U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

2018 Offshore Wind Technologies Market Report

Walter Musial, Philipp Beiter, Paul Spitsen,
Jake Nunemaker, Vahan Gevorgian

Report Contents

- Data and Project Classification
- U.S. Offshore Wind Market Assessment
- Global Offshore Wind Development
- Offshore Wind Technology Trends
- Cost and Pricing Trends

Key Findings

United States

- The U.S. offshore wind pipeline stands at 25,824 megawatts (MW) and includes:
  - 30 MW of installed capacity
  - 2,043 MW of capacity with site control and offtake pathways
  - 19,151 MW of potential capacity where developers have exclusive site control over a defined lease area
  - 2,250 MW of potential capacity in unleased wind energy areas (North Carolina)
  - 2,350 MW of potential capacity in unsolicited project applications (Pacific region).
- State-level policies continue to drive the U.S. market. By June 2019, the sum of official state offshore wind targets increased to 11,468 MW to be operating in 2030 and 19,968 MW to be operating by 2035.
- Increased U.S. market interest spurred increased competition at auctions for new lease areas. Three lease areas in Massachusetts were each sold for $135 million—more than tripling the previous highest winning bid.
- Several projects made progress in their permitting and offtake processes. Overall, four projects submitted construction and operations plans, nine projects received site assessment plan approvals, and six signed power offtake agreements.
- Offtake prices for the first commercial-scale offshore wind project (Vineyard Wind) were lower than expected. The project signed two 400-MW power purchase agreements for 20 years at $74/megawatt-hour (MWh) and $65/MWh, respectively.
- The Bureau of Ocean Energy Management (BOEM) is examining new Call Areas for offshore wind development. In 2018, the agency assessed commercial interest in multiple Call Areas in the New York Bight and along the central and northern California coast.

Key Findings (continued)

Global Offshore Wind Market

- The global offshore wind industry installed 5,652 MW of new capacity in 2018, bringing the cumulative global capacity to 22,592 MW.
- The pace of European offshore wind auctions slowed in the second half of 2018, but forecasts show sustained industry growth through 2030. In the future, annual capacity additions in Asia, especially China, are expected to outpace Europe.

Offshore Wind Technology Trends

- The offshore wind industry is developing larger turbines (10 MW+) to increase energy output and accelerate cost declines.
- The offshore wind industry is adopting 66-kilovolt array cables to lower electrical infrastructure costs.
- The nascent floating wind energy project pipeline is growing slowly relative to the fixed-bottom pipeline, but floating pilot projects are advancing. The global pipeline for floating offshore wind energy reached 4,888 MW in 2018, with 38 announced projects and 46 MW of operating projects.

Offshore Wind Pricing Trends

- New offshore wind strike prices from 2018 auctions validated cost reduction trends. Prices dropped from $200/MWh for projects coming on line between 2017 and 2019 to roughly $75/MWh for projects in 2025.

Future Outlook

- Offshore wind market projections show accelerated growth in the next decade, with global cumulative capacity ranging from 154 to 193 gigawatts (GW) by 2030, and long-range predictions of over 500 GW by 2050.
- Industry forecasts indicate U.S. offshore wind capacity growth to reach a range of 11–16 GW by 2030.

Data and Methodology

2018 Market Report Data Sources

- NREL's Offshore Wind Database (OWDB) is built from internal research using peer-reviewed literature, press releases, industry news reports, manufacturer specification sheets, subscription-based industry databases, and global offshore wind project announcements.
- The data in this report—both globally and domestically—are derived from the OWDB.
- Data gaps were filled using the best judgment of the authors and industry subject matter experts that were consulted.
- The OWDB is verified against the following sources:
  - The 4C Offshore Wind Database
  - BOEM
  - The WindEurope Annual Market Update
  - Bloomberg New Energy Finance's (BNEF's) Renewable Energy Project Database
  - The University of Delaware's Special Initiative on Offshore Wind (SIOW).

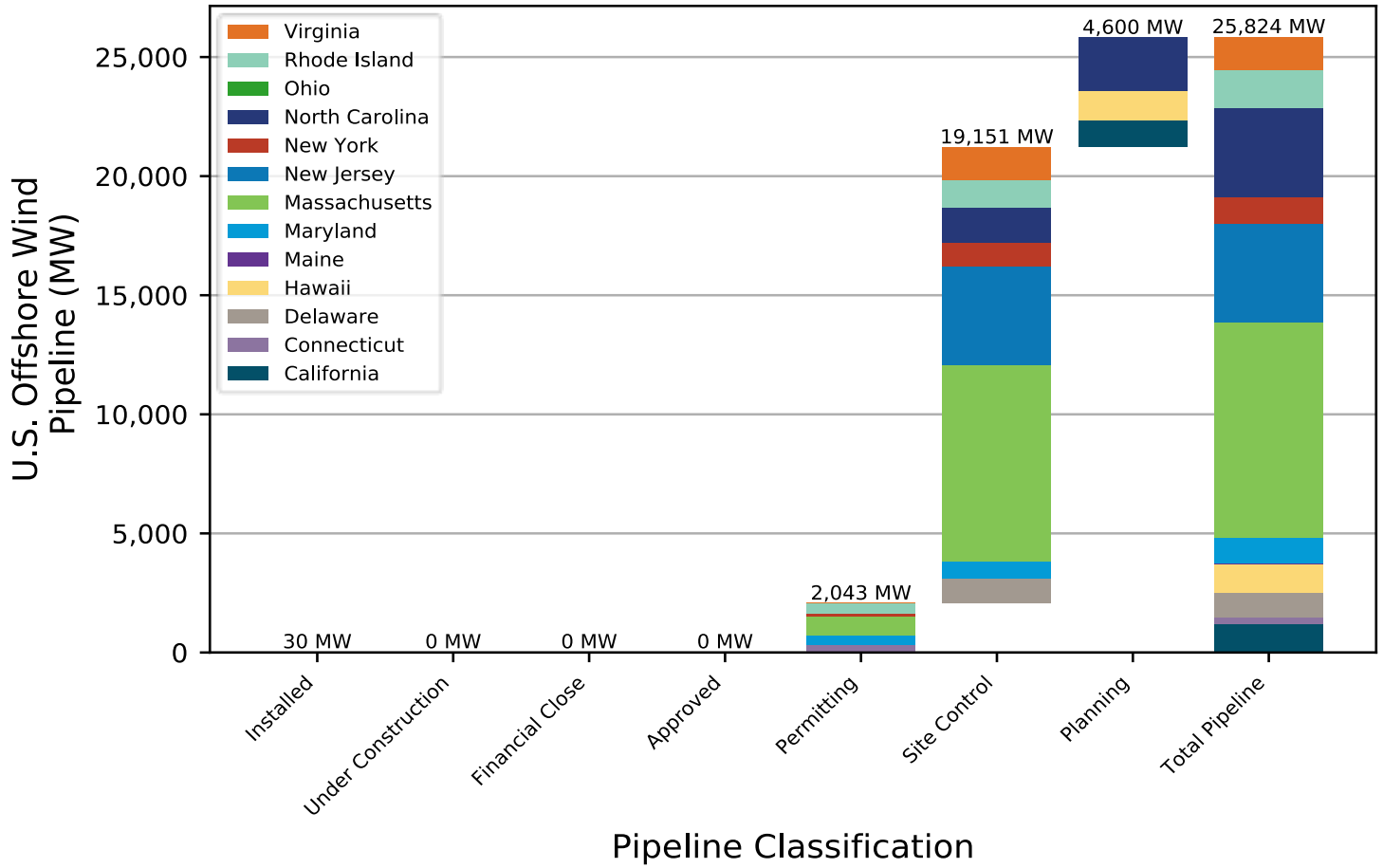
Offshore Wind Pipeline Criteria for Market Report

Step	Phase Name	Start Criteria	End Criteria
1	Planning	Starts when a developer or regulatory agency initiates the formal site control process	Ends when a developer obtains site control to a site (e.g., through competitive auction or a determination of no competitive interest in an unsolicited lease area [United States only])
2	Site Control	Begins when a developer obtains site control (e.g., a lease or other contract)	Ends when the developer files major permit applications (e.g., a construction and operations plan for projects in the United States) or obtains an offtake agreement
3	Permitting = Site Control + Offtake Pathway	Starts when the developer files major permit applications (e.g., construction and operations plan or an offtake agreement for electricity production)	Ends when regulatory entities authorize the project to proceed with construction and certify its offtake agreement
4	Approved	Starts when a project receives regulatory approval for construction activities and its offtake agreement	Ends when sponsor announces a "financial investment decision" and has signed contracts for construction work packages
5	Financial Close	Begins when sponsor announces a financial investment decision and has signed contracts for major construction work packages	Ends when project begins major construction work
6	Under Construction	Starts when offshore construction is initiated[10]	Ends when all turbines have been installed and the project is connected to and generating power for a land-based electrical grid
7	Operating	Commences when all turbines are installed and transmitting power to the grid; COD marks the official transition from construction to operation	Ends when the project has begun a formal process to decommission and stops feeding power to the grid
8	Decommissioned	Starts when the project has begun the formal process to decommission and stops transmitting power to the grid	Ends when the site has been fully restored and lease payments are no longer being made
9	On Hold/Cancelled	Starts if a sponsor stops development activities, discontinues lease payments, or abandons a prospective site	Ends when a sponsor restarts project development activities

U.S. Offshore Wind Market Assessment

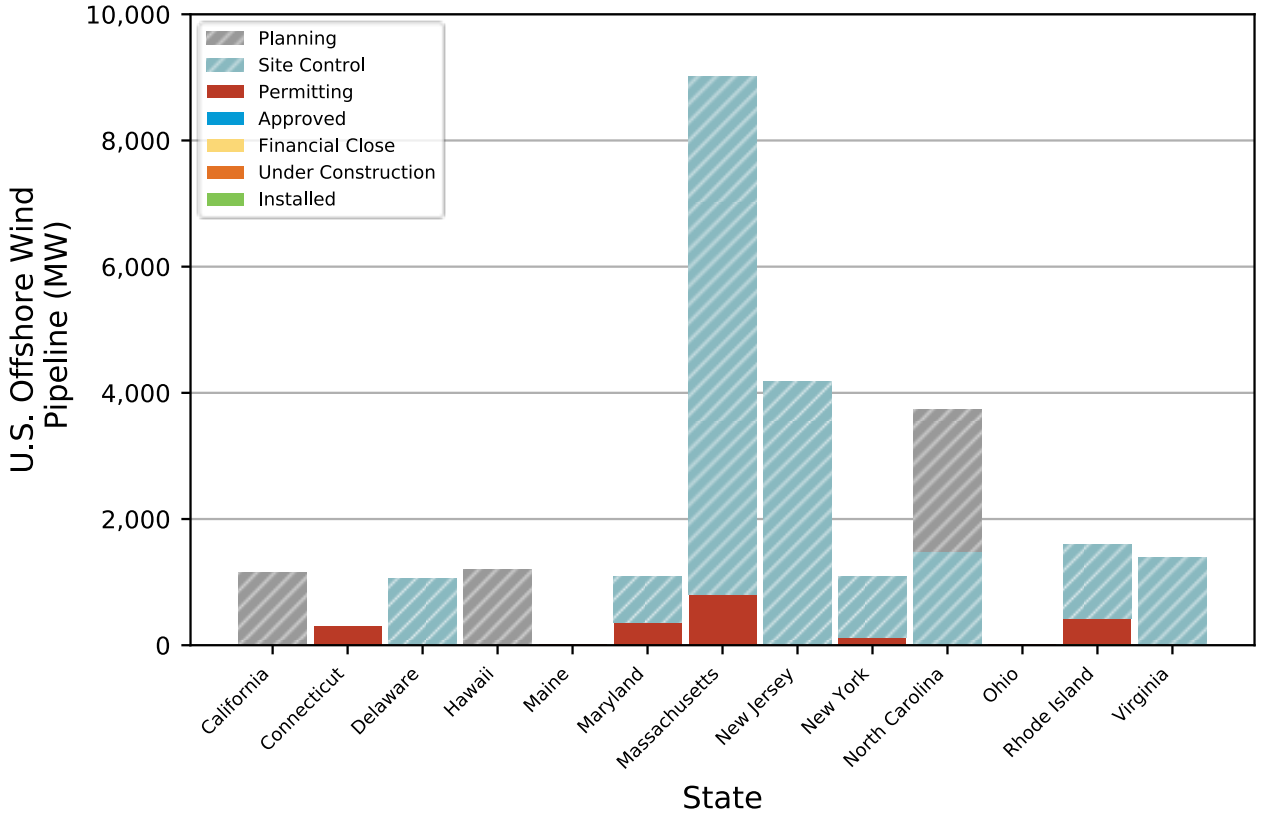
U.S. Offshore Wind Pipeline Calculated at 25,824 GW

The 2018 U.S. pipeline is 25,824 MW, growing by 1.4% relative to 2017. Changes were caused by cancellation of the 24-MW Nautilus Offshore Wind Project (New Jersey), expansion of South Fork from 90 MW to 130 MW, the addition of the150-MW Redwood Coast Offshore Wind Project (California), and the proposed size increase of Castle Wind (California) from 765 MW to 1,000 MW.



U.S. Market Driven by State Offshore Wind Policies

- Massachusetts, New York, New Jersey, Maryland, Connecticut, and Rhode Island all have policies enabling developers to sign offtake agreements.
- Most of the U.S. market is still in the Northeast, but other states like California are becoming interested in offshore wind.



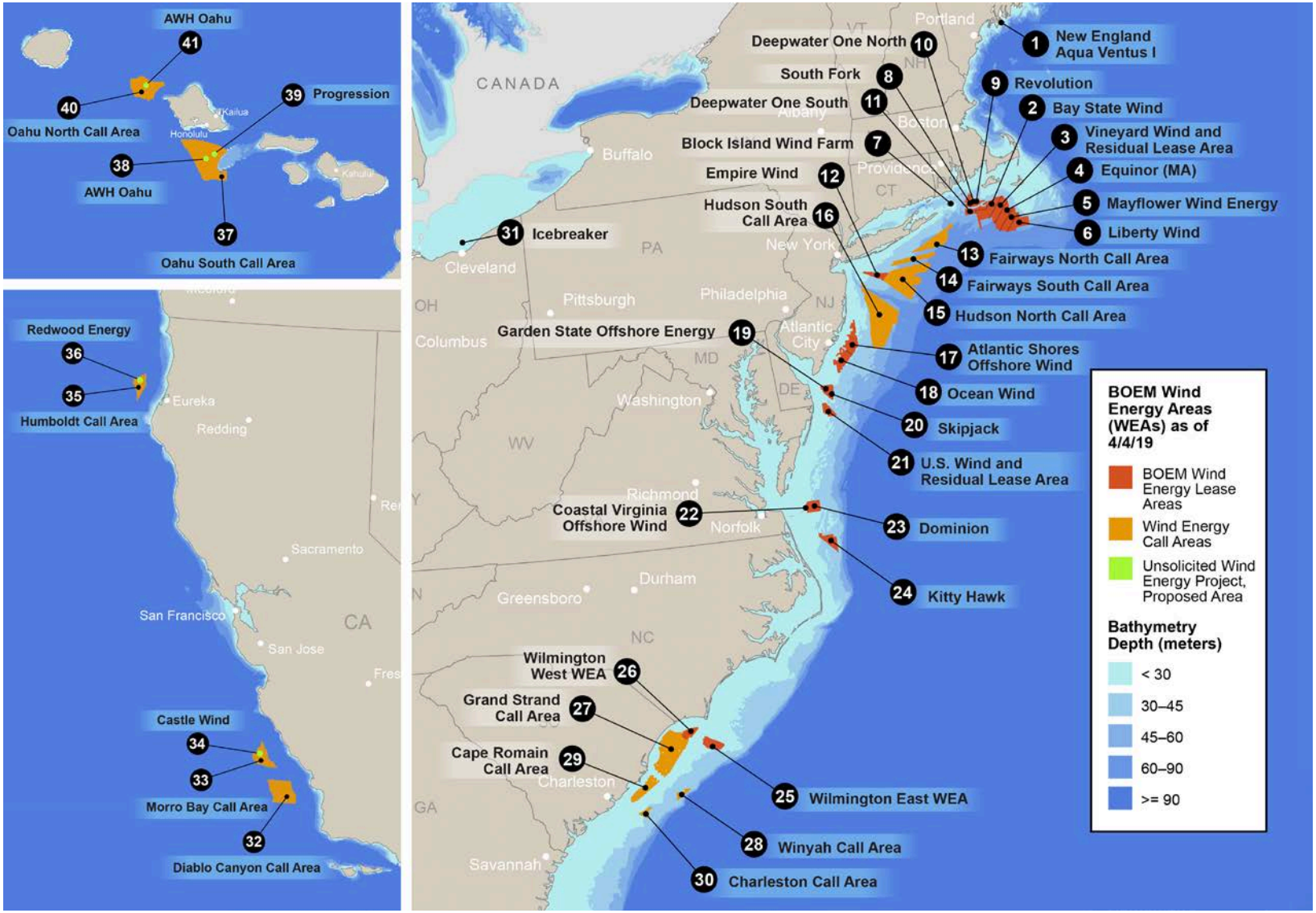
U.S. Offshore Wind Project Activity

#	Location	Project Name[1]	Status	COD[2]	Developer Capacity (MW)[3]	Lease Area Potential (MA)[4]	Pipeline Capacity (MW)[5]	Lease Area	Size (km2)[6]	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	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	Permitting	2022	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	Unsold Lease Area	-	0	1,623	1,623	N/A	209	TBD	TBD
26	NC	Wilmington West WEA	Unsold Lease Area	-	0	627	627	N/A	541	TBD	TBD
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	-	-	-	-	N/A	-	-	-
33	CA	Morro Bay	BOEM Call Area	-	-	-	-	N/A	-	-	-
34	CA	Castle Wind	Unsolicited Project Application	-	0	1,000	1,000	N/A	334	TBD	Trident Winds/EnBW
35	CA	Humboldt Bay	BOEM Call Area	-	-	-	-	N/A	-	-	-
36	CA	Redwood Coast	Unsolicited Project Application	-	0	150	150	N/A	50	TBD	EDPR/PPI
37	HI	Oahu South	BOEM Call Area		-	-	-	N/A	-	-	-
38	HI	AWH Oahu	Unsolicited Project Application	-	0	400	400	N/A	133	TBD	AW Wind
39	HI	Oahu North	BOEM Call Area	-	-	-	-	N/A	-	-	-
40	HI	AWH Oahu	Unsolicited Project Application	-	0	400	400	N/A	133	TBD	AW Wind
41	HI	Progression	Unsolicited Project Application	-	0	400	400	N/A	133	TBD	Progression Wind
Total					2,073 MW	23,751 MW	25,824 MW				

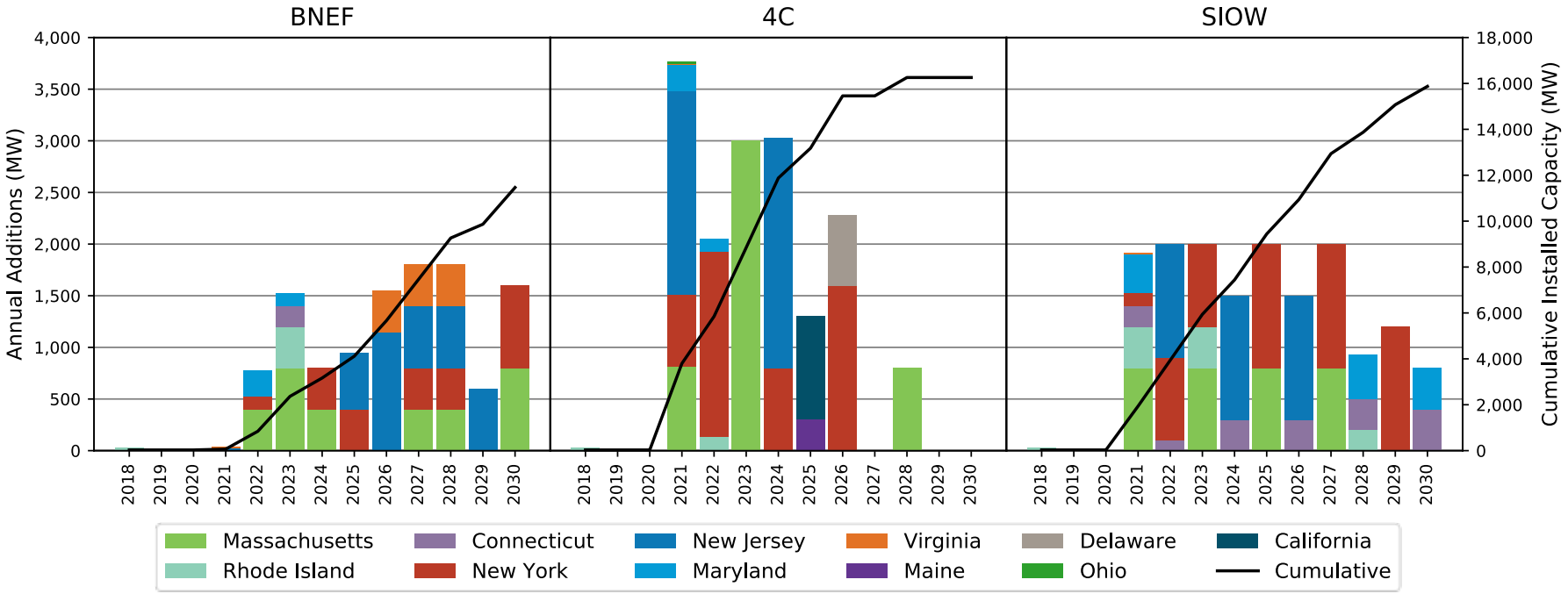
1. Some project names may change based on successful bids to state procurement solicitations
2. Future commence operation dates are subject successfully negotiating offtake agreement and may change
3. Developer announced capacity describes the size of a project as stipulated by a developer to regulators
4. Lease Area Potential describes the potential capacity that could be installed in a lease area using a 3MW/km2 density
5. Pipeline capacity represents the lease area potential minus any developer announced capacity.
6. Sizes for Unsolicited Project Applications are likely to change during stakeholder and regulatory review processes. Call Areas sizes are not included because

See map on next page for location of index numbers

U.S. Offshore Wind Development Activity



U.S. Market Predicted To Grow to at Least 10 GW by 2030



- Forecasts estimate the U.S. offshore wind market will cumulatively deploy between 4 and 13 GW by 2025, and 11 to 16 GW by 2030.

- The size and speed of build-out are uncertain and depend on state policies, regularity of future procurements, availability of installation vessels and specialized ports, land-based and offshore electrical infrastructure, and evolving market demand.

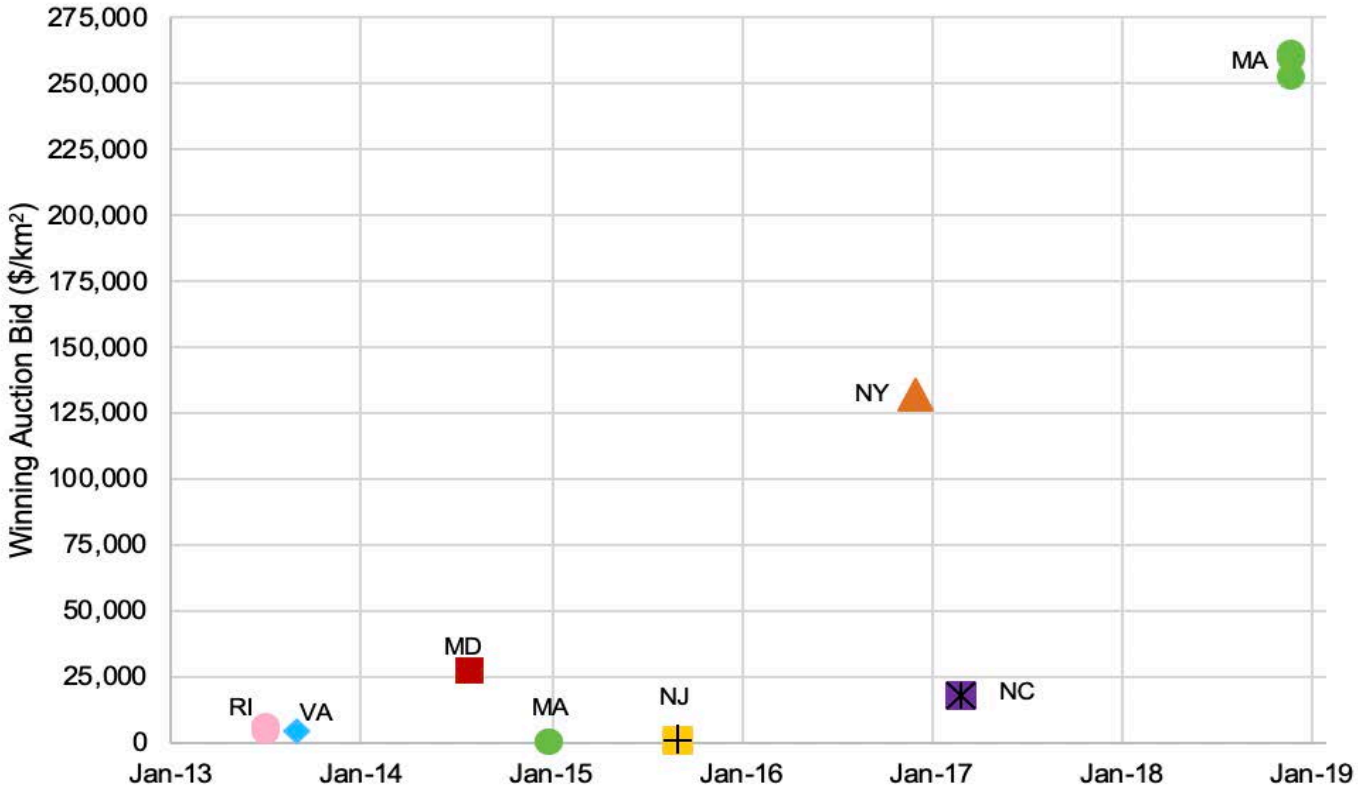
Ørsted Acquires More Lease Areas While New Developers Enter Market Through Lease Area Acquisitions

- In April 2018, Ørsted asked BOEM to reassign 107 square kilometers (km^2) in the southern portion of lease area OCS-A 0482 (Garden State Ocean Energy) in Delaware to the Skipjack project. Skipjack now has its own lease area: OCS-A 0519.
- In November 2018, Ørsted completed the acquisition of Deepwater Wind's offshore assets including their lease areas for a reported $510 million.
- In December 2018, Atlantic Shores Offshore Wind, a partnership between Électricité de France Renouvelables (EDF) and Shell New Energies, bought lease area OCS-A 0499 from US Wind for $215 million pending regulatory approval.
- In December 2018, BOEM held an auction for three lease areas off Massachusetts. In aggregate, the three lease areas have the potential to support 4.7 GW of new capacity. Each lease area was sold for at least $135 million.

2018 Massachusetts Lease Auction Results

State	Lease Area	Auction Date	Provisional Winner	Winning Bid	Size (km^2)	Lease Area Potential
MA	OCS-A 0520	12/14/18	Equinor	$135,000,000	521	1,564 MW
MA	OCS-A 0521	12/14/18	Mayflower Wind Energy	$135,000,000	516	1,547 MW
MA	OCS-A 0522	12/14/18	Vineyard Wind	$135,100,000	536	1,607 MW

The Auction Prices of U.S. Lease Areas Increased in 2018



- Three Massachusetts lease areas were auctioned in December 2018. Each sold for at least $135 million ($258,000/km^2), more than tripling the previous record of $42 million ($132,255/km^2).
- Increased lease sale prices may indicate the offshore wind market is maturing.
- Higher lease prices could increase the delivery price of offshore wind.

BOEM Issued Calls for Information and Nominations in the New York Bight and Along the California Coast

- Calls for Information and Nominations (Call Areas) are used to assess commercial offshore wind interests in federal ocean areas and receive feedback from a variety of local stakeholders.

- BOEM identified four Call Areas in the New York Bight (off the states of New York and New Jersey) and found there was commercial interest in all sites. These additional lease areas are essential for supporting the states' offshore wind procurement policy goals.

- The three California Call Areas total approximately 2,784 km^2 and could potentially deliver a generating capacity of up to 8.4 GW. In response to the California call, BOEM received 14 nominations indicating interest in developing some portions of each Call Area.

New Offshore Wind Call Areas in 2018

State	Name	Call Period
NY	Fairways North Call Area	4/11/2018–7/30/2018
NY	Fairways South Call Area	4/11/2018–7/30/2018
NY/NJ	Hudson North Call Area	4/11/2018–7/30/2018
NY/NJ	Hudson South Call Area	4/11/2018–7/30/2018
CA	Humboldt Call Area	10/19/2018–1/28/2019
CA	Morro Bay Call Area	10/19/2018–1/28/2019
CA	Diablo Canyon Call Area	10/19/2018–1/28/2019

U.S. Offshore Wind Offtake Agreements Decreased in Price

- Offshore wind prices in the United States have decreased from approximately $244/MWh in 2014 to less than $95/MWh for projects expecting to enter commercial operations around 2023.

- Price declines have been driven by market certainty created by state policies, technology improvements, better project financing terms, and access to federal investment tax credits.

2018 Most Advanced U.S. Offshore Wind Projects

Project	Offtake State	Offtake Mechanism	Public Utility Commission Approved	Offtake Mechanism Price	Description
Block Island Wind Farm	RI	PPA	Yes	$244/MWh	In 2014, Deepwater Wind signed a 20-year PPA with National Grid for $244/MWh, with a 2.5% annual escalator.
South Fork	NY	PPA	Yes	Undisclosed	In 2017, Deepwater Wind signed a 20-year PPA with Long Island Power Authority for 90 MW at an undisclosed price. In 2019, Long Island Power Authority executed an amendment in the PPA to increase the offtake agreement to 130 MW.
US Wind	MD	MD ORECs	Yes	$131.92/MWh	In 2017, Maryland awarded US Wind ORECs for 248 MW of capacity for 20 years. Each year, 913,945 ORECs will be sold. The levelized OREC price is $131.94/MWh.
Skipjack	MD	MD ORECs	Yes	$131.92/MWh	In 2017, Maryland awarded Skipjack ORECs for 120 MW of capacity for 20 years. Each year, 455,482 ORECs will be sold. The levelized OREC price is $131.94/MWh.
Vineyard Wind	MA	PPA	Yes	$74/MWh $65/MWh	In 2018, Vineyard Wind signed two 400-MW PPAs with Massachusetts utilities for 20 years. The levelized prices of the PPAs were $74/MWh and $65/MWh, respectively.
Coastal Virginia Offshore Wind	VA	Utility Owned	Yes	$780/MWh	In 2018, Virginia regulators approved Dominion/Ørsted to construct a 12-MW demo project. The estimated levelized cost of energy is $780/MWh.
Revolution Wind	CT	PPA	Yes	$94/MWh	In 2018, Ørsted signed a 20-year PPA with Eversource and United Illuminating for 200 MW with a levelized PPA price of approximately $94/MWh. Ørsted has been approved to start negotiations on an additional 100 MW.
Revolution Wind	RI	PPA	Yes	$98.43/MWh	In 2019, Ørsted signed a 20-year PPA with National Grid for 400 MW. The proposal was approved by the Public Utility Commission, and the all-in price is $98.43/MWh.
Icebreaker	OH	PPA	Pending	TBD	LEEDCo is working to secure offtake with multiple partners for the project's electricity.
Aqua Ventus I	ME	PPA	Pending	TBD	Aqua Ventus I is negotiating a PPA with Central Maine Power.

U.S. Offshore Wind Market Is Driven by State Policies

- In 2018 and early 2019, new targets were established or upgraded in New Jersey (3.5 GW), Massachusetts (3.2 GW), Maryland (1.2 G.W), Connecticut (2.3 GW), and New York (9.0 GW).
- In 2018, offshore wind request for proposals were issued in New York (800 MW) and New Jersey (1,100 MW).
- As of June 2019, state policy commitments call for 19,968 MW of offshore wind capacity by 2035–almost four times the aggregate state-level targets identified at the end of 2017.

2018 Summary Table of U.S. State Policy Commitments

State	2018 Capacity Commitment (MW)	Offshore Wind Solicited (MW)	Contract Type	Target Year	Statutory Authority	Year Enacted	RPS Goal	State RPS Year
MA	1,600	1600	PPA	2027	An Act to Promote Energy Diversity (H.4568)	2016	35%	2030
	1,600	-	PPA	2035	An Act to Advance Clean Energy (H.4857)	2018		
RI	400	400	PPA	-	-	-	31%	2030
NJ	3,500	1,100	OREC	2030	Executive Order 8 AB No. 3723	2018	50%	2030
MD	368	368	OREC	2030	Maryland Offshore Wind Energy Act	2013	24%	2020
	400	-	OREC	2026	Senate Bill 516	2019		
	400	-		2028				
	400	-		2030				
NY	2,400	930	OREC	2030	Case 18-E-0071 Order Establishing Offshore Wind Standard and Framework for Phase 1 Procurement	2018	50%	2030
	6,600	-	TBD	2035	Climate Leadership and Community Protection Act	2019		
CT	300	300	PPA	2020	House Bill 7036 (Public Act 17-144)	2017	44%	2030
	2,000	-	TBD	2030	House Bill 7156	2019		
VA	-	12	Utility Owned	2028	Virginia Energy Plan	TBD	-	-
TOTAL	19,968 MW	4,710 MW						

Investments in Port Infrastructure Start To Manifest

- No investments have been made to build U.S.-flagged turbine installation vessels.
- Developers and states began making investments in port infrastructure.
- The development and timing of port infrastructure could impact development timelines.
- Growth of turbine and project sizes may hinder the acquisition of enough heavy-lift capacity, ship access, overhead clearances, channel draft, and physical laydown space.
- At least five ports may be required to install 10 GW of offshore wind capacity along the Atlantic Coast.

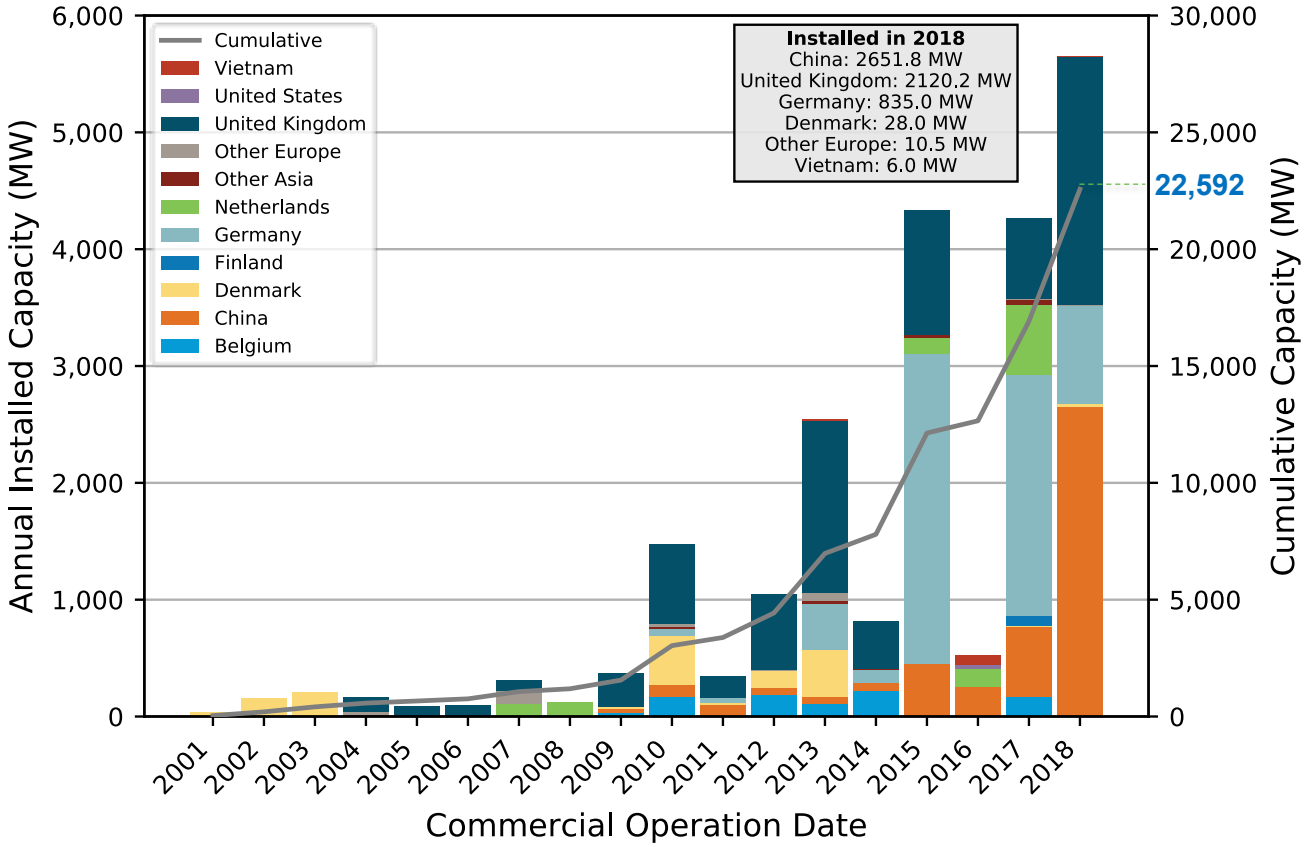
2018 Port Infrastructure Investment Activity

State	Location	Description	Offshore Wind Projects
MA	Port of New Bedford	Vineyard Wind is leasing the New Bedford Commerce Terminal for 18 months as the primary staging and deployment base for its 800-MW project (Mass Live 2018).	Vineyard Wind
MA	Brayton Point	Anabaric and Commercial Development Company signed an agreement to invest $650 million into Brayton Point's Commerce Center to create an offshore wind hub that has a 1.2-GW high-voltage direct current converter, 400-MW battery storage, and additional wind turbine component laydown space.	Multiple in MA and RI
CT	New London	Ørsted, the Connecticut Port Authority, and Gateway will invest $93 million in the State Pier at New London to expand the laydown space, increase its heavy-lift capacity, and add other features necessary for large-scale offshore wind development activities. Ørsted will lease rights to use the pier for 10 years.	Revolution Wind
MD	Tradepoint Atlantic (Formerly Sparrow Point)	In 2017, US Wind and Deepwater Wind agreed to invest $115 million in new manufacturing and port infrastructure.	US Wind and Skipjack

Overview of Global Offshore Wind Development

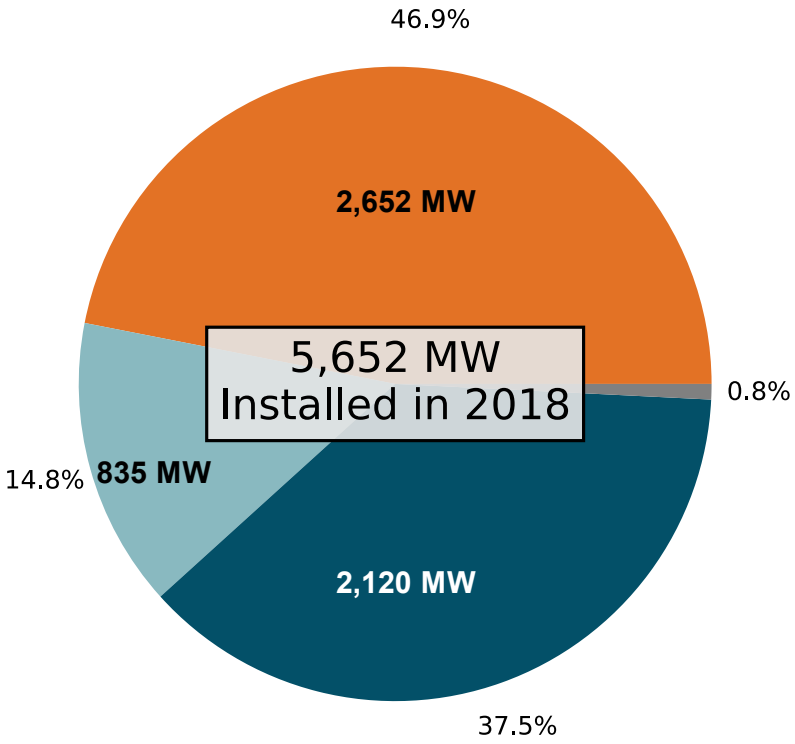
A Record 5,652 MW of Offshore Wind Capacity Was Installed Globally in 2018

- In 2018, 5,652 MW of new offshore wind capacity was installed–a significant increase over the 3,500 MW installed in 2017.
- China and the United Kingdom represent the majority of new capacity in 2018.



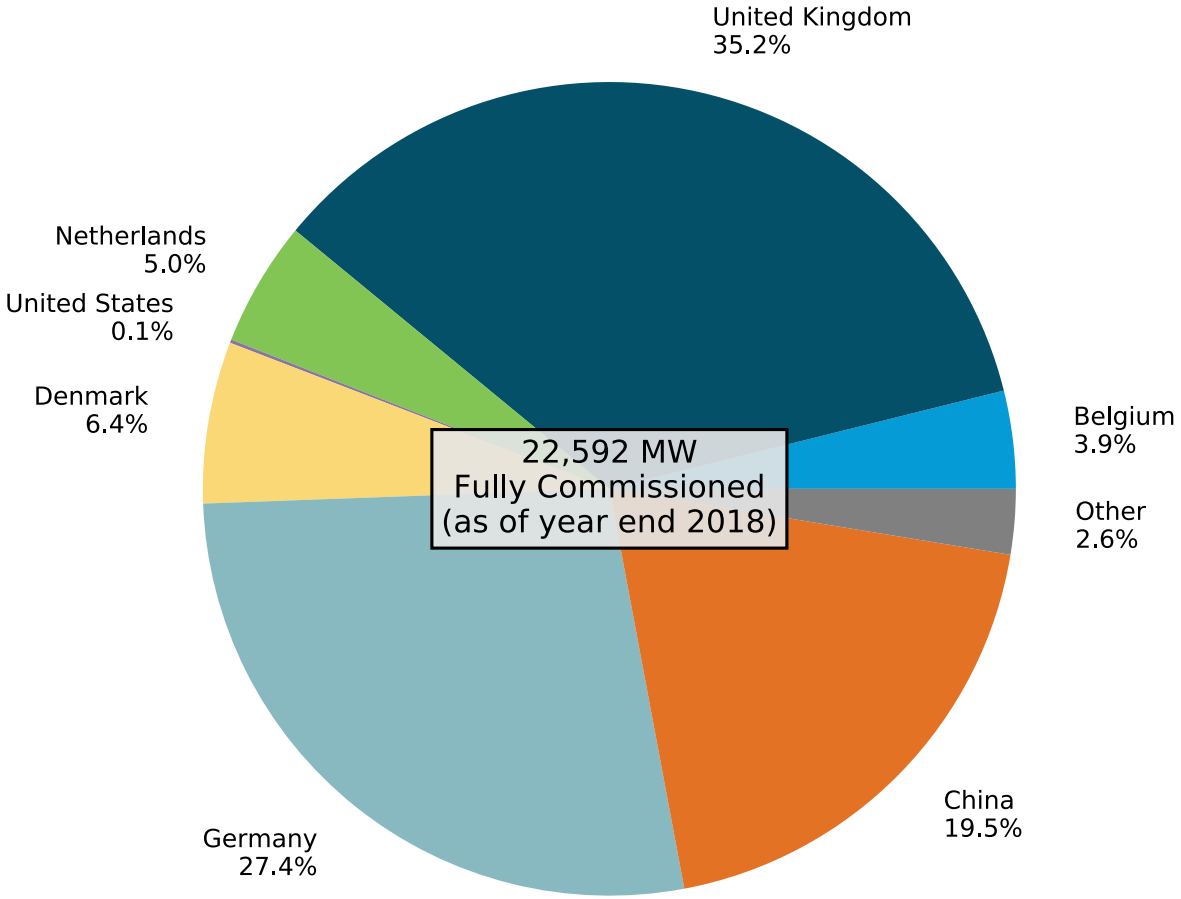
China Installed the Highest Amount of New Capacity in 2018

China installed 2,652 MW, the United Kingdom installed 2,120 MW, Germany installed 835 MW, Denmark installed 28 MW, and about 17 MW were divided between the rest of Europe and Vietnam.



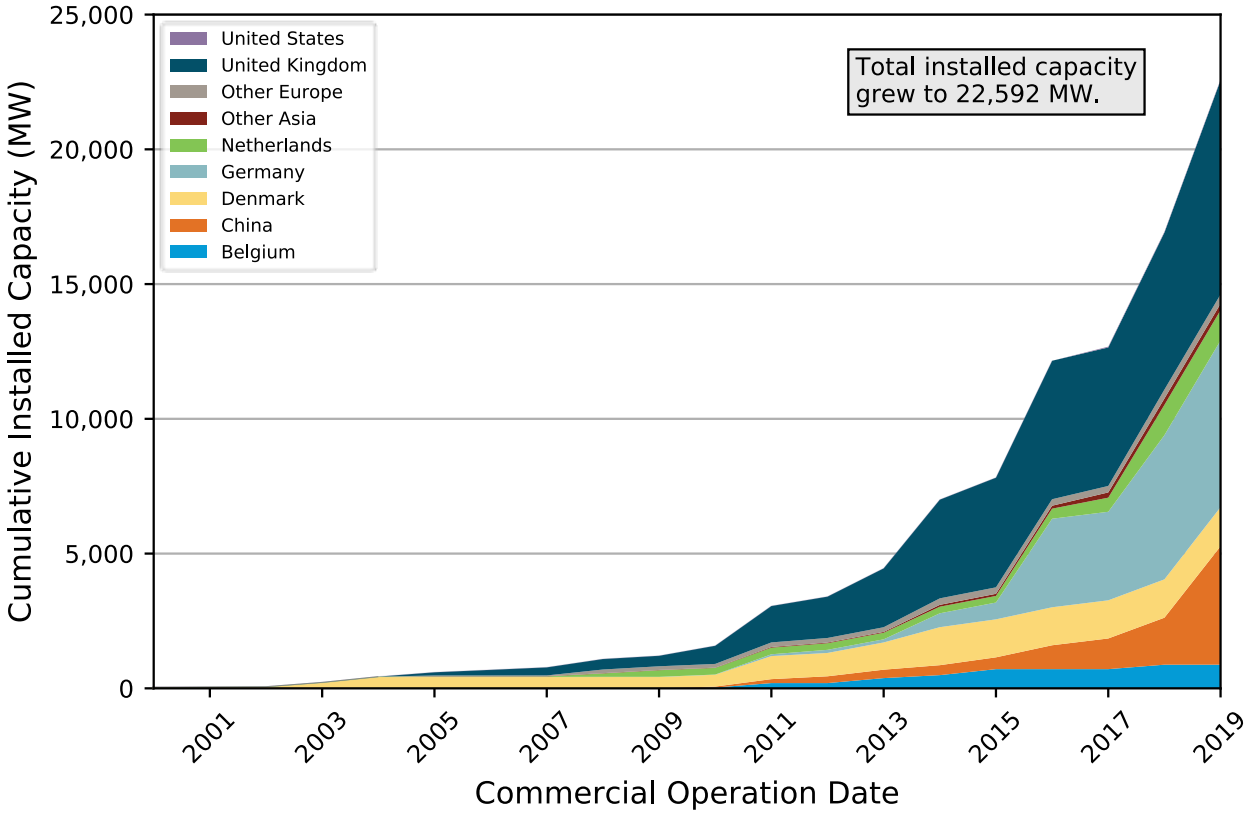
The Majority of Cumulative Capacity Is Still in Europe

The United Kingdom continues to lead the world in total offshore wind deployment, with 35.2%, followed by Germany (27.4%), China (19.5%), Denmark (6.4%), the Netherlands (5%), and Belgium (3.9%).



Global Offshore Wind Capacity Grew to 22,592 MW

- Europe has 17,979 MW of installed cumulative capacity.
- Asia is the second largest regional market, with 4,639 MW installed.
- North America has 30 MW installed but market share may increase to 8% by 2030.
- Asian offshore market demand is expected to remain strong.
- Annual installed capacity in Asia may soon surpass Europe.



In 2018, 2,994 MW of New Capacity Was Installed in Europe

- In 2018, Denmark installed 28 MW, France installed 2.2 MW, Germany installed 835 MW, Spain installed 5 MW, Sweden installed 3.3 MW, and the United Kingdom installed 2,130 MW.
- Beyond 2018, European offshore wind activities related to policy, procurements, permits, and offtake agreements indicate continued market growth.

2018 European Offshore Wind Projects

Country	Project Name	Capacity (MW)	Developer
Denmark	Nissum Bredning Vind	28	Nissum Bredning Vindmallelaug
France	EOLINK 1/10 Scale Prototype	0.2	EOLINK
France	Floatgen	2	Ideol
Germany	Arkona	385	E.ON
Germany	Borkum Riffgrund 2	450	Ørsted
Spain	Elisa/Elican Demonstration	5	Elican & ESTEYCO
Sweden	Bockstigen	3.3	Momentum Gruppen A/S
United Kingdom	Aberdeen Offshore Wind Farm	93.2	Vattenfall
United Kingdom	Blyth Offshore Demonstration Array 2	41.5	EDF
United Kingdom	Galloper	353	Innogy
United Kingdom	Race Bank	573.3	Ørsted
United Kingdom	Rampion	400.2	E.ON
United Kingdom	Walney Extension	659	Ørsted

In 2018, 2,658 MW of New Capacity Was Installed in Asia

- In 2018, China added 2,652 MW and Vietnam added 6 MW.
- Future market growth is expected to be primarily driven by China, but Taiwan, Japan, and South Korea have also announced multiple new project proposals that are expected to come on line in the early 2020s.

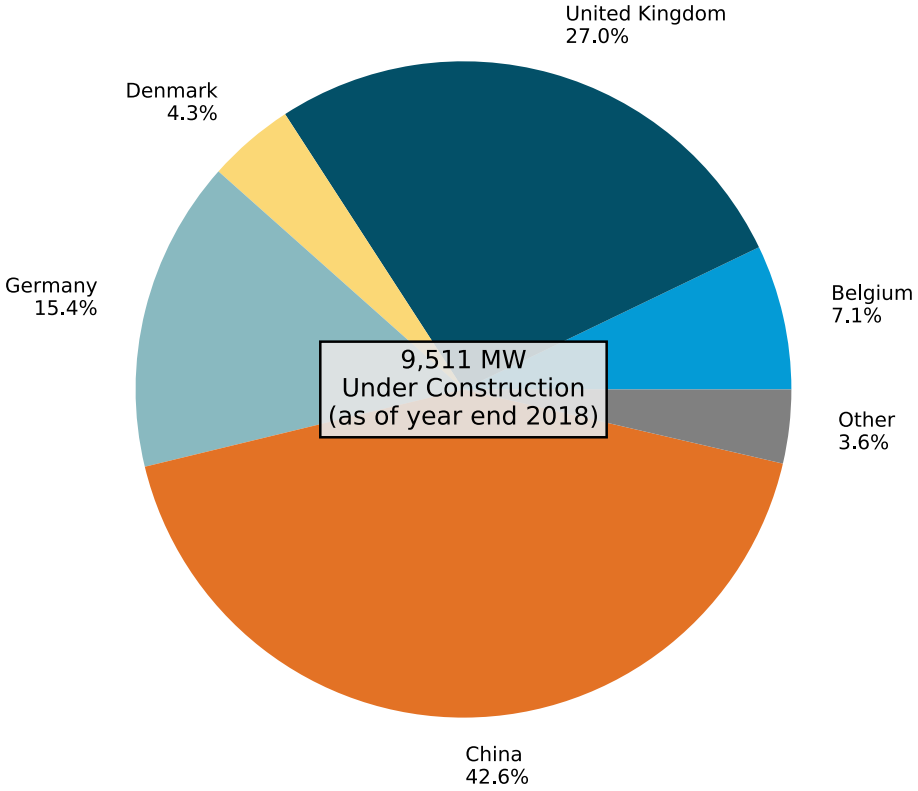
2018 Asian Offshore Wind Projects

Country	Project Name	Capacity (MW)	Developer
China	Fuqing Xinghua Bay - Phase 1	77.4	China Three Gorges New Energy Co.
China	Guodian Zhoushan Putuo District 6 Zone 2	252	GD Power Development Co.
China	Jiang Su Ru Dong Jiangjiasha H2	300	Shanghai Electric Power
China	Jiangsu Longyuan Chiang Sand H1	300	China Longyuan Power Group
China	Jiangsu Luneng Dongtai	200	Shandong Luneng
China	Laoting Bodhi Island Demonstration	300	Jointo Energy Investment
China	Longyuan Jiangsu Dafeng (H12)	200	China Longyuan Power Group
China	Longyuan Putian Nanri Island I	200	China Longyuan Power Group
China	SPIC Binhai North H2	400	State Power Investment Corporation
China	SPIC Jiangsu Dafeng H3	302.4	State Power Investment Corporation
China	Zhuhai Guishan Hai Demonstration - Phase 1	120	China Southern Power Grid
Vietnam	Ben Tre 10 – Phase 1	6	Mekong Wind Power

Over 9.5 GW of Offshore Wind Is Under Construction

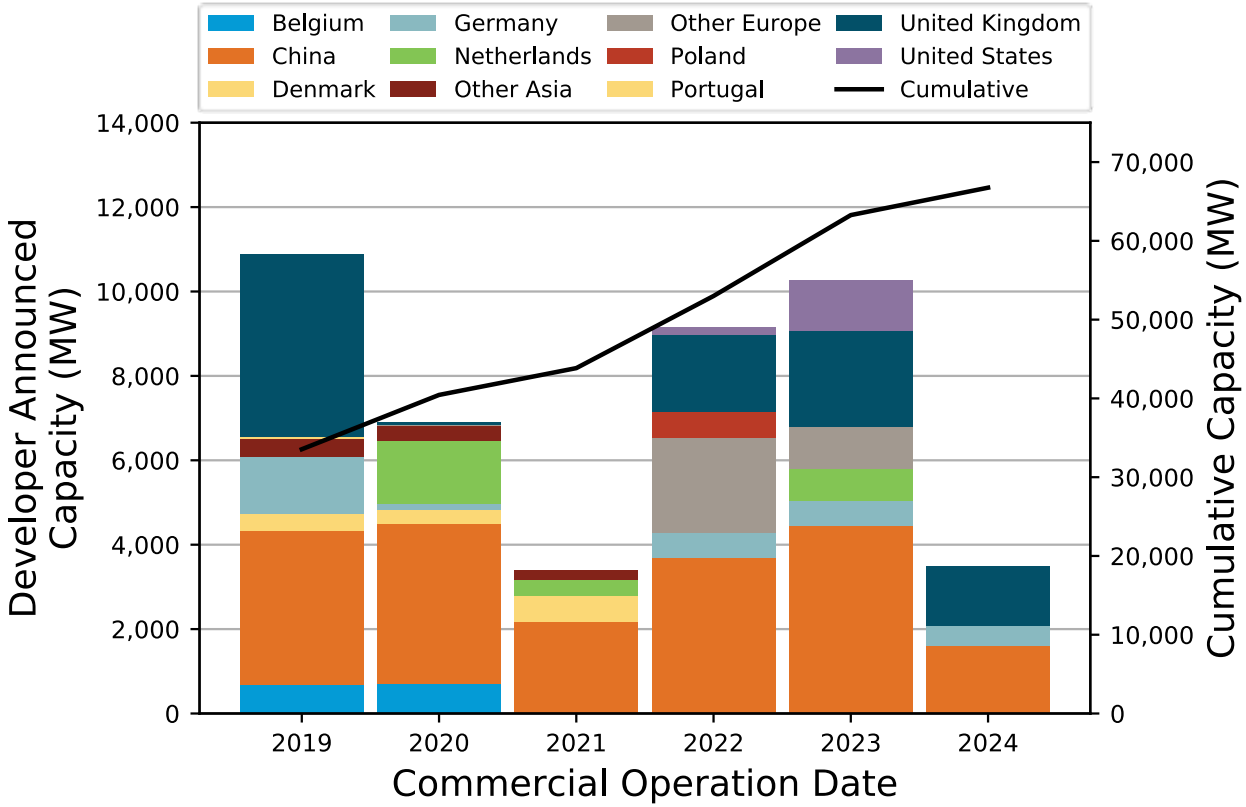
- By the end of 2018, there were 12 European projects under construction representing 5,115 MW of new capacity. Most of the construction in Europe is in the United Kingdom, with 2,520 MW, followed by Germany with1,460 MW, Belgium with 678.6 MW, and Denmark with 406 MW.

- In Asia, there were 17 projects under construction at the end of 2018, with a combined capacity of 3,469 MW; 12 projects in China, 3 in Vietnam, 1 in Japan, and 1 in South Korea.

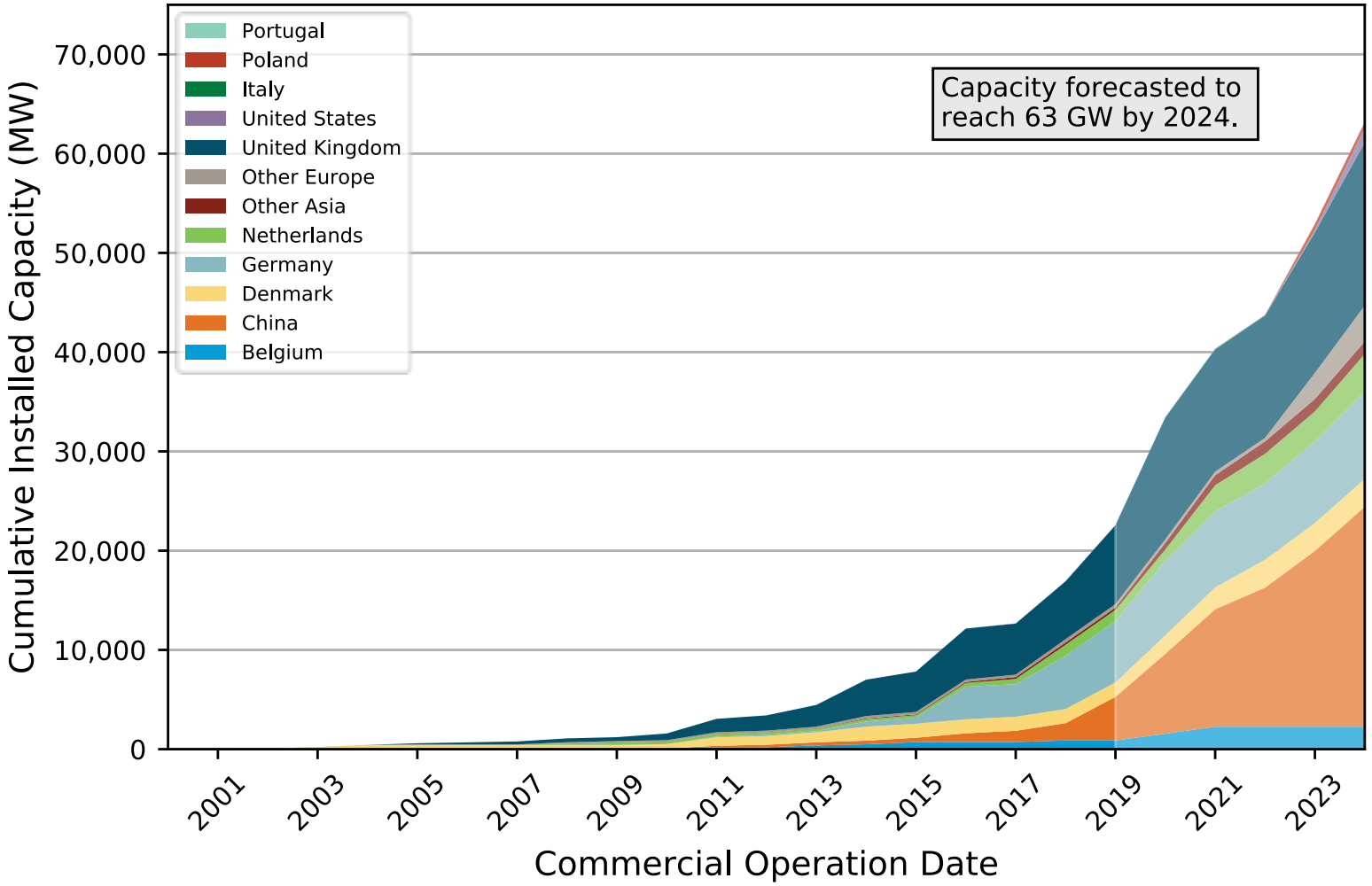


Near-Term Data Indicate 44 GW of New Capacity by 2024

- Globally, there are about 19 GW of projects that have reached financial close or are under construction as of 2018. By the end of 2018, about 10 GW of projects had reached financial close prior to construction.
- In Europe, 14 projects, representing 6,052 MW of capacity, reached financial close in 2018.
- In the Asian market, 17 projects, representing 4,178 MW of capacity, reached financial close.

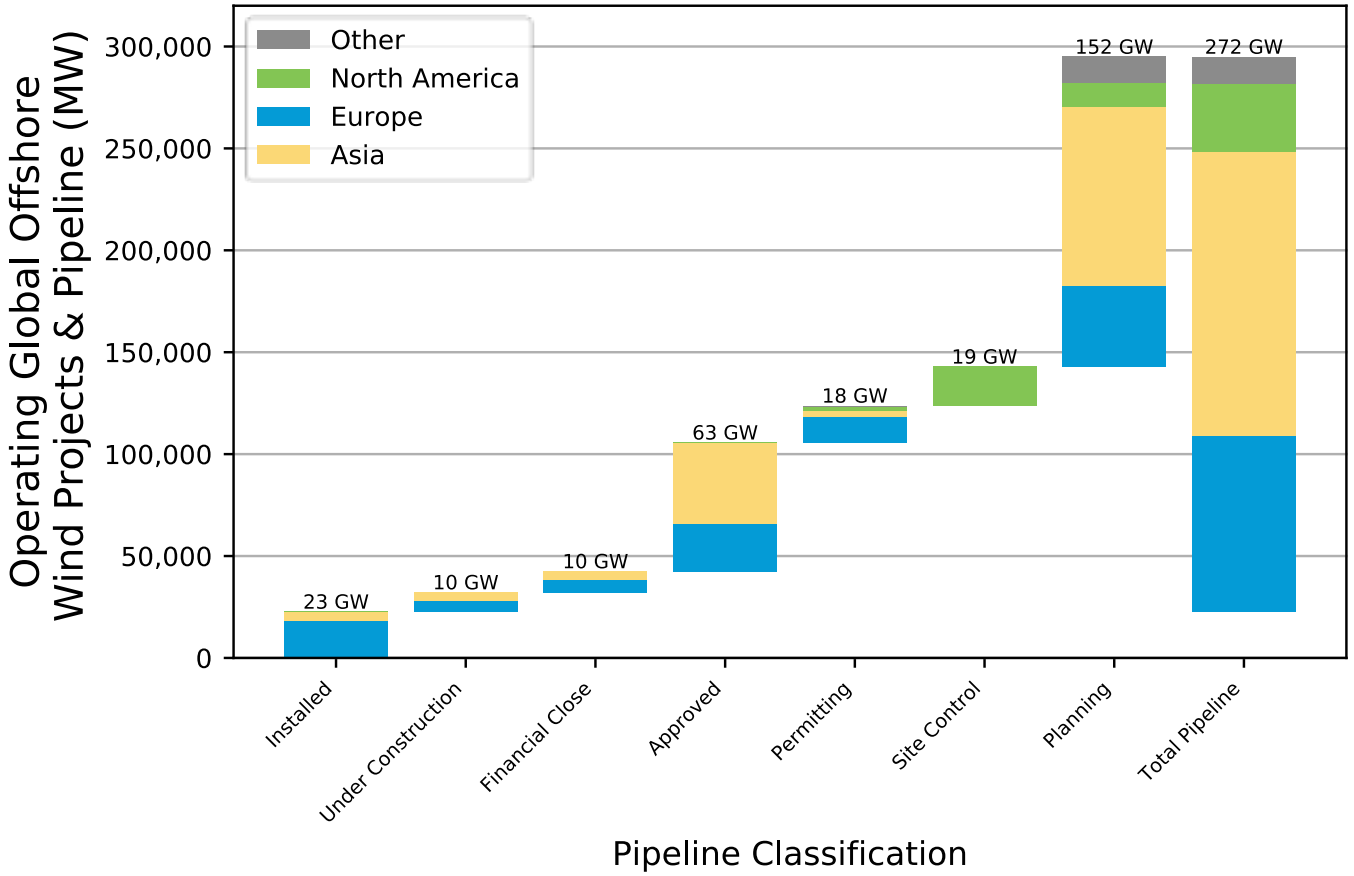


Global Cumulative Capacity To Reach 63 GW by 2024

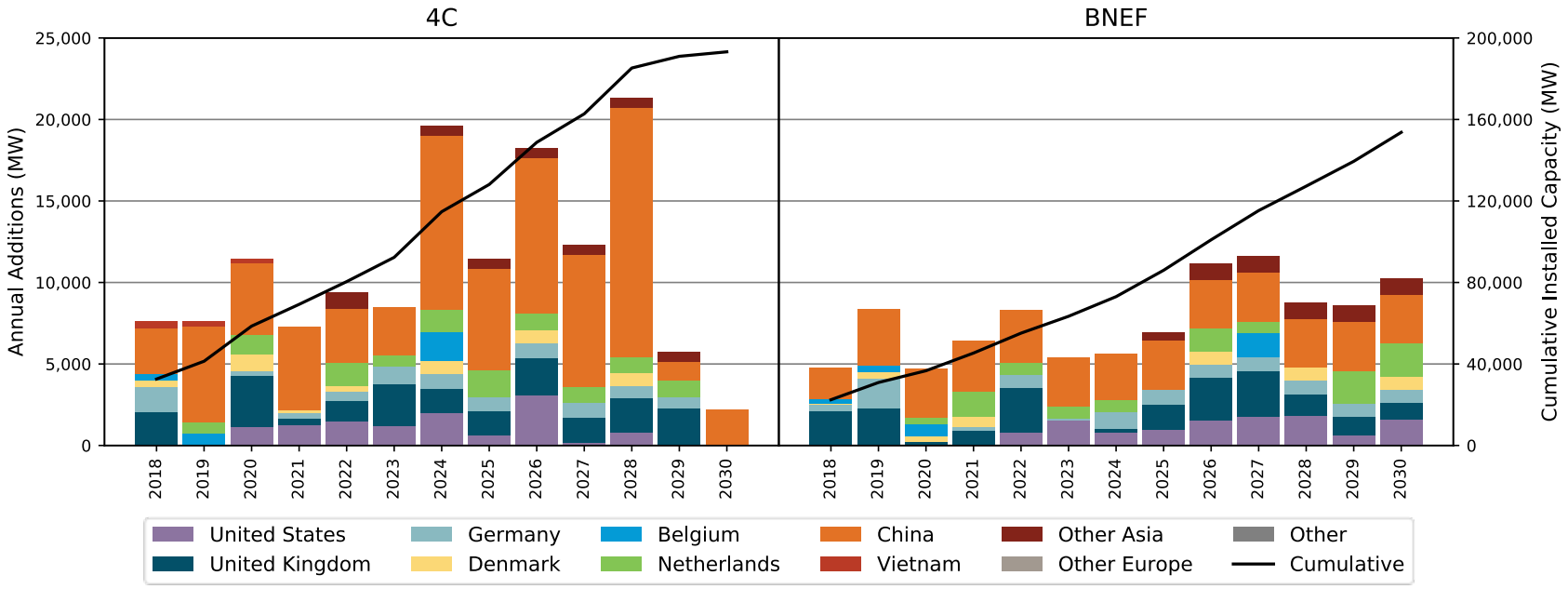


Global Offshore Wind Project Pipeline Capacity at 272 GW

- The global pipeline capacity grew by 42 GW in 2018 to reach 272 GW.
- The increase in pipeline capacity is attributed to many new Asian projects that recently entered the planning phase.



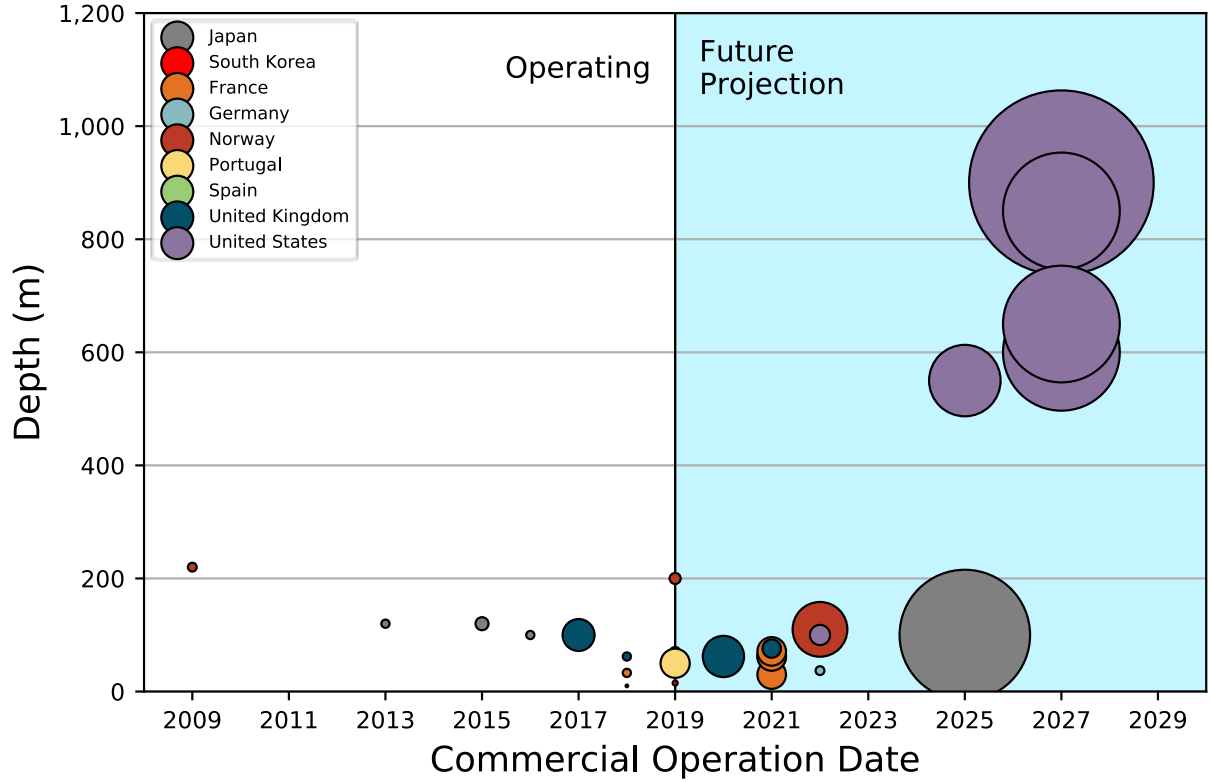
Global Forecasts Predict 154 to 193 GW of Offshore Wind by 2030



- The estimated growth of the Chinese offshore wind market is likely to shift market dynamics out to 2030.
- BNEF and 4C Offshore forecast China will deploy between 41 and 84 GW by 2030.
- Forecasts predict European developers will build projects at a similar rate relative to today, with Europe holding about 47% of the total installed global offshore wind capacity in 2030.

Floating Offshore Wind Projects Are Predicted To Increase in Size and Push to Deeper Water

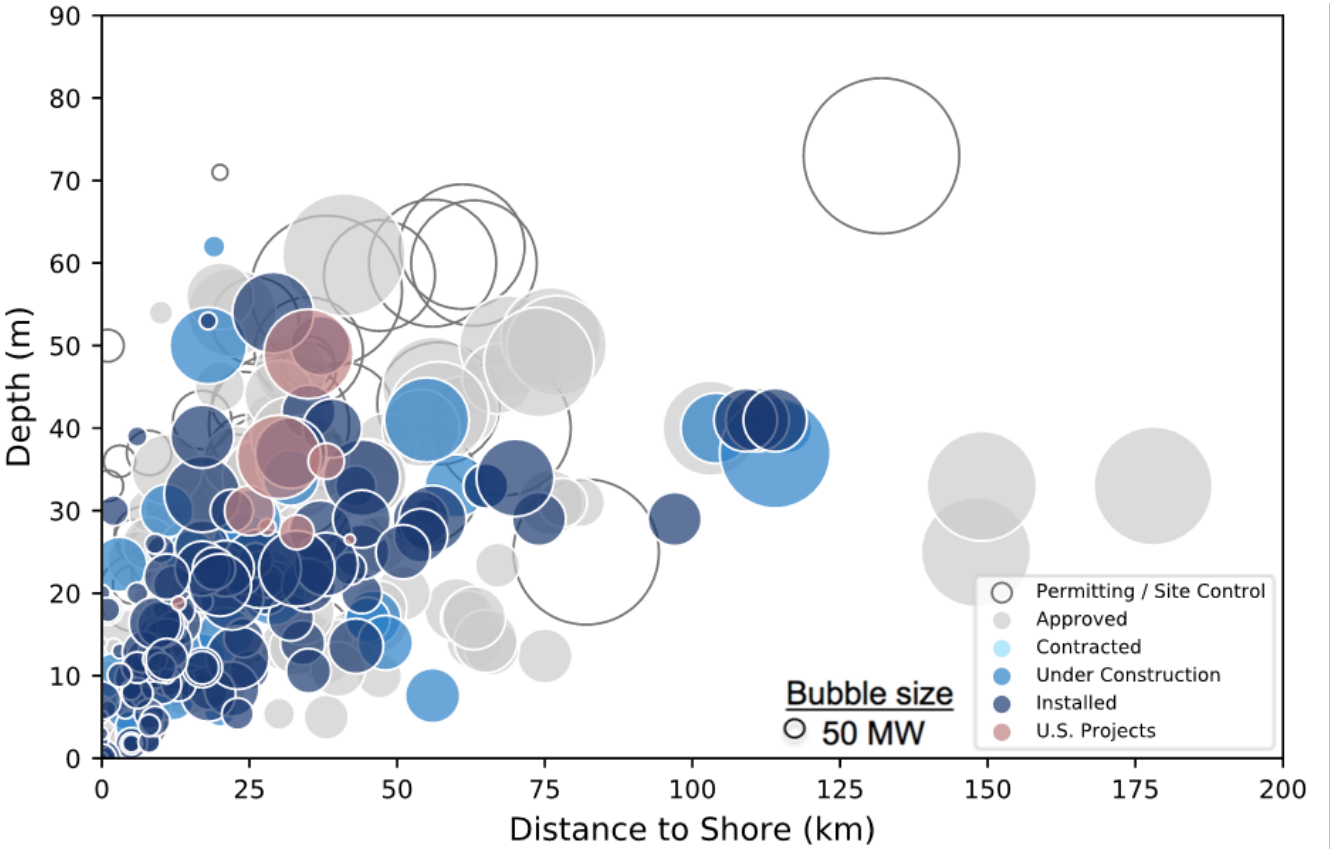
- The 2018 global floating offshore wind pipeline had approximately 4,888 MW of capacity, growing by 2,000 MW relative to the *2017 Offshore Wind Technologies Market Report Update*.
- There are eight floating wind projects installed globally with 46 MW of total capacity; five projects (37 MW) are in Europe and three (9 MW) are in Asia.
- There are 14 floating projects totaling about 200 MW that are under construction or have achieved either financial close or regulatory approval.



Offshore Wind Technology Trends

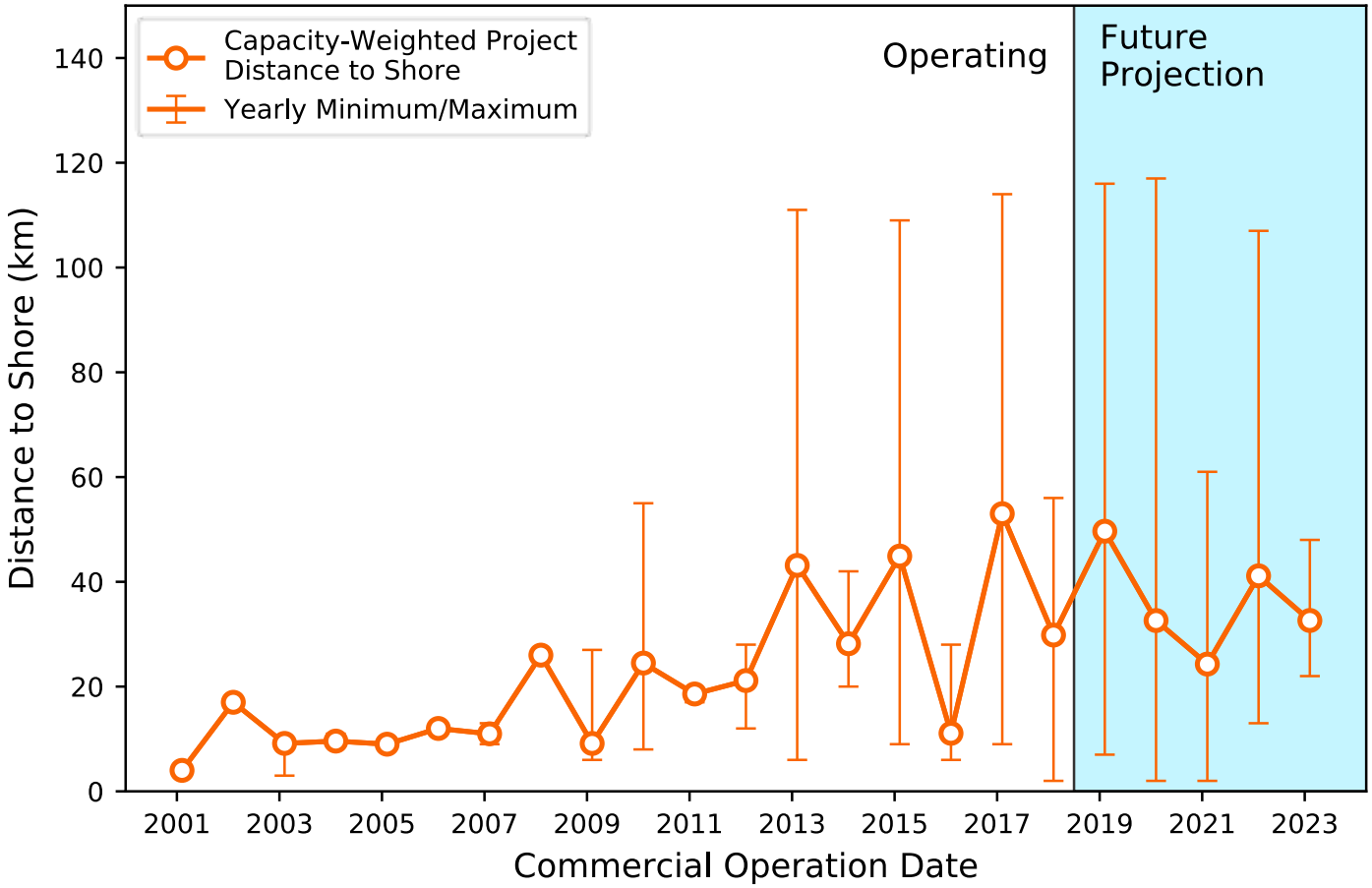
Fixed–Bottom Projects Continue to be Larger in Size, Farther from Shore, and in Deeper Water

- Fixed-bottom projects are being deployed in deeper waters farther from shore.
- Developers are building larger projects and taking advantage of economies of scale to reduce cost.
- U.S. projects are in a narrower band in their distance to shore, constrained by geography of lease areas.



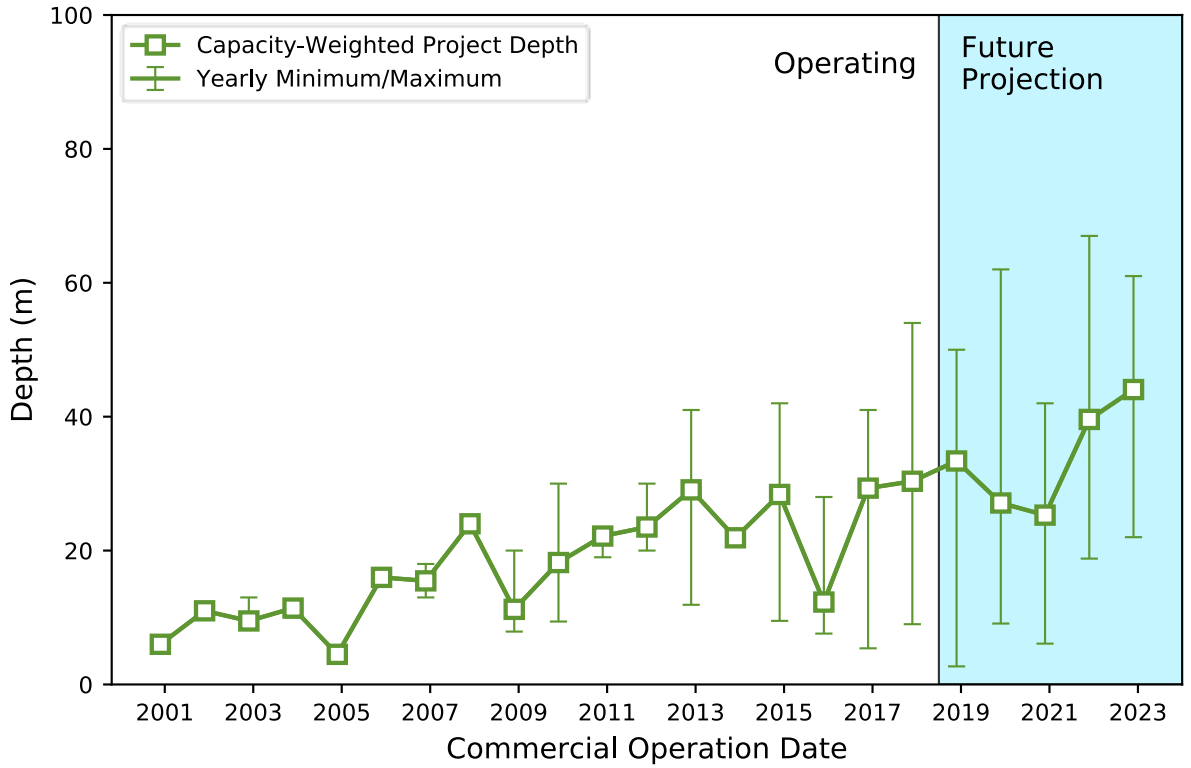
Global Projects Are Increasingly Farther from Shore

Average distance to shore is not changing much but some projects are moving very far from shore (>100 km), which is made possible by high-voltage direct-electric current export systems.



Projects Increasingly Deployed in Deeper Water

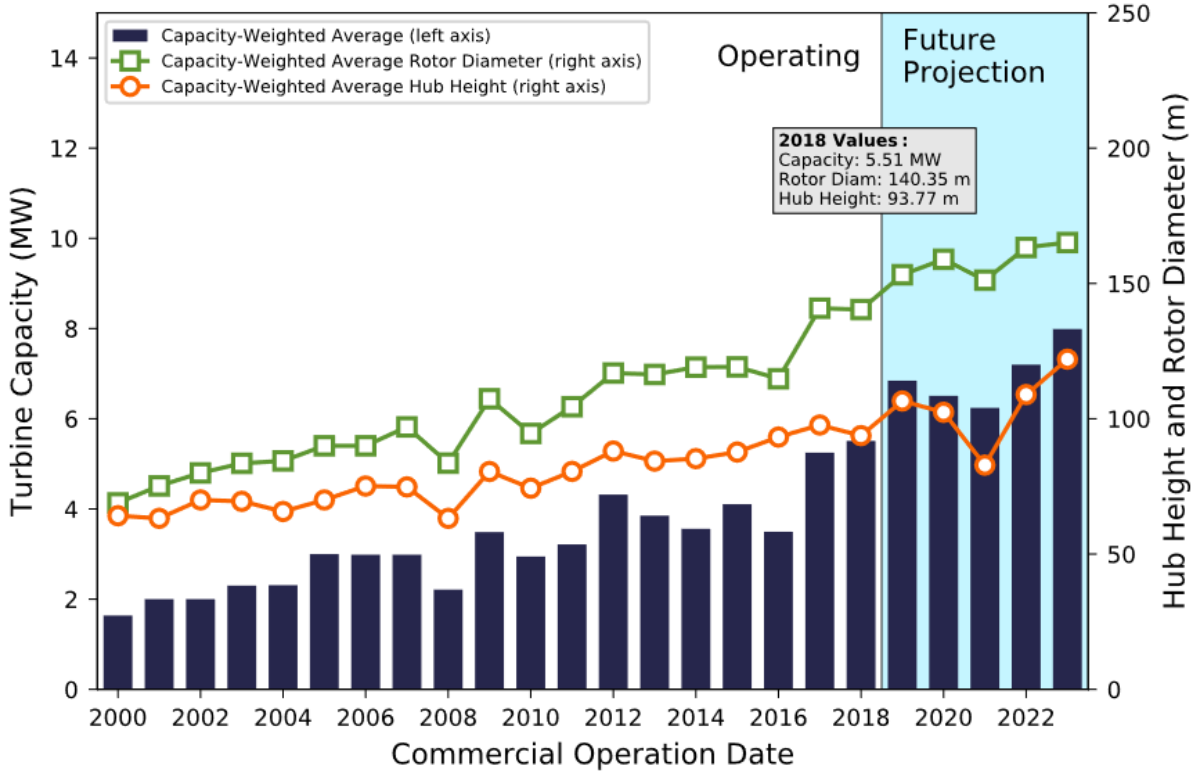
- New technology and experience increase access to greater water depths, but fixed-bottom turbines will pay a premium.
- The trend toward deeper water is more defined than toward greater distances to shore.
- Deployments have already been made in 50-meter (m) depths, and installations over 60-m depths are planned before 2024.
- Variability increased because of Asian developments in shallow water (less than 40 m).



Offshore Turbines Continue To Increase in Capacity, Height, and Rotor Diameter

- Increasing turbine size is a major factor attributed to cost declines in offshore wind. Larger-capacity turbines yield lower balance-of-plant costs, fewer installations, and lower maintenance, as well as more energy yield per unit of ocean area.

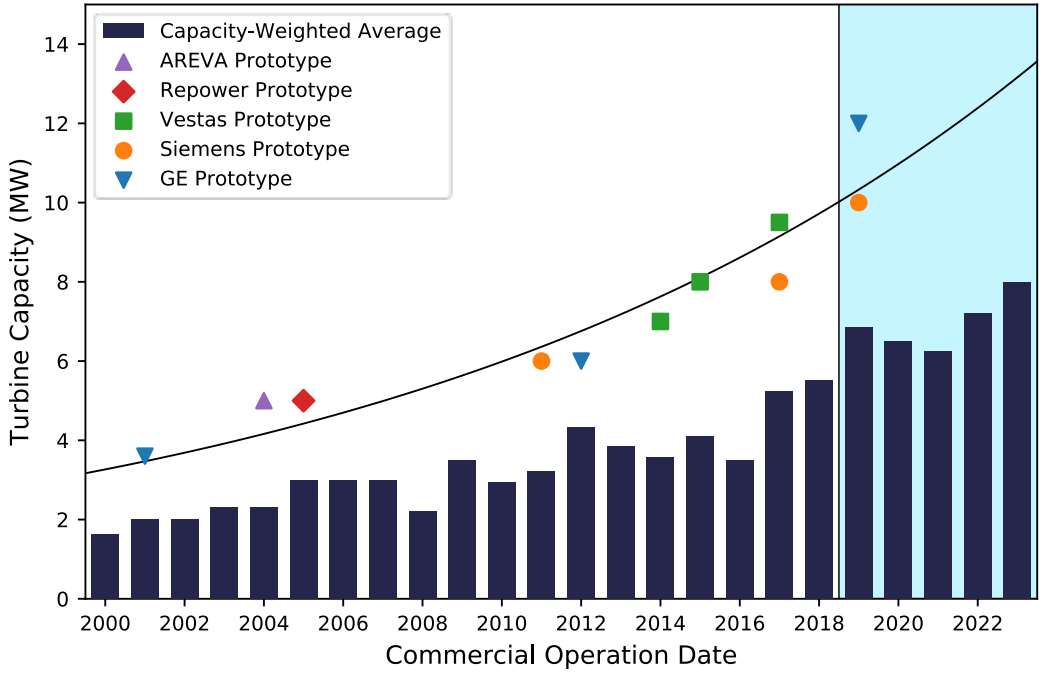
- Developers will generally select the largest turbine available. At the end of 2018, the largest turbine installed was the MHI-Vestas V164 – 8.8-MW turbine at the Aberdeen Bay (European Offshore Wind Development Centre) project in Scotland.



New Turbine Prototypes Foretell Continued Turbine Growth to 12 MW and Beyond

- In March 2018, GE announced the new 12-MW Haliade-X turbine prototype will be installed in Rotterdam in 2019 and is planned to be on the market in 2021.The turbine is first in class, with a 12-MW direct-drive generator, 220-m rotor, and 140-m hub height.

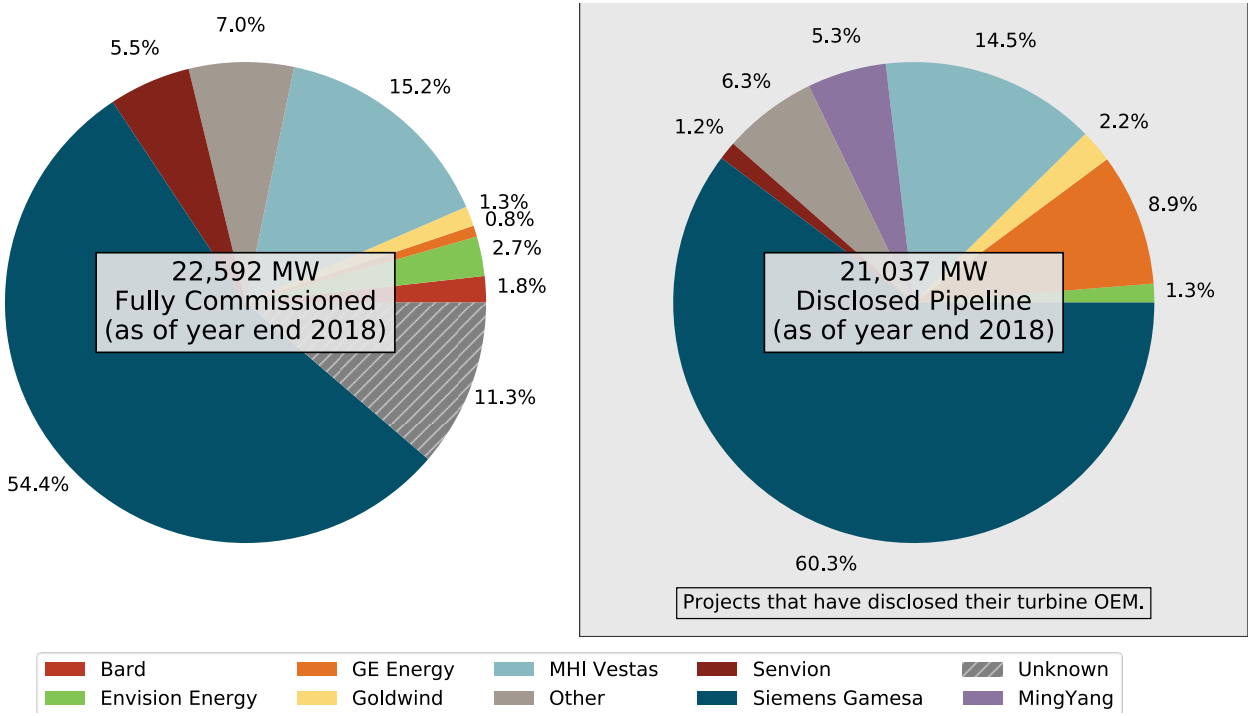
- In January 2019, Siemens Gamesa announced the development of the SG10.0-193 DD turbine—a 10-MW direct-drive turbine with a 193-m rotor—which is planned to be ready for market in 2022.



Sources: Ragheb (2019), GE (2018), de Vries (2012), Composites World (2014), Adwen GmbH (2019), Power Engineering (2005), 4C Offshore (2017), Siemens (2013, 2019), Dvorak (2017)

Siemens Gamesa and MHI Vestas Dominate Offshore Turbine Market

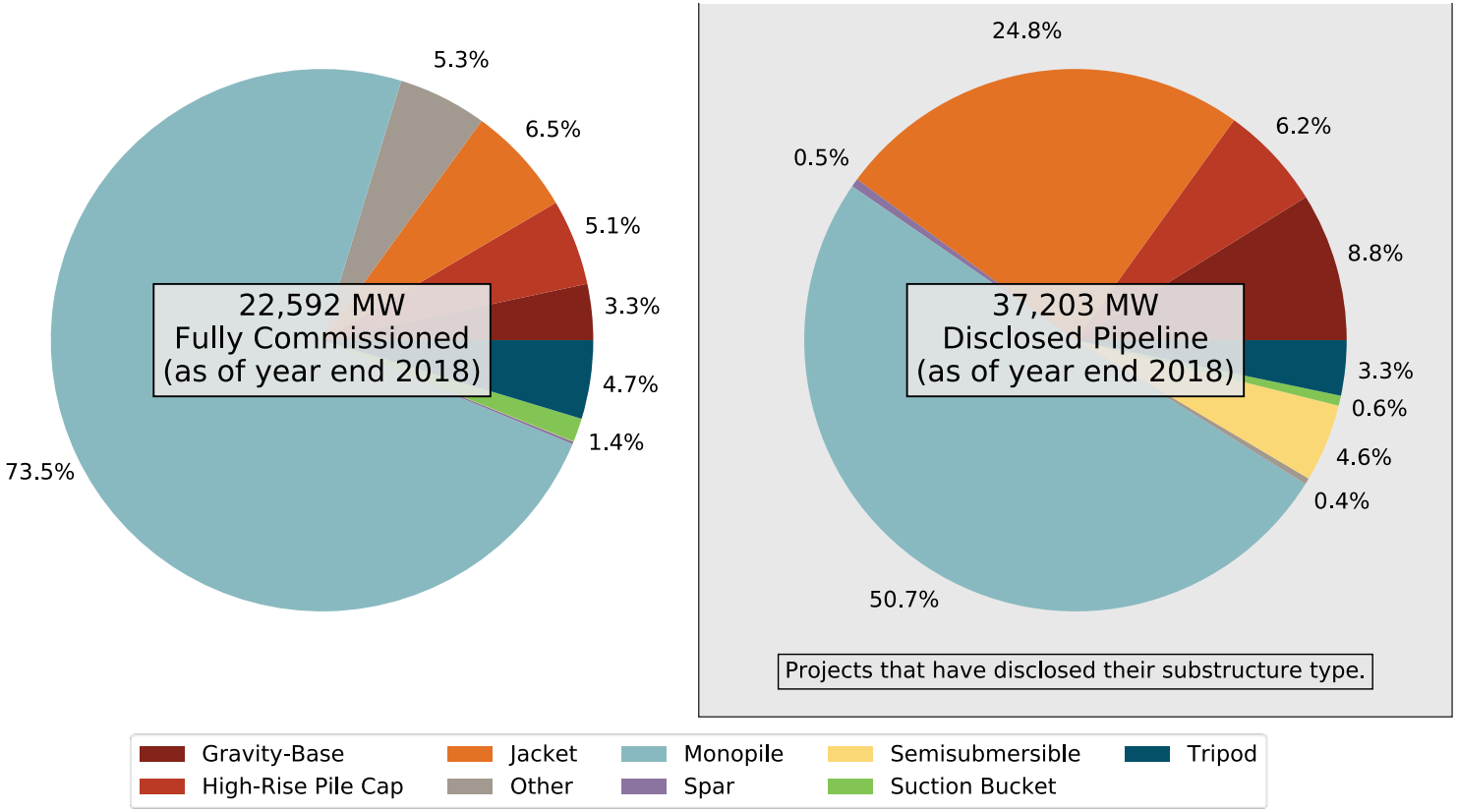
- Siemens Gamesa continues to be the largest global supplier of offshore wind turbines, with 55% of installed capacity (12.3 GW) operating.
- MHI Vestas has just over a 15% share of installed offshore wind capacity.
- The Siemens Gamesa share of global capacity is projected to grow to 60.3% for new projects, whereas Vestas is expected to hold about 14.5%.
- GE's share is projected to grow to 8.9%.
- Goldwind and Ming Yang are building strength in the emerging Chinese market.



OEM: original equipment manufacturer

Monopiles Are the Preferred Foundation Type; More Substructure Diversity Is Predicted in the Future

- Monopiles represented over 70% of total installed offshore wind capacity globally at the end of 2018.
- Deeper water is pushing the industry toward more diverse foundation types including jackets, gravity bases, and suction buckets.
- For depths greater than 60 m, the industry is developing multiple types of floating substructures.



Array Cable Supply Divided Between Three Major Companies

- Forty-two percent of new intra-array cables energized in 2018 were supplied by Nexans, whereas JDR Cable Systems supplied 32.1% and Prysmian supplied 16.1%.

- Continued development of several offshore projects in Southeast Asia has created new market opportunities for the undersea cable industry, which is expected to grow in the future.

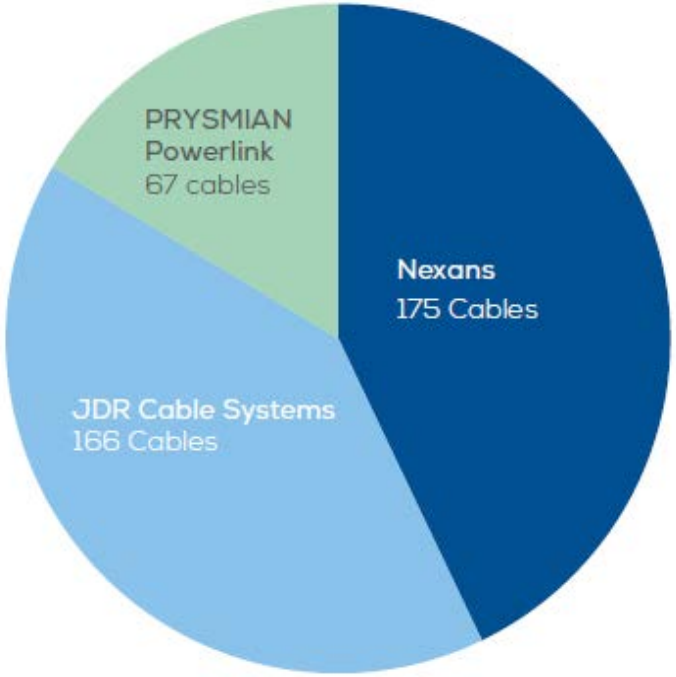


Chart courtesy of WindEurope 2019

NKT Group Leads Export Cable Market in 2018

Eight export cables manufactured by NKT Group were energized in 2018, representing 53.3% of the annual market. Prysmian, Ls Cable & System, and JDR Cable Systems each had about a 13.3% share, and Nexans represented the remaining 6.7%.

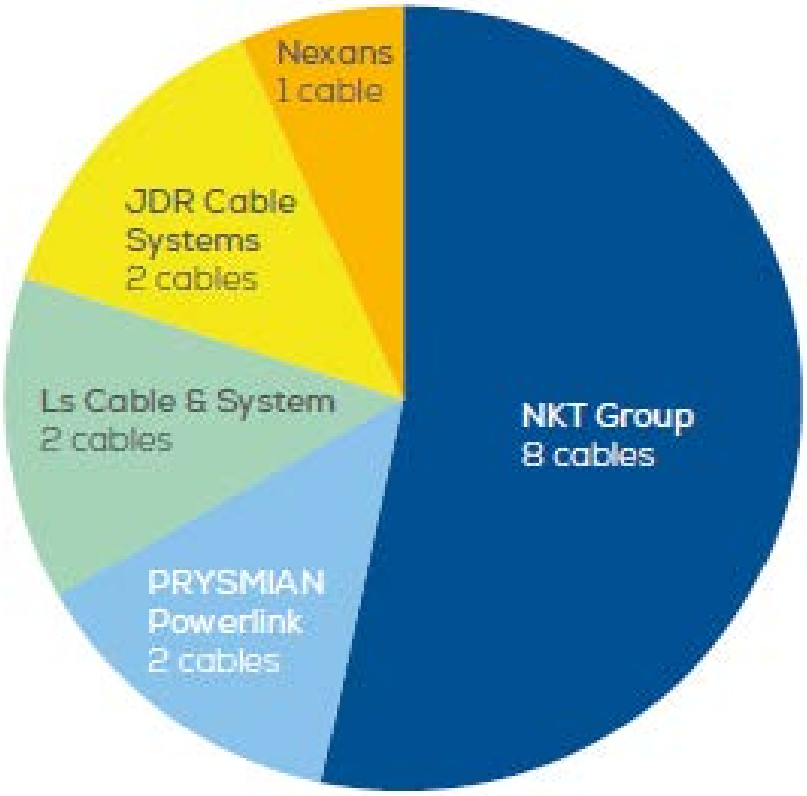


Chart courtesy of WindEurope 2019

Offshore Wind Power Plant with Battery Energy Storage System

- A battery energy storage system was coupled with Equinor's first floating offshore wind power plant.
- The project is the first of its kind in the world.
- The battery energy storage system technologies can provide a wide range of utility-controlled and self-directed services.

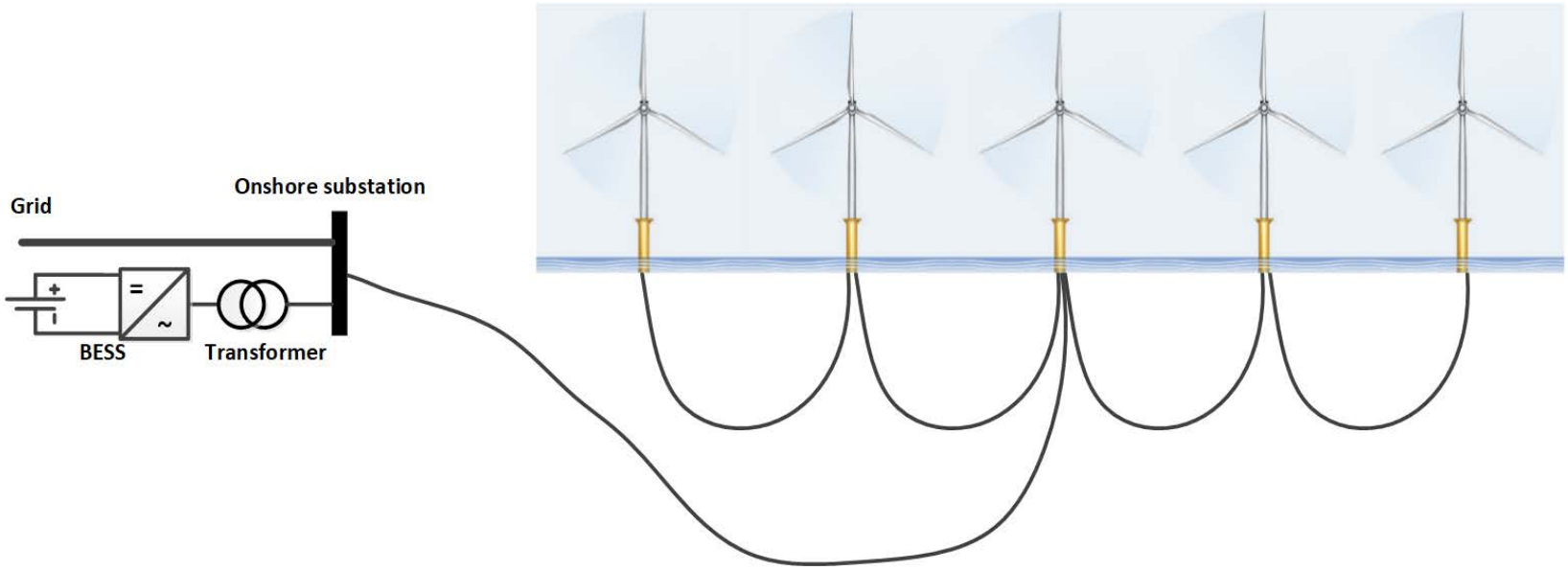
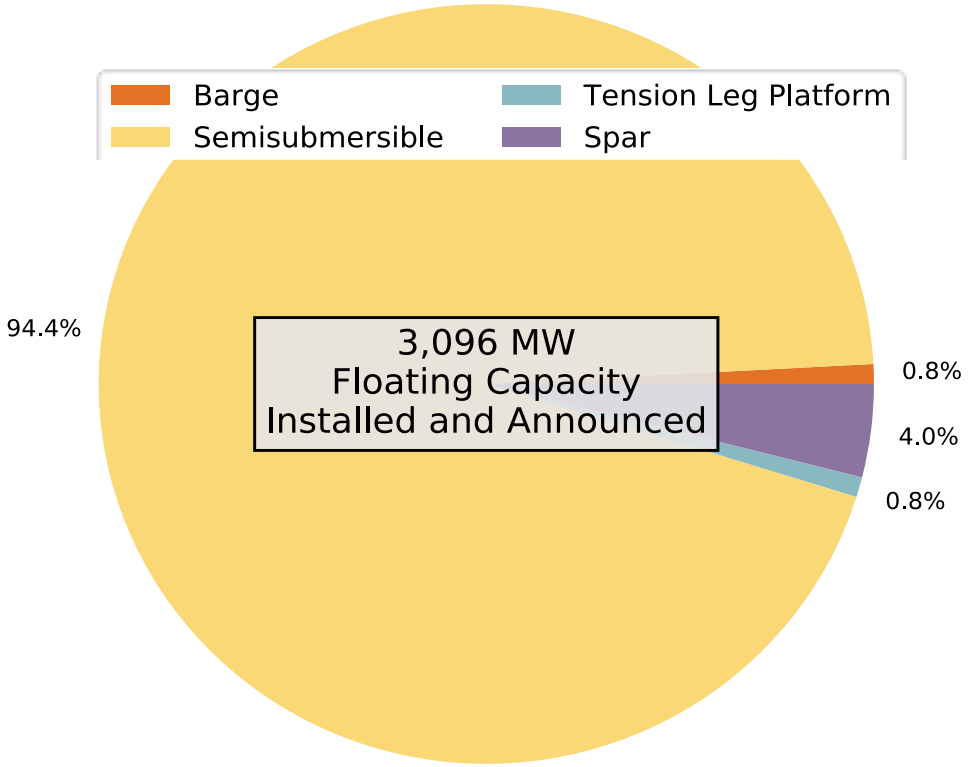


Illustration by NREL

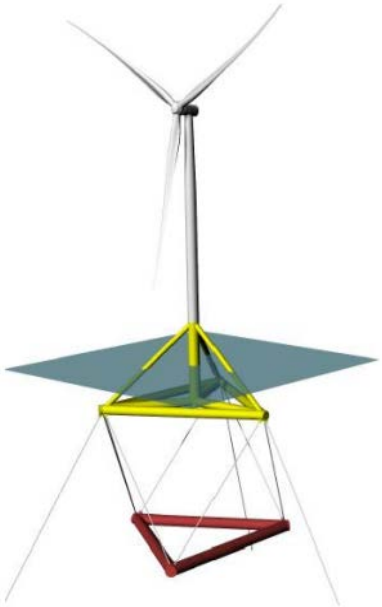
Semisubmersibles Dominate in Nascent Floating Market

- In 2018, 94% of floating projects reporting plan to use semisubmersible substructures.
- Semisubmersibles allow full assembly and commissioning at quayside, as well as tow-out to an offshore station without the use of heavy-lift installation vessels.
- Approximately 4% use or plan to use spars (e.g., Equinor's 30-MW floating wind plant).
- The remaining substructures are tension leg platforms and barges.
- Hybrid substructures are beginning to emerge.



Next-Generation Hybrid Floating Substructures May Compete with Semisubmersibles and Lower Costs

- Hybrid platform designs in the next generation of floating substructures have desirable characteristics of the semisubmersible but strive to be lighter.
- In 2018, Stiesdal Offshore Technologies introduced the TetraSpar; a stable floating platform with low draft for inshore assembly and a deployable ballast weight.
- SBM has developed a lightweight tension leg platform that is stable during assembly and load-out.



SOT TetraSpar

SBM Tension Leg Platform

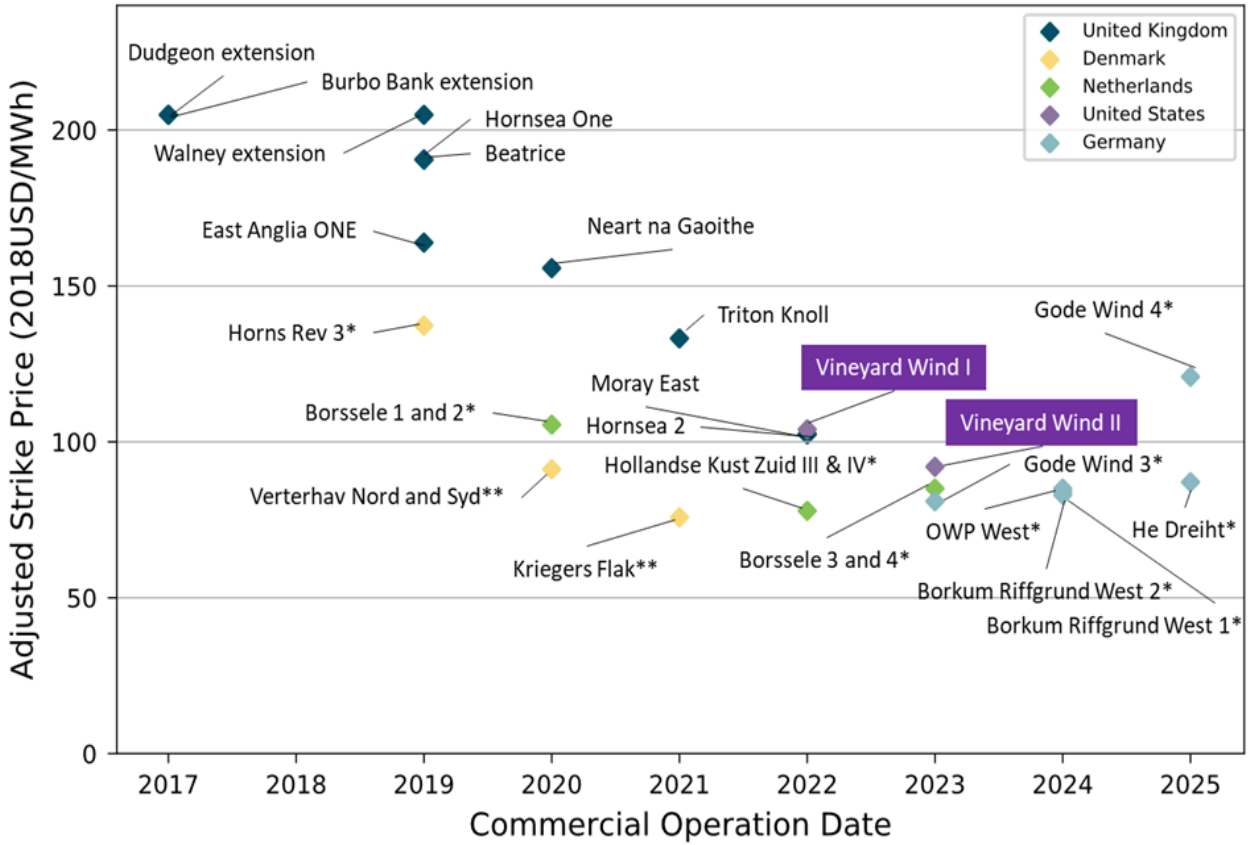
Images courtesy of Stiesdal Offshore Technologies (left) and SBM Offshore (right)

Cost and Pricing Trends

Vineyard Wind Power Purchase Agreement Terms Match European Fixed-Bottom Auction Prices

- European strike price data (adjusted for comparisons) show declining prices from about $200/MWh (2017–2019 commercial operation date [COD]) to about $75/MWh for projects with a 2024–2025 COD.

- Vineyard Wind (800 MW), likely the first commercial-scale U.S. offshore wind project (COD in 2022–2023), signed a 20-year PPA at a price that aligns with European projects for the same years.



Notes: *Grid and development costs added; **Grid costs added and contract length adjusted; includes data for commercial-scale projects only

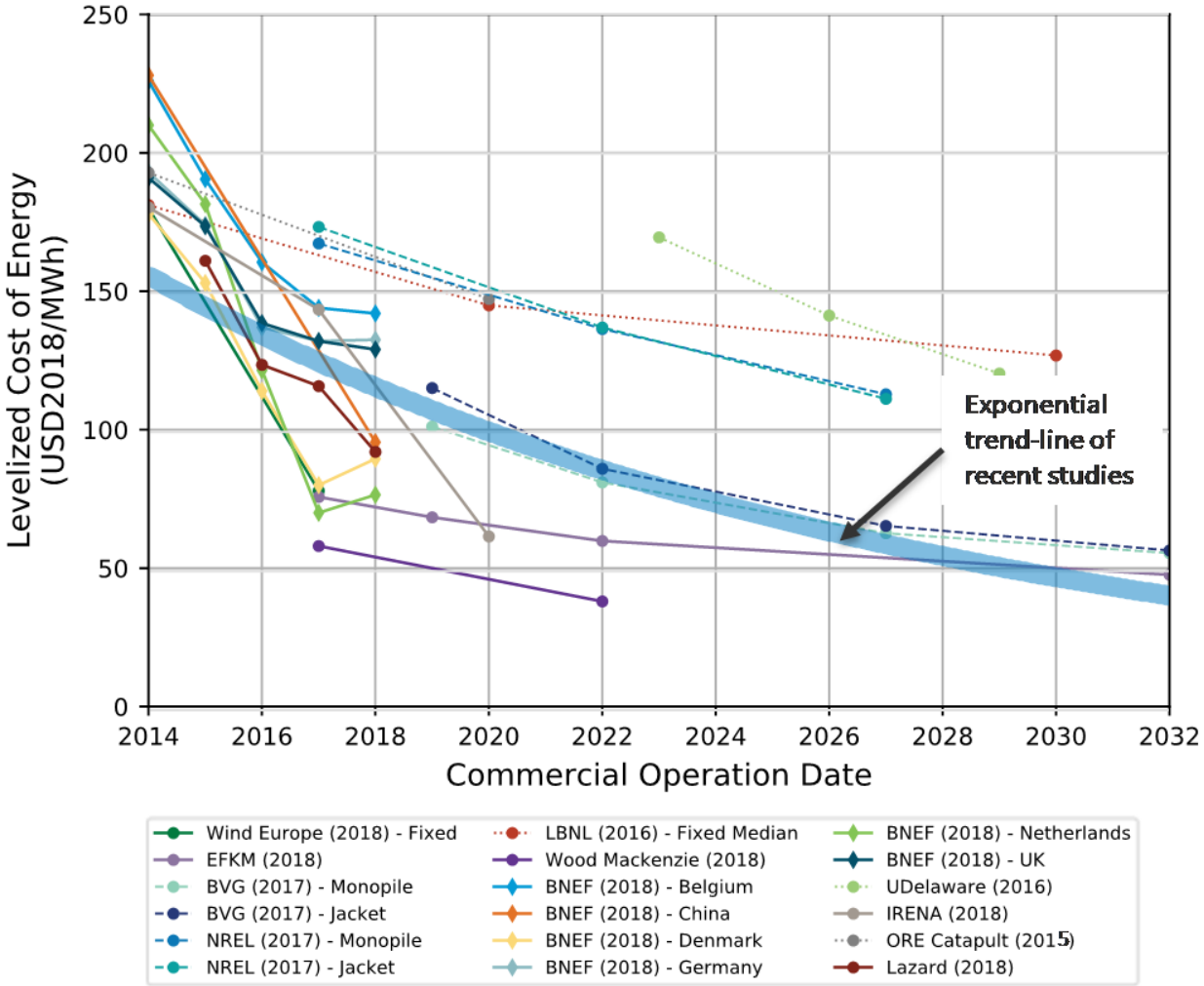
2018 European Offshore Wind Auction Prices Upheld Cost Reduction Trajectory from Previous Cost Declines

- **Netherlands**: The Hollandse Kust Zuid I and II projects (700–750 MW) received an auction award for a zero-subsidy bid on March 19, 2018. Hollandse Kust (zuid) wind farms III and IV (700 MW) tenders were awarded in March 2019. The projects are expected to enter commercial operation by 2023.
- **Germany:** The first two rounds of offshore wind auctions were held under the § 26 Offshore Wind Act (WindSeeG) during 2017–2018. No further auction activity is planned for 3 years.
- **United Kingdom:** Third contract-for-difference allocation round ("AR3") planned in May 2019. The tender budget is specified at £ 60 million, with a delivery cap of 6 GW.
- **Denmark:** DK selected the location of (800 MW) off Nissum Fjord to be auctioned during 2019, with a COD between 2024 and 2027.

2018 European Auction Results

Project	Country	Auction	Award Date	Capacity (MW)	Auction Price (2016$/MWh)	Adjusted Auction Price Estimate (2016$/MWh)
Borkum Riffgrund West 1	Germany	Second Auction (§ 26 WindSeeG)	04/27/18	420	0	~79
Gode Wind 4				132	118	~115
Hollandse Kust Zuid III and IV	Netherlands		03/19/18	700	0	~74
Note: For more details on these auctions, see Beiter et al. (2018).						

Fixed-Bottom Levelized Cost of Energy Forecasted To Decline to $50/MWh by 2030

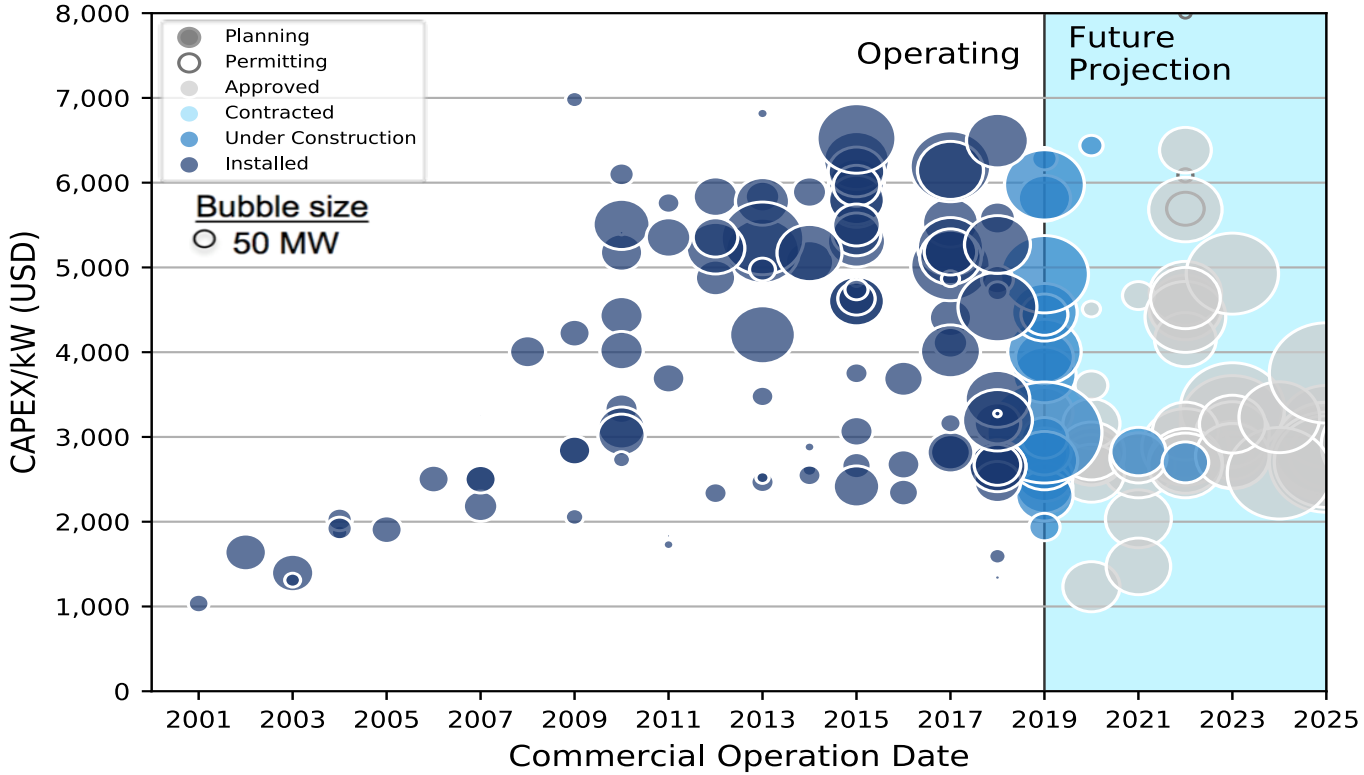


- Analysts agree the cost reduction trend for fixed-bottom projects will continue globally and in the United States.
- Levelized cost of energy projections from the most recent studies suggest a decrease from $120/MWh in 2018 to $50/MWh by 2030.

Sources: WindEurope (2018), Danish Ministry of Energy, Utilities and Climate (2018), Valpy et al. (2017), Beiter et al. (2017), Wiser et al. (2016), Barla (2018), BNEF (2018b, 2018c), Kempton et al. (2016), IRENA (2018), ORE Catapult (2015), and Lazard (2018)

Offshore Wind Capital Costs Continue To Decline Globally

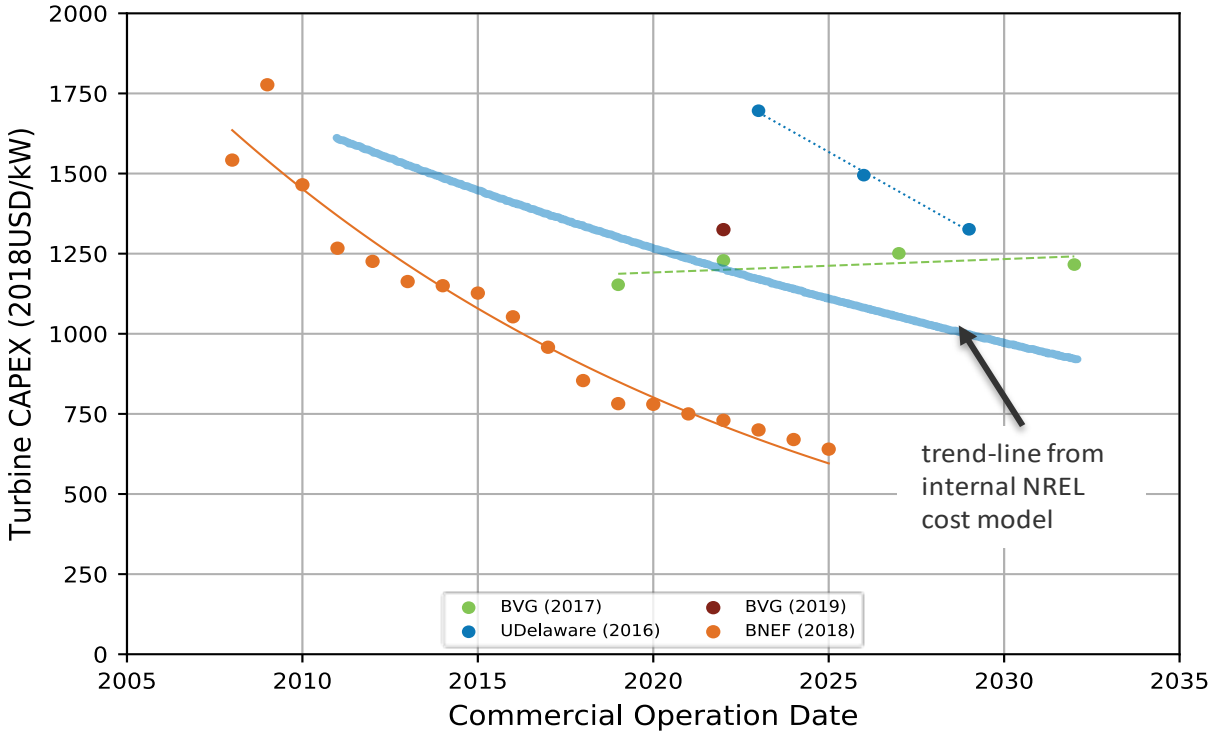
- In 2018, the capacity-weighted average capital expenditure (CapEx) was estimated at $4,350/kilowatt (kW) globally.
- For projects with a COD in 2018 and capacities greater than 100 MW, CapEx falls into a range from $2,470/kW (Jiangsu Luneng Dongtai project, China [200 MW]) to $6,500/kW (Galloper project, United Kingdom [353 MW]).
- Data indicate a decline of CapEx to a range of $2,500–$4,000/kW between 2020 and 2030.



Turbine Cost Projections Decrease Despite Turbine Upscaling

- Limited cost studies indicate turbine CapEx ranges between $800/kW and $1,200/kW in 2018–2019.

- Innovations such as the use of lightweight materials, advanced manufacturing methods, systemwide load control, and economies of scale in production and delivery, may allow turbine manufacturers to offset cost increases from upscaling.



Sources: Valpy et al. (2017), Kempton et al. (2016), BVG Associates (2019), and BNEF (2018e)

Financing Conditions in Europe Continue Favorable Trends

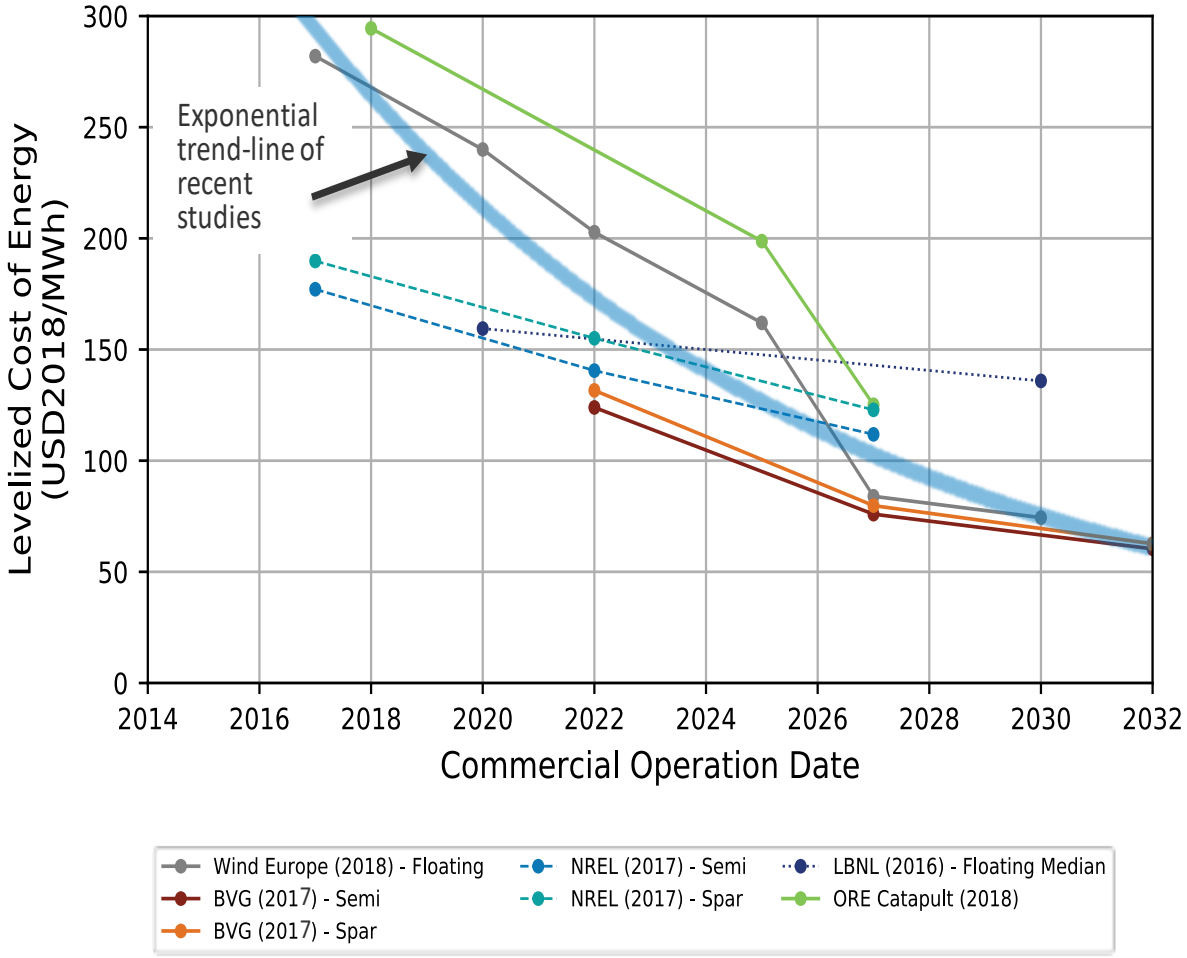
- During 2018, offshore wind projects in Europe and Asia continued to access low-cost capital.
- The share of debt (versus equity) has consistently been at 70% or above since 2012 for European projects, including in 2018.
- Debt rates for global offshore wind financing remain at historically low levels, ranging between 3% and 4% for 15-year debt terms.
- U.S. investment tax credits are being phased out by 2020, thereby limiting these benefits to near-term offshore wind projects.

Offshore Wind Financing Trends

Year	Debt-to-Equity Ratio	Pricing[1]
2006-2007	60:40	150-200 bps
2009-2011	65:35	300-350 bps
2012-2013	70:30	200-250 bps
2014-2015	70:30	200-250 bps
2016-2017	75:25	150-225 bps
2018	70:30	120-175 bps

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

Levelized Cost of Energy for Floating Projects Projected To Decline to $75/MWh by 2030



- The most recent levelized cost of energy projections from industry analysts predict floating cost reductions to $75/MWh by 2030.
- Technological innovations and commercial progress benefits from fixed-bottom wind systems could help accelerate floating wind cost declines.

Sources: WindEurope (2018), Hundleby et al. (2017), Beiter et al. (2017), Wiser et al. (2016), ORE Catapult (2018)

References

- 4C Offshore. 2017. “Siemen’s 8-megawatt wind turbine up and running.” January 30, 2017. https://www.4coffshore.com/news/siemens-8-megawatt-wind-turbine-up-and-running-nid5241.html.
- 4C Offshore. 2018. Offshore Wind Farms Intelligence. http://www.4coffshore.com/windfarms/request.aspx?id=owfdb.
- 4C Offshore. 2019. Global Offshore Wind Farms Intelligence. http://www.4coffshore.com/windfarms/request.aspx?id=owfdb.
- Adwen GmbH. 2019. “Adwen (company).” Accessed April 26, 2019. https://en.wikipedia.org/wiki/Adwen_(company).
- Barla, Sashi. 2018. “Global Wind Turbine Technology Trends.” Market Report. Wood Mackenzie.
- Beiter et al. 2017. *An Assessment of the Economic Potential of Offshore Wind in the United States from 2015 to 2030*. NREL/TP-6A20-67675. https://www.nrel.gov/docs/fy17osti/67675.pdf.
- Beiter, Philipp, Paul Spitsen, Jake Nunemaker, Tian, Walter Musial, Eric Lantz, and Vahan Gevorgian. 2018. *2017 Offshore Wind Technologies Market Update*. Washington, D.C.: U.S. Department of Energy Office of Energy Efficiency & Renewable Energy. https://www.energy.gov/eere/wind/downloads/2017-offshore-wind-technologies-market-update.
- Bloomberg New Energy Finance (BNEF). 2018b. “Current LCOE by Technology.” https://www.bnef.com/core/lcoe?tab=Current%20LCOE%20by%20Technology.
- BNEF 2018c. “Historic LCOEs: 2H 2018.” https://www.bnef.com/core/lcoe?tab=Historic%20LCOE.
- BNEF. 2018e. “2H 2018 Wind Turbine Price Index.” Accessed February 1, 2019. https://www.bnef.com/core/.
- BVG Associates. 2019. “Guide to an Offshore Wind Farm.” Published on behalf of The Crown Estate and the Offshore Renewable Energy Catapult. https://www.thecrownestate.co.uk/media/2860/guide-to-offshore-wind-farm-2019.pdf.
- Composites World 2014. “Vestas 8-MW turbine begins operation.” February 3, 2014. https://www.compositesworld.com/news/vestas-8-mw-turbine-begins-operation.
- Danish Ministry of Energy, Utilities and Climate. 2018. “Note on technology costs for offshore wind farms and the background for updating CAPEX and OPEX in the technology catalogue datasheets.” https://ens.dk/sites/ens.dk/files/Analyser/havvindsnotat_translation_eng_final.pdf.
- de Vries, E. 2012. “Close up - Alstom Haliade 6MW prototype.” *Windpower Monthly*. July 11, 2012. https://www.windpowermonthly.com/article/1140792/close---alstom-haliade-6mw-prototype.
- Dvorak, P. 2017. “Inching toward 10 MHI Vestas unwraps a 9.5-MW design.” *Windpower Engineering*. August 2017. https://www.windpowerengineering.com/design/inching-toward-10-mhi-vestas-unwraps-9-5-mw-design.

References (continued)

- GE (General Electric). 2018a. "GE announces Haliade-X, the world's most powerful offshore wind turbine." March 1, 2018. Accessed May 2018. https://www.genewsroom.com/press-releases/ge-announces-haliade-x-worlds-most-powerful-offshore-wind-turbine-284260.
- GE. 2018b. "Haliade-X Offshore Wind Turbine Platform." Accessed May 2018. https://www.ge.com/renewableenergy/wind-energy/turbines/haliade-x-offshore-turbine.
- Guillet, Jerome. 2018. "Who will fund U.S. Offshore Wind—and on what terms?" Presented at the Offshore Wind Implementation Summit, Teaneck, New Jersey, September 7. https://green-giraffe.eu/presentations/who-will-fund-us-offshore-wind-%E2%80%93-and-what-terms.
- Hundleby, Giles, Kate Freeman, Andy Logan, and Ciaran Frost. 2017. "Floating Offshore: 55 Technology Innovations That Will Have Greater Impact on Reducing the Cost of Electricity from European Floating Offshore Wind Farms." KiC InnoEnergy and BVG Associates. http://www.innoenergy.com/new-floating-offshore-wind-report-55-technology-innovations-that-will-impact-the-lcoe-in-floating-offshore-wind-farms/.
- International Renewable Energy Agency (IRENA). 2018. *Offshore innovation widens renewable energy options: Opportunities, challenges and the vital role of international co-operation to spur the global energy transformation*. Brief to G7 policymakers. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2018/Sep/IRENA_offshore_wind_brief_G7_2018.pdf.
- Kempton, W., S. McClellan, and D. Ozkan. 2016. *Massachusetts Offshore Wind Future Cost Study*. Technical Report. Special Initiative on Offshore Wind. University of Delaware. https://www.ceoe.udel.edu/File%20Library/About/SIOW/MA-Offshore-Wind-Future-Cost-Study-rev-4-April-16.pdf.
- Lazard. 2018. "Levelized Cost of Energy Analysis, Version 12.0." https://www.lazard.com/media/450784/lazards-levelized-cost-of-energy-version-120-vfinal.pdf.
- MAKE Consulting. 2018. Global Offshore Wind Power Project Database. http://www.consultmake.com/research/databases.
- Mass Live. 2018. "Vineyard Wind signs $9 million lease at New Bedford Commerce Pier." October 23, 2018. https://www.masslive.com/news/2018/10/vineyard_wind_signs_9_million.html.
- McClellan. 2019. "Supply Chain Contracting Forecast for U.S. Offshore Wind Power." Special Initiative on Offshore Wind White Paper. Accessed July 2019. https://www.ceoe.udel.edu/File%20Library/About/SIOW/SIOW-White-Paper---Supply-Chain-Contracting-Forecast-for-US-Offshore-Wind-Power-FINAL.pdf.

References (continued)

- ORE Catapult. 2015. “Cost Reduction Monitoring Framework: Summary Report to the Offshore Wind Programme Board.” ORE Catapult and The Crown Estate. https://ore.catapult.org.uk/app/uploads/2018/02/Cost-Reduction-Monitoring-Framework-2015.-Summary-report-to-the-OWPB.pdf.
- ORE Catapult. 2018. “Macroeconomic Benefits of Floating Offshore Wind in the UK.” Glasgow, UK: Crown Estate Scotland. https://www.crownestatescotland.com/maps-and-publications/download/219.
- Power Engineering. 2005. “REpower 5 MW turbines to power Borkum West offshore wind park.” September 7, 2005. https://www.power-eng.com/articles/2005/09/repower-5-mw-turbines-to-power-borkum-west-offshore-wind-park.html.
- Ragheb, M. 2019. Modern Wind Generators. http://mragheb.com/NPRE%20475%20Wind%20Power%20Systems/Modern%20Wind%20Generators.pdf.
- Siemens. 2013. *Fact Sheet: The new SWT-6.0; The next-generation offshore wind turbine. Status: February 2013*. https://www.siemens.com/press/pool/de/feature/2013/energy/2013-01-rotorblade/factsheet-6mw-e.pdf.
- Siemens. 2019. “Siemens Gamesa launches 10 MW offshore wind turbine; annual energy production (AEP) increase of 30% vs. predecessor.” https://www.siemensgamesa.com/en-int/newsroom/2019/01/new-siemens-gamesa-10-mw-offshore-wind-turbine-sg-10-0-193-dd.
- Valpy, B. G. Hundleby, K. Freeman, A. Roberts, A. Logan. 2017. *Future renewable energy costs: Offshore wind; 57 technology innovations that will have greater impact on reducing the cost of electricity from European offshore wind farms*. InnoEnergy and BVG Associates. http://www.innoenergy.com/wp-content/uploads/2014/09/InnoEnergy-Offshore-Wind-anticipated-innovations-impact-2017_A4.pdf.
- WindEurope. 2018. Wind in power 2017. https://windeurope.org/about-wind/statistics/european/wind-in-power-2017/.
- WindEurope. 2019. *Offshore Wind in Europe: Key trends and statistics 2018*. February 2019. https://windeurope.org/about-wind/statistics/offshore/european-offshore-wind-industry-key-trends-statistics-2018/.
- Wiser, R., K. Jenni, J. Seel, E. Baker, M. Hand, E. Lantz, A. Smith. 2016. *Forecasting Wind Energy Costs & Cost Drivers. The Views of the World’s Leading Experts*. LBNL-1005717. Lawrence Berkeley National Laboratory. http://eta-publications.lbl.gov/sites/default/files/lbnl-1005717.pdf.