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2016 **Offshore Wind Technologies Market Report**

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2016 Offshore Wind Technologies Market Report

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Acronyms and Abbreviations

ATD	advanced technology demonstration
BIWF	Block Island Wind Farm
BOEM	Bureau of Ocean Energy Management
BPU	Board of Public Utilities (New Jersey)
CapEx	capital expenditures
COD	commercial operation date
DOE	U.S. Department of Energy
FID	final investment decision
GW	gigawatt
HVAC	high-voltage alternating current
HVDC	high-voltage direct current
kV	kilovolt
kW	kilowatt
LEEDCo	Lake Erie Energy Development Corporation
LCOE	levelized cost of energy
LIPA	Long Island Power Authority
LLC	Limited Liability Company
m	meter(s)
METI	Ministry of Economy, Trade and Industry
MHI	Mitsubishi Heavy Industries
MW	megawatt
MWh	megawatt-hour
NREL	National Renewable Energy Laboratory
O&M	operation and maintenance
OCS	Outer Continental Shelf
OEM	original equipment manufacturer
OpEx	operational expenditures
OREC	offshore renewable energy certificate
OTM	offshore transmission module
OWDB	Offshore Wind Database
PPA	power purchase agreement
R&D	research and development
RES	Renewable Energy Systems
TBD	to be determined
TSO	Transmission System Operator

Executive Summary

The 2016 Offshore Wind Technologies Market Report was developed by the National Renewable Energy Laboratory (NREL) for the U.S. Department of Energy (DOE) and is intended to provide offshore wind policymakers, regulators, developers, researchers, engineers, financiers, and supply chain participants, with quantitative information about the offshore wind market, technology, and cost trends in the United States and worldwide. In particular, this report is intended to provide detailed information on the domestic offshore wind industry to provide context to help navigate technical and market barriers and opportunities. The scope of the report covers the status of the 111 operating offshore wind projects in the global fleet through December 31, 2016, and provides the status and analysis on a broader pipeline of 593 projects at some stage of development.[1] In addition, this report provides a wider assessment of domestic developments and events through the second quarter of 2017 to provide a more up-to-date discussion of this dynamically evolving industry. A summary of the key findings are provided below.

The United States commissioned its first commercial offshore wind project off Rhode Island. In December 2016, Deepwater Wind completed the commissioning of the Block Island Wind Farm, marking a milestone as the first commercial offshore wind project in the United States. The 30-megawatt (MW) project is in Rhode Island state waters off the southern coast of Block Island. It is comprised of five 6-MW Haliade wind turbines manufactured by General Electric (formerly Alstom Wind Power). In addition, the project included laying a power cable to connect the grid on Block Island to the mainland grid. The project is expected to produce enough electricity to power 17,000 Rhode Island homes (Chesto 2017).

Strike prices from offshore wind energy procurement auctions plummet in European wholesale electricity markets. European auction strike prices[2] from July 2016 through June 2017 indicate a trend of offshore wind price declines. Although there is some variability in these recent price signals caused by differences in auction design (e.g., differences in the allocation of grid connection costs, development costs, and contract length), market and policy environment, and project characteristics, winning bid prices have declined from approximately $200/megawatt-hour for projects, with a commercial operation date between 2017 and 2019 down to about $65/megawatt-hour for projects, with a 2024/2025 commercial operation date. Although the normalized adjusted strike prices presented in this report do not comprehensively account for all possible differences among projects (e.g., site conditions, project-specific risk profiles, or future electricity prices), a significant drop in offshore wind bid prices over the past year has emerged as a clear trend. However, the impacts on cost, the future trajectory of these prices and whether these downward trends will be sustained, and their transferability to the U.S. market have not been fully evaluated.

[1] Note that the *2014–2015 Offshore Wind Technologies Market Report* covered operating projects through June 30, 2015, with a focus on developments in 2014 and the first half of 2015 (Smith, Stehly, and Musial 2015).

[2] The strike price for an offshore wind project from an auction is usually the lowest bid price at which the offering can be sold. The strike price usually covers a specific contract term for which that strike price will be paid for the energy produced. The offeror of that strike price is awarded the rights to develop a particular parcel under predetermined conditions set in the tender offer that may vary by country or market. The strike price should not be confused with levelized cost of energy, which may be calculated using different financing and cost assumptions.

New offshore wind capacity, commissioned globally in 2016, dropped to 1,188 MW. Following 2015's record deployment of nearly 4,000 MW, new offshore wind installed capacity experienced a dip, with a total of 1,188 MW commissioned in 2016. This decrease can be mostly attributed to a transition in the United Kingdom market support mechanism and delays in interconnections for some projects in Germany and the Netherlands. Meanwhile, China's annual installed capacity increased slightly from 352 MW in 2015 to 430 MW in 2016. By the end of 2016, the global offshore market had accumulated 12,913 MW of commissioned capacity from 111 operating projects. Projections for 2017 indicate expected global new capacity additions to be above 4,000 MW based on the number of projects currently under construction. The pipeline of offshore wind development capacity as of December 31, 2016, was about 231,000 MW comprising 593 projects.

Industry-wide confidence that the U.S. offshore wind market is emerging has increased because of decreasing global costs and stronger state policy commitments. News of the declining costs for offshore wind projects in Europe has spurred confidence in the domestic U.S. offshore wind market this year. Several states including Massachusetts, New York, and Maryland have enacted new policies or bolstered their existing policies to incentivize the development of offshore wind. These policies include procurement targets for offshore wind and offshore renewable energy credits that could support over 4,000 MW. Some U.S. activities since the last U.S. offshore market report (Smith, Stehly, and Musial 2015) include:

- The Bureau of Ocean Energy Management (BOEM) held a competitive lease sale of 344,000 acres offshore New Jersey on November 9, 2015. The winners were RES America Developments Inc., (which later transferred to DONG Energy), with a bid of $880,715 (160,480 acres), and US Wind Inc., with a bid of $1,006,240 (183,353 acres).

- In August 2016, Massachusetts Governor Charlie Baker signed bill H.4568, allowing for 1,600 MW of offshore wind to be procured by June 2027 (General Court of the Commonwealth of Massachusetts 2016).[3]

- In September 2016, DOE and the U.S. Department of the Interior issued the *National Offshore Wind Strategy* (Gilman et al. 2016) to facilitate the responsible development of offshore wind in the United States. The strategy recognizes the environmental and economic benefits of offshore wind, identifies critical challenges, and presents a federal action plan.

- On December 15, 2016, Statoil was awarded rights to the BOEM lease area off the coast of New York for an unprecedented bid value of $42.5 million (Statoil 2016).

- On January 10, 2017, New York Governor Andrew Cuomo committed to develop up to 2,400 MW of offshore wind by 2030 in support of the state's 2030 Renewable Portfolio Standard target of 50% (Cuomo 2017). On January 25, 2017, the Long Island Power Authority approved a power purchase agreement for Deepwater Wind's 90-MW South Fork Wind Farm, which is located 30 miles off the coast of Montauk.

[3] Bill H.4568 excludes the Cape Wind project.

- On March 16, 2017, a competitive lease sale for a wind energy area of 122,405 acres offshore Kitty Hawk, North Carolina, was announced, with the highest bid of $9,066,650 from Avangrid Renewables, LLC, the provisional winner.

- In Massachusetts, a request for proposals was issued on June 29, 2017, seeking to procure a total of 400−800 MW from the BOEM lease areas off of Massachusetts and Rhode Island.[4]

- In May 2017, the Maryland Public Service Commission issued an offshore wind renewable energy certificate for the procurement of 368 MW from US Wind (248 MW) and Deepwater Wind's Skipjack project (120 MW).

- Two of the DOE advanced technology demonstration projects, the 21-MW Lake Erie Icebreaker project led by the Fred Olsen/Lake Erie Energy Development Corporation consortium and the 12-MW Aqua Ventus I project led by the University of Maine, continue to make progress. They will be considered for the next round of funding from DOE.

The U.S. offshore wind project pipeline is estimated to be 24,135 MW, with 14,785 MW under exclusive site control[5] by developers. The U.S. offshore wind project development pipeline includes 28 projects totaling 24,135 MW of potential installed capacity. Developers have obtained exclusive site control over 18 sites totaling 14,785 MW of potential capacity, including projects located in state waters. Most of the near-term activity is concentrated in the North Atlantic region, but projects have been proposed in all five U.S. regions (as defined by DOE's *Wind Vision)* (DOE 2015). Figure ES-1 shows a map of two advanced technology demonstration projects, the current projects in the U.S. pipeline, and the operational Block Island Wind Farm[6].

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[4] The request for proposals permits bidders to submit proposals with a nameplate capacity of no less than 200 MW and no greater than 800 MW.
[5] Federal law requires the Bureau of Ocean Energy Management to conduct a fair public auction for offshore wind sites in which there is interest from more than one developer (i.e., "competitive interest"). A developer cannot proceed until they have been awarded exclusive rights to the site through the competitive auction process.
[6] Deepwater Wind's two lease areas in RI/MA are shown as a single project and U.S. Wind's two lease areas in MD are shown as single project.

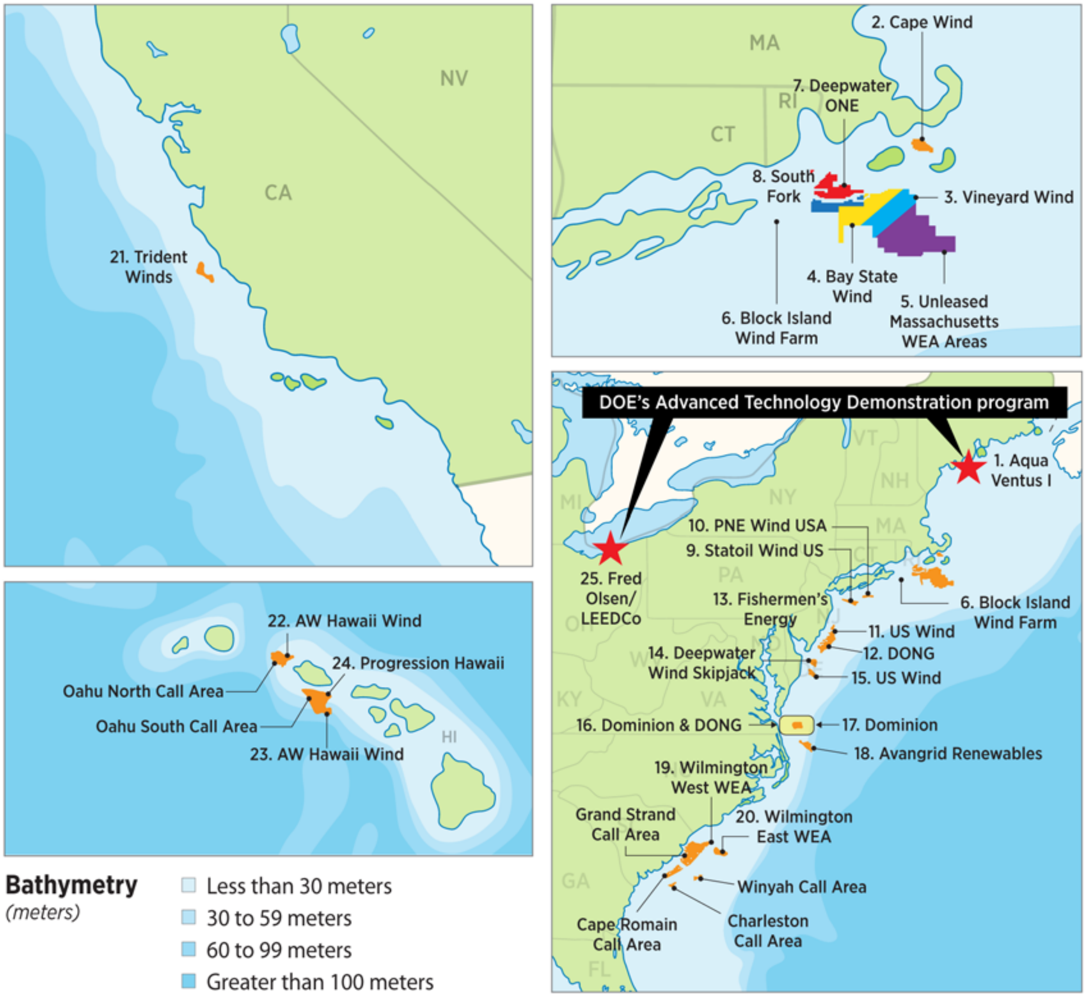

Figure ES-1. U.S. offshore wind projects

Source: NREL

Industry continues to push toward larger turbines, seeking rated capacities greater than 8 MW in deeper waters. Offshore wind turbine development is continuing its upscaling trend. For example, the completion of the Burbo Bank Extension project (United Kingdom) in early 2017 was the first commercial project to use a Vestas 164-meter rotor, 8-MW turbine (V164-8 MW) that was first prototyped in 2014. In addition, an upgraded V164 prototype 9.5-MW turbine was debuted in 2017 (Mitsubishi Heavy Industries [MHI] Vestas Offshore 2017b; Weston 2017a; de Vries 2017). Large turbine sizes are generally preferred in offshore applications because of fewer installations and lower maintenance, and many developers are anticipating continued turbine growth, with the expectation that the benefits of increased turbine size will continue to lower energy costs. Globally, the average turbine size for offshore wind projects increased from 3.4 MW for projects installed in 2015 to 4.7 MW for projects installed by the end of 2016. This trend is expected to continue, with average turbine size expected to reach 7.0 MW for projects installed in 2020.

The floating wind project pipeline triples in size to almost 3,000 MW. In sites where the water is too deep to use proven fixed-bottom commercial technology, floating foundations are beginning to be developed. The global floating offshore wind pipeline has reached 2,905 MW in 2016, with 26 announced projects including 21 demonstration/pilot-scale projects, as well as the five commercial-scale projects in Hawaii, California, and France. The total number of floating projects in the pipeline has increased by over a factor of three since 2015, when 819 MW of pipeline capacity was reported (Smith, Stehly, and Musial 2015). The floating offshore wind industry is moving away from proof-of-concept single turbine deployments that characterized the first wave of prototype development from 2009 through 2015. The current trend indicates a growing number of multiturbine, precommercial pilot projects. There are 11 individual precommercial floating projects totaling 229 MW in capacity that have advanced past the planning phase and are either under construction, approved, or have significant resources committed for project development. These projects are described in more detail in Section 6 and Appendix B.

After years of regulatory planning and leasing, confidence in the nascent U.S. offshore wind market has increased as the result of declining offshore wind costs globally, continued supply chain development, and higher levels of activity in supportive domestic state policy. U.S. industry activity is accelerating, emboldened not only by the first wind farm off Block Island, but by the assertive presence in the United States of well-capitalized and experienced offshore wind developers (e.g., DONG Energy, Statoil ASA, Iberdrola), and the rapid decline in European offshore wind auction strike prices approaching a market competitive range.

1 Introduction

The 2016 Offshore Wind Technologies Market Report was developed by the National Renewable Energy Laboratory (NREL) for the U.S. Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy. It is intended to provide stakeholders, including policymakers, regulators, developers, financiers, and supply chain participants, with quantitative information about the offshore wind market, technology, and cost trends worldwide. The data in this report are intended to provide context for the domestic industry and help inform the U.S. offshore wind industry and its stakeholders to identify risks and opportunities. The scope of the report covers the global fleet of operating projects through December 31, 2016.[7] However, the report emphasizes developments in the United States and draws on domestic developments and events through the second quarter of 2017. The report includes data, obtained from a wide variety of sources, about offshore wind projects that are both operating and under development to provide current and forward-looking perspectives. This report is part of a set of market reports funded by DOE. The other reports cover the status of utility-scale land-based wind[8] and distributed wind.[9] These companion reports provide quantitative, independent data for use by the wind industry and its various stakeholders.

After years of regulatory planning and leasing, confidence in the nascent U.S. offshore wind market is increasing and industry activity is accelerating. At the center of this activity is the commissioning of the nation's first commercial offshore wind project in December 2016, the 30-megawatt (MW) Block Island Wind Farm (BIWF) by Deepwater Wind in Rhode Island state waters. However, U.S. offshore wind industry members are emboldened not only by the first wind farm off Block Island, but by the assertive presence in the United States of well-capitalized and experienced offshore wind developers (e.g., DONG Energy, Statoil ASA, Iberdrola), initial supply chain developments, and the rapid decline in European offshore wind auction strike prices into a market competitive range. As a result, there has been a prominent rise in legislative activity in 2016 that supports offshore wind at the state level. These positive market signals are potentially setting the stage for large-scale offshore wind development across the country, from Massachusetts to Hawaii.

The data and information from this report provide insight into market, technology, cost, and performance trends and are key inputs to the annual *Cost of Wind Energy Review* report, which provides an updated summary of the cost of land-based and offshore wind energy in the United States to support DOE's programmatic reporting on the cost of wind energy (Moné et al. 2015; 2017; Tegen et al. 2012, 2013).

1.1 Approach and Method

The analysis in this report focuses on offshore wind projects at various stages of maturity within the project life cycle, starting with the first deployment in 1991 and extending into the future. It

[7] Note that the *2014–2015 Offshore Wind Technologies Market Report* covered operating projects through June 30, 2015, with a focus on developments in 2014 and the first half of 2015 (Smith, Stehly, and Musial 2015).
[8] The *Wind Technologies Market Report* is prepared by Lawrence Berkeley National Laboratory and is available for the period 2005 to 2016. For the most recent version, see Wiser and Bolinger (2017).
[9] The *Distributed Wind Market Report* is prepared by Pacific Northwest National Laboratory for the period 2012 to 2016. For the most recent version, see Orrell et al. (2017).

also covers projects in a range of countries, spanning North American, European, and Asian markets. Although, it is often difficult to compare between markets because of differences in political systems, regulatory conditions, and macroeconomic conditions, the breadth and diversity of the data allow the development of consistent methodologies to classify, compare, and analyze the data. As such, one of the primary objectives of this report is to make these comparisons and interpret the significance of major offshore wind market trends in deployment, cost, and technology.

1.1.1 NREL Offshore Wind Database

This report draws data from NREL's internal Offshore Wind Database (OWDB)[10], which contains information on 1,138 offshore wind projects located in 42 countries and totaling about 399,000 MW of announced project capacity (including both active and dormant projects). Projects in the database range in maturity and cover a time period from 1991 to 2034, although many have not yet announced a commercial operation date (COD). The OWDB contains information on project characteristics (e.g., water depth, wind speed, and distance from shore), economic attributes (e.g., project- and component-level costs and performance), and technical specifications (e.g., component sizes and masses). Additionally, the database contains information on the characteristics of offshore wind installation and transportation vessels, as well as ports that have been used to support the construction and maintenance of offshore projects.

The NREL OWDB is built from internal research using various sources of data including peer-reviewed literature, press releases, industry news reports, manufacturer specification sheets, and global offshore wind project announcements. It is NREL's best and most reliable source for offshore wind market information and is cited throughout this report. Unless stated otherwise, the data provided for project pipelines, both globally and domestically, are derived from the NREL OWDB. The database is also used extensively to assess technology trends, document equipment manufacturers, and assess economic data.

In cases in which sources used to build the OWDB conflict with each other or with other sources available to NREL, the data were adjusted to reflect the best-available information. Typically, the augmented data are based on the professional judgment of industry experts and/or NREL analysts. To ensure accuracy, NREL has verified the OWDB against other credible industry databases, publications from institutions and associations, and research organizations. These verification sources include:

- The 4C Offshore Wind Database (4C Offshore 2017)
- WindEurope Annual Market Update (WindEurope 2017a)
- Bloomberg New Energy Finance Renewable Energy Project Database (Bloomberg New Energy Finance 2016)
- MAKE Consulting Global Offshore Wind Database (MAKE Consulting 2017).

Although best attempts were made to validate the data and harmonize it against other available sources, minor differences in database methodology and definitions among sources may yield slightly different quantified results than found in other published reports. For example, reported

[10] NREL's Offshore Wind Database is used as an internal reference and is not published publically.

annual capacity additions often vary among sources because of the use of different criteria for considering a project as "operating" or "installed." Despite variability in annual numbers, longer-term trends among all sources are broadly consistent with the NREL OWDB. NREL considers a project to be "commissioned" when all turbines are fully operational and capable of feeding power into the land-based electricity grid (stage 7 in Table 1).

The data also vary in quality, and, in many cases, are subject to some uncertainty. This is particularly true for future projects, in which values are largely based on the public announcements of developers and may be subject to change. Because of these uncertainties, the analysis presented here emphasizes the broader trends rather than data points corresponding to individual projects.

The cost and pricing data in NREL's OWDB spans a large chronology and is reported in a number of different currencies. To analyze these data, all information in this report was normalized into 2016 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 (United States Department of Agriculture Economic Research Service 2017)
- Inflating the values, which are in nominal USD after the exchange rate conversion, to 2016 USD using the U.S. Consumer Price Index (United States Department of Labor Bureau of Labor Statistics 2017).

Because this report focuses on data from 2016, NREL used 2016 average exchange rates to convert economic data not directly tied to projects (e.g., from studies or related to policy).

1.1.2 Classification of Project Status

This report adopts the system for classifying and tracking the progress of projects described in the *2014–2015 Offshore Wind Technologies Market Report* (Smith, Stehly, and Musial 2015), with some minor modifications. This includes projects that are proposed in both federal waters and state waters in the United States, as well as those operating and proposed in other countries.

The classification system defines discrete start and end points for each phase to avoid overlap or ambiguity. It divides the offshore wind project life cycle into nine stages: 1) planning, 2) site control, 3) permitting/offtake agreement signed, 4) approved, 5) financial close, 6) under construction, 7) operating, 8) decommissioned, and 9) on hold/canceled.[11] These stages attempt to track every potential project throughout its life cycle.

Table 1 summarizes the start and end criteria for the nine project phases in the U.S. offshore wind project pipeline and provides examples of some of the key milestones that exist within the U.S. regulatory framework. These criteria are broadly generalized across all international markets for offshore wind (see, for example, 4C Offshore 2015); however, criteria are not likely to be perfectly applicable to every market, particularly in project phases 1 through 5, in which

[11] Note that the Offshore Wind Database (OWDB) does not differentiate between the first category (planning – early stage) and the second (planning – site control) for international projects. Instead, both are tracked as a single, combined category labeled "Planning."

political and regulatory structures may impose different requirements. These different requirements will likely translate into some variability in the duration and financial resources required to progress from one stage to the next.

One significant change that was made to the classification criteria for U.S. projects in this report was in how offtake[12] agreements are considered. Market trends for U.S. projects indicate that offtake agreements may be signed as early as Phase 2 (site control) up until Phase 5 (financial close).

Table 1. Modified Criteria for Pipeline Classification of U.S. Offshore Wind Projects

Step	Phase Name	Phase Start Criteria	Phase End Criteria
1	Planning	Starts when developer or regulatory agency initiates formal site control process	Ends when a developer obtains exclusive development rights to a site (e.g., through competitive auction or a determination of no competitive interest in the United States)
2	Site Control	Begins when the developer obtains exclusive development rights to a site (e.g., through competitive auction or a determination of no competitive interest in the United States)	Ends when the developer files major permit applications (e.g., a construction operations plan for projects in federal waters in the United States)
3	Permitting / Offtake Agreement	Starts when the developer files major permit applications (e.g., construction operation plan for projects in federal waters in the United States)	Ends when a regulatory body(s) grants authorization to proceed with construction[13] or when the project has signed an offtake agreement
4	Approved	Starts when the project has been approved by the relevant regulatory bodies and is fully authorized to proceed with construction or when the project has a signed offtake agreement	Ends when sponsor announces financial investment decision (FID) and has signed contracts for major construction work packages
5	Financial Close	Begins when sponsor announces FID and has signed unconditional contracts for major construction work packages	Ends when project begins offshore construction work
6	Under Construction	Starts when offshore construction work is initiated	Ends when project has been connected to the power grid and all units fully commissioned; commercial operation date (COD) marks the official transition from construction to operations
7	Operating	Commences when project has been connected to the power grid and all units are fully commissioned; COD marks the official transition from construction to operations	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 a formal process to decommission and stops feeding power to the grid	Ends when the site has been restored and lease payments are no longer being made, or if the site has been repowered
9	On Hold/ Canceled	Starts if a sponsor stops development activities (i.e., discontinues lease payments) and/or abandons a prospective site	Ends when the sponsor announces the restart of project development activities

[12] A power purchase agreement is one type of offtake agreement. "Offtake" broadly refers to any mechanism that enables an offshore wind project to sell its electricity in an energy market or to an individual client.
[13] A rejection may cause the project sponsor to appeal (still permitting phase), place the project on hold, or cancel.

To allow U.S. projects to show advancement in the U.S. project pipeline for obtaining an offtake agreement,[14] the end criteria for phase 3 (permitting/offtake agreement) were expanded in this report to include the signing of an offtake agreement. Offtake agreements, such as power purchase agreements (PPAs), are a major milestone for a project owner as they comprise a fixed long-term revenue stream to finance the development, installation, and operation of a project.

For instance, Deepwater's BIWF project signed a PPA with National Grid on December 9, 2009, before the final approval on September 5, 2014, (Deepwater Wind 2015a). Similarly, the Long Island Power Authority (LIPA) voted to approve a "pay-for-performance" PPA with Deepwater Wind on January 25, 2017, for the proposed 90-MW South Fork wind farm project (Roggenkamp 2017) before major permit applications were submitted.

1.2 Report Structure

The remainder of this report is divided into five sections that focus on the following:

- Section 2 provides an overview of the global offshore wind market. Projects from all countries are tracked according to their status in the offshore wind development pipeline including operating wind plants around the globe.
- Section 3 summarizes offshore wind market developments in the United States. In-depth coverage of the U.S.-specific pipeline is given along with a state-by-state and regional summary of key activities.
- Section 4 provides insight into global offshore wind price, cost, and performance trends. Recent declines in European strike prices are examined and this trend in price declines is interpreted with some treatment given to capital cost and finance trends and what that might mean for the U.S. market.
- Section 5 analyzes trends in global and domestic offshore wind fixed-bottom technology. Recent changes in offshore wind turbines, foundation types, electrical infrastructure, and vessels are discussed.
- Section 6 analyzes trends in global and domestic offshore wind floating technology. This section includes a summary of the growing market for floating offshore wind systems and what factors might be driving it. Appendix B provides a detailed description of selected floating projects under development.

[14] Note that this change was not implemented for projects outside of the United States due to lack of data.

2 Overview of Global Offshore Wind Development

The global market for offshore wind energy is rooted in Europe. Even though Europe still dominates the market with 90% of global installed capacity at the end of 2016, Asia saw a significant increase in offshore deployment in 2015 and 2016. North America also witnessed the commissioning of its first offshore wind project, the 30-MW BIWF.

European experience and market data indicate progress in offshore wind technological innovation and market cost reduction. Operating and announced projects for the period ending December 31, 2016, are tracked to provide an overview of offshore market growth, project progress, commissioning date, and technologies. These indicators can provide insights to future market developments and technology research and development (R&D) strategies.

2.1 Global Offshore Market

As the *2014–2015 Offshore Wind Technologies Market Report* (Smith, Stehly, and Musial 2015) anticipated, 2015 marked a record year for global offshore wind deployment with a total of 3,917 MW commissioned.[15] Germany led deployment with 2,374 MW installed, followed by the United Kingdom with 1,055 MW, China with 352 MW, and the Netherlands with 129 MW.

Following 2015's high deployment record, new offshore wind installed capacity experienced a dip with a total of 1,188 MW commissioned in 2016. This decrease can be attributed to a variety of factors, including a transition in the United Kingdom from a green certificates program to a contract for difference (CfD)[16], as well as delays in interconnection for some projects in Germany and the Netherlands. China's annual installed capacity increased from 352 MW in 2015 to 430 MW in 2016, continuing the uptick in development activity after the government had issued a prioritized approval process for a list of offshore projects. At the end of 2016, the global offshore market had accumulated 12,913 MW of commissioned capacity.

Figure 1 shows the global cumulative (right axis) and annual (left axis) offshore wind installed capacity from 2000 through December 2016. These data are based on project-announced commission dates from publicly available data sources. The figure includes only projects in which all of the capacity has been fully commissioned (i.e., the entire wind plant is feeding power into the grid) in a given year, and does not include intertidal projects.[17] U.S. market trends and project developments are described in detail in Section 3.

[15] Smith, Stehly, and Musial (2015) anticipated 3,996 MW of offshore wind to be on track to begin operations by the end of 2015.
[16] A contract for difference (CfD) is a financial arrangement between two parties, stipulating that a power seller (the power generator) will be provided with a fixed price level for its power output. Under this contract, the seller is compensated by the CfD counterparty with the difference between the CfD strike price and a reference or market price. This contracting scheme has been applied in various European offshore wind markets (see Section 4).
[17] Europe and the United States are not expected to install intertidal projects, which are located on beaches or tidal plains, because of environmental and competing use concerns. Intertidal projects have limited relevance to other offshore projects because they use different foundational technologies, installation methods, and electric infrastructure designs. Most of the offshore installations in China prior to 2015 were intertidal projects. Intertidal projects have also been developed and installed in Vietnam.

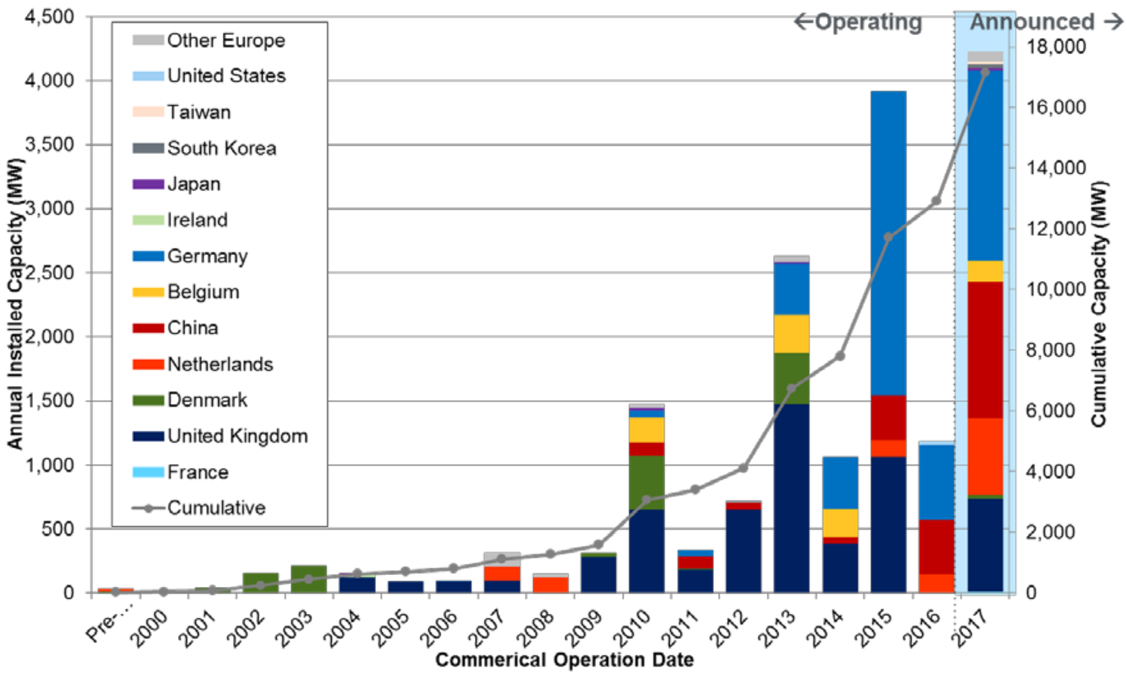

Figure 1. Operating global offshore wind capacity by market (annual and cumulative)

Source: NREL

Note: Figure 1 includes only projects in which all capacity within a phase (as defined by the developer) has been fully commissioned; does not include intertidal projects or scaled demonstration projects.

Note that in Figure 1, 2017, data are projections from the development pipeline of announced projects already under construction that indicate likely deployment levels of over 4,000 MW. This projection includes more than 1,000 MW in both Germany and China, as well as more than 700 MW in the United Kingdom. The following sections break down the global offshore wind market by the two key markets: Europe and Asia.[18]

2.1.1 European Market Activities

The European offshore wind industry is more than 20 years old and its technical practices and market data serve as the basis for assessing market potential and trends worldwide. It has grown from a fleet of less than 3,000 MW in 2010 to a cumulative installed base of more than 11,700 MW in 2016.

A combination of increasing plant size, technology improvements, infrastructure and related R&D investments, and favorable market, policy, and economic conditions has led to a downward trend in expected power generation prices for offshore wind in Europe, as evidenced by recent competitive auction results in Denmark, the United Kingdom, the Netherlands, and Germany (see Section 4 for more details). A development pipeline averaging 3,700 MW per year from 2017 to 2022 provides the market visibility required to sustain a robust supply chain. The production volume associated with this pipeline has several benefits for the industry that support

[18] U.S. activities are addressed in Section 3.

reduced costs, including increasing economies of scale, improving infrastructure and manufacturing facilities, increasing competition within the supply chain, and fostering a skilled workforce.

Based on announced commercial orders to date, the European market has recently seen the adoption of larger technology platforms with turbine generator nameplate ratings from 6 MW up to 8.4 MW, resulting in fewer turbines for a given project size. Innovations in foundation design, installation techniques, and electrical infrastructure are also being demonstrated and adopted in near-term commercial projects in Europe (see Section 5).

To meet the European Union's commitment of 20% renewable energy by 2020, which includes a set of legally binding and country-specific targets, European policymakers have developed support schemes and regulatory policies that are designed to minimize project cost and reduce the price impacts on ratepayers.

Some examples of these programs include:

- **Selecting development zones that emphasize site affordability**. The Danish government has held several rounds of tenders for offshore projects, including nearshore projects, which have low cost levels resulting from their proximity to shore (ranging from 4 to 8 kilometers (km) (Weston 2015a). These zones may, however, have lower wind speeds and therefore reduced capacity factors—relative to open-ocean sites—which tend to partially offset the levelized cost of energy (LCOE) advantage of nearshore siting.
- **Sponsoring early-stage development and permitting activities to reduce uncertainty about site conditions**. Denmark and the Netherlands have defined development zones and conducted initial environmental assessments, geotechnical surveys, wind resource assessments, and meteorological (met) ocean condition studies before holding auctions for development rights. These permitting and early-stage development activities can reduce the initial development cost of wind project for developers.
- **Implementing competitive auctions for subsidies**. Denmark, the United Kingdom, the Netherlands, France, and Germany are adopting market mechanisms to price subsidies based on competitive auctions. The use of market mechanisms to establish price is based on the idea that competition will drive developers to offer their lowest price, rather than a price set by a government agency that may not have full visibility of the cost structure of individual projects.[19] Auctions that include some portion of the transmission infrastructure with approved permits reduce the cost and risk to developers, which incentivizes project development. Auctions in 2016 and 2017 have procured nearly 4,000 MW of offshore capacity expected to be in operation between 2020 and 2025. They indicate a downward trend of LCOE, including the possible achievement of LCOE goals set by the United Kingdom and the European Union (see Section 4.1 for detailed analysis).

[19] It is challenging for government agencies to set prices that offer a balance between a level that is high enough to attract development but low enough to avoid excessive returns for developers. Moreover, a national-level cost estimate may not sufficiently reflect the cost structure of a variety of projects with diverse site conditions. The government may also face challenges in anticipating future cost changes.

Despite these developments, the industry has expressed concern regarding current political uncertainty for future offshore wind deployment levels within national energy plans, particularly after 2020. The industry maintains that clarity about the future pipeline is needed to drive supply chain investments in new technologies and efficient infrastructure (Campbell 2015; Steiner-Dicks 2015).

2.1.2 Asian Market Activities

China, Japan, Taiwan, South Korea, Vietnam, and India have market movement in offshore project development and have taken steps to stimulate domestic offshore wind industries. Future Asian supply chains could provide a counterweight to European suppliers and increase competition within the industry, which could reduce cost levels. Site conditions in many Asian markets are different than those in Europe. Many potential development zones are located in sites characterized by deep water and exposure to typhoons. Early experience gained through deploying and operating offshore wind projects in these conditions could be relevant for certain regions of the United States. Similarly, Asian markets offer an opportunity for exports, such as floating platform technologies that are under development around the world, including some U.S. companies (see Section 6).

China is currently the leading market for offshore wind power in Asia in terms of development potential and planned capacity. Barriers to land-based wind development in recent years, particularly because of grid integration issues, encouraged developers to seek offshore opportunities (Global Wind Energy Council 2017). However, deployment has been much slower than the government originally anticipated because of a fragmented permitting process and feed-in tariff rates that are insufficient to make projects economically viable. The National Energy Administration in China reduced deployment targets from 30,000 MW by 2020 down to 5,000 MW by 2020 (Global Wind Energy Council 2017). In response to the slowdown of offshore development, the National Energy Administration issued a list of 44 approved projects, totaling 10,530 MW, prioritized to receive approval from local, provincial, and grid authorities, which improved the development speed in China in 2015 and 2016 (National Energy Administration 2014). In 2016, China was second only to Germany in annual installed offshore wind capacity. Furthermore, all of the commissioned capacity came from nearshore projects (water depth of 10 meters (m)−15 m) instead of the intertidal projects (water depth <10 m) that dominated the Chinese market previously.

The Japanese government implemented an industry-wide shutdown of all nuclear power plants in Japan as a direct result of the Fukushima nuclear power plant meltdown caused by the earthquake and tsunami in March 2011. Out of Japan's remaining fleet of nuclear power plants, there are 42 operable reactors but only four have been restarted thus far (Nuclear Energy Institute 2017). According to the Japan Atomic Industrial Forum, a reactor must meet a series of post-Fukushima regulatory requirements to be allowed to restart; only 12 reactors at six sites meet those standards at this time. The gap left by nuclear, which accounted for about 30% of the electricity supply before the tsunami, has been mostly filled by fossil fuels, energy efficiency, and some renewable resources. Japan's Ministry of Economy, Trade and Industry (METI) plans to obtain 22%–24% of Japan's electricity needs from renewable energy by 2030, including 800 MW of offshore wind (METI 2015).

However, the waters off the Japanese coastline are too deep for a high volume of wind turbines with fixed-bottom foundation technologies. To address their dominant deepwater offshore wind resource, Japan is supporting the rapid development and deployment of floating offshore wind technology. Since 2013, Japan has deployed four floating wind turbines, including a 7-MW turbine in summer 2015, which is currently the largest floating offshore wind turbine in the world.[20] The government has enacted a feed-in tariff for offshore wind that will deliver 36,000 yen/megawatt-hour (MWh) ($350/MWh) for 20 years and expects that this subsidy will increase commercial interest in building offshore wind farms in Japan.

South Korea installed its first offshore wind turbines in 2012, following a 2011 announcement that the government would provide nearly $8 billion to fund the phased development of a 2,500-MW offshore project, with operations beginning in 2019. As of June 2016, the 30-MW Tamra Project, South Korea's first commercial offshore wind project, is under construction and expected to be fully operational by the end of the year (Verbruggen 2016). Offshore wind is expected to reach 10,600 MW by 2030, equivalent to 27% of South Korea's total renewable target set by their renewables portfolio standard (RPS). This RPS serves as the main policy driver for renewable energy in South Korea. It requires power producers to comply through generation of renewable energy certificates (RECs), providing offshore wind with an additional multiplier for every megawatt-hour generated. Approximately 500 MW of projects are advancing through the Korean regulatory pipeline for offshore wind. South Korea hopes to leverage its capabilities in the shipbuilding and marine industries to foster a domestic offshore wind manufacturing industry (Korea Environmental Industry & Technology Institute 2013).

Taiwan is also emerging as a potentially large offshore wind market. The government has announced targets of deploying 600 MW of capacity by 2020 and 4,000 MW by 2030. The government offers a demonstration incentive program for pilot projects. Phase I of Taiwan's first demonstration offshore wind project, Formosa I, was installed in 2016. The 8-MW project was fully commissioned in April 2017. The 120-MW Phase II project is expected to become operational in 2019. Additional pilot projects are expected to become operational before 2020 to take advantage of the incentives for demonstration projects. Several developers have proposed projects in Taiwan to be built between 2021 and 2024 (Global Wind Energy Council 2017). The government plans to designate commercial development zones in the post-2020 time frame (Hu 2012; Weston 2015b).

In 2015, the Indian Ministry of New and Renewable Energy announced India's Offshore Wind Policy, which sets up offshore wind R&D activities and outlines an international competitive bidding mechanism for the sector (Ministry of New and Renewable Energy 2015). Although no national targets have been established as of June 2017, the Ministry of New and Renewable Energy has been tasked with conducting a detailed offshore wind power potential assessment in the exclusive economic zones of the county. Preliminary resource assessment by NREL suggests a total potential of approximately 162 gigawatts (GW) of offshore capacity in India (Arent et al. 2012).

[20] The Fukushima Forward II floating project consists of one 7-MW and one 5-MW turbine. The 5-MW downwind Hitachi turbine has been deployed and is expected to become operational in 2017.

2.2 Offshore Wind Market Projections

2.2.1 Project Pipeline Through 2022

The projects under construction are the most predictable in terms of estimating a COD and can help illustrate the composition of the market over the next 1 or 2 years. As of December 2016, the pipeline project data show that there is 6,300 MW of new offshore wind capacity currently under construction. Figure 2 compares the global fleet of operating projects to the projects currently under construction by country.

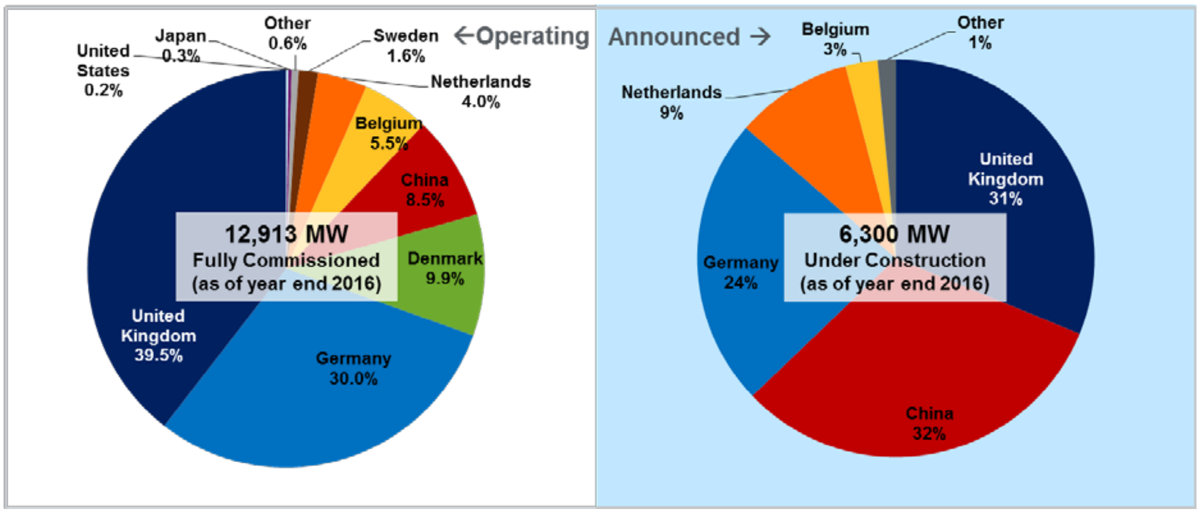

Figure 2. Comparison of market share for projects that are operating vs. under construction

Source: NREL

Table 2 summarizes the fully commissioned offshore wind capacity and the offshore wind capacity under construction, by country, as of December 31, 2016.

Table 2. Summary of Operating and Under Construction Offshore Wind Projects by Country

	Commissioned (as of end of 2016 [MW])	Under Construction (as of end of 2016)	Total
United Kingdom	5,097	1,966	7,062
Germany	3,877	1,483	5,360
China	1,092	1,994	3,086
Denmark	1,271	0	1,271
Netherlands	520	600	1,120
Belgium	712	165	877
Sweden	202	0	202
Japan	38	12	50
United States	30	0	30
Other	75	80	155
Total	**12,913**	**6,300**	**19,213**

Note: Totals may not sum as a result of rounding.

The United Kingdom leads the offshore wind market in cumulative capacity with 5,097 MW installed. Although no new U.K. projects achieved commercial operation in 2016, partly as a result of transitioning from the renewable obligation certificates to a CfD scheme, the market has a heavy under-construction pipeline with nearly 2,000 MW expected to be in commercial operation in 2017 and 2018. Germany follows the United Kingdom globally, with nearly 1,500 MW under construction. After the release of the 2014–2016 Offshore Wind Approval and Construction list, many projects in China have been able to progress along the development timeline. Nearly 2,000 MW are under construction and expected to come online in the next 2 years.

Figure 3 shows the global offshore wind project pipeline through 2022, including all offshore wind projects that have announced a COD in or before 2022 (regardless of development status). Annual planned capacity additions are shown and the grey line denotes the cumulative planned capacity additions. Figure 3 can be reviewed with Figure 1 to get a sense of the full offshore wind project history and outlook through 2022.

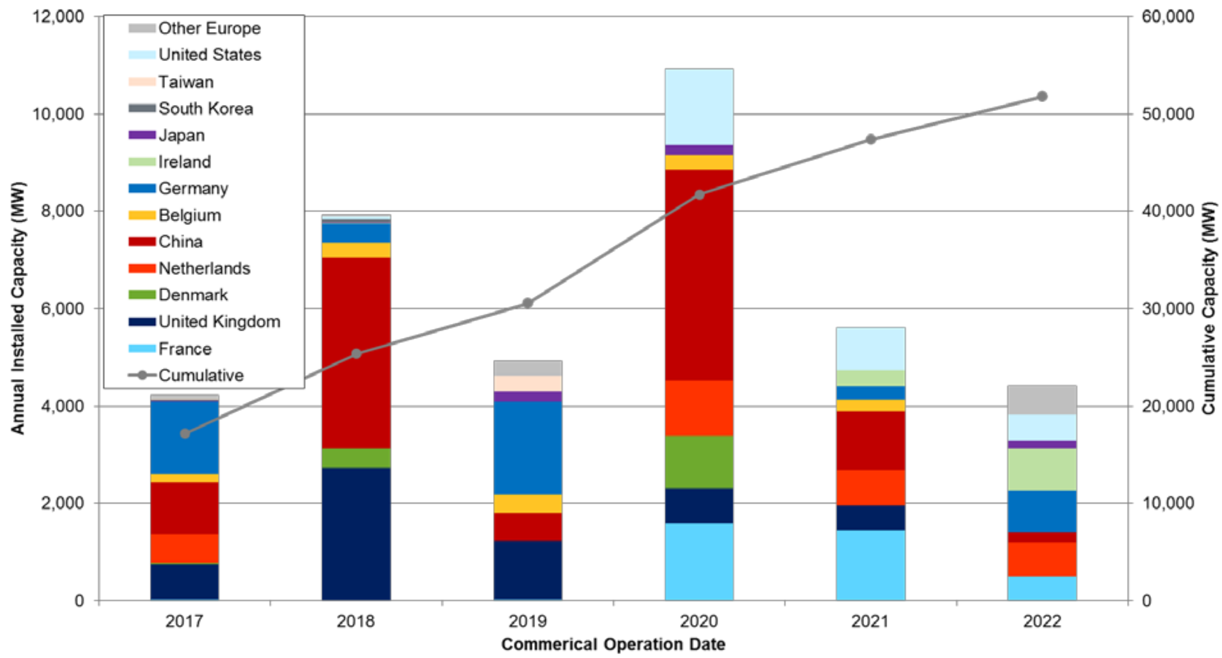

Figure 3. Global offshore wind pipeline of projects with announced commercial operation dates through 2022

Source: NREL

Based on these project pipeline data, 38,856 MW of installed capacity could be commissioned between 2017 and 2022, which would bring the cumulative installed capacity to 51,769 MW. The United States, France, and Denmark are expected to contribute a greater share of the market by 2022. Note that individual projects have not been evaluated to determine the likelihood of achieving their announced schedules, therefore the data presented in this report should not be treated as a forecast without conducting further investigation. Generally, these estimates are considered optimistic because deadlines often slip and occasionally projects are cancelled.

2.2.2 Long-Term Pipeline

Figure 4 shows the global capacity of the operating and announced development pipeline for all offshore wind projects by region. This figure does not provide information about the likely timing of developments within the long-term pipeline, but provides overall announced capacity for all active projects recorded in the NREL OWDB.[21] Generally, projects that are more advanced within the pipeline are likely to be installed earlier than those that are less mature; however, international differences in regulatory structure can result in a wide range of development timelines.

[21] The data in Figure 3 do not include projects that are dormant, cancelled, decommissioned, or development zones.

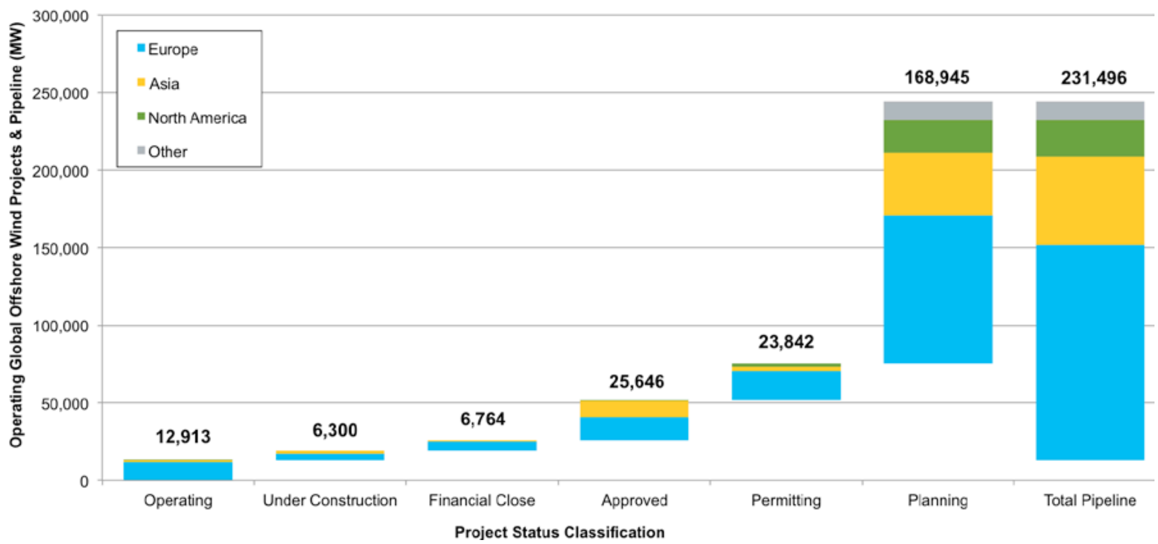

Figure 4. Operating and development pipeline for offshore wind projects by global regions

Source: NREL

The offshore wind project pipeline includes projects that are under construction, at financial close, approved, permits submitted, and undergoing planning. This classification is generally intended to adhere to the project phases defined in Table 1; however, because of differences in international regulatory processes, inconsistencies will arise. In particular, NREL's global project pipeline from the OWDB combines the U.S. status categories "planning" and "site control" into a single category called "planning." Therefore, "site control" is not recognized as a separate phase for non-U.S. projects because it is not always relevant when examined across varying national regulatory structures. The pipeline is segmented into four global regional categories: Europe, North America, Asia, and Other. The "other" category includes several early-stage projects that have been announced in Latin America and Australia.

The estimated global offshore wind pipeline currently totals more than 231,000 MW in capacity, with approximately 13 MW of operational capacity.[22] Approximately 60% of the projects in the identified pipeline are located in Europe, 25% in Asia, 10% in North America, and 5% in the rest of the world (other).

[22] The pipeline capacity in the database decreased from 250,000 in 2015 to 231,000 MW of capacity mainly because of projects under development entering the on hold/cancelled category and reductions in announced capacity of projects as they advance to the permitting or approved stages.

3 U.S. Offshore Wind Market Assessment

The U.S. offshore wind industry has experienced significant progress and a general upturn in its outlook for sustained market growth since the *2014–2015 Offshore Wind Technologies Market Report* was released in September 2015 (Smith, Stehly, and Musial 2015). Most notably, in December 2016, Deepwater Wind's 30-MW BIWF became the first commercial offshore wind facility commissioned in the United States. This milestone was also accompanied by increasing domestic policy support in states such as Massachusetts, New York, and Maryland to attract offshore wind, as well as dramatic and demonstrative cost declines in European offshore wind markets. In September 2016, a joint DOE/U.S. Department of the Interior (DOI) *National Offshore Wind Strategy* (Gilman et al. 2016) identified key research actions that would be needed to achieve the DOE *Wind Vision*'s deployment scenario of 86 GW of offshore wind by 2050 (DOE 2015).

Collectively, these recent actions have motivated prospective developers to secure U.S. wind areas for near-term offshore wind development. Since 2015, the Bureau of Ocean Energy Management (BOEM) auctioned six additional commercial offshore wind leases. Higher auction sales prices serve as an indicator that offshore wind energy areas (WEAs) are increasing in value to developers. BOEM has also identified six new Call Areas to determine commercial interest in potential future offshore wind lease sites and to engage with local stakeholders. As an update to the *2014–2015 Offshore Wind Technologies Market Report* (Smith, Stehly, and Musial 2015):

- Section 3.1 provides an overview of the U.S. offshore wind industry.
- Section 3.2 assesses changes to the U.S. project pipeline over the past 2 years.
- Section 3.3 discusses recent offshore leasing developments.
- Section 3.4 highlights new procurement and offtake policies impacting development.
- Section 3.5 explores DOE's advanced technology demonstration projects (ATD) program.
- Section 3.6 analyzes offshore wind developments by state in each U.S. offshore region.

In Section 2, the global database is current through December 31, 2016, for international market assessment. However, for the U.S. assessments made in this section, the authors attempted to capture current events as close to the publication date as possible to maximize the relevance of this report. Generally, this report captures relevant activities through June 2017.

3.1 U.S. Offshore Wind Industry Overview

Deepwater's BIWF became the first operational U.S. offshore wind facility in December 2016. The $360-million, 30-MW pilot project consists of five 6-MW GE/Alstom Haliade turbines and took 18 months to construct. Although this project's cost was comparatively higher than most European projects, it represents a first-of-a-kind project in the United States offshore wind energy market. Future projects are expected to have a reduced cost profile (Harrington 2017; Maryland Public Service Commission 2017a). Block Island's successful completion demonstrated that offshore wind can achieve commercial operation in the United States, and helped catalyze interest in the U.S. offshore wind market. The U.S. offshore wind industry's enthusiasm and optimism has also been bolstered by declining costs in European markets, an increased number of potential domestic project locations near areas with high renewable energy demand, maturing regulatory processes, continued federal R&D support, and the development of new state-level policies that mandate offshore wind procurement levels and create regimented pathways for offtake agreements.

The *National Offshore Wind Strategy* (Gilman et al. 2016) outlines a framework to develop a robust and sustainable offshore wind industry in the United States by reducing costs and technology risks, supporting effective resource stewardship, and clarifying the costs and benefits of offshore wind. To reduce costs and technology risks, the strategy indicates that research will be necessary to support offshore wind site characterization, data collection, and dissemination; ATD projects and industry partnerships; and installation, operation and maintenance (O&M), and supply chain solutions. BOEM acts as a steward of offshore resources and plans to enhance its regulatory processes to increase transparency, decrease developer risks, and encourage interagency and stakeholder cooperation. Potential DOE actions identified in the strategy include exploring the cost and benefits of offshore wind by identifying localized environmental and economic impacts, analyzing optimal offshore wind and electric system configurations, and conducting regional offshore wind integration studies.

Since the beginning of 2015, BOEM auctioned six additional offshore lease areas (two in Massachusetts, two in New Jersey, one in New York, and one in North Carolina) and identified six Call Areas (four in South Carolina and two in Hawaii) to assess potential commercial interest for additional development (see Section 3.2 and Section 3.3 for more information). BOEM has also issued a Request for Information to initiate a federal leasing process in California. The agency will most likely also hold additional competitive auctions to lease the two previously unauctioned lease areas in the Massachusetts WEA and the two unsold North Carolina WEAs in the near future.

BOEM's recent lease activities have also attracted a larger and more diverse group of industry participants. International oil companies with offshore experience and expertise such as Statoil (Norway) and Shell (Netherlands-United Kingdom) have registered to participate in U.S. offshore wind auctions (Schaps 2017). Statoil acquired New York's WEA and indicated in BOEM's California Request For Information that the company is interested in developing a potential project near Morro Bay, California. Statoil has also expressed interest in the Hawaii Call Areas. Fourteen different entities were approved by BOEM to participate in the New York WEA auction: Avangrid Renewables, DONG Energy, EDF Renewables, wpd Offshore, Alpha Energy, Deepwater Wind, New York State Energy Research and Development Authority, Fishermen's Energy, Sea Breeze Energy, CI-II NY Inc., Energy Management Inc., Convalt Energy, Clean Power Northeast Development Inc., and Innogy US Renewable Projects LLC (Federal Register 2016).

Beyond the BIWF becoming operational and BOEM successfully offering additional leases, optimism surrounding the U.S. offshore wind market has been driven by state-level policy actions in Massachusetts, New York, and Maryland. In August 2016, Massachusetts passed *An Act to Promote Energy Diversity* (H.4568) that requires state electricity providers to procure 1,600 MW of offshore wind capacity by 2027. The law also codifies a competitive solicitation process that will increase the likelihood of offshore projects establishing 15–20 year offtake agreements, decreasing a major source of uncertainty for project developers.

As part of this solicitation process, the electricity providers Eversource, National Grid, and Unitil, in coordination with Massachusetts Department of Energy Resources, issued a request for proposals on June 29, 2017, seeking to procure 400−800 MW of offshore wind energy generation (Massachusetts Clean Energy Center 2017).

New York's Governor Andrew Cuomo also increased industry interest by publicly committing the state to procuring 2,400 MW of offshore capacity by 2030 in his annual "State of the State" address in January 2017. Three weeks later, LIPA and Deepwater Wind reached an agreement on a 20-year PPA for the 90-MW South Fork project and announced that the site could become operational as early as 2022 (Stromsta 2017a).

On May 11, 2017, Maryland's Public Service Commission awarded offshore renewable energy credits (ORECs) to US Wind's 248-MW project and Deepwater Wind's 120-MW Skipjack project, both for 20 years (Maryland PSC 2017). As a precondition for receiving the credits, each developer has to invest in port infrastructure upgrades, local manufacturing, and workforce development. Maryland hopes this local investment will make the state an offshore wind industry hub for the mid-Atlantic region.

Despite increased industry optimism, several questions need to be answered before U.S. offshore wind markets can become self-sustaining and globally competitive in the long term:

- **Can the U.S. offshore wind market replicate the dramatic cost reductions achieved in Europe?** Large-scale offshore wind deployment in the United States is contingent on significant cost reductions that make it easier to sign long-term offtake agreements. Compared to the European market, greater water depth, farther distances from shore, and less favorable market conditions (e.g., cheaper fossil fuels and lower levelized avoided costs[23]) may challenge the economic feasibility of some projects (Beiter et al. 2017).
- **Is the U.S. project development pipeline large enough regionally to grow and sustain a domestic offshore wind industry similar to what Europe has now?** It is unclear whether the U.S. project pipeline will be large enough to drive cost reductions through economies of scale and incentivize investment in domestic offshore wind supply chains and specialized installation/O&M vessels.
- **Will the Jones Act[24] and other U.S. supply-chain limitations impede the construction of projects in the United States?** Currently the lack of specialized U.S.-flagged turbine, cable, and heavy lift platform installation vessels forces developers to rely on more complex and potentially more costly installation strategies.[25]

[23] The levelized avoided cost of electricity is a metric used to capture the value of electricity generation to the system (e.g., the electric grid) over the course of a technology's expected lifespan that measures how much "other," more costly generation is avoided.
[24] The Jones Act (also known as the Merchant Marine Act of 1920) requires U.S.-flagged vessels to transport merchandise or personnel between two points in waters controlled by the United States.
[25] See Section 5 for information on U.S. offshore wind vessel trends.

- **What new technologies will need to be commercialized to achieve the 86 GW by 2050 deployment scenario modeled in the 2015 *Wind Vision*?** High levels of offshore wind deployment in the Northeast and the Pacific may require deep-water floating platforms. Increased offshore wind deployment in southern latitudes will require systems designed to survive hurricanes and provide economic power generation using lower average wind speeds. Additional technology solutions may also be needed for turbines to survive in freshwater ice climates such as the Great Lakes, especially for deeper water.

Overall, new project announcements and the introduction of new offshore wind-specific policies have increased the offshore wind industry's enthusiasm for U.S. markets. However, a number of potential obstacles cast uncertainty on the future trajectory of U.S. offshore wind deployment. The next three subsections describe the U.S. offshore wind pipeline and breakdown events described earlier in more detail. Note that the size of the U.S. offshore wind project pipeline, recent leasing activities, and recent state-level offshore wind policy developments are interrelated topics and will be referenced in multiple sections.

3.2 U.S. Offshore Wind Project Development Pipeline Assessment

As of June 2017, the U.S. offshore wind project development pipeline includes 24,135 MW of potential installed capacity. The U.S. offshore wind project pipeline is made up of:

- Twelve commercial offshore wind projects that have obtained site control[26] by winning a competitive auction offered by BOEM: Cape Wind (Massachusetts), Vineyard Wind (Massachusetts), Bay State Wind (Massachusetts), Deepwater ONE (Rhode Island/Massachusetts [RI/MA]), Statoil Wind US (New York), US Wind (New Jersey), DONG Energy (New Jersey), Skipjack (Delaware), US Wind (Maryland), Dominion (Virginia), and Avangrid (North Carolina). In total, these projects represent 14,686 MW of potential installed capacity and are 60.8% of the total U.S. offshore wind project pipeline potential.

- Five commercial offshore wind projects that have submitted unsolicited applications to BOEM and intend to participate in future BOEM competitive leasing activities include: PNE Wind USA (New York), Trident Winds (California), AW Hawaii Northwest (Hawaii), AW Hawaii South (Hawaii), and Progression Hawaii (Hawaii). These projects represent 2,381 MW of potential installed capacity or 9.9% of the total U.S. offshore wind project pipeline.

- Five demonstration projects that have obtained site control from federal or state authorities include: BIWF (Rhode Island), Aqua Ventus I (Maine), Dominion and DONG Energy's offshore demonstration project (formerly the Virginia Offshore Wind Technology Advancement Project [VOWTAP]) (Virginia), Fred Olsen/LEEDCo Icebreaker (Ohio), and Fishermen's Energy Atlantic City Windfarm (New Jersey). These projects account for 99 MW of potential installed capacity and represent 0.5% of the total U.S. offshore wind project pipeline.

[26] Site control means that a developer has acquired an exclusive offshore wind lease from BOEM or a state entity and now has the ability to conduct site-specific tests and initiate construction when all regulatory requirements have been satisfied.

- Four unleased areas inside BOEM's WEAs that the agency plans to lease in the future include: lease areas OCS-A 0502 and OCS-A 0503 in the Massachusetts WEA, the Wilmington West WEA (North Carolina), and the Wilmington East WEA (North Carolina). These areas have the potential to accommodate 6,969 MW of potential installed capacity and represent 28.8% of the total U.S. offshore wind project pipeline.

For this report, project size is based on the developer's announced project capacity. In cases when the project size is unannounced or unknown, the project's potential installed capacity is estimated by multiplying the size of the lease area (km^2) by three. Based on U.S. resource estimates and historic wind plant array densities, an installed turbine density of 3 MW/km^2 was assumed for U.S. projects to maximize generation and minimize potential wake effects (Musial et al. 2016a). This method was carried over for early-stage planning projects wherein lease areas/WEAs are not yet under site control but their boundaries have been defined by BOEM and unleased areas inside existing WEAs. As such, counting capacity potential using 3 MW/km^2 could overestimate the U.S. offshore wind pipeline's potential installed capacity in the planning phases because full WEA development density may be lower based on the total lease area boundaries. Capacity density limitations may include required restrictions and easements to protect environmental resources, cultural resources, and other uses of the lease area; unsuitable seabed conditions; array loss trade-offs and setbacks; or limits imposed by the offtake agreement or investors.

Figure 5 breaks down the U.S. offshore wind project pipeline by status and state. Definitions for each project status category are identical to those used in Table 1 in Section 1.1.2 Classification of Project Status.

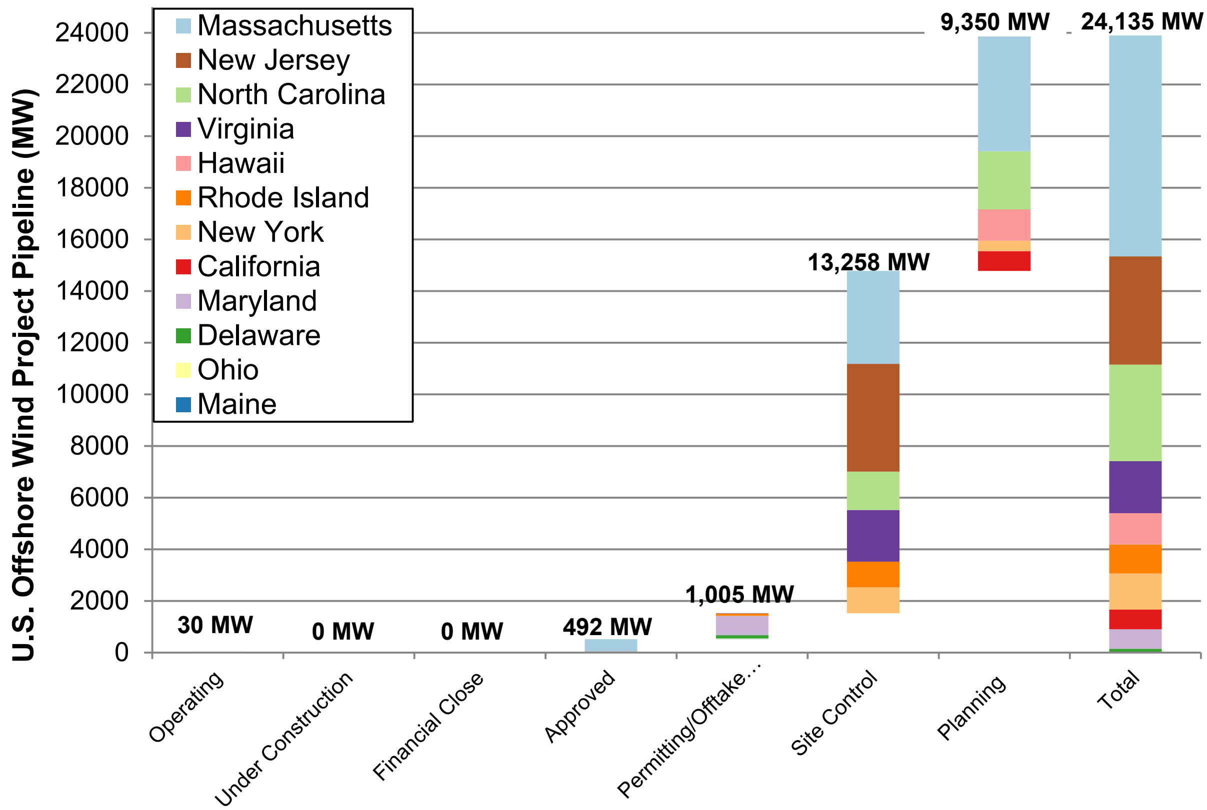

Figure 5. U.S. Offshore Wind Project Pipeline by Project Status as of June 2017

Source: NREL

One notable change to the U.S. pipeline this year is the absence of Oregon, with the removal of the 25-MW WindFloat Pacific (Principle Power) from the pipeline as a result of the company's decision to put the project on hold and BOEM's decision to suspend processing of the project's lease request (BOEM 2017a). WindFloat Pacific was originally intended to be a demonstration project 24 km west of Coos Bay, Oregon, and consisted of up to five turbines mounted on floating platforms. Principle Power received a Notice of Determination of No Competitive Interest and exclusive rights to the site from BOEM in 2014 and progressed to the second round of DOE's ATD projects program. However, legislation that would allow regional utilities to pass the above-market costs of a demonstration PPA on to rate payers was not enacted in the time frame required by DOE's program (Banister 2017). Because obtaining a viable PPA was a milestone of the program, the project did not advance to the next state of DOE funding. Principle Power has since indicated that it has no plans to proceed with the project as originally proposed.

Figure 6 illustrates the amount of potential pipeline capacity located in each state, arranged from largest to smallest. Figure 5 and Figure 6 show that most of the current offshore wind projects in the U.S. pipeline are concentrated in the North Atlantic region, although resource assessments indicate that there are viable offshore wind resources in other parts of the United States, such as in the South Atlantic, Great Lakes, Gulf of Mexico, and Pacific regions (Schwartz et al. 2010; Musial et al. 2016a; Beiter et al. 2017).

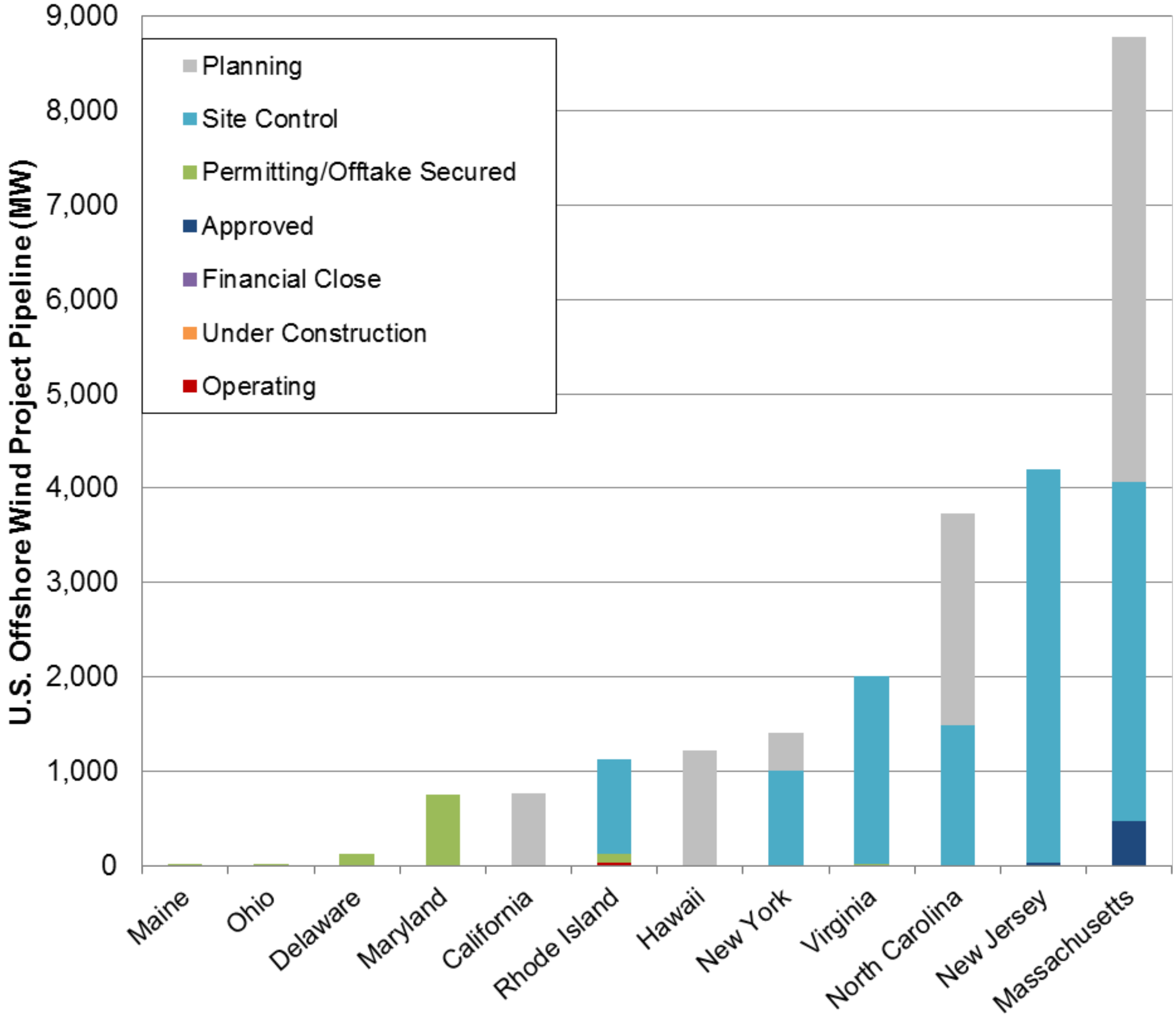

Figure 6. U.S project pipeline by state as of June 2017

Source: NREL

However, offshore wind does have several advantages in the North Atlantic including:

- Metocean and bottom conditions that resemble many North Sea sites, allowing developers to tap into global industry experience
- High population densities on land that limit other options for large-scale renewables
- High-priced electricity markets caused by limited natural gas pipeline infrastructure and constrained transmission delivery makes offshore wind a competitive generation option
- State governments wishing to diversify their energy supply, stimulate economic growth, and gain some measure of energy independence have created offshore wind procurement requirements, codified long-term offtake pathways, supply-chain requirements, and R&D programs. The North Atlantic is the only offshore wind marketplace in the United States with procurement and offtake policies.

Figure 6 also shows that the states with the largest estimated project development pipelines are not necessarily the ones with the most advanced projects. It is expected that projects' energy capacities will decrease as they move through more advanced development phases because of environmental sensitivities, techno-economic considerations, seafloor conditions, and land-use exclusions. For example, a lease area may have the potential to support 1,000 MW but after a developer has conducted detailed site assessments, they determine that it is only possible to install 800 MW.

Figure 7 shows a map of the 28 offshore wind projects that make up the U.S. offshore wind pipeline. Locations in Figure 7 are also numbered so that each one corresponds with a more detailed project description listed in Table 3. Note that there are 28 projects listed in Table 3 but only 25 projects are labeled in Figure 7. This is because three projects in Figure 7 comprise two separate lease areas including Unleased Massachusetts WEA areas (5), Deepwater One leases (7), and US Wind leases (15) in the Maryland WEA.

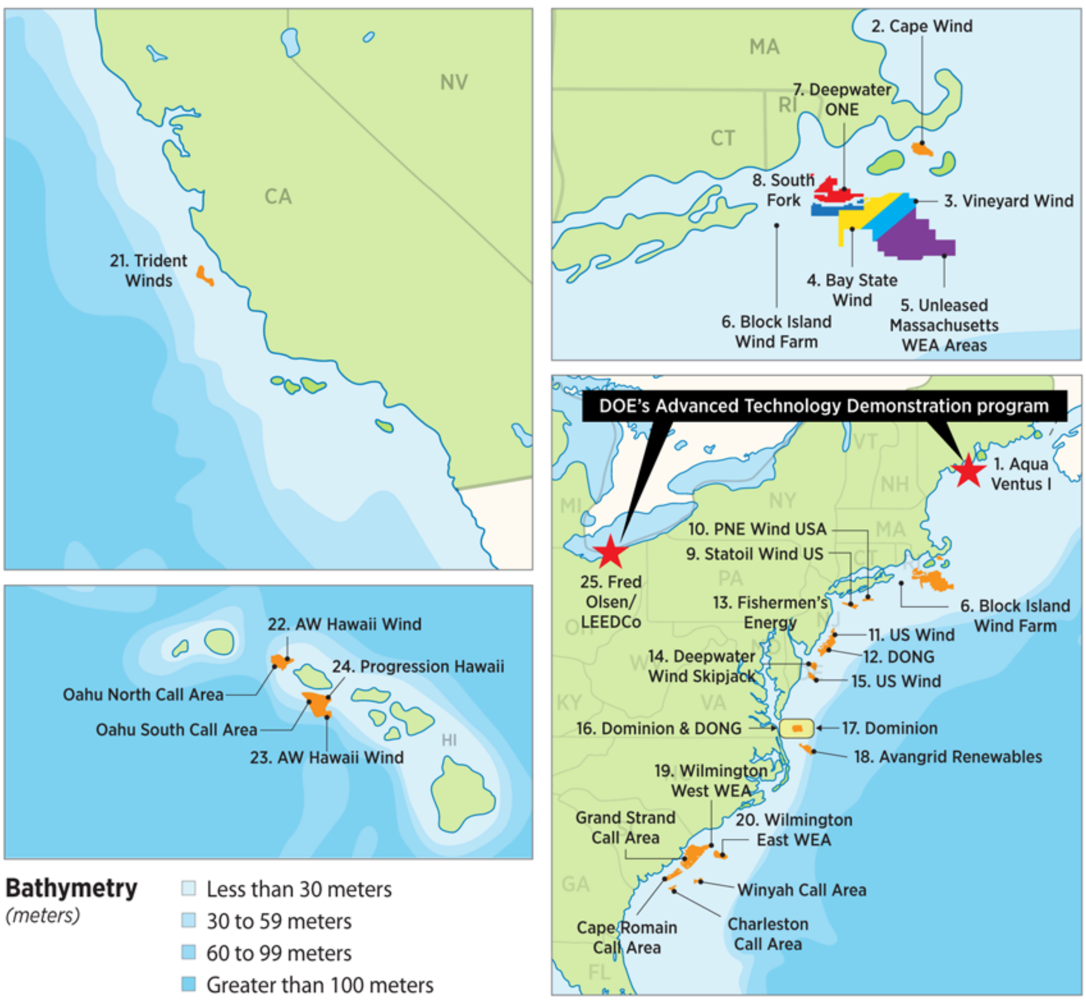

Figure 7. Map of U.S. offshore wind projects

Source: NREL

Table 3. U.S. Offshore Wind Activities by Region

Region	#	Project Owner (Project Name)	State	Current Status	Lease Area	Project Pipeline (MW)	Developer-Announced Capacity (MW)	Potential Generating Capacity (MW)	Area (km^2)	Winning Bid	Lease Issued	Water Depth (m)	Average Wind Speed (meters per second [m/s])
North Atlantic	1	Aqua Ventus I	ME	Permitting/Offtake Secured	ME State Lease	**12**	12	27	9	N/A	6/4/2009	61–110	8.75
	2	Cape Wind Associates (Cape Wind)	MA	Developer Suspended Lease	OCS-A 0478	**468**	468	357	119	N/A	10/6/2010	1–18	8.7
	3	Vineyard Wind	MA	Site Control	OCS-A 0501	**1,600**	1,600	2,025	675	$150,197	4/1/2015	36–58	9.3
	4	DONG Energy & Eversource (Bay State Wind)	MA	Site Control	OCS-A 0500	**2,000**	2,000	2,277	759	$281,285	4/1/2015	39–50	9.3
	5a	Unleased Area	MA	Planning/ Applications Received	OCS-A 0502	**3,012**	N/A	3,012	1,004	N/A	N/A	34–62	9.4
	5b	Unleased Area	MA	Planning/ Applications Received	OCS-A 0503	**1,707**	N/A	1,707	569	N/A	N/A	34–62	9.2
	6	Deepwater Wind (Block Island Wind Farm)	RI	Operating	RI State Lease	**30**	30	6	2	N/A	4/2/2010	23–28	9.7
	7a	Deepwater Wind (Deepwater One North)	RI	Site Control	OCS-A 0486	**500**	500	1,185	395	$3,089,461	10/1/2013	30–46	9.1
	7b	Deepwater Wind (Deepwater One South)	RI	Site Control	OCS-A 0487	**500**	500	816	272	N/A	10/1/2013	30–46	9.2
	8	Deepwater Wind (South Fork)	RI	Permitting/Offtake Secured	N/A	**90**	90	-	-	N/A	1/25/2017	31–36	9.2
	9	Statoil Wind	NY	Site Control	OCS-A 0512	**1,000**	1,000	963	321	$42,469,725	4/1/2017	20–40	9.3
	10	PNE Wind USA (Excelsior Wind Park)	NY	Planning	Unsolicited Application	**400**	400	498	166	N/A	N/A	20–40	9.2
	11	US Wind	NJ	Site Control	OCS-A 0499	**2,226**	N/A	2,226	742	$1,006,240	3/1/2016	17–34	8.6
	12	DONG Energy	NJ	Site Control	OCS-A 0498	**1,947**	N/A	1,947	649	$880,715	3/1/2016	17–34	8.4
	13	Fishermen's Energy (Atlantic City Windfarm)	NJ	Approved	NJ State Lease	**24**	24	6	2	N/A	6/5/2011	8–12	8.3
	14	Deepwater Wind (Skipjack)	DE	Permitting/Offtake Secured	OCS-A 0482	**120**	120	1,170	390	$24,108	12/1/2012	9–33	8.3
	15a	US Wind	MD	Permitting/Offtake Secured	OCS-A 0489	**750**	750	396	132	$3,841,538	12/1/2014	16–29	8.2
	15b	US Wind	MD	Permitting/Offtake Secured	OCS-A 0490			570	190	$4,859,560	12/1/2014	14–37	8.3
		North Atlantic Subtotal				**16,386**	**7,494**	**19,458**	**6,396**	**$56,602,829**			
South Atlantic	16	Dominion and DONG Energy	VA	Site Control	OCS-A 0497	**12**	12	27	9	N/A	11/1/2015	20–26	8.3
	17	Dominion	VA	Site Control	OCS-A 0483	**2,000**	2,000	1,371	457	$1,600,000	11/1/2013	18–33	8.5
	18	Avangrid Renewables	NC	Site Control	OCS-A 0508	**1485**	N/A	1,485	495	$9,066,550	3/17/2017	31–43	8.5
	19	WEA Wilmington West	NC	Planning		**1623**	N/A	1,623	541	N/A	N/A	14–20	8.3
	20	WEA Wilmington East	NC	Planning		**627**	N/A	627	209	N/A	N/A	15–29	8.4
		South Atlantic Subtotal				**5,747**	**2,012**	**5,133**	**1,711**	**$10,666,650**			
Pacific	21	Trident Winds (Morro Bay)	CA	Planning	Unsolicited Application	**765**	765	825	275	N/A	N/A	461–996	7.81
	22	AW Hawaii Wind (Oahu Northwest)	HI	Planning	Unsolicited Application	**408**	408	138	46	N/A	N/A	700–1,000	8.3
	23	AW Hawaii Wind (Oahu South)	HI	Planning	Unsolicited Application	**408**	408	138	49	N/A	N/A	500–700	8.4
	24	Progression Hawaii	HI	Planning	Unsolicited Application	**400**	400	138	46	N/A	N/A	350–550	8.4
		Pacific Subtotal				**1,981**	**1,981**	**1,239**	**416**				
Great Lakes	25	Fred Olsen/LeedCo (Ice Breaker)	OH	Permitting/Offtake Secured	OH State Lease	**21**	21	30	10	N/A	N/A	16–19	8.1
		Great Lakes Subtotal				**21**	**21**	**30**	**10**				
		United States Total				**24,135**	**11,508**	**25,590**	**8,533**	**$67,269,479**			

3.3 U.S. Offshore Wind Lease Area Assessment

In the United States, leases for potential offshore wind projects located 0–5.6 km (0–3 nautical miles) offshore are issued by state regulators and leases for potential projects located 5.6 km–370.4 km (3–200 nautical miles) offshore are issued by BOEM.[27] The development and execution of leasing processes allow private commercial developers to obtain site control of ocean areas and give developers the right to construct and operate offshore wind facilities. Site control is an important milestone in a project's development process because exclusive control allows developers to begin the site investigations necessary to design the project and obtain critical environmental information about the area. As of June 2017, developers have gained site control over 18 sites in the United States, marking a key milestone in the development of the U.S. offshore wind pipeline and offshore wind industry's effort to become commercially viable.

Currently, four projects in the pipeline are located in state waters and have been granted site control by the appropriate state agency, including the 30-MW BIWF in Rhode Island (operating), the 24-MW Fishermen's Atlantic City Windfarm in New Jersey, the 21-MW Fred Olsen/LEEDCo Icebreaker project in Lake Erie, and the 12-MW Aqua Ventus I project in Maine. These projects are included in Figure 7 and Table 3, and described in more detail in Section 3.6.

To date, BOEM has issued three leases on a noncompetitive basis[28] and conducted seven competitive auctions for 13 lease areas inside WEAs along the Atlantic Coast. In total, these lease areas and wind sites permitted in state waters could support a potential capacity of 17,592 MW.[29] As described earlier, BOEM has competitively auctioned six additional Atlantic WEAs off the Atlantic Coast since the beginning of 2015. In January 2015, OffshoreMW (now Vineyard Wind, a partnership between Copenhagen Infrastructure Partners & Avangrid Renewables) and RES America (now Bay State Wind, a partnership between DONG Energy and Eversource) each won a lease area inside the Massachusetts WEA. In November 2015, DONG Energy and US Wind each won lease areas inside the New Jersey WEA. Statoil won New York's first competitive auction in December 2016. In total, BOEM has raised $67,269,479 in revenue from the 13 offshore wind lease areas it has competitively auctioned. BOEM has also indicated that it plans to initiate competitive leasing processes for the two unleased areas inside the Massachusetts WEA (OCS-A 0502 and OCS-A 0503) and the Wilmington West and Wilmington East WEAs in North Carolina. In aggregate, these four lease areas have the potential to support 6,969 MW of new offshore wind capacity.

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[27] There are several exceptions to this including Texas state waters and the west coast of Florida, which define state waters at 9 nautical miles. Also, BOEM has no jurisdiction in the Great Lakes. For more details, see Musial et al. (2016a).

[28] Federal leases issued to Cape Wind Associates in Massachusetts, Bluewater Wind Delaware LLC (ultimately transferred to Deepwater Wind) in Delaware, and the Virginia Department of Mines, Minerals, and Energy (subsequently awarded to Dominion Power) were awarded without an auction because BOEM leasing processes identified that no other competitive interest existed for any of the locations.

[29] Capacity estimates for BOEM wind energy areas are based on a capacity density of 3 MW/km^2, which corresponds to turbine spacing between 9 and 10 rotor diameters if the entire area was developed with uniform array spacing. Wind developers may elect to use wider spacing. However, actual array spacing in Europe is less than 8 rotor diameters (Musial et al. 2013a; Musial et al. 2013b).

Offshore wind developers have also submitted seven unsolicited applications to develop projects in federal waters. PNE Wind USA and Statoil Wind US both submitted applications to develop the unleased areas inside the Massachusetts WEA. PNE Winds USA also submitted an application for a 400-MW project off the coast of Long Island. Trident Winds submitted an application to develop a 765-MW project in Morro Bay, California. Alpha Wind submitted two applications to develop projects on the northern and southern coast of Oahu, Hawaii. Progression Hawaii also submitted an application to develop a project off southern Hawaii.

Increased developer interest in similar geographic locations prompted BOEM to issue Requests for Interest and create six Call Areas[30] to determine which specific locations could support commercial offshore wind projects and should be competitively auctioned in the future. Two Call Areas are located off Oahu, Hawaii, and four other Call Areas are located off South Carolina. Figure 8a, 8b, and 8c show maps of all of BOEM's current offshore wind lease and Call Areas in the United States, including the northeast Atlantic (Figure 8a), the southeast Atlantic (Figure 8b), and the Pacific (Figure 8c).

[30] Please note that Call Areas only represent areas that may be suitable for commercial offshore wind development. If BOEM deems an area inside a Call Area commercially viable and free from environmental or use conflicts, it may use areas inside a Call Area to create a wind energy area that can later be leased to developers.

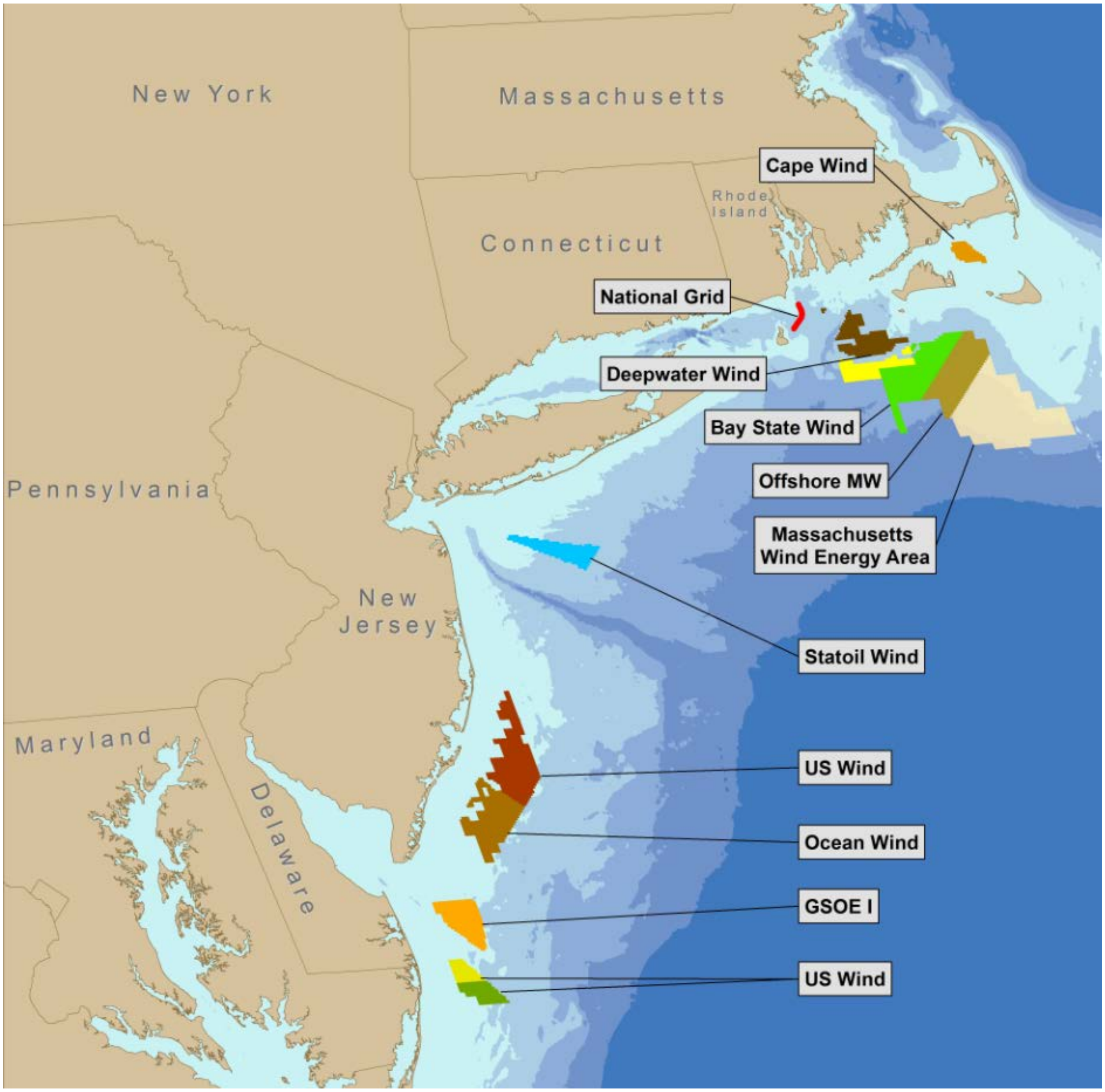

Figure 8a. BOEM map of U.S. offshore wind lease sites in the North Atlantic
Source: BOEM

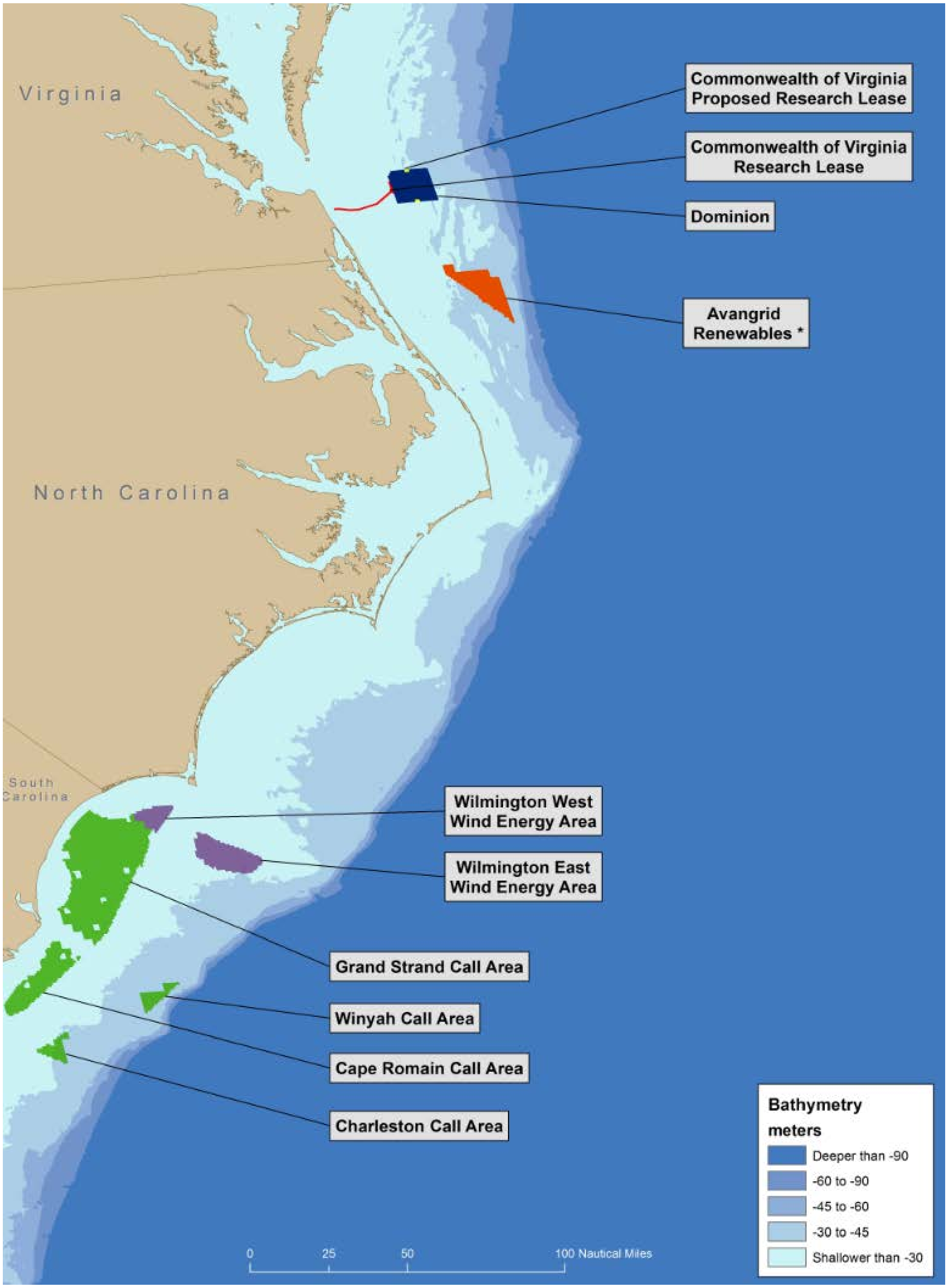

Figure 8b. BOEM map of U.S. offshore wind lease sites in the South Atlantic

Source: BOEM

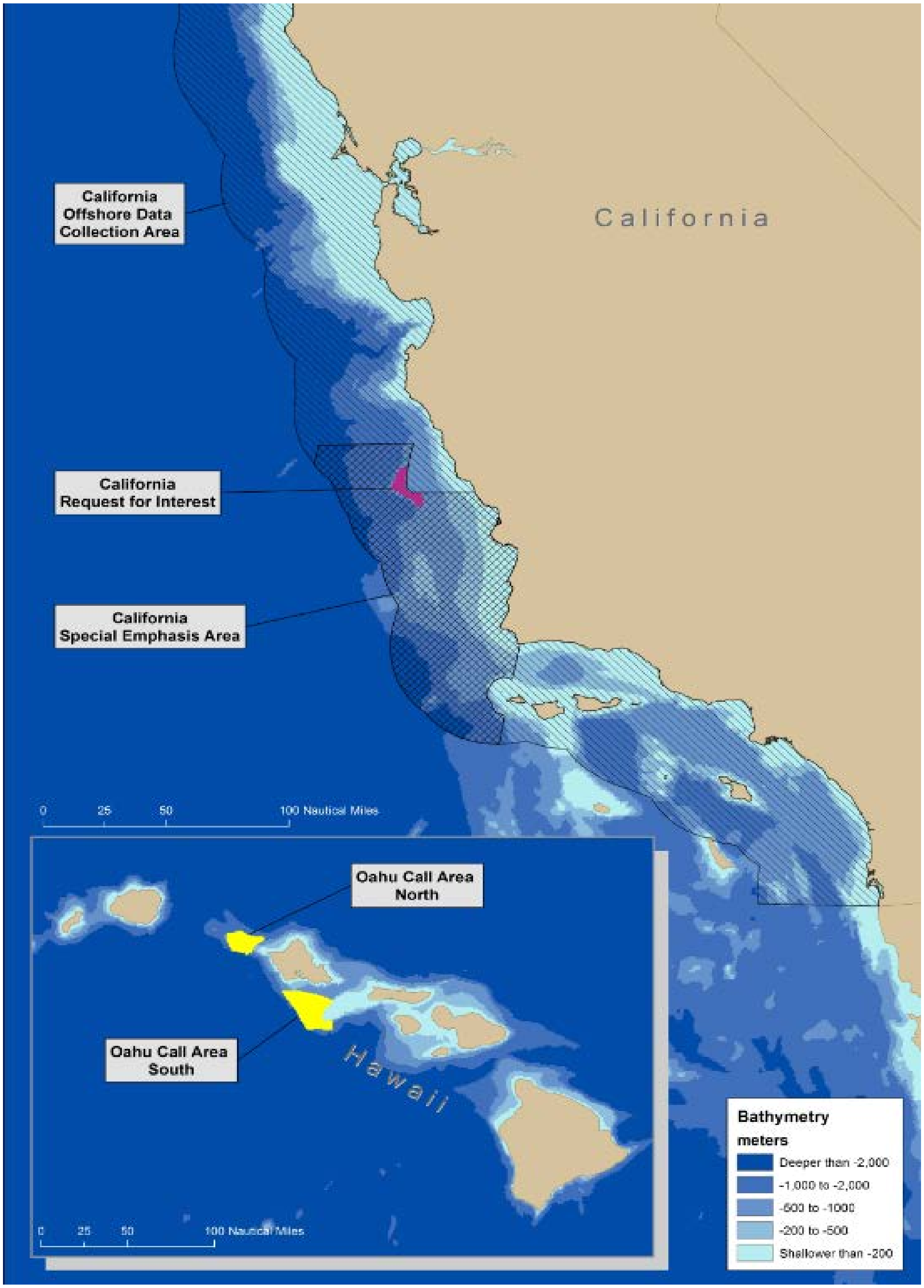

Figure 8c. BOEM map of U.S. offshore wind lease sites on the Pacific Coast

Source: BOEM

3.4 U.S. Offshore Wind Procurement and Offtake Policy Assessment

Commercial interest in offshore wind leases and the size of the U.S. offshore wind pipeline is still primarily driven by state-level policies that support accelerated project development. Since the last report, Massachusetts, New York, and Maryland have introduced new policies to procure offshore wind capacity and create pathways for offshore wind developers to sell their electricity to utilities and other customers.

- **Massachusetts**. H.4568 establishes that state electricity providers should procure 1,600 MW of offshore wind capacity by 2027, and competitively solicit long-term offshore wind offtake agreements at least every 24 months (starting in June 2017).
- **New York**. Governor Andrew Cuomo committed the state to procure 2,400 MW of offshore wind capacity by 2030.
- **Maryland**. The state's Public Service Commission awarded two offshore wind projects the right to receive ORECs that help minimize the premium cost of offshore projects and provide future certainty for developers and utilities about costs and revenues.

Table 4. U.S. Projects with Offtake Agreements or Codified Offtake Pathways

Developer/Project Name	Project Location	Offtake Agreement Type	Details
Deepwater Wind Block Island Wind Farm	RI	Power Purchase Agreement	Twenty-year agreement with National Grid for 30 MW of capacity. The price of electricity increases by 3.5% annually, starting at $244/MWh in the first year and ending at $479/MWh in year 20.
Aqua Ventus I	ME	Power Purchase Agreement	Twenty-year agreement with Central Maine Power for 12 MW of capacity at $230/MWh. May seek an additional agreement with Monhegan Plantation Power District.
Fred Olsen/LEEDCo Icebreaker	OH	Power Purchase Agreement	Signed a memorandum of understanding to provide Cleveland Public Power with 25% of its generation at an undisclosed price. American Municipal Power has agreed to purchase 30% of the project's generations. Cuyahoga County signed a 10-year PPA to buy 8.6% of the project's output.
Deepwater Wind South Fork	NY	Power Purchase Agreement	Twenty-year "pay-for-performance" agreement with the Long Island Public Power Authority (LIPA) for 90 MW of capacity at a yet-to-be-determined price. Harrington (2017) reports that Deepwater's PPA with LIPA is estimated to be around $160/MWh.
US Wind	MD	Offshore Renewable Energy Credit	Awarded 20 years' worth of ORECs for 248 MW of capacity. Each year 913,845 ORECs will be sold, with each credit valued at $131.93.MWh.
Deepwater Wind Skipjack	DE	Offshore Renewable Energy Credit	Awarded 20 years' worth of ORECs for 120 MW of capacity. Each year, 455,482 ORECs will be sold, with each credit valued at $131.93.MWh.
Massachusetts Clean Energy Center/ Massachusetts Department of Energy Resources	MA or RI	Power Purchase Agreement	Massachusetts is seeking to procure 1,600 MW of offshore wind energy generation by 2027. The first request for proposals was issued on June 29, 2017, and seeks 400–800 MW of offshore wind energy generation that would be considered for a 15–20-year long-term contract. Deepwater Wind, Bay State Wind, and Vineyard Wind all plan to participate in the request for proposals.

The availability of state-level procurement and offtake policies can potentially have a dramatic impact on the way developers view the attractiveness of certain U.S. offshore wind markets. Figure 9 shows a timeline with the winning bids for each of BOEM's auctions measured as dollars per square kilometers ($/km^2).[31] The data show a wide variation in final lease sale prices that may be potentially correlated with major industry events, especially the implementation of state-level offshore wind policies. The timeline begins in 2010, approximately when the 30 CFR 585 rule was finalized by BOEM (formally Minerals Management Service) (Federal Register 2009).

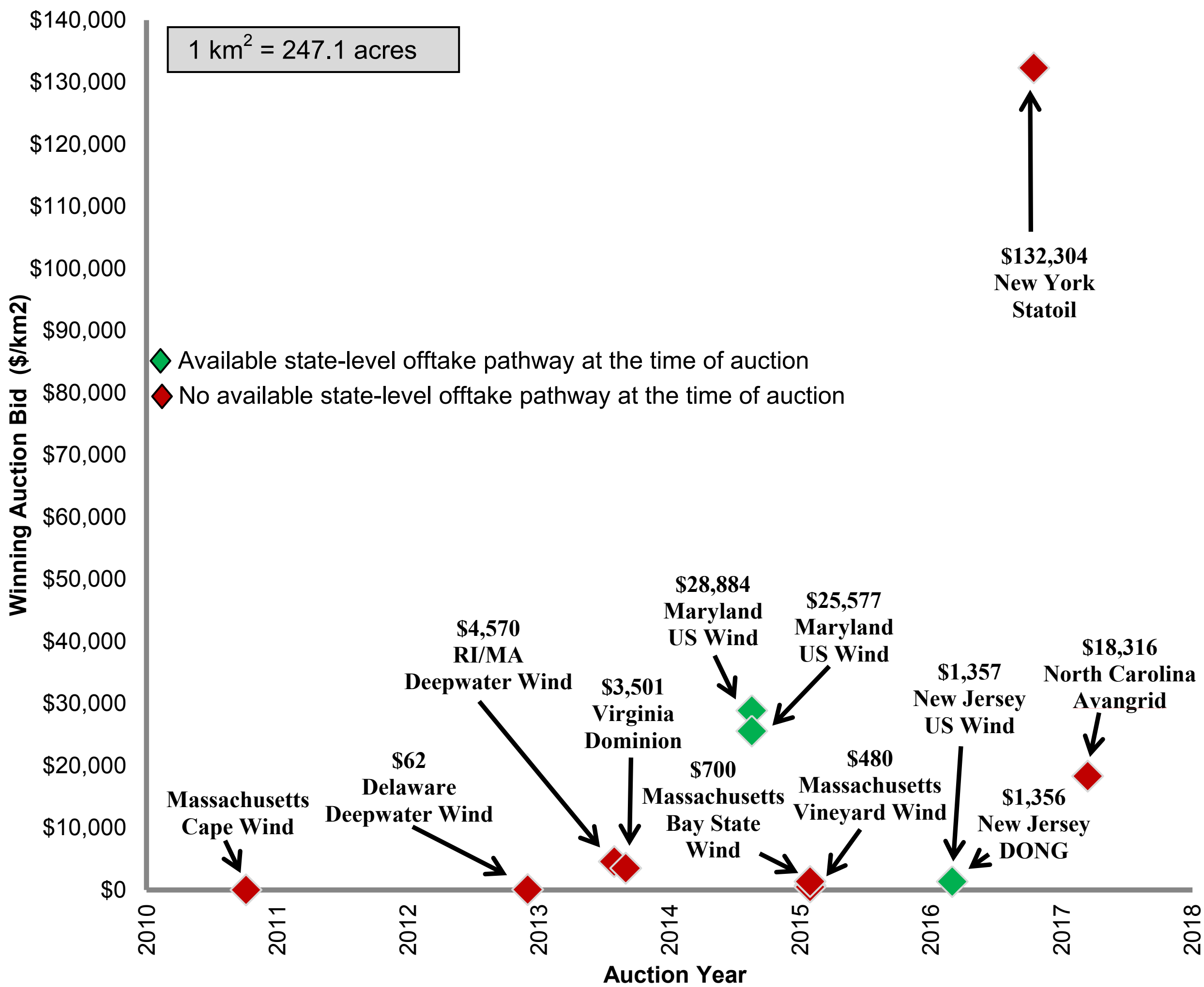

Figure 9. U.S. offshore wind lease prices ($/km^2)

Source: NREL

[31] Note that 1 km^2 = 247.1 acres

The first lease issued by BOEM was the Cape Wind project, but it did not strictly follow the 30 CFR 585 rule because the project began almost a decade before the rule was written (see Appendix C). Smart from the Start was initiated by DOI in late 2010 and began the formal process used today for competitive leasing of WEAs (DOI 2010). However, it took over 2 and a half years before BOEM conducted the first competitive lease auction for the RI/MA Area of Mutual Interest, which was won by Deepwater Wind in July 2013 for $4,570/km^2 (BOEM 2013a). Shortly after the RI/MA sale, in September 2013, the Virginia WEA was leased by BOEM as a single parcel to Dominion Power (BOEM 2013b) for $3,501/km^2. Dominion's commercial interest in offshore wind was largely spawned from their involvement in the DOE ATD projects that began in 2012. Although Dominion's project is no longer part of the DOE ATD program, the company is moving forward with construction plans.[32] Both the Virginia and RI/MA wind energy area auctions set the initial going price for a U.S. lease area with no associated offtake attributes at a level between $3,000 and $5,000 per km^2.

The next WEA auction did not occur until mid-2014 when the two Maryland lease areas were auctioned for a price almost seven times higher than the Virginia and Rhode Island price. This price difference can be explained almost entirely by the associated *Maryland Offshore Wind Energy Act of 2013*, which provides a direct pathway to an offtake through 2.5% RPS carve out and the availability of ORECs (House Bill 226 2013). The relatively large final lease sale prices ($28,800/ km^2 and $25,500/ km^2) may have surprised many industry bidders and revealed that having an offtake mechanism pathway can increase the perceived value of a lease area.

In contrast, the next competitive WEA lease sale was held January 29, 2015, when four lease areas that comprise the Massachusetts WEA, with no obvious offtake pathway at the time, went up for auction. Two weeks earlier, Cape Wind announced that their PPA was in default, which added to the uncertainty of the offshore wind market at the time of the auction. These circumstances likely decreased the attractiveness of acquiring new offshore wind leases, and as a result, developers only bid on two of the sites listed in the January auction. The final sale went to OffshoreMW and RES America Developments Inc. for $480/km^2 and $700/ km^2, respectively.[33] These low prices, which were roughly 2% of the price paid by US Wind in the Maryland sale, were indicative of a sharp decline in market confidence (Cardwell 2015).

Just 2 months later, Deepwater Wind announced that they had closed financing on the BIWF project, increasingly the likelihood that offshore wind in the United States could be a viable investment under the right conditions. However, the New Jersey Board of Public Utilities' (BPU) repeated rejections of Fishermen's Energy's applications to receive the New Jersey's ORECs[34] added more market uncertainty (New Jersey 2010; New Jersey BPU 2014). When the New Jersey WEA was auctioned in November 9, 2015, developers submitted winning bids that were sharply lower than the Maryland auction bids, in which OREC offtake mechanisms were likely

[32] On July 10, 2017, Dominion formed a strategic partnership with DONG Energy to construct a 12-MW demonstration project (formerly known as the Virginia Offshore Wind Technology Advancement Project) off Virginia, the project could potentially be operational as early as 2020 (Stromsta 2017b).
[33] Note that RES later partnered with DONG Energy, which now controls the lease, and OffshoreMW later changed its name to Vineyard Power and sold 50% of the lease rights to Avangrid.
[34] Offshore renewable energy credits are state-level incentives used to support the development of offshore wind.

believed to be more accessible. The two New Jersey WEAs were sold to DONG Energy and US Wind for \$1,356/km^2 and \$1,357/ km^2, respectively; about 20 times lower than Maryland.

In 2016, the U.S. offshore wind industry market outlook gained positive momentum. BIWF began turbine installations, European strike prices were at record lows (surpassing expectations), and state policies for aggressive offshore wind incentives were passed in both Massachusetts and New York. On December 15, 2016, BOEM held a competitive lease sale for the New York WEA that resulted in a record sale price of \$42.5 million (\$132,304/km^2) by Statoil Wind US. This price per square km was almost 100 times higher than the New Jersey lease sale price just 1 year earlier. This extremely high lease price can be attributed, in part, to the expectation that existing New York state policies would eventually lead to a PPA at an economical market price; although no such codified offtake policy yet exists.

Most recently, on March 15, 2017, BOEM held a competitive lease sale in North Carolina for a single lease area near Kitty Hawk. With no formal offtake mechanism in place, offshore wind procurement requirement, or large state RPS, Avangrid submitted a winning bid of \$9,066,550 (\$18,316/km^2). Some organizations have concluded that although companies like Avangrid are eager to develop offshore wind in the South Atlantic region, these lease purchases are long-term investments that will not be developed until some combination of favorable state policies are adopted, technology costs drop, or the wholesale cost of electricity increases (Ouzts 2017).

3.5 DOE's Advanced Technology Demonstration Projects Program

A National Offshore Wind Strategy identified the need to create offshore wind demonstration projects to accelerate innovative R&D to reduce costs and timelines associated with offshore wind energy projects (DOE 2011). In 2012, DOE launched the U.S. Offshore Wind Advanced Technology Demonstration Projects Funding Opportunity (DE-FOA-0000410) to catalyze regionally diverse public-private partnerships that can rapidly and responsibly deploy demonstration projects in U.S. waters. The ATD program's goal is to test and validate innovative technology, installation methods, O&M strategies, and regional offshore wind infrastructure that can ultimately lower the technology's LCOE. The ATD projects also allow state and federal agencies to test their environmental assessment, siting, and leasing processes and make improvements to increase efficiency, ensure public transparency, and reduce uncertainty for investors.

During the first phase of the funding, seven participants were selected and each received \$4 million to complete preliminary engineering, design, site evaluation, and planning for their proposed offshore demonstration projects. In 2014, Principle Power's WindFloat Pacific, Fishermen's Energy's Atlantic City Windfarm, and Dominion's VOWTAP advanced to the next round of funding and received an additional \$6.7 million to complete their final engineering design, permitting, installation plan, and O&M strategy, and secure power off-take agreements. Additionally, University of Maine's New England Aqua Ventus I and LEEDCo's Icebreaker were selected as alternates and received \$3 million. DOE evaluated each project's progress in May 2016 to determine if they should receive additional funding and whether the alternate proposal should be added to the main ATD program. Based on their merit, DOE concluded that LEEDCo's Icebreaker and University of Maine's Aqua Ventus project should be considered for the next round of funding and on boarded the two projects in 2016. Each project is eligible to receive an additional \$40 million if they are able to meet DOE's budget period criteria. Figure 10 provides representations of the substructure types being used by the ATD respective developers. The photo on the left shows the 1/8-scale concrete semisubmersible substructure deployed in Penobscot Bay, Maine in 2012. The illustration on the right of Figure 10 (Funk 2015) shows the monobucket concept that Fred Olsen/LEEDCo intend to deploy in Lake Erie.

Figure 10. Representative substructures proposed in DOE's ATD program

Sources: University of Maine (left); LEEDCo (right)

3.6 Regional Analysis of U.S. Wind Developments

This section analyzes the offshore wind market in each offshore region of the United States. Within each region, individual states are examined to highlight the variation in offshore wind market development and state-level policy implementation. Each subsection assesses the location's offshore wind characteristics using technical potential[35] data published in Musial et al. (2016a) and economic potential[36] estimated in Beiter et al. (2017), state-level policies impacting the offshore wind market, and recent offshore wind project developments. Additional information regarding offshore wind policies and state-specific developments can be found in Appendix A.

[35] Net technical offshore wind energy potential refers to the total amount of electricity that can be generated from offshore turbines given technical and siting limitations. Estimates assume a hub height of 100 meters, a resource area that extends to the edge of the United States Exclusive Economic Zone (370 km), includes a maximum water depth of 1,000 meters, excludes areas with wind speeds lower than 7 meters per second, and includes an installed capacity density of 3 MW/km^2.

[36] Economic potential refers to the amount of offshore wind resource potential that can be developed in the near term to generate electricity at a cost below the technology's minimum revenue requirements. Economic potential estimates are highly uncertain because they depend on economic assumptions and market factors that are constantly changing. Locations listed with zero economic potential in this report may still be economically viable in the future or when using different economic assumptions.

3.6.1 North Atlantic

Maine

Maine does not currently have any operational full-scale offshore wind projects; however, the state has significant market potential (Table 5), especially in deeper water depths that could be exploited using floating offshore wind technologies.

Table 5. Maine's Offshore Wind Characteristics

Ocean Area with Minimum Average Wind Speeds of 7 Meters Per Second (Musial et al. 2016a)		
State Waters	17,990 km^2	
Federal Waters	108,304 km^2	
Total	126,294 km^2	
Net Technical Offshore Wind Energy Potential **(Musial et al. 2016a)**		
Water Depth: 0–30 meters	23,902 Gigawatt-hours (GWh)/year	9,355 MW
Water Depth: 31–60 meters	20,120 GWh/year	14,772 MW
Water Depth: 61–700 meters	367,162 GWh/year	44,659 MW
Total	411,184 GWh/year	94,498 MW
Offshore Wind Unsubsidized Economic Potential (Beiter et al. 2017)		
By 2027	65,000 MW	

Knowing that widespread offshore wind deployment requires floating platforms, the state legislature created an offshore wind test site in 2009 to obtain real-world data and deploy pilot projects to validate floating platform designs. The test site is located roughly 5 km south of Monhegan Island and can be used to deploy up to two offshore wind turbines, six meteorological towers, an ocean sensor package, and two wave energy converters on a submerged utility line with a maximum capacity of 25 MW (Public Law Chapter 270 2009). The Maine state legislature also passed Maine Public Law 615 requiring the state Public Utility Commission to solicit a long-term PPA for a potential offshore wind energy pilot project[37] and the state to procure at least 5,000 MW of offshore wind capacity by 2030. This procurement requirement complemented Maine's RPS to generate at least 40% of their electricity from renewable sources by 2017. Currently, offshore wind activity in Maine is limited to the proposed New England Aqua Ventus I demonstration project[38] that is participating in DOE's ATD program and an unsolicited lease application submitted by Statoil Wind in 2011, which is currently inactive.

New Hampshire

Despite having offshore wind resources that could be economically exploited by 2027 (Table 6) and a RPS that requires 24.8% of electricity sold in the state to come from renewable energy sources by 2025 (House Bill 1312 2014), developers have not shown any interest in deploying projects offshore New Hampshire. Because of the lack of commercial interest, BOEM is currently not conducting any offshore wind leasing activities in the state.

[37] Maine's Public Utility Commission approved a 20-year power purchase agreement for the New England Aqua Ventus I demonstration project with Central Maine Power in 2013.

[38] Aqua Ventus I is a proposed 12-MW offshore wind pilot project located 21 kilometers from the mainland in 61-110 meters of water depth. The project consists of two 6-megawatt turbines mounted on VolturnUS floating concrete semisubmersible platforms designed by the University of Maine that will be assembled in port and towed to presecured mooring lines at the wind site.

Table 6. New Hampshire's Offshore Wind Characteristics

Ocean Area with Minimum Average Wind Speeds of 7 Meters Per Second **(Musial et al. 2016a)**		
State Waters	486 km^2	
Federal Waters	1,555 km^2	
Total	2,041 km^2	
Net Technical Offshore Wind Energy Potential **(Musial et al. 2016a)**		
Water Depth: 0–30 meters	693 GWh/year	253 MW
Water Depth: 31–60 meters	976 GWh/year	679 MW
Water Depth: 61–700 meters	3,322 GWh/year	363 MW
Total	4,991 GWh/year	1,295 MW
Offshore Wind Unsubsidized Economic Potential **(Beiter et al. 2017)**		
By 2027	2,000 MW	

Massachusetts

Massachusetts has become one of the United States' main offshore wind markets because of its excellent offshore wind resource and state-level policies intended to provide long-term market certainty, minimize developer risk, catalyze the development of domestic offshore wind supply chains, and accelerate offshore wind research and development. The state was home to the first commercial offshore wind lease application (submitted by Cape Wind Associates in 2001) and may potentially draw power from five other proposed commercial projects39 (Table 9).

Relative to all other states in the North Atlantic, Massachusetts has the largest amount of technical offshore wind resource (Table 7).

Table 7. Massachusetts' Offshore Wind Characteristics

Ocean Area with Minimum Average Wind Speeds of 7 Meters Per Second **(Musial et al. 2016a)**		
State Waters	16,506 km^2	
Federal Waters	270,002 km^2	
Total	286,508 km^2	
Net Technical Offshore Wind Energy Potential **(Musial et al. 2016a)**		
Water Depth: 0–30 meters	84,384 GWh/year	8,583 MW
Water Depth: 31–60 meters	279,883 GWh/year	13,182 MW
Water Depth: 61–700 meters	664,758 GWh/year	65,336 MW
Water Depth: 701–1,000 meters	24,142 GWh/year	152,754 MW
Total	1,053,166 GWh/year	239, 855 MW
Offshore Wind Unsubsidized Economic Potential **(Beiter et al. 2017)**		
By 2027	55,000 MW	

Massachusetts' offshore wind market is currently being driven by: 1) an offshore wind procurement policy that provides transparency about the future level of offshore wind demand, 2) offtake agreement pathways that minimize developers' uncertainty about how they can sell their power, 3) infrastructure investments that can catalyze the development of a domestic supply chain and reduce project costs, and 4) R&D policies that are helping develop next-generation technologies to improve efficiencies, drive down costs, and develop a well-trained offshore wind workforce. See Table 8 for more detail.

[39] Please refer to Figure 8a for a detailed map of offshore wind lease areas issued by BOEM.

Table 8. Policies and Programs Impacting the Offshore Wind Market in Massachusetts

Type	Name	Year Enacted (Revised)	Description
Offshore Wind Procurement	*An Act to Promote Energy Diversity* (H.4568)	2016	Establishes electric distribution companies in the state to competitively procure 1,600 MW of offshore wind capacity by June 30, 2027, from sites competitively leased by BOEM and located at least 16 km offshore. Also establishes electric distribution companies to hold competitive solicitations at least every 24 months (starting June 29, 2017) to seek proposals for offshore wind energy generation. During each subsequent solicitation, electric distribution companies cannot enter into a long-term PPA if the offshore wind generator's levelized energy price (including transmission costs) is not lower than the preceding procurement. State regulators will allow electric distribution companies to receive remuneration from their rate base up to 2.75% of the annual PPA payments.
Supply Chain & Infrastructure	New Bedford Marine Commerce Terminal	2015	Massachusetts Clean Energy Center (MassCEC) upgraded the New Bedford Marine Commerce Terminal to support the construction, assembly, and deployment of offshore wind projects. The site has 26 acres of storage, can handle specialty barges, lifts, turbine installation vessels, and mobile cranes rated to lift turbine components. In September 2016, DONG Energy, Deepwater Wind, and Offshore MW (now Vineyard Wind) signed letters of intent to lease space at the site.
Research & Development	Wind Test Center	2011	MassCEC and DOE funded the construction of Wind Technology Testing Center located in Boston. The facility is the largest blade test center in North America and enables R&D that can improve reliability and drive down costs for both land-based and offshore applications.
	Offshore Wind Research	2016	Governor Charlie Baker announced that $700,000 will be awarded to Massachusetts' academic and research institutions via MassCEC's Renewable Energy Trust to support research projects that "identify industry workforce and training and safety requirements; establish a multi-university partnership focused on innovation and driving down costs; and develop a new technique to evaluate the structural integrity of wind blades." (Massachusetts Clean Energy Center 2016)

Table 9. Proposed Commercial Offshore Wind Projects in Massachusetts

Developer (Project Name)	Description
DONG Energy and Eversource (Bay State Wind)	The 759-km^2 project is located 24–40 km south of Martha's Vineyard and was acquired by DONG Energy in May 2015 from RES America Developments Inc., who won the original BOEM auction in January 2015 for $281,285 (BOEM 2015b). In December 2016, DONG Energy entered into a 50/50 partnership with Eversource Energy (DONG Energy 2016). Bay State Wind submitted their Site Assessment Plan for review on May 1, 2017, and BOEM approved the plan on June 29, 2017, giving Bay State Wind the ability to conduct on-site testing (BOEM 2017b). The developers also continue to complete presite feasibility studies and engage in stakeholder outreach (Del Franco 2016).
Copenhagen Infrastructure Partners & Avangrid Renewables (Vineyard Wind)	In January 2015, Offshore MW LLC signed a community benefits agreement with Vineyard Power Coop (a local sustainable energy nonprofit organization) and formed Vineyard Wind LLC to develop an offshore wind project in the Massachusetts WEA. Offshore MW LLC (now Vineyard Wind) acquired lease area OCS-A 0501 in a competitive auction held by BOEM in 2015 for $150,197. The 675-$km^2$ project is located 23 km south of Martha's Vineyard (BOEM 2015). In August 2016, Copenhagen Infrastructure Partners acquired 100% control of Vineyard Wind LLC (Weston 2017b). In May 2017, Avangrid acquired a 50% ownership interest in Vineyard Wind LLC (Reuters Staff 2017). The Vineyard Wind project opened office space in New Bedford, Massachusetts, in June 2017 and plans to participate in Massachusetts' first competitive long-term offshore wind offtake contract solicitation (Barnes 2017).
Deepwater Wind (Deepwater ONE)	The 667-km^2 project is located roughly 45 km east of Montauk, New York, 23 km southeast of Block Island, Rhode Island, and 28 km southwest of Martha's Vineyard, Massachusetts. In 2013, Deepwater Wind submitted winning bids for both of the Rhode Island/Massachusetts WEAs (OCS-A 0486 and OCS-A 0487) for a combined total of $3,838,288. The project's proximity to multiple offshore wind markets (Rhode Island, Massachusetts, New York, Connecticut, and so on) gives Deepwater Wind the ability to potentially sell the project's electricity to a variety of electricity providers in different states.
Cape Wind Associates (Cape Wind)	The 468-MW, 119-km^2, Cape Wind project initially applied for a lease in 2001, and was ultimately granted a commercial lease by BOEM in 2010. Cape Wind has had difficulty securing a long-term PPA partner, and in 2015 asked BOEM for a 2-year lease suspension, which was granted (DOI 2015). In May 2017, BOEM, in accordance with a previous court ruling, issued an updated Supplemental Environmental Impact Statement for public comment (BOEM 2017c). The project continues to look for a long-term offtake agreement.
Statoil Wind US LLC (inactive)	Statoil Wind submitted unsolicited applications to BOEM for the unleased areas in the Massachusetts WEA on December 16, 2016: OCS-A 0502 (1,004 km^2) and OCS-A 0503 (569 km^2). In its application, Statoil indicated that it proposes to install between 400 and 600 MW of offshore wind capacity on the site (Statoil 2016). Because other parties have indicated that they have commercial interest in the site, BOEM plans to initiate a competitive leasing process as per federal regulations (BOEM 2017d).
PNE Wind USA (inactive)	PNE Wind also submitted unsolicited applications to BOEM for the unleased areas in the Massachusetts WEA on December 16, 2016: OCS-A 0502 (1,004 km^2) and OCS-A 0503 (569 km^2). PNE proposes to deploy 400 MW of capacity in the area (PNE Wind 2016). BOEM plans to initiate a competitive leasing process for these sites because other parties have also demonstrated commercial interest.

Rhode Island

Rhode Island possesses the potential to develop a significant offshore wind market because of its offshore wind characteristics (Table 10), Renewable Energy Standard requiring electricity providers to supply 38.5% of their electricity from renewable sources by 2035,[40] support from the state government, and experience gained from the installation of the BIWF.

Table 10. Rhode Island's Offshore Wind Characteristics

Ocean Area with Minimum Average Wind Speeds of 7 Meters Per Second **(Musial et al. 2016a)**		
State Waters	2,597 km^2	
Federal Waters	17,053 km^2	
Total	19,650 km^2	
Net Technical Offshore Wind Energy Potential **(Musial et al. 2016a)**		
Water Depth: 0–30 meters	6,107 GWh/year	1,350 MW
Water Depth: 31–60 meters	21,081 GWh/year	2,840 MW
Water Depth: 61–700 meters	31,359 GWh/year	6,608 MW
Water Depth: 701–1,000 meters	1,636 GWh/year	3,780 MW
Total	60,363 GWh/year	14,578 MW
Offshore Wind Unsubsidized Economic Potential **(Beiter et al. 2017)**		
By 2027	16,000 MW	

Deepwater Wind's 30-MW BIWF began generating electricity in December 2016, becoming the first operational wind farm in the United States. It took 18 months, 300 workers, and 41 different vessels to install five 6-MW GE Haliade turbines on steel jackets designed by Keystone Engineering and manufactured by Gulf Island Fabrication in Louisiana (see Figure 11).

Figure 11. Block Island Wind Farm (commissioned in December 2016): the first commercial offshore wind farm in the United States

Source: Dennis Schroeder, NREL 40448

[40] Please refer to Rhode Island (2016) for more information on the state's Renewable Energy Standard.

Rhode Island was the first state to work with BOEM to facilitate auctions for offshore wind leases. In 2013, Deepwater Wind acquired both lease areas inside the RI/MA WEA[41] (667 km^2 in total), with a winning bid price of $3,838,288. The two lease areas, now known as Deepwater ONE, could potentially support over 2,000 MW of offshore wind capacity, assuming 3 MW/km^2 array densities (Musial et al. 2013c). To date, Deepwater Wind has indicated that the Deepwater ONE project may support over 1,000 MW of capacity. In 2016, Deepwater Wind submitted its Site Assessment Plan to BOEM for the northern lease area in Deepwater ONE. Pending BOEM's approval, the developer can start conducting site testing for up to 5 years and begin drafting its Construction and Operations Plan, which is due in 2020 (BOEM 2017e). Deepwater Wind started its 5-year site assessment term for the southern lease site in July 2014 and has indicated that it will not install a met tower or buoy. A Construction and Operations Plan is due for the southern lease area by January 2019 (BOEM 2017e).

Deepwater Wind plans to construct a 15-turbine project known as South Fork in the northern Deepwater ONE lease area to supply 90 MW of power to LIPA via the town of East Hampton (Deepwater Wind 2015b). Because of its proximity to shorelines in multiple states, projects in the Deepwater ONE lease areas have the potential to sell power to markets in multiple states. The South Fork project also plans to integrate two GE lithium-ion battery storage systems at Montauk and Wainscott (Deepwater Wind 2015b). On January 25, 2017, New York's Governor Andrew Cuomo announced that LIPA agreed to a 20-year PPA with Deepwater Wind for the South Fork Project (New York State Energy Research and Development Authority [NYSERDA] 2017). Depending on permitting, the project could start construction as early as 2019 and commence operations in 2022.

New York

The interest in the offshore wind market in New York has been driven by the state's offshore wind resource (Table 11), increased RPS requirements, ambitious procurement goals laid out by the governor, and long-term interest from local utilities.

Table 11. New York's Offshore Wind Characteristics

Ocean Area with Minimum Average Wind Speeds of 7 Meters Per Second **(Musial et al. 2016a)**		
State Waters	19,468 km^2	
Federal Waters	78,805 km^2	
Total	98,273 km^2	
Net Technical Offshore Wind Energy Potential **(Musial et al. 2016a)**		
Water Depth: 0–30 meters	6,107 GWh/year	10,123 MW
Water Depth: 31–60 meters	21,081 GWh/year	9,164 MW
Water Depth: 61–700 meters	31,359 GWh/year	28,776 MW
Water Depth: 701–1,000 meters	10,553 GWh/year	25,391 MW
Total	60,363 GWh/year	73,454 MW
Offshore Wind Unsubsidized Economic Potential **(Beiter et al. 2017)**		
By 2027	1,000 MW	

[41] The Rhode Island/Massachusetts WEA was jointly developed by the two states and BOEM because of overlapping stakeholders and the site's proximity to multiple jurisdictions and energy markets.

In August 2016, New York replaced its existing RPS with a new Clean Energy Standard that requires load-serving entities to supply at least 50% of their electricity from zero-emission energy sources (renewable or nuclear) by 2030.

New York utilities' became interested in offshore wind in 2009 when Consolidated Edison and LIPA commissioned an Offshore Wind Power Integration Project Feasibility Assessment that evaluated transmission requirements for approximately 350 to 700 MW of offshore wind capacity (Consolidated Edison and LIPA 2009). Long Island and New York City then issued a Request for Information to support a possible request for proposals for an offshore wind project south of Long Island off the Rockaway Peninsula (Offshore Wind Collaborative). In response to commercial offshore interest, NYSERDA began a series of site, meteorological, geophysical, and environmental studies to streamline the potential development of offshore wind projects. In 2011, BOEM received an unsolicited application from the New York Power Authority, LIPA, and Consolidated Edison for a commercial lease to house an up-to-700-MW project. Having received other commercial inquires, BOEM initiated a competitive leasing process for New York in 2013, with a plan to lease a site in 2016 (BOEM 2016).

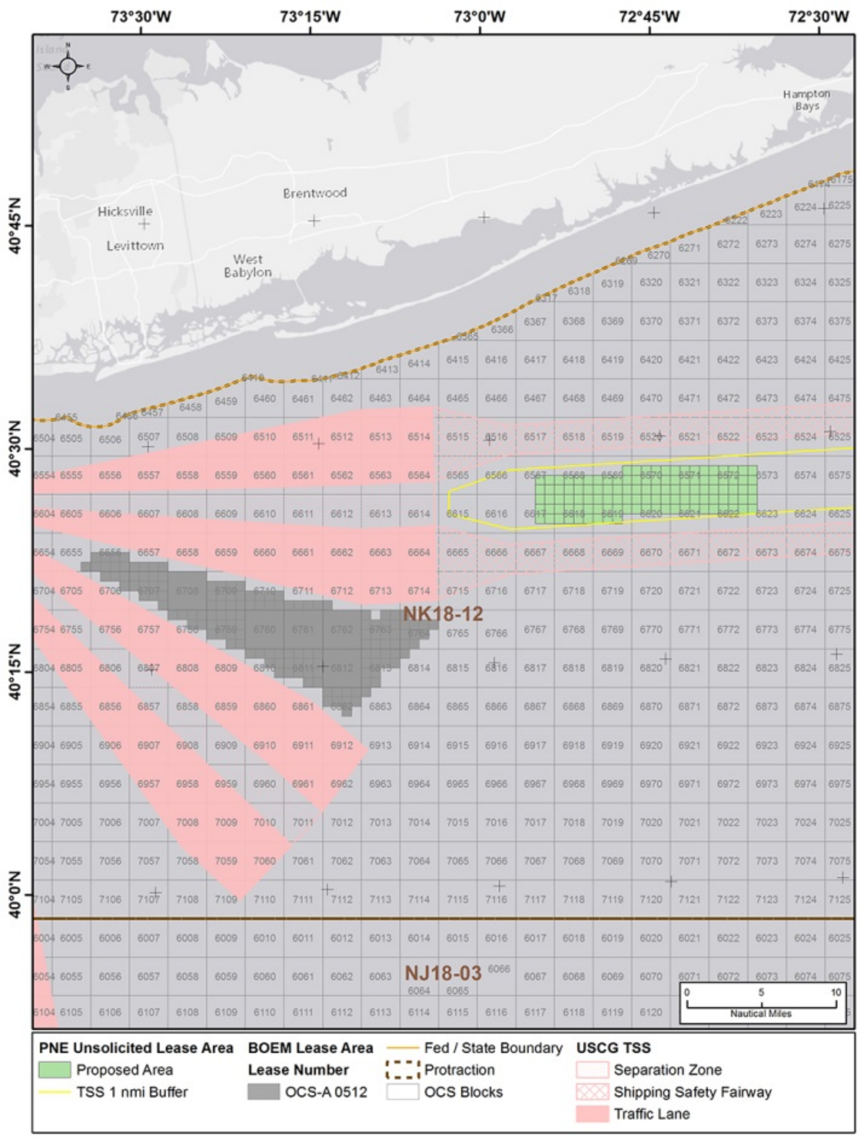

Figure 12. Map of New York wind energy area and unsolicited lease request

Source: BOEM

On December 16, 2016, after 33 rounds of bidding with five other participants, Statoil Wind US LLC won the rights to the New York WEA (OCS-A 0512) (Figure 12). Statoil won the 321-km2 site with a $42,469,725 bid, the largest received in any U.S. auction to date. The final rounds of bidding were a competition between Statoil and NYSERDA. NYSERDA had a strategy to gain site control of the New York WEA, derisk the project with an offtake agreement, and then select a developer under a state-run competition to build and operate the facility. Statoil plans to work closely with NYSERDA during the development of the estimated 400- to 600-MW project.

PNE Wind USA Inc. submitted an unsolicited application to BOEM on December 30, 2016, for 166 km2 southeast of Roland Road Substation to build a 300- to 400-MW facility called Excelsior Wind Park by 2027 (PNE Wind 2016).

Building on the Clean Energy Standard announcement, Governor Andrew Cuomo made a public commitment that New York would adopt 2,400 MW of offshore wind capacity by 2030 and directed state agencies to determine a cost-effective pathway for the state to use 100% clean energy during his “State of the State” address on January 9, 2017 (Cuomo 2017). He also announced that NYSERDA would complete an Offshore Wind Master Plan by the end of 2017 that would act as a comprehensive strategy for exploiting the state’s offshore wind resources, identifying optimal sites, determining leasing mechanisms, conducting environmental assessments, signing offtake agreements, and engaging local stakeholders. The governor also urged LIPA to sign a PPA for Deepwater Wind’s South Fork project (the two parties agreed to terms on January 25, 2017).

New Jersey

Despite developer interest, significant offshore wind resource availability (Table 12), and the relatively early adoption of supportive offshore wind policies, New Jersey has not been able to commercially develop any offshore wind sites.

Table 12. New Jersey’s Offshore Wind Characteristics

Ocean Area with Minimum Average Wind Speeds of 7 Meters Per Second **(Musial et al. 2016a)**		
State Waters	7,477 km^2	
Federal Waters	82,668 km^2	
Total	90,145 km^2	
Net Technical Offshore Wind Energy Potential **(Musial et al. 2016a)**		
Water Depth: 0–30 meters	62,564 GWh/year	3,888 MW
Water Depth: 31–60 meters	118,033 GWh/year	6,815 MW
Water Depth: 61–700 meters	91,587 GWh/year	33,228 MW
Water Depth: 701–1,000 meters	8,010 GWh/year	27,246 MW
Total	280,193 GWh/year	71,177 MW
Offshore Wind Unsubsidized Economic Potential **(Beiter et al. 2017)**		
By 2027	0 MW	

New Jersey’s RPS, first adopted in 1999 and later augmented, requires energy providers to supply 24.39% of their electricity from renewable sources by 2028 (New Jersey 2012). In August 2010, the New Jersey legislature passed the Offshore Wind Economic Development Act, mandating the development of 1,100 MW of offshore wind capacity that yields a net benefit to the state, offering up to $100,000,000 of investment tax credits, and requiring the New Jersey BPU to create a ratepayer-funded OREC that can accelerate project development. Although by law ORECs should be available to developers, the New Jersey BPU has not formally adopted processes to offer or award ORECs to developers.

Fishermen’s Energy worked with the state of New Jersey and the U.S. Army Corps of Engineers to secure an offshore lease in state waters for their proposed 24-MW Atlantic City Windfarm demonstration project in 2011. From 2013 until 2017, Fishermen’s Energy and the state legislature unsuccessfully tried to find ways to qualify the project to receive ORECs and establish an offtake agreement. The governor vetoed legislation for Fishermen’s ORECs twice, S-2711 in January 2016 and S-988 in May 2016 (Christie 2016; Johnson 2016).

In 2011, BOEM issued a Call for Information and Nominations for offshore wind projects in federally controlled waters off New Jersey. BOEM received 11 notifications of commercial interest and after determining the optimal lease sites, issued a proposed sales notification in 2014. BOEM held competitive leases for two sites in November 2015, with US Wind winning a 742-km2 site for $1,006,240 and RES America Development Inc. winning the other 649-km2 site for $880,715 (the site was acquired by DONG Energy in September 2016).

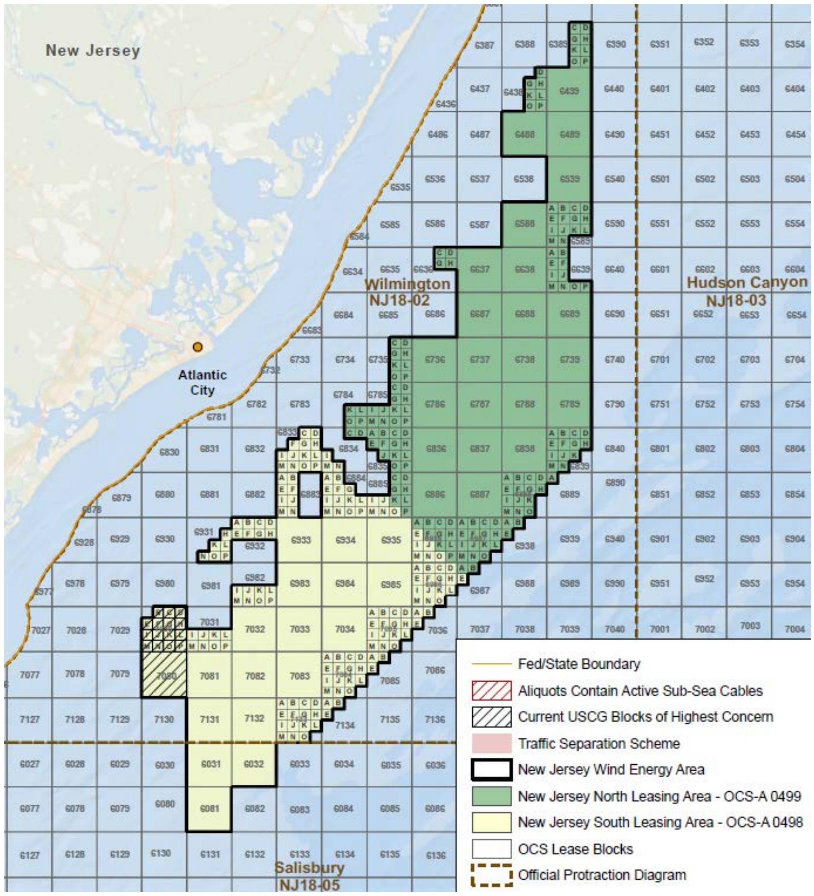

Figure 13. Map of the New Jersey wind energy area

Source: BOEM

US Wind's New Jersey lease site is located approximately 11 km off the coast of Atlantic City. If the entire lease area is used, the site has the potential to generate over 2,200 MW of capacity (Musial et al. 2013b). US Wind has yet to release any project-specific plans. DONG Energy's project in New Jersey could support 1,950 MW of capacity. The company will use its site control to assess the site's seafloor conditions, resource quality, and potential cable pathways. To date, DONG Energy has not released any project-specific plans.

Delaware

A federal lease area off Delaware's coast is being developed for an offshore wind project that was awarded the ability to sell power and receive ORECs in Maryland. Future offshore wind development may take advantage of the state's offshore resource (Table 13) and Delaware's existing RPS that requires utility providers to supply 25% of their electricity from renewable sources by 2025.

Deepwater Wind currently controls the OCS-A 0482 lease area for its Skipjack project. The project is located northeast of Ocean City and is expected to include fifteen 8-MW wind turbines mounted on monopiles, providing 120 MW of capacity. The project will interconnect at an Ocean City substation, begin operations in 2023, and cost $720 million (Maryland PSC 2017a).

Table 13. Delaware's Offshore Wind Characteristics

Ocean Area with Minimum Average Wind Speeds of 7 Meters Per Second **(Musial et al. 2016a)**		
State Waters	3,474 km^2	
Federal Waters	5,580 km^2	
Total	9,054 km^2	
Net Technical Offshore Wind Energy Potential **(Musial et al. 2016a)**		
Water Depth: 0–30 meters	14,719 GWh/year	1,806 MW
Water Depth: 31–60 meters	5,528 GWh/year	1,249 MW
Water Depth: 61–700 meters	358 GWh/year	2,794 MW
Total	20,604 GWh/year	5,876 MW
Offshore Wind Unsubsidized Economic Potential **(Beiter et al. 2017)**		
By 2027	0 MW	

In May 2017, Maryland's Public Service Commission ruled that Deepwater Wind's Skipjack was eligible to receive 455,483 Maryland ORECs (at $131.39 per MWh) per year for 20 years. This eligibility is contingent on Deepwater Wind using a port located in the greater Baltimore area for project installation, utilizing a port in Ocean City for O&M activities, and investing $25 million in a Maryland steel fabrication plant, $13.2 million at the Tradepoint Atlantic Shipyard, and $6 million in the Maryland Offshore Wind Business Development Fund (Maryland Public Service Commission [PSC] 2017b [Order No.88192]).

Maryland

Maryland's offshore wind resource is summarized in Table 14.

Table 14. Maryland's Offshore Wind Characteristics

Ocean Area with Minimum Average Wind Speeds of 7 Meters Per Second **(Musial et al. 2016a)**		
State Waters	13,040 km^2	
Federal Waters	22,196 km^2	
Total	35,236 km^2	
Net Technical Offshore Wind Energy Potential **(Musial et al. 2016a)**		
Water Depth: 0–29 meters	25,735 GWh/year	3,751 MW
Water Depth: 31–60 meters	29,656 GWh/year	1,738 MW
Water Depth: 61–700 meters	35,036 GWh/year	13,136 MW
Water Depth: 701–1,000 meters	5,863 GWh/year	7,903 MW
Total	96,289 GWh/year	26,529 MW
Offshore Wind Unsubsidized Economic Potential **(Beiter et al. 2017)**		
By 2027	0 MW	

Maryland's RPS, originally introduced in 2005 and subsequently amended, requires in-state utilities to each procure at least 25% of their total annual load from renewable energy technologies by 2020 (House Bill 1106). The state also adopted the *Maryland Offshore Wind Energy Act of 2013,* which made a maximum 2.5% RPS carve out for electricity generated by offshore wind energy starting in 2017, created ORECs, and created the Maryland Offshore Wind Business Development Fund and Advisory Committee within the Maryland Energy Administration.

BOEM issued offshore wind Call Areas in 2012 and ultimately conducted a competitive auction in August 2014 for the two Maryland lease areas that equal 322 km^2. The auction lasted 19 rounds and saw US Wind submit the winning bid for both OCS A-0489 ($3,841,538) and OCS A-0490 ($4,859,560), for a combined total of $8,701,098. US Wind's lease areas could support over 1,000 MW of capacity, but the developer has only announced it plans to develop 750 MW Musial et al. 2013d). The company states that the project could consist of 85–187 4- to 6-MW turbines (750 MW) mounted on steel jackets and connected at the Indian River Substation in Maryland (Maryland PSC 2017). A 750-MW project is expected to cost $2.5 billion but if the company decreases the projects size to 248 MW, the project is expected to cost $1.375 billion (Maryland PSC 2017a).

In May 2017, Maryland's PSC ruled that both US Wind's Maryland project and Deepwater Wind's Skipjack project located in Delaware (see earlier section on Delaware) were eligible to sell power in Maryland and receive ORECs. The PSC determined that both projects could receive ORECs valued at $131.93/MWh. US Wind is eligible to receive 913,845 credits per year (for 248 MW of capacity). This eligibility is contingent on the company using a port located in the greater Baltimore area for project installation, utilizing a port in Ocean City for O&M activities, and investing $51 million in a Maryland steel fabrication plant, $26.4 million in the Tradepoint Atlantic Shipyard, and $6 million in the Maryland Offshore Wind Business Development Fund (Maryland PSC 2017b [Order Number 88192]).

3.6.2 South Atlantic

Virginia

Virginia's offshore wind resource is summarized in Table 15.

Table 15. Virginia's Offshore Wind Characteristics

Ocean Area with Minimum Average Wind Speeds of 7 Meters Per Second **(Musial et al. 2016a)**		
State Waters	17,195 km^2	
Federal Waters	46,677 km^2	
Total	63,872 km^2	
Net Technical Offshore Wind Energy Potential **(Musial et al. 2016a)**		
Water Depth: 0–29 meters	87,924 GWh/year	8,941 MW
Water Depth: 31–60 meters	45,128 GWh/year	5,665 MW
Water Depth: 61–700 meters	24,983 GWh/year	24,190 MW
Water Depth: 701–1,000 meters	3,776 GWh/year	6,366 MW
Total	161,812 GWh/year	45,163 MW
Offshore Wind Unsubsidized Economic Potential **(Beiter et al. 2017)**		
By 2027	0 MW	

Although Virginia does not have a mandatory RPS, it does have a voluntary RPS goal of providing 15% of base retail electricity sales with renewable energy by 2025. In 2012, the state passed legislation (SB 413) that allows investor-owned utilities to achieve up to 20% of a voluntary renewable energy goal through accredited R&D activities, recover their costs for voluntary RPS programs, and receive an increased rate of return for each RPS goal achieved using offshore wind or nuclear facilities built after July 2013 (Virginia 2012). Under this rule, offshore wind facilities would receive triple credit toward meeting a utility's voluntary RPS goal.

Offtake pathways or incentives may not be needed because Virginia is a fully regulated market, meaning utilities like Dominion can fully recover their capital expenditures plus a rate of return through their retail electricity rates.

BOEM published a Call for Information and Nominations in 2012 to determine the competitive interest in development offshore Virginia, and after receiving multiple indications of commercial interest, decided to create the Virginia WEA (457 km^2) and competitively offer the site via auction in September 2013 (Figure 14). After six rounds, Virginia Electric and Power Company (Dominion Energy) beat out Apex Virginia Offshore Wind LLC with a bid of $1,600,000. Dominion submitted a complete Site Assessment Plan to BOEM in March 2016 to install a floating WindSentinel lidar buoy. Dominion has 4 and a half years to submit a Construction and Operations Plan to BOEM. The lease can support approximately 2,000 MW of offshore wind capacity.

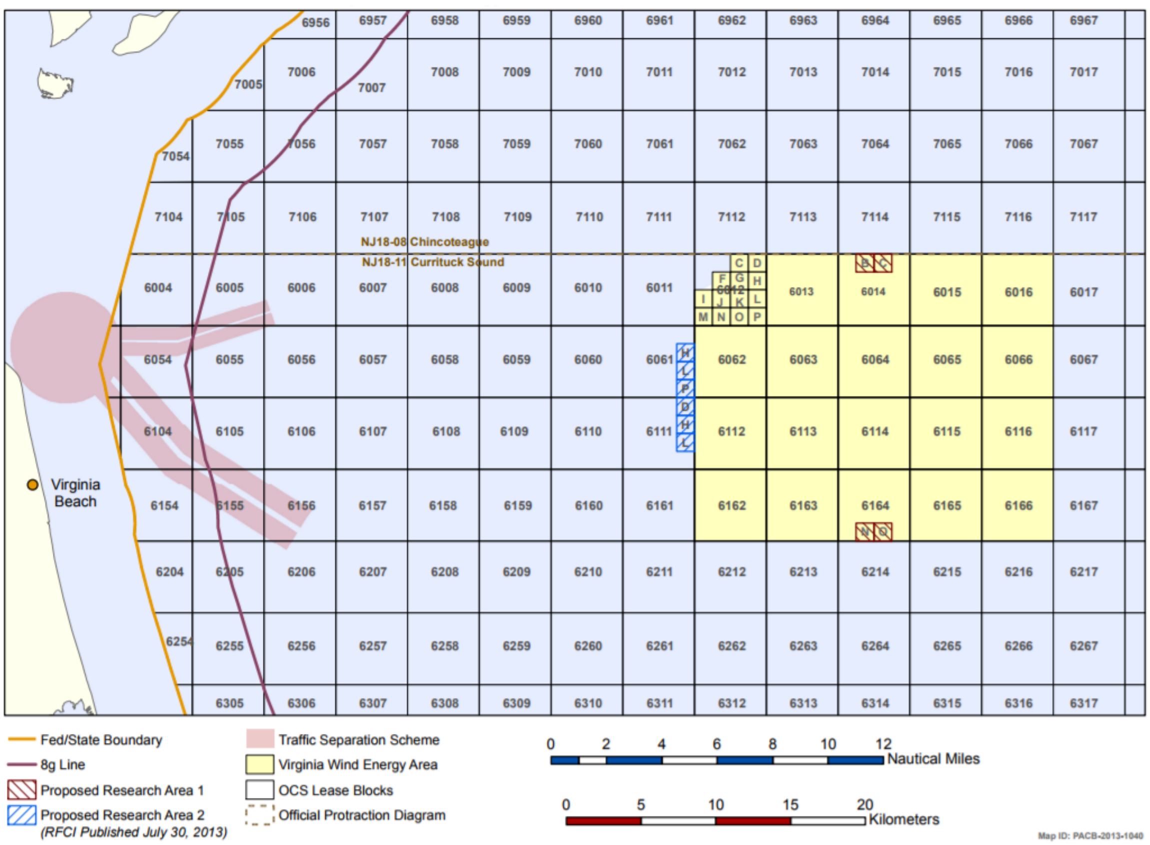

Figure 14. Virginia wind energy area and research lease area

Source: BOEM

In 2012, Dominion also submitted a project proposal for VOWTAP to participate in DOE's ATD program and was awarded $4 million of initial funding from DOE. The project aimed to install two 6-MW GE Haliade turbines on inward battered guided structures designed by Keystone Engineering that are also known as "twisted jackets." The project's goal was to validate the substructure design and verify the structural integrity of the configuration in hurricane conditions. In 2014, DOE selected the project to receive the second round of funding, bringing the total to $10.7 million. VOWTAP was also awarded the first-ever wind energy research lease in federal water by BOEM in March 2016. VOWTAP's lease site borders Dominion's commercial lease site. In May 2016, DOE stopped funding the VOWTAP project because Dominion could not guarantee that project would become operational before 2020. Dominion formed a strategic partnership with DONG Energy on July 10, 2017, to immediately initiate engineering and development work on the 12-MW demonstration project (previously named VOWTAP) (Stromsta 2017b).

North Carolina

Table 16 shows that North Carolina potentially has the best offshore wind resource in the South Atlantic region.

Table 16. North Carolina's Offshore Wind Characteristics

Ocean Area with Minimum Average Wind Speeds of 7 Meters Per Second **(Musial et al. 2016a)**		
State Waters	28,670 km^2	
Federal Waters	195,719 km^2	
Total	224,389 km^2	
Net Technical Offshore Wind Energy Potential **(Musial et al. 2016a)**		
Water Depth: 0–29 meters	203,990 GWh/year	14,908 MW
Water Depth: 31–60 meters	143,936 GWh/year	16,713 MW
Water Depth: 61–700 meters	211,934 GWh/year	81,600 MW
Water Depth: 701–1,000 meters	74,292 GWh/year	60,234 MW
Total	634,153 GWh/year	173,455 MW
Offshore Wind Unsubsidized Economic Potential **(Beiter et al. 2017)**		
By 2027	0 MW	

North Carolina's main renewable procurement policy is its Renewable Energy and Energy Efficiency Portfolio Standard. The standard was created in 2007 and subsequently amended to require investor-owned utilities to provide 12.5% of their electricity from renewable sources by 2021.

BOEM issued a Request for Information about potential Call Area sites in December 2012. Based on stakeholder feedback, BOEM identified three WEAs in August 2014: Kitty Hawk, Wilmington West, and Wilmington East. On March 16, 2017, BOEM auctioned the Kitty Hawk WEA (BOEM 2017f). Eight entities participated in the auction, and after 17 rounds, Avangrid acquired the lease area for $9,066,650 (BOEM 2017g). Avangrid's North Carolina lease site contains 495 km2 and could support up to 1,468 MW of capacity based on a 3-MW/km2 array power density. Avangrid's Chief Executive Officer James Torgerson has indicated that the Kitty Hawk project is a long-term effort that will not be operational until well after 2020 (Ohnesorge 2017). To date, Avangrid has not released any project-specific plans.

South Carolina

South Carolina has significant offshore wind resources (Table 17), but currently does not have any state-level policies that support the procurement of utility-scale renewables or offshore wind.

In November 2015, BOEM published a Call for Information to gauge industry interest in obtaining commercial offshore wind leases in South Carolina. In parallel, BOEM solicited comments to determine the main issues to consider during the agency's forthcoming environmental assessment.

Table 17. South Carolina's Offshore Wind Characteristics

Ocean Area with Minimum Average Wind Speeds of 7 Meters Per Second **(Musial et al. 2016a)**		
State Waters	5,777 km^2	
Federal Waters	208,605 km^2	
Total	214,382 km^2	
Net Technical Offshore Wind Energy Potential **(Musial et al. 2016a)**		
Water Depth: 0–29 meters	128,518 GWh/year	3,004 MW
Water Depth: 31–60 meters	70,389 GWh/year	9,800 MW
Water Depth: 61–700 meters	242,215 GWh/year	45,853 MW
Water Depth: 701–1,000 meters	171,571 GWh/year	123,975 MW
Total	612,639 GWh/year	182,633 MW
Offshore Wind Unsubsidized Economic Potential **(Beiter et al. 2017)**		
By 2027	0 MW	

3.6.3 Pacific

Oregon

Oregon's offshore wind resource is substantial but predominantly located in deeper waters where floating technology will be required (Table 18). In 2012, Principle Power Inc. proposed its 25-MW WindFloat Pacific project under the DOE ATD program funding opportunity and was competitively awarded $10.7 million to conduct initial R&D, design validation, and stakeholder outreach. The proposed project was located 29 km off the coast of Coos Bay, Oregon, in water depths averaging 350 m, and including an array of 6- to 8-MW turbines installed on floating WindFloat semisubmersible foundations. In 2016, the project was cancelled because Principle Power was unable to obtain a power off-take agreement (Principle Power 2015).

Table 18. Oregon's Offshore Wind Characteristics

Ocean Area with Minimum Average Wind Speeds of 7 Meters Per Second (Musial et al. 2016a)		
State Waters	6,036 km^2	
Federal Waters	79,918 km^2	
Total	85,954 km^2	
Net Technical Offshore Wind Energy Potential (Musial et al. 2016a)		
Water Depth: 0–29 meters	1,504 GWh/year	3,139 MW
Water Depth: 30–60 meters	3,877 GWh/year	15,960 MW
Water Depth: 60–700 meters	183,961 GWh/year	42,725 MW
Water Depth: 701–1,000 meters	40,888 GWh/year	86 MW
Total	230,230 GWh/year	61,910 MW
Offshore Wind Unsubsidized Economic Potential **(Beiter et al. 2017)**		
By 2027	0 MW	

California

In September 2015, Governor Edmund G. Brown (Jerry Brown) signed California SB 350 to reduce greenhouse gases to 40% below 1990 levels by 2030. This new policy requires renewable energy electric generation to increase to 50% of the state's total (Brown 2015). California was already on a trajectory to meet its 2020 goals for 33% renewable energy using largely land-based wind and solar, but the challenge to go to 50% renewables spurred interest in other renewable energy technologies.

An offshore wind cost and feasibility study was commissioned by BOEM in 2016 to assess possible siting options and cost trajectories for offshore wind in California, assuming that floating technology would probably not be commercially available for a decade (Musial et al. 2017). The study indicated that the cost of floating offshore wind could drop below $100/MWh by 2030 at most viable sites in California. It also indicated that large-scale (up to 15 GW) deployment of offshore wind was possible in California. Finally, it showed that the corresponding daytime wind patterns along the coast were somewhat complementary to the preexisting solar production curve, which ramps down in the early evening (Musial 2016). In March 2017, a compilation of findings from NREL studies was submitted in a motion by Magellan Wind to the California Public Utilities Commission as evidence that offshore wind should be considered in the state's energy portfolio (Musial 2016). California's offshore wind resource is summarized in Table 19.

Table 19. California's Offshore Wind Characteristics

Ocean Area with Minimum Average Wind Speeds of 7 Meters Per Second **(Musial et al. 2016b)**		
State Waters	7,833 km^2	
Federal Waters	150,774 km^2	
Total	158,607 km^2	
Net Technical Offshore Wind Energy Potential **(Musial et al. 2016b)**		
Water Depth: 0–29 meters	8,920 GWh/year	4,073 MW
Water Depth: 31–60 meters	8,068 GWh/year	39,474 MW
Water Depth: 61–700 meters	216,579 GWh/year	68,246 MW
Water Depth: 701–1,000 meters	158,348 GWh/year	662 MW
Total	391,915 GWh/year	112,455 MW
Offshore Wind Unsubsidized Economic Potential **(Beiter et al. 2017)**		
By 2027	0 MW	

In 2016, Trident Winds submitted an unsolicited application to BOEM for a proposed project. The project is a commercial-scale offshore wind farm off the coast of Point Estero, California, with a grid connection in Morro Bay. The initial project is planned with the nameplate capacity of 765 MW, but may be expanded to 1,000 MW at a later date if additional transmission capacity and market off-take can be obtained. In August 2016, BOEM issued a Request for Interest for the Morro Bay site. Statoil Wind US indicated that they also have commercial interest in the site.

In 2016, Governor Jerry Brown sent a letter to DOI requesting that a state renewable energy task force be created to explore the options for renewable energy projects on the Outer Continental Shelf. California regulatory activities are expected to continue under BOEM leadership, working closely with the task force and other stakeholders to reduce possible conflicts with marine use and coastal environments.

Hawaii

On June 8, 2015, Governor David Ige signed a bill into law drafted by the Hawaii state legislature augmenting the state RPS so that electricity providers must supply 100% of their net electricity sales from renewable energy resources by 2045. The law, HB623, made Hawaii the first state in the nation to set a 100% RPS for the electricity sector.[42]

BOEM has received three unsolicited applications for commercial floating projects in Hawaii. Two applications were submitted by Alpha Wind in January 2015 and one by Progression Wind in October 2015. Each application is for a project that is approximately 400 MW in capacity. In June 2016, BOEM established Call Areas for the north and south sides of Oahu. Hawaii's offshore wind resource is summarized in Table 20.

Table 20. Hawaii's Offshore Wind Characteristics

Ocean Area with Minimum Average Wind Speeds of 7 Meters Per Second **(Musial et al. 2016a)**		
State Waters	34,638 km^2	
Federal Waters	11,036 km^2	
Total	45,674 km^2	
Net Technical Offshore Wind Energy Potential **(Musial et al. 2016a)**		
Water Depth: 0–29 meters	2,049 GWh/year	5,738 MW
Water Depth: 30–60 meters	6,127 GWh/year	15,559 MW
Water Depth: 61–700 meters	64,100 GWh/year	6,970 MW
Water Depth: 701–1,000 meters	27,608 GWh/year	662 MW
Total	99,885 GWh/year	28,930 MW
Offshore Wind Unsubsidized Economic Potential **(Beiter et al. 2017)**		
By 2027	30,000 MW	

Figure 15 shows the approximate location of each of these proposed projects with respect to Oahu and the BOEM Call Areas.

[42] Compliance with Hawaii's 100% RPS requirement is not the same as obtaining every megawatt-hour of grid-delivered electricity from renewable resources. Distributed generation systems, such as rooftop solar, are deducted from utility electric sales that allow behind-the-meter power to reduce the 100% Hawaii RPS target.

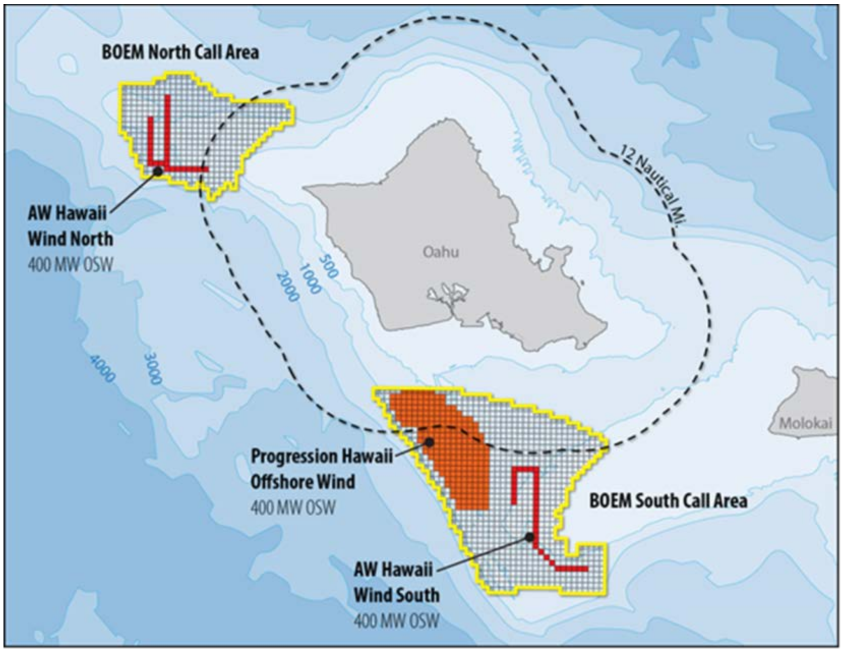

Figure 15. Map of Hawaii Call Areas showing the proposed offshore wind projects

Source: NREL

3.6.4 Great Lakes

The Great Lakes region contains significant offshore wind resource potential and consists of eight states: Wisconsin, Minnesota, Michigan, Illinois, Indiana, Ohio, Pennsylvania, and New York. The offshore wind resource for the Great Lakes region is summarized in Table 21.

Table 21. The Great Lakes' Offshore Wind Characteristics

Ocean Area with Minimum Average Wind Speeds of 7 Meters Per Second **(Musial et al. 2016a)**		
Total	164,767 km^2	
Net Technical Offshore Wind Energy Potential **(Musial et al. 2016a)**		
Water Depth: 0–29 meters	213,129 GWh/year	62,441 MW
Water Depth: 30–60 meters[43]	130,981 GWh/year	36,354 MW
Total	344,110 GWh/year	98,795 MW
Offshore Wind Unsubsidized Economic Potential **(Beiter et al. 2017)**		
By 2027	30,000 MW	

Fred Olsen/LEEDCo's Icebreaker project is the only active offshore project in the Great Lakes region, and is also part of DOE's ATD program. The 21-MW project planned location is 16 km off the coast of Cleveland, Ohio, and could be the first offshore wind project deployed in freshwater with exposure to surface ice. Icebreaker consists of six 3.45-MW MHI Vestas turbines mounted on suction monobucket foundations designed by Universal Foundation. To date, LEEDCo has signed a PPA with Cleveland Public Power, American Municipal Power, and Cuyahoga County. In December 2016, Norway's Fred Olsen Renewables agreed to lease the

[43] Depths of greater than 60 m were excluded because the floating technology needed to survive freshwater ice is not yet developed (Musial et al. 2016a).

development, construction, and operation of Icebreaker and is negotiating with LEEDCo to buy project-related research data. Icebreaker plans to become operational by the end of 2018 and is eligible for an additional $40 million under DOE's ATD program in future project performance periods after reaching specific milestones, and subject to DOE progress reviews.

3.6.5 Gulf of Mexico

The Gulf of Mexico region contains five states: Texas, Louisiana, Mississippi, Alabama, and the Gulf Coast of Florida. The region has a sizeable offshore wind resource potential although there is presently no development activity (Table 22).

Table 22. The Gulf of Mexico's Offshore Wind Characteristics

Ocean Area with Minimum Average Wind Speeds of 7 Meters Per Second **(Musial et al. 2016a)**		
State Waters	75,441 km^2	
Federal Waters	833,622 km^2	
Total	909,063 km^2	
Net Technical Offshore Wind Energy Potential **(Musial et al. 2016a)**		
Water Depth: 0–30 meters	583,929 GWh/year	189,227 MW
Water Depth: 31–60 meters	376,683 GWh/year	122,374 MW
Water Depth: 61–700 meters	632,144 GWh/year	214,127 MW
Water Depth: 701–1,000 meters	603,544 GWh/year	208,761 MW
Total	2,196,298 GWh/year	734,489 MW
Offshore Wind Unsubsidized Economic Potential **(Beiter et al. 2017)**		
By 2027	250,000 MW	

4 Cost and Pricing Trends

Winning auction prices for offshore wind bids, commonly referred to as "strike prices," [44] saw a significant decline during 2016, which is likely an indication of commensurate reductions in the LCOE for offshore wind. These falling costs continue a trend seen in recent years. Between 2010 and 2016, for projects that had reached a final investment decision (FID), the LCOE is estimated to have dropped by approximately 32% in the United Kingdom, the market with the largest operating offshore wind capacity (Catapult 2017). There is optimism within the industry that this trend will continue,[45] as evidenced by continued reductions in the winning auction strike prices from various European auctions during 2016–2017; prices which establish the future purchase prices for wholesale electricity from the tendered offshore wind projects. Some believe that these auction strike prices may prove to be highly influential events for the industry (Radowitz 2017). Most recently, the award of 1,380 MW of "subsidy-free"[46] offshore wind capacity in Germany (Bundesnetzagentur 2017) for projects with CODs between 2023 and 2025 has highlighted the downward price trend for offshore wind energy procurement rates. These reductions in European procurement prices for offshore wind-produced electricity were made possible by a combination of favorable siting characteristics and increased project size; continued optimization of technology and installation processes; improved market, regulatory, and auction design structures; increased competition within the supply chain; favorable macroeconomic trends; and strategic market behavior.

For the discussion in this section, it is helpful to clearly distinguish between *costs* and *prices*. Generally, costs are the total expense incurred by an offshore wind developer to plan, install, operate, and decommission an offshore wind plant. Commonly, in this context, costs are reported as LCOE, which is the net present value cost of the electricity generated over the lifetime of a generation asset divided by the total electricity generated and expressed in dollars per megawatt-hour ($/MWh).[47] Costs can be estimated bottom-up by modeling the various cost components (see e.g., Beiter et al. 2016, Moné et al. 2017). Prices are the amount that a purchaser pays for the procurement of electricity (and capacity). For instance, the auction tender results mentioned above or a PPA established between a wind plant owner and a power purchaser comprise procurement prices. A price may also include other economic benefits, such as the complementarity to an existing (electricity system) production portfolio and a societal benefit reflected through various subsidy mechanisms, or be influenced by the dynamics of a price settlement mechanism (e.g., auction bidding strategies and dynamics). For these reasons and

[44] The strike price for an offshore wind project from an auction is usually the lowest bid price at which the offering can be sold. The strike price usually covers a specific contract term for which that strike price will be paid for the energy produced. The offeror of that strike price is awarded the rights to develop a particular parcel under predetermined conditions set in the tender offer that may vary by country or market. The strike price should not be confused with levelized cost of energy, which may be calculated using different financing and cost assumptions.
[45] Note that the offshore wind auctions during 2016–2017 were held for projects in Europe with commercial operation dates between 2020 and 2025.
[46] The German auction followed a "market premium" model (Huebler 2017), in which bids effectively form a minimum price that is paid to the awardee. An €0/MWh bid as submitted in this recent auction can be interpreted to be not completely subsidy-free because some project costs, such as the grid connection, are paid for by the end consumer.
[47] Note that levelized cost of energy does not encompass total system costs (e.g., integration costs), nor does it capture any revenue opportunities (Beiter et al. 2017).

more, costs and prices are typically considered as distinct metrics. It may be possible, however, to infer some cost trends from pricing. Assuming that projected revenues (based on the price) will ultimately balance the project cost, prices can be used as a proxy to understand LCOE (and vice versa).

Coincident with reductions in offshore wind procurement prices and costs in Europe, the offshore wind market has begun to take hold in the United States with the commissioning of the first commercial offshore wind farm and a number of legislative actions, thereby setting the stage for large-scale offshore wind development (Section 3). For the nascent U.S. offshore wind industry, it is critical to understand to what degree realized and anticipated cost reductions in Europe can be leveraged. A direct comparison is difficult, as there are a number of key factors that differentiate the United States from European markets. These factors include (but are not limited to): exchange rates, infrastructure and supply chain maturity, vessel availability, workforce readiness, and physical characteristics of the offshore wind siting environment. Further, the cost level might be influenced by U.S.-specific market and policy considerations, including regulatory structure, the tax code, and the design of incentive programs.

4.1 Pricing Trends

A number of auctions were held in Germany, the Netherlands, and Denmark during 2016 and 2017, procuring a total capacity of nearly 4,000 MW scheduled for commercial operation between 2020 and 2025. The winning tenders from these auctions show a clear reduction trend in procurement prices over this time frame.

These recent auction price results have been surveyed and analyzed by a range of studies and press articles (see e.g., Huebler, Radov, and Wieshammer 2017, Smart 2017, Garlick et al. 2017, IEA-RETD 2017, Radov, Carmel, and Koenig 2016, Roland Berger 2016, Hundleby 2016 and 2017, Snieckus 2017, Andresen 2017, and Hill 2017). This body of literature indicates that the industry is confident that cost reductions can exceed prominent LCOE goals issued by The Crown Estate in the United Kingdom (£100/MWh [$130/MWh] by 2020) (Catapult 2017) and a group of developers and manufacturers (€100/MWh [$110/MWh] by 2020) (WindEurope 2017c). This growing cost reduction trend has led a number of leading offshore wind developers[48] to issue a declaration that offshore wind "can be fully competitive with coal and gas by 2025, achieving a cost of €80/MWh and below […] if the industry achieves long-term stability through right policies and closer international cooperation" (WindEurope 2017c).

Context is needed to understand these recent European auction results because the auction design, market and policy environment, and project characteristics differ significantly between countries. As can be observed from Table 23, various mechanisms are applied across European countries and the United States in the allocation of site development and grid connection costs, as well as available incentives and supra-national (e.g., the European Union), national and state goals that provide market visibility (e.g., offshore wind deployment goals).

[48] Including Adwen, EDPR, Eneco, E.ON, GE, Iberdrola, MHI Vestas, RWE, Siemens, Statoil, and Vattenfall.

Table 23. Comparison of Key Market Structures in Germany, Denmark, the Netherlands, United Kingdom, and United States

Source: Based on IEA-RETD (2017); NREL research

	Germany	Denmark	Netherlands	United Kingdom	United States
Market Visibility Goals	European Union Directive 2009/28/EC (35% renewables by 2020); Renewable Energy Act [EEG]; Offshore Wind Act ("WindSeeG") (6.5 GW by 2020; 15 GW by 2030)	European Union Directive 2009/28/EC (30% renewables by 2020)	European Union Directive 2009/28/EC (12% renewables by 2020); annual offshore wind tender rounds (~700 MW/yr)	European Union Directive 2009/28/EC (15% renewables by 2020); Levy Control Framework/Contract for Differences scheme (energy technology funding for 10 GW by 2020)	Massachusetts bill to procure 1.6 GW of offshore wind by 2027; New York commitment to 2.4 GW of offshore wind by 2030; state RPS policies
Site Development	Centralized model[49] (Erneuerbare-Energien-Gesetz [EEG] 2017)	Centralized model	Centralized model	Decentralized model[50]	Not yet determined for large-scale commercial projects
Grid Connection	Shallow charging model[51]	Super-shallow charging model[52]	Shallow charging model	Hybrid deep-shallow charging model[53]	Not yet determined for large-scale commercial projects; deep-charging model[54]
Key Incentive Mechanisms	EEG 2017 (subsidy level determined by auction; duration of 15 years)	Feed-in premium (subsidy level determined by auction; duration of 50,000 load hours/~12 years)	Stimulation of Sustainable Energy Production grant (SDE+) (subsidy level determined by auction; duration of 15 years)	Renewable Obligation Certificates (1.8-2.0; duration of 20 years); Contracts for Difference (subsidy level determined by auction; duration of 15 years)	Not yet determined for large-scale commercial projects

[49] A centralized model is defined as: "Government bears the majority of the up-front financial risk and undertakes the site identification, surveying, consenting, and grid permitting prior to auctioning the site" (IEA-RETD 2017).

[50] A decentralized model is defined as: "Developer takes the lead in undertaking site surveys, acquiring grid permits and consent, and designing and constructing the electrical infrastructure" (IEA-RETD 2017).

[51] A shallow charging model is defined as: "Developer is responsible for intra-array cabling and offshore substation. Transmission System Operator [TSO] provides transmission infrastructure to export electricity back to shore" (IEA-RETD 2017).

[52] A super-shallow charging model is defined as: "Developer is responsible for intra-array cabling and connection into a substation only. TSO provides substation, export cabling, and onshore reinforcements" (IEA-RETD 2017).

[53] A hybrid deep-shallow charging model is defined as: "This can entail a developer constructing the offshore assets but transferring ownership and operation to a TSO or third party" (IEA-RETD 2017).

[54] A deep-charging model is defined as: "Developer is responsible for constructing and operating all offshore transmission assets, often including onshore reinforcements (i.e., onshore substation and cable routing)" (IEA-RETD 2017).

Figure 16 depicts an initial assessment of (adjusted) offshore wind auction strike prices from Germany, the United Kingdom, the Netherlands, and Denmark for projects to be deployed between 2017 and 2025 (COD). The underlying project data for the most recent tenders held from July 2016 to June 2017 is shown in Table 24 (Germany), Table 25 (Denmark), and Table 26 (Netherlands). It should be noted that many of the projects shown in Figure 16 with future CODs have not yet reached FID, and some caution is appropriate when determining whether these projects will be realized. For instance, the recent winning tenders in Germany (as generally in most jurisdictions) may have an option to not build, subject to paying a penalty (Huebler, Radov, and Wieshammer 2017). Some of the recent tenders shown in Figure 16 have also benefitted from a set of favorable conditions that may not be present in upcoming European auctions (e.g., the U.K. CfD auction in fall 2017 [OffshoreWIND.biz 2017a]) or in early U.S. projects. Some of these generally favorable conditions include:

- Proximity to shore
- High average wind speeds
- An auction design and regulatory regime that shifts the development risk to the public/ratepayers
- Ability to leverage tax advantages
- Local electrical system and operational synergies
- Strategic bidding behavior
- Favorable project realization timelines
- Extended project design lifetimes beyond 20 years
- General macroeconomic conditions (e.g., low lending rates and prices for materials and vessels).

The strike price data shown in Figure 16 features data published in market reports and analysis from Garlick et al. (2017), NERA (2017), Smart (2017), and parametric relationships documented in Beiter et al. (2016). These initial estimates depend on various assumptions and will benefit from further validation as more project details and analysis becomes available. The strike price data from the Netherlands, Denmark, and the United Kingdom shown in Figure 16 were derived by Garlick et al. (2017), which include an adjustment of strike prices to allow for project-to-project comparisons. These strike price data adjustments include:

- The electrical system cost (e.g., array cables, substation, export cable, and land-based interconnect), which was added whenever these were provided by the tender offeror
- Site development costs (e.g., initial environmental assessments, geotechnical surveys, wind resource assessments, and metocean condition studies) were added whenever these were provided by the tender offeror
- A uniform contract length of 15 years.

The German strike prices were derived from NERA (2017) and Smart (2017), with development costs added. The development costs were derived from parametric cost relationships documented in Beiter et al. (2017). Development costs were assumed to be approximately 4% of the combined balance-of-station and turbine capital costs of a fixed-bottom reference scenario defined in Beiter et al. (2017). The "adjusted" German strike prices do not include any adjustments for the export system and land-based grid connection costs between the offshore substation to shore, which are paid for by the grid operator in Germany. These bid price adjustments will be assessed in future work. Therefore, the "adjusted" German auction prices presented in Figure 16 and Table 24 will likely increase when these corrections are made. All reported strike prices were converted to 2016 USD from their native currency, unless noted otherwise.

Note that the "adjusted strike prices" do not comprehensively account for the entire set of possible differences between countries and projects (e.g., differences in spatial conditions, project-specific risk profiles, or future electricity prices). They also do not capture effects from different levels of competitive bidding behavior or nonexecution of the option to build.

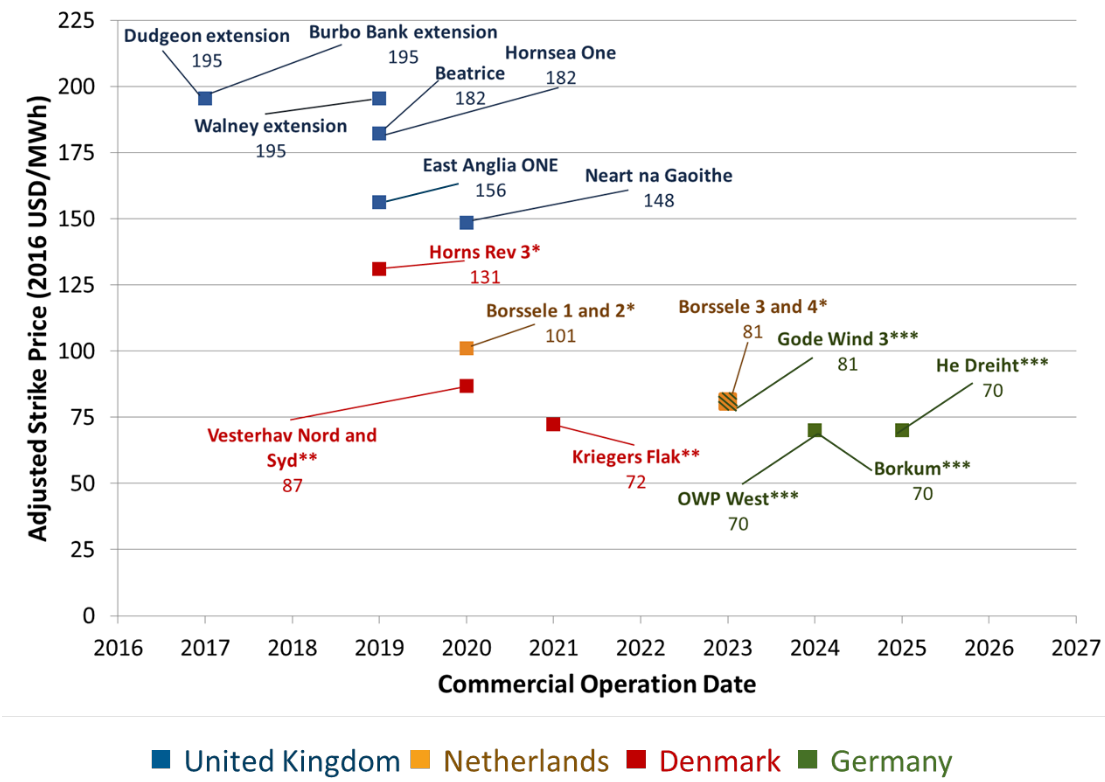

Figure 16. Adjusted strike prices from European offshore wind auctions

Sources: Garlick et al. (2017) and NREL analysis

Notes: *Grid and development costs added; **Grid costs added and contract length adjusted; ***Development costs added[55]

[55] Note that these strike price adjustments for Germany do not include export system and land-based grid connection costs between the offshore substation to shore, which are paid for by the grid operator in Germany. Therefore, the "adjusted" strike price levels are likely underestimated.

As displayed in Figure 16, auction strike prices indicate a clear trend of price declines over time from levels of approximately $200/MWh for projects with a COD between 2017 and 2019 to approximately $65/MWh for projects with a 2024–2025 COD. In general, these adjusted costs are higher than the unadjusted strike prices[56] but still reflect a steep decline in price for European offshore wind out to projects installed in 2025 COD.

4.1.1 Germany

On April 1, 2017, Germany held its first offshore wind auction under a *market premium* model (Huebler, Radov, and Wieshammer 2017) for a total of 1,490 MW of offshore wind capacity. Three of the four winning tenders secured "subsidy-free" bids of €0/MWh with CODs of 2024–2025; the remaining bid with an earlier 2023 COD was auctioned at $65/MWh (Table 24). The projects from DONG Energy and EnBW are located in average water depths of 29–39 m. After adjusting for the development costs, which are largely covered by the government under the 2017 *Erneuerbare-Energien-Gesetz* (EEG), these most recent German tenders are the lowest in Europe to date with an adjusted strike price of approximately $70/MWh for the Borkum Riffgrund West 2, He Dreiht, and OWP West projects. Key factors that may have contributed to these low bid levels include an optimistic expectation of future turbine sizes (in the range of up to 15 MW), reduced financing costs, optimized and integrated wind farm controls (Smart 2017), and the option of not executing the tender if expected wholesale prices over the lifetime of the project do not meet revenue requirements at FID (Huebler, Radov, and Wieshammer 2017).[57] Additional factors include project up-scaling and synergies with existing offshore nearby wind farms (e.g., He Dreiht is in close proximity to the Hohe See and Albatros projects), the option to apply for a lifetime extension of the project to 30 years under the *Offshore Wind Act* (*WindSeeG*), and clustering of multiple projects to aggregate grid connections (Huebler, Radov, and Wieshammer 2017).

[56] Depending on the site conditions, adjusting the site conditions was estimated by Garlick et al. (2017) to increase strike prices by up to approximately 40%.

[57] See for example, NERA (2017) for a discussion on how these recent auction results can be understood in the context of "real option" theory.

Table 24. 2016–2017 German Offshore Wind Tender Results

Sources: NERA (2017); Smart (2017)

Auction	First Offshore Wind Auction (§ 26 WindSeeG)			
Award Date	04/01/2017			
Project Name	Borkum Riffgrund West 2	Gode Wind 3	He Dreiht	OWP West
Capacity (MW)	240	110	900	240
Bidder	DONG Energy	DONG Energy	EnBW	DONG Energy
COD	2024	2023	2025	2024
Distance from Shore (km)	67	39	85	58
Water Depth (m)	29–31	30–34	39	29–33
Duration (years)	20			
Inflation-Indexed	No			
Nonexecution Penalty ($/kW)	~112 (Huebler, Radov, and Wieshammer 2017)			
Auction Price (2016$/MWh)	0	65	0	0
Adjusted Auction Price (2016$/MWh)[58]	~70	~81	~70	~70

4.1.2 Denmark

In Denmark, a nearshore tender (Vesterhav Nord and Syd) and Baltic Sea tender (Kriegers Flak) were auctioned during 2016 (Table 25) to Vattenfall. The nearshore 350-MW Vesterhav Nord and Syd project is only 4 km from shore (in a water depth of 20 m), whereas the 610-MW Kriegers Flak is located at a distance from shore of 15 km (in water depths of approximately 24 m). Based on the tender results, these two projects were estimated to have an adjusted price of $72/MWh (Kriegers Flak) and $87/MWh (Vesterhav Nord and Syd) after adjusting for grid connection costs and contract length. Kriegers Flak is expected to have the first interconnection installed offshore in which the export system grid system can be shared with the operating Baltic 1 & 2 projects in German waters. Smart (2016) has noted a range of project-specific factors that may explain the low Vesterhav Nord and Syd LCOE levels. These factors include its proximity to shore, the deployment of an 8-MW turbine, and O&M cost benefits because of its proximity to other operating wind farms.

[58] Development costs were added to all four projects. The adjusted strike price for the two project tenders with zero bids (Borkum Riffgrund West 2 and He Dreiht) were estimated by Smart (2017). Note that the strike price adjustments for Germany do not include export system and land-based grid connection costs between the offshore substation to shore, which are paid for by the grid operator in Germany. Therefore, the "adjusted" strike price levels are likely underestimated.

Table 25. 2016–2017 Danish Offshore Wind Tender Results

Sources: Garlick et al. (2017); NREL OWDB

Auction	Baltic Sea Tender	Nearshore Tender
Award Date	11/9/2016	9/12/2016
Project Name	Kriegers Flak	Vesterhav Nord and Syd
Capacity (MW)	610	350
Bidder	Vattenfall	Vattenfall
COD	2021	2020
Distance from Shore (km)	15	4
Water Depth (average) (m)	24	20
Duration (years)	50,000 load hours	50,000 load hours
Inflation-Indexed	No	No
Nonexecution Penalty ($/kW)	N/A	N/A
Grid Connection	Combined grid solution project (first offshore interconnection), connecting Kriegers Flak and the operating German Baltic 1 & 2	New land-based substation (60/33, 150/33, or 150/60 kilovolts) close to coastline needed with connection to existing substation Lem Kaer and Idomlund or Herning
Auction Price (2016$/MWh)	55	71
Adjusted Auction Price (2016$/MWh)[59]	~72	~87

4.1.3 The Netherlands

The Dutch auctions during 2016–2017 indicate an adjusted strike price of $81/MWh and $101/MWh for the 2016 tenders Borssele 3 and 4 (740 MW) and Borssele 1 and 2 (760 MW), respectively (Table 26). These two projects represent average site conditions with respect to water depth (~27 m) and distance from shore (~22 km). LCOE was adjusted for grid and development costs. Beyond the site location and Dutch market configuration, some key project-specific factors that have led to these auction prices include more favorable financing (i.e., higher debt-to-equity ratios, lower debt rates), larger turbine size (i.e., optimized 6-MW+ turbines), and engineering-procurement-construction contract wrap approaches (Smart 2016).

[59] Grid costs added and contract length adjusted.

Table 26. 2016–2017 Dutch Offshore Wind Tender Results

Source: Garlick et al. (2017); NREL OWDB

Auction	Borssele I-IV	
Award Date	7/5/2016	12/12/2016
Project Name	Borssele 1 and 2	Borssele 3 and 4
Capacity (MW)	760	740
Bidder	DONG Energy	Shell, Van Oord, Eneco, Mitsubishi/Diamond Generating Corporation
COD	2020	2023
Distance from Shore (km)	22	21
Water Depth (average) (m)	27	26
Duration (years)	15	15
Inflation-Indexed	No	No
Nonexecution Penalty ($/kW)	N/A	N/A
Auction Price (2016$/MWh)	81	60
Adjusted Auction Price (2016$/MWh)[60]	~101	~81

4.1.4 United States

There are a limited number of early cost signals from U.S. projects. These include:

- The operating BIWF project (PPA)
- Projects that qualify for the recent Maryland OREC award notice
- The Massachusetts competitive solicitation for offshore wind energy generation
- The LIPA PPA with Deepwater Wind.

Table 27 provides details on these U.S. remuneration mechanisms and reported prices, where available. The BIWF project signed a 20-year PPA agreement with National Grid for its entire capacity of 30 MW. The PPA price is set at $244/MWh for the first year of operation, with an increase by an escalation factor of 3.5% annually, resulting in $469/MWh in year 20 of its operation. On January 25, 2017, LIPA approved a 20-year pay-for-performance PPA with Deepwater Wind's 90-MW South Fork project, allowing the utility to only pay for delivered energy without taking construction or operating risk. The project was determined to be the least-cost choice of the competitive solicitation, owing its win in part to its ability to operate at utility scale, as well as land restrictions limiting the number of possible generation options on Long Island.

[60] Grid and development costs added.

Table 27. 2016–2017 Cost Signals from Early U.S. Projects

Developer/ Project Name	Block Island Wind Farm	Wind South Fork	Deepwater Wind Skipjack	US Wind	Deepwater Wind Deepwater One	DONG Energy	Vineyard Wind
State	Rhode Island	New York	Delaware	Maryland	Massachusetts		
Capacity (MW)	30	90	120	248	400–800 MW[61]		
Offtake Agreement Type	PPA	PPA	Maryland OREC	Maryland OREC	Competitive solicitation for long-term contracts		
Duration (years)	20	20	20	20	Not yet available		
Approval Conditions	TBD	TBD	Maryland PSC Order No. 88192	Maryland PSC Order No. 9431	Not yet available		
Status	PPA in effect	PPA approved	OREC terms accepted by Deepwater Wind	OREC terms accepted by US Wind	Competitive solicitation issued on June 29, 2017, with proposals due on December 20, 2017; Contracts are expected to be submitted to Department of Public Utilities for approval by July 31, 2018		
Counterparty	National Grid	LIPA	Not yet available	Not yet available	Eversource, National Grid, and Unitil		
COD (announced)	2016	2022[62]	2022[63]	2020[64]	Before June 30, 2027[65]		
Price (2016$/MWh)	244[66]	Not disclosed	131.93	131.93	Not yet available	Not yet available	Not yet available

As part of the Maryland Offshore Wind Energy Act of 2013, the Maryland PSC issued unbundled ORECs for the Deepwater Wind Skipjack (120 MW) and US Wind (248 MW) projects on May 11, 2017, requiring buyers to procure a total of 1,369,327 ORECs/yr. The award notice specifies an OREC of $131.93/MWh over 20 years. Specifically, 913,845 ORECs per year are to be procured from US Wind at a price schedule equivalent to a levelized price of $131.93 per OREC (2012 USD) using a 1.0% price escalator, beginning on January 1, 2021, for a duration of 20 years; and 455,482 ORECs per year are to be procured from the Deepwater Wind Skipjack project at a price schedule equivalent to a levelized price of $131.93 per OREC (2012 USD) using a 1.0% price escalator, beginning on January 1, 2023, for a duration of 20 years (Maryland Public Service Commission of Maryland [2017b]). A set of nearly 30 conditions applies to this OREC (order no. 88192 and 9431), including that the developers create a minimum of 4,977 direct jobs during the development, construction, and operating phases of the projects; pass 80% of any construction costs savings to ratepayers; contribute $6 million each to the Maryland Offshore Wind Business Development Fund; and use port facilities in the greater Baltimore region and Ocean City for construction and O&M activities. A total of at least $76 million collectively must be invested by the developers in a steel fabrication plant in Maryland

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[61] The *Act to Promote Energy Diversity* (H.4568) seeks up to 1,600 MW of offshore wind energy generation to be contracted by June 30, 2027 (Massachusetts Clean Energy Center [2017])
[62] offshoreWIND.biz (2017b)
[63] Maryland PSC Award Notice (2017)
[64] Maryland PSC Award Notice (2017)
[65] The request for proposals encourages proposals that include committed offshore wind energy generation delivery as early as reasonably possible to maximize the Commonwealth's ability to meet its *Global Warming Solution Act* (Massachusetts Department of Energy Resources and Distribution Companies [2017]).
[66] Subject to an increase of 3.5% annually, starting at $244/MWh in year 1 and ending at $479/MWh in year 20.

and at least $39.6 million must be invested to support port upgrades at the Tradepoint Atlantic (formerly Sparrows Point) shipyard in Baltimore County. On June 29, 2017, Massachusetts utilities Eversource, National Grid, and Unitil issued a Request for Proposals for the procurement of 400 to 800 MW of offshore wind energy generation. This competitive solicitation permits bidders to submit alternative proposals with a nameplate capacity of no less than 200 MW and no greater than 800 MW. Proposals are due on December 20, 2017, and contracts are expected to be submitted by July 31, 2018, to the Department of Public Utilities for approval.

4.2 Capital Expenditures

Capital expenditures (CapEx) are the single largest contributor to the life cycle costs of offshore wind plants and include all expenditures incurred prior to the COD. Figure 17 shows the reported CapEx over time for operational projects as well as for those in various stages of the near-term project pipeline. Each bubble represents the cost estimate for a single project and bubble size represents the project's rated capacity. The orange line shows the capacity-weighted average CapEx and provides an indication of the overall trend from 2000 to 2025.

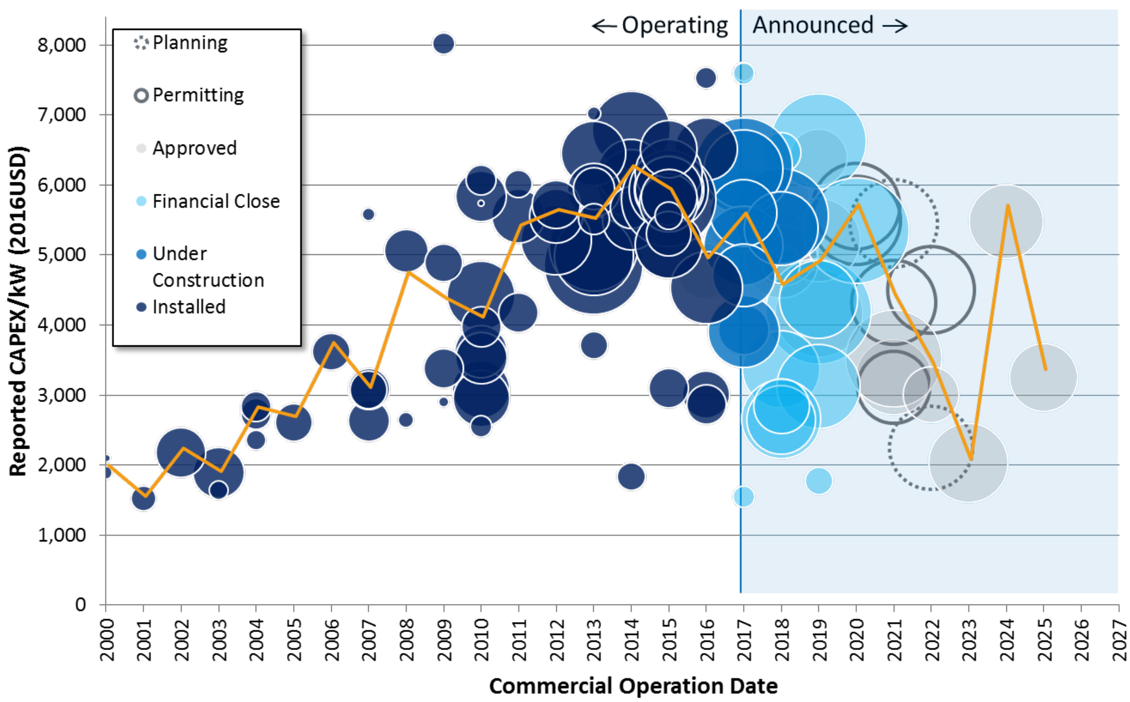

Figure 17. Capital expenditures of global offshore wind projects capital by commercial operation date and project size (in terms of capacity)

Note: Capacity-weighted average shown by orange line. Source: NREL

Costs have been reported for 11,745 MW of global offshore wind projects, or about 91% of the total installed capacity as of December 31, 2016. Figure 17 also includes the announced costs for nine projects (3,371 MW) that have started construction, 16 projects (4,500 MW) that have closed contracts, 18 projects (6,110 MW) that have received regulatory approval, five projects (2,238 MW) that are in the permitting process, and two projects (946 MW) that are still in the planning phase. Generally, greater confidence can be placed in cost estimates that are in more mature stages of the project life cycle (i.e., costs for projects that have reached FID are typically more accurate than for a project that has not yet received permits); however, preliminary estimates do provide insight into developer expectations about cost trends.

These CapEx data have some uncertainty associated with them for various reasons: 1) the CapEx data shown here are normally self-reported by developers and difficult to verify independently, 2) there is limited transparency into the financial impact of cost overruns, and 3) it is often unclear whether the reported CapEx fully captures the total cost of installing the project and connecting it to the grid.[67] When viewed together, though, these data can provide insight into the long-term cost trends.

Average CapEx has exhibited an increasing trend over the past decade, roughly tripling in real terms from a low of approximately $2,000/kilowatt (kW) in the early 2000s to a record high of approximately $6,000/kW for the projects installed in 2014. There is also considerable variation of CapEx within a given year (e.g., CapEx of projects installed in 2016 ranged from approximately $2,900/kW [Lingang phase I, China] to $7,500/kW [BIWF, United States]). As described in Smith, Stehly, and Musial (2015), the variation during a given year and the change through June 30, 2015, in CapEx during this period were driven by a number of factors, including:[68]

- Spatial variation and associated technical difficulties of installing turbines in deeper water, farther from shore, and in more demanding metocean conditions (e.g., wind speeds, wave heights, and currents), which pose challenges for both technical design and construction
- Project size
- Shortages in the supply chain (e.g., components, vessels, and skilled labor)
- Increasing prices for commodities and energy
- Macroeconomic trends, such as fluctuating exchange rates
- An improved appreciation of the costs and risks associated with offshore wind project implementation, leading to more conservative pricing strategies from equipment suppliers and installation contractors.

Since 2014, there are growing indications of a significant decline in CapEx from the existing project pipeline. Although a considerable degree of variation in CapEx in a given year may continue because of varying conditions among sites, CapEx is expected to decline to a range of $4,400/kW to $5,400/kW between 2017 and 2020 and a range of $2,000 to $5,400/kW between 2020 and 2025 (Figure 17).[69] Note that only limited CapEx data are available from 16 projects between 2020 and 2025. As a result of this relatively small sample and the projects' early

[67] For example, it is unclear if the announced capital expenditure values include soft costs such as construction, financing, insurance, or fees.
[68] For a full discussion, see Greenacre, Gross, and Heptonstall (2010), Deloitte (2011), and Greenacre et al. (2010).
[69] Note CapEx levels that approach $2,000/kW are difficult to assess when these costs were being reported at the early stages of the industry. The authors speculate that these earlier costs may have been understated as a result of the immaturity of the industry.

planning stage in which firm contracts for capital equipment have yet to be executed, the level of confidence is relatively low. In a comprehensive expert elicitation conducted by Wiser in 2016, key CapEx reduction drivers were identified. A complete list of possible cost reductions can be found in Wiser et al. (2016).

4.2.1 Wind Turbine Capital Expenditures

Offshore turbine costs are a significant fraction of the capital cost expenditures, with a percentage contribution estimated between 30% and 45%. For this report, turbine costs were compiled from publicly available data sources. Typically, turbine price data come from turbine supply agreements that are negotiated for each project, but because of their proprietary nature, these data are very limited. As a result, these limited data make statistical extrapolation of industry trends more difficult and raise some uncertainty in specific cost projections. Table 28 provides a summary of the available turbine supply agreement cost data for 4,378 MW of capacity (~34% of total capacity) for projects with CODs between 2012 and 2017.

These publicly available turbine supply agreement prices range from $1,699/kW to $2,141/kW, with an average of $1,937/kW, and typically include delivery to the staging port as well as a 5-year warranty term. The turbine supply deal for Gemini is a clear outlier in this data set and is excluded for the purpose of calculating these statistics; the Gemini turbine supply agreement price is $3,363/kW—57% above the next highest value. This difference is presumably because the contract includes turbine supply costs as well as a 15-year long-term service agreement that will see Siemens take responsibility for the operation of the project (Radowitz 2014). Variability in turbine supply agreement prices is likely introduced by differences in order size, commercial terms (e.g., warranty period and availability guarantees), and machine attributes (e.g., turbine rating and drivetrain topology). Turbine suppliers who are seeking to gain market share may also be willing to offer turbines at lower prices than original equipment manufacturers (OEMs) that have existing market share and long-term operational experience.[70]

Table 28. Turbine Supply Agreement Costs

Project Name	Country	COD	Order Size (MW)	OEM	Turbine Model	Turbine Rating (MW)	Number of Turbines	Cost ($2016/kW)
Dudgeon	United Kingdom	2017	402	Siemens	SWT-6.0-154	6.0	67	2,141
Gemini	Netherlands	2017	600	Siemens	SWT-4.0-130	4.0	150	3,363
Nordsee One	Germany	2017	332	Senvion	6M	6.15	54	2,026
North Sea	Various	Various	1,800	Siemens	Siemens SWT-3.6	3.6	500	1,740
Various	Germany	Various	1,494	Senvion	5M and 6M	5.0 & 6.0	250	2,080
Wikinger	Germany	2017	350	Adwen	M5000-135	5.0	70	1,699

[70] Insight based on NREL's involvement in the market and discussions with industry contacts.

Because of the proprietary nature of turbine supply agreements, more recent turbine costs were not available. Some anecdotal evidence points to expectations within the industry that increases in turbine sizes up to 13−15 MW (Shankleman, Parkin, and Hirtenstein 2017)71 within the next decade may have the potential to generate significant cost savings (Smart 2017).

4.3 Operational Expenditures

Operational expenditures (OpEx) cover all costs incurred after COD—but before decommissioning—that are required to operate the project and maintain turbine availability to generate power. These expenditures are generally thought to contribute between 20% and 30% to life cycle costs for offshore wind projects, depending on site characteristics. The strongest drivers are distance from shore, accessibility limits related to local metocean conditions (e.g., wave height), and turbine rating (i.e., fewer, larger turbines suggest lower O&M costs per megawatt). To optimize the balance between OpEx and availability, operators adopt different logistical strategies for individual projects depending on site conditions (DNV GL 2013).

OpEx for offshore wind projects are subject to considerable uncertainty because of a lack of empirical data. Although wind project owners commonly report CapEx, they rarely report OpEx. Uncertainty from the lack of available data is further amplified because it is standard practice in the offshore wind industry for turbine OEMs to offer 5-year warranties,[72] meaning that as of 2016–2017, only projects that were installed before 2011—approximately 3,400 MW of installed capacity—are subject to the full range of operating costs.

4.4 Performance

Improving the performance of offshore wind turbines and arrays has been a continued focus of industry and research activities. Figure 18 shows the net capacity factor[73] (CF_{NET}) for offshore wind projects by COD. These data cover 93% of operating projects (8,290 MW), 78% of projects under construction (3,800 MW), and 71% of projects that have reached FID (2,410 MW). The data represent modeled capacity factors of offshore projects and come from developer and other publicly reported sources. Project performance is based on expected generation levels rather than measured generation and should therefore be interpreted with a degree of caution. Figure 18 shows a trend of performance improvements since 2000 with considerable variance in any given year because of differences in technology and site conditions. Note that these improvements in performance often require higher CapEx investment.

[71] At the time of this writing, Vestas had announced its V164-9.5 MW wind turbine (offshoreWind.biz 2017).
[72] Warranty costs are normally wrapped into turbine supply agreement prices.
[73] Net capacity factor (CF_{NET}) is a ratio of the actual energy delivered to the point of interconnection in a given period (typically a year) over the theoretical potential energy that could be delivered if the plant were to operate continuously at nameplate capacity over the same period of time. CF_{NET} accounts for electrical losses, availability losses, and losses caused by environmental factors.

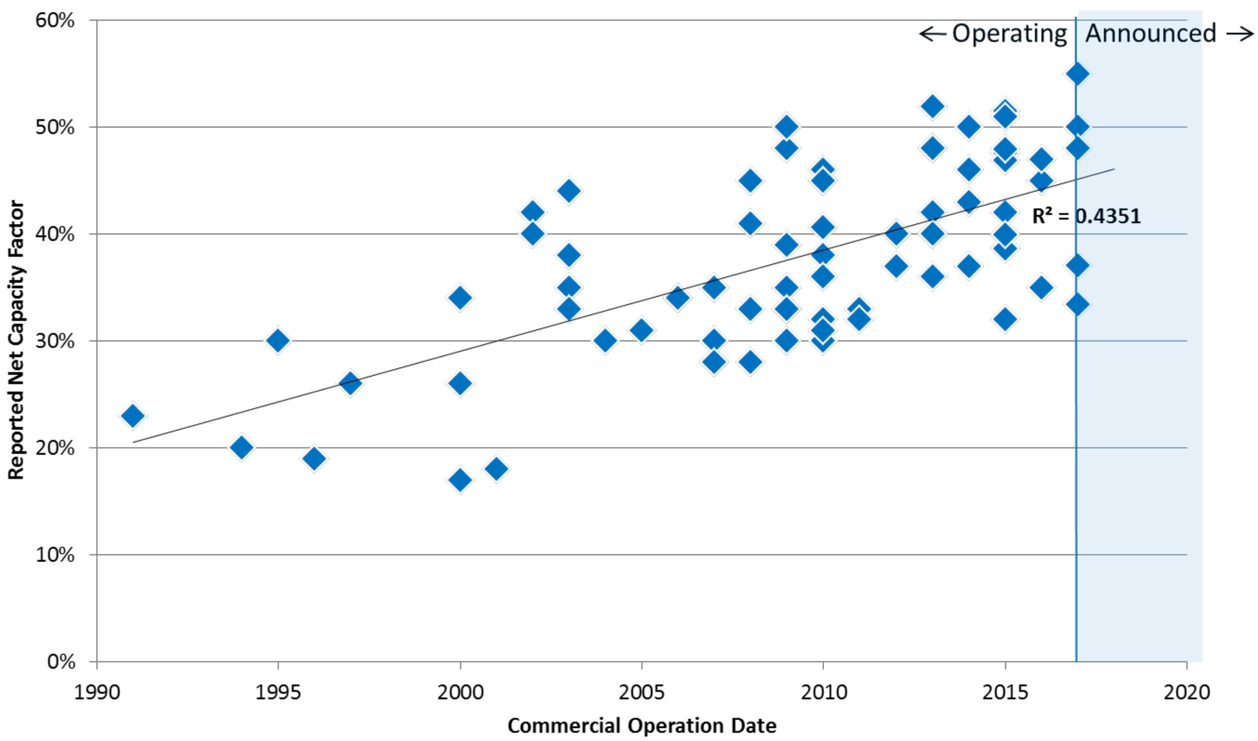

Figure 18. Net capacity factor for selected European offshore wind projects

Source: NREL; modeled data

Generally, capacity factors are improving for two main reasons. First, siting decisions for initial projects emphasized locations that were close to shore and somewhat sheltered so that developers could gain experience before moving into open-ocean conditions. Offshore wind development zones are now increasingly located farther from shore to allow for larger projects and enable access to a more energetic and consistent wind resource. Second, offshore wind turbine performance has improved over the last decade with higher drivetrain efficiency and greater energy capture for a given site. For example, offshore wind turbine designers have been lowering specific power (expressed as the ratio of nameplate capacity to rotor swept area in Watts/m^2). Generally, this means that rotor areas are larger, which increases the amount of energy that can be captured. As machines increase in size, the tower heights have also increased, and with that, energy output increases because winds at higher elevations are typically more energetic because of wind shear. For instance, Walney Phase 1 and 2 are located in close proximity to each other but their capacity factors vary significantly. Walney Phase 1 exhibits a lifetime capacity factor of 40.70% using the Siemens SWT-3.6 MW turbine with a 107-m rotor, whereas Walney Phase 2, using the Siemens SWT-3.6 MW turbine with a 120-m rotor, has had a lifetime capacity factor of 47.50% (Garlick et al. 2017).

Capacity factors in the United States are expected to vary widely depending on the project location and turbine technology. The northeastern Atlantic has a very strong offshore wind resource, with average annual wind speeds between 9 and 10 meters per second (m/s). The 30-MW BIWF, for example, expects a net capacity factor of 47.5%, which is comparable to net capacity factors at the best European project locations (AWS Truepower 2012). Wind speeds gradually diminish from the north southward in the Atlantic and Gulf of Mexico where annual average wind speeds are typically between 7 and 8 m/s; however, annual average wind speeds exceeding 8 m/s can be found at sites farther from shore and on the western edge of the Gulf of Mexico (Musial et al 2016).

4.5 Financing Trends

Offshore wind projects are capital-intensive, with utility-scale projects (>200 MW) generally requiring investments of more than $1 billion. Because the majority of lifetime costs are incurred through CapEx in the development and construction of the project, LCOE is highly sensitive to the cost of financing those capital expenditures. The effective cost of financing is typically expressed as the weighted-average cost of capital, which averages the cost of all sources of capital based on the percentage contribution to the total capital structure. To take advantage of the large impact of the weighted-average cost of capital on the all-in cost of energy, offshore wind project owners are placing considerable effort on securing access to low-cost capital, which involves adopting project structures that minimize risk to investors as well as attracting new investor classes to the sector (PricewaterhouseCoopers 2012).

The European offshore wind market saw significant financing activity in 2016 consisting primarily of debt and owner equity. WindEurope reports that 11 projects, totaling 4,948 MW, closed financing in 2016, with a total value of over €18.2 billion ($20.2 billion USD). The total investment activity was an approximate 39% increase over 2015 investment levels (WindEurope 2017a). Of the total €18.2 billion invested in new offshore wind projects, WindEurope estimates that €5.3 billion ($5.9 billion USD) was secured using nonrecourse debt, with the remaining funding sourced from a combination of balance-sheet finance and sponsor equity (WindEurope 2017a).[74] The majority of investment activity in 2016 was centered in the United Kingdom, Germany, Belgium, and Denmark (WindEurope 2017a). Currently, more than 50 banks have participated in the nonrecourse debt transactions for offshore wind projects, with most projects requiring more than one lender because of an individual bank's lending limits. Individual banks have reportedly increased the maximum amount that they are willing to underwrite on a given deal from $50–$75 million in 2012 to $100–$150 million in 2016 (Green Giraffe 2016). Although there are limited data available on actual transactions, debt for European offshore wind projects in 2016 is estimated to be priced at 150 and 225 basis points[75] above the London Interbank Offer Rate.

Additional debt terms are generally characterized by the following elements:

- Debt percentages reportedly near 75% of total required capital with remaining capital needs sourced from primarily sponsor (i.e., owner) equity
- Debt lengths varying between 10 and 17 years, possibly longer, depending on the market; the length of the loan is limited by the term of the subsidy available to the project to

[74] Nonrecourse debt is one form of debt investment in which the providers (typically commercial banks) supply capital that only has claims on the assets and future cash flows of the project itself. As such, these investors tend to be conservative and conduct considerable due diligence to ensure that their downside risk exposure (in which returns are lower than expected) is limited. For more detailed information on the different types of capital sources used for offshore wind projects, see Green Giraffe (2016) and Arapogianni and Moccia (2013).
[75] Note one basis point is equal to 1/100 of a percent and 100 basis points equals 1%.

include a 2–5 year buffer between the loan repayment date and the end of the power offtake agreement

- A debt service and maintenance reserve account with enough funding set aside to cover 3−6 months of debt obligations and maintenance expenditures.

There are several different types of entities that have participated in offshore wind investments including commercial banks, export credit agencies, and, increasingly, institutional investors (e.g., pension funds, insurance funds, and infrastructure investors). International financial institutions, such as the European Investment Bank, also continue to play an important role, particularly for the financing of new technology solutions, such as floating offshore wind. Corporate investors (a nondescript industry term generally comprised of businesses not including utility or other energy service providers) appear to offer a relatively new source of capital source of capital (WindEurope 2017b).

Harries and Kruger (2017) also note the emergence of oil and gas corporations as well as supply chain companies (i.e., manufacturers and marine contractors) as new equity investors in wind projects in 2016–2017. These companies may seek to diversify their investment portfolios, ensure a market for their product or services, or help secure the developer's access to financing (Harries and Kruger 2017). For example, Enbridge—a Canadian oil and gas pipeline, processing, and storage company—took nearly 50% ownership interests in both an operational offshore wind farm as well as an offshore wind development company (WindEurope 2017a). Additionally, a Royal Dutch Shell-led consortium won a bid for construction of a 700-MW wind project and has decided to purchase the output from existing offshore wind projects (OffshoreWIND.biz 2017c).

5 Offshore Wind Technology Trends

The following section updates trends in offshore wind site characteristics (e.g., water depth and distance from shore) for offshore wind technologies to provide context for understanding the key drivers behind recent technology innovation. Using NREL's OWDB described in Section 1, empirical data of planned projects advancing through the pipeline provide insight into global technology trends through 2022, with a focus on offshore wind turbine capacities, substructures, electric infrastructure, and logistical approaches for construction and maintenance activities. Much of the discussion is focused on fixed-bottom technologies, although some limited comparisons to floating technologies are made, such as in substructure trends. Section 6 provides a more detailed discussion on floating offshore wind technologies.

5.1 Site Characteristics for Global Offshore Wind Projects

Figure 19 shows the trends of global offshore wind projects that have, at a minimum, advanced to the site control phase, as a function of water depth and distance from shore, color-coded by project phase. Figure 19 also illustrates the project size. This figure indicates a possible trend toward larger projects (i.e., larger bubble sizes) sited farther from shore (i.e., moving to the right on the x-axis), particularly for those projects in the permitting and approval phase of development.

Figure 19 also highlights a sample of approximately 1,000 MW of future U.S. offshore wind projects (shaded in red). Because of the higher fidelity of the data for a U.S.-based project in the OWDB, Figure 19 only shows U.S. projects that have advanced beyond the site control phase and announced project size. This second screening criteria provides a more specific characterization of potential future U.S. projects. The U.S. projects appear to be following trends similar to the fleet of projects installed or under construction globally in terms of water depth. U.S. projects, however, extend to less than 40 km from shore as compared with some European projects that are sited up to 200 km from shore. Also, it appears that the first few U.S. projects are smaller than the average European project but large-scale projects are already in the planning stage. Note that this figure is truncated at a 60-m water depth for scale purposes.[76]

As discussed later in this section, wind projects designed for deeper water and greater distances to shore will require innovative technologies and approaches to both enable deployment and simultaneously lower the cost of energy. Water depth along with seabed soil conditions influences the selection and design of the substructure including its height, weight, footprint, and material thickness. Distance from shore has several impacts on cost including the design of subsea electrical cabling and system configuration (e.g., consideration of a high-voltage direct current) as well as logistical challenges during the project's construction and operation phases (e.g., transport time, effective length of working day).

[76] Figure 19 does not show floating projects with a water depth greater than 60 meters. The OWDB includes 26 projects, either operating or under some phase of development, in water deeper than 60 meters, with a combined capacity of approximately nearly 3,000 megawatts.

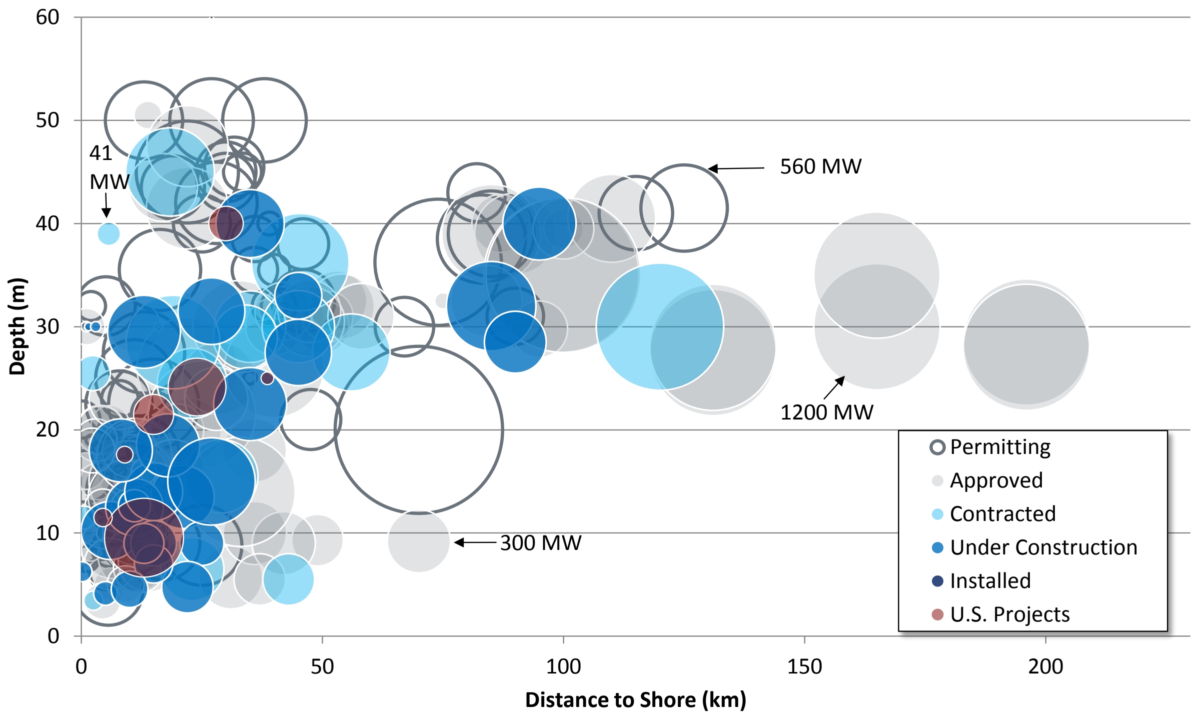

Figure 19. Global offshore wind projects as a function of water depth and distance to shore
Note: Bubble size represents project rated capacity (in MW). Source: NREL

5.2 Offshore Wind Turbine Trends

Offshore wind turbines are continuing their upscaling trend. For example, the completion of the Burbo Bank extension in early 2017 was the first commercial project to use a V164 8-MW turbine that was first prototyped in 2014. Additionally, an upgraded V164 prototype 9.5-MW turbine was debuted in 2017 (MHI Vestas Offshore 2017a, 2017b). Larger turbine sizes are enabled in offshore applications, in part, because there are fewer transportation and installation limits than for land-based projects. Furthermore, incorporating larger turbines in a project's design may also reduce the nonturbine balance-of-plant costs as well as having fewer turbines to service.

Figure 20 shows global offshore wind turbine trends since 2000 along with the capacity-weighted[77] average turbine rating (blue bars; left axis), capacity-weighted average rotor diameter (green line; right axis), and hub height (orange line; right axis). Note that the forecast through 2022 for weighted average turbine capacity, rotor diameter, and hub height is based on a subsample of projects that have announced an agreement or partnership with a turbine OEM, which represents 38,856 MW.

[77] A capacity-weighted average weighs the contribution of given characteristic (e.g., turbine rating) by the associated amount of capacity (megawatts) based on its percentage contribution to the total capacity installed in a given year.

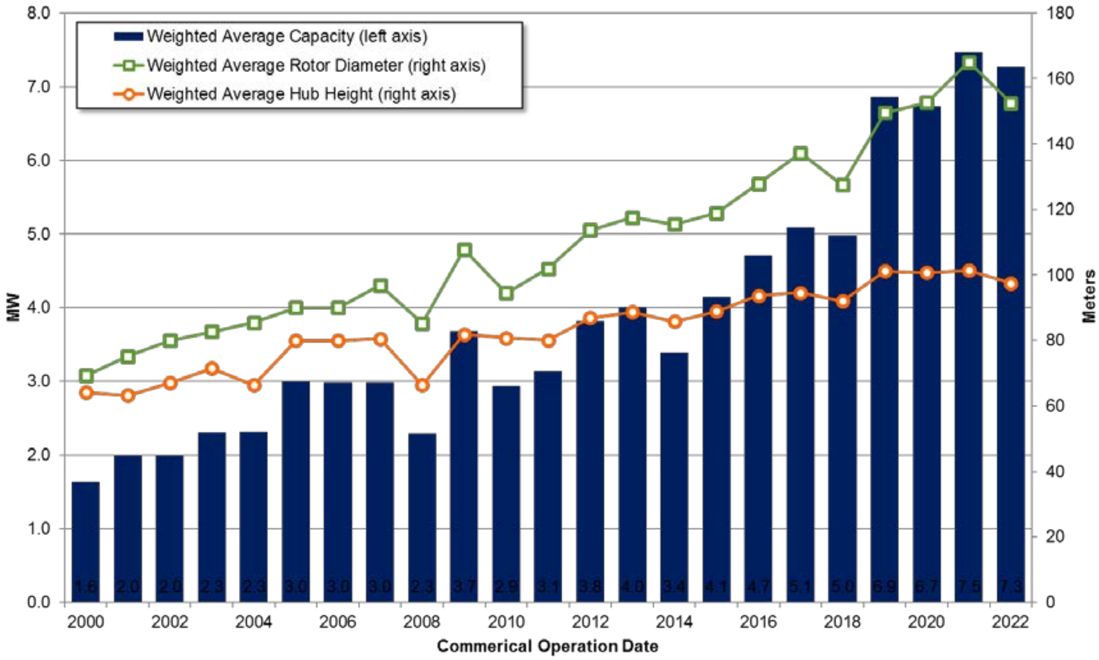

Figure 20. Global turbine capacities, rotor diameters, and hub heights over time

Note: The values for the expected turbine capacities, rotor diameters, and hub heights from 2017 to 2022 are weighted average capacity determined from projects that have announced turbine supply agreements. Source: NREL

Figure 20 shows that the average nameplate capacity of turbines installed in 2016 was 4.7 MW, a 14% increase from 2015. The capacity-weighted average rotor diameter and hub height increased slightly to 127 m (8% growth from 2015) and 93 m (5% growth from 2015), respectively. These 2016 capacity-weighted averages are consistent directionally with longer-term industry trends. The data suggest that turbines increased from largely 3 MW and under in 2010 to more than 4 MW beginning in 2015, with some year-to-year fluctuations. The average rotor diameter also increased from a capacity-weighted 94 m in 2010 to over 127 m by 2016. An increase in rotor diameter raises the amount of energy that a turbine can extract from the wind at a given site and has contributed to improvements in energy production across the offshore wind industry.

Looking ahead, the forecast of rated turbine capacity does show evidence of continued upscaling, with an expected step up to over 6 MW in 2019. This turbine size increase is evidenced by a general industry shift to turbines rated between 6 and 8 MW from the previous 2- to 5-MW class turbines. Commensurate with turbine size, the forecast in Figure 20 also shows a continued growth in rotor diameter to a capacity-weighted average of over 150 m beginning in 2020.

Some notable steps in development that OEMs have taken recently to demonstrate and commercialize advanced turbines include the following:

- Siemens installed the first prototype and certification of its 8-MW SWT-8.0-154 turbine at the national test center in Østerild, Denmark, in January 2017. The new turbine increased annual electricity production by approximately 10% and rated capacity by 14% over the previous 7-MW model (SWT-7.0-154) (Froese 2017).

- As noted previously, MHI Vestas, a joint venture between MHI and Vestas, completed the Burbo Bank Extension project for DONG Energy in the United Kingdom in early 2017 using V164 8-MW turbines. The project is the first commercial application of these turbines and comprises 32 turbines for a total project capacity of 258 MW (MHI Vestas Offshore 2017a).
- Adwen, owned by Gamesa, was in the final assembly stages in early 2017 in Bremerhaven, Germany, for its 8-MW AD 8-180 turbine. The turbine is contracted for multiple projects totaling 1,500 MW (1.5 GW) off the coast of France (OffshoreWIND.biz 2017d).

Although it may take some time for the industry to fully adapt to new 6- to 8-MW turbine sizes (similar to 2010 through 2015 in Figure 17), further long-term growth in turbine size is still likely. Offshore wind turbine OEMs, Siemens, MHI Vestas, and Senvion have indicated that they will have a 10-MW+ design in the works (Weston 2017b; Weston 2017b). Fewer larger-sized turbines reduce the balance-of-system requirements (i.e., less substructures and other infrastructure required to achieve the same project size). These larger machines do, however, require larger vessels and equipment, as well as enhanced logistical facilities to enable efficient transportation, installation, and operation (Elkington et al. 2013). In addition, blade and drivetrain validation testing and component manufacturing facilities may require further upgrades. These increased infrastructure requirements have the potential to slow the adoption of ultra-large turbines in the near term, especially in the nascent U.S. market, which currently lacks purpose-built ports and vessels.

5.2.1 Offshore Wind Turbine Original Equipment Manufacturer Activities

There were several notable industry partnerships, mergers, and acquisitions in 2015 and 2016 by turbine OEMs. Some of the major announcements include:

- French nuclear group Areva sold its 50% stake in Adwen to Gamesa to focus on its nuclear business (Weston 2016b)
- Siemens Wind Power and Gamesa announced a merger in June 2016 (4C Offshore 2016); the Siemens-Gamesa merger took effect in April 2017 with a new moniker of Siemens Gamesa Renewable Energy
- Shanghai Electric Wind Power Equipment (abbreviated as Sewind) built both Siemens-licensed offshore wind turbines as well as some of its own design
- The GE and Alstom power and grid merger process announced in 2014 was completed in late 2015 resulting in a GE division titled GE Renewables that is based in Paris (WINDPOWER Monthly 2015); the merger was noted as the largest industrial deal in GE’s history and was noted in part for allowing GE greater access to the offshore wind market (Egan and Kellner 2015).

Figure 21 shows the market share for the top offshore wind OEMs for the operating projects (left pane), as well as market share for the project pipeline through 2020 (right pane, shaded blue). Of projects operating by December 31, 2016, (left pane in Figure 21), Siemens has dominated the market with a 61% cumulative share, followed by MHI Vestas at 16%, and Senvion at 6%.78

The market share for the announced pipeline (right pane in Figure 21) shows more balance in the market in the future. There are approximately 18,564 MW that have disclosed a turbine supplier through an unconditional turbine supply agreement, a conditional turbine supply agreement, a preferred supplier agreement, or a development partnership agreement. Of the announced 18,564 MW in the project pipeline, Siemens Gamesa Renewable Energy remains a market share leader with approximately 53% of the announced portfolio but this share is down from the combined 66% of the operational market when Siemens and Gamesa were independent entities. MHI Vestas accounts for 17%, whereas GE[79] (formerly Alstom) and Gamesa (formerly Adwen) account for 16% and 14%, respectively. As noted by Smith, Stehly, and Musial 2015, some of the main drivers accounting for increased market share competition include a larger total market size and increased geographical diversification.

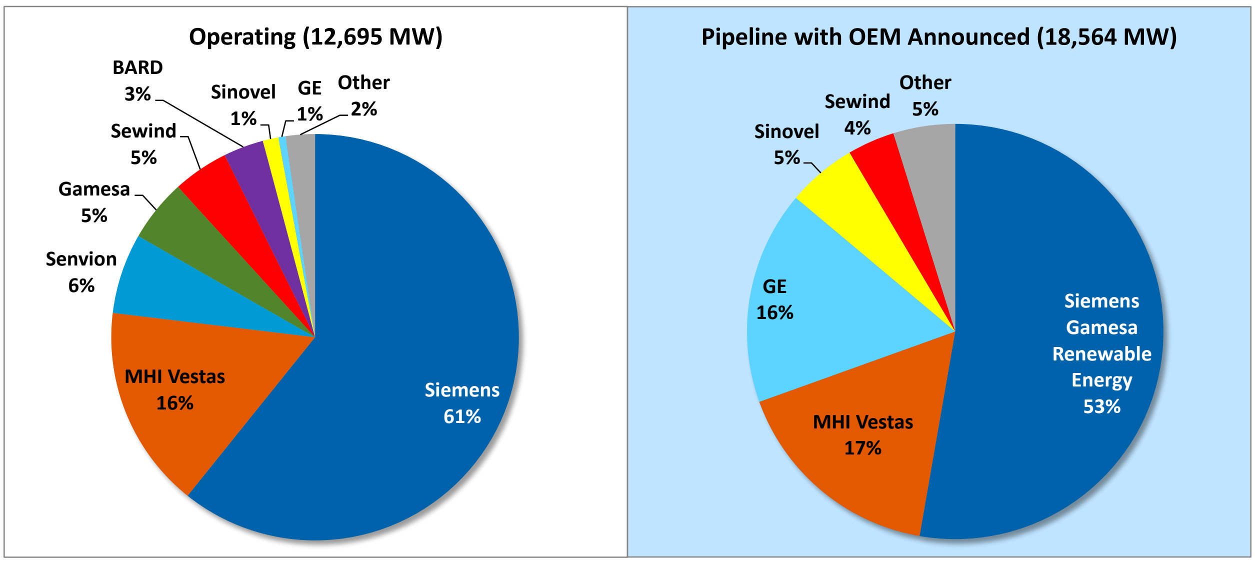

Figure 21. Global market share for offshore wind turbine OEMs shows increased competition

Source: NREL

5.3 Substructure Technology and Market Trends

Substructures for offshore wind projects are evolving to meet the new demands associated with deeper water and larger, heavier turbines. Designers and fabricators are simultaneously innovating to lessen costs by:

- Adopting more efficient substructure geometries that seek to minimize material intensity and increase the ease of fabrication
- Simplifying installation operations, either by decreasing installation time or reducing dependencies on expensive vessels

[78] Gamesa's 5% share of the operating assets reflects its ownership of Adwen.
[79] Note that GE also deployed offshore turbines in 2003 at Arklow Banks using other turbines.

- Maturing the supply chain by incorporating more efficient, purpose-built equipment and processes into manufacturing facilities and staging ports.

Figure 22 shows the market share for offshore wind substructures for the operating projects and project pipeline through 2022. Approximately 44% of the 38,856 MW in the development pipeline has disclosed a foundation type, although, in many cases, these announcements may simply be initial proposals and may not reflect a commercial agreement with a supplier.

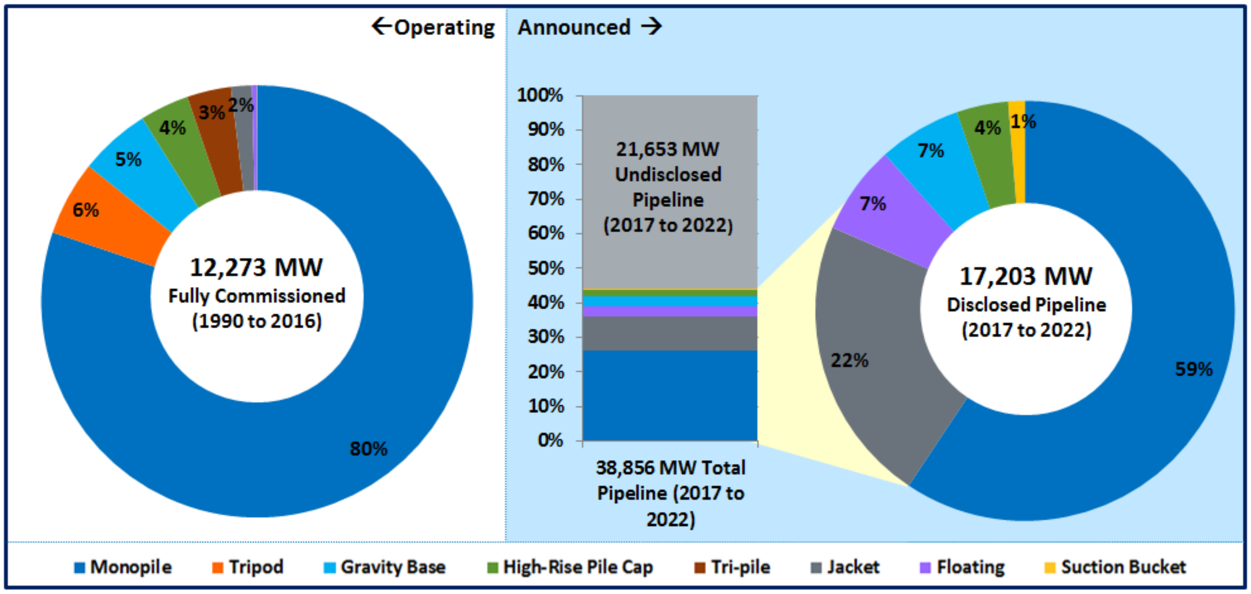

Figure 22. Global offshore wind substructure market share

Source: NREL

Figure 22 reveals that monopiles have historically been the dominant substructure, with 9,840 MW installed as of December 31, 2016, or an 80% market share. Monopiles are followed by tripods (6% share), gravity bases (5%), high-rise pile caps (4%), and tri-piles (3%), supporting turbines that are already installed and operating. Each of the substructure types are designed differently:

- **Monopile**. Consists of a cylindrical foundation pile and a transition piece (transitional section between the tower and monopile); the diameter of the pile is specified by the water depth and seabed conditions (Yanguas Minambres 2012)

- **Jacket**. Consists of three or four legs connected by slender braces; the elements are tubular and are typically joined by welding

- **Gravity base**. Relies on the weight and ballast of the base structure (typically consisting of steel-reinforced concrete) to keep the tower and turbine in place

- **High-rise pile cap**. Typically consists of a series of piles that are capped by a rigid structure mainly used in Asia in shallow waters and soft soil conditions (Wind Energy Update 2013)

- **Suction bucket**. Combines the properties of a monopile and a gravity-base substructure to resist overturning with the interface with the seabed provided by a steel skirt

- **Tripod**. A three-leg structure made of cylindrical steel tubes connected to a main tubular section at the center that makes the connection to the wind turbine tower; the substructure is driven into the seabed using foundation piles through sleeves at the end of each leg

- **Tri-pile**. Made of three tubular steel piles and a three-legged transition piece placed on top of them that also connects the turbine tower; the joints between the piles and transition piece are grouted together permanently

- **Floating**. Appeared in the offshore wind market with the tendency of the industry to move into deeper water; floating substructures are covered in more detail in Section 6.

Looking ahead, monopiles are expected to remain the dominant substructure type but are expected to lose some market share, representing about 59% of the future disclosed pipeline. Jackets are expected to gain market share, moving up to 22%, reflecting the industry's move to deeper water sites and larger turbine sizes. However, the adoption of jackets has been much slower than expected, largely as a result of the emergence of extra-large monopiles that have extended the depth range of monopiles out to 40 m or more while remaining suitable for large turbines.

Floating substructures also seem to be emerging and may soon be a significant contributor. However, predictions based on the current pipeline may be artificially high. The majority of the floating projects in the global pipeline (2,905 MW) are driven by some large proposed projects in Hawaii and California that are at a very early stage of development. Realistically, these projects are unlikely to be built before 2025. To date, several precommercial and commercial floating projects are being proposed, but the timing of deployment remains uncertain for many projects.

Gravity-base structures appear to be gaining market share—from 5% of installed turbines to 7% of offshore turbines planned. This increase may be an indication of interest in advanced gravity-base structures, which can be installed without the use of expensive heavy-lift vessels, thereby potentially making gravity-base substructures more competitive (Snieckus 2014).

5.3.1 Fixed-Bottom Substructure Trends

Monopiles tend to be the most cost-effective, fixed-bottom substructure technology both in terms of fabrication and installation. Until recently, many experts thought that monopiles would have limited applicability for waters deeper than 30 m or turbine sizes greater than 5 MW. But new extra-large monopiles, enabled by improved processes that allow for the fabrication and installation of larger-diameter piles and vessels with increased driving capacity, have greatly expanded the design envelope.

The industry is maturing a number of innovative, fixed-bottom substructures that are expected to be adopted for commercial projects in the near term including:

- A three-legged jacket with a suction pile foundation, like the one designed by SPT Offshore, may optimize installation procedures and may lead to cost savings (SPT Offshore undated)
- The use of a twisted jacket technology, designed by Keystone Engineering, which has the potential to optimize installation procedures
- The use of a monobucket foundation (Funk 2015), which combines a monopile with a suction bucket, designed for soft soil conditions may solve freshwater and sea icing issues (LEEDCo 2017)
- An advanced gravity-base foundation, which can be installed without the use of crane vessels, was installed in 2015 to support a met tower at the Fecamp site in France. The 498-MW Fecamp project expects to use 83 gravity-base foundations supporting 6-MW turbines, to be commissioned in 2021 (Weston 2015c).[80]

The BIWF is the first offshore wind project to use a gulf-style jacket, in which piles are driven through the legs of the jacket after it has been placed on the seabed. Although this design has been widely employed in the offshore oil and gas industry, the jackets at the BIWF are the first application of the design for offshore wind turbines. The offshore wind industry has historically driven piles into the seabed and the jacket placed directly on the piles or the jacket placed on the seabed and piles driven through sleeves attached to the jacket legs.

5.4 Electrical Infrastructure Technology and Market Trends

Electrical infrastructure typically has three components: the array cable system, the export system, and the land-based transmission infrastructure. The array system collects power from the transformers of individual wind turbines and delivers it to the offshore substation transformer via a grid of submarine cables (typical rating of 33 kilovolts [kV]). The export system usually includes a substation that transforms 33-kV array voltage up to the voltage of the export cable to shore (typical rating of 132 and 220 kV). Land-based transmission infrastructure includes transmission lines and substation upgrades or new construction required to connect to the existing power grid on land.

5.4.1 Array Cable System Trends

Array cable systems for commercial projects are typically rated at 33 kV and connected radially to the substation. The rated capacity of cables at this voltage is approximately 36 MW for a single cable connected to the substation, which has worked well with turbines rated below 6 MW. Moving to larger turbine sizes limits the number of turbines that can be connected to the substation with a single cable, which, all else equal, will increase the length of array cables required for a given project, and will contribute to higher electrical losses in the array.

Increasing the array system voltage to ~66 kV would enable more efficient array cable layouts for projects using larger turbine ratings and reduce CapEx. Other benefits of 66-kV array voltage would be: lighter cables from reduced conductor size with higher voltages, fewer electrical losses (up to 75% for the same cable cross-sectional area) within the array cable system, decreased

[80] http://parc-eolien-en-mer-de-fecamp.fr/le-parc-eolien-en-mer/agenda-du-projet/. The website can be translated to English using Chrome. The website provides high level information about the Fecamp project.

substation transformer weight and number of substations, and the ability to adopt more redundant array cable layouts (e.g., ring configurations) to increase reliability. Progress towards higher-voltage array systems has been slower than anticipated (DNV GL 2015). The 66-kV cable technology has been selected for the Blyth Offshore Wind Farm demonstration project currently under construction in the United Kingdom and is planned to be used at the WindFloat Atlantic project (EDF Energy Renewables 2017; JDR 2017). In 2016, Nexans completed its qualification for 66-kV cross-linked polyethylene array cables as part of the Carbon Trust's Offshore Wind Accelerator program, supported by the UK Department of Energy and Climate Change and the Scottish Government (Nexans 2016).

In 2017, ABB unveiled the 66-kV WindSTAR transformer. As wind turbine capacity has reached 8 MW and is still increasing rapidly, transformer technology needs to adapt. ABB's specialty transformers are compact, with a 30-year lifetime to enable the next generation of turbines to operate at 66 kV. The WindSTAR transformers will debut in 2017 at the 41.5-MW Blyth Offshore Demonstrator Wind Farm Project—the world's first wind farm to use 66-kV technology. ABB will also supply another eleven 66-kV transformers to the European Offshore Wind Deployment Centre.

5.4.2 Export System Trends

The trend toward siting projects farther from shore is increasing the length of export cables and driving offshore wind project developers to adopt system designs based on higher voltages. These changes indicate that export system costs are contributing more to overall life cycle costs, and are increasingly becoming a focal point for cost reduction efforts.[81]

In 2015, Siemens first unveiled its high-voltage alternating current (HVAC) offshore transmission module (OTM), which packages the electrical conversion equipment typically found on stand-alone offshore substations into smaller, lighter units that can be installed directly on (slightly modified) turbine substructures. Each OTM weighs 630 metric tonnes (mT), is approximately 10 m high by 30 m long, and can accommodate 250 MW of power (a more than 50% reduction of weight and volume compared to conventional designs). The compact size and light weight means that the units can be installed by the jack-up crane vessel used for turbine installation, removing dependencies on expensive heavy-lift vessels that can cost between $300,000 and $850,000 per day. It is estimated that the OTM can reduce substation CapEx, including procurement and installation costs, by up to 40% (Siemens 2016). The 448-MW Neart na Gaoithe project in the United Kingdom announced that it will adopt this technology (Mainstream Renewable Power 2014). The transformer for the first OTM module was shipped by Siemens for the Beatrice Offshore Wind Farm in May 2017 (OffshoreWIND.biz 2017f).

For projects that are located far from shore, conventional HVAC systems can be prohibitively expensive when evaluated in terms of CapEx and potential revenue losses. In these situations, developers or transmission system operators (TSOs) have opted for HVDC solutions. An example of a case study is shown in Figure 23, which shows a cost comparison between two transmission cable scenarios. An AC and a DC submarine transmission cable connecting an

[81] For developers who are responsible for offshore grid connection. The export system is less of a focus in markets in which grid connection responsibility lies with the transmission system operator.

offshore substation to a shore power system are compared (note that the cost of offshore substation is included) (Van Hertem, Gomis-Bellmunt, and Liang 2016). For 1,500 MW of transmission capacity, 245-kV AC and ±320-kV DC voltage-source converter transmission options show a break-even distance of 190 km is reached before the active power transmission capability of the AC system is reached. Thus, the DC option is not economical for this specific case. In general, the break-even distances between HVAC and HVDC transmission depends on many factors including transmission distances, capacities, and voltage levels.

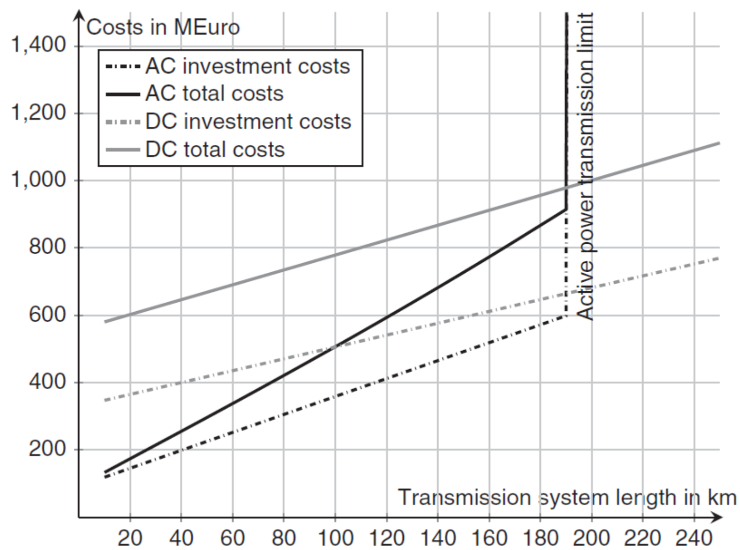

Figure 23. Cost comparison between AC and DC submarine transmission

Source: Van Hertem, Gomis-Bellmunt, and Liang 2016

The German government is planning the construction of offshore wind power plants with a total capacity of 6,500 MW, and TenneT, the German TSO, will be involved in developing infrastructural projects in the North Sea utilizing both HVAC and HVDC transmission technologies (TenneT 2017). Several of these connections have been completed; however, technical and logistical challenges led to significant schedule delays and cost overruns. Major contractors, including Siemens and ABB, have announced cost overruns, which total over €1 billion ($1.3 billion USD) when combined, and expressed that they will be taking a more cautious approach to future bids from pricing and risk acceptance perspectives (Smith 2014; Webb and De Beaupuy 2014).[82]

These developments introduce uncertainty into how future HVDC contracts will be priced; yet, available evidence suggests that prices will likely increase. In 2017, researchers from Norway, the United Kingdom, and Spain formed a consortium to combat technical barriers currently hampering the practical deployment of HVDC grids in the North Sea needed to exploit the potential of the region's wind resource (OffshoreWIND.biz 2017g). Also, in 2017, the First U.K. HVDC Test Centre opened for business (OffshoreWIND.biz 2017h). The centre is expected to

[82] For example, ABB indicated that it will no longer provide a wrap on converter system contracts, thereby guaranteeing a fixed-price value for executions.

play a crucial role in the development of HVDC technology projects that are a result of the increasing number of offshore wind power plants in the United Kingdom.

In 2016, Vattenfall won a bid to build the 600-MW Kriegers Flak offshore wind plant in Denmark, the largest in the Nordic region, with a combined grid solution allowing integration of offshore wind power into the interconnector between two asynchronous grids—Germany and eastern Denmark (part of the Nordic grid). The HVDC back-to-back-based interconnector will allow the connection of asynchronous AC power grids of eastern Denmark and Germany, and also make it possible to export the wind-generated power to Germany. Part of the wind production will be exported to Denmark via a HVAC link because of shorter transmission distances (Weston 2016c).

5.5 Vessel and Logistical Trends

Offshore wind projects are expected to move to sites that are farther from shore, in deeper water, and subject to more severe metocean conditions. Simultaneously, there is a trend toward larger turbine sizes, which are characterized by bigger, heavier components and higher hub heights. As a result of this growth in size and weight, new logistical challenges related to construction and maintenance activities have surfaced. The U.S. industry has its own particular set of challenges, introduced by Jones Act requirements,[83] which are leading developers to modify installation strategies to match the capabilities of the existing U.S. vessel fleet. These strategies, which are generally less efficient than those that can be achieved with the purpose-built fleet of vessels in Europe, are likely to result in a cost premium for the initial U.S. projects. The U.S. offshore wind industry is currently investigating options to obtain a Jones-Act-compliant turbine installation vessel by retrofitting an existing vessel or constructing a new vessel. In July 2017, Zentech Inc. and Renewable Resources International announced their intention to deliver the first Jones-Act-compliant, four-legged, self-propelled, dynamically positioned level 2 (DP2) jack-up vessel to the emerging U.S. offshore wind industry (Runyon 2017; Clean Energy Group 2017).

5.5.1 Construction Vessels and Logistics Trends

Douglas Westwood (2014) discussed trends in installation vessels that are generally increasing in size to handle the bigger components associated with larger turbines. However, there are few vessels that can handle the 8- to 10-MW turbine sizes announced for many future offshore wind projects. The shortage could be exacerbated when turbines are to be installed in deeper water sites (e.g., greater than 40 m); the maximum effective crane hook height is a function of water depth, jack-up leg length, soil properties (which determines leg penetration), and crane height. Today, the offshore wind industry is installing 6-MW offshore turbines with wind turbine OEMs announcing the release of 10-MW turbines. The larger machines will continue to push the limits of current offshore installation vessel capabilities.

The 30-MW BIWF remained compliant with the Jones Act as the turbine components were transported by U.S.-flagged lift boats from the Block Island, Galilee, Quonset Point, and

[83] The Jones Act (also known as the *Merchant Marine Act of 1920*) prohibits the transfer of merchandise between “points in the U.S.” unless the owner and crew of the vessel are “American,” as certified by the Secretary of Transportation. The Secretary may, however, choose to grant an exemption if no suitable American vessels exist (Hamilton et al. 2014).

ProvPort construction and staging ports to the project site. The turbine installation was completed by a foreign-flagged turbine installation vessel named the Brave Tern that remained at the offshore site while the balance-of-system installation and assembly activities utilized a fleet of U.S.-flagged vessels. The offshore wind industry in collaboration with the U.S. shipping industry is looking to identify other efficient turbine installation methods compliant with the Jones Act including the potential use of U.S.-flagged turbine installation vessels staged in local ports.

5.5.2 Maintenance Vessels and Logistics Trends

Offshore wind O&M costs are expected to vary considerably among offshore wind power plant locations. From previous experience, (Maples et al. 2013; Jacquemin 2011; van de Pieterman 2011) the two largest locational drivers of O&M cost differences between offshore wind projects are the distance between the project and maintenance facilities (e.g., O&M port and/or inshore assembly area) and the prevailing metocean climate at the project site. The siting of offshore wind projects in locations that are farther from shore and in more severe metocean conditions (e.g., higher wind speeds and wave heights) has amplified the challenges of safely delivering technicians and components to the project site. Operators are addressing these challenges by rapidly incorporating next-generation O&M vessels and optimizing related strategies.[84]

For example, for projects that are a medium distance from port (nominally between 40 km and 70 km), operators are testing vessels known as surface effect ships, such as the Umoe Wave Craft, which increases vessel speed from 20 to 35 knots and increases the limit above which technician transfers cannot occur from a 1.5-m significant wave height to a 2.5-m significant wave height. This type of vessel is being utilized by DONG Energy at the Borkum Riffgrund 1 project, located 54 km from its O&M base in Norddeich (DONG Energy 2014).

For projects that are a greater distance from port (nominally beyond 70 km), operators are beginning to use service operations vessels. These vessels are designed to stay on-site for extended deployments, with endurance generally exceeding 1 month. These crafts are outfitted with the capability to launch small service vessels and typically have motion-compensated gangways to allow for technician transfers in harsh weather. Siemens is deploying service operations vessels at four projects and estimates that its deployment of one such vessel at Westernmost Rough will cut weather-related downtime from the current levels of 40%–45% down to 10%–15% (Snieckus 2015).

[84] An optimized O&M strategy is one that simultaneously minimizes direct OpEx while maximizing the revenue that the project can generate through power sales (maximizing availability).

6 Floating Offshore Wind Trends

6.1 Global Market Assessment

Globally, the trend toward floating wind turbines continues to accelerate. A number of successful proof-of-concept projects and research programs across Asia, Europe, and North America have begun to stimulate commercial interest. The push to develop new floating technology is motivated by large deepwater resources off the coasts of major energy markets where the offshore wind resource in water depths less than 60 m may be limited (Musial 2016; James and Ros 2015).

The floating offshore wind industry appears to be evolving from proof-of-concept single turbine deployments that characterized the first wave of prototype development from 2009 through 2015. The current trend is characterized by the deployment of multiturbine, precommercial pilot projects. From the 26 worldwide floating wind projects under some phase of development, there are about 11 individual projects totaling 229 MW of capacity that have advanced past the planning phase and are either under construction, approved, or have significant resources committed to move forward with development. These projects are dispersed globally and are identified in Figure 24 and Table 29 (green shading in table). The figure shows water depth, estimated COD, project-rated capacity, and the development phase. It shows the 26 operating, decommissioned, and announced projects (with a total capacity of 2,905 MW) including 21 demonstration-scale projects, and five commercial-scale projects in Hawaii, California, and France. The total number of floating projects in the pipeline has increased more than threefold since 2015 when a capacity of 819 MW was reported (Smith, Stehly, and Musial 2015). The projects shown range in scale from 2 MW (Floatgen) to the 50-MW Kincardine (4C Offshore 2017b).

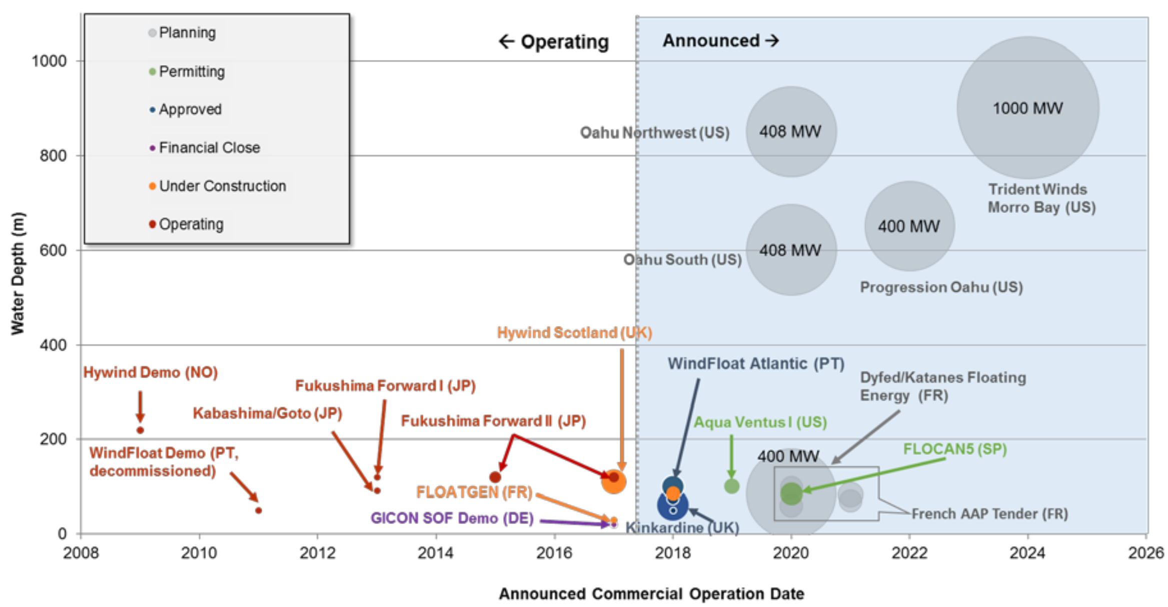

Figure 24. Global timeline for floating offshore wind projects

Source: NREL

Table 29. Floating Offshore Wind Projects (as of June 2017)

	Project	Year Online	Lead Organization	Status	Market	Turbine Capacity (MW)	Project Capacity (MW)	Water Depth (m)	Foundation Type
Americas	Aqua Ventus I	2019	University of Maine	Permitting	United States	6	12	100	Semisubmersible
	Oahu Northwest Lease Request	2020	Alpha Offshore Wind	Planning	United States	6–8 MW	408	850	Semisubmersible
	Oahu South Lease Request	2020	Alpha Offshore Wind	Planning	United States	6–8 MW	408	600	Semisubmersible
	Progression	2022	Progression Energy	Planning	United States	8+ MW	400	650	Semisubmersible
	Morro Bay Offshore Wind	2024	Trident Energy	Planning	United States	8+ MW	1,000	900	Semisubmersible
	WindFloat Pacific	2018	Principle Power	Cancelled	United States	6–8 MW	-	435	Semisubmersible
Asia	Kabashima/Goto	2013	MOE	Installed	Japan	2	2	91	Spar
	Fukushima Forward I	2013	METI	Installed	Japan	2	2	120	Semisubmersible
	Fukushima Forwad II - MHI	2015	METI	Installed	Japan	7	7	120	Semisubmersible
	Fukushima Forward II - Hitachi	2017	METI	Installed	Japan	5	5	120	Spar
	Kitakyushu NEDO Next Generation Demo	2018	NEDO	Approved	Japan	3–4 MW	7.45	75	Barge
	WindFloat Japan	2018	Principle Power, NEDO	Planning	Japan	6	6	70	Semisubmersible
Europe	Floatgen	2017	Gamesa/Ideol	Under construction	France	2	2	30	Barge
	Inflow/Vertiwind Demo	2018	EDF, Nenuphar	Approved	France	2	2	50	Semisubmersible
	Les éoliennes flottantes de Groix & Belle-Île (La Groix)	2020	Eolfi	Planning	France	6.15	24.6	60	Semisubmersible
	Provence Grand Large (Faraman)	2020	EDF	Planning	France	8	24	99	Tension-leg platform
	EolMed (Gruissan)	2021	Quadren/Ideol/Bouygues	Planning	France	6.15	24.6	70	Barge
	Les éoliennes flottantes du Golfe du Lion (Leucate)	2021	Engie/EDPR/CDC	Planning	France	6	24	70.5	Semisubmersible
	Hywind Scotland	2017	Statoil	Under construction	United Kingdom	6	30	100	Spar
	Dounreay Tri	2018	Highland and Islands Enterprise	Under construction	United Kingdom	6–8 MW	10	85	Two turbine semisubmersible
	Kincardine	2018	Pilot Offshore Renewables	Approved	United Kingdom	6	50	62	Semisubmersible spar hybrid
	Dyfed/Katanes Floating Energy	2020	Dyfed Floating Energy Ltd	Planning	United Kingdom	5–8 MW	400	85	Semisubmersible
	WindFloat I	2011	Principle Power	Installed (decommissioned in 2016)	Portugal	2	2	50	Semisubmersible
	WindFloat Atlantic	2018	Principle Power	Approved	Portugal	8.33	25	100	Semisubmersible
	Hywind 1 Demo	2009	Statoil	Installed	Norway	2.3	2.3	220	Spar
	GICON Pilot	2017	Gicon	Financial close	Germany	2.3	2.3	20	Tension-leg platform
	FLOCAN5	2020	Canary Islands Government	Permitting	Spain	5–8 MW	25	85	Semispar

Note: Blue shading indicates projects that have been installed; green shading indicates projects that are described in more detail later; white shading indicates future floating projects not highlighted; yellow shading indicates projects that are cancelled and not counted.

Leading countries in the deployment of floating offshore wind are France, Norway, Japan, United Kingdom (Scotland), United States, Portugal, and Germany. Other countries such as Spain and Denmark are also contributing to the development of floating wind technology.

A significant part of this new phase of development comes from the French tender for floating offshore wind projects that was launched on August 5, 2015. The French government is supporting the development of four precommercial floating wind farms, each at about 24 MW, and all at a similar water depth and distance from shore (see Appendix B-9 through B-12). Three of the projects will be located in the Mediterranean Sea and one will be sited in the Atlantic Ocean.

Although the industry is reporting significant progress in the development of these next-generation pilot projects, the global installed capacity of floating wind did not increase significantly since the previous market report documenting industry progress up to June 30, 2015, (Smith, Stehly, and Musial 2015). The only turbine deployed during this period was the Hamakaze spar under Fukushima Forward, Phase 2, using the Hitachi 5-MW prototype in September 2016 (see Appendix B-4).

6.2 Floating Offshore Wind Trends

Although still in the precommercial phase of maturity, over the past year floating wind technology appears to have gained credibility and mainstream recognition. It is now being considered a viable future renewable technology. The following summarizes the major trends identified in this study that point to the likely emergence of a floating wind industry in the next decade.

6.2.1 Floating Offshore Wind Resource

Globally, the offshore wind energy resource for floating technology exceeds the resource for technologies that rely on fixed-bottom foundations. In Europe, the Carbon Trust (2015) estimates that 80% of the available offshore wind energy resource is located in waters with a depth greater than 60 m. The same study indicates that in Japan, 80% of the offshore wind resource has a depth of greater than 60 m. In the United States, 58% of the resource potential was estimated to be located in depths greater than 60 m.[85] In terms of generating capacity, the deep-water technical resource was estimated to be 1,196 GW for the entire United States (excluding Alaska) (Musial et al. 2016a). In the eastern United States, up to 25 GW of fixed-bottom offshore wind sites may be available for near-term development as described in Section 3.0. However, significant expansion of the Atlantic resource area beyond this near-term development may require (lease) sites that are farther from shore and in deeper waters. In the Pacific, over 90% of the available offshore wind resource is located in waters that have a depth greater than 60 m. California, the world's 8th largest economy and a major energy market, has 95% of its available 112 GW of offshore wind resource in waters greater than 60 m (Musial et al. 2016a). Musial et al. (2016a) found that up to 15 GW of that resource may be located in areas without competing or environmental use conflicts, so that development may be considered. In the Great Lakes, freshwater ice may impede floating offshore wind deployment, but over 500 terawatt-hours/year of new resource could potentially be available if new technology is developed to resist floating ice (Gilman et al. 2016).

Figure 25 shows a map estimating the modeled economic "break point" for the cost-optimal choice between fixed-bottom and floating technology dependent upon certain spatial factors (e.g., wind speeds, water depth, distance from shore, metocean conditions) for a commercial operation date of 2022 (Beiter et al 2016).

[85] Assuming wind speeds greater than 7 m/s and water depths no greater than 1,000 m; excluding all water in the Great Lakes above 60 m because of ice limitations (Musial et al. 2016a).

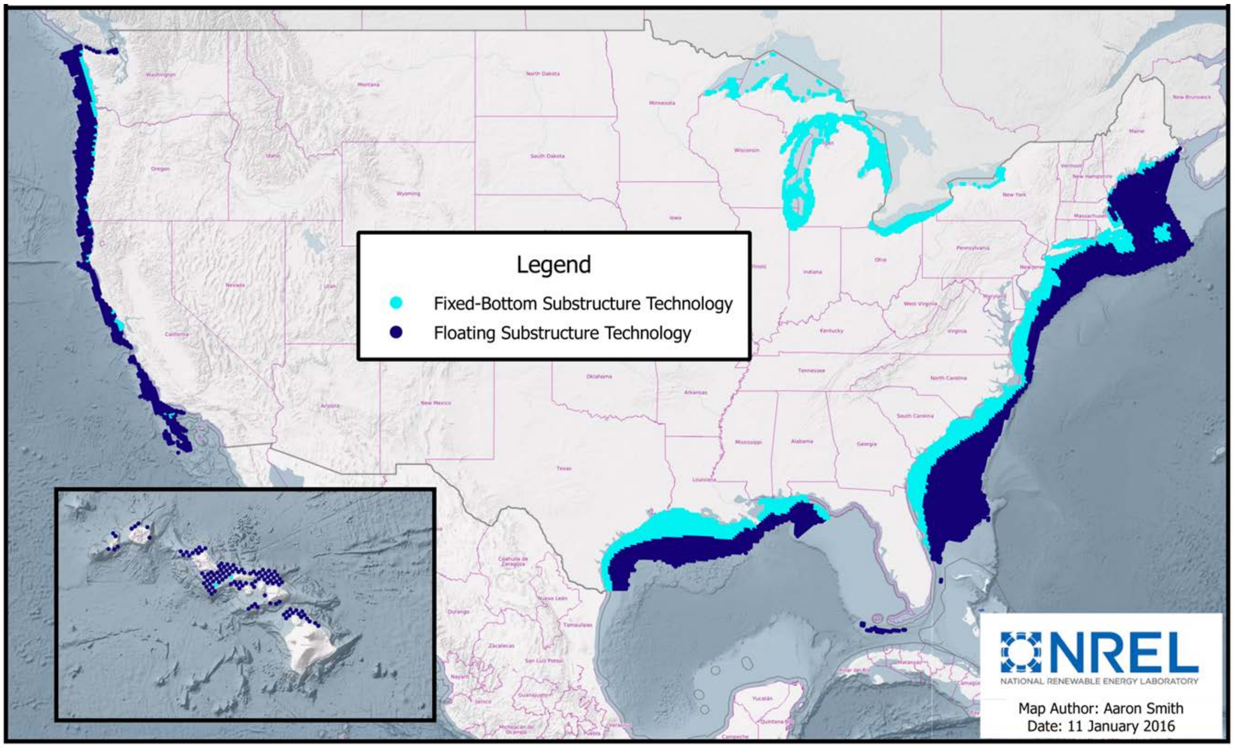

Figure 25. LCOE break points between fixed and floating technologies in the United States for potential offshore wind project locations (2022 COD)

Source: Beiter et al. 2016

As the current technology for floating wind energy matures beyond the single turbine demonstration stage over the next few years, more of this deep-water resource is likely to become part of an evolving commercial market for large floating wind energy projects.

6.2.2 Existing Floating Offshore Wind Projects

To date, only six utility-scale floating offshore turbines have been deployed globally. Because of the precommercial status, the first floating offshore wind turbines were arguably overdesigned, undersized, and not cost optimized. They are shown in the blue shading in Table 29. Their purpose was to prove technical viability, and to that end were successful. The early design approach used methods that were already demonstrated successfully in the offshore oil and gas industry and were modified for wind applications. These early prototypes relied on the use of relatively heavy land-based or fixed-bottom offshore turbines designed as independent subcomponents. The major components of floating offshore wind systems were integrated after the design parameters were already set, allowing only incremental design adjustments to ensure survival of the floating systems. In most cases, construction and maintenance of the floating offshore wind systems were integrated after the core system designs were already fixed. This first wave of floating turbines demonstrated a sufficiently high degree of technological success, but, cost and long-term operational issues were still poorly understood. Appendix B-1 through B-4 provide more information on these early-stage floating wind projects.

6.2.3 Floating Offshore Wind Research Investments

Tracking the level of global research funding is one way to gauge the interest in floating offshore wind technology. Although an accurate record of historic data is not available to derive trends, Figure 26 shows the results of a survey conducted by NREL that focused on offshore wind research spending.

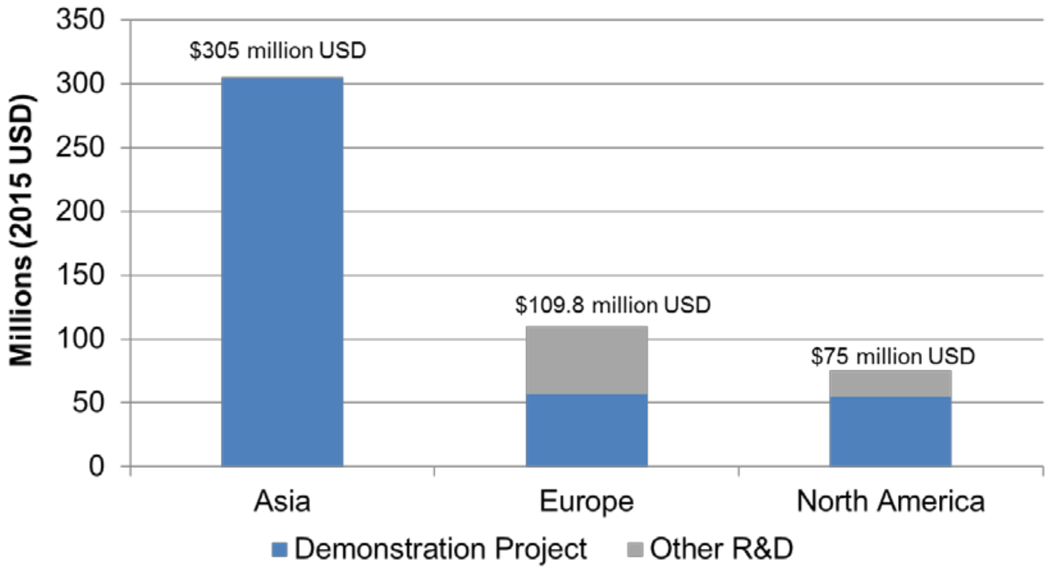

Figure 26. Global estimate of floating wind energy research and development spending between 2013 and December 31, 2015

Source: NREL Offshore R&D Activities Database[86]

Figure 26 shows the level of research dollars that are estimated to have been spent in three regions of the world—Asia, Europe, and North America (mostly by government sources)—between 2013 and 2015. It shows funding for projects that have disclosed their funding amounts, so the totals may be underestimating the actual amount. The funding is broken down into two categories: "demonstration projects" and "other R&D," which include basic and applied research.

R&D funding of $416 million is estimated to have been allocated to nine demonstration projects globally. In the United States, the funding for demonstration projects went to Aqua Ventus I & WindFloat Pacific, funded by DOE under the ATD program.[87]

DOE also devoted $74 million to funding 19 other floating wind R&D projects. Research areas that were funded include floating wind project design, foundation design, foundation testing and

[86] Note: Project list consists of active projects (as of end of 2015 and projects finished after 2013). It does not comprehensively encompass all R&D projects for floating wind technology in all regions. Certain projects without available funding amounts are not accounted for in Figure 26.

[87] Note that Wind Float Pacific received $10.7 million in research funding before leaving the DOE ATD program. Similarly, Aqua Ventus received $10.7 million as of July 2017, but DOE has funds set aside to bring the Aqua Ventus total to $50 million pending the project's completion of established milestones.

evaluation, O&M of floating wind turbines, materials for floating foundations, environmental studies and surveying, and simulation of floating wind projects.

6.2.4 Floating Technology Trends

Market analysis indicates that the future potential for new floating offshore wind is considerable and may eventually exceed the market for fixed-bottom offshore wind energy, based on the resource size and estimates of the cost reduction potential.

The next phase for floating offshore wind technology is the deployment of about 11 projects around the world totaling 229 MW. These are generally multiturbine, precommercial pilot projects with significant committed resources to potentially advance with development. The first of these projects is likely to be the Statoil 30-MW pilot wind farm in the Buchan Deep, located approximately 25 km off the coast of Scotland. This project is under construction as of June 2017 and expected to be commissioned before the end of the year. It is comprised of five 6-MW Siemens wind turbines mounted on Statoil's Hywind 2 spar platforms.

A variety of other pilot projects, similar in size to the Statoil Hywind 2 demonstration in Scotland, are also underway and are individually described in more detail in Appendix B. Collectively, these projects will provide the first commercial industry benchmark for floating offshore wind costs and will help the industry take a necessary step toward cost reduction and bankability.

One way to differentiate the next generation of floating pilot projects from their first generation predecessors is to consider the scale of these projects, which are generally an order of magnitude larger on a power capacity basis. Although the cost per megawatt is expected to drop considerably from the nominal 2-MW prototype phase, these 20- to 30-MW projects are considerably more costly on a total project cost basis and can usually not be financed solely using research funding.[88] Most projects are typically the beneficiaries of some support from government programs that provide funding intended to be leveraged to help garner the balance of the project's financing under more traditional financing methods. These next-generation pilot projects are therefore structured as public/private partnerships to share the risk of this new technology development. The government programs sponsoring these projects include the French Tenders (ADEME 2015) in France, the ATD Projects in the United States (DOE 2012), and direct funding from METI in Japan (Carbon Trust 2014). Because private capital must be raised, each project will be subject to additional due diligence with the expectation of long-term survivability and a predictable revenue stream.

Floating platform types may be a good indicator of technology trends and industry maturation. Platform types have been classified based on their method of achieving static stability as buoyancy stabilized (e.g., semisubmersible, barge), mooring line stabilized (tension-leg platform), or ballast stabilized (spar) (Musial and Ram 2010). In practice, most platforms are hybrids that rely on one dominant method. For example, most semisubmersibles also incorporate ballast for stability. The early-stage designs were limited to semisubmersibles and spars, with

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[88] Pilot project costs for 30-MW-scale projects have been in the range of $300 million USD using the Block Island Wind Farm as an example, although these costs are expected to drop.

semisubmersibles making up the majority of deployed systems. This approach was primarily to simplify installation because semisubmersible platforms could be assembled at quayside, and towed to an offshore site in a stable configuration with minimal concerns about water depths in port or stability during installation. Within the next fleet of floating pilot projects, this trend is likely to continue. Out of the 11 most advanced projects in the pipeline (Table 29), six projects use semisubmersible platforms. However, the first demonstrations of tension-leg platforms are also expected with two pilot projects using technology developed by SBM and GICON. These new tension-leg-platform concepts promise to overcome some of the stability disadvantages by designing configurations that are stable without mooring system connections to facilitate installation and tow-out. In addition, there are two spar concepts underway, by Statoil and an advanced 5-MW spar concept as part of the Fukushima Forward consortium. Finally, Ideol continues to develop their barge concept (similar to the semisubmersible in terms of static stability), in two separate floating projects; the 2-MW Floatgen project and the 24-MW Elomed project awarded as one of the French tenders.

Most of these projects that are under development are being led by platform technology developers with foundational expertise and knowledge in offshore oil and gas and marine operations. Almost all projects continue to use wind turbines that were designed for fixed-bottom applications, and are therefore not optimized for floating platforms.[89] Considerations to minimize weight, control nacelle motion, manage construction and O&M logistics, and maximize floating wind power plant yield have generally not yet been fully addressed. It is likely that turbines optimized for floating platforms will not be available until there is sufficient market visibility in the floating offshore wind pipeline and will require additional cooperation between turbine manufacturers, platform designers, and project developers.

Beyond these pilot-scale floating wind farms, the next phase of floating technology design and development is likely to address the functional requirements of the full system, optimized on a life-cycle cost basis. This future phase of floating turbine development would move toward fully integrated holistic designs. These systems would consider all aspects of development and operation including supply chain utilization, manufacturability of major components, minimizing costly construction bottlenecks, building in maintenance procedures that eliminate major operations and repairs costs, and eventually optimizing the wind turbines themselves.

6.2.5 Floating Cost Trends

The cost of floating wind technology is currently based on a small set of data from the first prototype machines. These baseline costs are relatively high, with initial LCOE estimates exceeding $200/MWh. However, the potential for cost reduction for floating wind is significant. Cost estimates from NREL’s geospatial analysis (Beiter et al. 2016; Gilman et al. 2016) indicate that floating costs may show a steeper rate of cost reduction over the next 15 years with the potential for approaching cost parity with fixed-bottom wind turbine technology. The basis for technology-specific cost reduction potential comes from a range of factors, including (but not limited to) the technology’s ability to:

[89] One exception is the inflow project, which uses the Vertiwind vertical-axis turbine concept. This turbine is under development at subscale and is undergoing land-based testing at a 600-kW scale (4C Offshore 2017).

- Eliminate construction steps
- Take advantage of automated production in fabrication of the floating platforms
- Increase energy production to offset higher costs resulting from harsher conditions and increased O&M at further distances from shore.

For a more detailed discussion of possible methods to reduce cost in floating systems see Beiter et al. (2016). Ultimately, floating system optimization may lead to lighter systems and increased modularity, making better use of existing supply chains (OffshoreWIND.biz 2017e).

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Appendix A. U.S. Offshore Wind Policy Types

Table A1. U.S. Offshore Wind Policy Types and Examples

Policy Type	Existing U.S. Examples
Market Scale & Visibility **These policies determine the minimum or maximum market size for a given technology or set of technologies and provide certainty for developers to make long-term investment decisions. For the offshore wind market, procurement policies and renewables portfolio standard (RPS) carve-outs require a set amount of offshore capacity to be deployed by a certain date. Technologically crosscutting RPSs provides additional clarity about states' goals to deploy renewable energy.**	**Massachusetts's "H.4568"** requires the procurement of 1,600 MW of offshore wind capacity by 2027 and creates a solicitation process for long-term offtake agreements. **New York's Governor Cuomo** committed New York to procuring 2,400 MW of offshore wind by 2030. **Maryland's "HB 226**" requires a maximum of 2.5% of the state's total retail electric sales come from offshore wind sources starting in 2017. Exact yearly totals will be set by the state's Public Service Commission. **New Jersey's Offshore Wind Economic Development Act** mandates that the state develop 1,100 MW of offshore wind capacity and creates offshore renewable energy credits to make it easier for developers to sign offtake agreements. **Rhode Island's RIWINDS Program** has a goal of meeting 15% of Rhode Island's electricity demand with wind energy but has not set a specific date. **California's RPS** requires the state's utilities derive at least 50% of their total sales from renewable energy technologies by 2030. **Hawaii's RPS** requires the state's utilities to provide 100% of their net electricity from renewable energy technologies by 2045.
Offtake Policies **Offtake policies provide codified mechanisms to reduce uncertainty and/or subsidize the cost for utilities signing long-term offtake contracts with offshore wind developers. In the United States, these types of policies have mainly taken the form of organized long-term solicitations or offshore renewable energy credits. Grid connection policies in conjunction with procurement policies provide developers with a high level of transparency and certainty about their ability to construct a project and find a buyer for the project's energy.**	**Massachusetts's** "**H.4568**" requires load-serving entities to conduct competitive long-term contract solicitations every 2 years, starting in June 2017, and allows utilities to pass up to 2.75% of the cost to their rate base. Each subsequent round of offshore wind developers will have to demonstrate lower levelized costs to enter into long-term power purchase agreements.
Incentive Mechanism **Incentives are used to catalyze the growth of nascent industries or markets until they become self-sustaining.**	**U.S. Internal Revenue Service's production tax credit** is an inflation adjusted per kilowatt-hour tax credit awarded for renewable electricity generation. Projects that commence construction after January 1, 2017, will be awarded $0.0184/kilowatt-hour during the first 10 years of operation. IRS Notice 2016-31 provides additional guidance on what constitutes the start of construction. IRS's guidance increases developers' eligibility to receive the production tax credit for 4 years if they start physical construction or spend 5% of the project's total costs. The credit decreases by 20% each year before expiring in 2020. **U.S. Internal Revenue Services' investment tax credit** provides a 30% tax credit on a renewable energy project's capital costs. Both wind and solar are eligible to claim this credit. For wind projects larger than 100

Policy Type	Existing U.S. Examples
	kilowatts, the investment tax credit decreases in value by 6% annually and expires in December 31, 2020. The IRS also has additional guidance on what constitutes construction activities for the investment tax credit.
Regulatory Support **Regulatory support policies encourage collaboration between various types of government organizations and stakeholders to accelerate and reduce uncertainty in the site selection, environmental review, and auction processes.**	**BOEM's "Smart from the Start " initiative** works with state-level task forces to identify sites with the highest amount of resource potential and the lowest number of potential use conflicts in an effort to reduce costs, provide additional certainty, and streamline the offshore wind leasing process.
Supply Chain Development **Supply chain development policies focus on catalyzing capital investment in port infrastructure, manufacturing, maritime assets, and workforce development for the offshore wind industry.**	**Maryland's offshore renewable energy credit** award requires recipients to invest $76 million in a steel fabrication plant in Maryland, $39.6 million in port infrastructure upgrades, and $6 million in the Maryland Offshore Business Development Fund. **The Massachusetts Clean Energy Center** upgraded the New Bedford Marine Commerce Terminal for offshore wind activities.
Innovation Support **Research and development policies are used to improve the efficiency and drive down the cost of offshore wind systems. In some instances, these policies can be used to reduce technological risk by supporting the evaluation and validation of new offshore wind components or systems (e.g., floating platforms).**	**Maine's LD 1465** created University of Maine's Deepwater Offshore Test Site to evaluate floating substructures in real-world conditions. **The Massachusetts Clean Energy Center and the U.S. Department of Energy** funded the Wind Technology Testing Center in Boston to test new blade designs that can improve reliability and reduce project costs. **The Massachusetts Clean Energy Center's** Renewable Energy Trust funded three offshore wind analyses focused on workforce training, blade integrity, and project/component cost reductions. **The Bureau of Ocean Energy Management and the Bureau of Safety and Environmental Enforcement's Technology Assessment Program** funds research and development that supports industry development and improves operational efficiency, safety, and pollution prevention. **The U.S. Department of Energy's advanced technology demonstration program** supports the validation of the latest offshore wind technologies by working with developers to deploy full-size demonstration projects in the field. **The U.S. Department of Energy's Wind Energy Technologies Office** funds energy science research and development to enable innovations that drive down offshore wind system costs, eliminate market barriers, and minimize siting and environmental impacts.

Appendix B. Floating Projects

Existing Floating Offshore Wind Projects

B-1 Hywind 1 Demo

The Hywind demonstration project is the world's first full-scale floating wind system. Deployed in 2009, the single 2.3-megawatt (MW) system is still producing energy today. As the first project deployed, Hywind had to overcome many obstacles and uncertainties. A spar platform was used to simplify construction and build on the knowledge Statoil gained from the oil and gas industry. A novel control system was developed to ensure stability of the floating system during pitch-motion excursions that could induce instabilities when using a land-based wind control system. The system was designed to endure the harsh conditions of its location in the North Sea, surviving a 100-year extreme condition in 2011.

Figure B1. Statoil's 2.3-MW Hywind 1 demonstration turbine during loadout in 2009

Source: Photo by Siemens AG, NREL 27845

Table B1. Details of the Hywind Demo Project

Developer	Statoil
Location	Rogaland, Norway
Turbine	Siemens SWT-2.3
No. of Turbines	1
Rotor Diameter	82.4 meters (m)
Hub Height	65 m
Platform	Spar
Draft	100 m
Displacement	5,000 m^3
Distance to Shore	10 km
Water Depth	210 m
Year Deployed	2009

B-2 Hywind Scotland Pilot Park

Following the success of the Hywind demonstration project, Statoil was awarded an exclusivity agreement by The Crown Estate to develop a pilot wind farm in the Buchan Deep, located approximately 25 kilometers (km) off the coast of Scotland. The project is expected to be commissioned in 2017, making it the first multiunit floating wind farm. It will include five 6-MW Siemens wind turbines that will be mounted on the Hywind 2 spar platform. Hywind 2 is a similar spar platform to that used in the Hywind demonstration project in 2009, but has been optimized to be lighter with a shallower draft (that is, the length of the buoy that is submerged under the water), for lower cost and greater siting potential. Installation methods have also been updated to lower costs compared to the original Hywind 1 demonstration project. This project is counted as an "existing project" but it will not actually be commissioned until later in 2017.

Table B2. Details of the Hywind Scotland Pilot Park Project

Developer	Statoil
Location	Peterhead, Aberdeenshire, Scotland, United Kingdom
Turbine	Siemens SWT-6.0-154
No. of Turbines	5
Rotor Diameter	154 m
Hub Height	101 m
Platform	Spar
Draft	Not applicable (NA)
Displacement	NA
Distance to Shore	25 km
Water Depth	95–120 m
Estimated Commercial Operation Date	2017

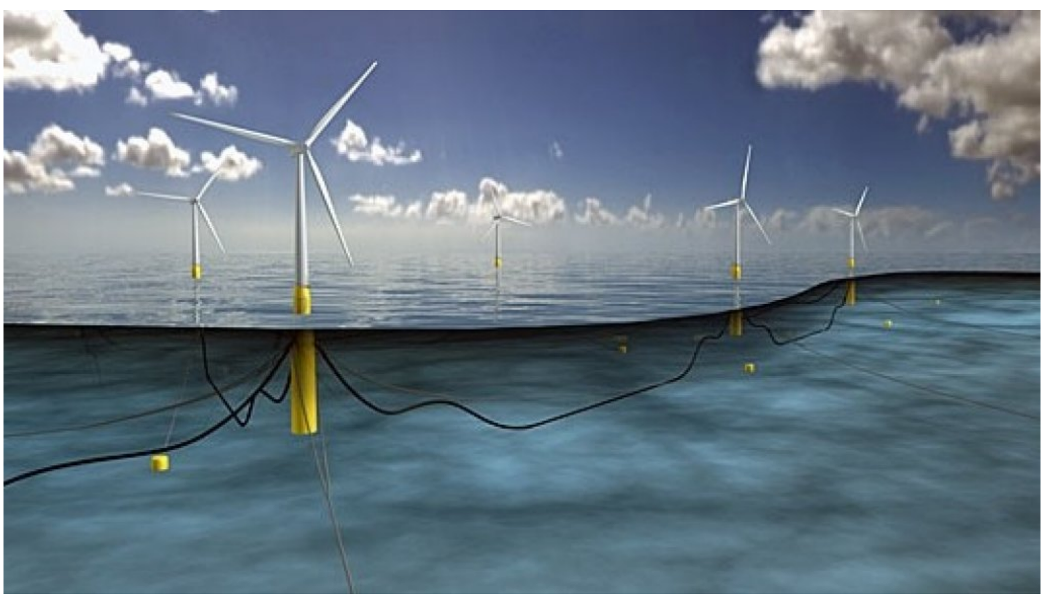

Figure B2. Hywind 2 30-MW demonstration project to be commissioned in Scotland in 2017

Source: Statoil

B-3 WindFloat I Prototype

The 2-MW WindFloat demonstration project was deployed in 2011 in Portugal. It was the second full-scale floating wind system deployed in the world. The system was completely assembled and commissioned at quayside, and then towed at sea over 400 km to its installation site. The structure is a three-column semisubmersible, with an active ballast system in the columns to keep the mean pitch offset of the structure near zero degrees to maximize power capture. WindFloat operated successfully for 5 years, and was decommissioned in July 2016.

Table B3. Details of the WindFloat I Prototype Project

Developers	Principle Power, Damen Shipyards, WavEC, LNEG, ISQ, Caixa, SgurrEnergy, National Renewable Energy Laboratory (NREL), WindPlus
Location	Norte, Portugal
Turbine	Vestas V80-2.0
No. of Turbines	1
Rotor Diameter	80 m
Hub Height	NA
Platform	Semisubmersible
Draft	NA
Displacement	NA
Distance to Shore	5 km
Water Depth	50 m
Years Deployed	December 2011–2016

Figure B3. WindFloat I Prototype on station in Portugal—deployed 2011–2016

Source: Principal Power Inc.

B-4 Fukushima Forward

The Fukushima offshore wind consortium, funded by the Japanese Ministry of Economy, Trade and Industry, developed three separate floating wind systems (illustrated in Figure B4) over a span of 3 years and two separate phases. In Phase I (2013), a traditional three-column semisubmersible called the Mirai system was deployed with a 2-MW Hitachi downwind turbine, along with a 25-megavolt Ampere floating spar substation located approximately 20 km southeast of the Fukushima nuclear power plant. Phase II (2014–2015) then introduced two new systems: a V-shaped semisubmersible called the Shinpuu that supports a Mitsubishi Heavy Industries (MHI) 7-MW turbine, and an advanced spar called the Hamakaze that supports a 5-MW downwind Hitachi turbine. Full power generation is expected in 2017 (4C Offshore 2017).

Table B4. Fukushima Forward Project

Developers	Marubeni Corporation, University of Tokyo, Mitsubishi Heavy Industries, Japan Marine United, Mitsui Engineering and Ship Building, Nippon Steel Corporation, Hitachi, Furukawa Electric, Shimizu Corp., Mizuho Information and Research
Location	Fukushima, Japan
Turbine	2-MW Hitachi downwind, 7-MW MHI, 5-MW Hitachi downwind
No. of Turbines	3 (one of each type)
Rotor Diameter	80 m, 164 m, 126 m
Hub Height	65 m, 105 m, 86 m
Platform	Semisubmersible, V-shape semisubmersible, advanced spar
Draft	16 m, 17 m, 33 m
Displacement	Unknown, 10,000 t, 8,000 t
Distance to Shore	20 km
Water Depth	120 m
Years Deployed	2013, 2015, 2016

Figure B4. Fukushima Phase 1 and 2 turbines from 2013 to 2016

Source: Windfair 2015

B-5 Kabashima/Goto Spar

Prior to the development of the Fukushima project, the 2-MW Goto spar, funded by the Japanese Ministry of Environment, was deployed off Goto Island in the Kabashima area off the southwest coast of Japan. This one-turbine demonstration used a concrete spar structure with a Hitachi 2-MW downwind turbine. This turbine was installed in the fall of 2013 and was the first commercial-scale floating wind turbine in Japan. It operated for 3 years but was expected to be decommissioned in 2016. Its current status has not been confirmed.

Table B5. Details of the Kabashima/Goto Spar Project

Developers	Toda Corporation, Kyoto University, Fuji Heavy Industries, Fuyo Ocean Development & Engineering
Location	Kabashima, Japan
Turbine	Subaru 80/2.0
No. of Turbines	1
Rotor Diameter	80 m
Hub Height	56 m
Platform	Spar
Draft	100 m
Displacement	3,400 tons
Distance to Shore	10 km
Water Depth	96 m
Year Deployed	2013–2016

Figure B5. Kabashima spar near Goto Island in 2014

Source: Walt Musial, NREL

Floating Wind Projects Under Development

B-6 WindFloat Atlantic

After the successful demonstration of the 2-MW WindFloat prototype, Principle Power is planning multiple new projects. The project that is most likely to be commissioned next is a three-unit 25-MW wind farm with an updated version of the WindFloat I prototype semisubmersible design in Portugal. The project, which has now been approved for deployment in Viana do Castelo, Portugal, plans to use the new MHI Vestas 8.33-MW turbine. A follow-on commercial phase of this project is expected, with a deployment of 30 turbines, producing 150 MW of power.

Table B6. Details of the WindFloat Atlantic Project

Developers	Principle Power, WindPlus, Energias de Portugal (EDP)
Location	Viana do Castelo, Portugal
Turbine	MHI Vestas V164-8.33
No. of Turbines	3
Rotor Diameter	164 m
Hub Height	112 m
Platform	Semisubmersible
Draft	NA
Displacement	NA
Distance to Shore	20 km
Water Depth	100 m
Estimated Commercial Operation	2018

B-7 Dounreay Trì

The Dounreay Trì project is a demonstration project in Inverness, Scotland, showcasing the first multiturbine support structure. The platform is a three-column semisubmersible with a 5-MW turbine placed on each of the two back columns. The system is moored using a turret bearing, allowing the system to freely rotate into the wind. The two 5-MW turbines will be produced by CSIC Haizhuang Windpower. Construction of the system began in March 2017, and is expected to be completed in 2018.

Table B7. Details of the Dounreay Trì Project

Developers	Hexicon AB
Location	Inverness, Scotland, United Kingdom
Turbine	H 151-5MW
No. of Turbines	2
Rotor Diameter	151 m
Hub Height	124 m
Platform	Semisubmersible
Draft	15 m
Displacement	NA
Distance to Shore	9 km
Water Depth	75 m
Estimated Commercial Operation	2018

B-8 Kincardine

The 49.2-MW Kincardine offshore wind farm is under development about 15 km off Scotland's coastline. The project will contain a total of eight 6.15-MW Senvion wind turbines, making it the largest near-term floating wind pilot project (4C Offshore 2017b). The support structure is a novel spar/semisubmersible hybrid developed by Cobra. It consists of a central cylinder and three outer cylinders, similar to a traditional semisubmersible. A lower slab and solid ballast tanks at the bottom of the structure lower the center of gravity, giving it ballast-stabilizing attributes similar to a spar. The system will also have active ballasting to decrease the tilt angle during operation.

Table B8. Details of the Kincardine Project

Developers	Kincardine Offshore Windfarm, Pilot Offshore Renewables, Atkins
Location	Aberdeenshire, Scotland, United Kingdom
Turbine	Senvion 6.2M126
No. of Turbines	8
Rotor Diameter	126 m
Hub Height	107 m
Platform	Semisubmersible/spar hybrid
Draft	NA
Displacement	NA
Distance to Shore	15 km
Water Depth	62 m
Estimated Commercial Operation	2018

B-9 Elomed (Gruissan) French Tender

The French government is sponsoring the development of the 24.6-MW Elomed Gruissan project to be located 15 km into the Mediterranean Sea near Gruissan, France. It is comprised of up to four 6.15-MW turbines. This project will use the barge substructure developed by Ideol, which uses a central moon pool (see Figure B6) to help damp the motion of the floating structure.

Table B9. Details of the EolMed Gruissan French Tender Project

Developers	Quadran, Senvion, Ideol
Location	Gruissan, France
Turbine	Senvion 6.2M152
No. of Turbines	4
Rotor Diameter	152 m
Hub Height	NA
Platform	Barge
Draft	NA
Displacement	NA
Distance to Shore	20 km
Water Depth	50–72 m
Estimated Commercial Operation	2021

Figure B6. EolMed Gruissan floating wind project under French Tender

Source: Ideol/Bouygues Travaux Publics

B-10 Les éoliennes flottantes de Groix & Belle-Île (La Groix) French Tender

The 24-MW Groix offshore wind pilot project—another of the four French tender projects—will be located in the Atlantic Ocean. It will use a three-legged floating semisubmersible developed by DCNS. There will be four substructures each supporting a GE Haliade 6-MW wind turbine. Figure B9 provides details on one of these systems.

Table B10. Details of the Les éoliennes flottantes de Groix & Belle-Île (La Groix) French Tender Project

Developers	CGN, Eolfi, Alstom, DCNS, Vinci
Location	Groix, France
Turbine	GE Haliade 150-6MW
No. of Turbines	4
Rotor Diameter	150 m
Hub Height	NA
Platform	Semisubmersible
Draft	NA
Displacement	NA
Distance to Shore	22 km
Water Depth	54–71 m
Estimated Commercial Operation	2020

B-11 Provence Grand Large (Faraman) French Tender

The 24-MW Provence Grand Large offshore wind project is another of the French tender awards, and will be located near Faraman, France, approximately 22 km into the Mediterranean Sea. The Provence Grand Large project will use three 8-MW Siemens wind turbines. The support structure is a tension-leg platform, developed by SBM. The substructure design is unique, using a light, modular solution with angled, tensioned mooring lines to limit both rotational and translational motion (Figure B7). The angled lines also create a rotation point for the system above the nacelle, limiting the amount of turbine acceleration.

Table B11. Details of the Provence Grand Large (Faraman) French Tender Project

Developers	EDF Energies Nouvelles, SBM
Location	Faraman, France
Turbine	Siemens SWT-8.0-154
No. of Turbines	3
Rotor Diameter	154
Hub Height	NA
Platform	Tension-leg platform
Draft	NA
Displacement	NA
Distance to Shore	22 km
Water Depth	94–104 m
Year Deployed	2020

Figure B7. Illustration of SBM Offshore wind turbine system to be deployed in the Provence Grand Large project under the French tender at Faraman, France

Source: SBM Offshore

B-12 Les eoliennes flottantes du Golf du Lion (Leucate) French Tender

The 24-MW Leucate floating offshore wind project is the final project awarded under the 2015 French tenders, and is located near Leucate, France, in the Mediterranean Sea. This project uses four GE Haliade 6-MW turbines on the WindFloat semisubmersible substructure described earlier.

Table B12. Details of the Les eoliennes flottantes du Golf du Lion (Leucate) French Tender Project

Developers	Engie, EDP, Caisse des Depots and Eiffage, Alstom
Location	Leucate, France
Turbine	GE Haliade 150-6MW
No. of Turbines	4
Rotor Diameter	150 m
Hub Height	NA
Platform	Semisubmersible
Draft	NA
Displacement	NA
Distance to Shore	21 km
Water Depth	57–84 m
Estimated Commercial Operation	N/A

Figure B8. The WindFloat prototype with the substructure technology that will be used to support 6-MW Haliade turbines for the Les eoliennes flottantes du Golf du Lion (Leucate) floating project

Source: Principle Power Inc.

B-13 New England Aqua Ventus I

The New England Aqua Ventus I project is one of the two advanced technology demonstration projects being supported by the U.S. Department of Energy. The project follows the deployment in 2012 of a 1:8 scale VolturnUS turbine, which was the first grid-connected offshore wind turbine in the United States. The support structure is a three-column semisubmersible, made with concrete to extend its life and better utilize local content and manufacturing.

Table B13. Details of the New England Aqua Ventus I Project

Developers	Maine Aqua Ventus I (University of Maine, Cianbro, DCNS)
Location	Monhegan Island, Maine, United States
Turbine	6 MW
No. of Turbines	2
Rotor Diameter	TBD
Hub Height	N/A
Platform	Semisubmersible
Draft	N/A
Displacement	N/A
Distance to Shore	21 km
Water Depth	61–110 m
Estimated Commercial Operation	2019

Figure B9. Illustration of the New England Aqua Ventus I offshore wind turbine system awarded under the advanced technology demonstration projects

Source: University of Maine

B-14 FLOATGEN

Floatgen is a floating demonstration project funded through the European Union's Horizon 2020 consortium. The goal of the project is to prove the technical, economic, and environmental feasibility of floating wind technologies. The project includes one 2-MW Vestas turbine installed on the Ideol barge platform. Work has begun on this project, and is expected to be completed by 2018 (4C Offshore 2017c).

Table B14. Details of the FLOATGEN Project

Developers	Gamesa, Ideol, ECN, Zabala Innovation, University of Stuttgart, Fraunhofer IWES, RSK Environment
Location	France
Turbine	Vestas V80-2MW
No. of Turbines	1
Rotor Diameter	80 m
Hub Height	NA
Platform	Barge
Draft	NA
Displacement	NA
Distance to Shore	22 km
Water Depth	30 m
Estimated Commercial Operation	2018

B-15 GICON Pilot

Germany's first venture into floating wind involves the GICON pilot project. GICON has been developing a floating tension-leg platform over several years, and has validated the technology based on multiple tank testing campaigns. Tension-leg platforms are less common than other platform types but have the advantages of lower weight and less system motion (see SBM tension-leg platform in Appendix B-11). The disadvantage of tension-leg platform designs is the potentially more complex and risky installation procedure. These issues are being addressed in the next-generation designs. The GICON project was put on hold in 2016, but new activity gives the project a deployment trajectory. GICON representatives say that permits and contracts are in place for adding the GICON-SOF with a 2.3-MW turbine to the existing Baltic1 wind farm as an additional commercially operating turbine. The unique tension-leg platform substructure is reported to be under construction and is planned to be installed and commissioned in 2018. In addition, a next-generation development of the "SOF" design utilizing modular steel-reinforced concrete components is ongoing, with scale model tests scheduled for late 2017 and an anticipated installation of a 6-8 MW pilot plant in 2019.

Table B15. Details of the GICON Pilot Project

Developers	GICON
Location	Germany
Turbine	Siemens SWT-2.3
No. of Turbines	1
Rotor Diameter	93 m
Hub Height	NA
Platform	Tension-leg platform
Draft	NA
Displacement	NA
Distance to Shore	21 km
Water Depth	18 m
Estimated Commercial Operation	2018

Figure B10. Illustration of the GICON-SOF floating offshore wind turbine system under development in Germany

Source: GICON

Appendix C. Cape Wind Overview

In 2001, Cape Wind Associates LLC became the first company to apply for an offshore wind lease in the United States. Although the Cape Wind project had many supporters, it experienced a number of legal challenges that crippled the project. Nevertheless, Cape Wind was truly a groundbreaking project, which paved the way for many of the offshore wind projects in the United States today. When Cape Wind Associates applied for an offshore lease permit from the U.S. Army Corps of Engineers, there was no precedent for the regulation of offshore wind energy. Their application challenged numerous agencies that lacked any energy expertise and raised questions nationally about how the United States should proceed with renewable energy development on the Outer Continental Shelf. Motivated by the Cape Wind project, Congress assigned regulatory authority for renewable energy development on the Outer Continental Shelf to the U.S. Department of the Interior's Minerals Management Service under the *Energy Policy Act of 2005*. This policy required Cape Wind Associates to reapply for a commercial lease in 2005. In 2009, the Department of the Interior released their final regulations (30 CFR 585) for leasing renewable projects on the Outer Continental Shelf and issued their first commercial lease for an offshore wind farm to Cape Wind shortly after in 2010. However, the project was fraught with public concerns about its conflicts with tourism on Cape Cod as well as its presence within the viewshed of many prominent community stakeholders. From 2003 to 2014, a number of groups primarily led by the Alliance to Protect Nantucket Sound initiated 23 lawsuits against Cape Wind Associates to prevent the development of the Cape Wind project. The lawsuits drained Cape Wind of capital, created significant projects delays, and increased risk to make financing more difficult. In January 2015, National Grid and NSTAR dissolved their contracts with Cape Wind because the project missed deadlines to obtain financing and begin construction or post financial collateral to extend the deadline (McNamara 2015). Regardless of the final outcome, Cape Wind Associates were pioneers for the U.S. offshore wind industry. The company propelled offshore wind into the federal spotlight, accelerating the development of formal offshore wind site assessment, environmental evaluation, and federal leasing procedures. The lessons learned from leasing the Cape Wind site helped streamline the Bureau of Ocean Energy Management's "Smart from the Start" leasing process by providing valuable experience and practical knowledge about offshore wind. Others have also benefited from Cape Wind, using the project as a case study to avoid facing the similar regulatory, legal, and financial obstacles.

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