Supply Chain Contracting Forecast for U.S. Offshore Wind Power

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Special Initiative on Offshore Wind

White Paper

March 2019

University of Delaware | College of Earth, Ocean, & Environment

SPECIAL INITIATIVE ON OFFSHORE WIND

ABOUT THE SPECIAL INITIATIVE ON OFFSHORE WIND

The Special Initiative on Offshore Wind (SIOW) is an independent project at the University of Delaware's College of Earth, Ocean and Environment that supports the advancement of offshore wind power as part of a comprehensive solution to the most pressing energy problems facing the United States. SIOW provides expertise, analysis, information sharing and strategic partnership with industry, advocacy and government stakeholders to build understanding and drive the deployment of offshore wind.

ACKNOWLEDGMENTS

The Rockefeller Brothers Fund provided funding to SIOW to prepare this study. Many thanks to Doug Pfeister, Daniel Stevens, AJ Negrelli and Emily Kuhn at The Renewables Consulting Group (RCG) who completed the analyses for this report. Thanks also to Kevin Pearce, Michael Stephenson, Walt Musial and Willett Kempton for their review of the paper. Lastly, thank you to the National Ocean Industries Association (NOIA) for their assistance in communicating the findings contained herein to the oil and gas industry. All errors and omissions are the author's.

rcg Renewables Consulting Group

AWEA® AMERICAN WIND ENERGY ASSOCIATION

NOIA America's Offshore Energy Industry

Photo – Block Island offshore wind farm, Rhode Island. Source – *Vox.com*, June 14, 2018
https://www.vox.com/energy-and-environment/2018/5/25/17393156/offshore-wind-us-massachusetts-rhode-island-zinke

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LIST OF ACRONYMS AND ABBREVIATIONS

BOEM	Bureau of Ocean Energy Management
CAPEX	Capital expenditure
EPCI	Engineering, Procurement, Construction & Installation
GW	Gigawatt
LCOE	Levelized cost of energy
MW	Megawatt
OREC	Offshore Renewable Energy Credit
PPA	Power Purchase Agreement
RCG	Renewables Consulting Group
RFP	Request for proposal
RPS	Renewable Portfolio Standard
SIOW	Special Initiative on Offshore Wind
WTG	Wind Turbine Generator

EXECUTIVE SUMMARY

America's growing offshore wind power industry — now projected to generate 18.6 GW of clean, cost-effective power in seven states on the Atlantic Seaboard by 2030 — is presenting a nearly $70 billion CAPEX revenue opportunity to businesses in the offshore wind power supply chain over the course of the next decade.

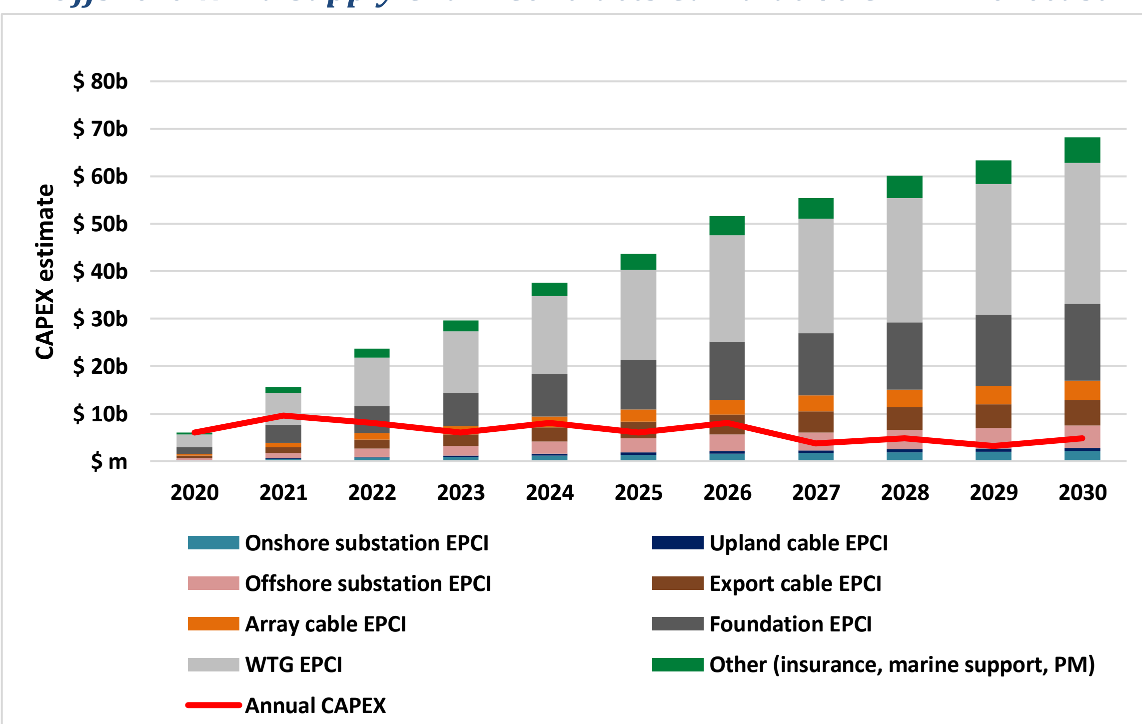
In this white paper, the Special Initiative on Offshore Wind (SIOW) quantifies the extensive supply chain business opportunities this $70 billion CAPEX is creating to build out the U.S. offshore wind sector between now and 2030, with quantification broken down by industry component, by state, and by year through 2030.

As such, SIOW's first-of-its-kind analysis offers a road map on the timing and pace of power and supply chain contracting prospects for U.S. offshore wind power suppliers and vendors. The analysis also provides an overview for states looking to attract supply chain facilities and build necessary infrastructure for offshore wind industry development.

Key industry components required to achieve an almost $70 billion utility-scale build-out of America's offshore wind power capacity by 2030 include:

More than 1,700 offshore wind turbines & towers ....$29.6 billion
More than 1,750 offshore turbine & substation foundations ....$16.2 billion
More than 8,000 kilometers of upland, export & array cables .....$10.3 billion
More than 60 onshore & offshore substations............................$ 6.8 billion
Marine support, insurance & project management......................$ 5.3 billion
TOTAL by 2030: $68.2 billion

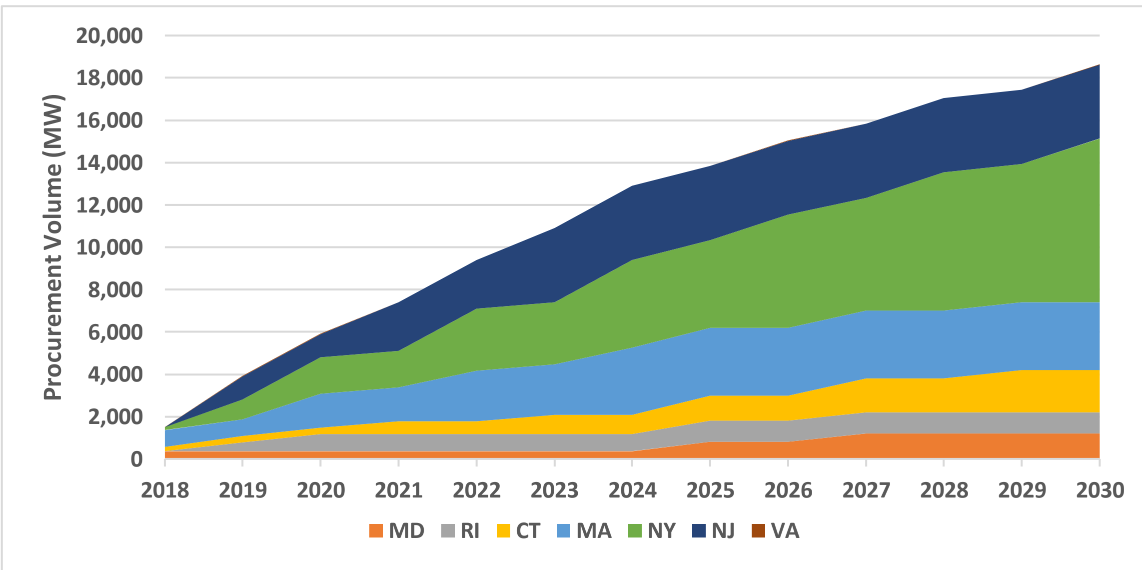
Figure ES-1:
Offshore Wind Supply Chain Contracts Cumulative CAPEX Forecast



This paper also provides forecasts of state offshore wind power procurements through 2030. Market visibility to rising state commitments is generating economies of scale and driving sustained industry momentum.

New Jersey		**3,500 MW**
New York	**(9,000 MW by 2035)**	**7,730 MW**
Massachusetts		**3,200 MW**
Connecticut		**2,000 MW**
Rhode Island		**1,000 MW**
Maryland		**1,200 MW**
Virginia		**12 MW**
	TOTAL by 2030:	**18,642 MW**

ES Figure ES 2:
*Offshore Wind Power Contracts Forecast 2018 – 2030**



** Data for Virginia included in this chart is not visible due to the small size of the contract (12 MW) compared with the overall scale of procurements.*

Taken together, these state commitments amount to almost 20 GW of offshore wind power and represent a $68 billion capital investment that will require a significant number of suppliers from many states around the country.

This SIOW white paper offers a new, granular view of what this utility-scale construction effort will mean for companies that can meet the demands of this growing industry. For states, it is also a timely indicator of the sizeable volume of components needed to meet the state's goal and the pace of offshore wind power procurements. As states work to secure supply chain facilities, the forecasts presented here have implications for timing offshore wind industry infrastructure development and supply chain incentives.

BACKGROUND

The U.S. offshore wind power sector is well underway. In 2016, the nation's first offshore wind farm was commissioned off Block Island, Rhode Island (30 MW). Today, offshore wind farms totaling 1.6 GW of capacity are contracted to provide electricity in Massachusetts (800 MW), Connecticut (300 MW), New York (130 MW), Maryland (368 MW) and Virginia (12 MW). Additional offshore wind power contracts are expected to be signed in 2019, including in Rhode Island (400 MW), New Jersey (up to 1,100 MW) and New York (up to 800 MW), bringing to seven the total number of states to which offshore wind power will soon be providing electricity.

This 1.6 GW is just the tip of the iceberg. Many of the same states have their own offshore wind power commitments stretching to 2030 and beyond. In addition to the 1.6 GW of offshore wind farms already contracted to supply power, contracts are expected to be signed for approximately 17 GW of additional projects as a result of state commitments in the period 2020-2030.[1] This brings the total forecasted amount of contracted offshore wind power between 2020 and 2030 to 18.6 GW.

Collectively, these state commitments are equivalent to the electrical capacity of 18 large nuclear power plants, an extraordinary capital expenditure (CAPEX) that requires many suppliers. This SIOW white paper provides the first calculation of what this massive construction effort means for offshore wind energy suppliers and vendors, in data broken down year-by-year and by key wind farm component. Specifically, this white paper forecasts:

1) the total quantity of components associated with the ~18.6 GW of offshore wind projects expected to be contracted with suppliers from 2020 to2030; and

2) the value of those supply chain contracts.

To date, supply chain analyses of the future U.S. offshore wind power market have focused on the number of jobs that will be created, based either on individual proposed wind farms, individual state offshore wind commitments and on national estimates of resource potential. This paper instead analyzes offshore wind commitments by state in order to forecast years when states are likely to solicit and procure offshore wind power. Second, using this power contract forecast, we analyze what it means for the supply chain (turbines, foundations, onshore and offshore substations, cable) in terms of quantities of components and contract value, and when supply chain work packages are likely to be forthcoming. We examine the revenue opportunity of this new industry for the supply chain irrespective of the locale of contract origination, acknowledging that the offshore wind supply chain has local, national and international participants. This new approach provides a more complete and granular view on how this industry will unfold, with detail on how much of, and when, multiple supply chain components are expected to be contracted.

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[1] We acknowledge that New York's commitment extends beyond 2030 and many other states may continue to develop offshore wind beyond 2030. We have limited this forecast to extend only to 2030 as there are likely to be technology and policy changes that we cannot predict post 2030.

METHODS

The Special Initiative on Offshore Wind worked with The Renewables Consulting Group (RCG) to develop an approach for analyzing the offshore wind power market and forecasting the required supply chain needs and supply chain participation. RCG conducted all analyses reported here. Please see the Appendix for details on the assumptions used in the modeling.

RCG's analysis addresses three research questions:

1. What is the likely scenario for offshore power contracting between developers and utilities during the period 2020-2030?

2. Given the forecast for power contracting, what quantities of components will be needed, and which years, to build the wind farms now required to meet state commitments?

3. Given the forecast for power contracting and the predicted volume of components that will be needed, what is the total CAPEX — and potential revenue opportunity — that can be expected from these contracts?

Part 1: Offshore wind power contracting forecast

The research team first compiled the data on wind power in each state, both contracted and in negotiation, for the state's offshore wind commitments and on announced power procurement timelines. For states that have made offshore wind commitments but not yet announced a procurement schedule, assumptions for power procurement timelines were based on their goals and past procurement schedules.

The team also made assumptions about how much offshore wind could be procured by states presently without offshore wind commitments. To do this, we took into consideration the states' Renewable Portfolio Standard (RPS) targets, public announcements from their political leaders, their offshore wind-related investments, and any legislation governing renewable energy policy.

An overview of assumptions for each state is listed in Table 6 in the Appendix.

The following definitions apply to the forecasted categories.

Contracted: A power contract and/or OREC has been agreed to between the offshore wind developer and the relevant state department and/or utility.

In negotiation: The final terms of a power contract and/or OREC are still to be agreed by the offshore wind developer and relevant state department and/or utility.

Bids under evaluation: The relevant state department and/or utility is in the process of evaluating bids from competing developers to supply electricity from eligible offshore wind projects.

Solicitations required by state policy: The relevant state department and/or utility has committed to the procurement of electricity from renewable energy sources, and/or offshore wind specifically, but the bidding window for eligible projects has yet to open.

Expected future state policy requirements: The relevant state department and/or utility has not yet committed to the procurement of electricity from energy sources, and/or offshore wind specifically, but procurement is expected to be announced as part of future state legislation at some point during the forecast period.

To forecast years in which procurements could take place in each state, we used the following information and assumptions. See Table 6 in the appendix for details.

Rhode Island is currently reviewing bids for an "all renewables" RFP.[2] We assumed that Rhode Island will procure 400 MW in 2020 via this RFP process and/or through an additional all-renewables RFP. The forecast also includes an additional 200 MW that Rhode Island is likely to procure in 2025 to meet state renewable energy targets.

Connecticut has procured relatively small projects in the past (100-200 MW) so the forecast assumes that biannual procurements of 300 or 400 MW would be needed to meet the 2,000 MW commitment included in pending state legislation.[3]

Massachusetts plans to open an 800 MW offshore wind procurement in June 2019 or earlier.[4] We have assumed that if the state's legislated study on the cost of offshore wind favorably reflects the appropriate cost benefit of offshore wind, they will schedule two additional 800 MW rounds for 2022 and 2024.

In **New York**, under current conditions, it takes approximately one year to approve an order from the state's Public Service Commission before running a procurement process. Based on this, we have assumed that a procurement process could take place every other year in New York. Taking into account this assumption, our forecast indicates that New York will procure approximately 7,730 MW by 2030. We are assuming that New York will procure the remaining projects between 2030-2035 to meet its 9,000 MW commitment; however, procurements past 2030 are beyond the scope of this study.

The forecast for **New Jersey** procurements is taken from the New Jersey Board of Public Utilities announced schedule.[5]

The **Maryland** forecast assumes the state will pass the Clean Energy Bill described above raising the offshore wind targets to 1,200 MW; it further assumes that this procurement will be obtained, in the late 2020s, from existing and underutilized lease sites near the Maryland coast.

[2] https://www.offshorewind.biz/2019/02/08/rhode-island-to-review-revolution-wind-power-contract
[3] https://www.theday.com/article/20190212/NWS01/190219820
[4] https://macleanenergy.com/83c-ii/
[5]https://www.bpu.state.nj.us/bpu/pdf/publicnotice/2019%20ANNUAL%20EO8%20REPORT%2002082019%20FNL%20V2.pdf

The assumptions above are reflected in the forecasts in Table 1, which are categorized in decreasing levels of certainty, the least certain being the quantities required in the future by state policy, which is subject to ever-changing political conditions.

Table 1: Offshore Wind Power Contracts Forecast by Category (2016-2030)

Contracted	300MW – CT
	368 MW – MD
	800 MW – MA
	130 MW – NY
	12 MW – VA
In negotiation	400 MW – RI
Bids under evaluation	1,100 MW – NJ
	800 MW – NY
Solicitations required by state policy	800 MW – MA
	2,400 MW – NJ
	6,800MW – NY*
Expected future state policy requirements	1,700 MW – CT
	832 MW – MD
	1,600 MW – MA
	600 MW – RI
Total	**18,642 MW**

*** This is an approximate figure for 2030, based on the knowledge that New York has a target of 9,000 MW by 2035.*

Part 2: Supply chain contracting forecast — quantities

The procurement schedule derived in Part 1 was used to estimate the quantities of components that each power contract will represent. A project-specific model was built based on site characteristics for those projects deemed likely to be selected as part of the various procurement rounds. As a general rule, a project/lease area located within the procuring state was selected before additional projects from nearby states were considered.

All areas that have been leased or are currently in the BOEM leasing process were included in the analysis and BOEM's leasing timeline was considered when making assumptions. For example, the proposed New York Bight areas were only considered to be eligible for bidding in procurements during or after 2022.

In the project-specific models, procurement volumes attributed to each lease area are lower or equal to the lease area's technical capacity. Table 2 illustrates the components and units considered.

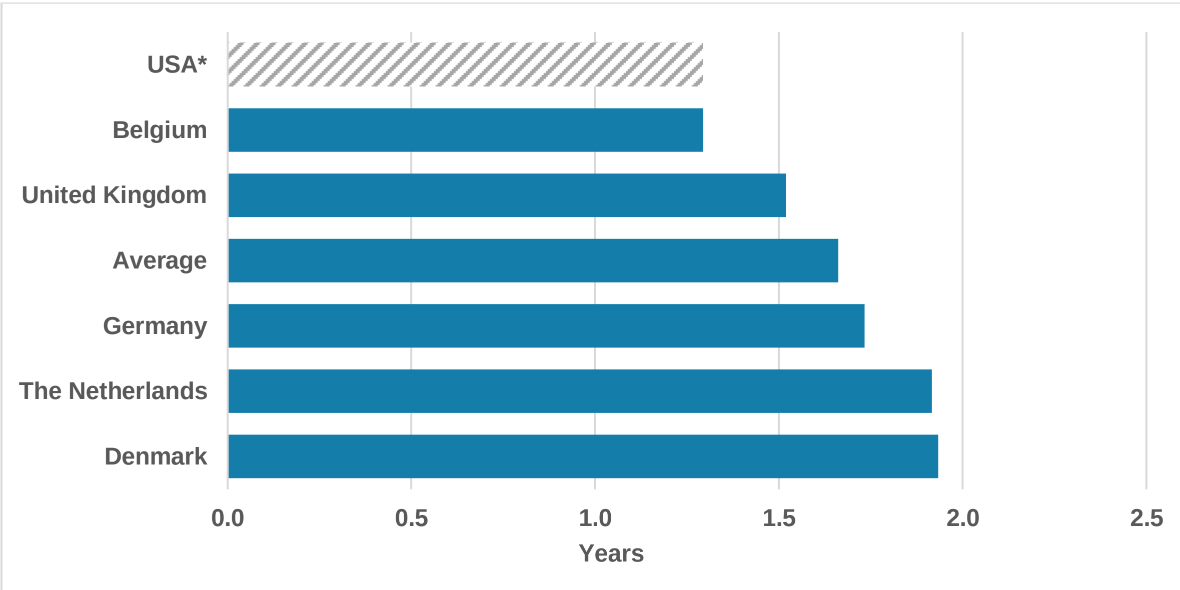
Table 2: Components Considered in the Analysis

Components considered	Unit
Onshore substations	Number
Upland Cable	Kilometers
Export Cable	Kilometers
Array Cable	Kilometers
Offshore Substation	Number
Wind turbine generators (WTG)	Number
Foundations	Number

Data from RCG's Global Renewable Infrastructure Projects database (GRIP) was used to calculate the average time delay, or gap, between the power contract being signed, and the signing of supply chain contracts for the components listed in Table 2 above.

The gap used in this analysis is 1.7 years, based on data illustrated in Figure 1. (That number is rounded up to two years throughout the remainder of this report). The gap is due to the additional time required for developers to secure all permits, obtain final construction approval, reach financial close and negotiate final contract terms with suppliers.

Figure 1: Time Delay (Gap) Between Power Contract Signing and Supply Chain Contract Signing



**While there is an the absence of relevant data points from commercial scale offshore wind projects in the U.S., supply chain contracts are presenting being negotiated for the 1.6 GW of projects that are currently contracted. This chart represents the average number of years between power contract signing and the date of publication; i.e., the average ongoing gap.*

Source: GRIP database, accessible at: https://grip.thinkrcg.com

There is an absence of data points from the offshore wind industry in the U.S. Therefore, we reviewed where the 'contracted' projects are in their respective permitting lifecycles, in order to arrive at a final gap of two years for this study. The consequence of this is that all results presented in Part 2 and Part 3 are shifted back two years from the procurement years presented in Part 1 (i.e., a 300 MW procurement in 2019 will result in contracts being signed in 2021). It should be noted that this is a high-level assumption and that actual contracting schedules for each project will vary and be determined by, but not limited to, the maturity of the project at the time of power contract award, the contract strategy of the owner, the availability of the onshore grid connection point, and the terms of the negotiated Power Purchase Agreement (PPA).

The forecast is also based on turbine-size assumptions. Wind-turbine size impacts the number of turbines, foundations and array cable length required to install a given project capacity (in MW). In order to take into account future technological advances in turbine design, different rated capacities for the turbines were assumed for power procured in different years, from 8.5 MW today to 15 MW in 2029-2030. These are presented in the Appendix, alongside assumptions around maximum substation capacity and the length of cable routes.

Part 3: Supply chain contracting forecast — CAPEX

This study estimates the capital expenditure (CAPEX) that each power contract represents was estimated using a different method than was used for estimating the quantities. To estimate CAPEX, a flat rate of $4 million/MW was assumed for U.S. projects.

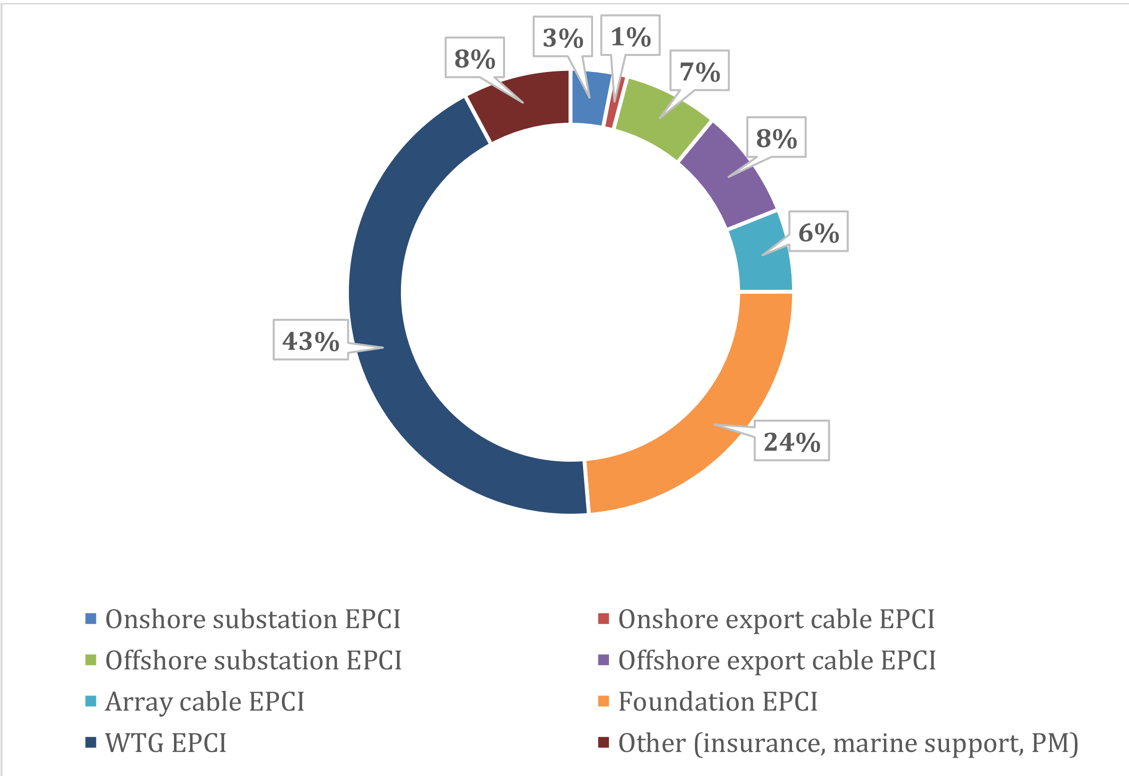
This number was derived by RCG's experts based on modeling of existing projects using RCG's proprietary Levelized Cost of Energy (LCOE) model. It should be noted that this $4 million/MW value is an installed cost, inclusive of all vessel costs.

The $4 million/MW rate was then applied to the procurement schedule shown in Table 3 below to calculate the annual CAPEX. As with the quantities, a two-year gap from power procurement date was applied to reflect the time required between power procurement and component contract signing.

A typical percentage breakdown of offshore wind CAPEX by component (Figure 2) was applied to the annual CAPEX obtained in the previous step to derive the total dollar value of each component contract. The breakdown in Figure 2 was derived using RCG's U.S.-specific LCOE model, benchmarked against some sample U.S. offshore wind power projects to come up with a "typical" breakdown of CAPEX costs. This LCOE model is fed by publicly available data.

The component breakdown was then checked against the quantities predicted in Part 2, to ensure a "bottom up" reconciliation of the CAPEX figures presented. No account is made of the growing proportion of components expected to be manufactured in the U.S. between now and 2030, as this is outside the scope of the study.

Figure 2:
CAPEX Contracts as a Percentage of Total CAPEX Costs



Final CAPEX numbers for each of the components were checked against recent market data for accuracy.

Costs per MW were used as a common metric for comparison. Detailed assumptions used in deriving CAPEX estimates are presented in the Appendix.

FINDINGS

Part 1: Offshore wind power contracting forecast

At the time of this paper's release, 1,610 MW of offshore wind farms were under contract in Connecticut, Maryland, Massachusetts, New York and Virginia. Ørsted (Ørsted U.S. Offshore Wind) is in negotiations with the National Grid in Rhode Island for a 400 MW project. New Jersey closed a solicitation for 1,100 MW at the end of 2018 and New York closed a solicitation for 800 MW in February 2019. In total, there is currently 3,910 MW of offshore wind contracted, in negotiation and under evaluation.

The analysis of additional procurements required by state policy and future expected procurements results in a forecast of 18,642 MW of offshore wind procured by 2030.[6] Table 3 details our state-by-state, year-by-year forecast for offshore wind power contracting.

Table 3:
Offshore Wind Power Contracts (in MW) Forecast by State

	MD	RI	CT	MA	NY	NJ	VA	Total
2018	368	400	200	800	130	0	12	**1,910**
2019	0	0	100	0	800	1,100	0	**2,000**
2020	0	400	0	800	800	0	0	**2,000**
2021	0	0	300	0	0	1,200	0	**1,500**
2022	0	0	0	800	1,200	0	0	**2,000**
2023	0	0	300	0	0	1,200	0	**1,500**
2024	0	0	0	800	1,200	0	0	**2,000**
2025	432	200	300	0	0	0	0	**932**
2026	0	0	0	0	1,200	0	0	**1,200**
2027	400	0	400	0	0	0	0	**800**
2028	0	0	0	0	1,200	0	0	**1,200**
2029	0	0	400	0	0	0	0	**400**
2030	0	0	0	0	1,200	0	0	**1,200**
Total	**1,200**	**1,000**	**2,000**	**3,200**	**7,730**	**3,500**	**12**	**18,642**

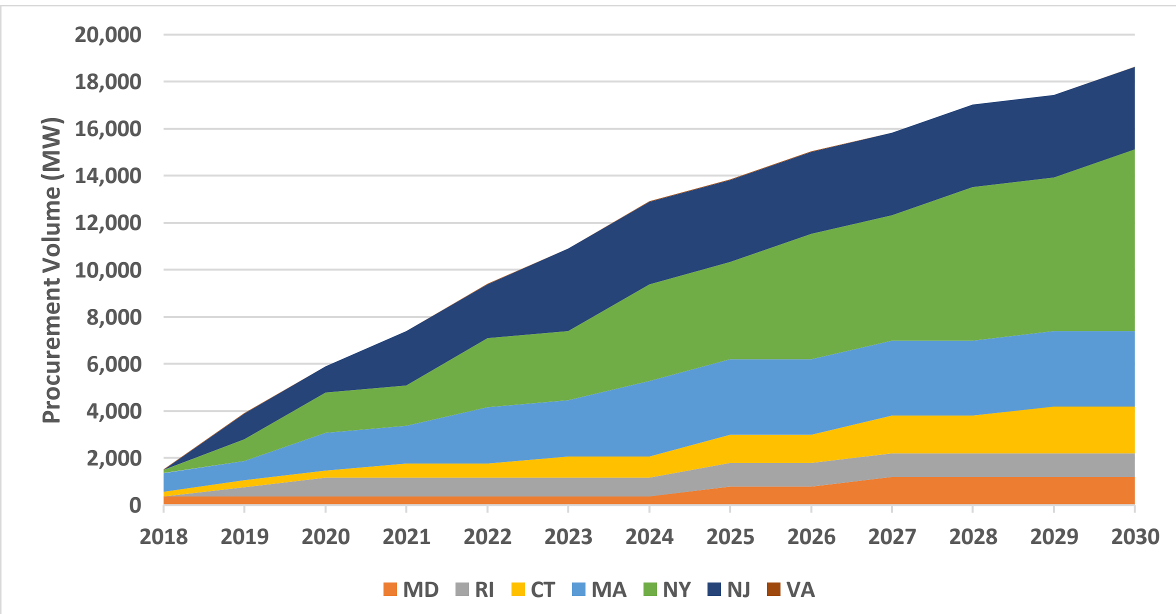
[6] States to date have been ambitious with their targets and are expected to procure additional volume post 2030. Due to the uncertainty of future commitments and of other routes to market, this analysis is limited to 2030.

Figure 3 illustrates the cumulative predicted growth in offshore wind power procurements. As it indicates, we forecast that offshore wind power contracts in Connecticut, Massachusetts, New Jersey, New York and Rhode Island will be signed during 2020-2022, representing an additional 5,500 MW of capacity.

In the years 2022-2025, we expect to see 6,432 MW contracted, with large procurements happening especially in New York and New Jersey, which both have large offshore wind commitments to meet.

Increases in offshore wind procurement from the years 2025-2030 will result from New York, Maryland and Connecticut continuing to meet their current targets for offshore wind power as well as RPS or other renewables mandates.

Figure 3:
Offshore Wind Power Contracts Forecast 2018 – 2030*



** Virginia, although included in this figure, does not show due to the small size of the contract (12 MW) compared with the overall scale of procurements.*

Part 2: Supply chain contracting forecast — quantities

Table 4 shows the total quantity of components expected to be contracted by 2030, for each key component, to meet the procurement volumes expected in the various states.

Although total procured volume by 2030 reaches 18,630 MW, only power procured up to 2028 will result in contracts by 2030 due to the nearly two-year gap between power procurement and contract signing explained in the Methods section above. Thus, only the quantities of components associated with the 17,042 MW of power procured from 2018 through 2028 are presented in this section. Contract signing for these components will start in 2020 and end in 2030.

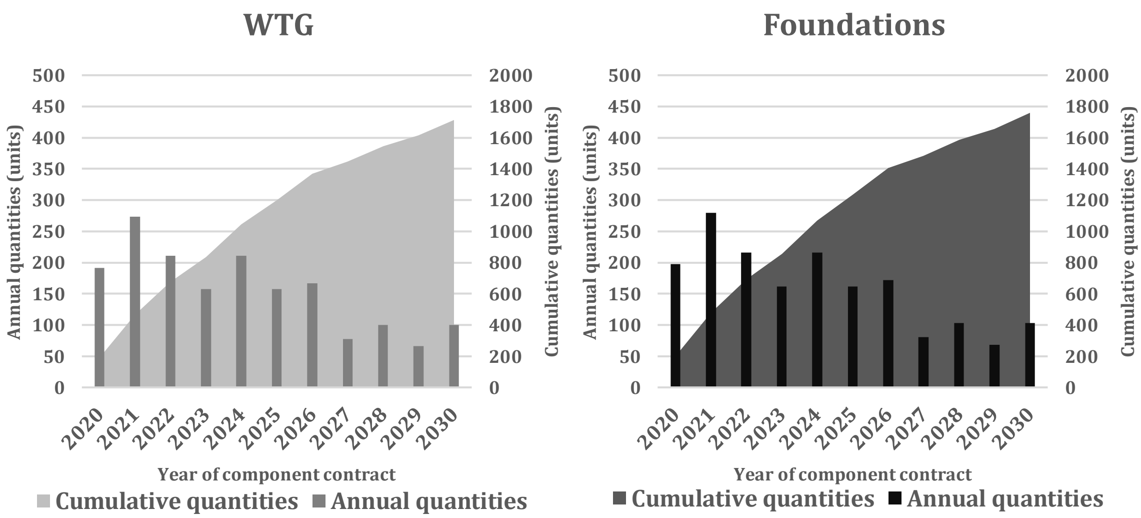
Table 4: Estimated Quantities of Components Required by 2030[7]

	Estimated Quantities
Onshore substations	17
Upland Cable (km)	457-512
Export Cable (km)	3,496-3,771[8]
Array Cable (km)	3,883-4,535
Offshore Substations (count)	46
WTGs (count)	1,713
Foundations (WTG and OSS)	1,759[9]

[7] Due to uncertainty in the timing of the procurement and build out across both project and state targets, the component quantity numbers presented here are subject to a reasonable level of uncertainty, but a full sensitivity analysis is beyond the scope of this assessment.
[8] Ranges are provided for cable lengths given the uncertainty around site characteristics (depth, landfall location, cable route etc.) but in such cases the median value has been plotted in the figures below.
[9] The number of foundations includes those for WTG's and for offshore substations. For simplicity, only one foundation is counted per substation, although some designs may have four per substation.

Figures 4 through 7 show the estimated quantity of each key component that will be needed over the course of the build out.

Figure 4: Turbine and Foundations Quantities Forecast



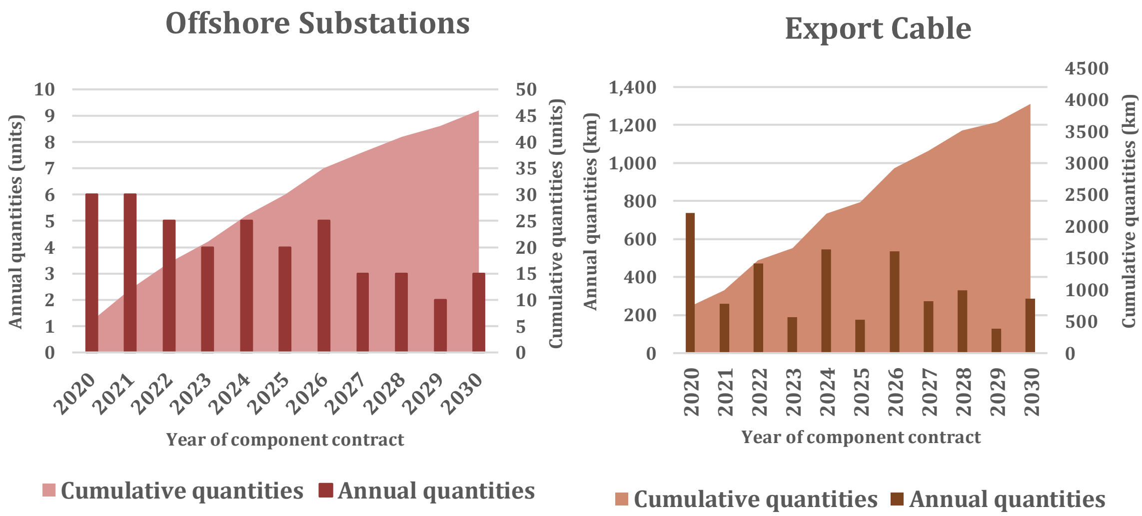
An estimated 1,713 WTGs will be contracted for installation in U.S. waters through 2030 for the 17,042 MW of power procurements from 2018 through 2028 (and therefore components contracted from 2020 through 2030). Contracts for WTGs will begin in earnest at the beginning of the 2020s. The bulk of contracts will be executed by 2027 but will continue until the end of the decade. On average, 200 WTGs are likely to be contracted each year from 2020 through 2026.

After 2026, only 100 WTGs a year are likely to be required, although this unit count reduction is due in part to the fact that the turbines are expected to be much larger than those currently on the market (see Appendix for assumptions around turbine size in this analysis) hence reducing the number of turbines needed rather than simply a reduction in demand in terms of MW.[10]

Lastly, it is estimated that 1,759 foundations, for both WTGs and offshore substations, will be contracted by 2030. An average of 200 foundations a year will be contracted through 2025. This will subsequently decrease to an average of 100 a year, once again due in part to an expected increase in the size of turbines to be used on the projects later in the decade.[15]

[10] This is for the time period 2020-2030. Additional procurements are expected beyond 2030.

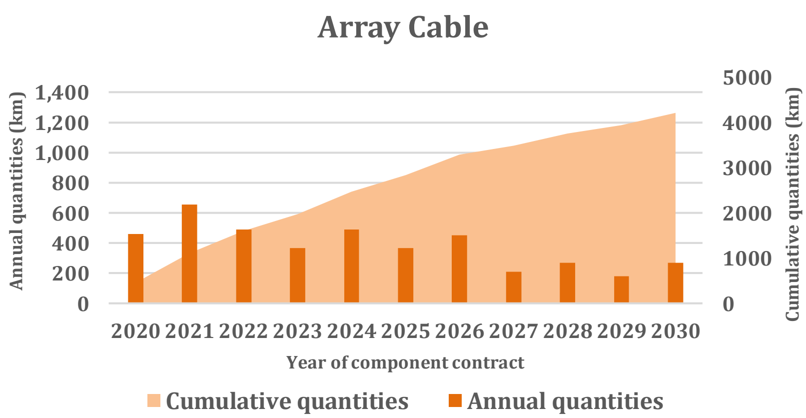
Figure 5: Offshore Transmission Components Quantities Forecast



It is estimated that 46 offshore substations will be contracted through 2030 with an average of four substations per year. The rate of increase is higher in the first half of the decade, slowing down after 2025 as most projects are expected to have their transmission capacity built out.

An estimated 3,492 to 3,771 km of export cable will be contracted (3,634 km is the median value presented in Figure 5 above) by 2030. There will be substantial demand starting in 2020 and continuing throughout the build out, with major increases in demand in 2022 and again in 2026, 2028 and 2030. The annual export cable length required is much more variable than any other components, with the bulk contracted in the first year. Likewise, the total length of cable is highly sensitive to factors such as the choice of landfall (and therefore the cable route), the size of the project, alternating versus direct current, and voltage of equipment.[11]

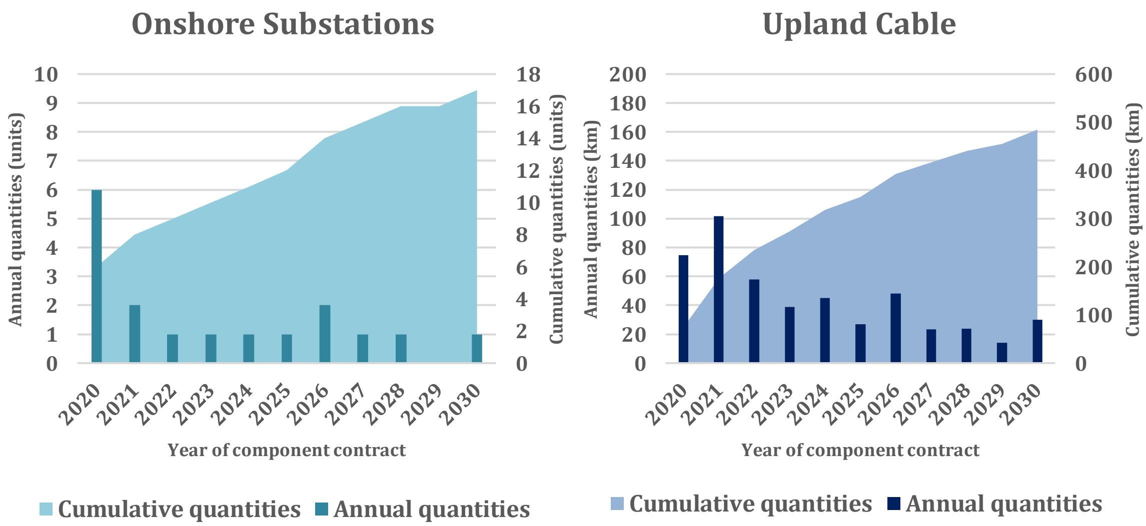
Figure 6: Array Cable Length Forecast



[11] To ensure accuracy, a high-level GIS analysis of likely landfalls of the projects/lease areas was conducted

Between 3,883 and 4,535 km of array cables are forecasted to be contracted by 2030 (4,209 km is the median value presented in Figure 6 above).[12] The demand for array cable will be rather stable with an average of about 300 km a year contracted.

Figure 7: Onshore Transmission Components Quantities Forecast



It is estimated that, in total, 17 onshore substations will be procured between 2018 and 2030. It is anticipated that the bulk of the substations for the offshore wind power procured during the time period of this analysis will be contracted in the first half of the decade-long build out, with almost half contracted within the first two years.[13] On average, one or two substations will be contracted every year after that, totaling 17. It is worth noting that the number of 'new-build' onshore substations required, or indeed the level of work required to upgrade pre-existing facilities, is a factor of the current specifications of the existing infrastructure in each state; offshore wind projects are expected to make use of existing facilities where possible.

Similarly, the bulk of the upland cable between now and 2030 will be contracted before 2025. In total, it was estimated that between 457 km and 512 km of upland cable will be needed (we represent the 485 km median, in Figure 7 above). Almost half of the total cable length is expected to be contracted between 2020 and 2022 when the first phases of the various projects start developing. Only about 30 km on average are expected to be contracted after 2022.[14]

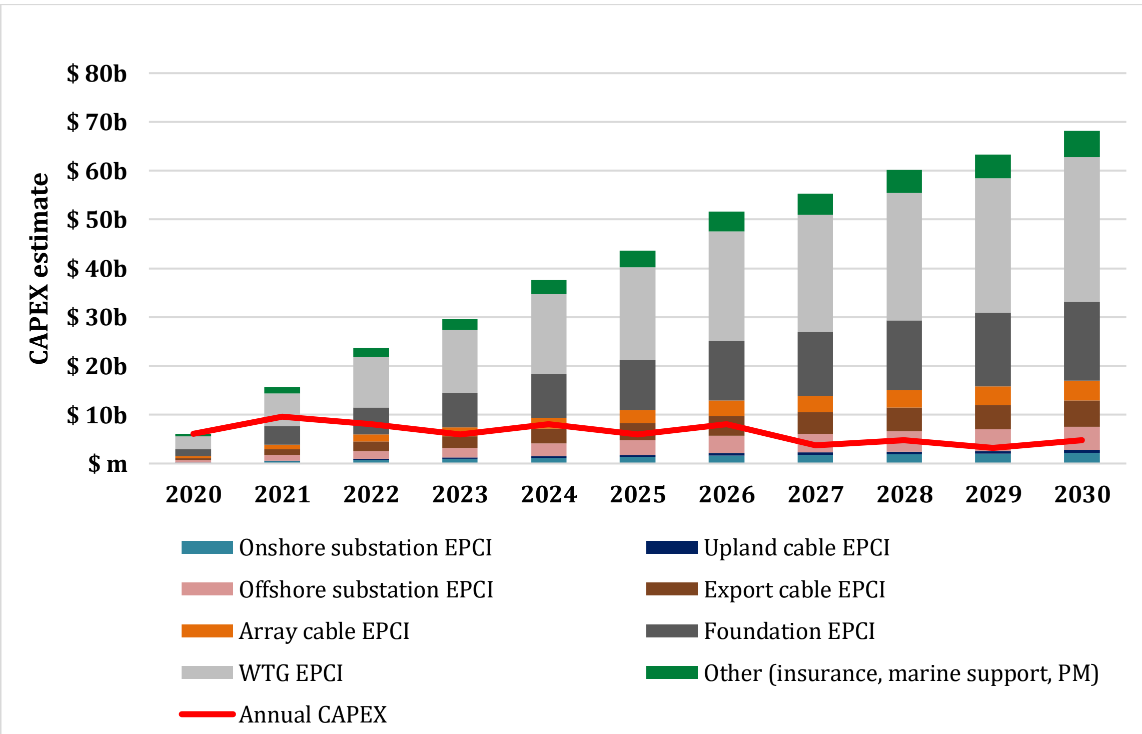
[12] The similarity between export cable and array cable length is a coincidence. The two aren't related: the length of array cable is dependent solely upon site area, turbine spacing and depth whilst export cable length is primarily dependent on the distance to shore and number of required cables, which is in turn driven by cable voltage.
[13] This analysis assumes one new-build substation per project, procured in the first half of the decade and subsequently sized to accommodate subsequent or future expansions of wind farms.
[14] This analysis assumes onshore substations built for the first phases of projects will be upgraded to take on the additional power of subsequent phases resulting in the same upland cable length for all project phases. In practice, this may not be the case and different connection points may need to be sought, typically increasing the required length of cable.

Part 3: Supply chain contracting forecast — CAPEX

We estimated CAPEX associated with the engineering, procurement, construction and installation (EPCI) contracts of the seven components quantified above. An EPCI contract bundles manufacture and installation of the component into one cost and therefore includes vessel costs. In addition to these components, "other" costs were included to account for additional marine support, insurance and project management. Assumptions around the costs of technological advances and economies of scale for the U.S. were taken into account in the $4 million/MW cost assumed in this analysis.

Figure 8 illustrates total estimated cumulative CAPEX associated with component contracts signed between 2018 and 2030. As explained in additional detail in Part 2, this is equivalent to contracts for 17,042 MW by 2030, due to the two-year gap between power procurement and contract signing explained in the method section above.

Figure 8: Offshore Wind Supply Chain Contracts Cumulative and Annual CAPEX Forecast



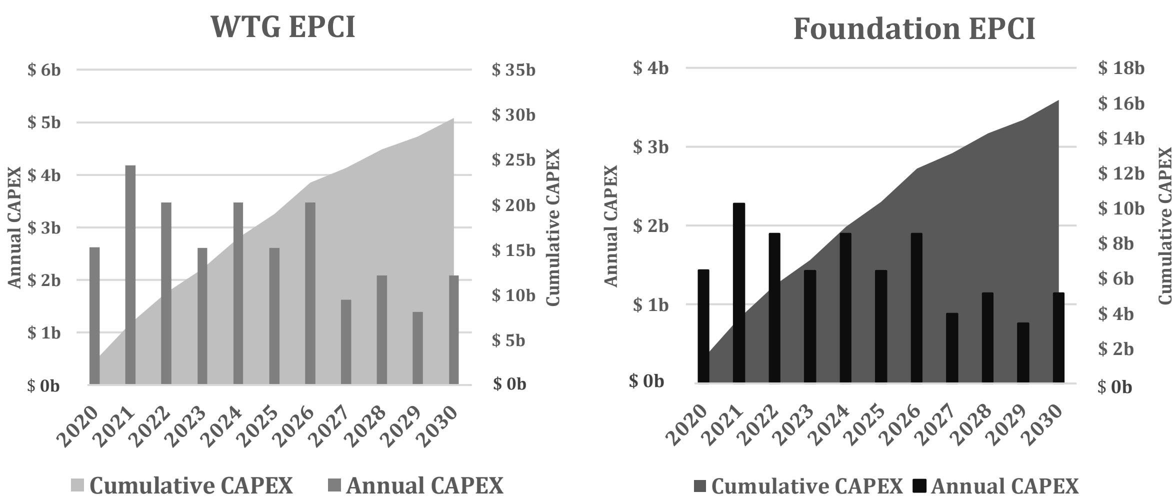
Specifically, Figure 8 illustrates that the primary drivers of offshore wind CAPEX, and therefore the largest value contracts, will be, in order of size:

- Turbine supply and installation
- Foundation supply and installation
- Offshore substation supply and installation
- Export cable supply and installation.

A smaller proportion of CAPEX is the array cable contracts and contracts for the onshore portion of the developments will account for a much smaller portion of the total industry CAPEX. Figure 8 also illustrates that these spending and activity levels are rather constant on an annual basis throughout the 17,042 MW of component contracts signed by 2030. That is, contrary to some prognostications, we do not predict an extreme boom/bust cycle for any of the key components; rather, we predict a steady CAPEX expenditure on these components.

Figures 9 through 12 below display the expected cost associated with the annual procurement volumes, for each key component, over the course of the build out.

Figure 9: Turbine and Foundation Components CAPEX Forecast

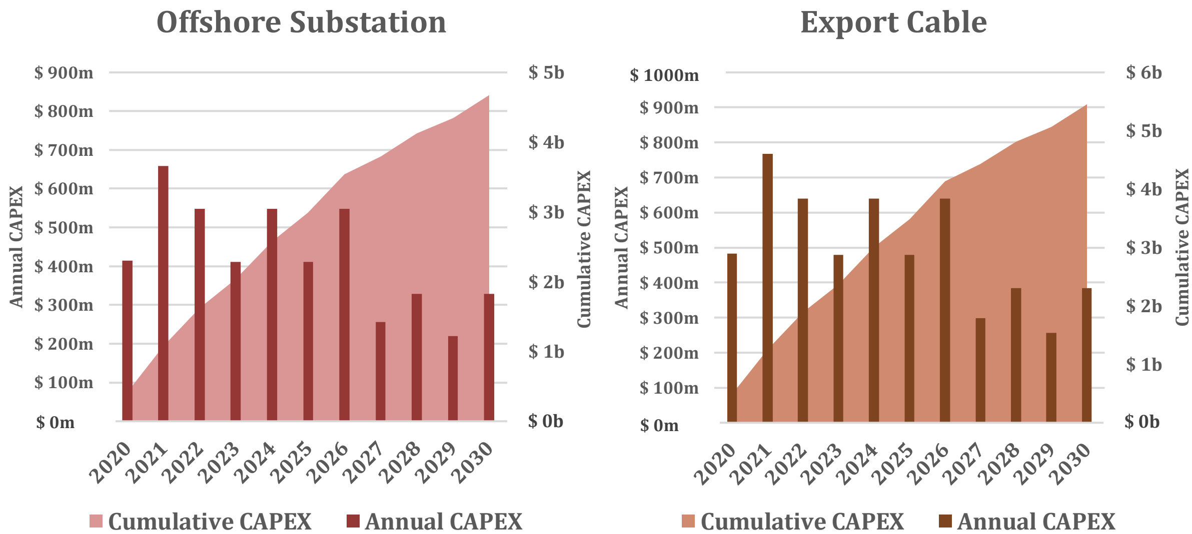


The major driver of CAPEX is the turbine followed by the foundation. The WTG market in the U.S. is expected to be worth about $30 billion between 2020 and 2030, almost double that of foundations, which are expected to bring revenues of $16 billion.

Annually, the turbine market will require, on average, a $3.2 billion expenditure in the first six years. This almost halves after 2026, with an average annual expenditure of about $1.8 billion. This is in part due to the fact that the turbines are expected to be much larger than those currently on the market today (see appendix for assumptions around turbine size in this analysis), hence reducing the number of turbines needed rather than simply a reduction in demand in terms of MW. It is also due to our conservatively not assuming any new state commitments during this period.

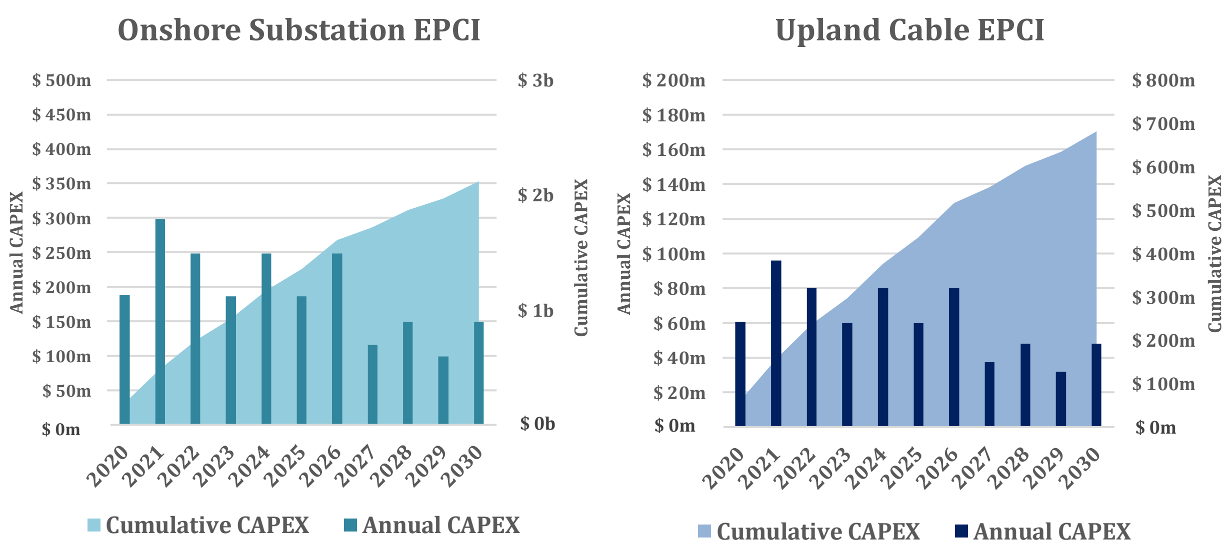
The foundation market will see a similar differential between the first and the second half of the decade, with an average annual expenditure of $1.8 billion dropping to about $1 billion after 2026.

Figure 10: Offshore Transmission Components CAPEX Forecast



The offshore substation market is expected to be worth more than $4.5 billion from 2020-2030, while the export cable market will bring revenues of approximately $5.5 billion over the same period. On an annual basis, expenditure associated with offshore substations will average $500 million between 2020 and 2026. This will drop slightly to an average of about $300 million after 2026. The expenditure for export cable is expected to average about $600 million a year in the first half of the decade, followed by a slight drop to a $350 million annual expenditure in the second half of the decade.

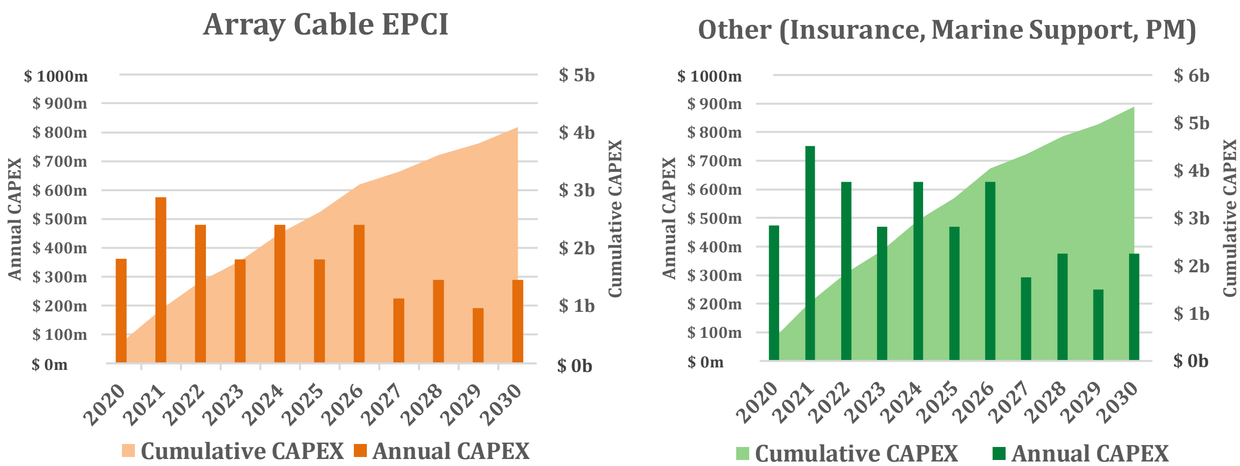
Figure 11: Onshore Transmission Components CAPEX Forecast



The contracts associated with the 17,042 MW procurement between 2018 and 2028, are expected to result in a $2 billion expenditure for onshore substations and an expenditure of nearly $700 million for onshore export cable by 2030.

For onshore substations, this is equivalent to an average annual expenditure of about $200 million for onshore substations during 2020-2026. This average expenditure decreases to about $125 million between 2027 and 2030. For upland cable, a similar trend can be observed with a higher average of about $70 million a year between 2020 and 2026, and a lower average of around $40 million a year thereafter.[15]

Figure 12: Array Cable and 'Other' CAPEX Forecast



Finally, the array cable market is expected to be $4 billion from 2020-2030. On average, this represents an investment of $400 million a year until 2026, investment that will fall to about $250 million a year on average thereafter. All other elements of CAPEX including insurance, marine support and project management (PM), are expected to be worth about $5 billion by 2030 for an annual average of almost $500 million a year.

Table 5 presents the expected cumulative value of contracts for the various components. The potential value flowing to offshore wind energy suppliers across the components in the period 2020-2030 is $68.2 billion.

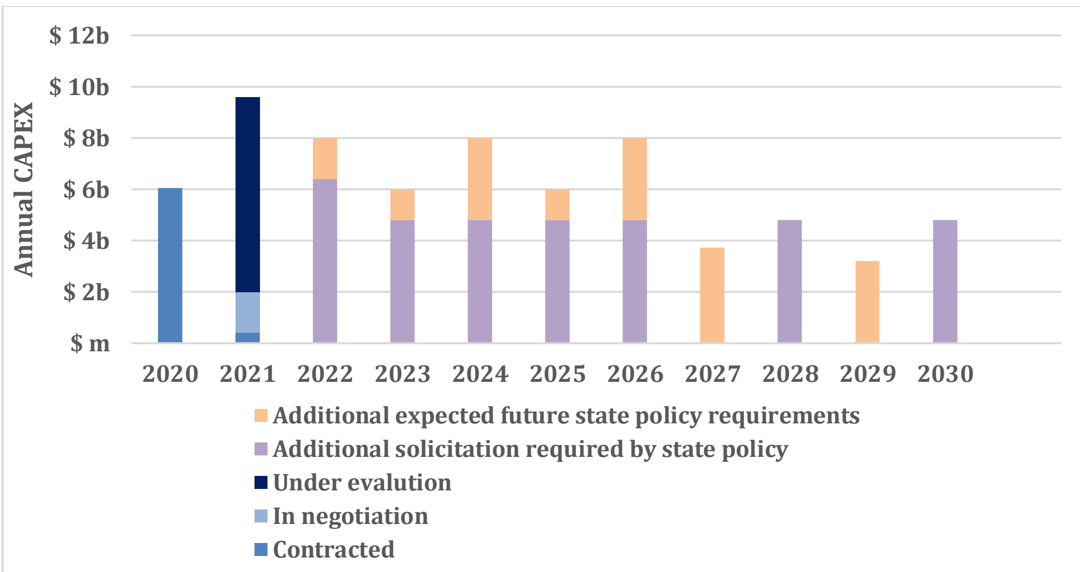
Table 5: Estimated Cumulative CAPEX by Component Type

Component	Cumulative CAPEX by 2030
Onshore substation EPCI	$2.1 bn
Upland cable EPCI	$0.7 bn
Offshore substation EPCI	$4.7 bn
Export cable EPCI	$5.5 bn
Array cable EPCI	$4.1 bn
Foundation EPCI	$16.2 bn
WTG EPCI	$29.6 bn
Other (insurance, marine support, PM)	$5.3 bn
Total	**$68.2 bn**

[15] This analysis assumes one new-build substation per project, procured in the first half of the decade and subsequently sized to accommodate subsequent or future expansions. This would also result in the same upland cable length for all project phases.

CAPEX estimates were also calculated by procurement status, for the various categories presented in Table 1. This is included to provide a sense of the uncertainty surrounding some of the estimates. The light orange bars are the most uncertain, associated with legislation currently being considered. Assuming this procurement volume is correct, Figure 13 demonstrates a rather stable market, with an expenditure of, on average, $6 billion a year from 2020 to 2026. This average expenditure then drops to about $4 billion a year between 2027 and 2030.[16]

Figure 13: CAPEX by Procurement Status



While this forecast includes some uncertainty, the analysis makes clear that the industry and its associated needs are quickly coming, and that there will be enormous opportunity for those who are prepared to meet it.

Activities such as facilitating training, partnership opportunities, expansion and East Coast facility investment will be critical, and many of these efforts are already underway.[17]

CONCLUSIONS

[16] It should be noted that due to uncertainty in the timing of the procurement and build out across both project and state targets, these numbers are subject to a reasonable level of uncertainty but a full sensitivity analysis is beyond the scope of this assessment.

[17] "Building the US offshore wind supply chain: how do we do it?" whitepaper (https://www.energycentral.com/system/files/ece/nodes/258443/supply_chain_paper_draft1.pdf); DOE U.S. Offshore Wind Manufacturing and Supply Chain Development report (https://www.energy.gov/eere/wind/downloads/us-offshore-wind-manufacturing-and-supply-chain-development) ; US Offshore wind supply chain optimization and bottlenecks (https://medium.com/unleash-lab/u-s-offshore-wind-supply-chain-optimization-and-bottleneck-analysis-c485b5ddda4b)

This study forecasts a nearly $70 billion revenue opportunity for U.S. offshore wind component suppliers through the end of the coming decade. A large number of states have made or are projected to make significant offshore wind power procurement commitments; other states will be procuring incrementally to help meet their RPS targets. The procurement schedule forecasted here suggests that when offshore wind power contracting slows down in one state, the momentum will continue in other states.

Furthermore, the nearly $70 billion CAPEX reflects only the direct cost portion of the economic activity expected to be generated by building the states' commitments for 18.6 GW of offshore wind power. Developing, operating, maintaining and decommissioning offshore wind farms also stimulates local economic activity not accounted for in this analysis of CAPEX.

This forecast is timely: the U.S. offshore wind power sector is at an important juncture, with a large visible market yet, until this analysis, a lack of detail on the market's timing and pace. The offshore wind supply chain remains largely global, with a growing number of U.S. offshore energy and onshore wind suppliers preparing to enter the industry. Many of the supply chain actors, both international and domestic, are grappling with questions of whether, when and where to set up shop on the Eastern Seaboard of the U.S.

This analysis predicts the volume and value of components and services needed to develop the committed offshore wind build. Initially, more of the components will come from Europe than from the U.S. We do not predict when production shifts to U.S. factories.

For states with offshore wind power commitments, this forecast is also a timely quantification of the enormous volume of components needed, especially early in the build out. This data may/should help guide the pace of offshore wind infrastructure development and the timing of supply chain incentives.

APPENDIX

Assumptions

Procurement Volumes

Table 6: Assumptions for States' Procurements

State	Contracted	In Negotiation	Bids under evaluation	Solicitations required by state policy	Expected future state policy requirements
Connecticut	300 MW PPA between Ørsted Energy and Eversource and United Illuminating.				The Energy and Technology Committee recently agreed to work on legislation that would call for a commitment of 2,000 MW of offshore wind[18]. Gov. Lamont's transition report also called for a 2,000 MW goal for offshore wind.
Maryland	Public Service Commission approved two offshore wind projects totaling 368 MW in May 2017, allowing the developers to receive ORECs.				*Clean Energy Jobs Act*, which would set a commitment of 1,200 MW of offshore wind power, will be considered by the legislature in 2019. [19]
Massachusetts	DPU approved 800 MW PPA between Copenhagen Infrastructure Partners/ Avangrid and the MA Distribution Companies.			Commitment to procure 1,600 MW offshore wind by 2027.	"An Act relative to the continued enhancement of the offshore wind industry in the Commonwealth" would increase the offshore wind target from 1,600 to 3,200 MW by 2027.[20]

[18] https://www.theday.com/local-news/20190212/lawmakers-eye-2000-megawatt-offshore-wind-power-buy
[19] https://www.delmarvanow.com/story/news/local/maryland/2018/11/16/maryland-clean-energy-bill-could-triple-offshore-wind-investment/1976089002/
[20] https://malegislature.gov/Bills/191/HD697/House/Bill/Text

New Jersey			First solicitation of 1,100 MW issued in September 2018. Closed December 28.	Commitment to Procure 3,500 MW by 2030.[21] DRAFT schedule: • 2020: issue 2nd solicitation (1,200 MW) • 2022: issue 3rd solicitation (1,200 MW)	
New York	130 MW contracted with LIPA for South Fork project.		New York's first 800 MW solicitation announced in Nov 2018.[22] Closed February 14.	Commitment to procure 9,000 MW by 2035 (subject to PSC order).[23]	
Rhode Island	30 MW operating (BIWF).	400 MW PPA in negotiation between Ørsted and National Grid.			State commitment of 38.5% renewables by 2035 and Gov. Raimondo announces Vision for Rhode Island's Clean Energy Future[24]. Due to political support, as well as the $40 million investment in Rhode Island from Ørsted on local port infrastructure, [25] we assumed an additional 600 MW would be procured in Rhode Island.

[21] http://njcleanenergy.com/nj-offshore-wind
[22] https://portal.nyserda.ny.gov/CORE_Solicitation_Detail_Page?SolicitationId=a0rt000000UTbqS
[23] https://www.nyserda.ny.gov/All%20Programs/Programs/Offshore%20Wind
[24] https://www.offshorewind.biz/2018/08/09/rhode-island-governor-shares-offshore-wind-vision/
[25] https://www.ri.gov/press/view/33345

Virginia	Dominion Energy's Coastal Virginia Offshore Wind (12MW) approved by the SCC.[26]				

Component Quantities

The following assumptions were made in the market demand modeling. Where ranges were derived, median values were used to produce the charts.

Onshore substations (units)

- One onshore substation per project.

Upland cable (km)

- *Length (km):* Upland cable routes were measured via GIS and/or approximated from a map scale, for each project from the most likely landfall site to most likely connection point and multiplied by the assumed number of cables.
- *Number of cables:* One cable assumed for each offshore substation.

Export cable (km)

- *Length (km):*
  a. Subsea export cable routes were measured via GIS and/or approximated from a map scale, for each project to the most likely landfall site and multiplied by the assumed number of cables.
  b. 15 km of inter link cable was also assumed for each additional substation required on projects >400 MW in size.
- *Number of cables:* x one HVAC cable for each offshore substation assumed.
  Note: For Vineyard Wind and South Fork, values were taken directly from COPs that are currently under review by BOEM and are in the public domain.

Array cable (km)

- Using RCGs array cable length model, a ratio of km/MW figure for each range of turbine size (see assumptions below) was derived using Vineyard Wind as a base case (density of ~2.7 MW/km^2).
- The inputs to the model include, but are not limited to, turbine size, area, density and number of substations.

[26] https://www.scc.virginia.gov/newsrel/r_windsol_18.aspx

Offshore substations (units)

- One conventional offshore substation per 400 MW of offshore wind capacity.

Wind turbines (units)

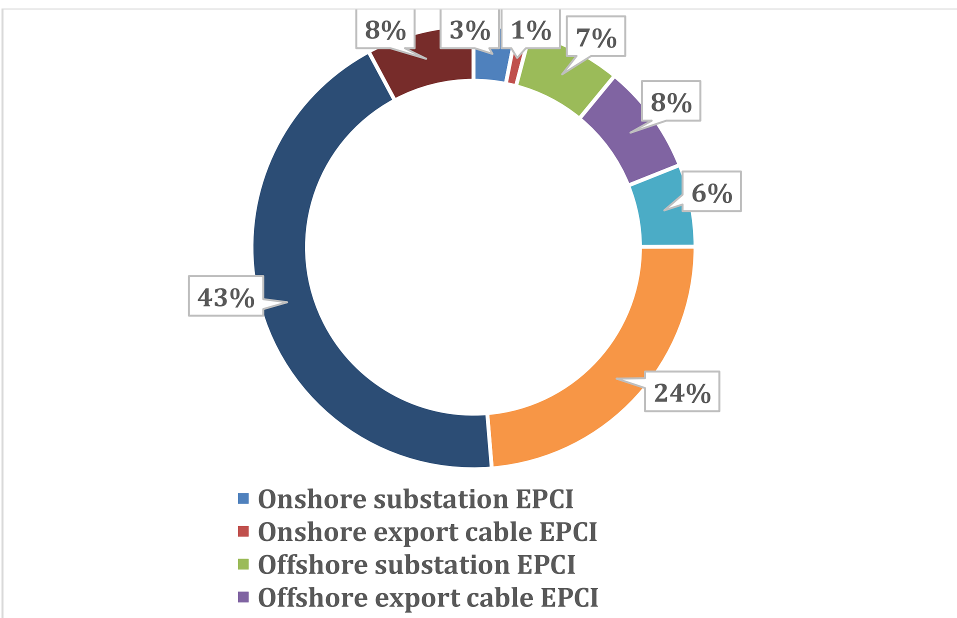
- The following assumptions were made about the size of turbines likely to be available to projects securing offtake in the following years:
  - *2018 - 2019 (inc.)*: 8.4 MW
  - *2020 - 2023 (inc.)*: 9.5 MW
  - *2024 - 2028 (inc.)*: 12 MW
  - *2029 - 2030 (inc.)*: 15 MW

Foundations (units)

- One foundation per turbine and one foundation per conventional offshore substation.

CAPEX

- Estimated cost per MW = $4 million.
- The following CAPEX breakdown was assumed:



Final predictions include an impact shift of two years for ITT and negotiation. Some contracts are predicted to be signed by 2032. Only contracts up to 2030 are included in the results.