Budget Period 2 Summary Report

Part 3

Hywind Maine Project

DE-FOA-0000410: U.S. Offshore Wind: Advanced Technology Demonstration Projects

August 15, 2015

Public Report

Performed under the Work for Others - Funds in Agreement FIA-14-1793 between Statoil and the Alliance for Sustainable Energy, manager and operator of the National Renewable Energy Laboratory (NREL)

Public report

WP3-Resource assessment: Spatio-Economic Potential of Hywind Technology in the United States

Notice

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Acronyms

AEP	annual energy production
AEP_{net}	net annual energy production
BP1	Budget Period 1
CAPEX	capital expenditures
DOE	Department of Energy
DR	discount rate
ECN	Energy Research Centre of the Netherlands
EPRI	Electric Power Research Institute
FOA	Funding Opportunity Announcement
GIS	Geographic Information Systems
Hs	significant wave height
HV	high voltage
Incl.	Included
km	kilometer
kW	kilowatt
kWh	kilowatt-hour
LCOE	levelized cost of energy
m	meter
m^3	cubic meters
MV	medium voltage
MW	megawatt
MWh	megawatt-hour
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
NPV	net present value
NREL	National Renewable Energy Laboratory
O&M	operation and maintenance
OPEX	operational expenditures
T	effective state and federal tax rate
U.S.	United States
U.S.$	United States dollars
Wv	maximum wind velocity
yr	year

Statoil

1 Introduction

This project was performed under the Work for Others—Funds in Agreement FIA-14-1793 between Statoil and the Alliance for Sustainable Energy, manager and operator of the National Renewable Energy Laboratory (NREL). To support the development of a 6-MW spar-mounted offshore wind turbine, NREL performed tasks on behalf of Statoil in the following three categories:

1. Design and analysis
2. Wake modeling
3. Concept resource assessment.

This document summarizes the work performed in Work Package (WP) 3, where the spatial variability and influence that relevant parameters have on levelized cost of energy (LCOE) were analyzed. The study allows Statoil to identify areas of interest for floating wind technology and the Hywind concept in particular.

This report describes the results of a study that NREL conducted to provide targeted insight into the United States (U.S.) offshore wind resource area that Statoil can use for taking strategic decisions about how to commercialize and market the company's Hywind technology. The report centers on a new spatio-economic methodology that NREL has developed to assess how variability in spatial parameters can influence levelized cost of energy (LCOE) for different technologies. The method combines wind plant performance modeling, economic modeling, and national geospatial data layers to estimate the cost of potential projects using Hywind technology, considering the following parameters:

- Water depth
- Wind resource
- Wave regime
- Seabed conditions
- Prospective staging ports
- Possible inshore assembly areas
- Existing grid features and potential connection points
- Environmentally sensitive areas
- Competitive use areas

The scope of the study covers the major offshore regions within the contiguous United States, including the Atlantic Ocean, Gulf of Mexico, Pacific Ocean, and the Great Lakes. The spatio-economic assessment extends to 92 km (50 nm) off of the nearest land mass, consistent with the available data on wind characteristics. The study is restricted to those locations that meet the depth criteria for Hywind technology—defined as water depths between 100 m to 1,000 m—and only considered sites with net capacity factors that exceed 30%.

2 Methodology and Limitations

The main analysis within the report is based on the Hywind 6-MW design, installation, and maintenance philosophies. Each project layout consists of 100 6-MW turbines arranged in a 10 x 10 km square grid at a constant spacing of seven rotor diameters (= 1078km). An illustration of a single wind farm as well as the GIS layer that successively places generic wind projects in a grid that provides seamless coverage of the U.S. offshore resource area are shown in Figures 1a and b.

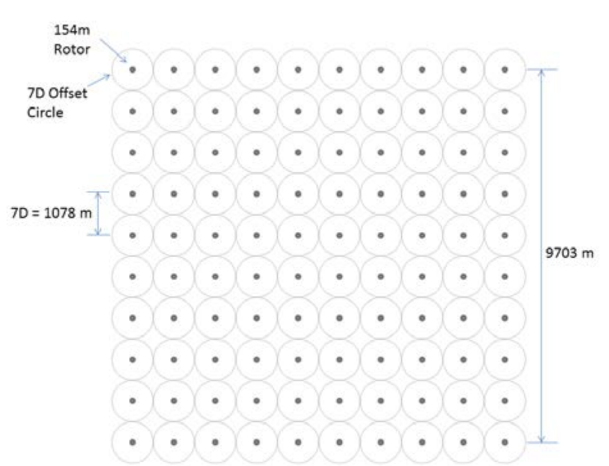	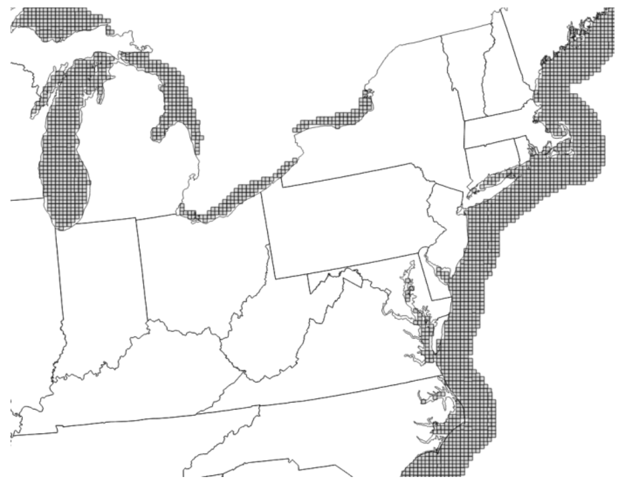
a) Project layout with 100 Statoil Generic 6-MW turbines.	b) Wind project grid: each cell represents a potential offshore wind project.

Figure 1 Generic project layout and project GIS layer illustration.

The central scenario in this analysis is based around a vertical-tow logistics strategy, in which Hywind units, including turbine and spar, are integrated at a sheltered inshore assembly area and then towed to the project site in an upright orientation. Suitable inshore assembly areas are, however, limited in U.S. waters due to a lack of sheltered deep water locations. Therefore, the assessment also considers an innovative horizontal-tow scenario that would remove this constraint. The horizontal-tow scenario assumes a novel vessel that enables Statoil to integrate the Hywind units at the staging port and tow the assembled units in an almost horizontal orientation to the site, where they can be upended.

The primary metric in this assessment is LCOE, which is best summarized as the net present value (NPV) of costs divided by the NPV of energy production. LCOE is a supply-side metric, in that it only considers the factors that are endogenous to the project and that influence the costs to supply power from the project to the grid. NREL did not consider factors that can influence demand (and therefore pricing) such as the market environment, renewable energy support mechanisms, or energy sector regulations. These demand-side factors play a key role in determining the value of revenue streams that an offshore wind project can generate and are equally as important as supply-side factors for determining economic viability of projects within a region.

A number of different methodologies have been developed to calculate LCOE; NREL uses a methodology adapted from A Manual for the Economic Evaluation of Energy Efficiency and Renewable Energy Technologies (Short et al. 1995), which offers the following equation:

$$\text{LCOE} = \frac{(FCR * CAPEX) + OPEX}{AEP_{net}}$$

where:

LCOE	=	levelized cost of energy ($/kWh)
FCR	=	Fixed Charge Rate (%)
CAPEX	=	Capital Expenditures ($/kW)
AEPnet	=	net annual energy production (MWh/MW/yr)
OPEX	=	Annual Operational Expenditures ($/kW/yr)

Figure 2 summarizes the LCOE framework that underpins economic calculations in this report.

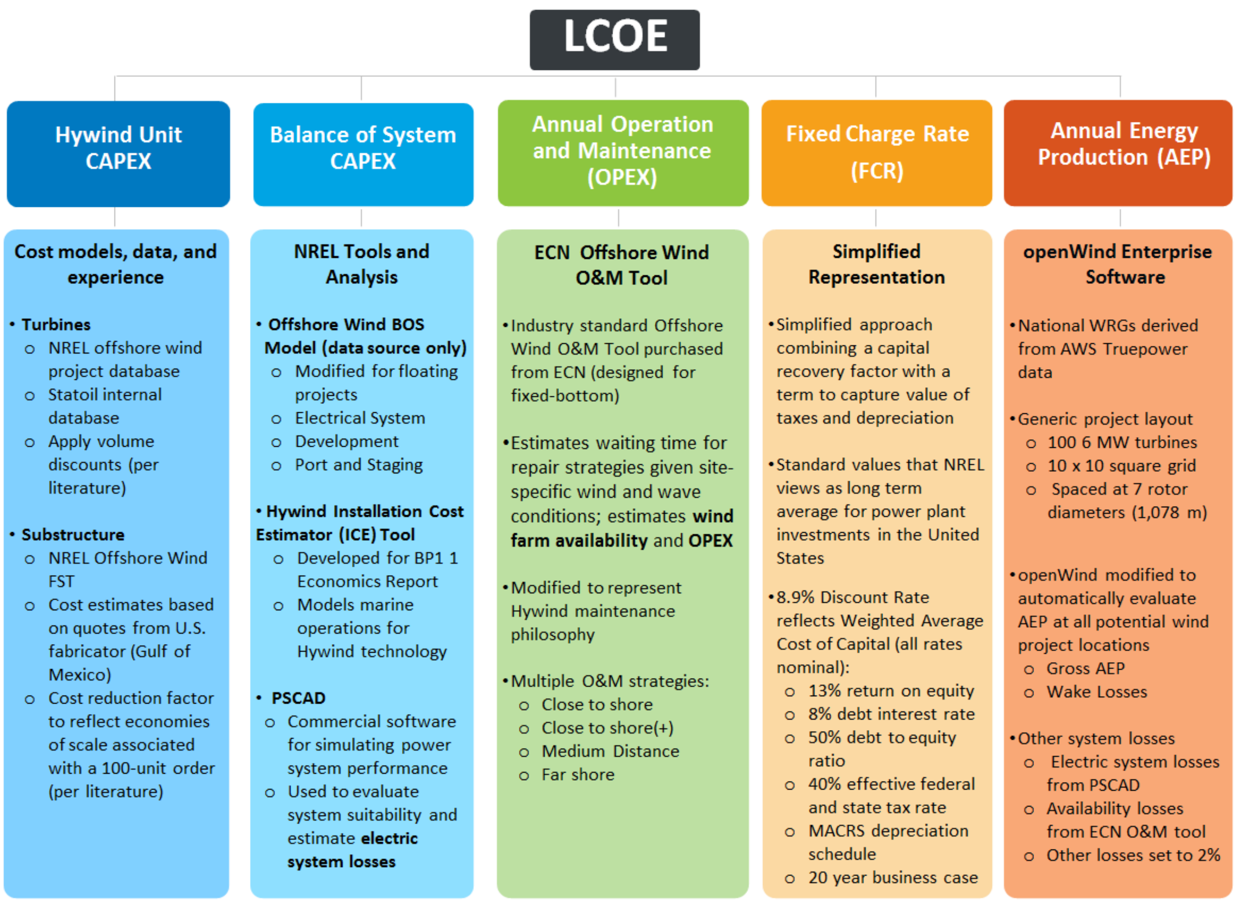

Figure 2 LCOE calculation framework

It is to be noted that the results of this assessment are subject to a number of limitations that the reader should be aware of before drawing conclusions. To conduct the analyses, NREL developed a methodology that balances between processing speed and fidelity. The emphasis is to develop solutions on a national scale that illustrate the relative differences in LCOE between potential sites rather than developing estimates that precisely describe the absolute LCOE value at a specific site. Furthermore, analysts performed the spatio-economic assessment with existing cost models; performed no new structural design work; and operated within the constraints of existing GIS datasets. As a result, NREL made a number of simplifications and assumptions that could have material implications on LCOE results.

NREL did not consider several important spatial variables that are likely to affect offshore wind project design:

- The Great Lakes region often develops significant ice formation in the winter months of the year. Icing imposes structural loads on the spar and this may require design changes, such as the addition of a conical ice cone to disperse loads. Ice coverage can also significantly reduce the ability of maintenance vessels to reach the project, which has implications for availability and OPEX. Results in the Great Lakes should be viewed with caution because they do not account for this major technical variable.
- The Gulf of Mexico, southern Atlantic, and mid-Atlantic regions of the United States all have exposure to hurricanes. These conditions extend beyond offshore wind industry experience, and, while efforts are under way to develop design standards, the implication on turbine and floating substructure design are currently not known.[1] It is reasonable to expect that there will be some cost premium for projects that have hurricane exposure, but NREL did not make an assumption about the magnitude of the premium in this assessment.
- NREL currently does not have access to a dataset that describes extreme design conditions across the United States (e.g., wind, wave, current). Without this dataset, NREL was unable to include this parameter in the analysis. Variability in extreme wave height data is also not anticipated to be a large cost driver for floating projects. The main driver is that the extreme wave determines the deck height required. While this may increase the cost of the substructure, these cost increases are likely to be offset, to a large extent; the wind turbine tower can be shorter and still achieve the same hub height. Extreme wave height can be important for mooring system design, especially in locations that have shallow water depths; however, this represents a small proportion of overall project costs. Current, however, can be a major driver of mooring system design and, in some locations like the eastern coast of Florida (where the Gulf Stream runs), current may even prevent deployment at any cost.
- BOEM's national database on sea bottom conditions identifies sediment type but does not describe the sediment thickness or composition at elevations below the mudline. This database only covers the OCS and does not include data for the Great Lakes region. The limitations associated with this GIS layer reduce confidence in mooring system cost estimates and likely underrepresent the variability that may exist between locations.

The relationships between cost, performance, and spatial variables are simplified in many cases and have some degree of uncertainty attached. These uncertainties fall in three categories. First, the cost relationships are derived, in many cases, from structural parameter studies using first-order design tools and approximations that do not fully capture the nuances of a detailed design tool. Second, cost factors are developed using best available knowledge but are imperfect, especially because no commercial-scale floating offshore wind project has been installed. Third, and related, the application zone considered in this relationship extends beyond industry experience, mostly in terms of water depth and the severe metocean conditions found at locations in the Pacific Ocean. These sites will require new components (e.g., suitable medium voltage [MV] and high voltage [HV] dynamic power cables) and equipment (e.g., O&M vessels) for successful installation and operation. Uncertainty exists because these enabling components and equipment remain to be qualified.

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[1] NREL also anticipates that projects with hurricane exposure will be treated by financiers as having increased risk exposure. This may lead to higher insurance premiums and elevated cost of capital.

3 Spatial Characteristics of the U.S. Offshore Resource Area

NREL obtained geographic data from several publicly available datasets and commercial licenses. Analysts normalized these source layers to align them with the generic wind plant grid (see Section 2.1), and processed them to create the layers that are necessary to calculate wind plant cost and performance. Table 1 summarizes the data layers used in this analysis.

Table 1: Summary of spatial data layers

GIS Layer Name	Sources	Notes on application within this report
Wind Resource Grid	AWST, MERRA, NDBC	Gridded 2km wind speed/direction shape files checked against MERRA and NDBC data, processed uniform UTM grid. Wind Resource Grid (WRG) enables ***AEP calculations*** at each potential project
Wind Plant Grid	NREL, Statoil	Turbine specifications combined with NREL layout assumptions; wind project grid enables ***AEP*** calculation and ***filtering of results***
Distance from Cable Landfall	Ventyx	Existing electric grid features; enable calculation of ***distance to interconnection*** and ***grid upgrade costs***
Bathymetry	NOAA/BOEM	NOAA bathymetry data at different resolutions combined to create composite continuous bathymetry layer; ***defines water depth***
Surface Sediment	NOAA/BOEM	Nearest surface sediment type determined for each wind plant grid cell; ***determines anchor type***
Logistical Distances	World Port Index	Logistical nodes including Staging ports and inshore assembly areas; allows identification of relevant ***installation distances*** and ***O&M distances***
Installation Metocean Layer	USACE/NREL	Weather data processed at non-exceedance limit of 2.5-m Hs and 16-m/s Vs; results in ***installation weather downtime estimates*** at each potential project
O&M Metocean Layer	USACE/NREL	Assigns each potential project to one of three representative sites 'mild,' 'moderate,' 'severe' with associated ***time series metocean data for the O&M parameter study***
Areas of Competing Use	Black & Veatch	Can be used to filter results
Regional CAPEX multipliers	SAIC[2]	Accounts for expected regional differences in wind project CAPEX (e.g., labor rates, freight costs; ***applied as an adder to CAPEX***
Regional Transmission Multipliers	EIPC[3]	Accounts for expected regional differences in transmission CAPEX (e.g., population density); ***applied as an adder to grid connection CAPEX***

The figures in the following sections show selected results from the data layers that were analyzed.

[2] Science Applications International Corporation (SAIC)
[3] Eastern Interconnect Planning Collaboration (EIPC)

3.1 Wind resource

Figure 3 shows the variation in wind speed across the offshore regions at 90 m above sea level. Note that these data are scaled to the 100 m hub height using location-specific shear factors in order to calculate Gross AEP. The northeastern Atlantic has a very strong offshore wind resource, with average annual wind speeds between 9 m/s and 10 m/s. Wind speeds gradually diminish from the north southward in the Atlantic and Gulf of Mexico, however; annual average wind speeds exceeding 8 m/s can be found at locations that are far from shore as well as areas towards the western edge of the Gulf of Mexico. Hurricane exposure is a significant concern in these latitudes, but each project location must be evaluated independently because the characteristics of these storms are dependent on the coastal geography (Musial et al. 2010).

The Pacific Coast has a strong offshore wind resource extending from the Channel Islands north to Seattle. Peak wind speeds approach 10 m/s and can be found near the border of Oregon and California. The area to the south of the Channel Islands displays some of the least energetic wind resource in the U.S. offshore resource area. The Great Lakes have a strong wind resource, which improves at the northern latitudes and with the distance to shore.

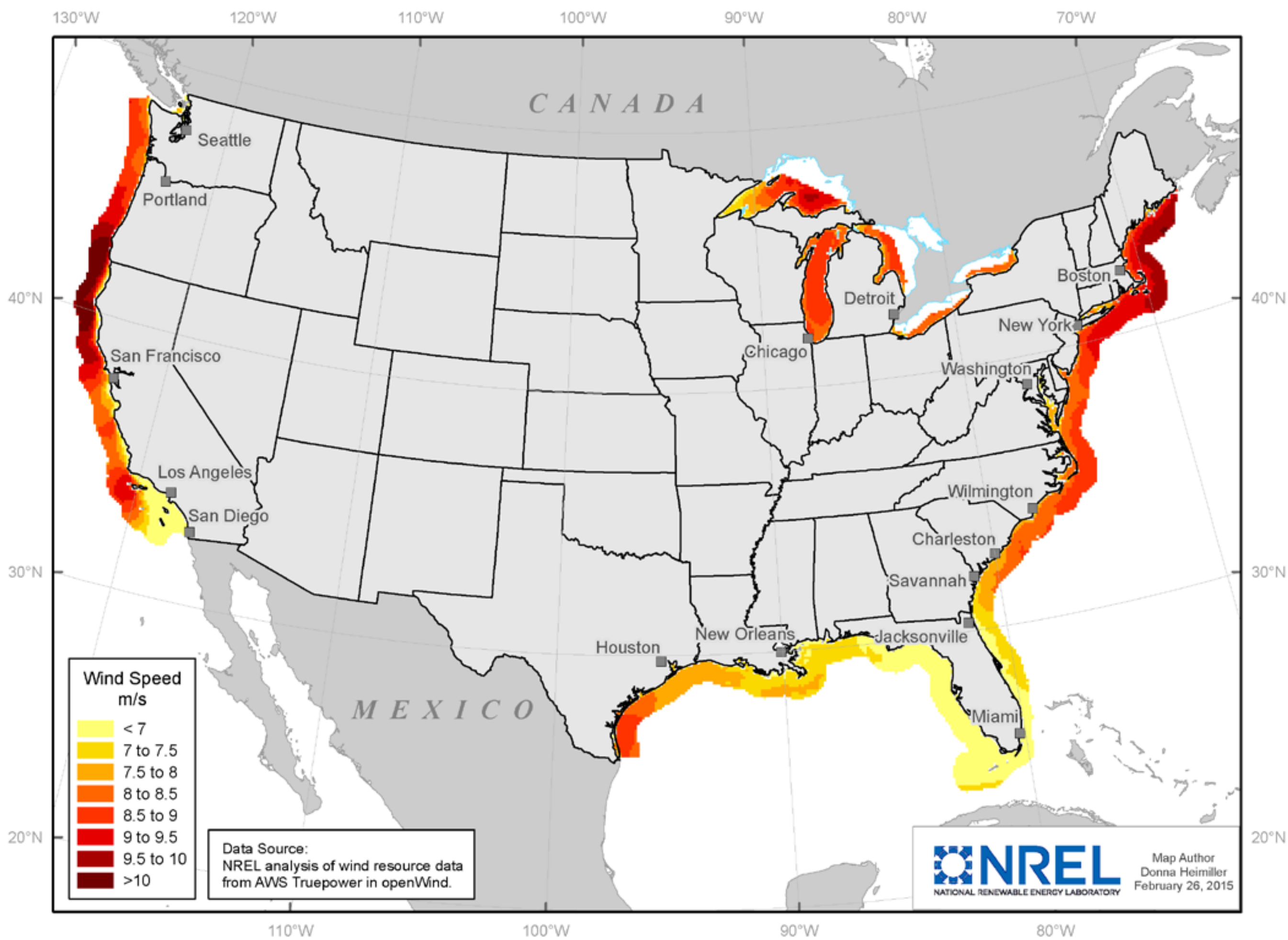

Figure 3: U.S. annual average wind speed (at 90-m elevation; 50 nautical miles from shore)

3.2 Bathymetry

Bathymetry is the primary parameter that influences the selection of a substructure technology for each offshore wind project location. Statoil is currently considering water depths between 100 m and 1,000 m for the Hywind technology. Figure 4 shows the U.S. bathymetry data divided into 5 bins. The first bin (<100 m) represents areas not suitable for Hywind installations and is helpful to understand where competing offshore wind substructure technologies could be deployed. The second set of bins, 100 m to 300 m, 300 m to 700 m, and 700 m to 1,000 m, represents the ideal application area of the Hywind technology; this report uses these bins to understand the influence of water depth on LCOE. The final bin (>1,000 m) represents areas that Statoil is not currently considering but may have potential in the future. Table 2 summarizes the number of potential project layouts within each depth band.

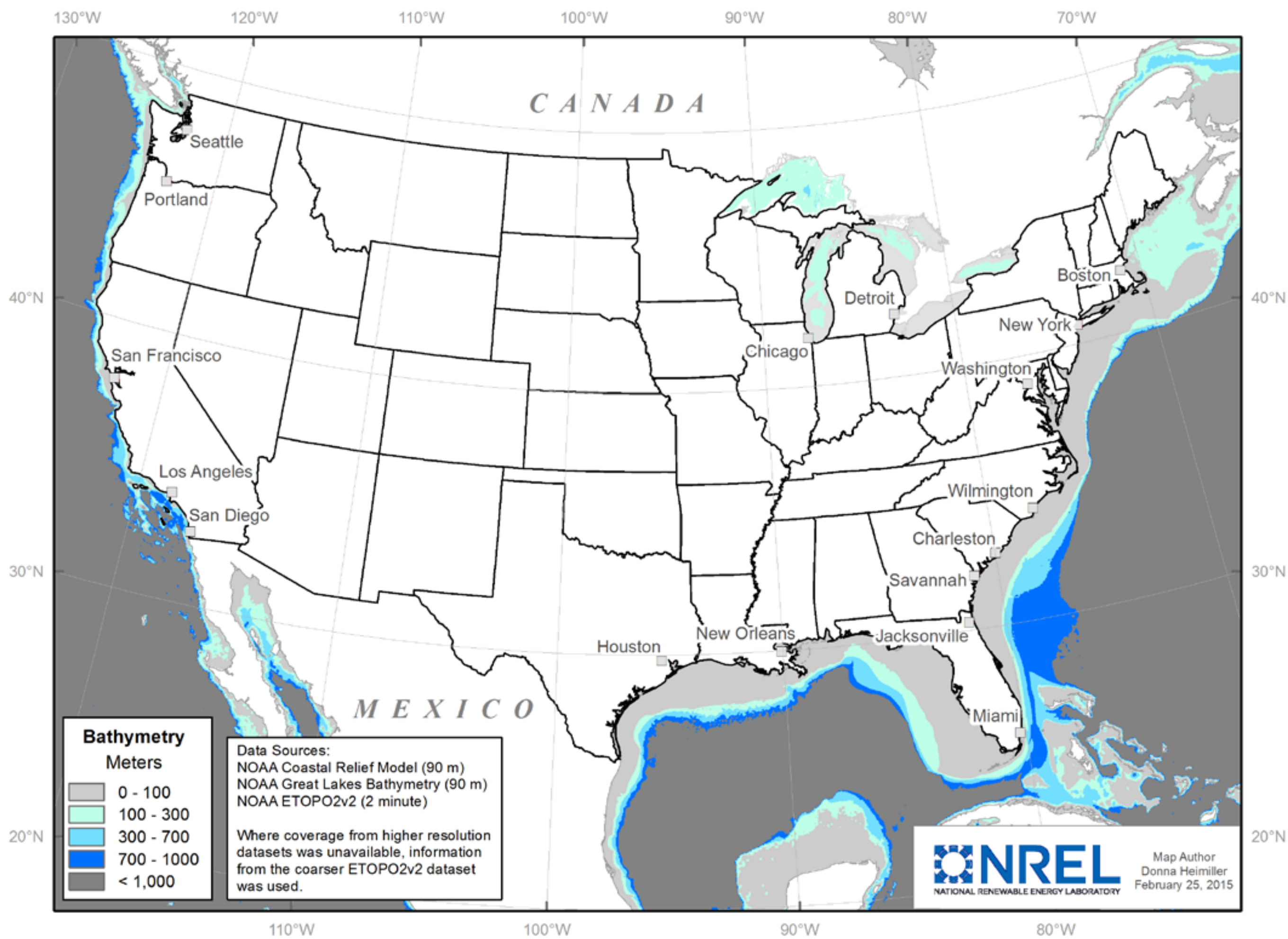

Figure 4: U.S. bathymetry highlighting areas where water depth is suitable for Hywind technology

Table 2: Summary of potential projects sites by region and water depth.

Region	Total US Offshore Resource Area (within 50 nautical miles of shore)					
		Application Zone for Hywind Technology				
	0 to 100m	100m to 300m	300m to 700m	700m to 1000m	100 to 1000m	All Depths
Atlantic	1,752	391	146	57	**594**	**2,419**
Pacific	180	270	282	249	**801**	**1,778**
Gulf	1,696	95	35	26	**156**	**1,887**
Great Lakes	530	539	6	0	**545**	**1,075**
Lake Superior	73	303	6	0	**309**	**382**
Lake Michigan	240	173	0	0	**173**	**413**
Lake Ontario	16	37	0	0	**37**	**53**
Lake Erie	74	0	0	0	**0**	**74**
Lake Huron	127	26	0	0	**26**	**153**
Total	**4,158**	**1,295**	**469**	**332**	**2,096**	**7,159**

3.3 Logistics

In order to estimate the sensitivity of installation and O&M costs to distance, NREL developed a data layer that identifies locations that may be suitable to support these operations. There are two relevant logistical nodes for the Hywind technology. Ports provide facilities for the receipt, storage, assembly, and load out of components during installation. The ports also serve as the O&M base from which the operator coordinates maintenance and repair operations. NREL used the World Port Index and applied basic filters, including the channel depth, degree of shelter, and unrestricted access to the offshore resource area. In practice, suitability will depend on a number of other considerations including, but not limited to existing infrastructure (alternatively, required upgrades), vertical/horizontal clearance limits, and competing port uses.

Sheltered inshore assembly areas are necessary to support the assembly and installation of Hywind units in the vertical-tow scenario. NREL identified three potentially suitable locations based on an inspection of the spatial characteristics including water depth, a viable transit path to open water, and benign environmental conditions during the construction season (e.g., wind, wave, current). These locations include the Atlantic inshore assembly area in Penobscot Bay, the South Pacific inshore assembly area behind the Channel Islands, and the North Pacific inshore assembly area in the Strait of Juan de Fuca. Metocean conditions in the Great Lakes are typically much less harsh than in the open ocean areas; NREL therefore treats any location with depths that exceed 80 m water depth as a potential inshore assembly area. Figure 5 shows relevant logistical points that could support installation and operations for projects using Hywind technology. The figure also shows a 500 km radius around each of the three inshore assembly areas; Statoil has stated that this is a reasonable limit for a project using a vertical-tow installation strategy.

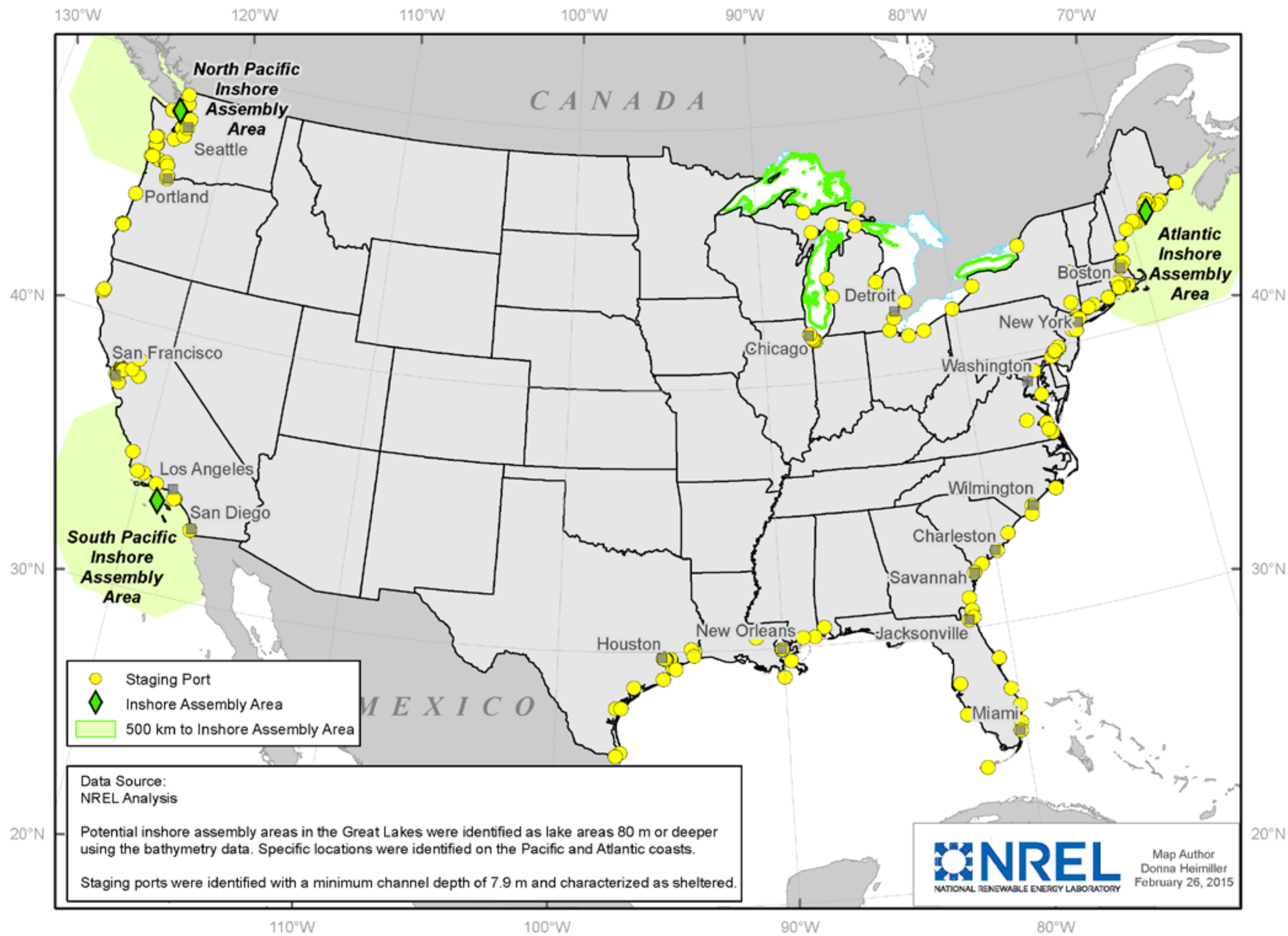

Figure 5: Staging ports and inshore assembly areas

3.4 Metocean Conditions

Metocean conditions vary considerably between project sites within the U.S. offshore resource area and can influence installation CAPEX, OPEX, and the technical availability of the project. For this assessment, NREL assessed national hindcast datasets of wind speed and significant wave height to identify the proportion of time in which operational thresholds for various marine operations might be exceeded.

All lifting operations for projects using Hywind technology are expected to occur at either a sheltered inshore assembly area (vertical-tow scenario) or at the staging port (horizontal-tow scenario). The marine operations therefore have a limited sensitivity to wind speed relative to fixed-bottom offshore wind projects. Although considered jointly with wind speed, the primary factor to determining weather-downtime is significant wave height. Figure 6 shows the variability in significant wave height across the U.S. offshore resource area (EPRI 2011). Note that this dataset does not cover the Great Lakes; metocean conditions in the Great Lakes are mild compared to offshore locations.

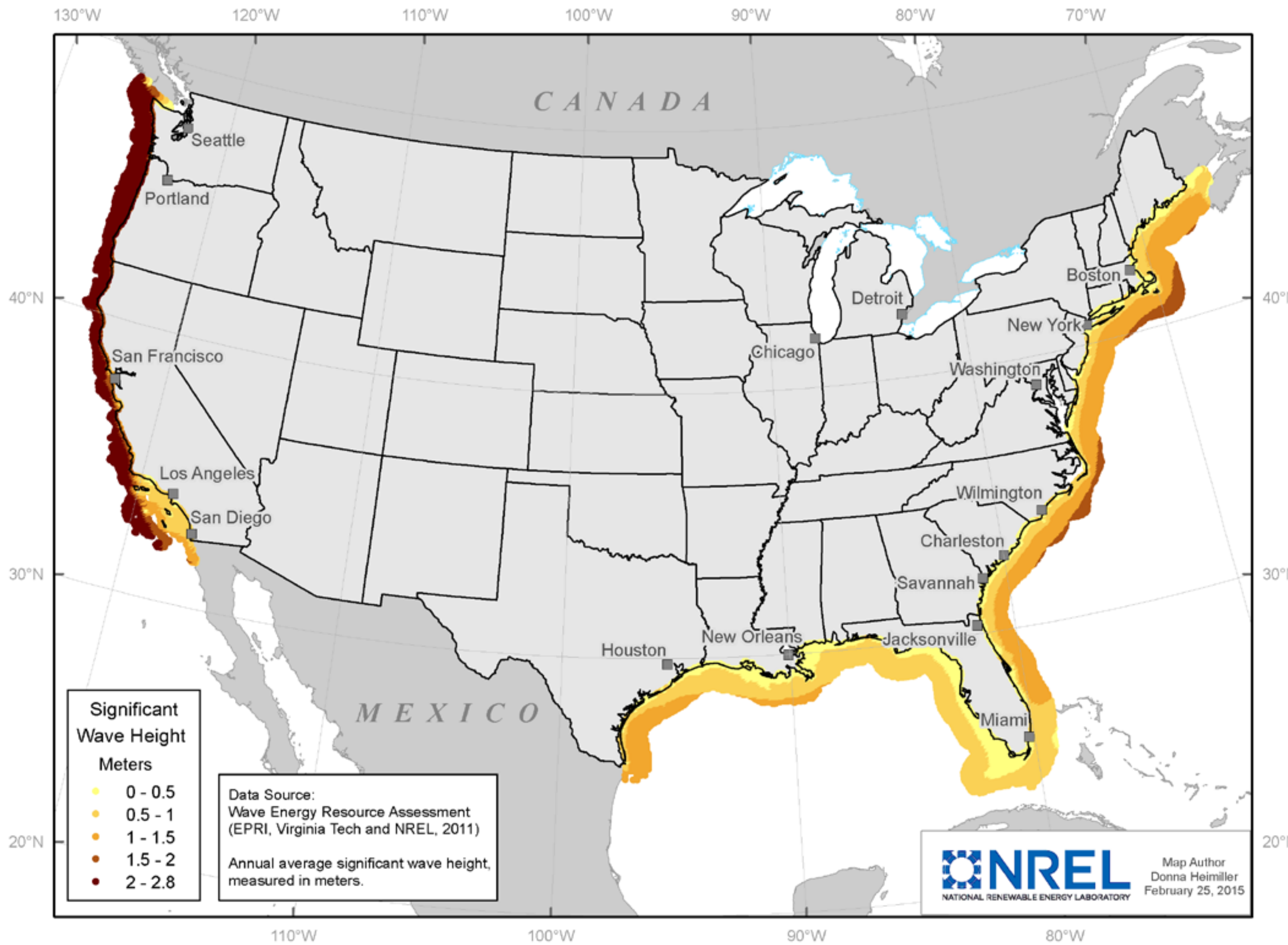

Figure 6: Yearly average significant wave height

Figure 11 shows that yearly average significant wave heights generally increase with distance from shore. It is also apparent that the metocean conditions on the West Coast are more severe than those in the Atlantic or Gulf of Mexico; significant wave heights exceed 2-m across the majority of the region.

3.5 Surface Sediment layers

The characteristics of the seabed are important parameters for site selection, especially for fixed-bottom offshore wind projects. Floating technology is expected to be less sensitive to seabed conditions because the major loads do not have to be transferred deep into the seabed. These seabed characteristics will, however, drive the type and size of anchor and may have implications for costs and even feasibility if ground conditions are particularly challenging.

National level information about seabed geotechnical characteristics is limited to information about the surface sediment. Information that would allow NREL to draw more reliable conclusions about anchor suitability, such as sediment thickness or composition at elevations below the mudline, is not available at this time.

3.6 Competing Use and Environmentally Sensitive Areas

Competing uses and environmentally sensitive areas account for a significant fraction of the coastal waters in the United States. The marine resource, consequently, has a large number of stakeholders, reflecting its importance for conservation, commerce, recreation, and defense. It is therefore reasonable to assume that the areas available for offshore wind development will be limited, to some extent, by these considerations. Limits might be defined by legislation, marine spatial planning, or simply by the willingness of offshore wind developers to pursue sites where stakeholder opposition is high.

In 2009 NREL commissioned Black & Veatch to identify areas where competing ocean uses and environmental exclusions may exist in the U.S. offshore resource area. Figure 7 shows the resulting GIS layer, which includes areas with environmental and wildlife concerns; offshore oil and gas platforms and pipelines; commercial fisheries; military use areas; cultural and historic areas; and social and recreational impacts. These competing use and environmentally sensitive areas are shown overlaid on a layer that shows potential offshore wind project locations.

Figure 7 shows that while much of the U.S. offshore resource area is subject to some competitive use, there is still a large amount of subsea land where no competing use has been identified. Also, competitive uses generally diminish with both distance to shore and water depth.

Note that these competing uses are not comprehensive; some considerations, such as high-density avian flyways and visibility from tourist areas with high economic value, were not included in the Black and Veatch dataset. The competing use areas also do not necessarily block offshore wind development in a specific location. While some designations, such as marine protected areas (MPAs) designated as no-take, no-access, or no-impact generally prohibit offshore energy development, other designations like those for shipping lanes, are more flexible.

Analysts use this set competing use areas in this report to provide an illustrative indication of how existing uses may impact the potential for offshore wind deployment in the United States. This dataset is most useful when looking at total offshore wind potential within a region. Screening of individual sites would require more detailed consideration of specific combinations of competing uses, and should include additional datasets. NREL recommends that Statoil perform this sort of detailed competing use analysis for offshore wind project locations that appear to be favorable from an economic perspective.

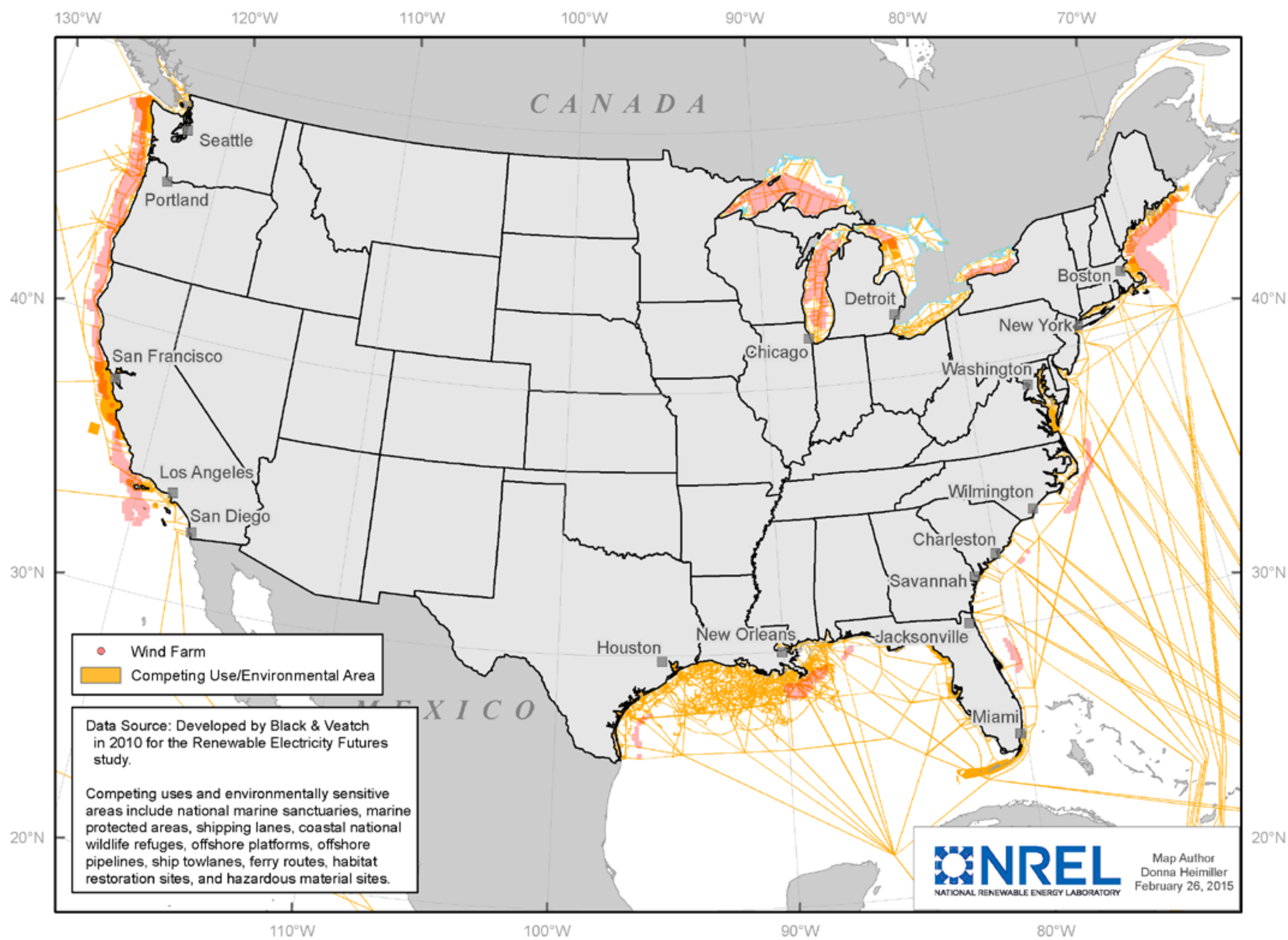

Figure 7: Competing use and environmentally sensitive areas

4 Cost modelling

In order to identify reasonable relationships between the variable cost items and environmental conditions at potential offshore wind project locations, NREL ran a series of parameter studies in structural, electrical, and process-based logistical models to identify how project economics change with respect to key spatial parameters. The resulting cost curves were then incorporated into the data processing framework, which aggregates all of the costs for a location and combines them with energy production estimates to calculate LCOE.

To simplify the calculation of site-specific costs, NREL sorted cost elements into 3 categories: fixed costs, variable costs, and cost factors.

Fixed costs refer to cost categories that do not have an empirically discernable relationship with the included spatial parameters, based on current knowledge and market context. Offshore wind turbine procurement costs, for example, are assumed to be site-agnostic, given that commercially-available models are typically designed for IEC class 1 sites. In practice, however, wind turbine original equipment manufacturers (OEMs) do hold liabilities associated with warranty provisions and may adjust the pricing structure for a given site to account for the perceived level of risk associated with exposure to environmental conditions. In general, NREL assumes that these costs are constant between projects and estimates these costs using methods that were established during budget period 1.

Variable costs refer to categories of expenditure that have distinct relationships with spatial parameters. For example, installation costs are expected to vary with logistical distances (e.g., distance from port to site), water depth, and prevailing metocean conditions.

Cost factors are indirectly related to environmental conditions. Cost factors are not explicitly linked to individual spatial factors but do tend to vary with total project cost to reflect the complexity of other items. In general, cost factors are estimated using the same method as in the BP1 Economics report.

Table 4 summarizes the major cost categories associated with offshore wind projects and sorts them into Fixed Costs, Variable Costs, and Cost Factors.

Table 3: Summary of cost categorization for spatio-economic assessment

Cost Category	Type	Cost ($/kW)	Comments
Turbine	CAPEX	$1,920	Statoil Generic 6-MW turbine; Costs based on BP1 report; horizontal-tow strategy adds 5%
Development	CAPEX	$109	Based on BP1 Report
Ports & Staging	CAPEX	$90	Based on BP1 Report; does not consider port upgrade costs; horizontal-tow strategy adds 25% premium
Operations	OPEX		Based on BP1 Report
Substructure	CAPEX	Variable	Cost dependent on water depth and ground conditions
Assembly & Install	CAPEX	Variable	Cost dependent on logistical distances, water depth, ground conditions, and metocean regime; horizontal-tow strategy changes cost structure
Electric System	CAPEX	Variable	Cost dependent on distance to cable landfall, water depth, and existing grid features
Maintenance	OPEX	Variable	Cost dependent on logistical distances, and metocean regime; horizontal-tow strategy changes cost structure
Engineering & Mgmt.	CAPEX	Factor	3.5% factor applied to fixed + variable CAPEX
Insurance	CAPEX	Factor	1% factor applied to fixed + variable CAPEX
Commissioning	CAPEX	Factor	1% factor applied to fixed + variable CAPEX
Contingency	CAPEX	Factor	30% of installation CAPEX and 5% of other CAPEX
Construction Insurance	CAPEX	Factor	1% factor applied to fixed + variable costs
Carrying Charges during Construction	CAPEX	Factor	Calculated; CAPEX schedule assumes 20% paid in year -2, 40% paid in year -1, and 40% paid in year 0
Decommissioning Fund	CAPEX	Factor	65% of installation CAPEX

5 Results and Conclusions

Specific cost results as well as the final LCOE results across the U.S. offshore resource area are not displayed in this section due to confidentiality reasons. Some high-level results and conclusions are outlined in the following. Note that because the analysis was conducted at a national-scale, it contains a number of simplifications and uncertainties that may affect the absolute accuracy of results at an individual location.[4] The analysis also does not consider several significant design variables that may contribute to variability between regions. For example, surface ice exposure will limit accessibility during winter months for projects in the Great Lakes with potentially large impacts on OPEX and availability; surface ice flows may also necessitate structural modifications (e.g., ice cones). Section 2 contains a more robust discussion of limitations.

The results suggest that there are many suitable locations for Hywind technology using a vertical-tow approach to logistics. NREL identified more than 450 GW that could be developed at LCOEs below $300/MWh after adjusting for areas where competing uses and environmental sensitivities have been identified. The results indicate that the lowest LCOEs in the United States are likely to be found in the northeastern Atlantic Ocean. The Great Lakes also appear to be promising from an LCOE perspective if the challenges associated with surface ice exposure can be addressed in a cost effective manner. The results suggest that the costs for Pacific projects will be slightly higher than either Atlantic or Great Lakes sites.

These promising locations, in the northeastern Atlantic, Great Lakes, and Pacific, share many common characteristics, including:

- Strong wind resources that result in net capacity factors greater than 40%.
- Close proximity to shore (less than 50 km), which minimizes electrical infrastructure costs
- Adjacent to an inshore assembly area (less than 300 km), which minimizes installation costs
- Shallower water depths (between 100 m and 500 m), which minimize substructure costs.

The cost premium observed for Pacific sites relative to Atlantic and Great Lakes sites is largely due to the severe metocean conditions that prevail in the region. The mean one-year average significant wave height in the Pacific is 2.5 m, which far exceeds the mean one-year significant wave height of in the Atlantic (1.3 m), as well as wave conditions found at European projects (0.5 m to 1.5 m). These severe metocean conditions are expected to increase installation costs and OPEX, while reducing availability. The results suggest that metocean conditions are a very important driver of site-specific LCOE, second only to net capacity factor. Although beyond the scope of this study, NREL envisions that technical advancements in vessel design could address the challenges associated with severe metocean conditions and reduce the LCOE premium for Pacific sites.

Sites in the mid-Pacific (between San Francisco and Portland), the southeastern Atlantic, and the Gulf of Mexico regions are not possible using a vertical-tow strategy because these sites are located beyond the 500 km radius from a suitable inshore assembly area.[5]

Statoil is, however, working to develop alternative approaches for marine logistics through the company's Hywind Installation Challenge. NREL considered one of these methods in this analysis through the development of a horizontal-tow scenario, which does not require an inshore assembly area.

The results suggest that a horizontal-tow strategy could increase the amount of feasible sites with LCOEs below $300/MWh by approximately 15%, to a total of 525 GW. More significantly, the horizontal-tow scenario would greatly

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[4] These uncertainties fall into four categories: 1) models—parameter studies were conducted with first-order tools and do not reflect detail design 2) cost data— no commercial-scale floating offshore wind projects have been installed and makes difficult the verification of assumptions 3) suitability/availability of technology—a new components (e.g., dynamic high-voltage cables) and equipment will be necessary to install projects in the range of site conditions considered in this analysis 4) macroeconomic factors (e.g., exchange rates, commodity prices).

[5] Statoil commented that it would not consider a vertical-tow strategy for logistics for projects that are located more than 500 km from a suitable inshore assembly area.

expand the geographic region in which Hywind Technology could be developed, unlocking potential sites in the mid-Pacific, southern Atlantic, and Gulf of Mexico. The horizontal-tow scenario would also reduce overall spatial variability in LCOE between sites; however, the strategy does improve the economics of the projects where LCOE is already low.

If LCOE was the only consideration, it is likely that development of floating technology would be concentrated in the Northeastern Atlantic (as well as the Great Lakes, if challenges related to surface ice can be overcome). Demand-side considerations, however, are likely to play a significant role in influencing the regional distribution of projects across the U.S. offshore resource area. For example, California has enacted the most aggressive climate change and renewable energy policies in the contiguous United States, which might lead to policies that are favorable to offshore wind.[6] Such policies have the potential to provide a revenue mechanism which could make the development of sites in the Pacific more attractive, despite the relatively higher LCOEs. The supply-side conclusions developed within this report should be considered within the context of demand-side drivers.

[6] Note that Hawaii enacted a 100% renewable portfolio standard (RPS) in June 2015 after completion of this study. While Hawaii was not included in the scope of this assessment, it is expected to be attractive for floating offshore wind because it has an energetic wind resource located in deep waters and favorable market characteristics, including an aggressive renewable energy standard and relatively high power prices,

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