



U.S. DEPARTMENT OF  
**ENERGY**

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**ENERGY EFFICIENCY &  
RENEWABLE ENERGY**

# 2018 **Offshore Wind Technologies Market Report**

## EXECUTIVE SUMMARY

# 2018 Offshore Wind Technologies Market Report

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## Executive Summary

Offshore wind energy is a rapidly growing global industry that creates electricity from wind turbines installed in coastal waters on either rigid or floating substructures anchored to the seabed or lake bottom. The *2018 Offshore Wind Technologies Market Report* was developed by the National Renewable Energy Laboratory (NREL) with support from the U.S. Department of Energy (DOE) and is intended to provide offshore wind policymakers, regulators, developers, researchers, engineers, financiers, supply chain participants, and other stakeholders with up-to-date quantitative information about the offshore wind market, technology, and cost trends in the United States and worldwide. This report provides detailed information on the domestic offshore wind industry to contextualize the U.S. market and help policymakers, researchers, and the general public understand technical and market barriers and opportunities. Globally, the scope of the report covers the status of the 176 operating offshore wind projects through December 31, 2018, and provides the status of, and analysis on, a broader global pipeline of 838 projects in various stages of development.<sup>1</sup> To provide the most up-to-date discussion of this dynamically evolving industry, this report also tracks the most significant domestic developments and events from January 1, 2018, through March 31, 2019. The following is a summary of the key offshore wind market findings.

### U.S. Offshore Wind Energy Market—Key Findings

**The U.S. offshore wind energy project development and operational pipeline<sup>2</sup> grew to a potential generating capacity of 25,824 megawatts (MW), with 21,225 MW under exclusive site control.<sup>3</sup>** The overall size of the U.S. offshore wind pipeline grew from 25,464 MW to 25,824 MW in 2018—about 1.4% growth (see Table ES-1, whose numbers correspond with those shown in Figure ES-1, a map of offshore wind pipeline activity as of March 31, 2019, as well as BOEM Call Areas, for the entire United States). The 25,824 MW that make up the U.S. offshore wind project development and operating pipeline comprise one operating project (Block Island Wind Farm), eight projects that have reached the permitting phase with either a construction and operations plan or a viable offtake mechanism for sale of electricity, 15 commercial lease areas in federal waters with exclusive site control, two unleased wind energy areas, and five projects (all Pacific-based) that have submitted unsolicited applications to the Bureau of Ocean Energy Management (BOEM),<sup>4</sup> the government agency that regulates energy development in federal waters. The pipeline has three projects located in state waters, including the operating Block Island Wind Farm, the Aqua Ventus I floating-wind project in Maine, and the Lake Erie Energy Development Corporation Icebreaker Wind project on Lake Erie. In addition, there is one BOEM research lease in Virginia federal waters.

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<sup>1</sup> Note that the *2016 Offshore Wind Technologies Market Report* covered operating projects through June 30, 2017, with a focus on developments in 2016 and the first half of 2017 (Musial et al. 2017).

<sup>2</sup> The project development and operational pipeline, commonly referred to as “the pipeline,” is represented by the database that the National Renewable Energy Laboratory uses to monitor the progress of the commercial offshore wind industry. It includes sites under development as well as operating projects. In the United States, the pipeline does not include Call Areas because their boundaries are not fixed. Unleased wind energy areas in the United States are included because they have a defined area.

<sup>3</sup> 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.

<sup>4</sup> A lease area is a parcel of ocean area that is auctioned to prospective developers. Wind energy areas can comprise one or more lease areas. A Call Area is a precursor to a wind energy area.

Table ES-1 2018 U.S. Offshore Wind Pipeline

#	Location <sup>1</sup>	Project Name <sup>2</sup>	Status	COD <sup>3</sup>	Announced Capacity (MW) <sup>4</sup>	Lease Area Potential (MW) <sup>5</sup>	Pipeline Capacity (MW) <sup>6</sup>	Lease Area	Size (km <sup>2</sup> ) <sup>7</sup>	Offtake (MW)	Developer(s)
1	ME	New England Aqua Ventus I	Permitting	2022	12	0	12	State Lease	9	ME-12	Aqua Ventus
2	MA	Bay State Wind	Site Control	-	0	2,277	2,277	OCS-A 0500	759	TBD	Ørsted/Eversource
3	MA	Vineyard Wind + Residual <sup>8</sup>	Permitting	2023	800	1,225	2,025	OCS-A 0501	675	MA-800	Avangrid/CIP
4	MA	Equinor (MA)	Site Control	-	0	1,564	1,564	OCS-A 0520	521	TBD	Equinor
5	MA	Mayflower Wind Energy	Site Control	-	0	1,547	1,547	OCS-A 0521	516	TBD	EDPR/Shell
6	MA	Liberty Wind	Site Control	-	0	1,607	1,607	OCS-A 0522	536	TBD	Avangrid/CIP
7	RI	Block Island Wind Farm	Installed	2016	30	0	30	State Lease	10	RI-30	Ørsted/Eversource
8	RI	South Fork	Permitting	2022	130	0	130	OCS-A 0486	395	NY-130	Ørsted/Eversource
9	RI	Revolution	Permitting	2023	700	0	700	OCS-A 0486		CT-300 RI-400	Ørsted/Eversource
10	RI	Deepwater ONE North	Site Control	-	0	355	355	OCS-A 0486		TBD	Ørsted/Eversource
11	RI	Deepwater ONE South	Site Control	-	0	816	816	OCS-A 0487	272	TBD	Ørsted/Eversource
12	NY	Empire Wind	Site Control	-	0	963	963	OCS-A 0512	321	TBD	Equinor
13	NY	Fairways North	BOEM Call Area	-	-	-	-	N/A	-	-	-
14	NY	Fairways South	BOEM Call Area	-	-	-	-	N/A	-	-	-
15	NY	Hudson North	BOEM Call Area	-	-	-	-	N/A	-	-	-
16	NY	Hudson South	BOEM Call Area	-	-	-	-	N/A	-	-	-
17	NJ	Atlantic Shores Offshore Wind	Site Control	-	0	2,226	2,226	OCS-A 0499	742	TBD	EDF/Shell
18	NJ	Ocean Wind	Site Control	-	0	1,947	1,947	OCS-A 0498	649	TBD	Ørsted
19	DE	Garden State Offshore Energy	Site Control	-	0	1,050	1,050	OCS-A 0482	284	TBD	Ørsted
20	DE	Skipjack	Permitting	2023	120	0	120	OCS-A 0519	107	MD-120	Ørsted
21	MD	US Wind + Residual <sup>8</sup>	Permitting	2023	248	718	966	OCS-A 0490	322	MD-248	US Wind
22	VA	Coastal Virginia Offshore Wind	Permitting	2022	12	0	12	OCS-A 0497	9	VA-12	Ørsted/Dominion Energy
23	VA	Dominion	Site Control	-	0	1,371	1,371	OCS-A 0483	457	TBD	Dominion Energy
24	NC	Kitty Hawk	Site Control	-	0	1,485	1,485	OCS-A 0508	495	TBD	Avangrid
25	NC	Wilmington East WEA	Unleased <sup>9</sup>	-	0	1,623	1,623	N/A	209	-	-
26	NC	Wilmington West WEA	Unleased <sup>9</sup>	-	0	627	627	N/A	541	-	-
27	SC	Grand Strand	BOEM Call Area	-	-	-	-	N/A	-	--	-
28	SC	Winyah	BOEM Call Area	-	-	-	-	N/A	-	-	-
29	SC	Cape Romain	BOEM Call Area	-	-	-	-	N/A	-	-	-
30	SC	Charleston	BOEM Call Area	-	-	-	-	N/A	-	-	-
31	OH	Icebreaker	Permitting	2022	21	0	21	State Lease	10	OH-21	LEEDCo/Fred Olsen
32	CA	Diablo Canyon	BOEM Call Area	-	-	-	-	-	-	-	-
33	CA	Morro Bay	BOEM Call Area	-	-	-	-	-	-	-	-
34	CA	Castle Wind	Unsolicited Project Application	-	0	1,000	1,000	N/A	334	TBD	Trident Winds/EnBW
35	CA	Humboldt	BOEM Call Area	-	-	-	-	-	-	-	-
36	CA	Redwood Energy	Unsolicited Project Application	-	0	150	150	N/A	50	TBD	EDPR/PPI
37	HI	Oahu South	BOEM Call Area	-	-	-	-	-	-	-	-
38	HI	AWH Oahu South	Unsolicited Project Application	-	0	400	400	N/A	133	TBD	AW Wind
39	HI	Progression	Unsolicited Project Application	-	0	400	400	N/A	133	TBD	Progression Wind
40	HI	Oahu North	BOEM Call Area	-	-	-	-	-	-	-	-
41	HI	AWH Oahu North	Unsolicited Project Application	-	0	400	400	N/A	133	TBD	AW Wind

**Total** 2,073 MW 23,751 MW 25,824 MW

1. Location refers to physical location of the project. The offtake column identifies where the project sells its power and other attributes.  
 2. Some project names may change based on successful bids to state procurement solicitations  
 3. Future commence operation dates are subject successfully negotiating offtake agreement and may change  
 4. Announced capacity describes the size of a project as stipulated by a developer to regulators  
 5. Lease Area Potential describes the potential capacity that could be installed in a lease area using a 3MW/km<sup>2</sup> density  
 6. Pipeline capacity represents the lease area potential minus any developer announced capacity  
 7. Sizes for Unsolicited Project Applications are likely to change during stakeholder and regulatory review processes and may be eliminated in the future  
 8. Lease areas can often accommodate multiple projects or project phases built incrementally. The “+ Residual” refers to remaining space in the lease area that may be utilized in the future  
 9. The two Wind Energy Areas in North Carolina have currently not been leased by BOEM

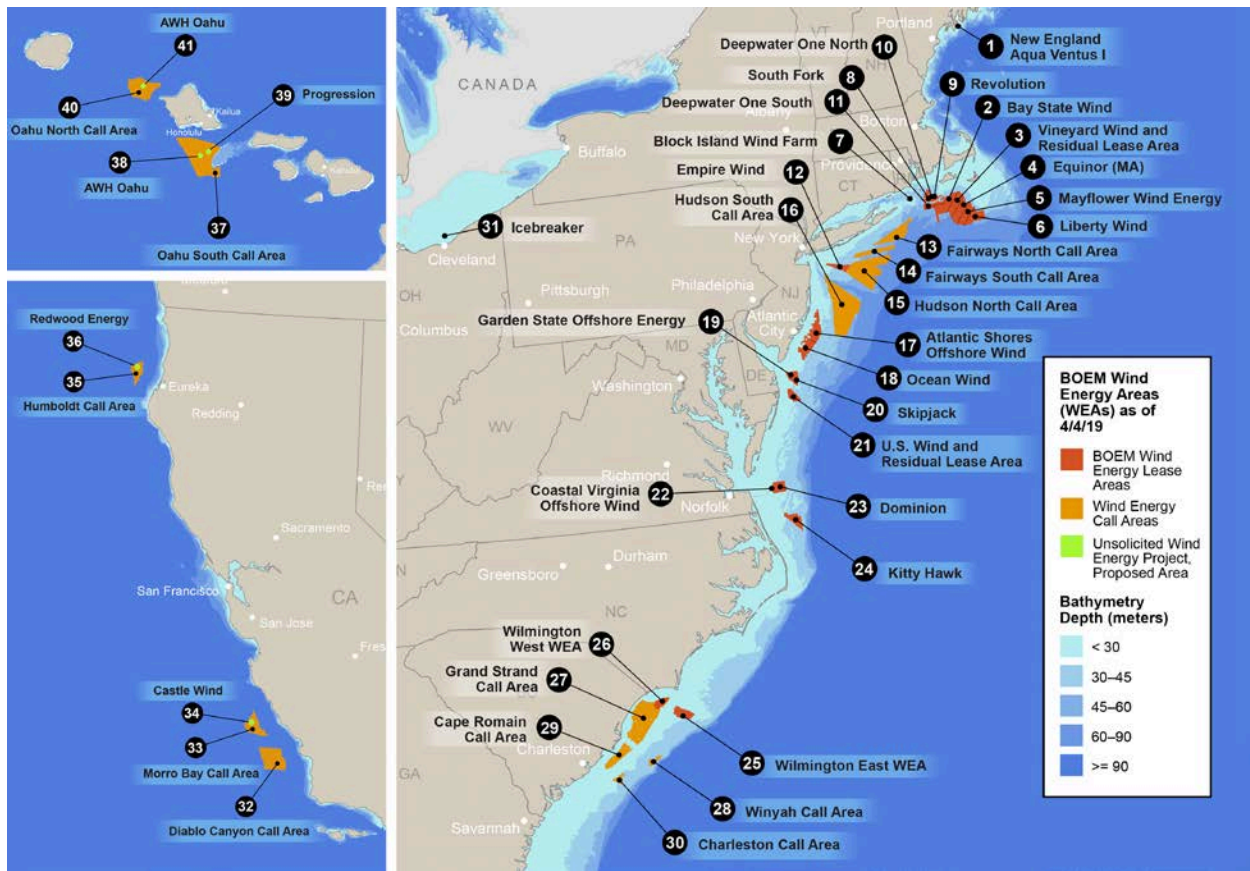


Figure ES-1. Locations of U.S. offshore wind pipeline activity and Call Areas as of March 2019. Map provided by NREL

**Offshore wind project development and regulatory activities span multiple U.S. regions.** Historic development and regulatory activities were concentrated in the North Atlantic region from Virginia northward. New offshore wind activities have been initiated in the Pacific, Great Lakes, and South Atlantic regions as well. In the past, there have been project proposals and leasing activity in the Gulf of Mexico that have been limited to Texas state waters, but in 2018 offshore wind development and regulatory activity in this region was inactive.

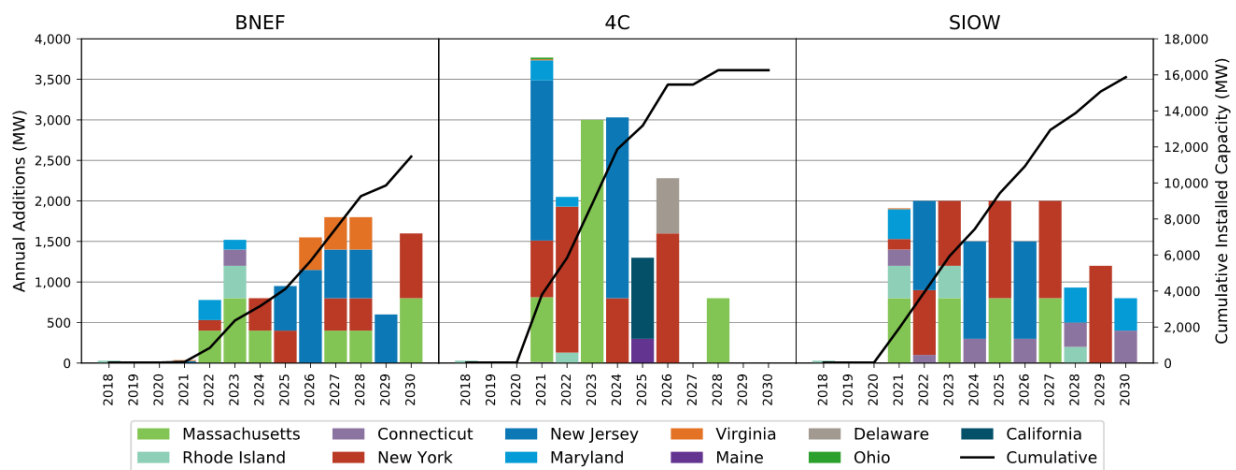
**State-level policy commitments accelerated, driving increased market interest.** At the end of 2017, U.S. offshore state wind procurement policies totaled over 5,300 MW targeted for deployment by 2030. By early 2019, the sum of official state offshore wind capacity commitments increased to 19,968 MW by 2035. In 2018, new commitments were added in Massachusetts (additional 1,600 MW authorized by 2035), New York (6,600 MW added by 2035), and New Jersey (2,400 MW added by 2030), while Connecticut and Rhode Island both agreed to purchase power from Ørsted’s 600-MW Revolution project. In 2019, new policy commitments were enacted in Connecticut (2,000 MW) and Maryland (1,200 MW). In some states without offshore-wind-specific targets, like California and Hawaii, 100% renewables portfolio standards and carbon reduction policies are driving these markets, which are progressing toward the creation of new offshore wind lease areas.

**Increased U.S. market interest spurred strong competition at offshore wind lease auctions.** BOEM auctioned a total of 1,573 square kilometers (km<sup>2</sup>), an area about half the size of Rhode Island, in three adjacent offshore wind lease areas off Massachusetts in December 2018. Each winner (Equinor, Mayflower Wind, and Vineyard Wind) submitted a bid of \$135 million, more than tripling the previous lease area sale price record for a single lease area of \$42 million in 2016 for the New York lease area submitted by Equinor. Higher offshore wind lease sale prices indicate 1) increased confidence in future market growth driven by state policies, 2) confidence in the regulatory and financial institutions to support offshore wind project

development in the nascent U.S. market, 3) continued cost reductions, and 4) heightened demand for offshore wind in the northeastern United States.

**Several U.S. projects advanced in the development process.** U.S. offshore wind market progress was more evident from the advancement of major projects in the pipeline in 2018 than the capacity growth of the pipeline. Most notably, the commercial-scale Vineyard Wind project and Ørsted’s Revolution project negotiated electricity sale offtake agreements with major electric distribution companies and utilities and took major steps in permitting at both the state and federal level. Overall, in the United States, four projects have submitted construction and operations plans, nine projects have had site assessment plans approved, and six have signed power offtake agreements. Vineyard Wind and South Fork are the most advanced commercial-scale U.S. projects, having both obtained a power purchase agreement (PPA) and completed state permits and site surveys, with a construction and operations plan under review by BOEM. Vineyard Wind reports a commercial operation date of 2022 for their Phase 1 facility, consisting of the first 400 MW.

**Industry forecasts suggest U.S. offshore wind capacity could grow from 11 to 16 gigawatts (GW) by 2030.** Figure ES-2 shows three industry forecasts for offshore wind deployment in the United States for the period extending to the year 2030. These estimates were developed by Bloomberg New Energy Finance (BNEF 2018a), 4C Offshore (2018), and University of Delaware’s Special Initiative on Offshore Wind (SIOW 2019),<sup>5</sup> respectively. Together, they illustrate the degree of possible market growth as well as the potential variability associated with future deployment.



**Figure ES-2. U.S. offshore wind market forecasts for annual additions (left axis) and cumulative capacity (right axis) through 2030**

**Offtake prices for the first commercial-scale offshore wind project in Massachusetts were lower than expected.** On July 31, 2018, Massachusetts electric distribution companies and Vineyard Wind LLC negotiated a PPA for delivery of offshore-wind-generated electricity at a first-year price of \$74/megawatt-hour (MWh) (2022\$) for Phase 1 (400 MW) and \$65/MWh (2023\$) for Phase 2 (400 MW). An NREL study showed that these PPA prices may not accurately reflect the true cost of the project at face value because other revenue sources, such as the investment tax credit, are not accounted for (Beiter et al. [2019]). Nevertheless, this price was lower than expected given the presumed risks associated with building the first U.S. commercial project with an immature U.S. supply chain. Vineyard Wind’s apparent ability to access relatively low-cost financing and take advantage of the waning federal investment tax credit helped them set a competitive benchmark for the U.S. offshore wind industry. The Vineyard Wind PPA price provides a reference point for commercial-scale offshore wind generation in the United States that falls within the price range of European

<sup>5</sup> Please note University of Delaware’s SIOW forecast is based on the expected date a state selects to procure offshore wind capacity. A 3-year time lag is assumed from the time the procurement occurs until the project becomes fully operational.

offshore wind projects scheduled to begin commercial operations in the early- to mid-2020s. Additional commercial price points are anticipated in New York and New Jersey in 2019.

**Attention to offshore wind in California increased in 2018.** California passed Senate Bill 100, The 100 Percent Clean Energy Act of 2018, making it the largest state to establish a 100% electric renewable energy goal, and setting a carbon-free target year of 2045. Amid continued negotiations with the U.S. Department of Defense, on October 18, 2018, BOEM published a Call for Information and Nominations and received 14 nominations from companies interested in commercial wind energy leases within three proposed Call Areas off central and northern California. All together, these three Call Areas total approximately 2,784 km<sup>2</sup> (687,823 acres), which could support an offshore-wind-generating capacity for nascent floating wind technology of up to 8.4 GW.

**New national technical research consortium was launched to spur innovation.** DOE has committed \$20.5 million to the New York State Energy Research and Development Authority to form a National Offshore Wind R&D Consortium. The New York State Energy Research and Development Authority agreed to match the DOE contribution and launched a funding organization to make research and development awards on prioritized topics that will support developers in achieving their near-term deployment and cost targets. The first solicitation was released on March 29, 2019, and the first awards are expected in 2019.

### Global Offshore Wind Energy Market—Key Findings

**Globally, industry installed a record 5,652 MW of offshore wind capacity in 2018.** Annual capacity additions increased by more than 50% relative to 2017. The increase in global generating capacity can be attributed to increased deployment in China, with 2,652 MW of new capacity, followed by 2,120 MW commissioned in the United Kingdom, 835 MW in Germany, 28 MW in Denmark, and about 17 MW divided among the rest of the world. By the end of 2018, cumulative global offshore wind installed capacity grew to 22,592 MW from 176 operating projects. Projections indicate 2019 global capacity additions will be even higher based on projects currently under construction. As of December 31, 2018, the global pipeline for offshore wind development capacity was about 272,000 MW.

**The pace of European auctions slowed in the second half of 2018, but forecasts show sustained industry growth.** European auction strike prices<sup>6</sup> in 2018 validated earlier cost reduction trends but the number of auctions decreased, with only three occurring in the first two quarters of 2018. Adjusted strike prices<sup>7</sup> for these auctions ranged from \$74/MWh to \$79/MWh for commercial-scale projects. The slowdown can be partially attributed to the depletion of viable grid connections in the German markets (Foxwell 2018a). However, long-term forecasts indicate that this trend may be temporary as global offshore wind capacity is projected to reach between 154 and 193 GW by 2030, with more than 50% coming from Europe (and another major fraction coming from China).

### Offshore Wind Energy Technology Trends—Key Findings

**Industry is seeking accelerated cost reductions through larger turbines with rated capacities of 10 MW and beyond.** Through technology innovation, turbine original equipment manufacturers have been able to limit the rise in turbine cost (\$/kilowatt) and manage the increase in mass (kilogram/kilowatt) to allow turbine growth to continue upward to at least 12 MW, if not 15 MW, in the next decade. There are no indications that turbine growth is slowing or has reached a limit for offshore wind. Although the market has experienced a steady upgrade of turbine drivetrain nameplate generating capacity, turbine rotor diameters have grown more

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<sup>6</sup> The strike price for an offshore wind project from an auction is usually the lowest bid price at which the offering can be sold. It 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. It should not be confused with leveled cost of energy, which may be calculated using different financing and cost assumptions.

<sup>7</sup> The strike prices were adjusted to enable comparisons among projects in different countries to consider a range of possible subsidies and benefits that are available to some projects, such as the cost of the electrical grid connections.

slowly. The MHI Vestas V174-9.5 is currently the largest machine in the commercial market (Richard 2019). However, the next generation of turbines promises larger rotors and lower specific power ratings<sup>8</sup> suited for U.S. offshore markets in the next few years. Specific examples of next-generation turbines include Siemens Gamesa SG 10.0–193DD turbine announced in January 2019, which is planned by Siemens Gamesa to be market ready by 2022, and the GE Haliade-X 12-MW turbine, which should arrive on the market by 2021 (Siemens 2019; GE 2018b).

**Adoption of 66-kV(kilovolt) array cables is increasing to lower electrical infrastructure costs.** As the rated power capacity of offshore wind turbines continues to grow, project developers and operators are increasing their use of 66-kV array cable technology instead of the conventional 33-kV systems to connect individual turbines within an array. In 2018, three projects incorporated 66-kV array cables versus only one in 2017. Operation at a higher voltage offers important life cycle cost-efficiency benefits, such as the possibility of reducing the number of offshore substations, decreasing the overall length of installed cables, and minimizing electric losses. During 2018, the 66-kV technology was demonstrated by Nexans in three pilot wind power plant projects: the Blyth Offshore Demonstrator (United Kingdom), Nissum Bredning Vind (Denmark), and Aberdeen Bay (United Kingdom).

**The floating wind energy project pipeline is growing, with multiple floating pilot projects advancing.** The global pipeline for floating offshore wind energy reached 4,888 MW in 2018. The pipeline comprises 38 announced projects, including 46 MW of operating projects. The floating offshore wind energy industry is well into a second-generation, multiturbine, precommercial pilot phase. There are 14 projects representing approximately 200 MW that are currently under construction, having achieved either financial close or regulatory approval. These projects are distributed over nine countries.

**Semisubmersible substructures dominate the market for floating support structures, but new hybrid platform technologies are being introduced that could compete in future projects.** Semisubmersibles, which use buoyancy and the water plane area to achieve stability, make up 94% of floating projects on a capacity-weighted average because they are inherently a stable buoyant floating substructure with low draft that allows for in-port or nearshore assembly. Several new hybrid technologies (platforms that combine the characteristics of spars, tension-leg platforms and semisubmersibles) are being introduced this year that may rival these substructures. Stiesdal Offshore Technologies's TetraSpar and the SBM tension leg platform may be deployed as early as 2019.

## Offshore Wind Energy Cost and Price Trends—Key Findings

**Offshore wind auction strike prices in 2018 validate current cost reduction trends.** Prices from European offshore wind auctions and PPAs in 2018 help validate the previously documented trends indicating prices dropping from approximately \$200/MWh for projects beginning operation between 2017 and 2019 to approximately \$75/MWh for projects beginning operation between 2024 and 2025. In the United States, Vineyard Wind LLC signed two PPAs with Massachusetts electric distribution companies in July 2018 for a combined 800 MW of offshore wind capacity expected to become operational in 2022 and 2023, respectively. After adjusting for contract type, transmission, policy, and access to external revenue, the Vineyard Wind project has an all-in price of \$98/MWh. The Vineyard Wind price point indicates that U.S. projects may not be subject to a large price premium because of nascent U.S. market structures or a limited domestic supply chain. Figure ES-3 indicates the adjusted Vineyard Wind PPA prices are competitive with European offshore wind prices.

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<sup>8</sup> Specific power is the ratio of the nameplate rating of the turbine divided by the rotor's swept area and is given in Watts per meter squared.



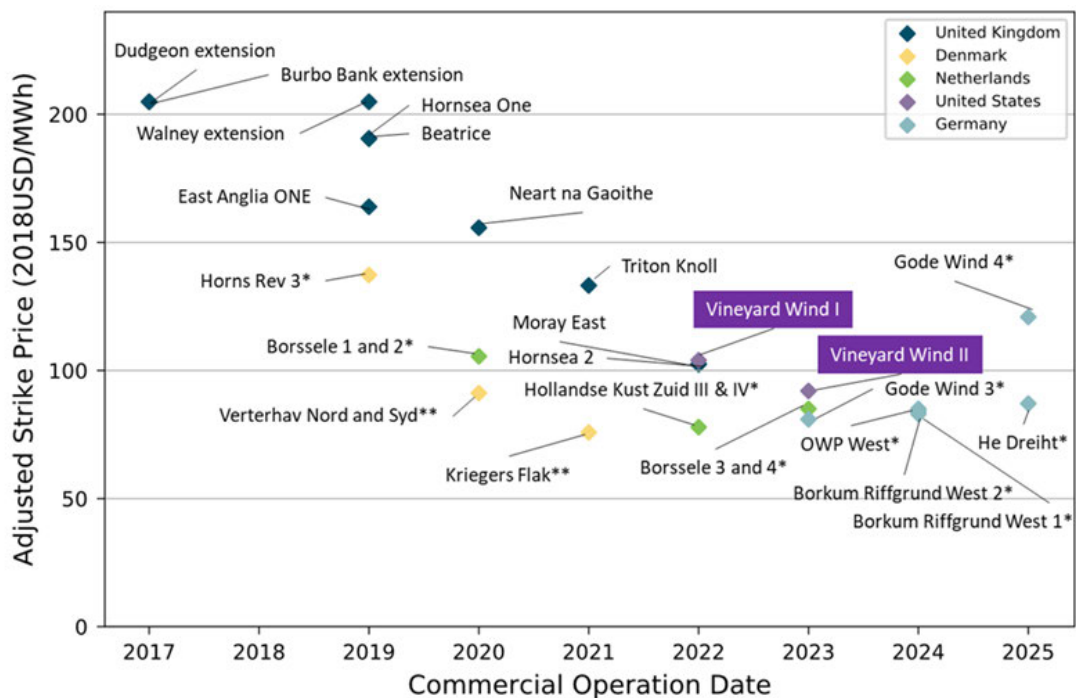


Figure ES-3. Adjusted strike prices from European offshore wind auctions

Sources: 4C Offshore (2018, 2019) and Beiter et al. 2019

Notes: \*Grid and development costs added; \*\*Grid costs added and contract length adjusted

## Future Outlook

Offshore wind market projections show accelerated growth in the next decade, with cumulative capacity ranging from 154 to 193 GW by 2030, and long-range predictions of over 500 GW by 2050 (BNEF 2018a; 4C Offshore 2018; International Renewable Energy Agency 2018). In this context, offshore wind is still at an early stage with respect to the maturity of the technology, supply chain, and infrastructure. The pace of progress and development of the global supply chain is likely to be strongly influenced in the near term by the growth in turbine generating capacity, rising toward 15 MW. Although larger turbines improve project costs in the long run, they may also delay industry maturity. It may take several years for the corresponding industrial facilities and infrastructure needed for fabrication, installation, and maintenance to stabilize at ever-increasing turbine scales. This upscaling issue is likely to persist not only in the United States but globally as well.

In the United States, individual states may continue to push for greater commitments for offshore wind, but further declines in offshore wind offtake prices are far from certain in the near term. Offshore wind projects, such as Vineyard Wind, will be able to take advantage of the expiring investment tax credit, which will enable low prices (on par with Europe) for the first commercial solicitation in Massachusetts. However, as the investment tax credit expires in 2020, projects will have to make up the difference by raising prices or lowering costs. This may increase the urgency to implement near-term solutions to manage costs, such as developing U.S.-flagged Jones-Act-compliant vessels or accelerating the growth and maturity of the domestic manufacturing supply chain.

If demand for offshore wind energy continues to increase in states along the U.S. Atlantic and Pacific coasts, as it did in 2018, state policy commitments that are now almost 20 GW could exceed the capacity of the available sites. Presently, there is just over 21 GW of capacity in BOEM lease areas where developers have been granted exclusive site control. Additional state policy commitments may create possible site shortages in some regions, which could trigger the development of more lease areas.

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# 2018 Offshore Wind Technologies Market Report

EXECUTIVE SUMMARY

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