2019 Offshore Wind Technology Data Update

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Data and Methodology

Data Sources

This update draws data from the U.S. Department of Energy's (DOE's) National Renewable Energy Laboratory's (NREL's) internal offshore wind database, which is built on internal research and a wide variety of data sources, including peer-reviewed literature, press releases, industry news reports, manufacturer specification sheets, and global offshore wind project announcements. For the database, NREL has verified and sourced data from the following publications:

- The 4C Offshore Wind Database (4C Offshore 2020)
- Bloomberg New Energy Finance (BNEF) Renewable Energy Project Database (BNEF 2020)
- 4C Offshore Vessel Database (4C Offshore 2020)
- Wood Mackenzie Wind Turbine Trends (Wood Mackenzie 2020).
- Link to 2019 Data Table

Scope and Pipeline Definitions

- This work defines the offshore wind project pipeline as potential offshore wind development indicated by developer announcements or by areas made available for offshore wind development by regulatory agencies.
- The scope of this report covers the global fleet of projects in the pipeline through December 31, 2019.
- This report also covers recent developments and events in the United States through March 31, 2020, projects that have been completed before March 31, 2020, and selectively covers significant industry events through August 2020.
- Any estimates of capacities and project dates are shown as reported by project developers or state/federal agencies.
- All dollar amounts are reported in 2019 U.S. dollars, unless indicated otherwise.
- In this analysis, the U.S. pipeline capacity includes the sum of project-specific capacities and the undeveloped lease area potential capacities based on a project density of 3 megawatts (MW)/km^2.
- For further discussion on methodology and data sources, please refer to the "2018 Offshore Wind Technologies Market Report" (Musial et al. 2019).

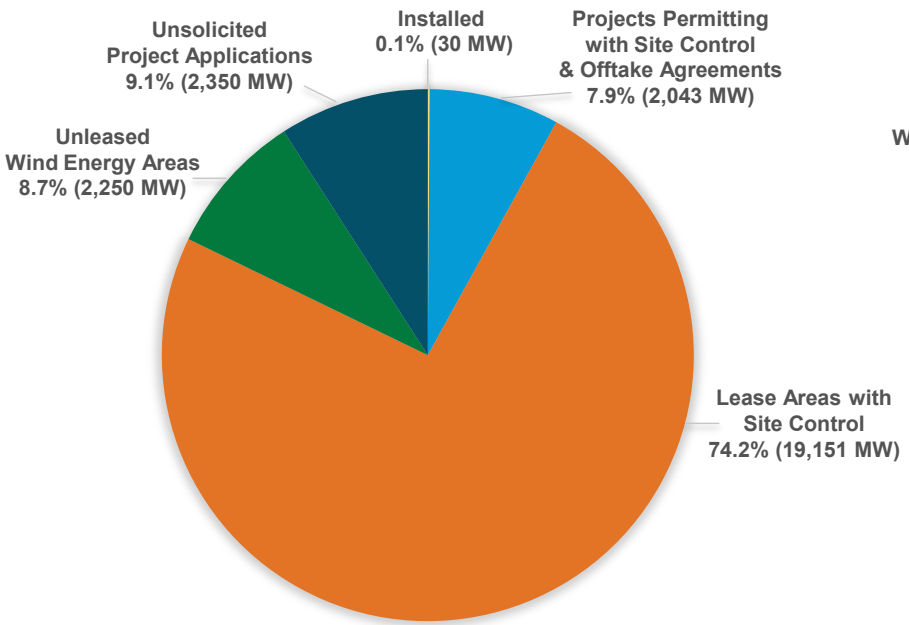
Project Pipeline Classification System

The following classification was used for global and U.S. pipeline capacity estimates (see Musial et al. 2019 for more details). The offshore wind pipeline is based on publicly available information.

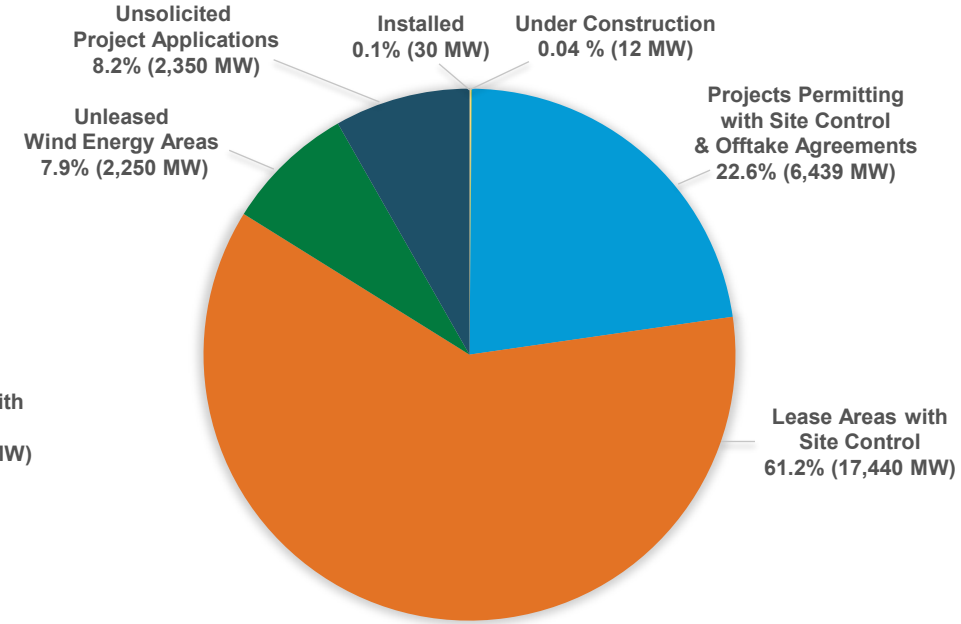
Step	Phase Name	Start Criteria	End Criteria
1	Planning	Starts when a developer or regulatory agency initiates the formal site control process	Ends when a developer obtains control of a site (e.g., through competitive auction or a determination of no competitive interest in an unsolicited lease area [United States only])
2	Site Control	Begins when a developer obtains site control (e.g., a lease or other contract)	Ends when the developer files major permit applications (e.g., a construction and operations plan 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., a 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 a sponsor announces a “financial investment decision” and has signed contracts for construction work packages
5	Financial Close	Begins when a sponsor announces a financial investment decision and has signed contracts for major construction work packages	Ends when a project begins major construction work
6	Under Construction	Starts when offshore construction is initiated	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; commercial operation date (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 activity

U.S. Offshore Wind Data

Breakdown of U.S. Offshore Wind Pipeline (28,521 MW)



2018 (25,824 MW)



2019 (28,521 MW)

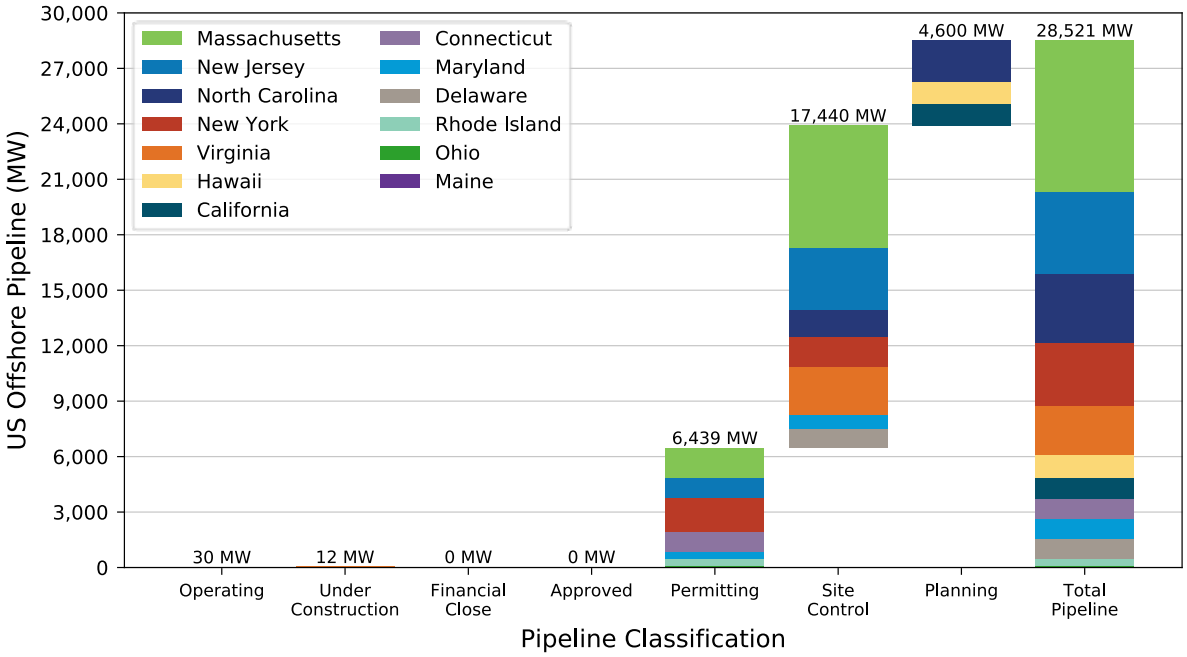
- From 2018 to 2019, U.S. projects with site control and offtake agreements grew over 200%.
- Up to 61% of the U.S. offshore wind pipeline is still made up of unspecified lease area potential.

U.S. Offshore Pipeline by Status

States	Project Name	Commercial Operation Date	Operating (MW)	Under Construction (MW)	Permitting (MW)	Site Control (MW)	Planning (MW)	Totals (MW)
Maine	New England Aqua Ventus I	2023			12			12
Massachusetts	Vineyard Wind	2023			800			8,220
	Vineyard Wind Residual	TBD				421		
	Mayflower Wind	2025			804			
	Mayflower Wind Residual	TBD				747		
	Beacon Wind	TBD				1,564		
	Liberty Wind	TBD				1,607		
	Bay State Wind	TBD				2,277		
Rhode Island	Block Island Wind Farm	2016	30					430
	Revolution Wind	2023			400			
Connecticut	Revolution Wind	2023			304			1,108
	Park City Wind	2025			804			
New York	South Fork	2023			130			3,410
	Empire Wind	2024			816			
	Empire Wind Residual	TBD				1,584		
	Sunrise Wind	2024			880			
New Jersey	Ocean Wind	2024			1,100			4,447
	Ocean Wind Residual	TBD				847		
	Atlantic Shores Offshore Wind	TBD				2,500		
Delaware	Garden State Offshore Energy	TBD				1,050		1,050
Maryland	Skipjack	2023			120			1,086
	MarWin	2023			248			
	MarWin Residual	TBD				718		
Virginia	Coastal Virginia Offshore Wind	2020		12				2,652
	Dominion	TBD				2,640		
North Carolina	Kitty Hawk	TBD				1,485		3,735
	Wilmington East Wind Energy Area	TBD					1,623	
	Wilmington West Wind Energy Area	TBD					627	
Ohio	Icebreaker	2023			21			21
California	Castle Wind	TBD					1,000	1,150
	Redwood Coast	TBD					150	
Hawaii	Oahu North	TBD					400	1,200
	Oahu South	TBD					400	
	Progression	TBD					400	
			30	12	6,439	17,440	4,600	28,521

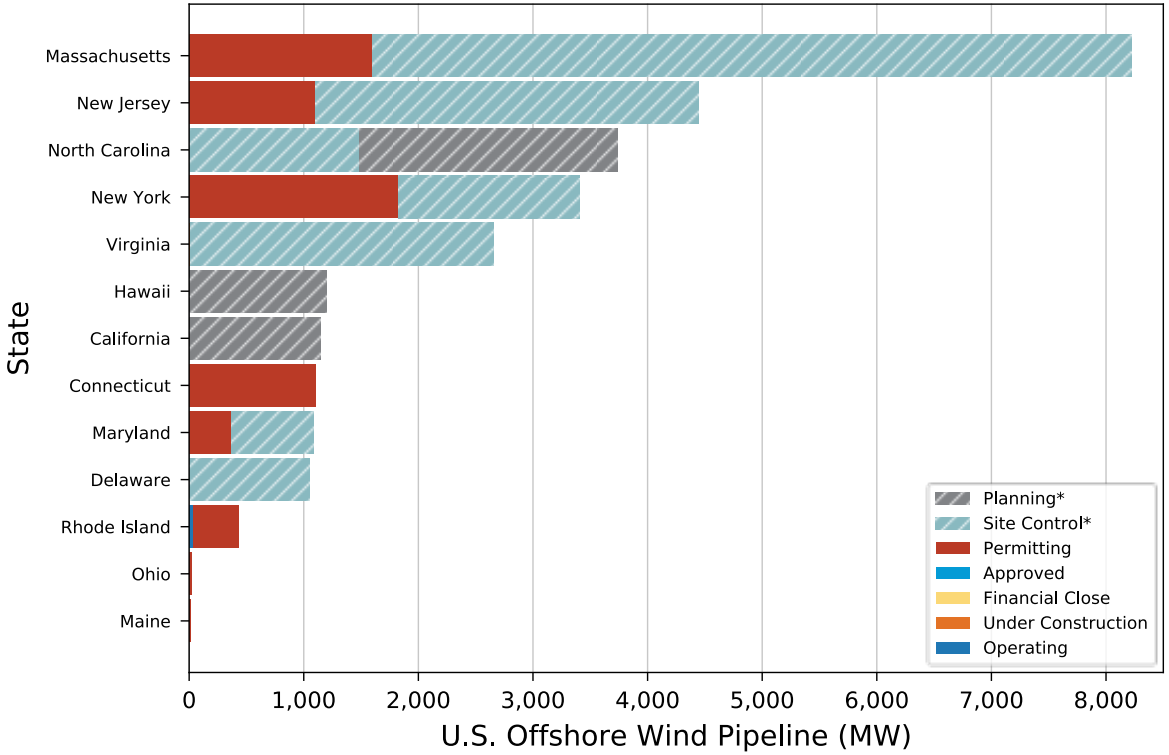
Note: Projects listed by state where power will be delivered (for projects with known offtake pathways)

2019 U.S. Offshore Wind Pipeline



- The U.S. offshore wind pipeline grew by 2,697 MW in 2019 to a total capacity of 28,521 MW.
- The U.S. offshore wind pipeline is broken down as follows:
  - 30 MW is operating, which was unchanged in 2019
  - 12 MW is under construction
  - 6,439 MW is in the permitting stage
  - 17,440 MW is under site control
  - 4,600 MW is in planning.

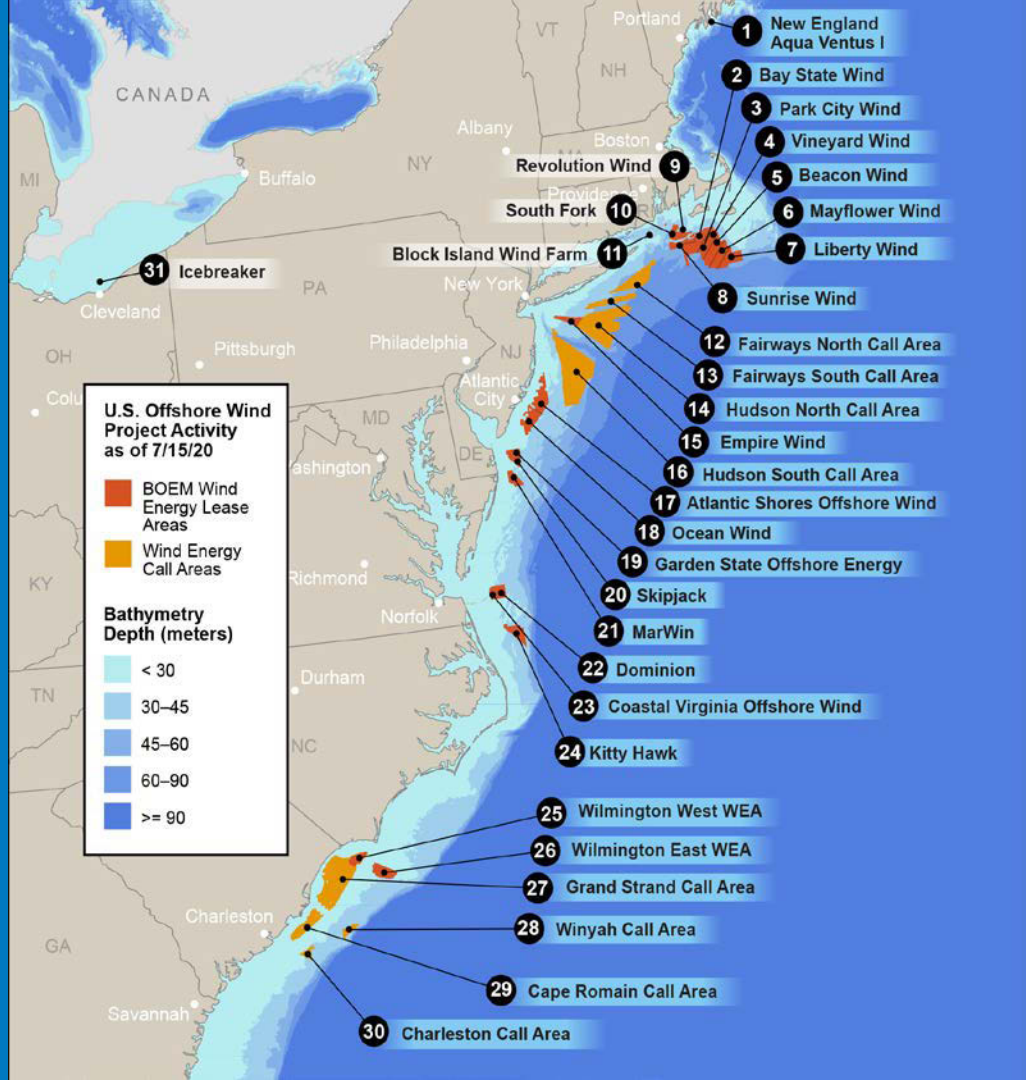
U.S. Offshore Wind Pipeline by State



There are 11 coastal states participating in the U.S. pipeline:

- 30 MW is operating in Rhode Island and 12 MW is under construction in Virginia
- Red shading totals 6,439 MW, which represent projects that have advanced to the permitting stage
- Project capacity is assigned to the state receiving the power (red shading)
- Lease areas where power offtake is unspecified (hashed shading) are assigned to the state where the lease area is located, as identified by the Bureau of Ocean Energy Management (BOEM).

Locations of U.S. Atlantic Coast Offshore Wind Pipeline Activity and Call Areas as of July 2020



Atlantic Coast Offshore Wind Pipeline

#	Location	Project Name	Status	COD	Announced Capacity (MW)	Lease Area Capacity (MW)	Total Pipeline Capacity (MW)	Lease Area	Size (km^2)	Offtake (MW)	Developers
1	ME	New England Aqua Ventus I	Permitting	2023	12	0	12	State Lease	9	ME 12	Aqua Ventus
2	MA	Bay State Wind	Site Control	-	-	2,277	2,277	OCS-A 0500	759	-	Ørsted/Eversource
3	MA	Park City Wind	Permitting	2025	804	-	804	OCS-A 0501	676	CT 804	Avangrid/CIP
4	MA	Vineyard Wind + Residual	Permitting	2023	800	421	1,221	OCS-A 0501		MA 800	Avangrid/CIP
5	MA	Beacon Wind	Site Control	-	-	1,564	1,564	OCS-A 0520	521	-	Equinor/BP
6	MA	Mayflower Wind + Residual	Permitting	2025	804	747	1,551	OCS-A 0521	516	MA 804	EDPR/Shell
7	MA	Liberty Wind	Site Control	-	-	1,607	1,607	OCS-A 0522	536	-	Avangrid/CIP
8	MA	Sunrise Wind	Permitting	2024	880	0	880	OCS-A 0487	272	NY 880	Ørsted/Eversource
9	RI	Revolution Wind	Permitting	2023	704	0	704	OCS-A 0486	395	RI 400/CT 304	Ørsted/Eversource
10	RI	South Fork	Permitting	2023	130	0	130	OCS-A 0517		NY 130	Ørsted/Eversource
11	RI	Block Island Wind Farm	Operating	2016	30	0	30	State Lease	10	RI 30	Ørsted/Eversource
12	NY	Fairways North Call Area	Planning	-	-	-	-	-	-	-	-
13	NY	Fairways South Call Area	Planning	-	-	-	-	-	-	-	-
14	NY	Hudson North Call Area	Planning	-	-	-	-	-	-	-	-
15	NY	Empire Wind	Permitting	2024	816	1,584	2,400	OCS-A 0512	321	NY 816	Equinor/BP
16	NY	Hudson South Call Area	Planning	-	-	-	-	-	-	-	-
17	NJ	Atlantic Shores Offshore Wind	Site Control	-	-	2,500†	2,500	OCS-A 0499	742	-	EDF/Shell
18	NJ	Ocean Wind + Residual	Permitting	2024	1,100	847	1,947	OCS-A 0498	649	NJ 1,100	Ørsted/PSEG
19	DE	Garden State Offshore Energy	Site Control	-	-	1,050	1,050	OCS-A 0482	284	-	Ørsted
20	DE	Skipjack	Permitting	2023	120	0	120	OCS-A 0519	107	MD 120	Ørsted
21	MD	MarWin + Residual	Permitting	2023	248	718	966	OCS-A 0490	322	MD 248	US Wind
22	VA	Dominion	Site Control	-	-	2,640	2,640	OCS-A 0483	457	-	Dominion
23	VA	Coastal Virginia Offshore Wind	Under Construction	2020	12	0	12	OCS-A 0497	9	VA 12	Dominion/Ørsted
24	NC	Kitty Hawk	Site Control	-	-	1,485	1,485	OCS-A 0508	495	-	Avangrid
25	NC	Wilmington West Call Area	Unleased	-	-	627	627	-	209	-	-
26	NC	Wilmington East Call Area	Unleased	-	-	1,623	1,623	-	541	-	-
27	SC	Grand Strand Call Area	Planning	-	-	-	-	-	-	-	-
28	SC	Winyah Call Area	Planning	-	-	-	-	-	-	-	-
29	SC	Cape Romain Call Area	Planning	-	-	-	-	-	-	-	-
30	SC	Charleston Call Area	Planning	-	-	-	-	-	-	-	-
31	OH	Icebreaker	Permitting	2023	21	0	21	State Lease	10	OH 21	LEEDCo/Fred Olsen
		Atlantic Coast Total			6,481	17,190	26,171		7,840		

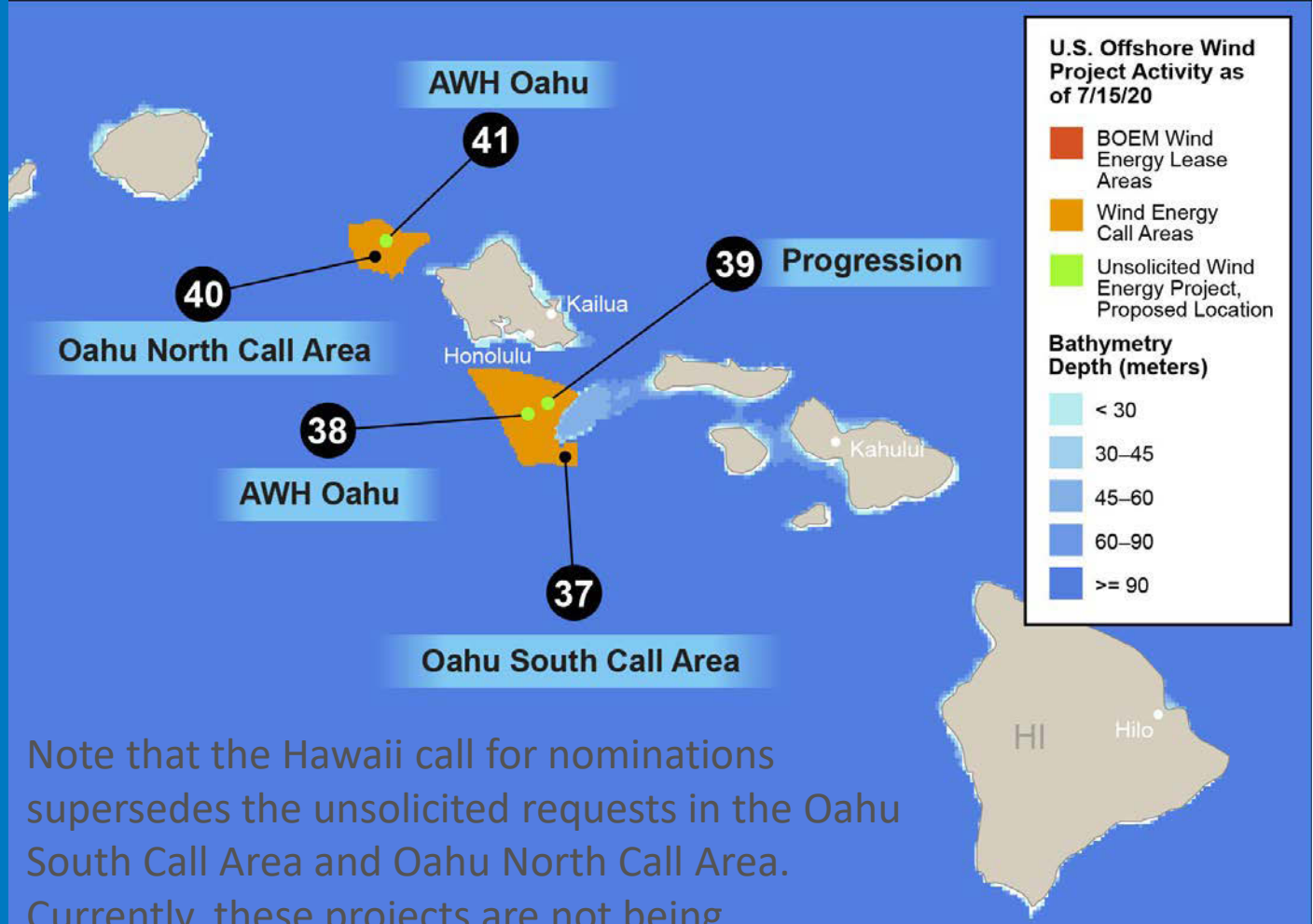
Note: Location indicates state closest to project site or call area

†Atlantic Shores capacity of 2,500 MW based on developer announcement

Locations of U.S. West Coast Offshore Wind Pipeline Activity and Call Areas as of July 2020

Note that the call for nominations supersedes the unsolicited requests in Morro Bay and Humboldt. Currently, these projects are not being processed by BOEM.

Locations of Hawaiian Offshore Wind Pipeline Activity and Call Areas as of July 2020

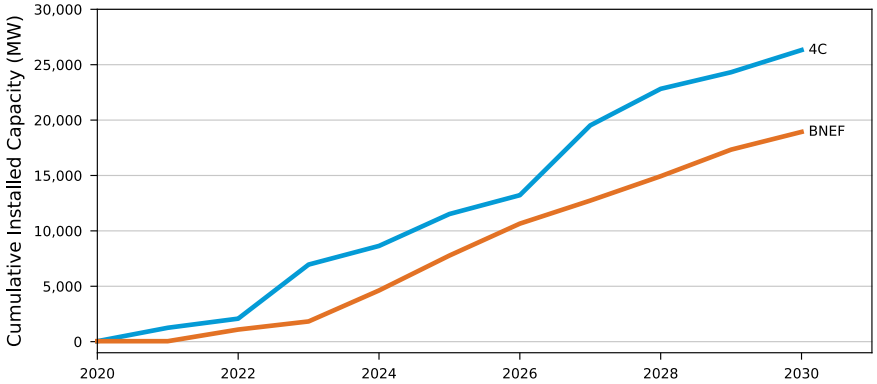


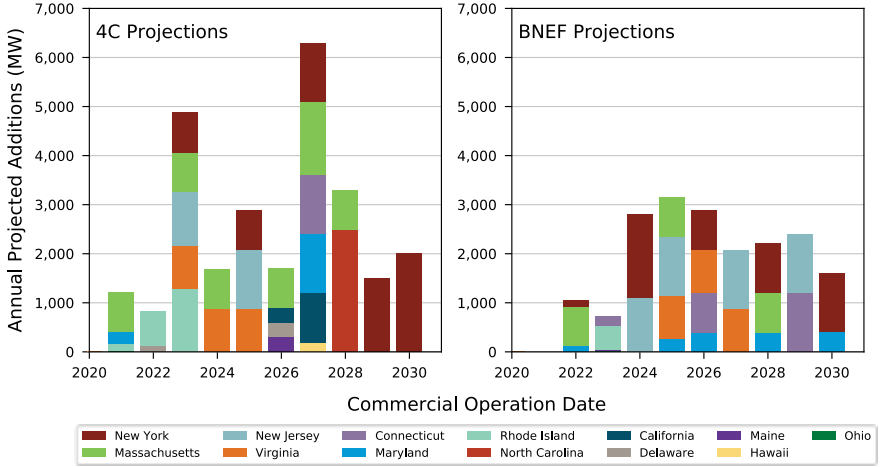
Note that the Hawaii call for nominations supersedes the unsolicited requests in the Oahu South Call Area and Oahu North Call Area. Currently, these projects are not being processed by BOEM.

U.S. West Coast and Hawaiian Offshore Wind Pipeline

#	Location	Project Name	Planning Stage	Commercial Operations Date	Announced Capacity (MW)	Lease Area Capacity (MW)	Total Pipeline Capacity (MW)	Lease Area	Size (km²)	Offtake	Developers
32	CA	Diablo Canyon Call Area	BOEM Call Area	-	-	-	-	-	-	-	-
33	CA	Morro Bay Call Area	BOEM Call Area	-	-	-	-	-	-	-	-
34	CA	Castle Wind	Unsolicited Project Application	-	1,000	-	1,000	-	334	-	Trident Winds/EnBW
35	CA	Humboldt Call Area	BOEM Call Area	-	-	-	-	-	-	-	-
36	CA	Redwood Coast Energy Authority	Unsolicited Project Application	-	150	-	150	-	50	-	EDPR/Aker/PPI
37	HI	Oahu South Call Area	BOEM Call Area	-	-	-	-	-	-	-	AW Wind
38	HI	AWH Oahu	Unsolicited Project Application	-	-	400	400	-	133	-	-
39	HI	Progression	Unsolicited Project Application	-	-	400	400	-	133	-	Progression Wind
40	HI	Oahu North Call Area	BOEM Call Area	-	-	-	-	-	-	-	-
41	HI	AWH Oahu	Unsolicited Project Application	-	-	400	400	-	133	-	AW Wind
		West Coast & Hawaii Total			**1,150**	**1,200**	**2,350**		**783**		

U.S. Offshore Wind Market Estimates Through 2030





- **4C Offshore** predicts that cumulative U.S. offshore wind deployment will exceed 25,000 MW by 2030 (4C Offshore 2019).
- **BNEF** predicts cumulative U.S. offshore wind deployment will grow to nearly 19,000 MW by 2030 (BNEF 2019).
- These estimates are 50% to 70% higher than in their 2018 estimates when BNEF and 4C Offshore predicted 11,000 MW and 16,000 MW, respectively, by 2030.

U.S. State-Level Offshore Wind Procurements

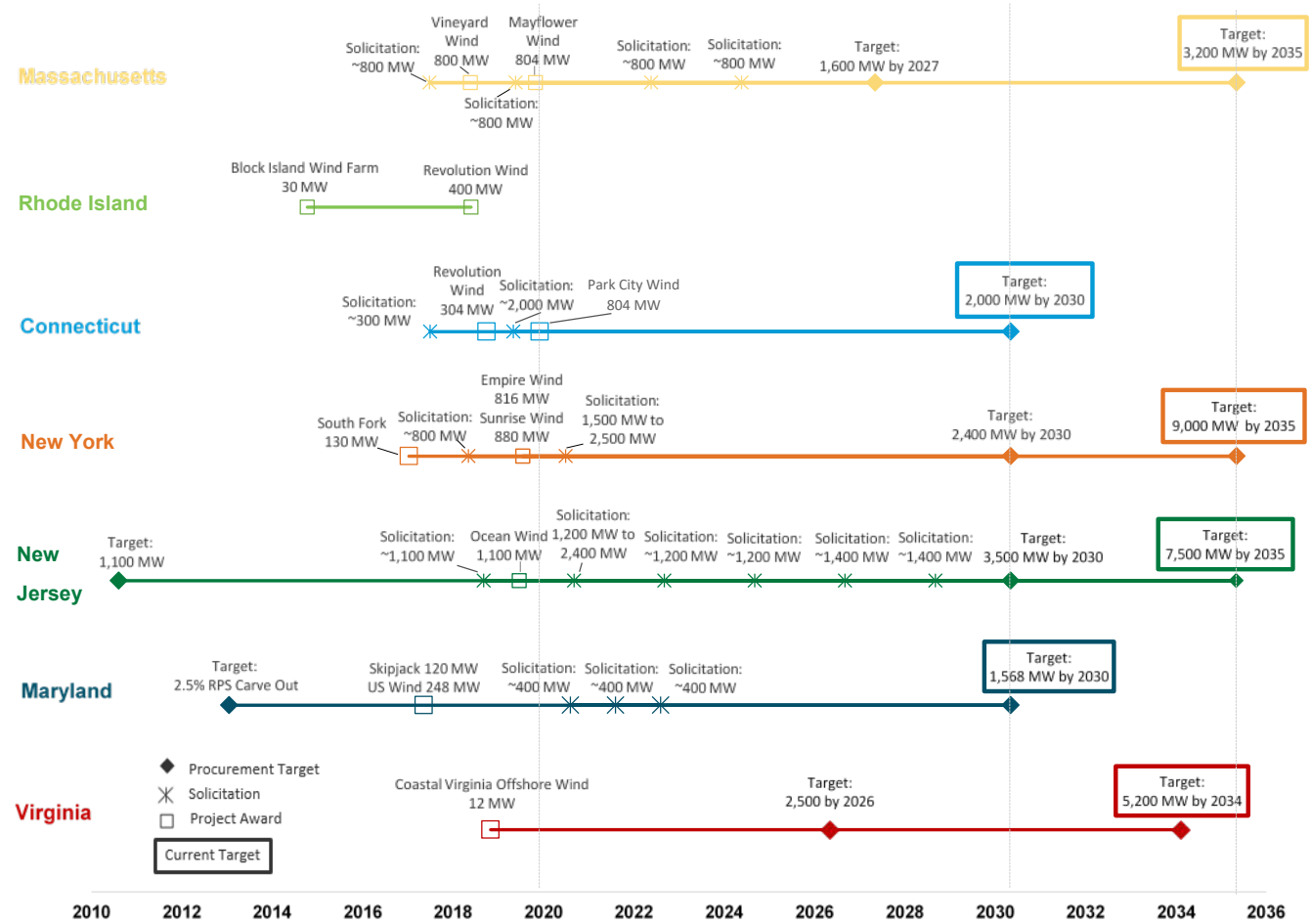
State	Capacity Commitment (MW)	Target Year	Amount Solicited (MW)	Contract Type	Year Enacted	Authority	Renewables Portfolio Standards (RPS) Goal
MA	3,200	2035	1,604	PPA	2016 2018	An Act to Promote Energy Diversity An Act to Advance Clean Energy	35% by 2030
RI	430	-	430	PPA		-	31% by 2030
NJ	**7,500**	2035	3,500[A]	OREC	2010 2018 **2019**	Offshore Wind Economic Development Act E.O. 8/Assembly Bill 3723 **E.O. 92**	50% by 2030
MD	**1,568**	2030	368	OREC	2013 **2019**	Maryland Offshore Wind Energy Act **Senate Bill 516**	50% by 2030
NY	**9,000**	2035	4,326[B]	OREC	2018 **2019**	Case 18-E0071 **Climate Leadership & Community Protection Act**	70% by 2030
CT	**2,000**	2030	1,104	PPA	2017 **2019**	Public Act 17-144 **House Bill 7156**	44% by 2030
VA	**5,200**	2034	12	Utility Owned	**2020**	**Virginia Clean Economy Act**	100% by 2050
Total	28,898		11,380				

A – In July 2020, New Jersey announced its second offshore wind solicitation for between 1,200 MW and 2,400 MW. Awards are expected in June 2021.
B – In July 2020, New York announced its next offshore wind solicitation for between 1,500 MW and 2,500 MW. Awards are expected in the fourth quarter of 2020.
Power purchase agreement (PPA)
Offshore renewable energy credit (OREC)

Source: Beiter et al. (2020)

- Five states implemented new procurement commitments in 2019 and early 2020 (see green text).
- State procurement commitments grew from 19,968 MW in 2018 to 28,898 MW in early 2020, corresponding to 8,930 MW of new commitments.
- State procurement goals of 28,898 MW are now larger than the U.S. pipeline of 28,521 MW.

Timeline of U.S. Offshore Wind Procurements by State



- To achieve their offshore wind procurement goals, states and utilities have started to plan out regular solicitations.
- New York issued its second solicitation in July 2020 for 2,500 MW of offshore wind.
- Planned solicitations in 2020 include Maryland (400 MW) and New Jersey (1,200 to 2,400 MW).

Source: Beiter et al. (2020)

U.S. Offshore Wind Project Offtake Agreements

Project	Year Signed	Size (MW)	Duration (years)	Offtake State	Offtake Mechanism	Regulator Approved	Levelized Price $/Megawatt-hour (MWh)	Power Delivery	Power Purchaser
Block Island Wind Farm	2010	30	20	RI	PPA	Yes	244	2016	National Grid
South Fork	2017	130	20	NY	PPA	Yes	163	2023	Long Island Power Authority (LIPA)
US Wind	2017	248	20	MD	MD OREC	Yes	131.94	2023	PJM
Skipjack	2017	120	20	MD	MD OREC	Yes	131.94	2023	PJM
Vineyard Wind	2018	400	20	MA	PPA	Yes	74	2023	National Grid, Eversource, Unitil
Vineyard Wind	2018	400	20	MA	PPA	Yes	65	2024	National Grid, Eversource, Unitil
Coastal Virginia Offshore Wind	2018	12	20	VA	Utility Owned	Yes	780	2020	Dominion Energy*
Revolution Wind	2018	200	20	CT	PPA	Yes	99.50	2023	Eversource & UIL
Revolution Wind	2018	104	20	CT	PPA	Yes	98.43	2023	Eversource & UIL
Revolution Wind	2019	400	20	RI	PPA	Yes	98.43	2023	National Grid
Ocean Wind	2019	1,100	20	NJ	NJ OREC	Yes	116.82	2024	PJM
Empire Wind	2019	816	25	NY	NY OREC	Yes	83.36	2024	New York Independent System Operator (NYISO)
Sunrise Wind	2019	880	25	NY	NY OREC	Yes	83.36	2024	NYISO
Aqua Ventus	2019	12	20	ME	PPA	Yes	Undisclosed	TBD	Central Maine Power
Mayflower Wind	2020	400	20	MA	PPA	Yes	58.47	2025	National Grid, Eversource, Until
Mayflower Wind	2020	404	20	MA	PPA	Yes	58.47	2025	National Grid, Eversource, Until
Park City Wind		804	20	CT	PPA	Pending	N/A	2025	Eversource & UIL
Icebreaker		21	TBD	OH	PPA	Pending	N/A	TBD	TBD

Source: Beiter et al. (2020)

Note: Offtake agreements signed in 2019 and 2020 are in green text

*Dominion Energy also filed an interconnection request with PJM for 2,640 MW from the Virginia Wind Energy Area (WEA). Because Dominion is both the project owner and the utility procuring the power, it is not considered to have an offtake agreement for the purpose of this list until a project is approved by the Virginia State Corporation Commission.

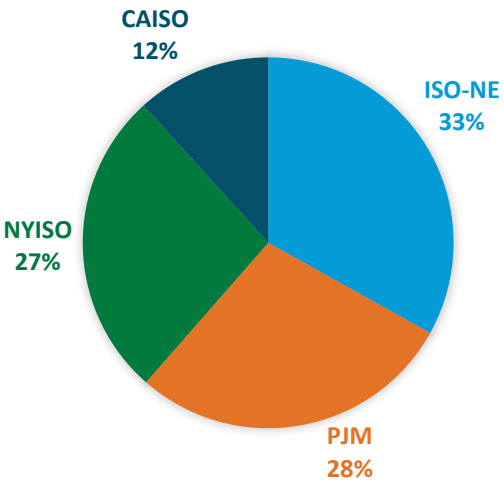
U.S. State Port and Infrastructure Investments Near $2 Billion

State	Location	Announced Date	Amount	Investor(s)	Description
Massachusetts	New Bedford Marine Commerce Terminal	2/10/2020	N/A	Avangrid/CIP EDPR/Shell	Vineyard Wind signed an 18-month lease starting in December 2020. They also signed a subsequent lease to use the terminal for the Mayflower Wind project, which is expected to start construction in 2024.
	Brayton Point	5/13/2019	$650 million	Anbaric Partners	Develop premier offshore wind development center. Investments include a 1,200-MW HVDC converter, a 400-MW battery, additional laydown space, and a maintenance dock.
Rhode Island	Port of Providence	6/3/2019	N/A	Ørsted & Eversource	Support the construction of the Revolution Wind projects.
	Quonset Point		N/A	Ørsted & Eversource	Support the construction of the Revolution Wind projects. Pier 2 is being upgraded to support offshore wind activities.
New Jersey	Port of Paulsboro	6/3/2019	N/A	Ørsted	Signed a memorandum of understanding with EEW, a German steel manufacturer, to construct a monopile manufacturing facility to support Ocean Wind project and other projects in the U.S. pipeline.
	New Jersey Wind Port	6/16/2020	$300–$400 million	NJ Economic Development Authority	Develop port in Lower Alloways Creek Township to support offshore wind construction and operations. Initial phase to include 30 acres for marshalling and 25 acres for component manufacturing, with construction to begin in 2021. Second phase to add 150 acres for marshalling and manufacturing.
Maryland	Tradepoint Atlantic	7/23/2019	$13.2 million	Ørsted	Strengthen ground-bearing capacity at the port to allow heavy-lift cranes and specialized transporters to move wind turbine components, some weighing as much as 2,000 tons, from ships onto the site. Will support the Skipjack project.
New York	Port of Coeymans	11/14/2019	$287 million	New York State	Increase laydown space and prepare the port to support construction and staging needs for the Empire Wind project. Partnered with heavy-lift specialists Mammoet to invest in a new heavy-lift crane and other specialty equipment.
	New York ports	7/21/2020	$400 million	New York State	Request for proposals for investment in port infrastructure. Priorities are offshore wind staging and/or manufacturing and related uses. Up to $200 million from New York state, matched 1:1 by private investment.
Connecticut	New London State Pier	2/12/2020	$157 million	Ørsted & Eversource	Increase laydown space, the number and size of vessel berths, and the ability to lift and store heavy cargo. The redevelopment is expected to be complete by 2022. The pier will be used for turbine preassembly and project staging for Revolution Wind, South Fork, and Sunrise Wind projects.
	Bridgeport	11/11/2019	N/A	Avangrid	Redevelop a currently underutilized 18.3-acre waterfront to do critical foundation transition piece steel fabrication and final outfitting. Port will also serve as an operation and maintenance hub for the Park City Wind project.
Virginia	Portsmouth Marine Terminal	1/28/2020	$33 million	Ørsted	Signed a lease for the construction of the Coastal Virginia Offshore Wind Project. Will also install cranes and other specialty improvements.

U.S. Offshore Wind Grid Interconnection Queues

State	Project	Potential Point of Interconnect	Electric Distribution Company Connector	Market
MA	Vineyard Wind (800 MW) Mayflower Wind (804 MW)	Barnstable, MA Falmouth, MA	NSTAR Electric Company/Eversource	Independent System Operator-New England (ISO-NE)
RI	Revolution Wind (704 MW)	Brayton Point, RI Davisville, RI	National Grid	ISO-NE
CT	Park City Wind	TBD	Eversource	ISO-NE
NY	South Fork (130 MW) Empire Wind (816 MW) Sunrise Wind (880 MW)	East Hampton Substation, NY Gowanus Substation, NY Holbrook Substation, NY	LIPA ConEd LIPA	New York Independent System Operator (NYISO)
NJ	Ocean Wind (1,100 MW)	Oyster Creek, NJ	PSEG	PJM
MD	Skipjack (120 MW) MarWin (248 MW)	TBD Indian River Power Plant, DE	Delmarva Power & Light	PJM
VA	Coastal Virginia Offshore Wind (12 MW) Dominion (2,640 MW)	Camp Pendleton State Military Reservation, VA Fentress, VA	Dominion Energy	PJM
CA	Castle Wind (1,000 MW) Redwood Coast (150 MW)	Humboldt Substation 115 kV, CA Round Mountain Substation 500 kV, CA Diablo Canyon Switching Station, CA Diablo Canyon Substation 230kV	PG&E	California Independent System Operator (CAISO)

*Interconnection requests allow grid operators to assess the potential reliability impacts of adding new generation. Project developers may submit multiple interconnection requests for a single project and can change or withdraw requests as needed. An interconnection request is just the first step of connecting a project to the grid and is independent of other state and federal permitting processes. Only a small portion of projects in interconnect queues are ever expected to be constructed.



Total Offshore Wind Capacity in Interconnect Queues in as Summer 2020 (55,866 MW)

- As of summer 2020, the majority of active offshore wind queue requests were in ISO-NE (18,486 MW), PJM (15,842MW), and NYISO (14,982 MW).
- CAISO also saw offshore wind interconnection requests for the first time (6,556 MW).

Other Related U.S. Developments

- In August 2019, BOEM announced that it would prepare a supplement to the draft Environmental Impact Statement for the Vineyard Wind project. The supplement was published in June 2020 and assessed effects from an expanded cumulative impacts scenario, previously unavailable fishing data, a new transit lane alternative, and changes to the project since the publication of the first draft Environmental Impact Statement.
- The U.S. Coast Guard published a report on May 14, 2020, with recommendations for turbine spacing to accommodate transit lanes, fishing, and search and rescue operations.
- The 12-MW Coastal Virginia Offshore Wind (CVOW) project is under construction and is the first project in U.S. federal waters. Installation of the two 6-MW turbines was completed in June 2020, with grid interconnect scheduled for fall 2020.
- Dominion Energy announced plans to develop a 2,640-MW offshore wind project in its Virginia lease area, with an estimated COD of 2026, based on experience gained from CVOW. Siemens Gamesa has conditionally agreed to supply 14-MW SG 14-222 direct-drive turbines for the project.
- GE announced that it will supply its 12-MW Haliade-X turbines to Ørsted for two projects: Skipjack, a 120-MW project off the coast of Maryland that is expected to be commissioned in 2022, and Ocean Wind, a 1,100-MW project off the coast of New Jersey, with a COD of 2024.

Other Related U.S. Developments (continued)

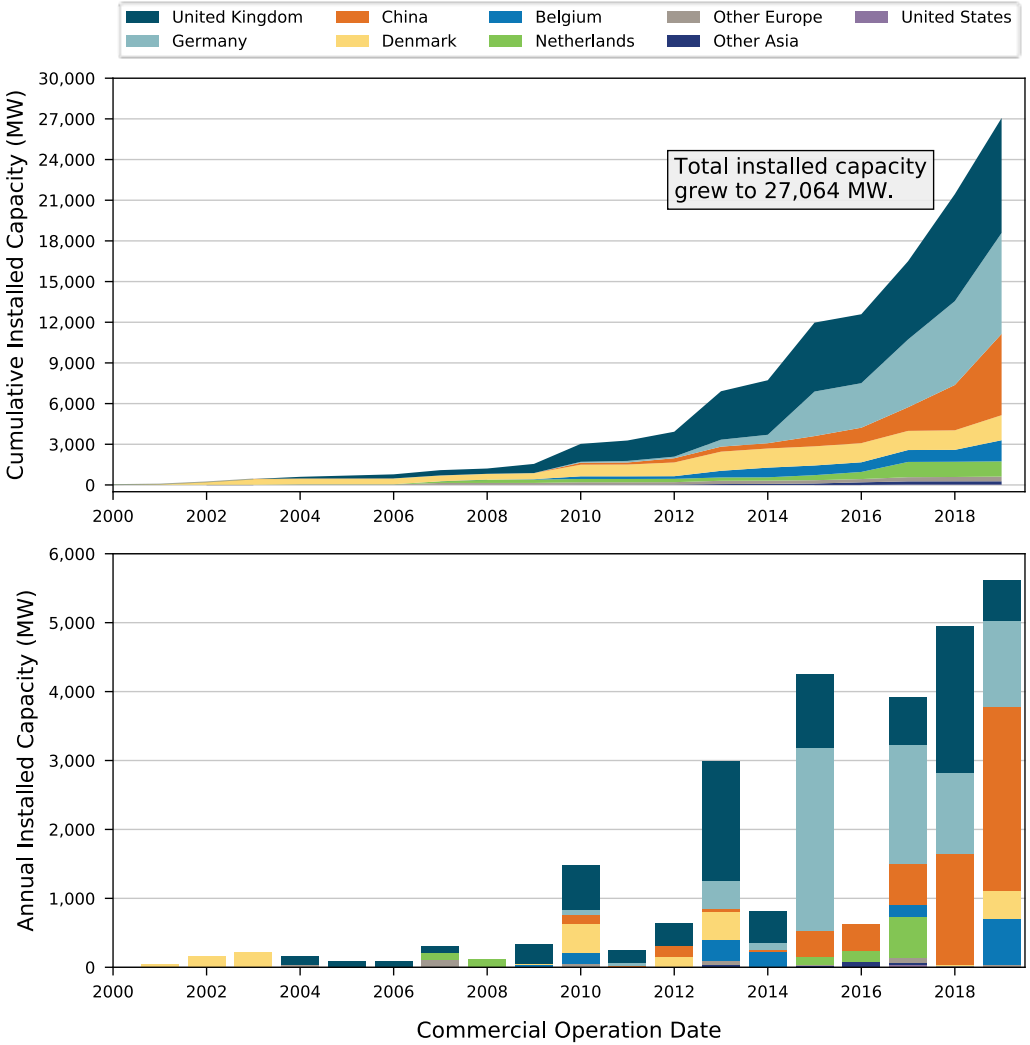
- In 2019, Maine's public utility commission approved an updated PPA for University of Maine's 12-MW Aqua Ventus floating demonstration project.
- In August 2020, the University of Maine announced a joint venture called New England Aqua Ventus, LLC, with Mitsubishi subsidiary Diamond Offshore Wind, and RWE Renewables, to develop the project, which is now positioned to be the first U.S. floating wind project using commercial technology.
- The Ohio Power Siting Board gave LEEDCo conditional approval to move forward with its 21-MW project in Lake Erie. The DOE-supported demonstration project is still in the process of finalizing its offtake agreements and other technical considerations before beginning construction.
- A consortium led by Dominion Energy is developing a Jones-Act-compliant turbine installation vessel (TIV). With a projected entry into service of 2023, it would be the first U.S.-flagged TIV.

Summary – U.S. Offshore Wind Data

- The U.S. offshore wind pipeline grew from 25,824 MW in 2018 to 28,521 MW by the end of 2019, due primarily to developers announcing additional project capacity within existing lease areas.
- In March 2020, the amount of offshore wind capacity under federal and state permitting with a signed offtake agreement was 6,439 MW. This was more than triple the 2,043-MW capacity reported in March 2019, indicating significant U.S. industry development over the past year.
- The Internal Revenue Service (IRS) modified its safe harbor guidance to allow projects under construction an additional year to be placed in service to mitigate effects of potential COVID-19-related delays for projects utilizing renewable energy tax credits.
- In 2019, a total of nearly $2 billion of investments were proposed for new offshore wind port and infrastructure upgrades.

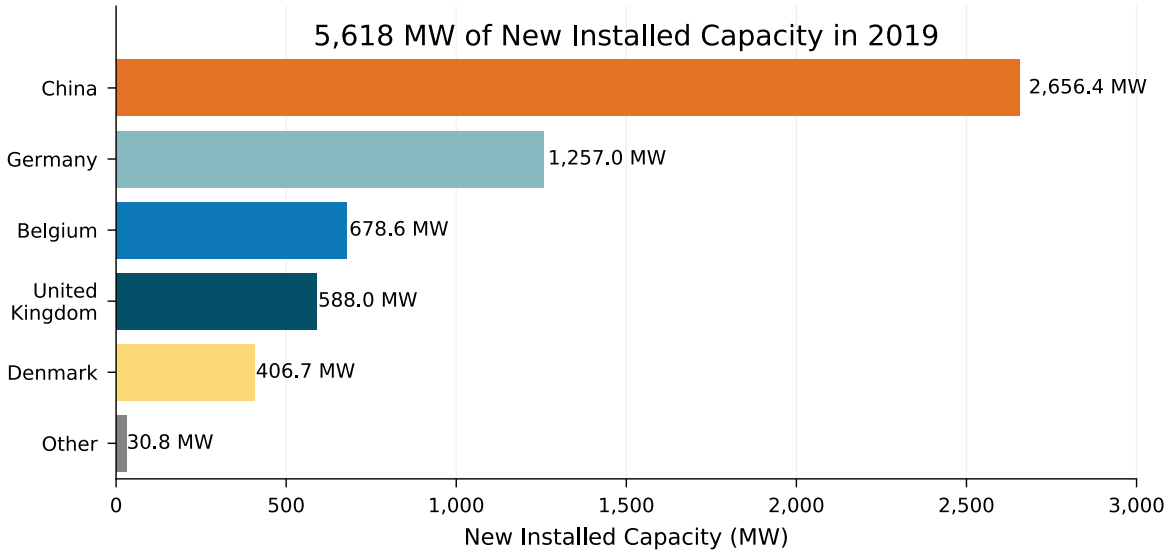
Global Offshore Wind Data

Global Offshore Wind in 2019



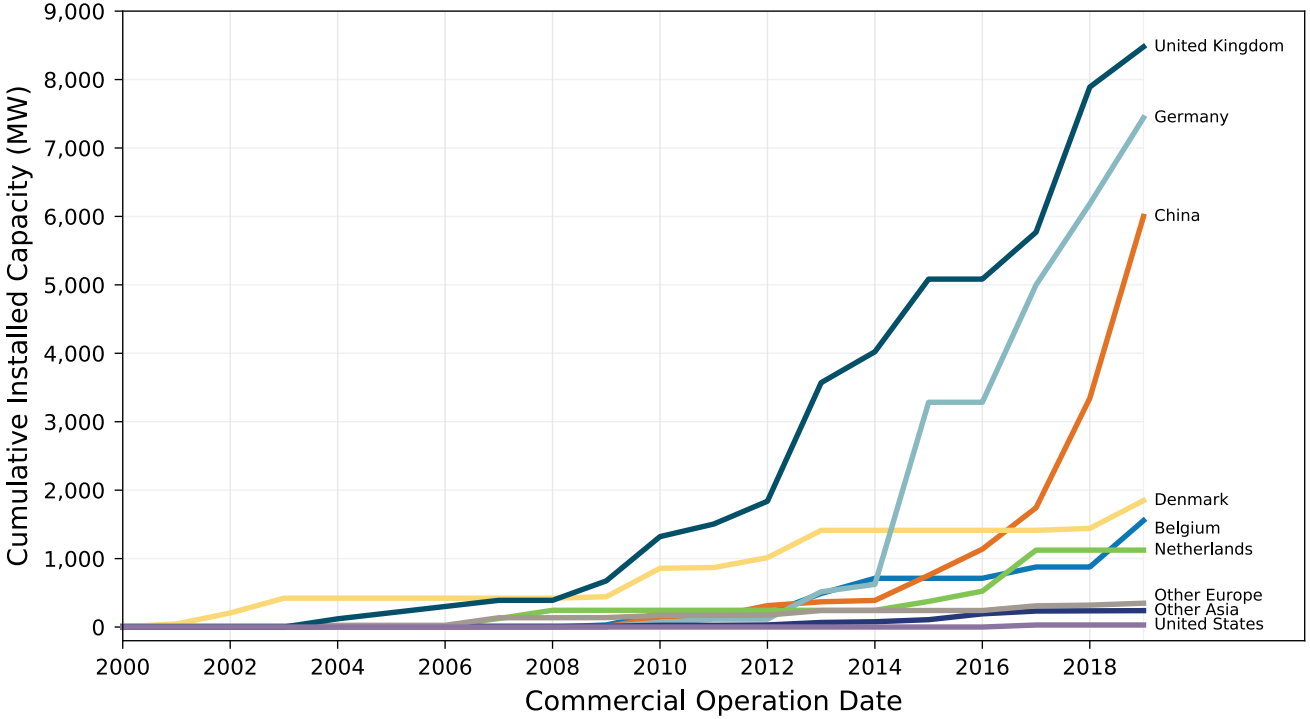
- Cumulative installed offshore wind capacity grew to 27,064 MW in 2019.
- New capacity additions reached a record high of 5,618 MW installed in 2019 and early 2020.

Installed Offshore Wind Capacity by Country in 2019



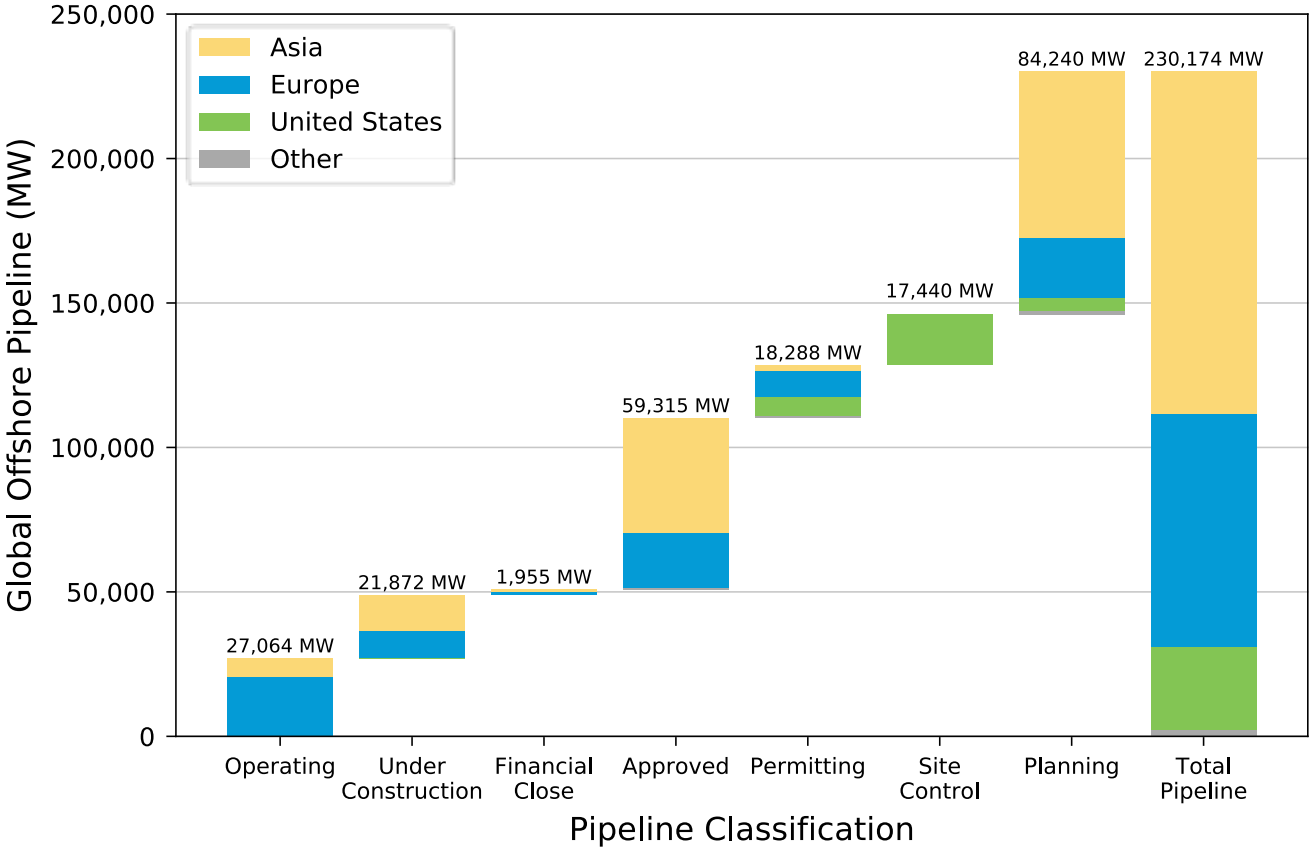
- Five countries contributed 99% of all new installations in 2019.
- China installed the most capacity, with 47% of the new additions.
- Germany installed 1,257 MW in 2019, or about 22% of new additions.
- Belgium, the United Kingdom (UK), and Denmark installed the remaining major share of offshore wind in 2019.

Cumulative Offshore Wind Installed Capacity by Country



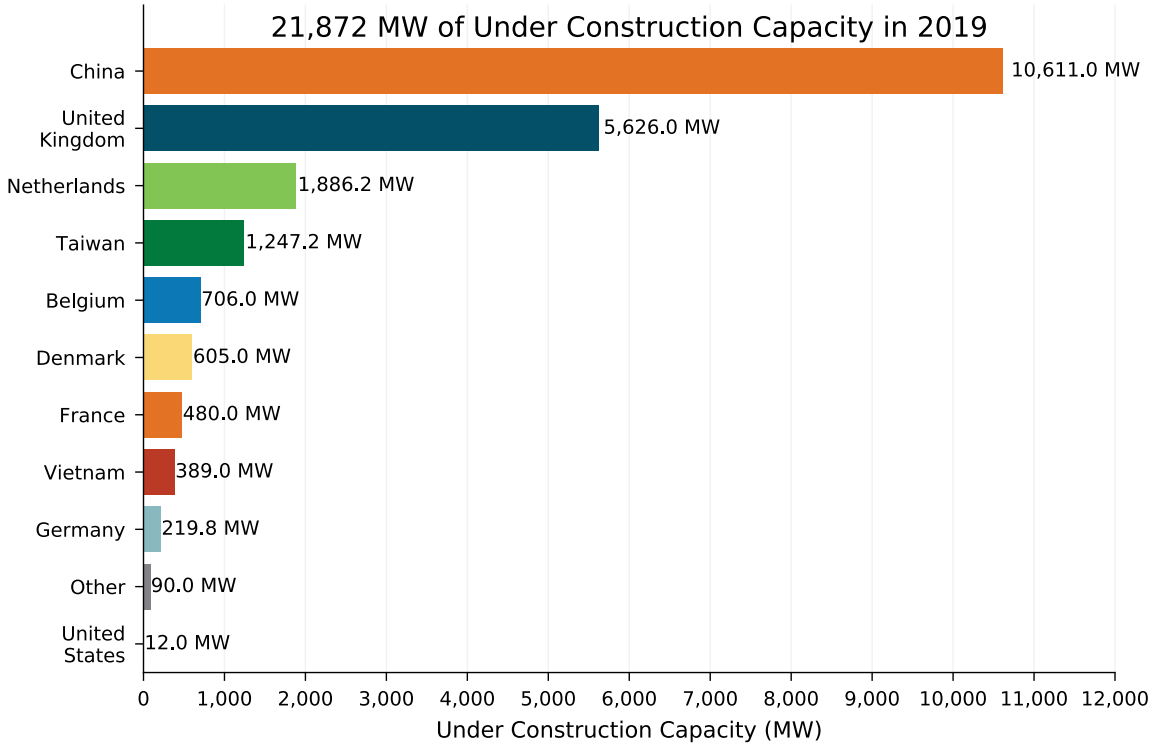
- At the end of 2019, the UK had the most installed offshore wind, with 8,478 MW.
- UK growth has been relatively steady for the past decade.
- Germany installed 7,441 MW of offshore wind by the end of 2019.
- German market accelerated in 2015 with steady growth since.
- China's cumulative capacity is third in the world, with a total of 6,000 MW installed, and is growing the fastest.

Total Global Offshore Wind Pipeline



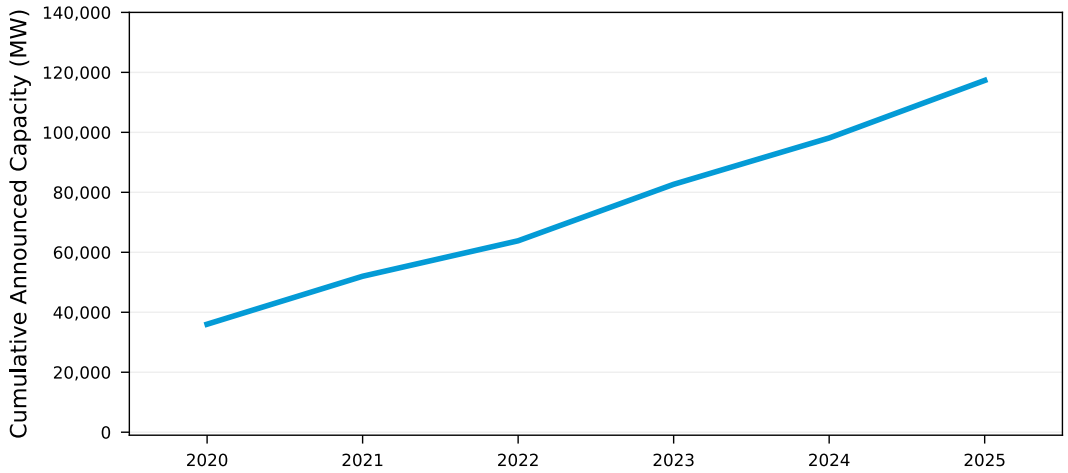
- The current global pipeline of offshore wind is 230,174 MW, including:
  - 27,064 MW operating
  - 81,872 MW approved through respective national regulatory processes, reached financial close, or under construction.
  - 203,110 MW of announced capacity.
- Most of these projects are in Europe and Asia.
- The pipeline encompasses projects completed (or reported) between 1990 and 2038.

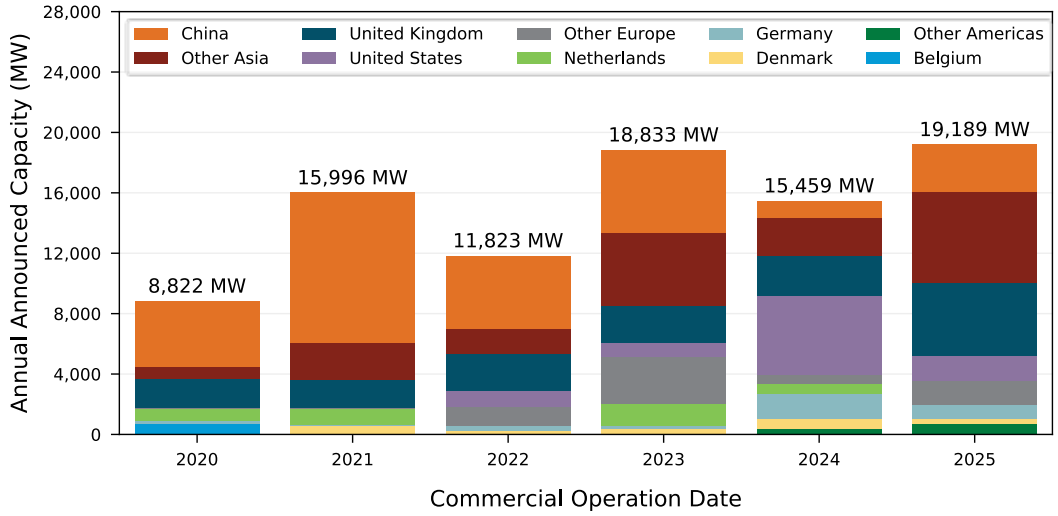
Offshore Wind Under Construction by Country in 2019



- Globally, 21,872 MW of offshore wind was reported to be under construction at the end of 2019.
- 10,611 MW of projects under construction indicate that China has the potential to lead in new capacity over the next few years.
- The UK has 5,626 MW under construction.
- The 12-MW Coastal Virginia Offshore Wind project is under construction in the United States and will be the second project in operation.

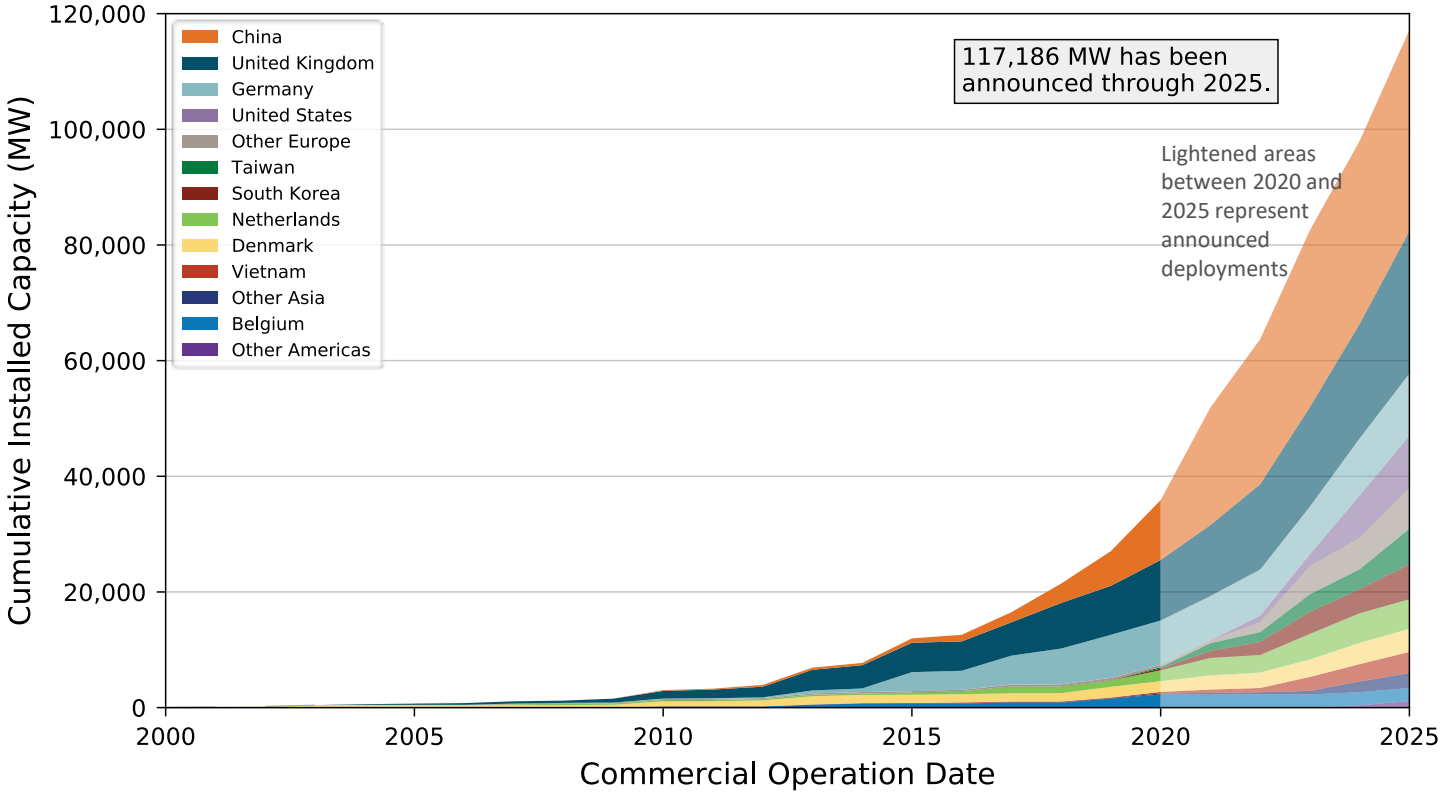
Offshore Wind Projects with Announced COD





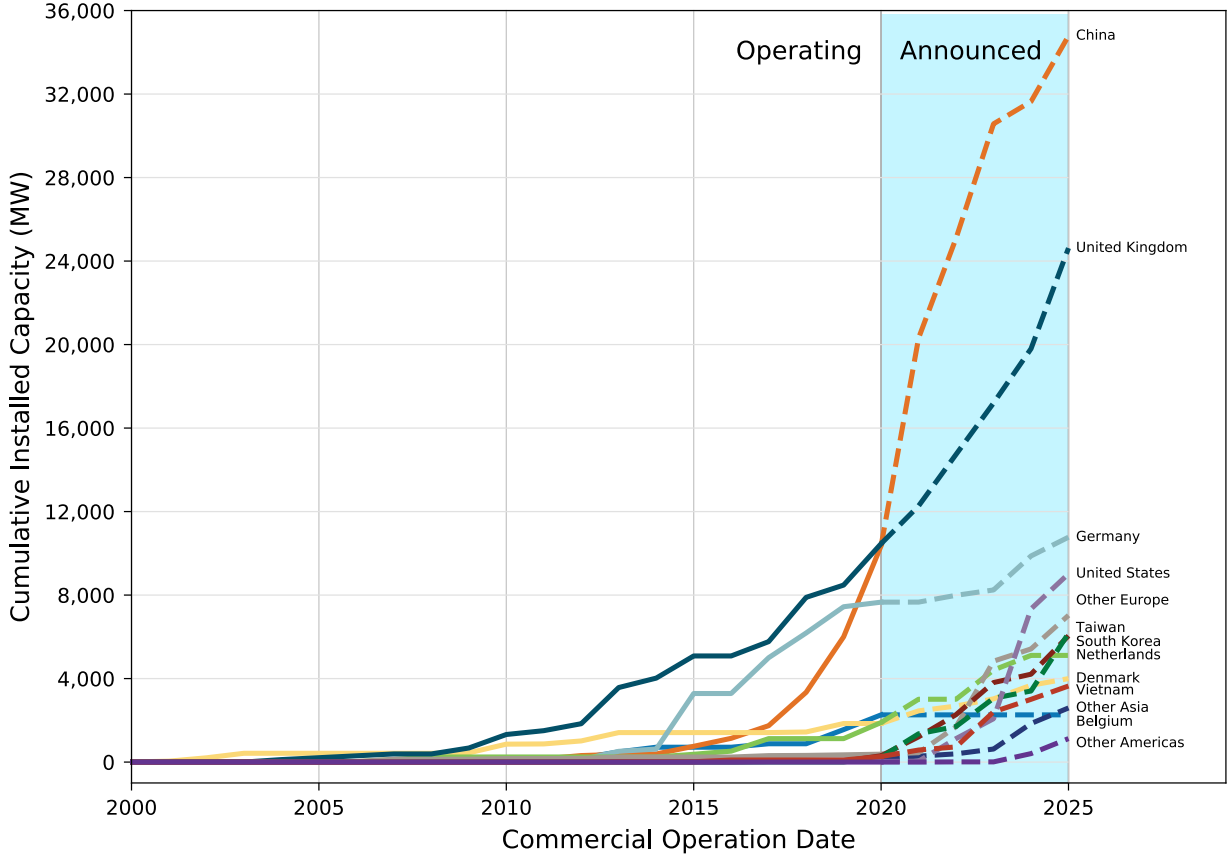
- Global offshore wind pipeline data show nearly 120,000 MW with announced COD by 2025
- Capacity expected to be installed annually (based on announced COD) grows from over 8,800 MW in 2020 to over 19,000 MW in 2025
- U.S. projects begin to comprise a greater number of offshore projects, thereby having a significant impact on global deployment in 2022 and 2023 based on announced CODs.

Estimated Cumulative Offshore Wind Capacity Based on Developer-Announced COD Through 2025



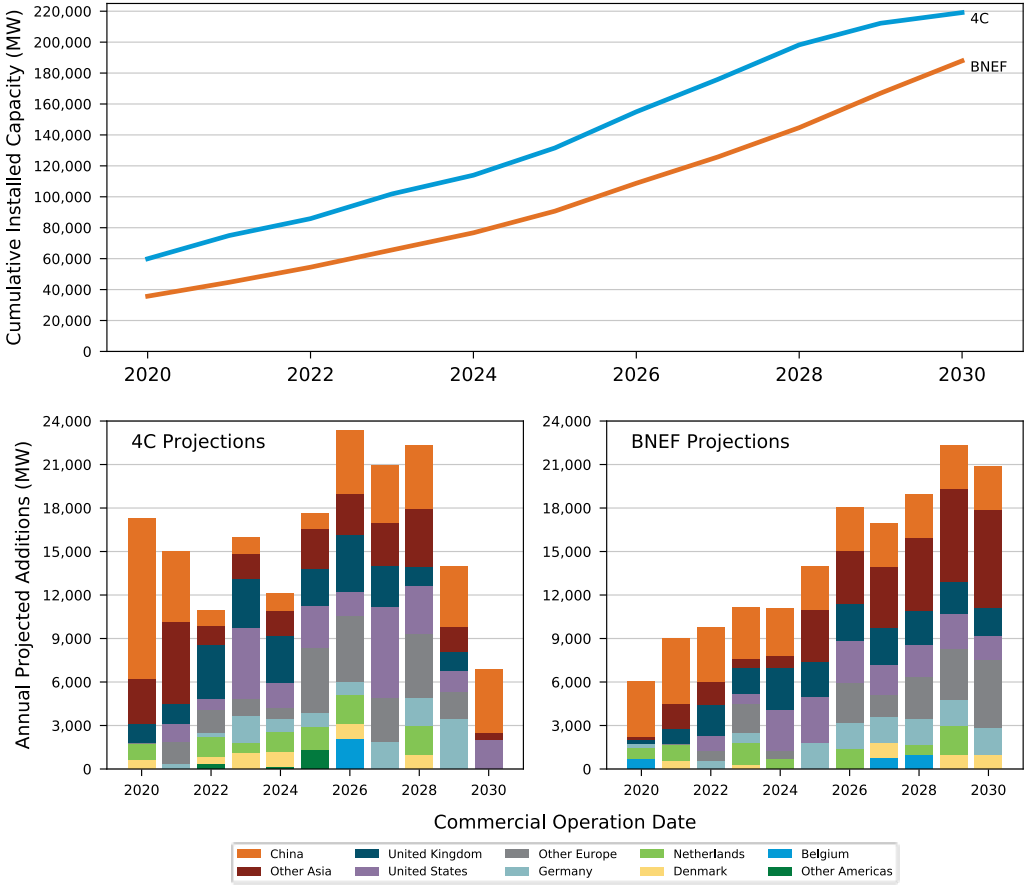
Beyond 2025, most projects have not yet announced a COD.

Cumulative Offshore Wind Capacity by Country Based on Developer-Announced COD Through 2025



- Developer-announced CODs show greatest installed capacity in China and the UK through 2025
- Announced U.S. projects increase significantly from 2023 to 2025
- Capacity by announced CODs grows significantly in other Asian markets (e.g., South Korea, Taiwan, Vietnam) through 2025.

Global Offshore Wind Estimates Through 2030



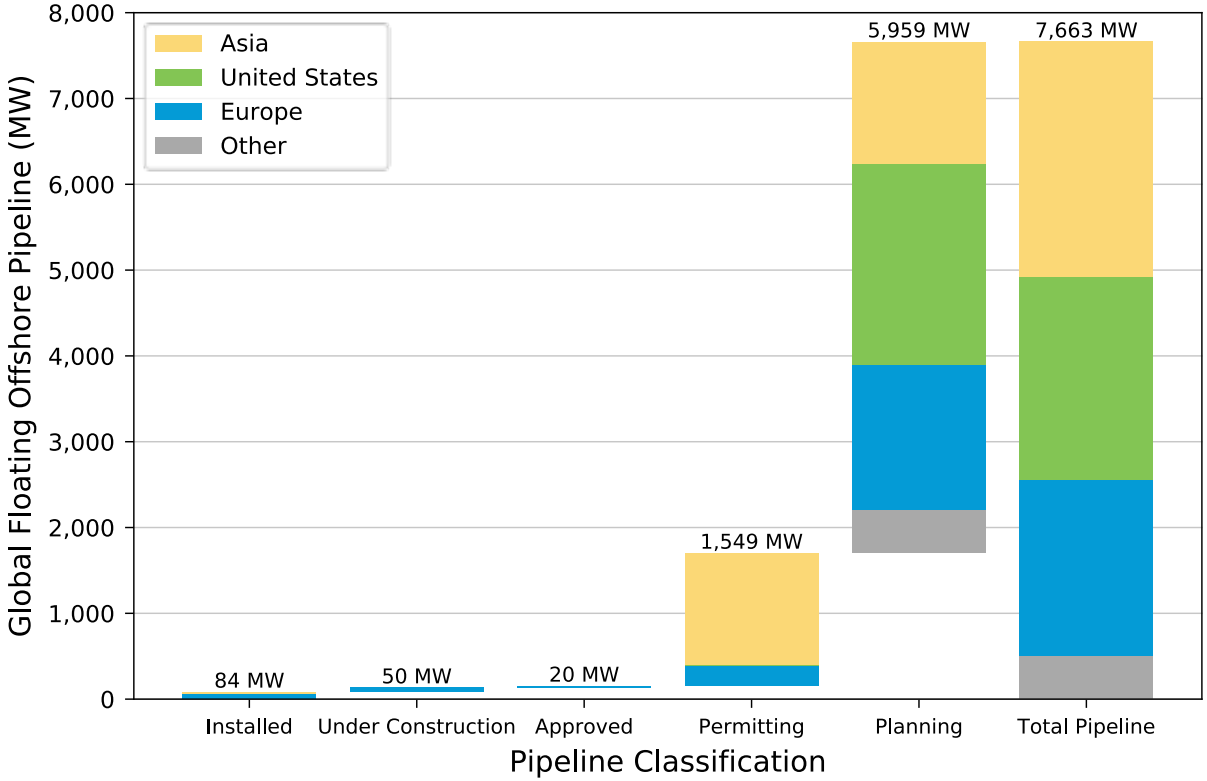
- In 2019, 4C Offshore estimates that cumulative global offshore wind deployment will grow to nearly 220,000 MW by 2030 (4C Offshore 2019).
- In 2019, BNEF estimates cumulative global offshore wind deployment will grow to nearly 188,000 MW by 2030 (BNEF 2019).
- For comparison, these 2030 estimates in 2018 were 154 gigawatts from BNEF and 193 gigawatts from 4C Offshore.

Summary – Global Offshore Wind Data

- In 2019, global installed offshore wind capacity grew by 19% from the previous year, reaching 27,064 MW. Europe and Asia were the most active markets, adding a combined total of 5,618 MW in new capacity.
- In 2019, 22 new offshore wind projects commenced operations globally: 12 in China, 4 in Germany, 2 in Belgium, and 1 each in Denmark, Japan, Norway, and the UK.
- In 2019, for the first time, China had the largest annual capacity addition of any country, with 2,656 MW added.

Global Floating Offshore Wind Data

Global Floating Offshore Wind Pipeline



- The total global floating offshore wind pipeline was 7,663 MW at the end of 2019, based on projects that have announced their planned capacity.
- 1,549 MW of floating offshore wind has reached the permitting stage.
- The 25.2-MW WindFloat Atlantic, the second floating project in Europe, became fully operational in 2020.
- The primary driver for pipeline expansion is the movement toward commercial-scale projects developing in Asia.

Floating Offshore Wind Pipeline

Region	Country	Installed (MW)	Under Construction (MW)	Approved (MW)	Permitting (MW)	Planning (MW)	Totals (MW)
Asia	China	0	0	0	0	16	**16**
	Japan	22.06	0	0	0	0	**22.06**
	South Korea	0	0	0	1,300	406	**1,706**
	Taiwan	0	0	0	0	1,000	**1,000**
Middle East	Saudi Arabia	0	0	0	0	500	**500**
Europe	France	2	0	10	108.5	256	**376.5**
	Germany	0	0	0	0	2.3	**2.3**
	Ireland	0	0	0	0	706	**706**
	Norway	2.9	0	10	101.6	0	**114.5**
	Portugal	25	0	0	0	0	**25**
	Spain	2.2	0	0.03	27	216.23	**245.46**
	Sweden	0.03	0	0	0	1	**1.03**
	United Kingdom	30	50	0	0	506	**586**
North America	United States	0	0	0	12	2,350	**2,362**
	Totals	**84.19**	**50**	**20.03**	**1,549.1**	**5,959.5**	**7,663**

Note: Values are estimated on developer's announced plant capacity and only include projects with specified CODs.

Floating Offshore Wind Projects (Asia and the Middle East)

Project Name	Country	Status	COD	Project Size (MW)	Substructure Type	Substructure Name	Turbine	Site Water Depth (m)
Shanghai Electric Floating Demonstrator	China	Planning	2023	4	TBD	TBD	TBD	TBD
V-Type Floating Demonstration	China	Planning	2023	12	Spar	TBD	TBD	TBD
Kyushu Wind Lens	**Japan**	**Operational**	**2012**	**0.06**	**Steel semisubmersible**	**Wind Lens Floater**	**3 kilowatts (kW) (RIAMWIND)**	**55**
Fukushima Phase 1	**Japan**	**Operational**	**2013**	**2**	**Steel semisubmersible**	**Fukushima Mirai**	**2 MW (Hitachi)**	**120**
Fukushima Phase 2	**Japan**	**Operational**	**2015**	**7**	**Steel semisubmersible**	**Fukushima Shimpuu**	**7 MW (Mitsubishi)**	**120**
Fukushima Phase 2	**Japan**	**Operational**	**2016**	**5**	**Steel spar**	**Hamakaze Spar**	**5 MW (Hitachi)**	**120**
Goto Sakiyama	**Japan**	**Operational**	**2016**	**2**	**Steel spar**	**Steel Spar**	**2 MW (Hitachi)**	**100**
Hibiki Demo	**Japan**	**Operational**	**2018**	**3**	**Barge**	**Ideol Damping Pool**	**3 MW (Aerodyn)**	**55**
Kitakyushu NEDO	**Japan**	**Operational**	**2019**	**3**	**Barge**	**Ideol Damping Pool**	**3 MW (Aerodyn)**	**100**
Equinor-Hitachi Zosen	Japan	Planning	2022	TBD (Commercial Scale)	TBD	TBD	TBD	TBD
Acacia	Japan	Planning	2023	TBD (Commercial Scale)	Barge	Ideol Dampening Pool	8 MW	TBD
WindFloat Japan	Japan	Planning	TBD	TBD	Steel semisubmersible	PPI WindFloat	TBD	TBD
KFWind	South Korea	Permitting	2025	500	Steel semisubmersible	PPI WindFloat	63 x 8 MW (MHI Vestas)	150
Donghae Gray Whale	South Korea	Permitting	2025	200	TBD	TBD	TBD	150
Donghae TwinWind	South Korea	Permitting	2025	200	Multiturbine steel semisubmersible	Hexicon	20 x 10 MW	150
KNOC/Equinor	South Korea	Permitting	2026	200	TBD	TBD	TBD	150
Ulsan White Heron	South Korea	Permitting	2026	200	TBD	TBD	TBD	150
Donghae - MOTIE	South Korea	Planning	2022	200	Steel semisubmersible	TBD	TBD	TBD
Donghae 1	South Korea	Planning	2023	200	Spar	TBD	TBD	TBD
Ulsan Demos	South Korea	Planning	2021	5.75	Steel semisubmersible	TBD	TBD	TBD
Floating W1N	Taiwan	Planning	2025	500	Steel semisubmersible	TBD	TBD	TBD
EOLFI – W3	Taiwan	Planning	2030	500	TBD	TBD	TBD	TBD
Plambeck Emirates	Saudi Arabia	Planning	2024	500	Steel semisubmersible	Saipem HexaFloat	TBD	TBD

Note: Operational projects are in bold. Project size is based on developer announcements.

Floating Offshore Wind Projects (Europe)

Project Name	Country	Status	COD	Project Size (MW)	Substructure Type	Substructure Name	Turbine	Site Water Depth (m)
Floatgen Demo	**France**	**Operational**	**2018**	**2**	**Barge**	**Ideol Dampening Pool**	**2 MW (MHI Vestas)**	**33**
EOLMED (Gruissan)	France	Permitting	2021	25	Barge	Ideol Dampening Pool	4 x 6.2 MW (Senvion)	55
Provence Grand Large Wind Farm	France	Permitting	2021	25.2	Steel tension-leg platform	SBM Windfloater	3 x 8.4 MW (Siemens Gamesa)	90
EOLink Demo	France	Permitting	2021	6	Steel semisubmersible	EOLink	6 MW	36
EFGL - Les éoliennes flottantes du Golfe du Lion	France	Permitting	2022	30	Steel semisubmersible	PPI WindFloat	3 x 10 MW (MHI Vestas)	70
Groix-Belle-Ile	France	Permitting	2022	28.5	Steel semisubmersible	Naval Sea Reed	3 x 9.5 MW (MHI Vestas)	60
Bretagne Sud	France	Planning	2025	TBD	Steel semisubmersible	Naval Sea Reed	TBD	TBD
EOLMED (Commercial)	France	Planning	2025	250	Barge	Ideol Dampening Pool	TBD	TBD
EOLink Commercial	France	Planning	TBD	TBD	Steel semisubmersible	EOLink	TBD	TBD
Gicon SOF	Germany	Planning	2021	2.3	Steel tension-leg platform	Gicon TLP	2.3 MW (Siemens Gamesa)	TBD
AFLOWT	Ireland	Planning	2022	6	Steel semisubmersible	Saipem HexaFloat	TBD	100
Inis Ealga floating wind farm	Ireland	Planning	2026	700	TBD	TBD	TBD	TBD
Hywind I Demo	**Norway**	**Operational**	**2009**	**2.3**	**Steel spar**	**Equinor Hywind**	**2.3 MW (Siemens Gamesa)**	**220**
TetraSpar Demo	Norway	Permitting	2021	3.6	Steel spar	TetraSpar	3.6 MW (Siemens Gamesa)	200
FLAGSHIP Demonstration	Norway	Permitting	2022	10	Concrete semisubmersible	OO-Star Wind Floater	10 MW+ (TBD)	TBD
Hywind Tampen	Norway	Permitting	2022	88	Concrete spar	Equinor Hywind	11 x 8 MW (Siemens Gamesa)	300
NOAKA	Norway	Planning	TBD	TBD	Steel spar	Equinor Hywind	8 MW (Siemens Gamesa)	200
Test Area Stadt	Norway	Permitting	2025	10	TBD	TBD	TBD	TBD

Note: Operational projects are in bold. Project size is based on developer announcements.

Floating Offshore Wind Projects (Europe [Continued])

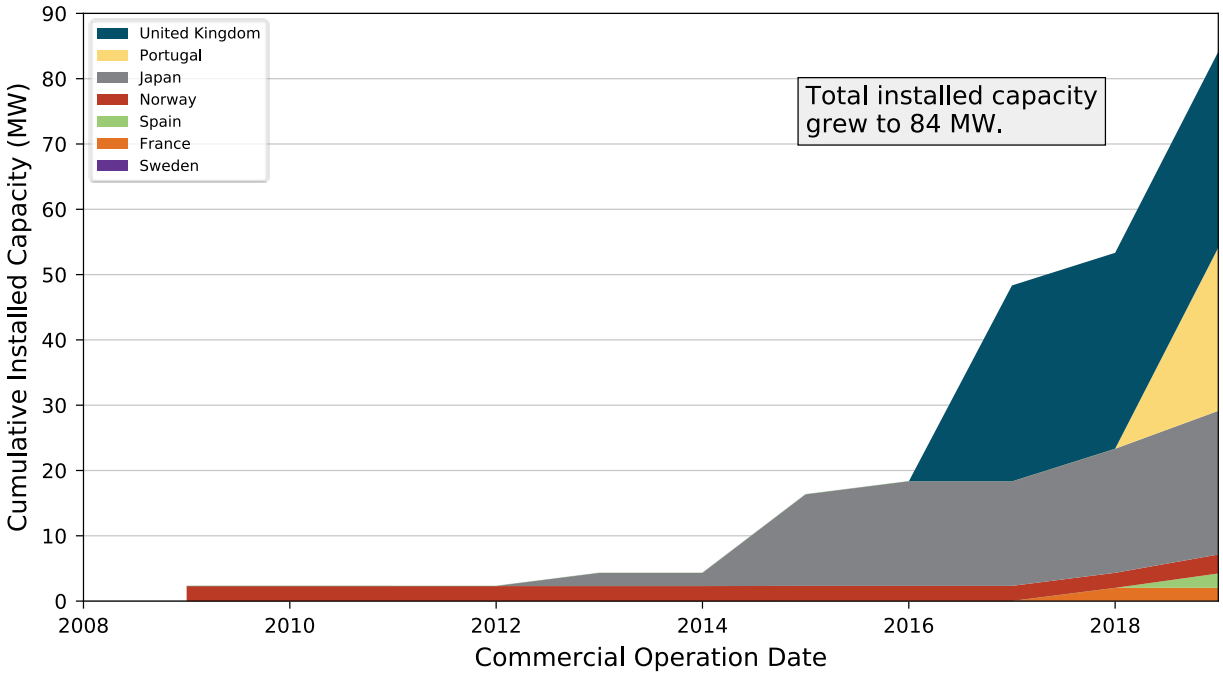
Project Name	Country	Status	COD	Project Size (MW)	Substructure Type	Substructure Name	Turbine	Site Water Depth (m)
WindFloat Atlantic	**Portugal**	**Operational**	**2020**	**25**	**Steel semisubmersible**	**PPI WindFloat**	**3 x 8.3 MW (MHI Vestas)**	**100**
W2Power	**Spain**	**Operational**	**2019**	**0.02**	**Multiturbine steel semisubmersible**	**W2Power**	**100 kW**	**600**
BlueSATH	**Spain**	**Operational**	**2020**	**0.03**	**Concrete semisubmersible**	**SATH**	**Aeolos-H 30kW**	**80**
DemoSATH	**Spain**	**Operational**	**2020**	**2**	**Concrete semisubmersible**	**SATH**	**2 MW (XEMC Darwind)**	**80**
Floating Power Plant	Spain	Planning	2021	8	Hybrid wind-wave semisubmersible	P80	5 MW+ (TBD)	600
FLOCAN 5	Spain	Planning	2024	25	Steel semisubmersible	TBD	TBD	TBD
X1 Wind	Spain	Permitting	2021	2	Steel tension-leg platform	PivotBuoy	2 MW (MHI Vestas)	600
Nautilus/Balea	Spain	Planning	2023	8	Steel semisubmersible	Nautilus Semi-sub	8 MW (TBD)	120
Equinor Floating Project (Juan Grande)	Spain	Planning	2024	200	Steel spar	Equinor Hywind	TBD	TBD
Iberdrola Demo	Spain	Planning	TBD	TBD	TBD	TBD	TBD	TBD
CanArray	Spain	Planning	TBD	TBD	Multiturbine steel semisubmersible	W2Power	6 MW (TBD)	600
SeaTwirl 1	**Sweden**	**Operational**	**2015**	**0.03**	**Steel spar (VAWT*)**	**SeaTwirl**	**30-kW VAWT**	**35**
SeaTwirl 2	Sweden	Permitting	2021	1	Steel spar (VAWT)	SeaTwirl	1-MW VAWT	100
Hywind Scotland	**UK**	**Operational**	**2017**	**30**	**Steel spar**	**Equinor Hywind**	**6 MW (Siemens Gamesa)**	**112**
Kincardine Phase 1	**UK**	**Operational**	**2018**	**2**	**Steel semisubmersible**	**PPI WindFloat**	**2 MW (MHI Vestas)**	**62**
Kincardine Phase 2	UK	Under Construction	2020	50	Steel semisubmersible	PPI WindFloat	5 x 9.5 MW (MHI Vestas)	62
Marine Power Systems	UK	Planning	2023	TBD	Wind-wave hybrid steel semisubmersible	DualSub	TBD	TBD
Dolphyn Phase 1	UK	Planning	2024	2	Steel semisubmersible	PPI WindFloat +Electrolyzer	2 MW (MHI Vestas)	TBD
Erebus	UK	Planning	2025	96	Steel semisubmersible	PPI WindFloat	TBD	70
Dolphyn Phase 2	UK	Planning	2027	400	Steel semisubmersible	PPI WindFloat +Electrolyzer	10 MW	TBD
Dounreay Tri	UK	Planning	TBD	10	Multiturbine steel semisubmersible	Hexicon	5 MW (TBD)	TBD
Katanes Floating Energy Park	UK	Planning	2022	8	Hybrid wind-wave semisubmersible	P80	5 MW+ (TBD)	TBD
Dyfed Floating Energy Park	UK	Planning	TBD	TBD	Hybrid wind-wave semisubmersible	P80	5 MW+ (TBD)	TBD

Note: Operational projects are in bold. Project size is based on developer announcements; *Vertical-axis wind turbine

Floating Offshore Wind Projects (North America)

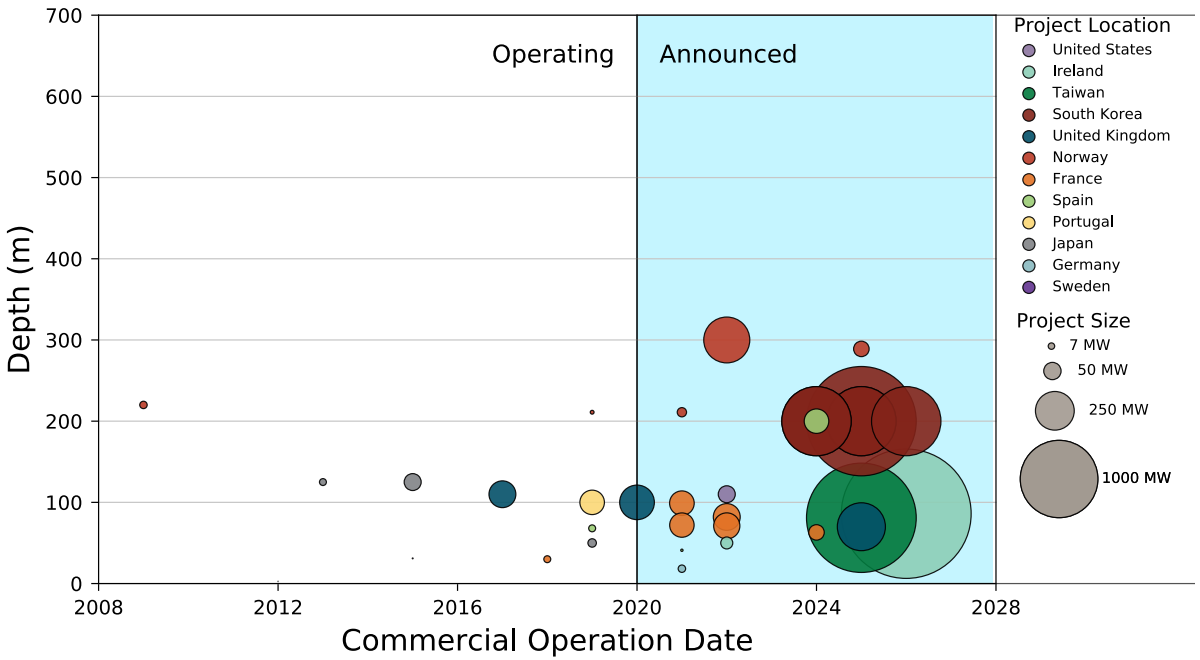
Project Name	Country	Status	COD	Project Size (MW)	Substructure Type	Substructure Name	Turbine	Site Water Depth (m)
Aqua Ventus	United States	Permitting	2023	12	Concrete semisubmersible	VolturnUS	10 MW + (TBD)	100
Castle Wind	United States	Planning	TBD	1,000	Steel semisubmersible	TBD	TBD	900
Magellan Stiesdal	United States	Planning	TBD	TBD	Steel semisubmersible	TetraSpar	TBD	TBD
Oahu North	United States	Planning	TBD	400	Steel semisubmersible	TBD	TBD	850
Oahu South	United States	Planning	TBD	400	Steel semisubmersible	TBD	TBD	650
Progression South	United States	Planning	TBD	400	Steel semisubmersible	TBD	TBD	600
Redwood Coast	United States	Planning	TBD	150	Steel semisubmersible	PPI WindFloat	8 MW+ (TBD)	600

Cumulative Installed Offshore Floating Wind Capacity by Country to Date



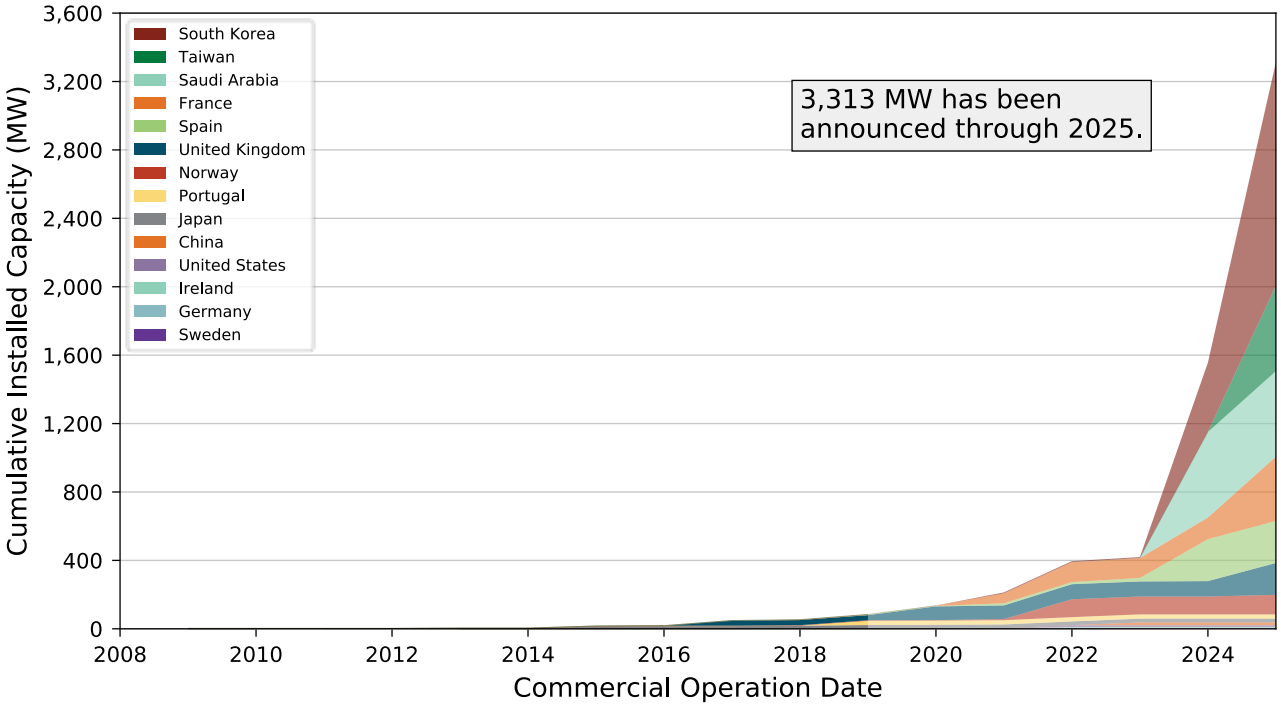
- At the end of 2019, there was 84 MW of installed floating wind capacity globally, growing by 36 MW from 2018.
- Of this installed capacity, there are 16 projects, with 9 projects (62.13 MW) in Europe and 7 (22.06 MW) in Asia.
- Two pilot-scale projects comprising 3 and 5 turbines have been installed in Portugal (2020—labeled as 2019) and Scotland (2017), respectively.

Global Floating Offshore Wind Project Timeline for Projects with Announced CODs



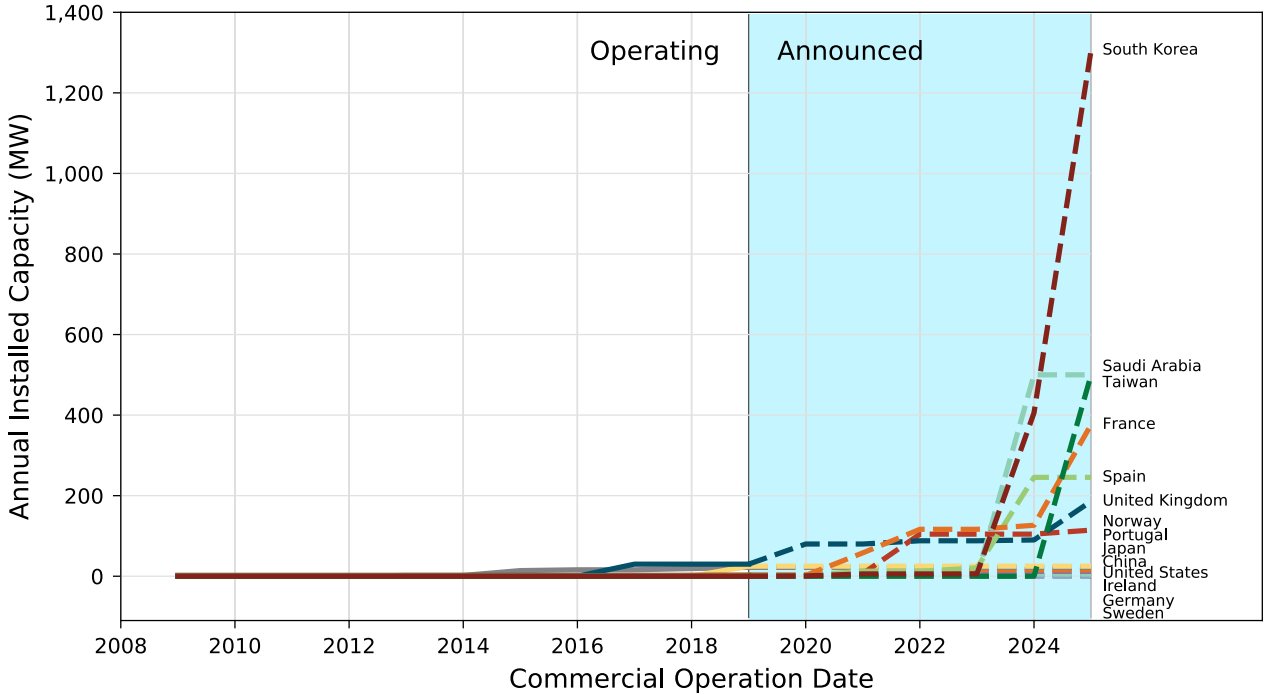
- There are roughly 12 projects (292 MW) that are under construction or in the permitting phase in Europe, which are scheduled for commercial operations between 2020 and 2022.
- There are 1,300 MW of projects in the permitting phase in Asia.
- Several projects have been announced without an anticipated commercial operation date. These projects are not shown on the chart.

Cumulative Offshore Floating Wind Capacity by Country Based on Announced COD Through 2025



- Projects with announced CODs in 2025 or before total 3,313 MW.
- A small number of commercial projects have announced a COD after 2025.
- Aqua Ventus I is the only U.S. project in the permitting stage and is now expected to reach commercial operations in 2023.

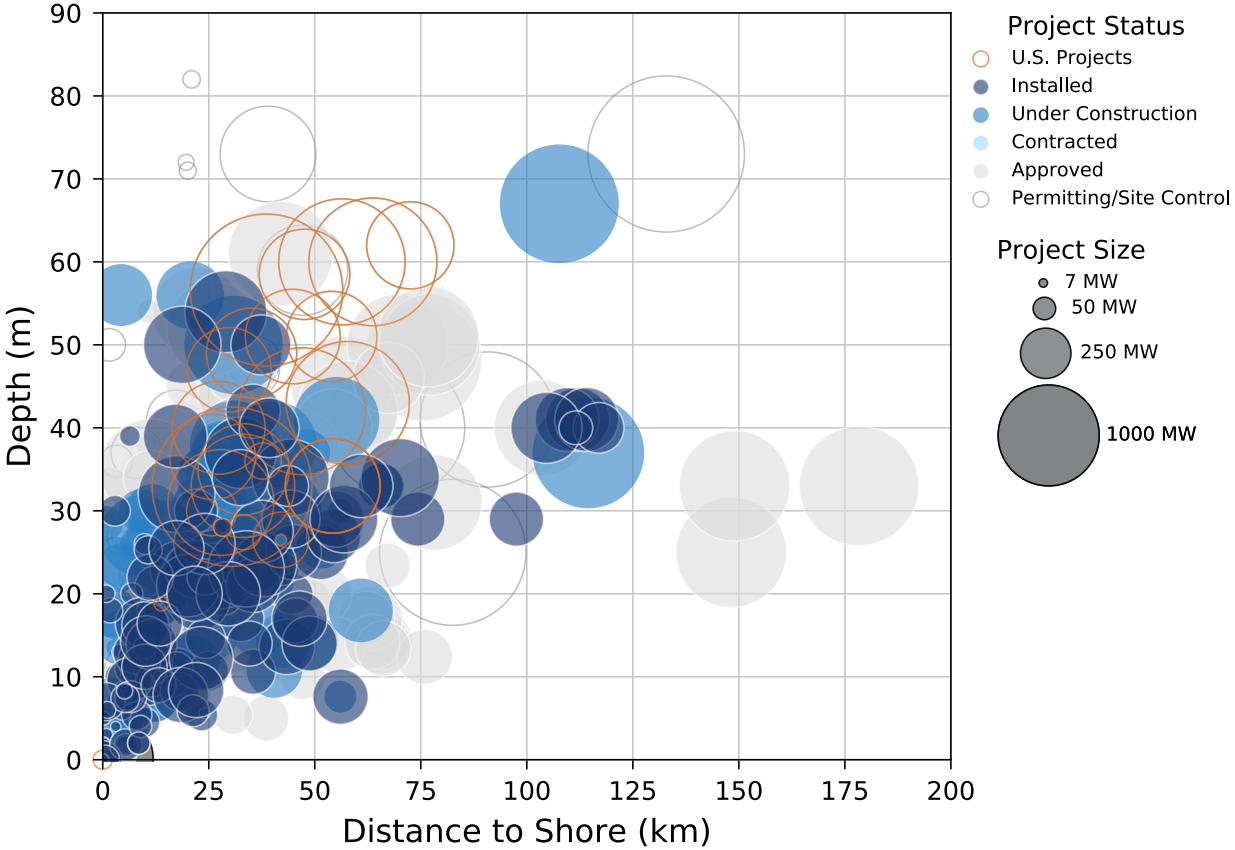
Country-Specific Offshore Floating Wind Capacity Based on Announced COD Through 2025



- Korea, France, Taiwan, Spain, and the UK account for the majority of announced CODs through 2025, with several commercial-scale projects announced for 2024.
- Pilot-scale projects (less than 50 MW) account for nearly all floating projects with announced CODs through 2023.

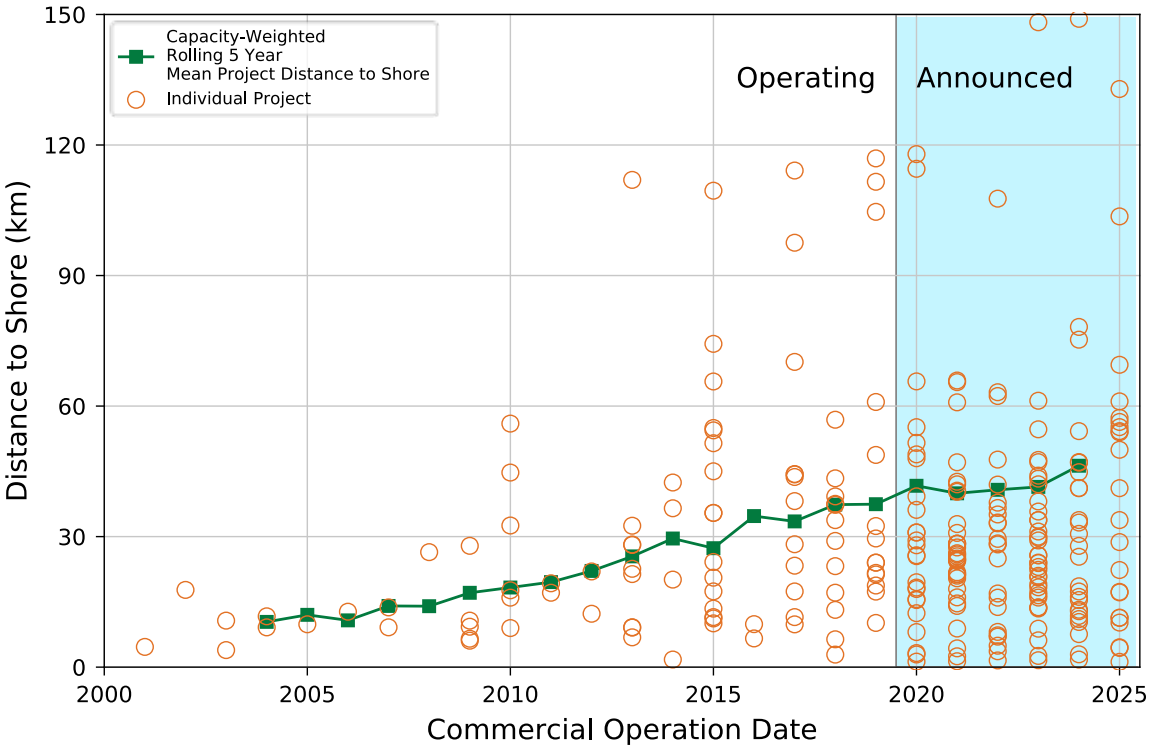
2019 Offshore Wind Technology Trends

Fixed-Bottom Offshore Wind Project Depths and Distances to Shore



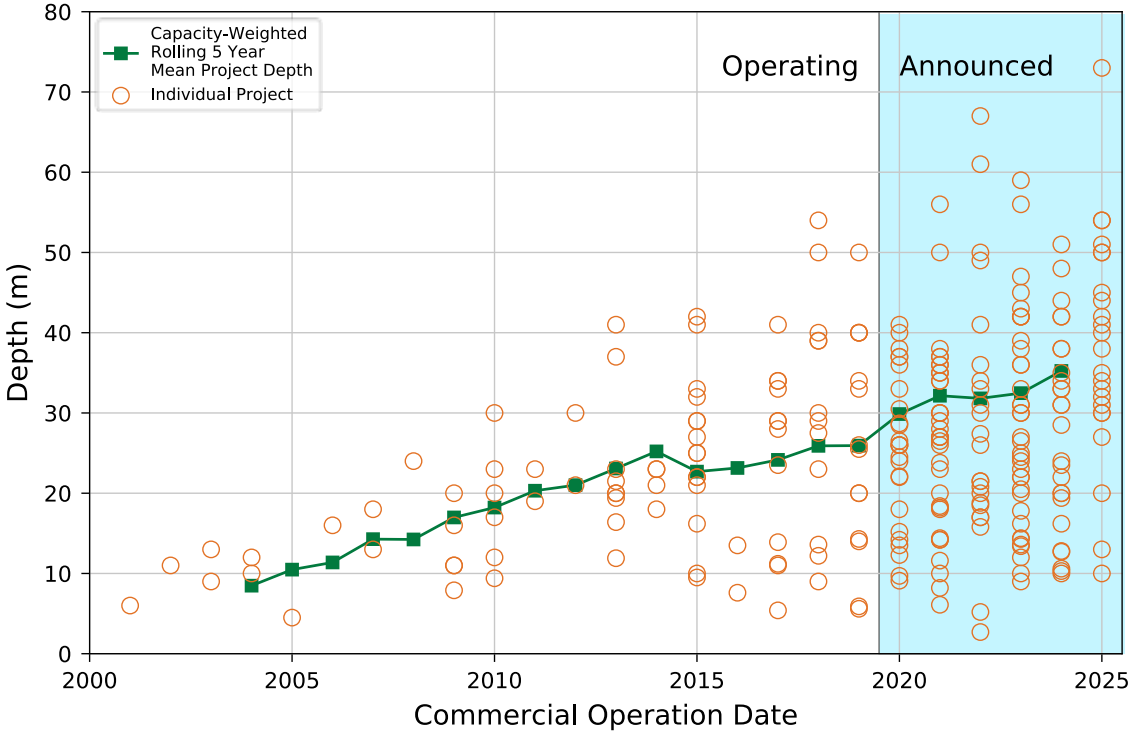
- Distance to shore is measured as the straight-line distance between the project and the shoreline.
- Announced European projects indicate increasing project size, water depth, and distance to shore.
- Announced U.S. projects have not been proposed farther than 75 kilometers (km) from shore but may push into water depths above 50 m.

Distance from Shore for Operating and Future Projects



- The green line, showing the capacity-weighted rolling average, indicates that, on average, projects are trending farther from shore globally.
- Most announced projects remain between 0 km and 60 km from shore.
- The capacity-weighted mean is slowly moving further away from shore driven by a few large projects between 90 km and 150 km.

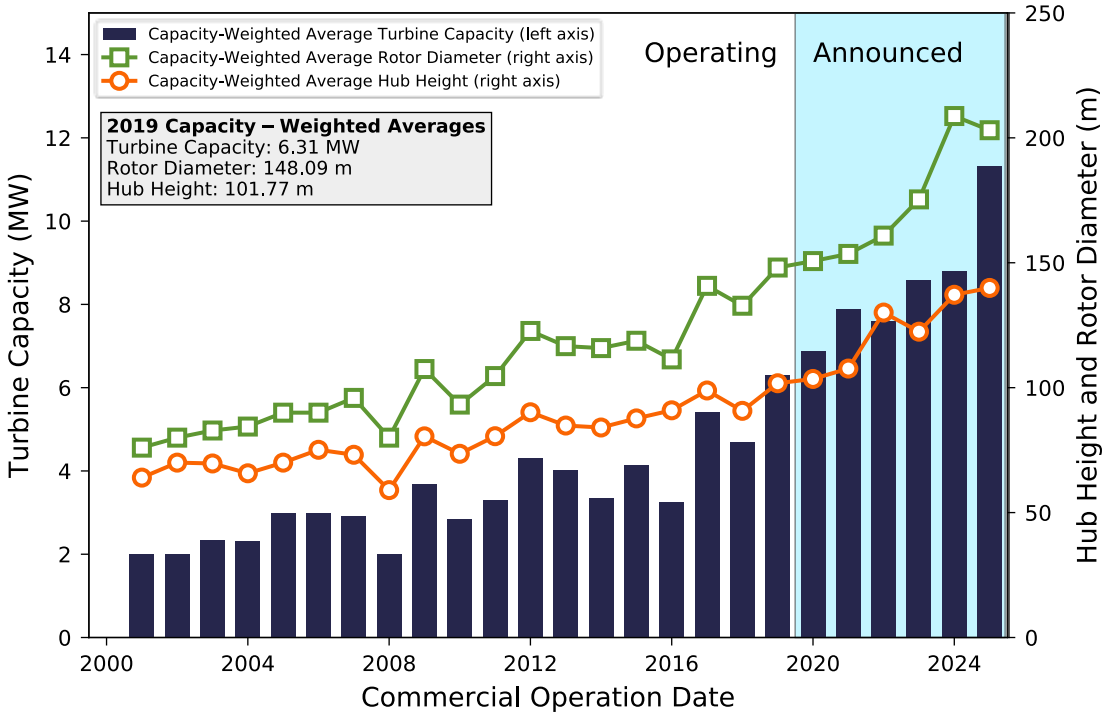
Water Depth for Operating and Future Projects



- The depth of water in which projects are installed is increasing.
- Green line shows capacity-weighted 5-year mean project depth is driven upward by some announced projects that are planned for depths of 60 m and greater.
- Data indicate that fixed-bottom foundations may be economical in deeper waters than previously thought (Musial et al. 2016).

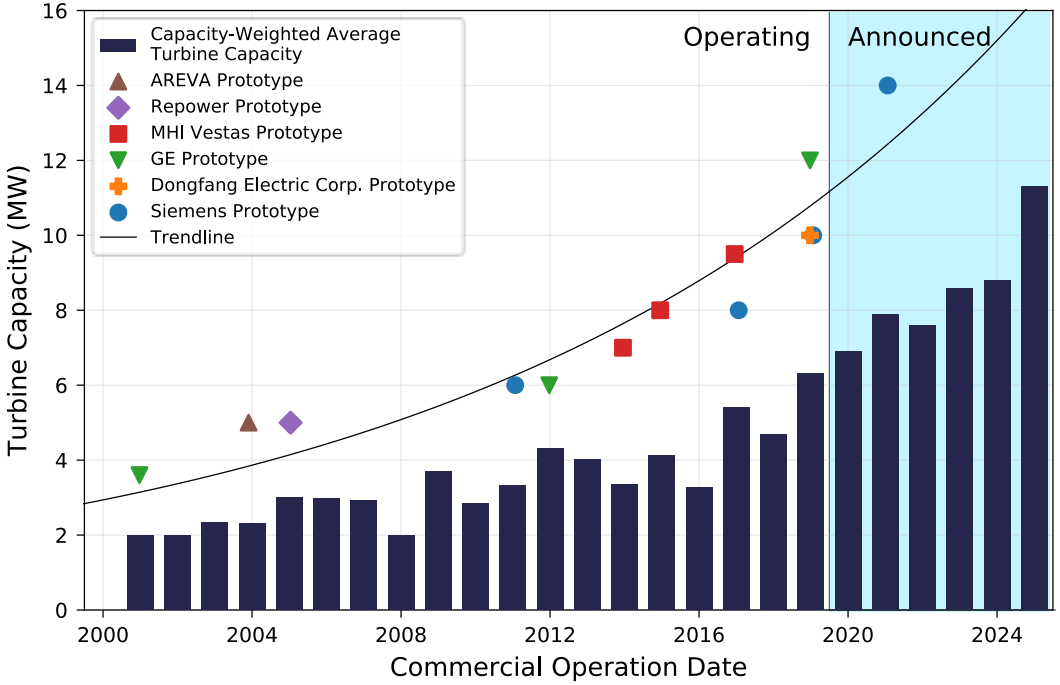
Source: Musial et al. (2016)

Average Offshore Wind Turbine Capacity, Hub Heights, and Rotor Diameters



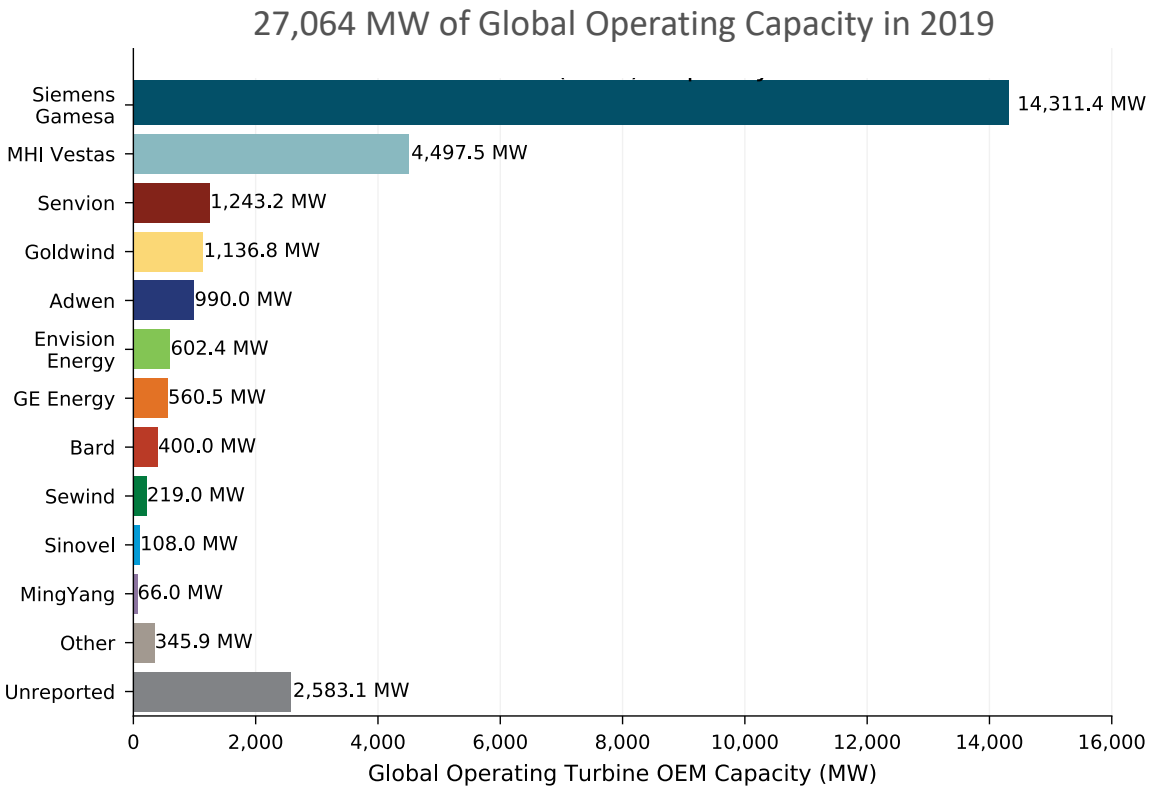
- Announced turbine supply agreements indicate continued growth in offshore turbine capacity, height, and rotor diameter.
- Data show average installed turbine capacity was about 6 MW in 2019 and 11 MW for projects announced for 2025.
- 12-MW turbines have been announced for some projects as early as 2023.

Comparison of Offshore Wind Turbine Prototypes with Commercial Offshore Turbine Growth



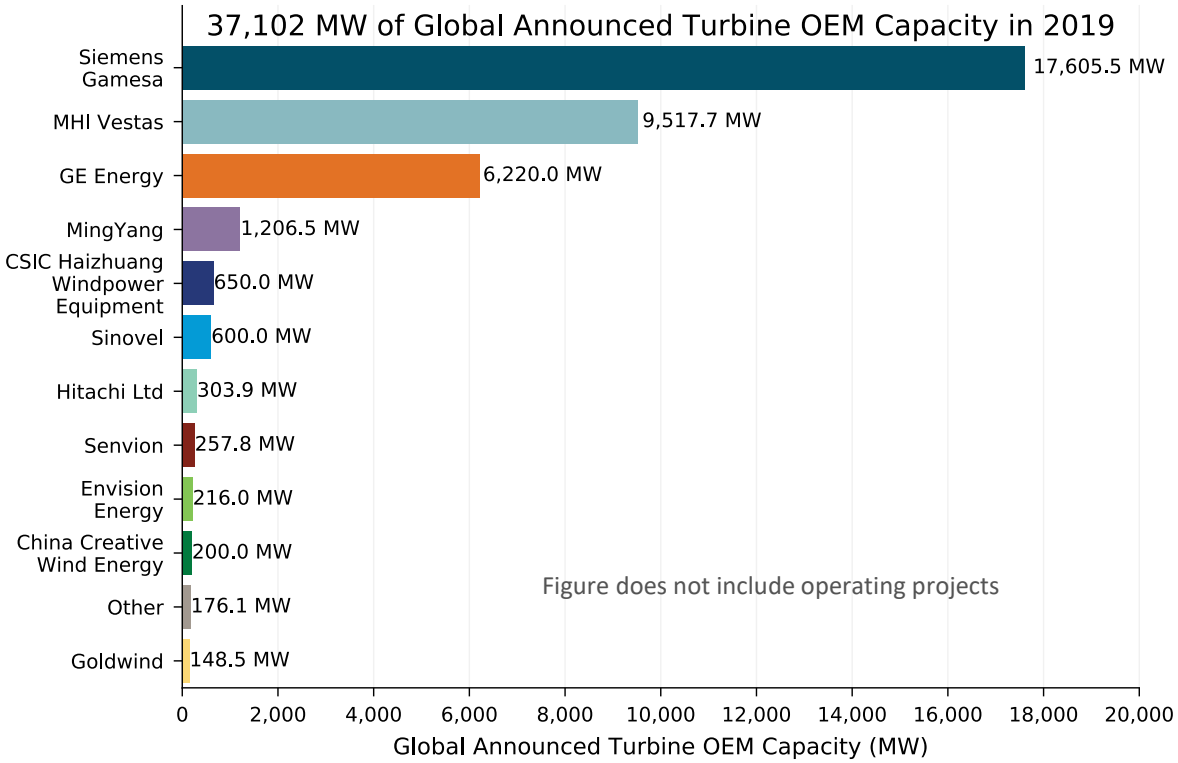
- Data show year of first deployment for offshore wind turbine prototypes compared with commercial capacity-weighted averages.
- Data indicate a multiyear lag before capacity-weighted averages reach prototype capacity levels.
- Progress in 12-MW to 14-MW prototype development was made in 2019.
- GE 12-MW Haliade-X prototype was installed onshore in Rotterdam in 2019.
- Siemens Gamesa announced the 10-MW SG 10.0-193 direct-drive turbine and the 14-MW SG 14-222 turbine.

Offshore Wind Turbine Manufacturer Market Share in Operating Projects



- In operating projects for which the turbine manufacturer is known:
  - Siemens Gamesa continues to be the largest global supplier of offshore wind turbines, with about 58% of installed capacity (14,311 MW).
  - MHI Vestas has about 18%market share of installed offshore wind capacity.
- The “Other” category includes offshore wind turbine manufacturers with less than a 60-MW share of the market.
- The “Unreported” category comprises the capacity of projects where turbine data are not available.

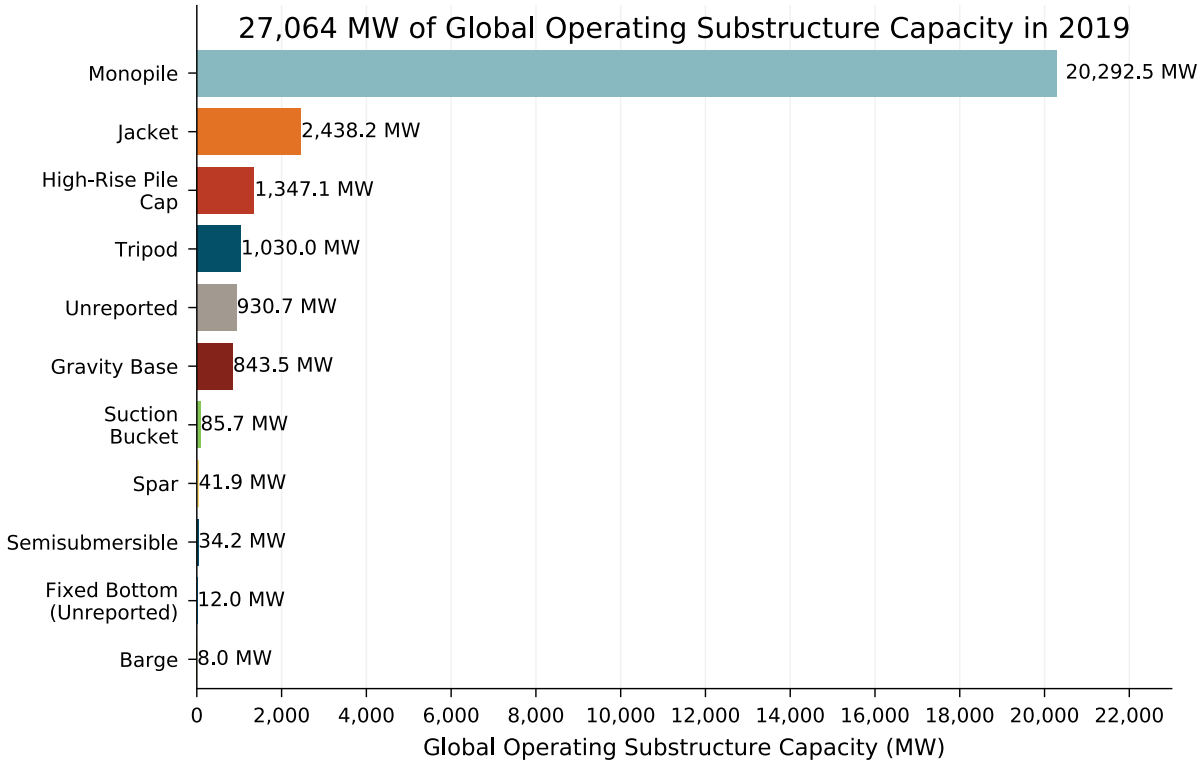
Announced Offshore Wind Turbine Manufacturer Market Share



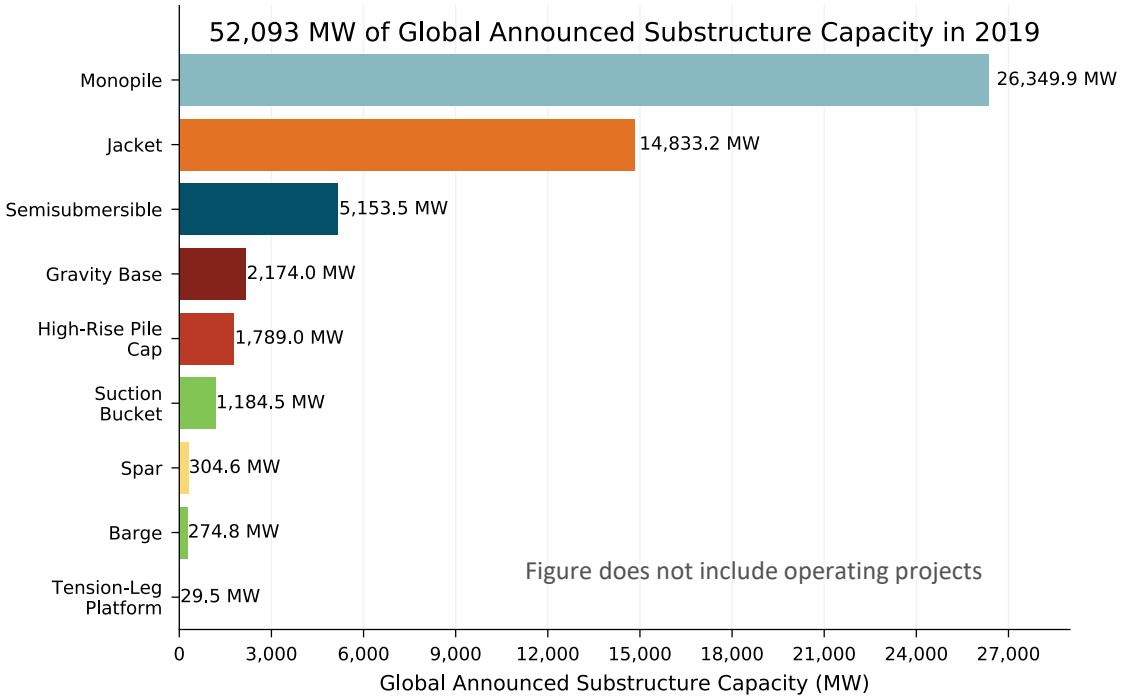
- Siemens Gamesa accounts for 47% of projects with announced turbine supply agreements.
- The MHI Vestas share is growing, with a 26% share of announced projects versus 18% of operating projects.
- GE's share is growing from 2% currently to 17% of announced projects.
- 166,008 MW of announced project capacity has not reported a turbine original equipment manufacturer (OEM).

Offshore Wind Substructure Technology Used in Operating Projects

Monopiles represented 75% of total installed offshore wind capacity globally at the end of 2019



Announced Offshore Wind Substructure Technology Market Share



- 74% of announced projects (151,017 MW) in the pipeline have not announced the substructure type.
- 51% of substructures for announced projects are monopiles, lower than the 75% share among operating projects.
- For depths greater than 60 m, the industry is developing multiple types of floating substructures.

Global Floating Substructure Market Share

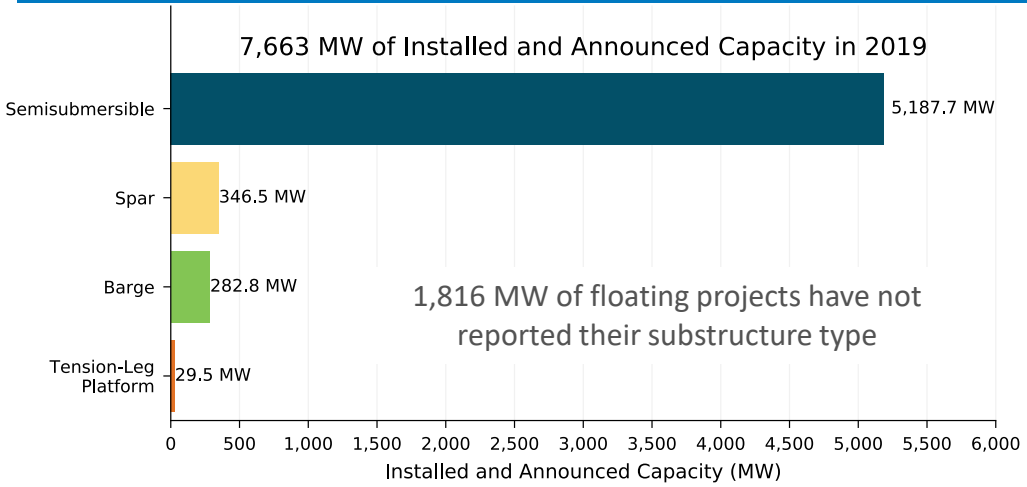
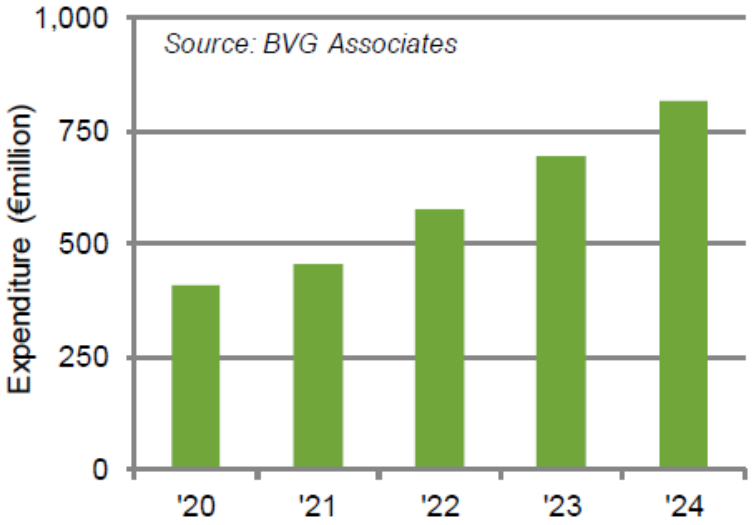


Illustration by Josh Bauer, NREL

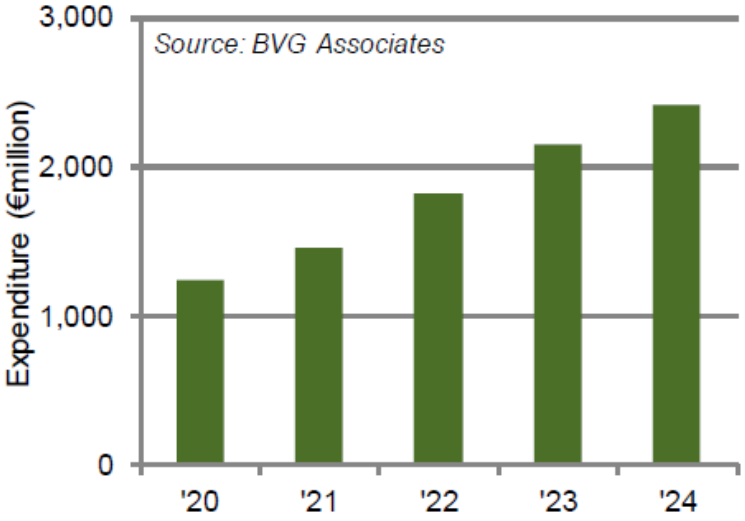
- In 2019, there were 7,663 MW of projects in the floating pipeline; the substructure type is announced for roughly 76% (5,847 MW) of the total pipeline.
- Semisubmersibles account for about 89% of installed and announced capacity for projects which the intended substructure type is known.
- Semisubmersibles have shallow draft, which allows for full assembly and commissioning at quayside, as well as tow-out to an offshore station without the use of heavy-lift installation vessels.
- Approximately 5% use or plan to use spars (e.g., Equinor's 30-MW floating wind power plant).
- The remaining substructures are tension-leg platforms and barges.

Offshore Subsea Cables Market Forecast

BVG estimates array cables market will grow from €0.4 ($0.4) billion in 2020 to €0.8 ($0.9) billion in 2024.

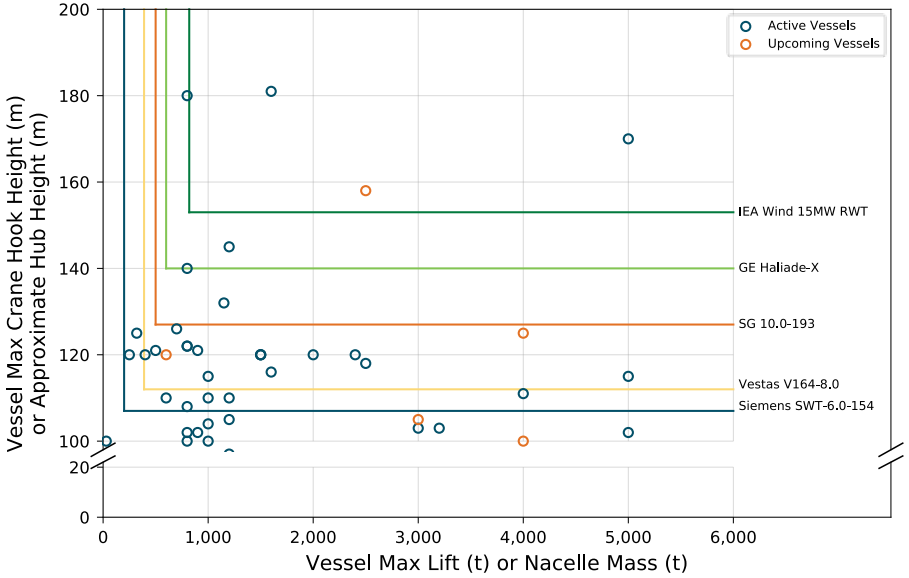


BVG estimates export cables market will grow from €1.2 ($1.3) billion in 2020 to €2.4 ($2.7) billion in 2024.



Source: BVG Associates (2019)

Global Turbine Installation Vessel Fleet



Turbine Model	Manufacturer	Rating (MW)	Nacelle Mass (t)	Hub Height (m)	Rotor Diameter (m)
Siemens SWT-6.0-154	Siemens Gamesa	6	225	107	154
Vestas V164-8.0	Vestas	8	390	112	164
SG 10.0-193	Siemens Gamesa	10	500	127	193
GE Haliade-X	General Electric	12	727	140	220
IEA Wind 15-MW RWT[3]	N/A	15	820	153	240

- With the introduction of the next generation of 12-MW to 15-MW wind turbines, the number of TIVs in the global fleet capable of installing these turbines diminishes significantly.[1]
- Lift height requirements are the most constraining factor.[2]
- New TIVs will be required to install and service the next generation of turbines both globally and in the United States.

[1] Some upcoming vessels are not included in this figure, as the maximum hook height or maximum lifting capacity have not been announced.

[2] This figure assumes a hub height sufficient for 30 m of water clearance at the lowest point of blade passage.

[3] The International Energy Agency (IEA) Wind 15-MW reference wind turbine (RWT) is a hypothetical wind turbine developed within the IEA Wind Task 37 (Gaertner et al. 2020).

Summary – Technology

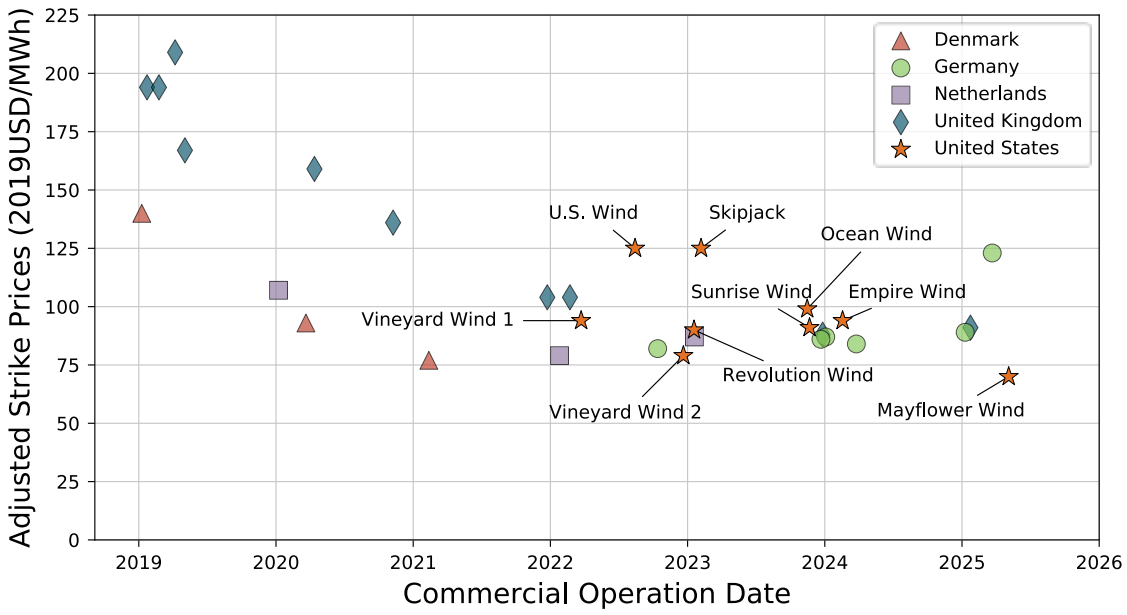
- Globally, the capacity-weighted average offshore wind turbine size has grown from 3.5 MW in 2010 to 6 MW in 2019. Similarly, rotor diameters have grown from a capacity-weighted average of 100 m in 2010 to 150 m in 2019. Announced turbine supply agreements for projects to be installed by 2025 show an increase in capacity to 10 MW and rotor diameter to 200 m.
- GE's Haliade-X 12-MW wind turbine prototype with a 220-m rotor was installed in Rotterdam, Netherlands, in fall 2019. GE reports that it will be commercially available in 2021.
- Siemens Gamesa announced that its 10-MW wind turbine prototype, with a 193-m rotor and a direct-drive generator, was installed in Osterild, Denmark, and will be commercially available in 2022.
- In May 2020, Siemens Gamesa also announced a new 14-MW turbine platform with a 222-m rotor and a direct-drive generator, which will be commercially available by 2024.
- Technology advancements in fixed-bottom substructures have enabled siting in deeper water. In 2019, capacity-weighted average depth of installed projects was 31 m. Project announcements indicate an increase in average depths to 43 m by 2025.

Summary – Technology (continued)

- The capacity-weighted distance from shore in 2019 was 47 km for installed projects. Project announcements indicate an increase to 70 km by 2025. More remote siting has been enabled by technology advancements in electrical grid infrastructure, such as high-voltage direct current (HVDC).
- In 2019, Siemens Gamesa and MHI Vestas were the two largest turbine suppliers, representing 53% and 16% of installed capacity, respectively. Of the projects that have announced turbine suppliers through 2025, Siemens Gamesa continues to hold the largest market share at 47%, with MHI Vestas at 26% and GE at 17%.
- Monopiles were used in 75% of installed fixed-bottom global capacity in 2019 while jackets accounted for 9%. The remainder of installations used various foundation types including high-rise pile cap, tripod, and gravity base.
- Hybrid versions of spars and tension-leg platform substructure types that achieve the same installation and commissioning benefits as semisubmersibles have been permitted in Europe and have announced deployment dates for pilot-scale demonstration in 2021 and 2022.

2019 Offshore Wind Cost Data

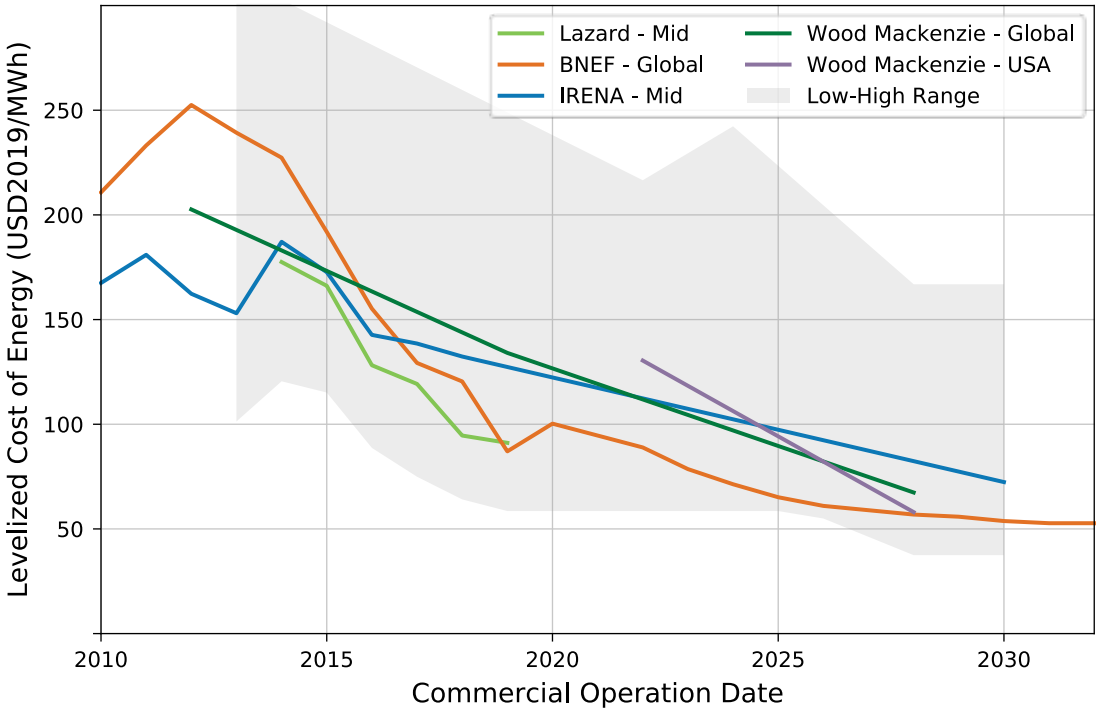
Adjusted Strike Prices from U.S. and European Offshore Wind Auctions



- In Europe, levelized adjusted[4] PPA/OREC strike prices have fallen from around $180/megawatt-hour (MWh) (2019 COD) to $90/MWh (2025 COD) on average; a decrease of 50%.
- Levelized power purchase agreement (PPA)/offshore renewable energy certificate (OREC) prices for U.S. projects have fallen by 40% over 2 years to $91/MWh on average, based on a total of 11 signed offtake agreements (with project COD between 2022 and 2025) by the end of 2019.
- With an adjusted PPA/OREC price of $69/MWh, the Mayflower Wind project is among the lowest-priced announced offshore wind projects globally.

[4] Strike prices were adjusted to obtain a "like-for-like" comparison of tendered offshore wind projects globally. Grid connection and development costs were added for those global projects where they are not part of the tender strike price; differences in contract length between global project tenders were accounted for by converting the annual strike price to a present value. The strike prices are shown in "levelized" terms (i.e., in terms of annualized $/MWh).

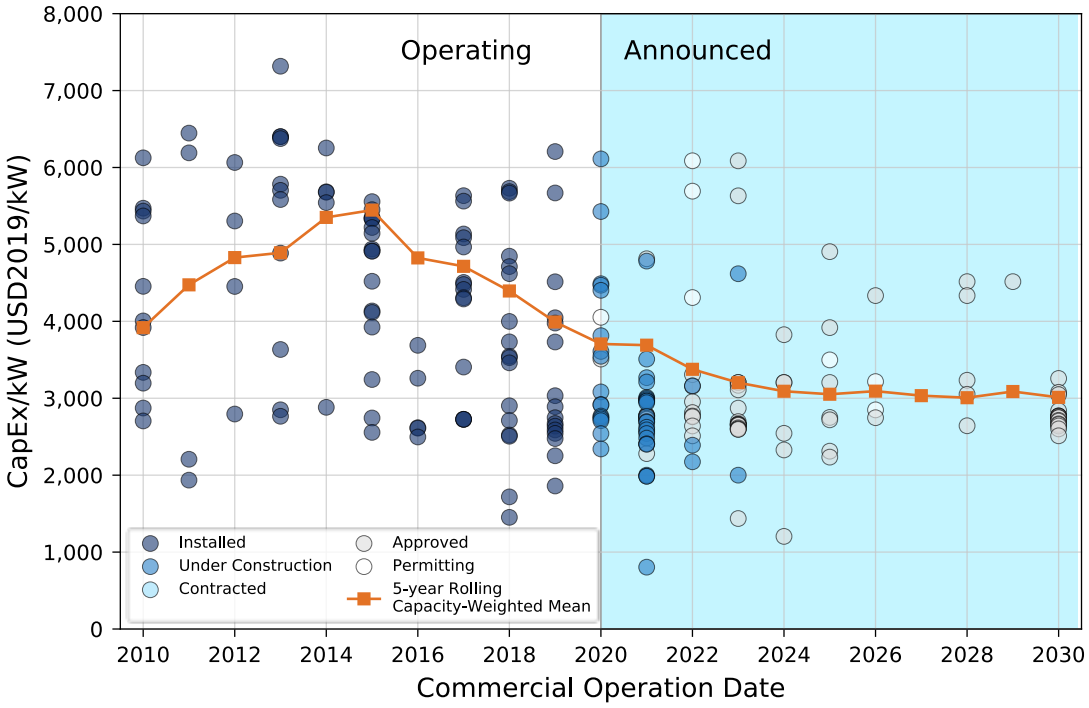
Global LCOE Estimates for Fixed-Bottom Offshore Wind



- Estimates by industry analysts suggest global levelized cost of energy (LCOE) levels reaching between $50/MWh and $75/MWh by 2030, continuing a trend of declining LCOE estimates since 2012.
- In any given year, LCOE estimates from industry analysts vary, in part, because of differences in site characteristics (e.g., wind speed), regulatory contexts, calculation methods, and assumptions about offshore wind industry maturity and growth.

Note:
- "Low-High Range" indicates the lowest and highest LCOE estimate among the depicted literature sources.
- In the legend, "Lazard" refers to Lazard (2014, 2015, 2016, 2017, 2018, and 2019), "IRENA" to IRENA (2019), "Wood Mackenzie" to Yang et al. (2019), and "BNEF" to Brandily (2020).

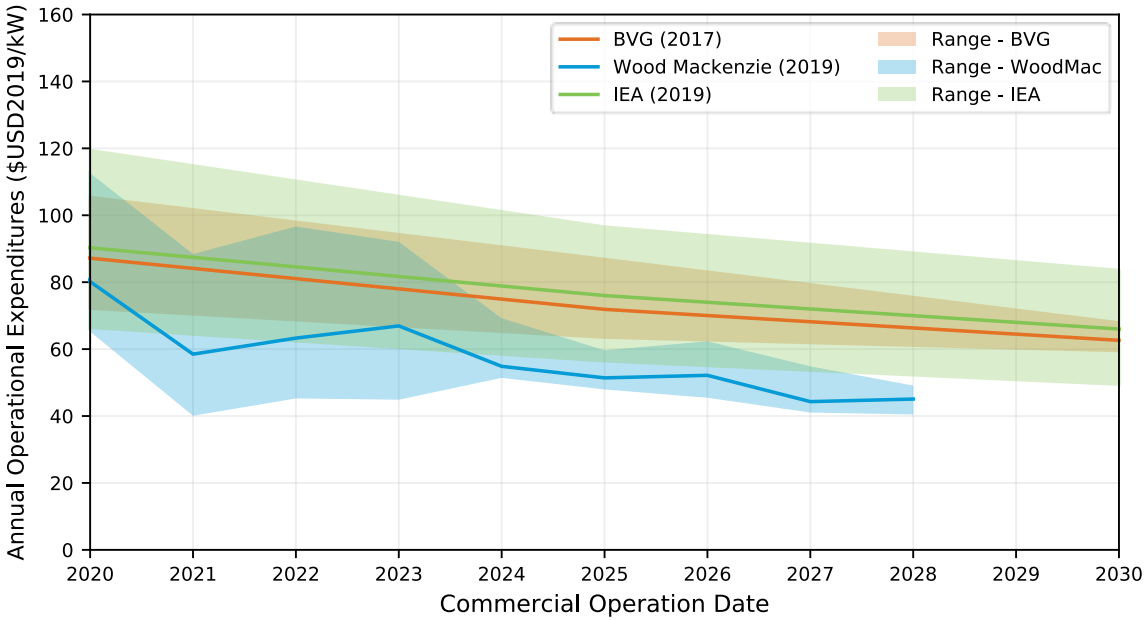
Capital Expenditures for Global Offshore Wind Projects



Note: CapEx data after 2020 as announced publicly by offshore wind developers (e.g., in corporate statements or press releases/reporting)

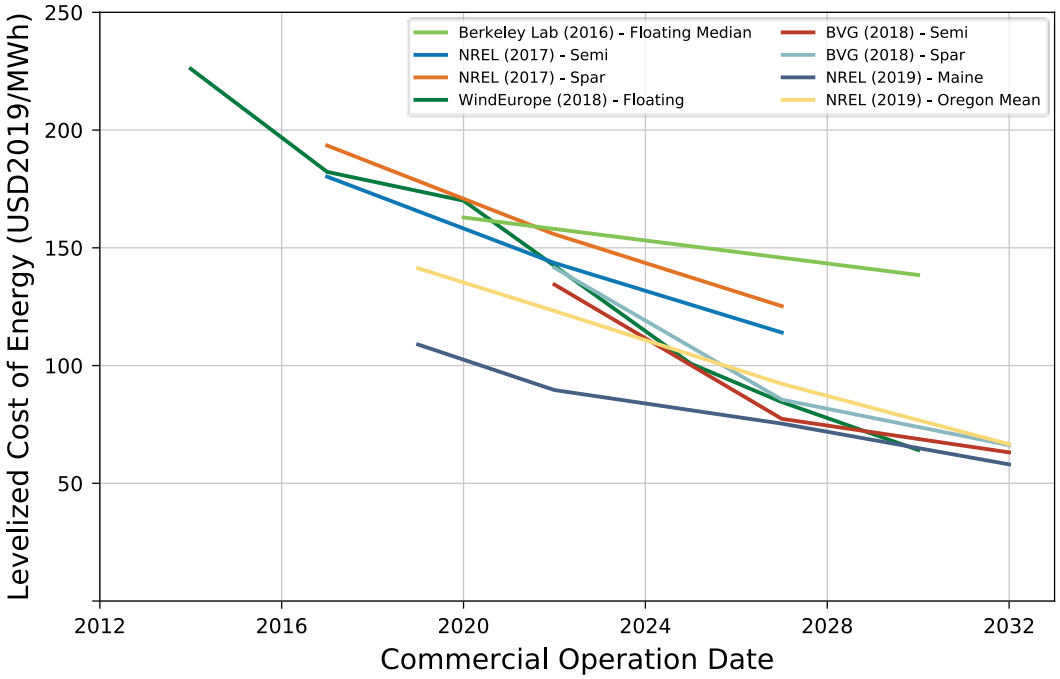
- Between 2019 and 2030, the capacity-weighted 5-year rolling average of developer-announced capital expenditures (CapEx) declines by approximately 25%; the rate of CapEx reductions decreases over this period.
- CapEx varies widely between projects each year because of differences in project siting characteristics, local supply chain maturity, deployed plant-scale and technology, and regulatory policy.
- Key drivers of CapEx decline include economies of scale from turbine and plant upsizing, technology innovation, increased experience, and a growing and more competitive supply chain.
- Turbine costs represent close to 30% of project CapEx. NREL estimates a turbine CapEx of approximately $1,300/kW for projects with a 2019 COD.

Global Offshore Wind Plant Operating Expenses



- Globally, industry analysts project that annual operational expenditures will decrease from approximately $100/kW in 2019 to less than $70/kW in the next decade.
- Technology advancements that contribute to the projected decrease in operational expenditures include:
  - Increasing turbine capacity
  - Increasing reliability
  - Adoption of remote monitoring, inspection, and maintenance technologies
  - Improvements in offshore access capabilities.

Global LCOE Estimates for Floating Technology



Notes:

- Not all years between 2014 and 2032 available from sources.
- In the legend, "Berkeley Lab" refers to Wiser et al. (2016), "BVG" to Hundleby et al. (2017), "NREL (2017)" to Beiter et al. (2017), "NREL (2019) – Oregon" to Musial et al. (2019b), and "NREL (2019)" to Musial et al. (2020).

- Industry analysts indicate floating wind LCOE levels of $110/MWh to $175/MWh for commercial-scale floating projects in 2019. The lower end of this range reflects recent advances in floating technology and cost reductions that have been realized by the fixed-bottom industry and may transfer to floating applications.
- By 2032, industry analysts estimate a floating wind LCOE of approximately $60/MWh.
- Drivers of future floating wind cost reductions include increases in turbine and plant size, substructure and logistical optimization, and the industrialization potential of floating applications.

Offshore Wind Financing

Year	Coverage	Debt/Sponsor Equity/Tax Equity (%)	Pricing (Basis Points)[6]	Source
2006–2007	Europe	60/40/0	150–200	Guillet (2018)
2009–2011	Europe	65/35/0	300–350	Guillet (2018)
2012–2013	Europe	70/30/0	200–250	Guillet (2018)
2014–2015	Europe	70/30/0	200–250	Guillet (2018)
2016–2017	Europe	75/25/0	150–225	Guillet (2018)
2018	Europe	70/30/0	120–175	Guillet (2018)
2019	United States	50/20/30[7]	150–175	Norton Rose (2019)

- Access to low-cost capital for offshore wind projects continues into 2019, consistent with a broader trend in renewable energy asset financing.
- 100% of European offshore wind projects with financial close in 2019 were project financed (i.e., nonrecourse) (Brindley 2020).
- U.S. financing is expected to be available at conditions similar to those in European offshore wind markets.
- The optimal debt-to-equity ratio in the United States is strongly influenced by the share of tax equity.

[5] Year 2008 not available from source (Guillet 2018).
[6] 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%.
[7] Based on Norton Rose (2019).

Offshore Wind Financing – Tax Extenders Act

Start of Construction/ 5% Safe Harbor[8] [Four calendar years expiration][9]	ITC level (of total investment)		PTC level (of $25/MWh)[10]	
	TEA (2019)	Previous	TEA (2019)	Previous
2016 [2020]	30%	100%	100%	100%
2017 [2021]	24%	24%	80%	80%
2018 [2022]	18%	18%	60%	60%
2019 [2023]	12%	12%	40%	40%
2020 [2024]	18%	0%	60%	0%
2021 [2025+]	0%	0%	0%	0%

- On December 20, 2019, the Tax Extenders Act (TEA) was signed into law.
- The TEA includes a 1-year extension of the production tax credit (PTC) and investment tax credit (ITC) for start of construction in 2020. The ITC or PTC effectively reduces the total project costs from a developer's/owner's perspective.
- The TEA changes incentivize projects with a construction start in 2019 to explore re-qualifying for higher levels (18% [ITC] and 60% [PTC]) stipulated for construction start in 2020.
- Offshore wind projects may choose to elect the ITC or PTC, depending on the relative financial value (e.g., capital costs and expected capacity factor) and risk. The ITC is generally more favorable for offshore projects.

Notes:

[8] The 5% Safe Harbor Rule stipulates that a project must incur at least 5% of the total cost of the facility to satisfy the "begin construction" requirement of the ITC/PTC and prove a "continuous program of construction" or "continuous efforts to advance towards completion of the facility" (Internal Revenue Service [IRS] 2013).

[9] A facility meets the Safe Harbor Rule if it is placed in service 4 calendar years from the calendar year during which construction began (IRS 2013). Also note that on May 27, 2020, the IRS issued Notice 2020-41, providing a 1-year extension to the Continuity Safe Harbor for projects that began construction in 2016 or 2017 (IRS 2020).

[10] On June 5, 2019, the IRS released a notice increasing the PTC to reflect inflation from $24/MWh to $25/MWh (IRS 2019).

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