy (2023); Wind Europe (2022a)
Denmark	2.31	12.9 GW by 2030; 35 GW by 2050	The Danish government signed a joint declaration to make the North Sea a green powerhouse in Europe.	Fine (2022)
Finland	0.04		The national climate and energy strategy to become carbon neutral by 2035 intends to have the first large-scale offshore wind energy projects operational by 2030, and several more in production by 2035.	Ministry of Economic Affairs and Employment of Finland (2022)
France	0.48	6–8.75 GW by 2028; 40 GW by 2050	French government signs offshore sector deal with wind energy industry to build over 50 offshore wind plants by 2050.	Durakovic (2020); Wind Europe (2022b)
Germany	8.01	30 GW by 2030; 50 GW by 2035	Plans set in place for 1 GW of wind-powered green hydrogen production at sea by 2030.; Berlin will deploy 4 GW of wind energy capacity at sea annually from 2027 on.	Reuters (2023); Ivanova (2022)
Greece	0.00	2 GW by 2030	The parliament approved Greece’s first offshore wind law.	Tisheva (2022)
Ireland	0.03	7 GW by 2030	The Irish government increased the 2030 offshore wind target from 5 to 7 GW.	renews.biz (2022)
Italy	0.09	0.9 GW by 2030	Italy’s current target is 900 MW, but a target of 3.5 GW of floating wind by 2030 is being considered.	Wind Europe (2019); OWC (2022)
Lithuania	0.00	0.7 GW by 2030	The Baltic country submitted a National Energy and Climate Plan to the European Commission.	Radowitz (2019)
Norway	0.09	30 GW by 2040	Norway’s prime minister announced the country’s goal of 30 GW of offshore wind capacity by 2040.	Wind Europe (2022c)
Poland	0.00	5.9 GW by 2030; 11 GW by 2040	Government pledges to launch a new auction system and to set aside € 22.5 billion for offshore wind energy development over the coming two decades to reach these targets.	Wind Europe (2021a)

Country	Installed Capacity in 2022 (GW)	Target(s)	Key Developments or Procurements	Source(s)
Portugal	0.03	10 GW by 2030	Portugal has increased the target for its debut offshore wind power auction to 10 GW.	Reuters (2022)
Spain	0.01	3 GW by 2030	The Spanish government has approved an offshore wind road map that aims to install up to 3 GW of floating offshore wind energy in Spanish waters by 2030.	Wind Europe (2021b)
Sweden	0.19		The Swedish government has launched a search for areas to support the plan to generate 120 terawatt-hours annually.	Durakovic (2022b)
The Netherlands	2.99	4.5 GW by 2023; 21 GW by 2030; 70 GW by 2050	The Climate Agreement (2019) and the coalition agreement (2021) include a commitment to maintain the offshore wind energy policy. The government has presented its offshore wind energy road map.	Government of the Netherlands (n.d.); Buljan (2022a)
United Kingdom	13.67	50 GW by 2030	The UK Energy Strategy aims to dedicate 5 GW to floating offshore wind.	Wind Europe (2022d)

3.3.2 Asian Market Activities

Table 20. Asian National Offshore Wind Energy Targets

Country	Installed Capacity in 2022 (GW)	Target(s)	Key Developments or Procurements	Source(s)
China	32.06	90 GW by 2030	The regional cumulative targets by 2030 increased to 90 GW.	Wood Mackenzie (2023)
India	0.00	30 GW by 2030	The Union Ministry of New and Renewable Energy has set a target of installing 30 GW by 2030.	Infrastructure Investor (2018)
Japan	0.15	10 GW by 2030; 30–45 GW by 2040	The Japanese government aims to deploy 45 GW by 2040 as part of its 2050 decarbonization target.	Power Technology (2020)
South Korea	0.13	12 GW by 2030	South Korea’s president reaffirms goal of 12 GW of offshore wind energy by 2030.; The Framework Act on Low Carbon, Green Growth sets an optimistic scenario of 18–20 GW by 2030.	InfoLink Consulting (2021); Skopljak (2020a)
Oman	0.00	-	Oman calls for 16 GW of wind energy by 2040 but offshore wind energy is not specified.	McQue (2021)

Country	Installed Capacity in 2022 (GW)	Target(s)	Key Developments or Procurements	Source(s)
Philippines	0.00	21 GW by 2040	The Department of Energy of the Philippines published its Offshore Wind Roadmap to aim for that deployment ambition.	Pinsent Masons (2022)
Taiwan	2.25	15 GW over 10 years between 2026 and 2035	The Ministry of Economic Affairs said that 1.5 GW of offshore wind capacity would be added each year from 2026 until 2035, instead of the previously planned 1 GW.	Yihe (2021)
Vietnam	1.47	7 GW by 2030	The Ministry of Industry and Trade of Vietnam published a new Power Development Plan VIII draft with new capacity targets.	GWEC (2022a)

3.3.3 Rest of World

Outside of Europe and Asia, Australia, Brazil, Colombia, and Algeria all took steps in 2022 toward developing offshore wind energy in the coming decades. The United States has the largest target in this group with the administration's 30-GW-by-2030 goal.

Table 21. Rest-of-the-World National Offshore Wind Energy Targets

Country	Installed Capacity in 2022 (GW)	Target(s)	Key Developments or Procurements	Source(s)
United States	0.04	30 GW by 2030	The current midterm national target is 30 GW by 2030. Achieving this target could unlock a pathway to 110 GW by 2050.	
Canada	0.00	5 GW by 2030	Nova Scotia has set a target to offer leases for 5 GW of offshore wind energy by 2030.	Nova Scotia (2022)
Australia	0.00	2 GW by 2032; 4 GW by 2035; 9 GW by 2040	The Victorian Offshore Wind Policy Directions Paper sets nation-leading policy targets.	The Victorian Government (2022)
Brazil	0.00	16 GW by 2050	Brazil's government long-term energy expansion plan sees the potential to deploy 16 GW by 2050.	Radowitz (2020)
Colombia	0.00	0.2–1 GW by 2030; 0.5–3 GW by 2040; 1.5–9 GW by 2050	The Colombian Ministry for Mines and Energy launched the Roadmap for the Deployment of Offshore Wind Energy in Colombia. The road map shows the offshore wind potential from a low-case to a high-case scenario.	Argus (2022)

4 Offshore Wind Energy Technology Trends

This section details offshore wind energy technology trends in 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. These recent cost reductions have allowed fixed-bottom offshore wind systems to compete with existing electricity generation technologies in some energy markets without subsidies. 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.

4.1 Global Offshore Wind Energy Siting Trends

Figure 29 summarizes water depth, distance to shore and project size, and development status for global offshore wind energy projects in the pipeline. Note that U.S. projects are outlined in orange; they stand out as being larger, and most are at least 20 km from shore and between 20 m and 60 m in depth.

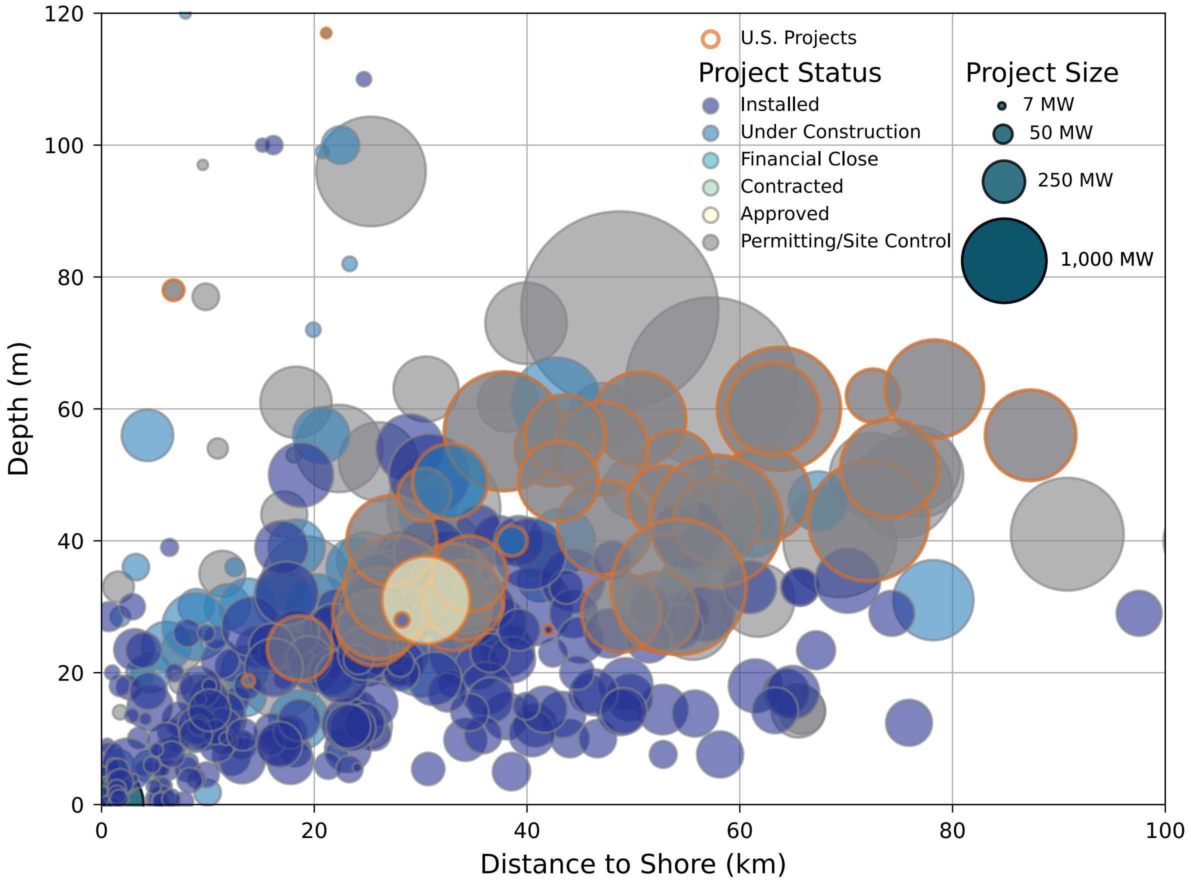

Figure 29. Global offshore wind energy project depths and distances to shore

Newer projects show a trend toward increased size, deeper waters, and farther from shore. Figure 30 and Figure 31 explore these siting trends over time and by region.

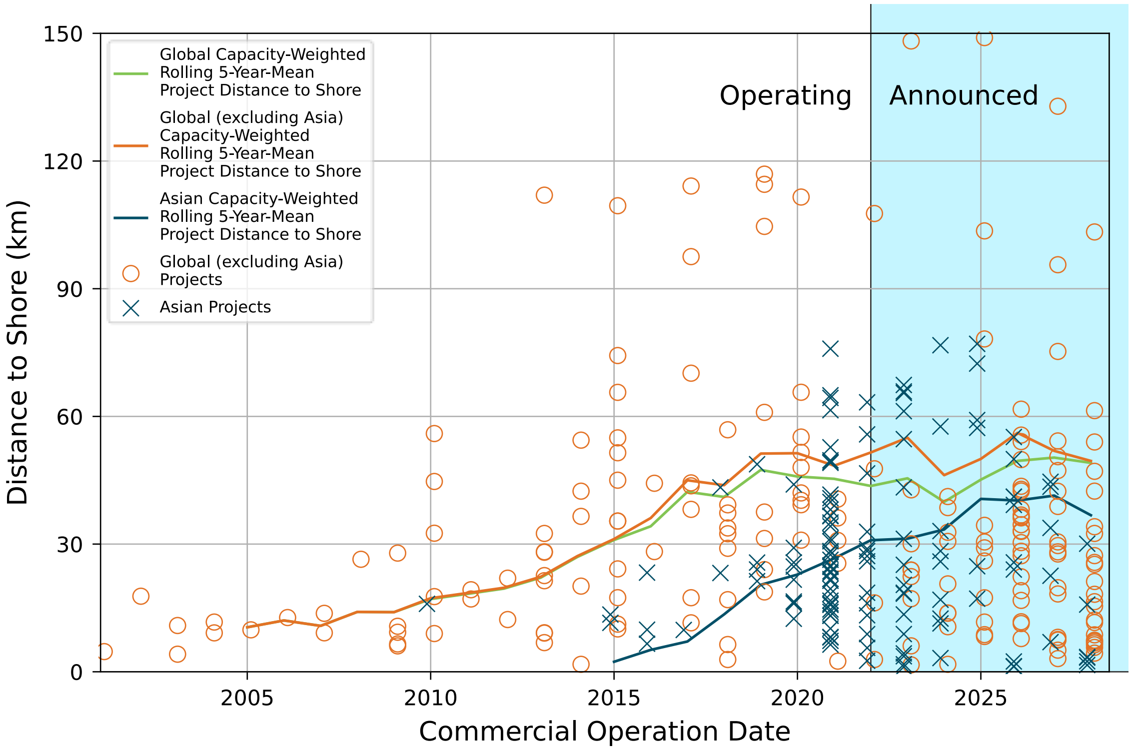

Figure 30. Distance to shore for global offshore wind energy projects (excludes floating)

Figure 30 illustrates how global projects have been installed farther from shore over time. This trend continued in 2022, after a slight dip in the global capacity-weighted average distance from shore in 2021, which was largely due to the volume of nearshore projects coming online in China. Projects in Asia have generally been installed closer to shore than in the rest of the world. Averages are divided into projects in Asia (installations dominated by China) and projects for the rest of the world to better understand these regional trends. For announced projects through 2028, the data indicate that projects in Asia are approaching but not yet converging with the global average distances from shore in other regions. There is a greater degree of uncertainty for projects with later CODs.

Projects are expected to be sited in deeper waters, as shown in Figure 31. Through 2022, most projects have been installed in waters no more than 45 m deep. To date, the deepest fixed-bottom substructure in operation is located at the Seagreen offshore wind farm (Scotland), with a maximum jacket substructure installed in waters 58.6 m deep (Seagreen Wind Energy Limited 2023). Note that, as of December 31, 2022, the estimated maximum depth (61 m) in the NREL OWDB for this project was slightly higher than the developer reported upon project completion. This explains why the Seagreen Offshore Wind Farm is plotted at 61 m in Figure 31, rather than 58.6 m. Data from announced projects suggest that fixed-bottom projects could be installed in maximum depths of over 70 m in the coming years. It is likely that the 60-m-depth reference commonly used to delineate fixed-bottom and floating offshore wind resources will become blurred in the future, with floating projects in waters shallower than 60 m and fixed-bottom projects in waters deeper than 60 m. The exact depth of the economic crossover will become clearer in the coming years as the industry is working on new technologies that could enable feasible projects for fixed-bottom or floating wind at 60 m.

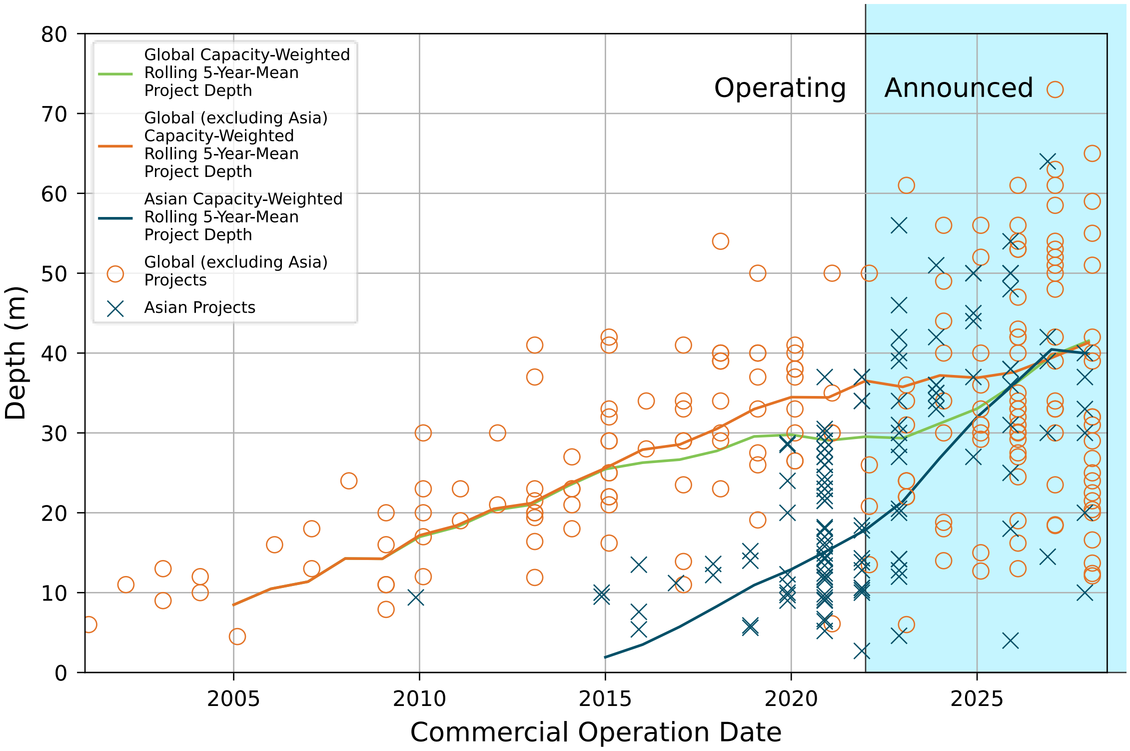

Figure 31. Maximum water depths for global fixed-bottom offshore wind energy projects (excludes floating)

As observed with distance to shore, projects in Asia have generally been constructed in shallower waters than in the rest of the world (mainly Europe) to date, though projections for announced projects indicate that water depths for projects in this region will converge with the global averages for water depth around 2027.

4.2 Offshore Wind Energy Substructures

To date, most installed offshore wind capacity uses fixed-bottom substructures, which are rigidly attached to the seabed. Floating substructure technologies connected to anchors via mooring lines are rapidly maturing, with multiple operating demonstration-scale floating projects. Figure 32 presents the substructure technology mix for currently operating projects worldwide.

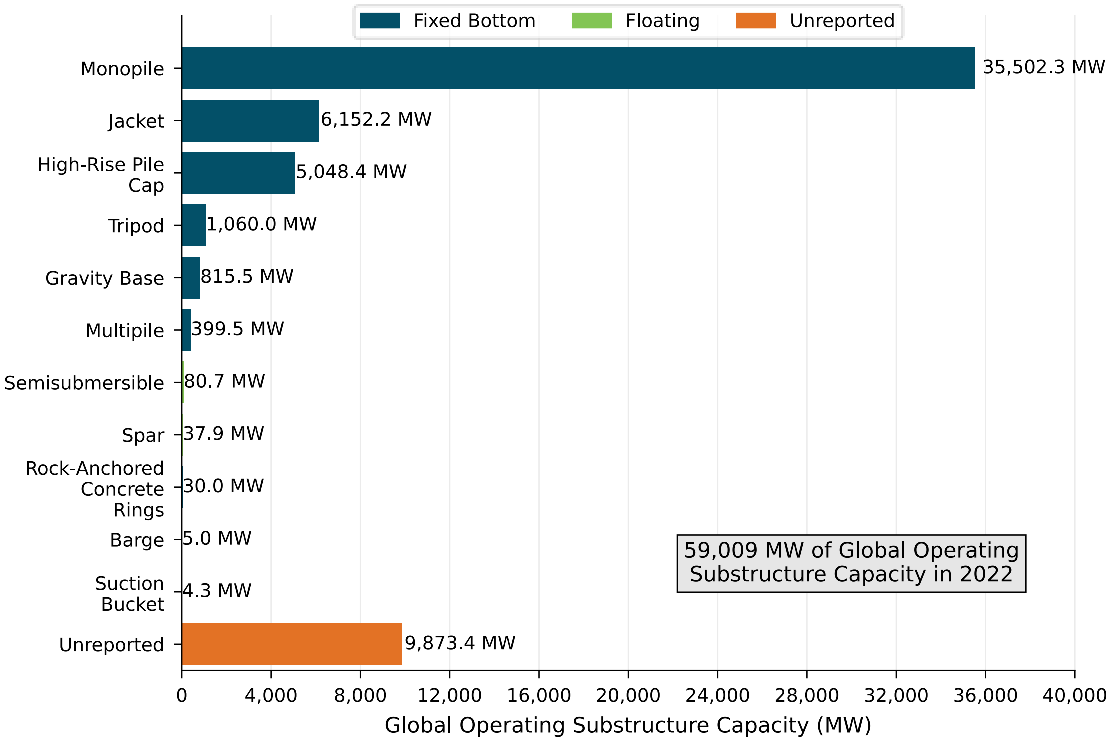

Figure 32. Offshore wind substructure technology types used in operating projects

Of the 59,009 MW of existing offshore wind energy projects, monopiles represent the most common substructure type (60.2%), followed by jackets (10.4%), pile caps (8.6%), tripod (1.8%), and gravity-base (1.4%) designs, with about 17.6% unreported in the current database. Pile cap substructures are more common in Asia than Europe and include multiple piles driven into the seabed, joined by a cap to which the wind turbine tower is mounted (Wang et al. 2018).

Figure 33 presents substructure technology choices for 109,698 MW of future projects that have announced plans publicly including both fixed bottom (blue bars) and floating (green bars) technologies. Monopiles are expected to remain the dominant choice even as floating technologies are commercialized with a 47.5% share of announced capacity. With the growing pipeline of floating projects, semisubmersibles are expected to hold 25.7% share of the announced market for all substructure types. Jacket substructures are expected to claim 14.8% of the announced market.

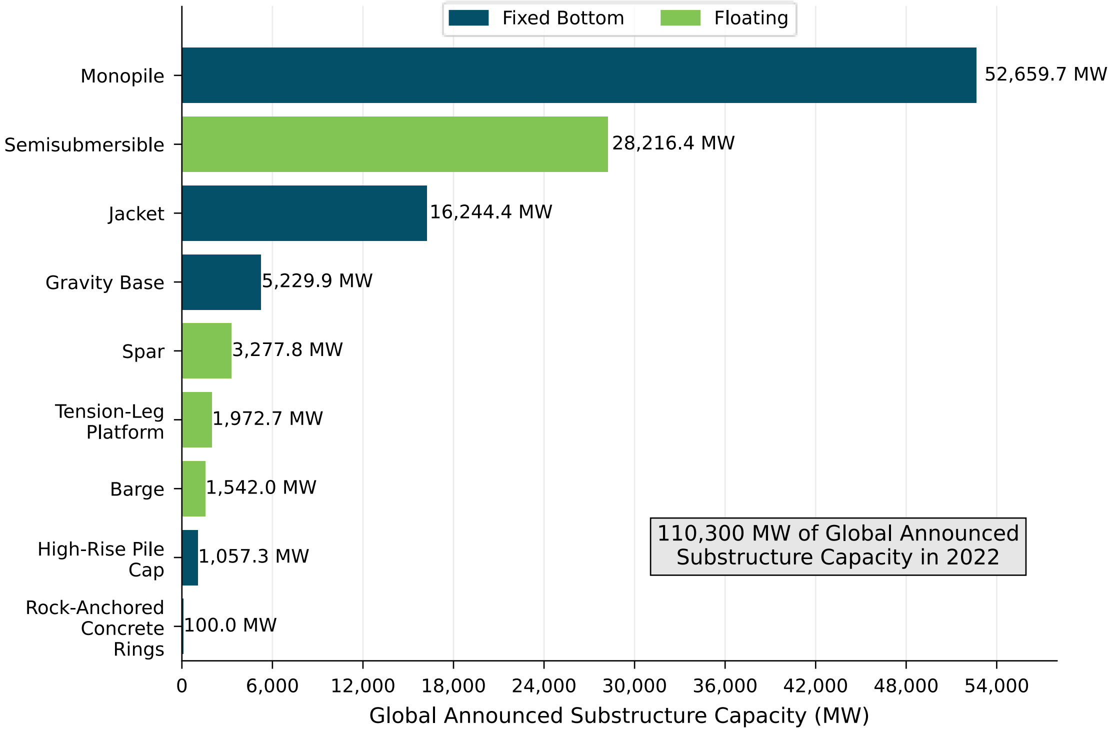

Figure 33. Announced offshore wind substructure technology for future projects

The prevalence of monopiles is largely due to the simple design and industrialization of the manufacturing process. The supply chain for monopile fabrication is the most mature and has been replicated internationally, making it more cost competitive through standardized processes and serial production. Siting projects in deeper waters, further wind turbine upsizing, unsuitable soil types (e.g., boulders, glauconite), construction noise restrictions, and preferences for domestic content could limit the dominance of monopiles in the future. However, potentially competitive substructure alternatives for fixed-bottom wind turbines are finding market entry difficult, even though the first operating offshore wind plant in the United States—Block Island Wind Farm—opted to install jacket substructures (Fried et al. 2022).

Figure 34 presents the distribution of floating substructures among operating and announced projects by the end of 2022. Floating offshore wind energy projects are expected to move from the multiturbine demonstration scale (10 MW to 50 MW) to the commercial scale (greater than 500 MW) in the next few years. While there are dozens of floating substructure designs vying for market share in the pipeline of future projects, they are broadly classified as either semisubmersible, spar, tension-leg platforms, or barges. Each design typology has trade-offs impacting draft, hydrodynamic stability, and ease of installation and repair. Semisubmersibles are the prevalent choice in both operational and announced projects (80.5%) largely due to relatively shallow drafts and stability after the wind turbine is installed on the platform. They can be assembled in port and towed out to the project location without relying on heavy-lift WTIVs.

Spars are also hydrodynamically stable after installing a wind turbine but require drafts (deep water to accommodate a large portion under the surface) that are only available at a limited number of ports globally (e.g., Norwegian fjords). Tension-leg platforms are challenging to install, but the small anchor footprint may allow for greater project capacity densities in deeper water (Cooperman et al. 2022).

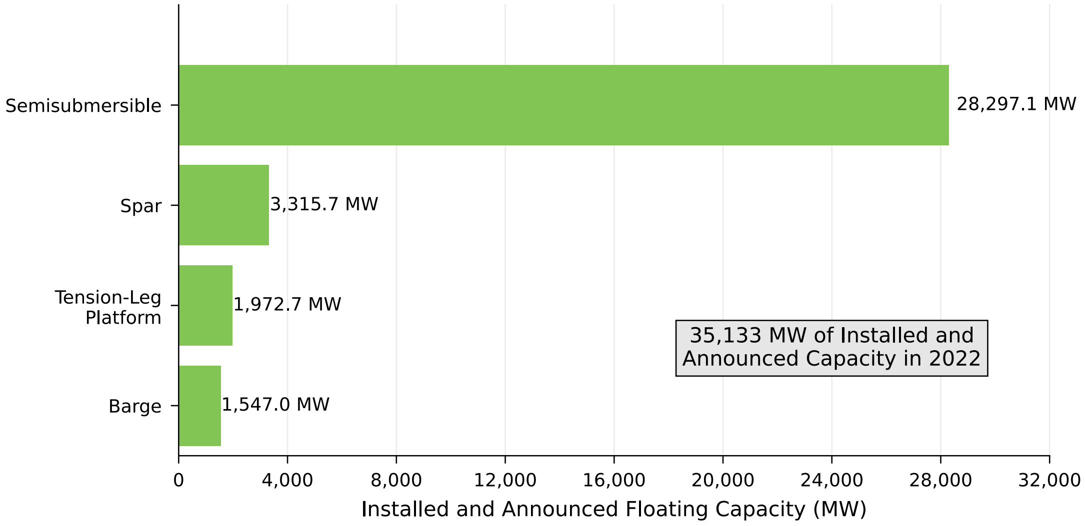

Figure 34. Global floating substructure market share (operating and announced)

4.3 Offshore Wind Turbines

Inflation, supply chain constraints, geopolitical uncertainty, and warranty provisions hampered the profitability of western wind turbine manufacturers across their land-based and offshore portfolios in 2022, with GE Renewable Energy reporting a $2.2-billion loss, Vestas reporting a $1.69-billion loss, and Siemens Gamesa Renewable Energy reporting just under a $1-billion loss in 2022 (Richard 2023; Vestas Wind Systems A/S 2023b; Siemens Gamesa Renewable Energy 2022a). Siemens Energy intends to acquire and integrate Siemens Gamesa Renewable Energy (Siemens Energy 2022). General Electric began a corporate restructuring in early 2023, combining GE Renewable Energy with other energy-related business units into a new entity called GE Vernova (Hampton and Singh 2021).

In early 2023, Siemens Gamesa and GE Renewable Energy settled a patent dispute, resolving an earlier ruling that would have barred GE from new sales of the Haliade-X wind turbine platform in the United States (GE Renewable Energy 2023; Brittain 2022). The details of the settlement were not disclosed, but the companies granted each other worldwide cross licenses for the patents in question.

Many project developers are pushing wind turbine manufacturers to supply larger turbines that they believe will be needed to achieve the lowest-cost capital expenditures for projects based on current market component prices. Larger turbines can allow developers to reduce the number of wind turbine locations for a given area, thereby lowering costs for installation, maintenance, and many Tier 1 components such as array cables and support structures. However, continued turbine upscaling has created supply chain pressures and risk to development timelines as the global industry retools its factories, test facilities, ports, and vessels for the most recent turbine size increase to 15 MW.

Figure 35 shows the trend of increasing wind turbine size over the history of offshore wind energy and highlights how installations in 2022 had a capacity-weighted-average turbine rating of 7.7 MW, rotor diameter of 174.6 m, and hub height of 116.6 m.

Offshore wind resources vary spatially but tend to experience lower vertical wind shear (change in wind speed with height) than land-based wind energy. As a result, there is less energy to be gained by increasing offshore wind tower heights and the costs can be greater due to the heavier components and higher lifting requirements. As a result, offshore wind energy developers almost always specify the lowest hub height that is needed to maintain rotor tip clearance with extreme waves and allow safe ocean navigation. This minimum blade tip clearance is usually between 25 and 30 m above the still water level.

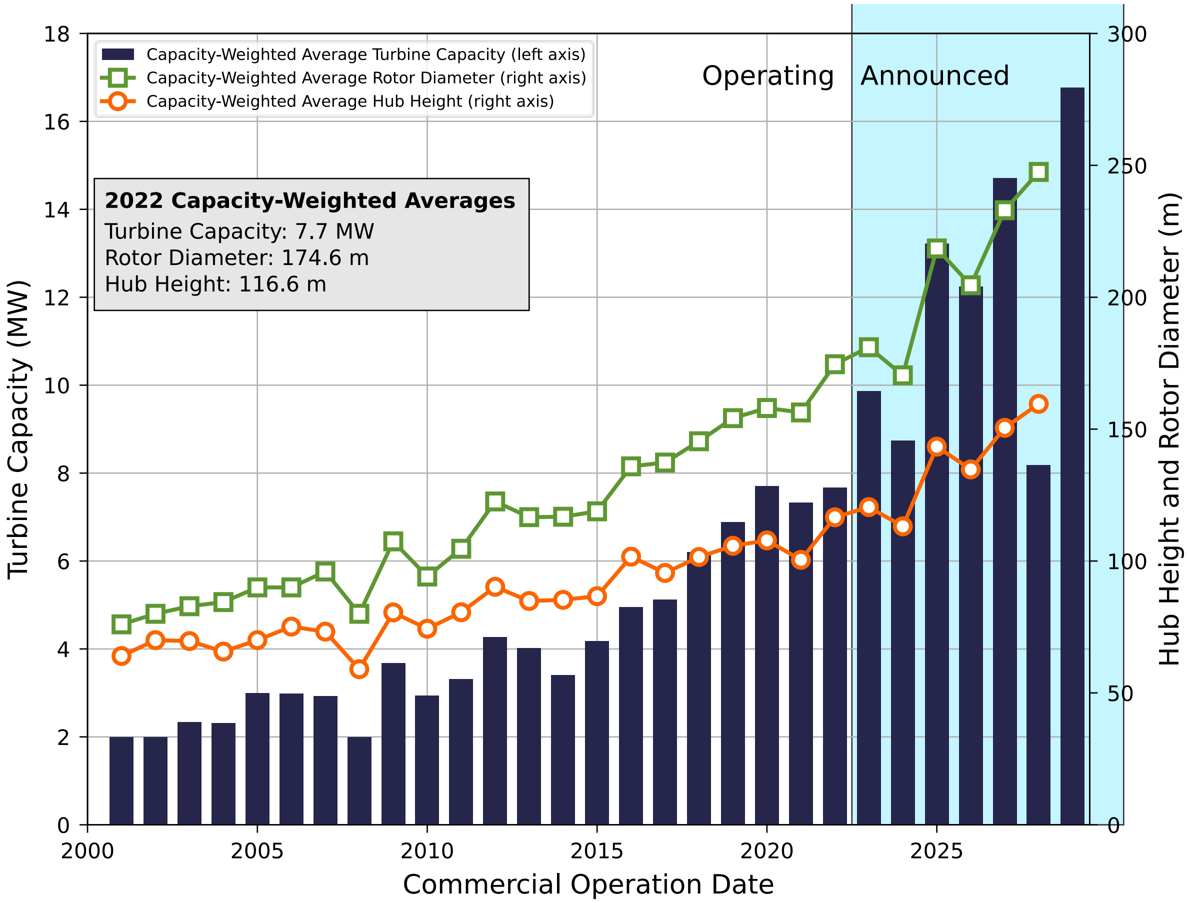

Figure 35. Global average offshore wind turbine capacities, hub heights, and rotor diameters

While the global capacity-weighted average turbine rating has yet to exceed 8 MW, wind turbines of up to 11 MW are beginning to operate at commercial scale, including the first subsidy-free offshore wind plant (Vattenfall 2022).

Figure 36 illustrates the upscaling trend for offshore wind turbines by comparing the dates of operational prototypes with annual capacity-weighted installed turbine ratings over time. Only wind turbine prototypes that could be verified as operational in a given year are included in the figure. Note the newest prototypes deployed in 2023 are shown on the right side of the line between “announced” and “operating,” which represents approximately the end of 2022. Also note that most prototype data are plotted above the average capacity-weighted turbine capacity bar for the year in which they were installed. The data are staggered horizontally only to allow multiple points to be plotted for the same generator capacity in the same year.

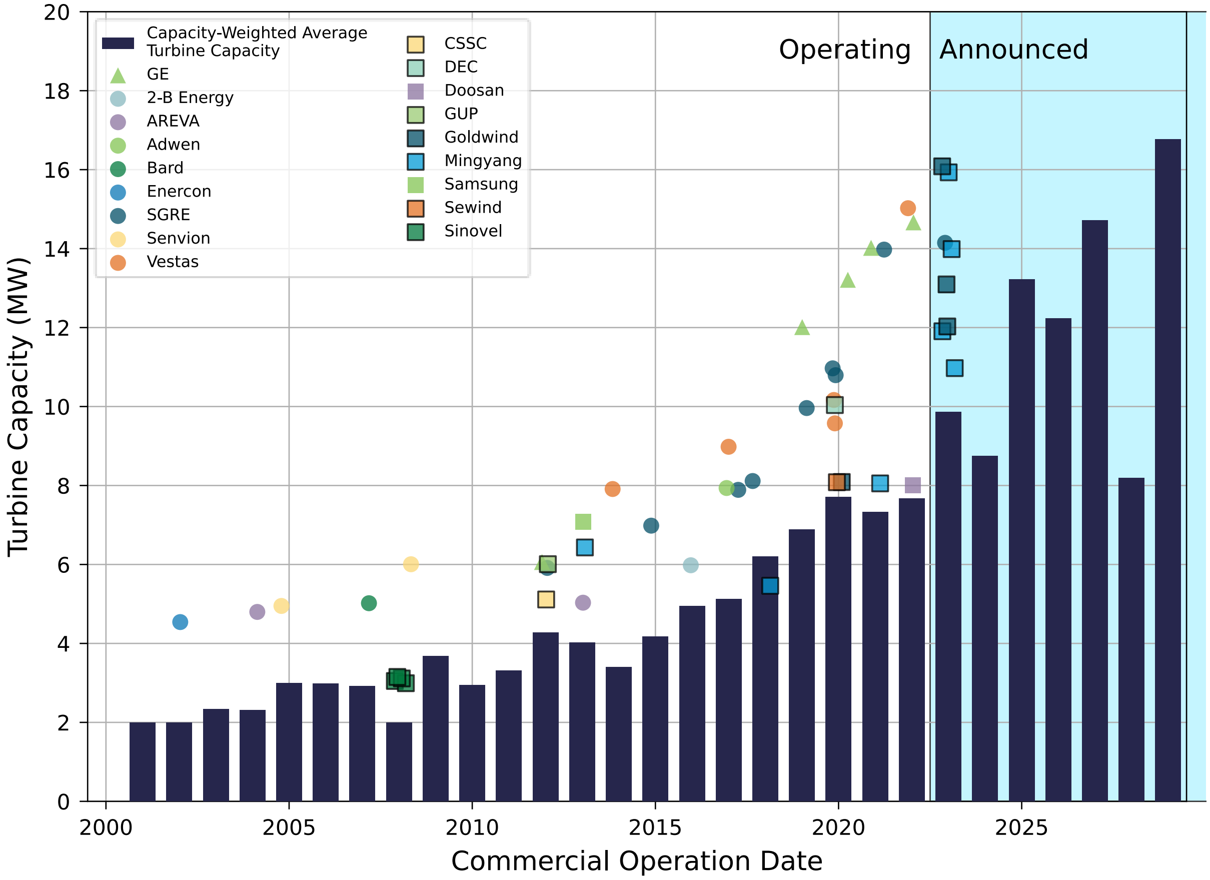

Figure 36. Comparison of offshore wind turbine prototypes with commercial offshore wind turbine growth.

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

The Vestas V236-15.0MW produced its first power near the end of 2022, and Siemens Gamesa's (SGRE) 14-236 DD prototype came online in early 2023 (Memija 2022c; Siemens Gamesa Renewable Energy 2023b.

Some of the most recent wind turbine upsizing announcements have come from Chinese manufacturers. Mingyang produced the first wind turbine blade for its prototype of the MySE 16.0-260/242 platform in December 2022, and installed a prototype offshore in June 2023 (for commissioning and testing before grid connection) with planned commercial availability in 2024 (Buljan 2022c, 2023c; Durakovic 2023b). Goldwind completed fabrication of its GWH 252-13.6MW (13.6 MW) turbine, and China Three Gorges completed manufacturing of their 16-MW wind turbine nacelles in 2022. They reported operation of these prototypes in 2023 (China Three Gorges Corporation 2022a, 2022b; Buljan 2022b).

Three other turbine manufacturers announced they are pursuing platforms of 18+ MW in early 2023. CSSC Haizhuang, a subsidiary of the China State Shipbuilding Corporation, is developing the H260-18MW offshore wind turbine with a rotor diameter of 260 m (CSSC Haizhuang 2021, 2023; Durakovic 2023a). CSSC Haizhuang stated they had completed production of the first nacelle for their 18-MW prototype. Mingyang Smart Energy indicated that their MySE 18.X-28X platform will have a rotor diameter of 280 m (Mingyang Smart Energy 2023; Durakovic 2023b). GE confirmed plans to develop a new iteration of their Haliade-X in the 17- to18-MW range (Lewis 2023a; Buljan 2023a).

Although wind turbine upscaling has been recognized as one of the primary factors in reducing offshore wind energy costs to date, there is an increasing debate about the trade-off between continuing this upscaling trend versus remaining at the current 15-MW scale and industrializing the turbine product lines and associated balance-of-plant components. Techno-economic cost analysis has shown that upscaling from 2 MW in the early 2000s to 15 MW in 2022–2023 has claimed most of the available benefits by reducing the number of wind turbines required for the same plant size. There are diminishing returns on the rewards of continued upscaling and the increased technology and market risks can be significantly underestimated (MARKETWIRE 2022; Shields et al. 2021).[26] The costs of upscaling may include project time delays, immature production lines, reduced field learning, inability to standardize and optimize wind turbines, and higher insurance costs, which may keep overall costs higher in the near term (Ferry 2023).

Based on the growth trend in prototype development shown in Figure 36, a possible conclusion is that the upscaling trend will continue. However, the current 15-MW size for offshore wind turbines is already an enormous scale that requires hundreds of millions of dollars of investment in design and the development of new prototypes. Each increase in capacity also requires massive additional investment in supporting infrastructure to handle, install, and maintain the new turbine scale, such as upgrades to factories and ports and new or upgraded vessels, and

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[26] The rotor of a 15-MW Vestas wind turbine will sweep an area that is approximately the size of eight football fields.

threatens to render investments made only a few years before for smaller wind turbine sizes obsolete.

The data in Figure 36 show the historic development timelines from prototype to commercialization. The data indicate that it usually takes many years from the development of a new turbine platform scale, beginning with the first prototype installation, to the time it is commercialized and deployed in large enough quantities to impact the average wind turbine size in the market. This development time is needed to not only prove the reliability of the turbines but also build the infrastructure and supply chains needed for serial manufacturing of the larger components that make up those turbine systems. Despite the billions of dollars in capital investments being made currently, competition among wind turbine developers and manufacturers has increased upscaling in recent years, leading to speculation of even larger platforms (Proctor 2023a, 2023c).

Figure 37 presents offshore wind turbine market share by manufacturer for operating projects and Figure 38 presents market share for announced projects.

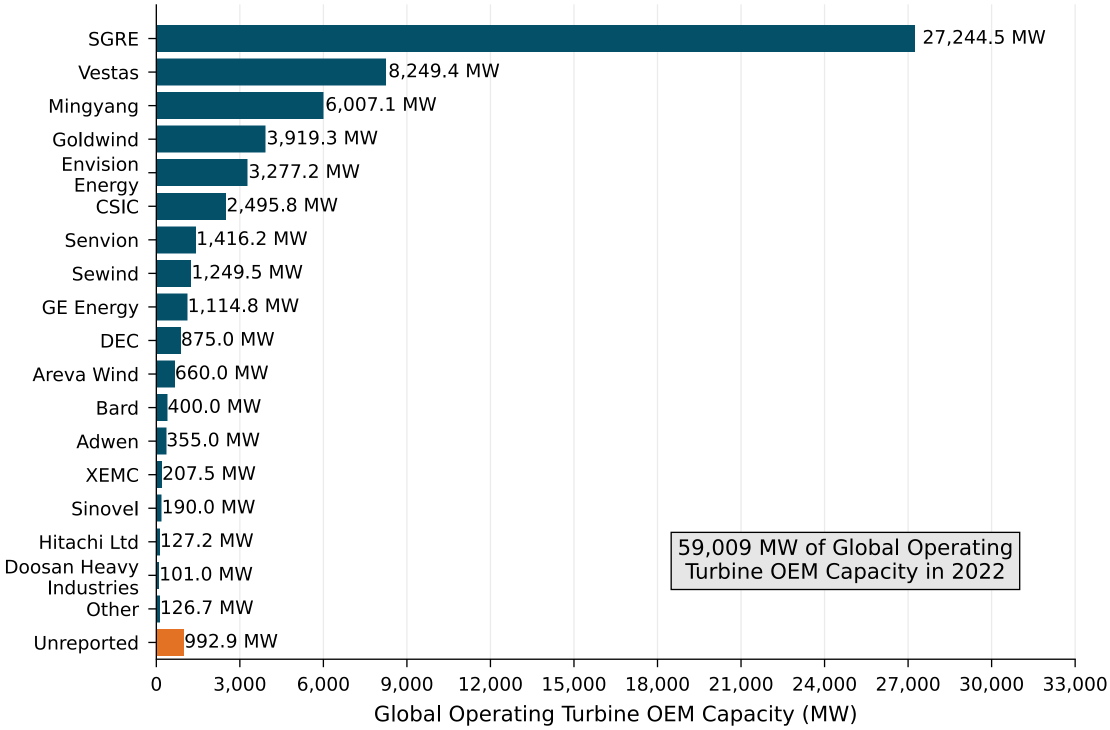

Figure 37. Offshore wind turbine manufacturer market share for operating projects.

OEM = original equipment manufacturer

Figure 37 shows that at least 46.2% of all operational offshore wind capacity is from Siemens Gamesa Renewable Energy (SGRE). Vestas wind turbines comprise the next-largest share of the operational market at 14.0%, followed by Mingyang (10.1%), Goldwind (6.6%), and Envision Energy (5.6%).

Among future projects with announced wind turbine suppliers, SGRE is expected to hold a 48.0% share of announced capacity while General Electric (18.1%), Vestas (17.8%), Doosan Heavy Industries (4.6%), and Mingyang (2.4%) have the next-largest market shares. While Chinese manufacturers have focused on the domestic market to date, Mingyang, Envision Energy, Dongfang, Goldwind, Windey, and Harbin Electric have all secured contracts for projects outside China (e.g., Vietnam, Japan, Italy, the United Kingdom, Norway, and France), representing a potential for greater competition in global offshore wind turbine markets (Barla 2023).

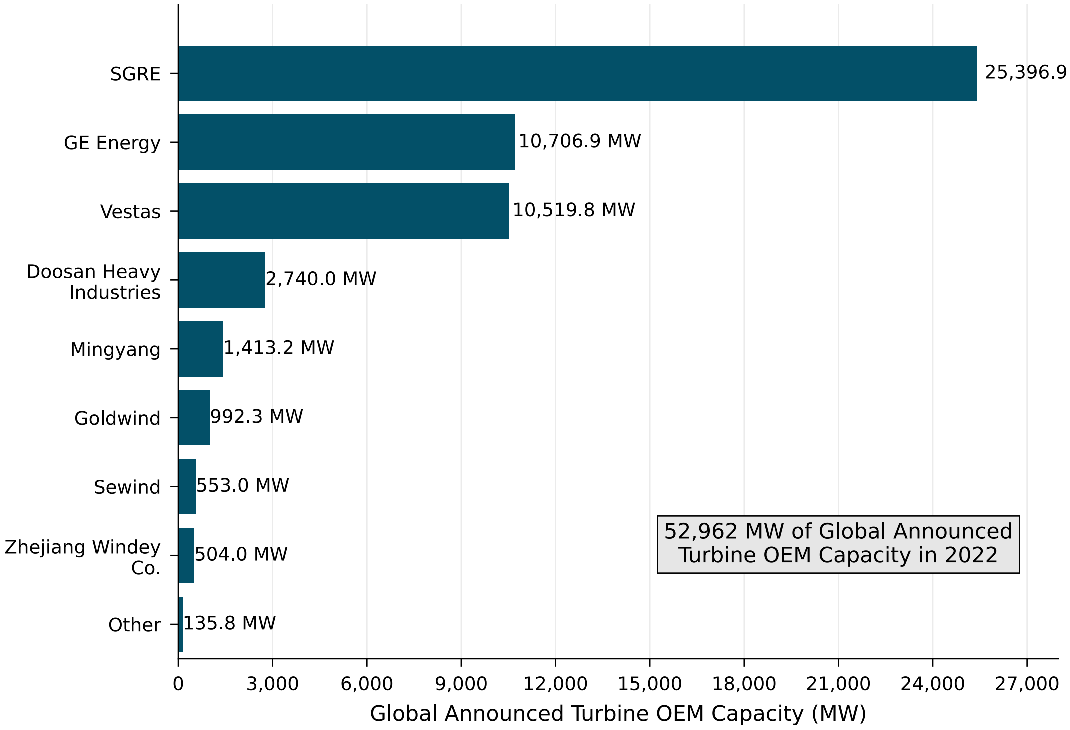

Figure 38. Global offshore wind turbine manufacturer market share for announced projects

4.4 Future Offshore Wind Technologies

As offshore wind becomes more integrated into the global energy mix, there are several global technology trends that will likely affect the long-term U.S. market and help shape the economics, infrastructure, and the degree to which offshore wind will participate among many other players in the net-zero-carbon energy transition. Research and technology development for offshore wind life cycle sustainability, its role in providing energy for storage technologies and hydrogen, and its integration and hybridization with other carbon-free technologies are ramping up throughout the industry, but significant market investments have not yet begun. Appendix B provides a summary of these emerging future technology activities.

4.5 Offshore Wind Technology Summary

The current state of offshore wind energy technology can be summarized as follows:

- Globally, projects continue to be built in deeper waters, farther from shore. This trend has been ongoing and generally indicates better technology is available to overcome these challenges combined with increased siting constraints that move projects away from shore where there may be fewer conflicts with other ocean users.
- Most operational projects have fixed-bottom monopile substructures. Monopiles are still the most common substructure choice for announced projects both globally and in the United States. The market dominance of monopiles can be largely attributed to their simplicity and manufacturing maturity, which makes them the lowest-cost option in most markets. However, alternatives may be necessary in the supply chain to avoid unsuitable soil types and construction noise, and to provide more domestically manufactured content.
- Floating offshore wind energy represents an opportunity to tap into new wind resources over deeper waters. While there is significant competition among floating substructure designs, most announced floating projects have opted to use some variation of the semisubmersible because it is expected to be the easiest to deploy from existing ports.
- Offshore wind energy developers continue to choose the largest wind turbines available. Multiple firms (e.g., Vestas, Siemens Gamesa, and General Electric) deployed operational prototypes in the range of 15 MW before the end of 2022. Several manufacturers (e.g., Mingyang, Goldwind/CSSC Haizhuang, and General Electric) announced plans to develop 16-MW and 18-MW offshore wind turbines in the future.
- Calls to slow the pace of upsizing grew as concerns about availability of port, vessel, and manufacturing infrastructure became more apparent, but the costs of delayed industrialization and higher technical risk have not yet been evaluated. Nevertheless, some wind turbine manufacturers claim they are moving to larger turbine nameplate ratings.
- Fierce competition persists among wind turbine manufacturers even as western manufacturers faced significant financial challenges—attributing billions of dollars of financial losses to supply chain constraints, geopolitical uncertainty, and warranty provisions.

5 Cost and Price Trends

5.1 Cost and Price Overview

Supply chain constraints, higher commodity prices, and rising interest rates have resulted in cost increases around the world for offshore wind energy projects that are in the process of procuring components during 2022/23. This section presents cost trends from empirical project data and estimates from leading research organizations, both for fixed-bottom and floating offshore wind energy technologies. Our cost reporting and figures in this section focus on projects that have attained COD in 2022. Because component procurement typically precedes COD by several years, the data shown for 2022 do not capture the rise in procurement prices during 2022/23 because many of the major components were procured prior to major inflation increases. Nonetheless, we still highlight these cost drivers in this section.

Our data sources report cost trends on a regular basis and are established references within the sector with at least a basic level of review and validation. 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 different in practice, 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, and price data are sourced from public tenders. The project sample size varies across the cost and price metrics featured in this section.

5.2 Fixed-Bottom Offshore Wind Energy Cost Trends

5.2.1 Levelized Cost of Energy Trends

The estimated levelized cost of energy (LCOE) for a hypothetical, commercial-scale offshore wind project in the United States is estimated to be \$89/megawatt-hour (MWh) on average (using mid-case estimates only), with a wide range of \$59/MWh to \$144/MWh (Figure 39). This difference can be explained in good part by varying assumptions about whether the costs represent commercial (vs. precommercial) projects. The sources depicted in Figure 39 are from leading research organizations and consultancies that have published LCOE estimates and projections during 2022. These costs represent an increase of about 6% on average compared to 2021 U.S. estimates of LCOE (Musial et al. 2022). However, such growth might underestimate the cost increases observed over the past year. We reckon that this is a result of cost reporting, as it tends to be retrospective (i.e., projects with a COD in 2023 typically procure 1–3 years ahead) and that it often takes a longer-term view, which does not (fully) represent the variability of costs in any single year. Considering only the 6% increase noted for 2022, offshore wind costs have fallen approximately 50% since 2014 (Wiser et al. 2021). Increasing LCOE values were found to extend to all renewable and fossil-fueled power generation sources as well. For instance, global benchmark solar photovoltaic (fixed-axis) and land-based wind energy costs between 2021 and 2022 have seen recent increases of 14% and 7%, respectively (BNEF 2022c). Electric generation sources powered by fossil fuels have also been subject to cost escalation because of global fuel and carbon price increases (Henze 2022). The estimates shown in Figure 39 indicate a fixed-bottom offshore wind LCOE of $63/MWh on average (using mid-case estimates only) by 2030.

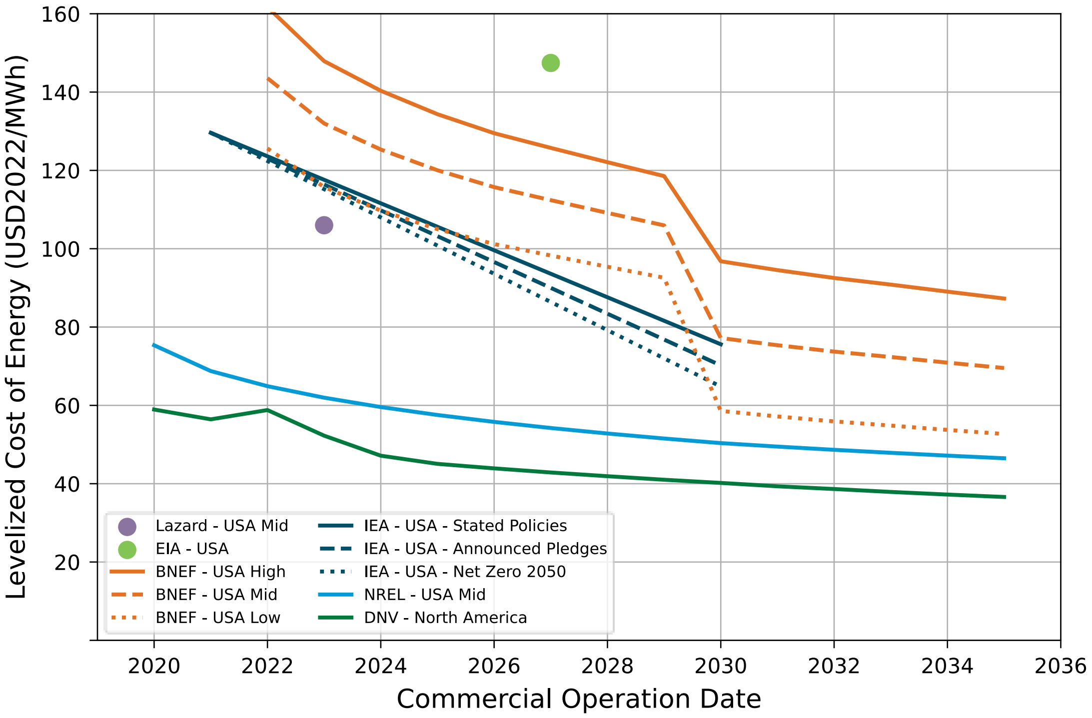

Figure 39. LCOE estimates for fixed-bottom offshore wind energy in the United States.

Sources: Lazard (2023); U.S. Energy Information Administration (EIA; 2022); BNEF (2022b); International Energy Agency (2022); NREL (2022); DNV (2022).

Several U.S. developers indicated that the disrupted supply chains and higher inflation for commodities (e.g., steel, copper, energy) and offshore goods, services, and labor have caused offshore wind energy costs to rise since 2021. Interest rates and prices for certain goods and materials used in offshore wind have seen a dramatic increase since 2020. These factors have resulted in significant reported increases in capital expenditures and LCOE. For instance, a recent industry survey suggests cost inflation in the offshore wind sector of 11%–20% since 2021, with a smaller number of respondents indicating increases of more than 30% (Westwood Global Energy Group 2023; Memija 2023b).[27] Such cost inflation has reportedly increased land-based wind turbine prices by 38% (Ferris 2023) with a similar magnitude that might apply to offshore wind turbine pricing.

Concerns about rising project costs were filed by Mayflower Wind (now SouthCoast Wind) and Commonwealth Wind in their appeal to contest the Massachusetts Department of Public

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[27] The survey from Westwood Global Energy Group (2023) refers broadly to "cost inflation" without specifying what cost component specifically (e.g., levelized cost of energy or capital expenditure) respondents refer to.

Utilities' approval of PPA contracts, "claiming that the PPAs were no longer financially viable" (Young 2023; SouthCoast Wind 2023). The impacts of inflation on costs are likely widespread but may affect project entities differently because of (among other things) the timing of procurement and the extent to which they have indexed their assets for inflation (i.e., to hedge their procurement against inflation risk) (Eversource 2021). Some states have now implemented a price adjustment factor that is part of the solicitation award (e.g., as stipulated in New York's third large-scale offshore wind solicitation of 2022–2023) to mitigate the adverse effects of inflation on project economics.

5.2.2 Capital Expenditure Trends

Capital expenditures (CapEx) are 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, with the 5-year rolling average (2018-2022) reaching approximately $3,550/kilowatt (kW) for projects installed in 2022 (COD) globally. The 5-year rolling average of CapEx for European and U.S. projects is reported to be higher at just above $4,000/kW, while the Asian 5-year rolling average is just above $3000/kW. While the reported CapEx in 2022 are higher in Europe and the United States than in Asia, the two markets have been converging since 2015.

Reported global project data suggest a decline of the 5-year rolling capacity-weighted mean CapEx globally from $3,550/kW in 2022 to about $3,000/kW by the late 2020s but recent cost increases may not be completely accounted for in these long-term projections. Note that the annual project data also plotted in Figure 40 indicate considerable variation of CapEx within a given year.

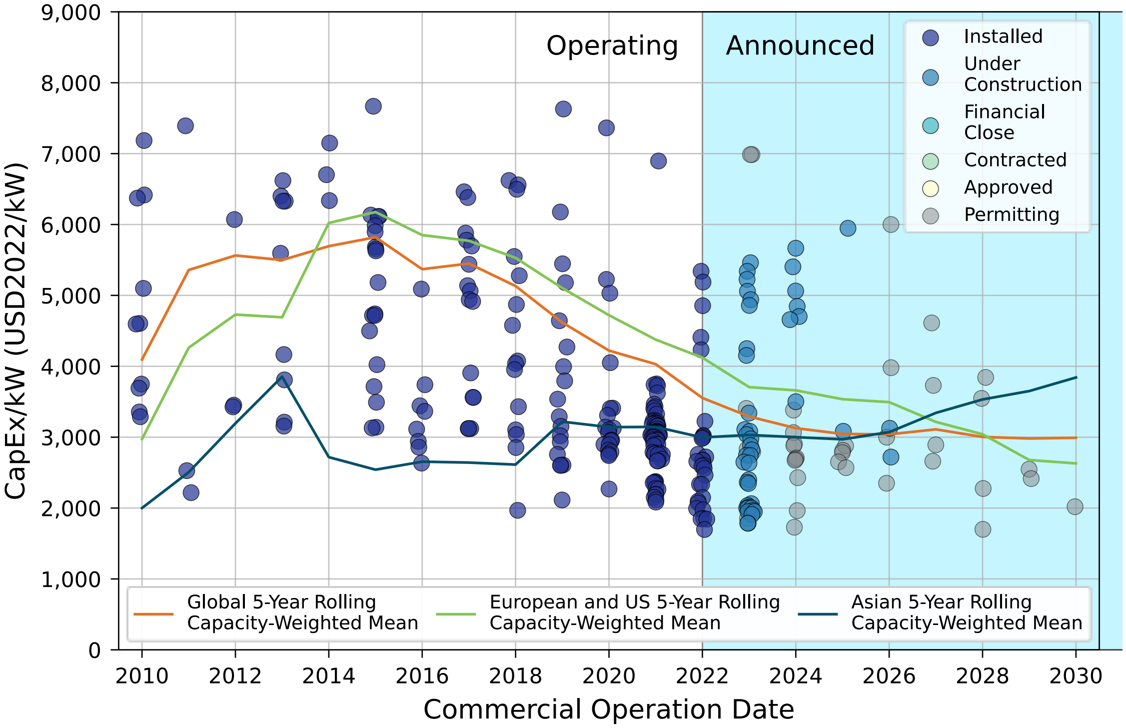

Figure 40. Capital expenditures for global offshore wind energy projects

Several factors contribute to 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 plant)
- Project size
- Differences in supply chains (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.

5.2.3 Operational Expenditures Trends

Data on operational expenditures (OpEx) are not publicly available for the only two U.S. operating projects—the Block Island Wind Farm (30 MW) and CVOW pilot project (12 MW). Using industry research based on European experience, we estimated OpEx to range from $64/kW-year to $97/kW-year for U.S. projects with a COD between 2021 and 2030. This estimated range is above the reported OpEx of $51/kW-year by Dominion Energy (announced

2026 COD), although Dominion might be able to realize lower OpEx through economies of scale from its relatively large project size of 2,587 MW.

5.3 Floating Offshore Wind Energy Cost Trends

Various research organizations estimate that the LCOE for U.S. floating offshore wind energy projects will decline from approximately \$82–\$255/MWh in 2022 to \$66–\$128/MWh in 2030 (Figure 41). This wide LCOE range can be attributed in good part to varying assumptions as to whether a precommercial or commercial-scale plant is modeled. The depicted costs from NREL ("USA Mid," "Oregon," "Hawaii") are representative of a commercial-scale project, even though the floating sector is currently at a precommercial, multiturbine demonstration phase. These estimates assume commercial-scale floating wind power plants and learning-curve benefits commensurate with a mature industry. The cost of floating offshore wind energy technology is currently based on a small set of data from the first phase of demonstration projects.

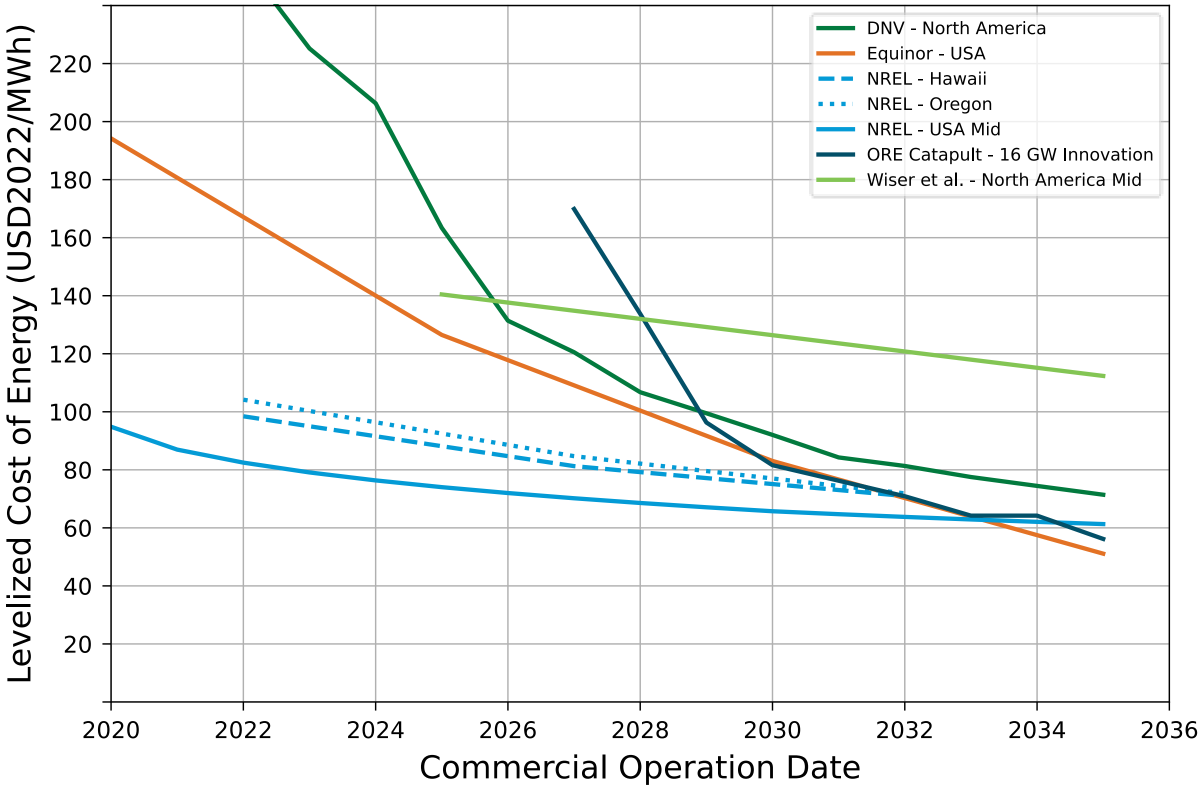

Figure 41. U.S. LCOE estimates for floating offshore wind technologies.

Sources: DNV (2022); Equinor (2021); NREL - Hawaii, Shields et al. (2021); NREL - Oregon, Musial et al. (2021); NREL - USA Mid, Averaged from NREL spatial cost studies; ORE Catapult (2021); Wiser et al. (2021).

Generally, floating offshore wind costs are predicted to decrease significantly (see e.g., Wiser et al. 2021). This prediction is consistent with general trends for early-stage technologies, which usually see significant cost reductions as their market expands. 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 more remote siting that could offset the higher O&M and installation costs associated with greater distances to shore and harsher meteorological conditions.

5.4 Financing Trends

In contrast with 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 upfront 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, 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 for offshore wind energy projects in Europe has become more favorable since the mid-2000s, as demonstrated by the growing debt share and decrease in the pricing premium over the benchmark London Inter-Bank Offered Rate (LIBOR) and Secured Overnight Financing Rate (SOFR) interest rates. Notably, during 2021 the LIBOR/SOFR interest base rates increased by more than 4%, which has significantly increased the cost of financing for offshore wind (and all other energy assets). Between 2018 and 2022, U.S. financing terms have been reported to range between 50% and 80% (debt share) and 20%–50% (equity share), with the equity portion being split between sponsor and tax equity (Table 22). From a review of Martin (2022), we infer that U.S. offshore wind energy premiums over LIBOR/SOFR have not changed considerably in 2022 from the prior year.

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

Year	Coverage	Debt/Sponsor Equity/Tax Equity (%)	Pricing Over LIBOR/SOFR (Basis Points)[28]	Contingency Budget (%)	Source
2006–2007	Europe	60/40/0	150–200	12–15	Guillet (2022)
2009–2013	Europe	65/35/0	300–350	10–12	Guillet (2022)
2014–2015	Europe	70/30/0	200–250	15–20	Guillet (2022)
2016–2017	Europe	75/25/0	150–225	12–15	Guillet (2022)
2018–2019	Europe	75/25/0	125–175	8–12	Guillet (2022)
	United States	50/20/30	-	-	Martin (2019)
2020–2021	Europe	80/20/0	125–175	8–10	Guillet (2022)
	United States	55/45 (combined)[29]	-	-	Martin (2021)
2022–2023	United States	55/45 (combined)	-	-	Martin (2022)

Note: Year 2008 not available from sources.

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

[29] The split between sponsor and tax equity is not clear from the source (Martin 2021) and is reported here as an aggregate. The same limitation applies to the reporting in 2022–2023.

6 Future Trends

Fallout from recent cost increases may hinder many U.S. offshore wind energy projects in the near term with significant relief possible from the Inflation Reduction Act.

The first two commercial-scale offshore wind plants in the United States, Vineyard Wind 1 (800 MW) and South Fork Wind (132 MW), are scheduled to deliver power to the grid in 2023, which could help establish offshore wind to potentially become one of the principal energy sources for domestic grid electrification and decarbonization.

However, many U.S. offshore wind energy projects are struggling to remain solvent after rising costs from inflation and higher financing have eroded profit margins and caused some projects to cancel offtake agreements. This may impact projects that have negotiated offtake agreements prior to the current rise in cost and are not protected with robust inflationary hedging strategies, particularly those expecting to start commercial operations between 2025 and 2028. Some projects have asked their offtake counterparties to renegotiate their offtake terms (e.g., Massachusetts Department of Public Utilities 2022). For future power purchase agreements, there may be some added buffers as some states have since introduced inflation indexing as part of their forthcoming offshore wind procurements.

The IRA, passed in 2022 at the height of inflation, provides a strategically important instrument to soften the adverse macroeconomic impacts affecting offshore wind project costs. The act extends the 30% investment tax credit at least a decade and offers bonuses that incentivize investments in energy communities and the domestic supply chain so that U.S. businesses can become established to support this emerging industry. The IRA can have a significant positive impact in offsetting the challenges that threaten this nascent industry from achieving commercial success.

Assuming today's significant hurdles can be overcome, growth in the U.S. market could parallel anticipated and massive continued global market growth. According to BNEF (2022a) and 4C Offshore (2023) global forecasts, offshore wind energy could reach about 380 GW or 394 GW by 2032, representing a sixfold increase in capacity over the next decade. By region, China is forecasted to deploy between 60.5 GW and 113 by 2032, increasing its market share to 19%–36% while the European market continues to grow and is expected to hold roughly 34%–39% of the installed global offshore wind capacity by 2032. Other Asian countries (e.g., Taiwan, Korea, Japan, and Vietnam) are forecast to have a 13% to14% share of installed capacity, whereas the U.S. portion is forecast to be about 11% to 19% of the global total by 2032. These forecasts notwithstanding, global markets could potentially change unpredictably in the future because the number of countries currently generating electricity from offshore wind is also expected to double over the next decade, expanding into places like Brazil, India, and Australia (Ferris 2022).

State-level procurement targets strengthened by federal policy are likely to remain the predominant U.S. market driver, but ambitious project timelines depend on maintaining a commensurate pace in supply chain and infrastructure build-out, regulatory approvals, and the financial integrity of prenegotiated utility and corporate power offtake agreements to avoid industry delays. However, around $17 billion has already been announced or invested in infrastructure, supply chain, and early project capital since 2014 (including $8.1 billion in 2022), which suggests a robust emerging offshore wind energy industry in the North and mid-Atlantic regions (Business Network for Offshore Wind 2023; ACP 2023a). Moreover, commercial offshore wind leasing is beginning to ramp up in other U.S. regions such as the Pacific Coast, Gulf of Mexico, and Gulf of Maine. Thirteen states having planning goals or procurement mandates for over 100 GW of offshore wind capacity by 2050.

Emerging energy technologies such as floating offshore wind may stimulate long-term development opportunities.

Wind energy is generally recognized as an important means to meet the immense challenge of electrifying our energy supply. A recent NREL study to investigate the current U.S. goal to achieve a greenhouse-gas-emissions-free power sector by 2035 indicates that achieving this goal could require more than two terawatts (2,000 GW) of wind and solar (Denholm et al. 2022). Specifically, the study estimates that between 1,000 GW and 1,200 GW of wind energy will be needed. Because the current U.S. capacity of wind energy is about 140 GW (mostly all on land), the result implies that almost 1,000 GW of additional wind may be needed. Offshore wind may contribute a significant fraction, but more studies are needed to assess the ratio of land-based wind energy to offshore wind energy.

As deployment increases, offshore wind turbines will likely be sited farther from shore. Shallow-water sites are already becoming scarcer, and to meet decarbonization targets more offshore wind resource area will be required. This means that floating wind technology will be needed to access sites with deeper water. In September 2022, the Biden administration announced the Floating Offshore Wind Shot, which calls for a nationwide, concerted effort to reduce the cost of floating offshore wind by 70% to $45/MWh, and sets a goal to deploy 15 GW of floating offshore wind capacity by 2035 (DOE 2022). This level of cost reduction can be achieved by simultaneously developing and implementing multiple innovations within the floating system design while concentrating on volume production, standardization, industrialization of the supply chain, and reaping the benefits of the associated global industry experience (Barter et al. 2020; Beiter et al. 2016). Techno-economic cost modeling indicates that floating offshore wind technology has the potential to achieve the same cost (or lower) as fixed-bottom offshore wind (Beiter et al. 2016, 2017; Gilman et al. 2016). In concert with the 15-GW floating offshore wind energy deployment goal, the U.S. Department of the Interior is engaged in planning for potential commercial leasing in the Atlantic and Pacific regions, with the December 2022 auction in California being the first commercial lease sale for floating offshore wind energy in the United

States. Beyond 2030, the United States could also see offshore wind energy develop in regions like Hawaii, Puerto Rico, and the Great Lakes, where technology requirements and decarbonization strategies including offshore wind are already being investigated (Musial et al 2023a).

To adapt to the conditions in these regions, new technical challenges, such as hurricane survival, ultradeep water, and lower average wind speeds, will need to be overcome (National Offshore Wind Research and Development Consortium 2023; DOE 2022c).

To connect these large quantities of offshore wind, coordinated approaches to shared transmission solutions that address transmission cost allocation, interconnection queues, and competition for limited coastal points of interconnection will be necessary. Some of this coordination is already underway in the northeast states. Similarly, as the industry matures and regulators gain more experience, we should expect to see increased efficiency in the permitting process with possible benefits emerging from the pending Modernization Rule, and efficiencies that BOEM, cooperating federal agencies, and developers should find from knowledge gained in the existing process.

The net-zero carbon energy transition presents enormous challenges nationally and globally, including growing concerns about potential conflicts with other ocean users, but there are market opportunities for offshore wind energy that are equally as large over the coming decades. These challenges are being addressed by a growing sector of academic, government, and industry research organizations. In the United States, we can measure the size of the expanding offshore wind energy industry opportunities through the tremendous annual growth in commercial leasing—through state targets, procurement policies, and offtake agreements—and through new federal support in the IRA that both provides a long-term policy framework for offshore wind and prioritizes U.S. jobs and supply chain development.

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Appendix A. Capacity Density Assessment for U.S. Projects

The capacity density is an important parameter in calculating the magnitude of the offshore wind energy development pipeline. It is a measure of the concentration of wind energy capacity within a given area, specified in terms of megawatts per square kilometer. For announced wind planning areas earlier in the development process, the National Renewable Energy Laboratory has historically estimated lease area capacity potential before project details are known based on the announced developable area and an assumed capacity density of 3 MW/km^2 (Musial et al. 2013, 2016, 2022). To improve our quantitative estimates of the project pipeline, we calculated the capacity density values for all proposed U.S. offshore wind plants with available data. We collected the project capacities and the areas of each of the emerging U.S. offshore wind projects from published Draft Environmental Impact Statements (DEIS), Construction and Operations Plans (COPs), site assessment plans (SAPs), and press releases. Their respective capacity density values are shown in Table A-1. Some of the DEISs, COPs, and SAPs published by the Bureau of Ocean Energy Management specify the wind development area. When that is the case, we use the wind development area instead of the lease area to better assess nameplate capacity in megawatts that are planned for a specific area. We do not include pilot projects in this assessment as their capacity density is not representative of a full-sized commercial array. The projects are sorted by state based on where the Bureau of Ocean Energy Management associates the development efforts so that capacity density can be compared by state.

Table A-1. Proposed Capacity Density of U.S. Projects

Project	Lease Area Name	State	Area (acres)	Area (square kilometers [km^2])	Project Capacity (megawatts [MW])	Capacity Density (MW/km^2)
Revolution Wind	OCS-A 0486	Rhode Island (RI)/Massachusetts (MA)	82,732	335	704	2.10
South Fork Wind Farm	OCS-A 0517	RI/MA	13,700	55	132	2.38
Sunrise Wind 1	OCS-A 0487	RI/MA	86,823	351	924	2.63
Bay State Wind	OCS-A 0500	MA	187,523	759	2,000	2.64
Vineyard Wind 1	OCS-A 0501	MA	65,296	264	800	3.03
Ocean Wind 2	OCS-A 0532	New Jersey (NJ)	84,955	344	1,148	3.34
Ocean Wind 1	OCS-A 0498	NJ	75,525	306	1,100	3.60
SouthCoast Wind	OCS-A 0521	MA	127,388	516	2,004	3.89
Beacon Wind	OCS-A 0520	MA	128,811	521	2,430	4.66

Project	Lease Area Name	State	Area (acres)	Area (square kilometers [km^2])	Project Capacity (megawatts [MW])	Capacity Density (MW/km^2)
New England	OCS-A 0534	MA	101,590	411	2,036	4.95
US Wind	OCS-A 0490	Maryland	79,707	323	1,678	5.20
Atlantic Shores Offshore Wind South 1	OCS-A 0499	NJ	70,272	284	1,510	5.31
CVOW (Commercial)	OCS-A 0483	Virginia	112,799	456	2,587	5.67
Kitty Hawk	OCS-A 0508	North Carolina	122,405	495	3,500	7.07
Empire Wind 1	OCS-A 0512	New York (NY)	27,951	112	816	7.44
Empire Wind 2	OCS-A 0512	NY	38,363	155	1,260	8.12
Skipjack	OCS-A 0519	Delaware	26,332	107	966	9.07

Note: We select the wind energy development area stated in the COP/DEIS/SAP. Under a conservative approach, we select the Project 1 area plus the Project 1 and 2 overlap area available for use.

Four of the 17 projects analyzed (Table A-1) have a lower capacity density than the 3 megawatt (MW)/square kilometer (km^2) default value reported in previous years for the unspecified lease area capacity. All four of these projects are in the Massachusetts or Rhode Island wind energy areas where uniform wind turbine and offshore substation spacing has been fixed in a 1-nautical-mile-by-1-nautical-mile uniform layout pattern. This spacing was adopted from the U.S. Coast Guard recommendations for navigation safety reasons, (U.S. Coast Guard, Department of Homeland Security 2020), which are wider than industry norms. Projects under development in other states are not constrained by specific spacing requirements and typically have chosen layout patterns that position the wind turbines closer to each other with greater capacity density.

Figure A-1 presents weighted-average capacity densities by state. The total weighted-average capacity density for U.S. projects is 4.42 MW/km^2 (orange bar). If the projects that are constrained by wide turbine spacing in Massachusetts and Rhode Island are excluded, the weighted-average capacity increases to 5.64 MW/km^2 (yellow bar) for projects in the United States. These averages are comparable to capacity densities for existing European offshore wind energy projects that range from 2 to 19 MW/km^2 with planning recommendations ranging from 4.90 to 5.90 MW/km^2 (Borrmann et al. 2018; Müller et al. 2017; Hundleby and Freeman 2017).

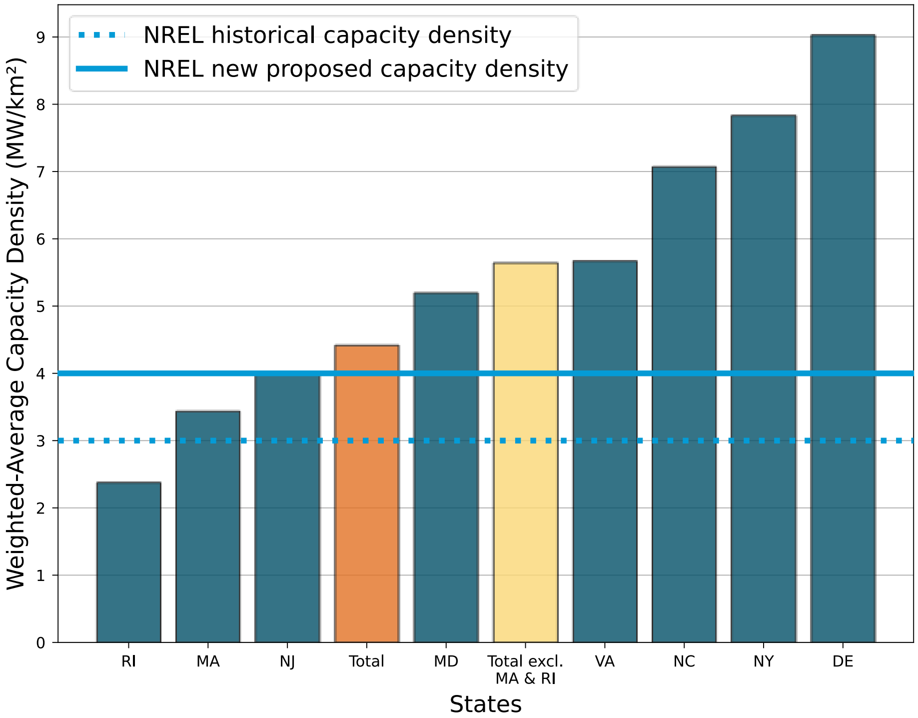


Figure A-1. Weighted-average capacity densities by state calculated from project data.

RI = Rhode Island; MA = Massachusetts; NJ = New Jersey; MD = Maryland; VA = Virginia; NC = North Carolina; NY = New York; DE = Delaware

Wind turbine spacing is the primary capacity density driver; therefore, if spacing is fixed between turbines, the remaining factors that can be used by a developer to affect capacity density are turbine rating and minimizing the number of unused turbine positions through foundation design and stakeholder negotiations. Therefore, developers in Massachusetts and Rhode Island with fixed 1-nautical-mile spacing are more likely to push for larger turbines to increase capacity density.

Based on these data, we adopted a new 4 MW/km^2 assumption for calculating the U.S. regulatory project pipeline presented in this report. Although this metric is closer to the actual capacity densities of the planned projects, we selected it to remain conservative because the actual built project could have lower densities than the COPs due to many factors including incompatible soils, conflicts with other ocean users, and availability of components.

All the projects analyzed are fixed bottom as there are no published COPs or similar records for U.S. floating offshore wind projects. Floating offshore wind projects may require additional space to ensure that the mooring systems and anchors are kept within the lease area. Further research needs to be done to understand how the mooring and array spacing design challenges of a large-scale floating offshore wind plant could affect capacity density (Cooperman et al. 2022).

Appendix B. Future Offshore Wind Technologies

Offshore Wind Sustainability Considerations

While most of the material (e.g., metal, fiberglass, and resin components) in a wind turbine is recyclable (85%–90% by weight), the composites used to make the blades have been challenging to separate and recycle. This challenge is key to the sustainability of the offshore and land-based wind energy industries as more wind turbines are installed, and eventually decommissioned after the 25- to 35-year design life has expired.

In March, 2022, LM Windpower produced a recyclable thermoplastic blade for General Electric as part of the Zero wastE Blade ReseArch (ZEBRA) consortium (General Electric 2022). Siemens Gamesa developed the RecyclableBlade, which relies on a mild acidic solution to separate the materials at the end of the wind turbine's lifetime so materials can be recycled (Siemens Gamesa Renewable Energy [SGRE] 2022b). The RecyclableBlades were installed on turbines at the German Kaskasi project in July 2022 and have been ordered for the Sofia Offshore Wind Farm in the United Kingdom and Calvados in France (SG RE 2022b, 2023a; Memija 2022a). Vestas developed a process for recycling epoxy-based wind turbine blades, which allows turbine blades currently in operation as well as those already in landfills to be recycled into new material (Vestas Wind Systems A/S 2023c).

Siemens Gamesa calculated the energy payback time for a typical offshore wind plant comprising 80 SG 8.0-167 DD offshore wind turbines to be 7.4 months (SGRE n.d.). They define energy payback time as the "length of time the wind power plant has to operate in order to produce as much energy as it will consume during its entire lifecycle." Vestas provides public life cycle assessments for turbines up to 6.2 megawatts (MW) (mostly land-based machines) (Vestas Wind Systems A/S 2023a). The National Renewable Energy Laboratory published an updated comparison of life cycle greenhouse gas emissions from electricity generation technologies including land-based and offshore wind in 2021 (National Renewable Energy Laboratory 2021). A study by Wood Mackenzie found that wind energy, including offshore wind, had the lowest carbon footprint of all energy types except nuclear (Liew 2021).

Notably, one recent life cycle assessment of floating offshore wind plants indicated that depending on the operations and maintenance strategy, the contribution of the operations and maintenance phase to the total life cycle greenhouse gas emissions from the project ranged from 21% to 49% (Garcia-Teruel et al. 2022). A range of 6% to 40% of this came from the operations and maintenance vessels, suggesting that decarbonizing vessels is critical to reducing the life cycle emissions of offshore wind plants. There are opportunities to power these vessels with electricity or alternative fuels generated from wind.

Offshore Wind Electrical Infrastructure

Array cable voltages are trending higher with the possibility of 132-kilovolt (kV) cable technology soon replacing 66-kV cables. This trend is helping enable the deployment of wind turbine ratings larger than 15 MW. Emerging U.S. projects like Sunrise Wind, New England, Atlantic Shore South, and Ocean Wind 1 are considering the use of 132-kV cables for their array systems in their project design envelopes (Bureau of Ocean Energy Management 2023a). Carbon Trust (2023) anticipates that most of the offshore wind energy industry will be moving to 132-kV array cable systems. The transition to 132-kV cables as the maximum voltage level in the array system enables developers to connect more wind turbines on a single cable for a given turbine size, which leads to more cost-effective layouts. Offshore adaptations for 132-kV transformers required to support the array cable transition are not yet implemented; however, the technology is considered mature as these transformers are commonly available in the land-based distribution grid.

Although no obstacles for the transition to higher voltages were identified, more engagement across cable manufacturers and developers—especially in the cable connectors sector—and further technical development and testing for offshore applications are needed to accelerate the transition to 132-kV cables (Carbon Trust 2023). Some of the emerging U.S. offshore wind energy projects include high-voltage direct current (HVDC) options in the project design envelopes for their respective export systems. Sunrise Wind's preferred option is a 320-kV DC cable, whereas other projects like SouthCoast Wind or Atlantic Shore South provide a wide range of possible HVDC options in their Construction and Operations Plans (Bureau of Ocean Energy Management 2023a). In Europe, TenneT, a leading European grid operator, will build at least 14 HVDC offshore grid connection systems with a transmission capacity of 2 gigawatts (GW) each in the North Sea by 2031 through the "2 GW Program." The objective of the program is to design a new standardized platform (2-GW bipole) and a new certified cable system (±525 kV) for eight offshore wind plants in the Netherlands and six in Germany (TenneT 2023). No HVDC floating converter stations exist yet. Aibel, together with Hitachi, DNV, and SINTEF Ocean, are developing concepts for a ready-for-sale floating substation and utility systems rated at 1.4 and 2.2 GW (Ocean Grid 2022).

The delays in transformer manufacturing and shipping at the federal level could cause potential delays in the offshore wind energy industry. Some bottlenecks have been identified in the supply of power transformers (Congressional Research Service 2022). These bottlenecks have forced U.S. utilities to source transformers overseas for higher prices, wait times, and uncertainty than under normal circumstances (T&D World 2023). In June 2022, the Biden administration issued a memorandum allowing the U.S. Department of Energy to use Defense Production Act authority to increase domestic production of transformers, among other electrical equipment (The White House 2022b). The U.S. Department of Energy also joined with the Electricity Subsector Coordinating Council to identify supply chain challenges and potential solutions for grid components, including transformers (Congressional Research Service 2022).

Offshore Wind Power to X

Firming Technologies and Sector Coupling

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 hydrogen that can be used in other sectors of the economy as a zero-emission fuel. As countries look to achieve ambitious decarbonization goals, finding ways to maximize the value of offshore wind energy infrastructure is a key objective. In addition, by co-locating other technologies with offshore wind energy, the use of existing infrastructure can be maximized while minimizing the need for extensive transmission build-out. Fuels production and energy island concepts allow for products to be made and transported from offshore locations, avoiding the need to build the expensive electricity export system to shore, especially as wind plants are developed at greater distances offshore. This section focuses on multiple approaches to maximizing the value of offshore wind energy systems through co-generation and storage, hydrogen, and energy islands and sector coupling.

Co-Generation and Storage

Offshore wind energy systems can be paired with other electric generation and storage technologies to increase the capacity factor of the facility, maximize the use of offshore infrastructure, and provide grid services. Multiple projects are being proposed and/or built worldwide including:

- Ørsted has plans to build a large-scale storage facility to operate alongside Hornsea 3, which is a 2.4-GW offshore wind installation in the North Sea. This storage facility will increase the flexibility of the United Kingdom energy system as it transitions to clean energy (Proctor 2023b).
- Pattern Energy and Green Power Investment Corporation in Japan have announced a 112-MW offshore wind project with 180-megawatt-hour battery storage capacity that is scheduled to be operational by late 2023 (Dallas 2022).

Hydrogen

Offshore wind-to-hydrogen systems can maximize the use of offshore infrastructure and minimize the risk of transmission build-out, especially if hydrogen electrolysis is co-located offshore with wind energy generation. Although generally this technology is at a nascent stage of development, hydrogen is expected to provide the foundation for many sectors to transition to clean energy technologies including industrial decarbonization, transportation, and energy storage (BOEM 2022d). The Inflation Reduction Act provides a pathway to cost-competitive wind-hydrogen systems in the United States in the near future. The potential for offshore-wind-hydrogen systems is being recognized with many projects being proposed and/or built including:

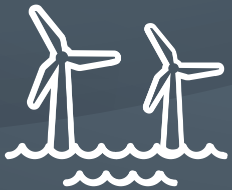
- The Netherlands has announced a 759-MW offshore wind plant with a pilot co-generation and hydrogen production plant that includes 500 kilowatts of floating solar and megawatt-scale battery storage and hydrogen production (Lewis 2023b).

- The Netherlands has announced another offshore hydrogen facility with a 500-MW capacity that will be connected to an existing natural-gas pipeline that can be used for hydrogen transport (Meijer and Heavens 2023).
- Sweden has announced SoutH2port, a 240-ton/day hydrogen production facility to be powered by a 1-GW offshore wind plant in partnership with ABB (Power Technology 2023).

Energy Islands and Industrial Sector Coupling

As land use becomes a bigger concern for the global clean energy transition, large industrial loads and energy generation can be taken offshore and supported by energy islands. Having generation and multiple end uses co-located can significantly decrease costs while exploiting synergies across technologies, thereby sharing balance of system, power electronics, controls, resources and heating, labor, and more. Early adopters have announced plans for energy islands built farther offshore at the gigawatt-scale including:

- Belgium has announced an energy island endeavor to begin construction in 2024. This offshore energy island will be 24 miles offshore in the North Sea. End uses are currently under discussion including the potential for hydrogen production (Hatchwell 2023). Several other countries have also expressed interest in energy islands including Denmark, the Netherlands, and United Kingdom.
- Hydrogen and ammonia offshore facilities are being developed including one that has been announced by the Netherlands to develop floating hydrogen, ammonia, and storage to be connected with offshore wind energy (Buljan 2023b).
- Norway has announced an offshore wind energy system with plans for ammonia production and transport. The system size would provide approximately 1.5 GW of renewable energy generation and power a floating ammonia and hydrogen production vessel that would be transported with small shipping vessels (Business Standard Web Team 2023).



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DOE/GO-102023-6059 · August 2023

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