Offshore Wind Energy Technical Potential for the Contiguous United States

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Outline

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Background and Objectives

Research Objectives

This study evaluates the technical potential of offshore wind (OSW) energy for the contiguous United States (CONUS). The analysis uses high spatial resolution layers and a technical siting model.

Specific objectives include:

- Updating and quantifying a suite of assumptions used in previous estimates, including:
  - Spatial siting constraints for OSW farms
  - Capacity density for OSW turbines
  - Depth constraints of OSW energy technologies
  - Inclusion of the Great Lakes' floating OSW energy potential.

- Quantifying the total technical potential for OSW energy as well as the relative contribution of fixed and floating substructure technologies.

Note: This briefing deck emphasizes results from the study's relatively optimistic "Open Access" scenario; given substantive uncertainties in characterizing technical and spatial constraints of the nation's offshore wind resource, a complementary "Limited Access" scenario is also in development with details to be included in the study's comprehensive final report. This briefing deck notes key differences in assumptions between these two scenarios on slide 12.

Background

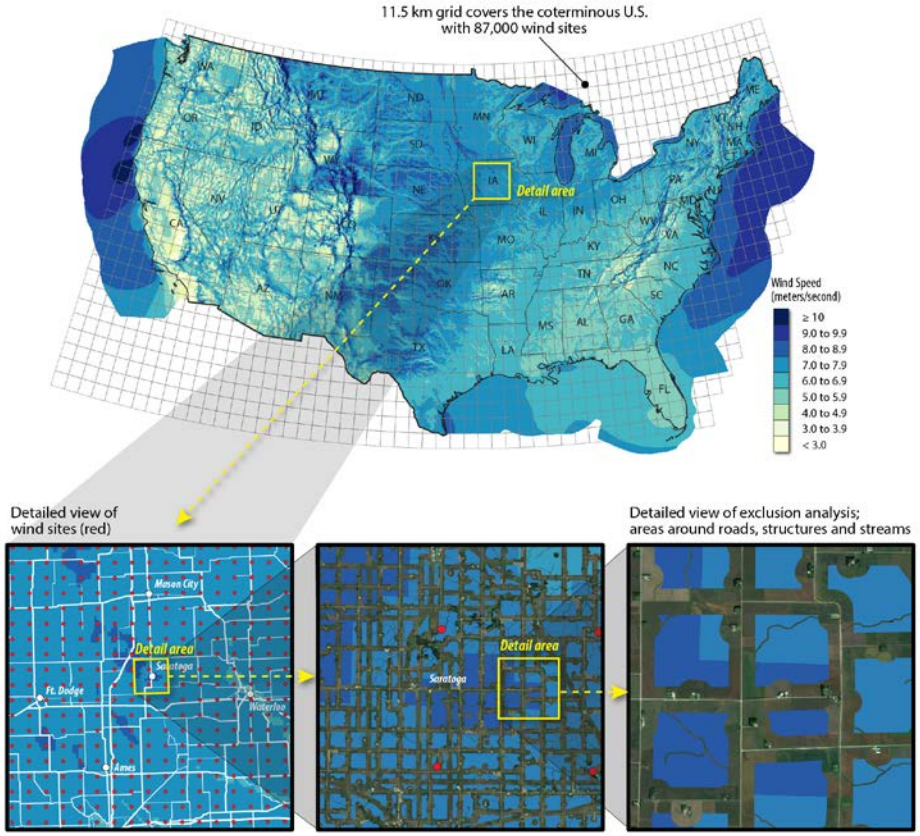
- OSW energy has a dynamic industry with rapid technology advancements and accelerating global deployment.
- In the United States, OSW energy is at a more nascent stage with only seven turbines, totaling 42 megawatts (MW), installed through 2021.
- Over 40 gigawatts (GW) of OSW energy capacity are at various stages of development as of 2021 (Musial et al. 2022).
- The most recent national assessment of OSW resource potential in the United States was published in 2016 (Musial et al. 2016). Several assumptions used within that study require updating, based on new data and trends in the OSW energy sector. These include:
  - Updating siting layers initially developed in 2010
  - Removing a low wind speed economic threshold to accommodate rapidly evolving OSW energy technology
  - Updating capacity density to align with empirical data from European offshore wind farms
  - Extending the assumed total depth constraints (from 1,000 meters to 1,300 meters) within the study boundaries and for the purposes of this effort.

Methods and Assumptions

Methods

The Renewable Energy Potential (reV) is used for the modeling in this study, which has a:

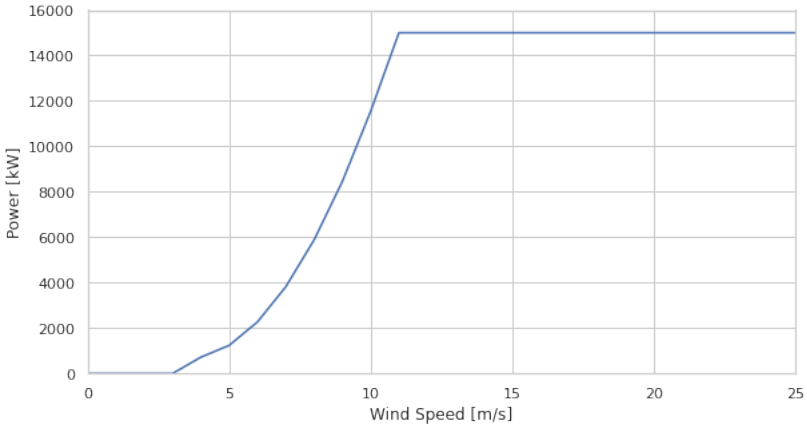
- Scope including:
  - The conterminous United States.
  - Spatial and temporal resolution(s) of:
    - 90-meter spatial siting constraints/characterizations (>1 billion pixels)
    - 2-kilometer (km) wind resources (>2 million pixels × 8760 hours × 7 years)
    - 11.5-km land-based wind energy “sites” (~67,000)
    - 11.5-km OSW energy “sites” (~20,000).
  - Wind energy site critical outputs with:
    - Hourly generation profiles for years 2007-2013
    - Installable capacities
    - Site and spur-transmission costs
    - Land and water characteristics (e.g., land-cover, species habitat, avian risk, radar line-of-sight, and more).
- Website at https://www.nrel.gov/gis/renewable-energy-potential.html.
- Latest model documentation at https://www.nrel.gov/docs/fy19osti/73067.pdf.



Graphics by Billy Roberts, NREL

Turbine Assumptions

	Moderate (2030)
Rating (Megawatts [MW])	15
Rotor diameter (meter [m])	240
Hub-height (m)	150
Specific power (Watt [W]/m^2)	332
Capacity density (MW/km^2)	5.3



Graphics by NREL

The Annual Technology Baseline (ATB) provides a consistent database of turbine performance and cost. In this study, we use the ATB Moderate turbine design for the year 2030. Detailed ATB assumptions can be accessed at the following website: https://atb.nrel.gov/electricity/2021/offshore_wind

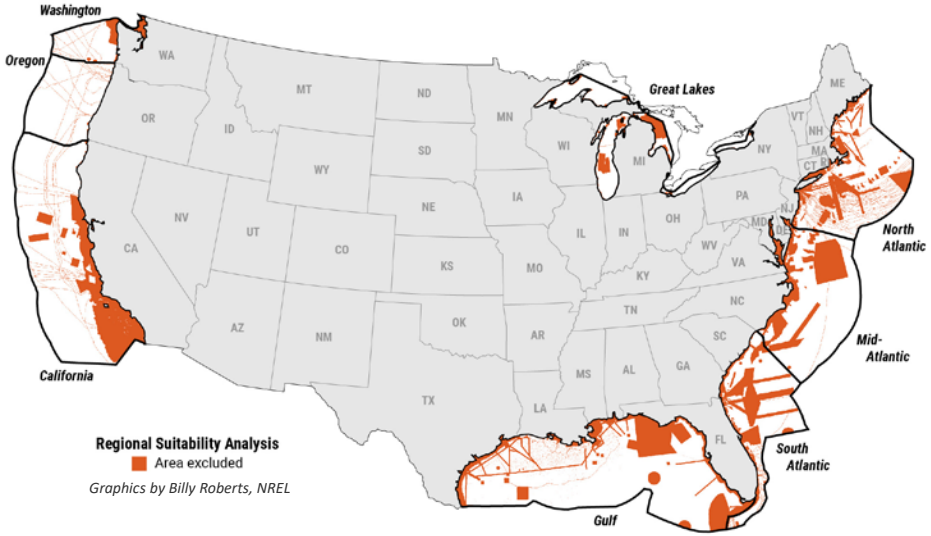
The power curve associated with the ATB turbine can be seen in the left graph. The power curve (and others) can be accessed at NREL's turbine power curve GitHub: https://github.com/NREL/turbine-models

Capacity density was determined using a 7-rotor-diameter spacing assumption. This results in a capacity density assumption of 5.3 MW/km^2, within the range of empirical European OSW energy observations (Boremann et al. 2018); Musial et al. 2016 used a density assumption of 3 MW/km^2.

Open Access Siting Assumptions
(Primary Spatial Drivers of OSW Energy Potential)

Siting Layer	Exclusion/Setback/Inclusion	Description/Citation
U.S. Department of the Interior Bureau of Ocean Energy Management (BOEM) wind leases	Included	Blocks which have been leased by a company with intent to build a wind energy facility. Areas are included regardless of spatial overlap with constraints. (BOEM, Renewable Energy Geospatial Information Systems Data)
Oil/gas pipelines, platforms	61-m, 250-m setback applied	Existing infrastructure exclusion (Homeland Security Infrastructure Database)
Shipping lanes	Constraint applied	Shipping fairways, lanes, zones defined by BOEM as exclusions (MarineCadastre)
Conservation areas	Constraint applied	Combination of several categories (marine protected areas, conservation areas, etc.) using 30CFR585 as a guide (MarineCadastre)
Danger zones and restricted areas	Constraint applied	Areas defined as restricted due to danger potential, including ship shock boxes, submarine transit lanes, unexploded ordinances (MarineCadastre)
U.S Department of Defense (DOD) OSW mission compatibility assessment	Constraint applied	Defined wind exclusion areas (MarineCadastre, California State Lands Commission)
State waters	Constraint applied	Variable by state water extent but typically ~4.8–8 kilometers. We apply a distance exclusion of 4.8 kilometers to the Great Lakes (MarineCadastre)
Shipwrecks	50-m setback applied	BOEM guidance to avoid by using a generalized setback of 50 m (MarineCadastre)
National Oceanic and Atmopsheric Administration chartered submarine cables	500-m setback applied	Assumed through guidance from NYSERDA 2018 (MarineCadastre)
Ocean disposal sites	Constraint applied	Active disposal sites to be avoided (MarineCadastre)
Atlantic outer continental shelf aliquots	Constraint applied	Aliquots in the Atlantic Canyons part of the Development and Production (DPP) oil/gas lease program (MarineCadastre)
Bathymetric depth limit	>1,300-m constraint applied	Current depth limit guidance established by BOEM (Global Gridded Bathymetry Data, derived)
Exclusive economic zone	>370-km constraint applied	Domain boundary for the study (MarineCadastre, Musial et al. 2016)

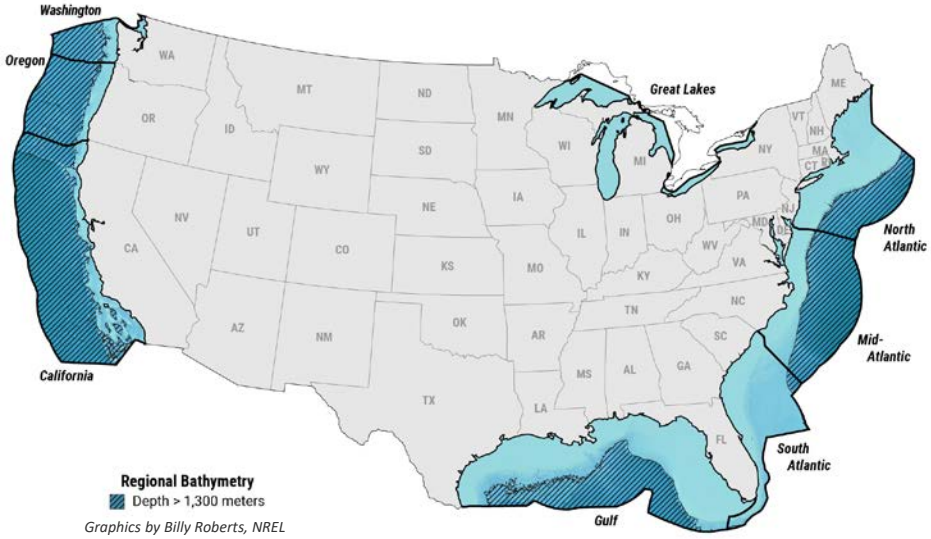
Open Access Siting Assumptions



Combined Siting Constraints

Siting considerations for wind energy projects include competing use, existing infrastructure, protected areas, and more (full list on slide 9). Collectively, these factors affect development suitability and are important for understanding cumulative wind resource potential.

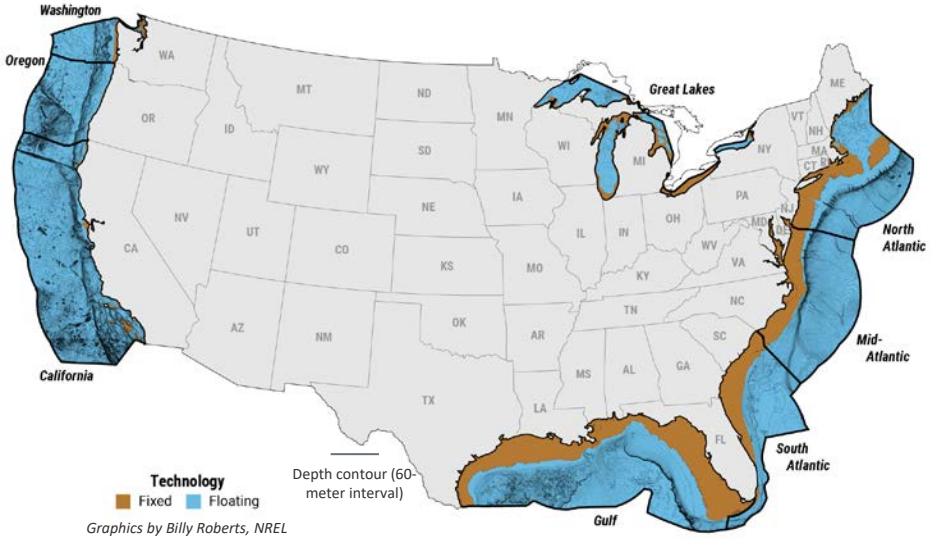
Note: Large portions of the U.S. West Coast fall under DOD-defined wind exclusion areas; development may be possible in these regions pending outcomes from a detailed mission compatibility assessment. The total California resource affected by this constraint is equivalent to 428 GW of OSW energy technical potential.



Bathymetric Constraints

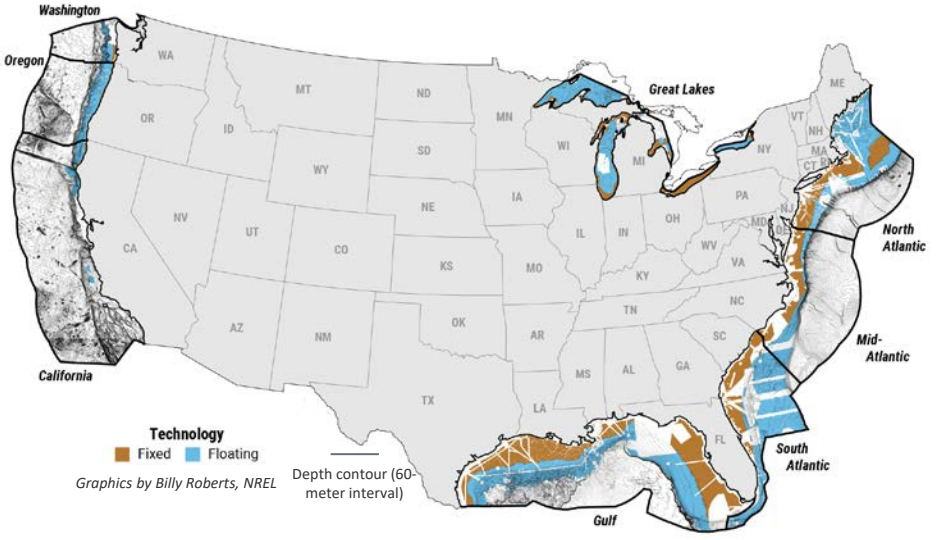
1,300 m is generally the depth limit BOEM applies when considering offshore waters for leasing areas and is loosely based on turbine capability and cost. This limit has changed over time, most recently from 1,000 m to 1,300 m. As turbine technology advances and costs continue their downward trajectory, this limit may be relaxed.

Open Access Siting Assumptions



Substructure Technology Bathymetric Demarcation

A 60-m ocean depth is a common delineator used to differentiate waters with either fixed or floating OSW energy technology. While site specific conditions would influence ultimate technology selection, 60 m is seen as a reasonable upper economic limit for fixed-bottom systems (Musial et al. 2016).



Combined Spatial Constraints by Technology

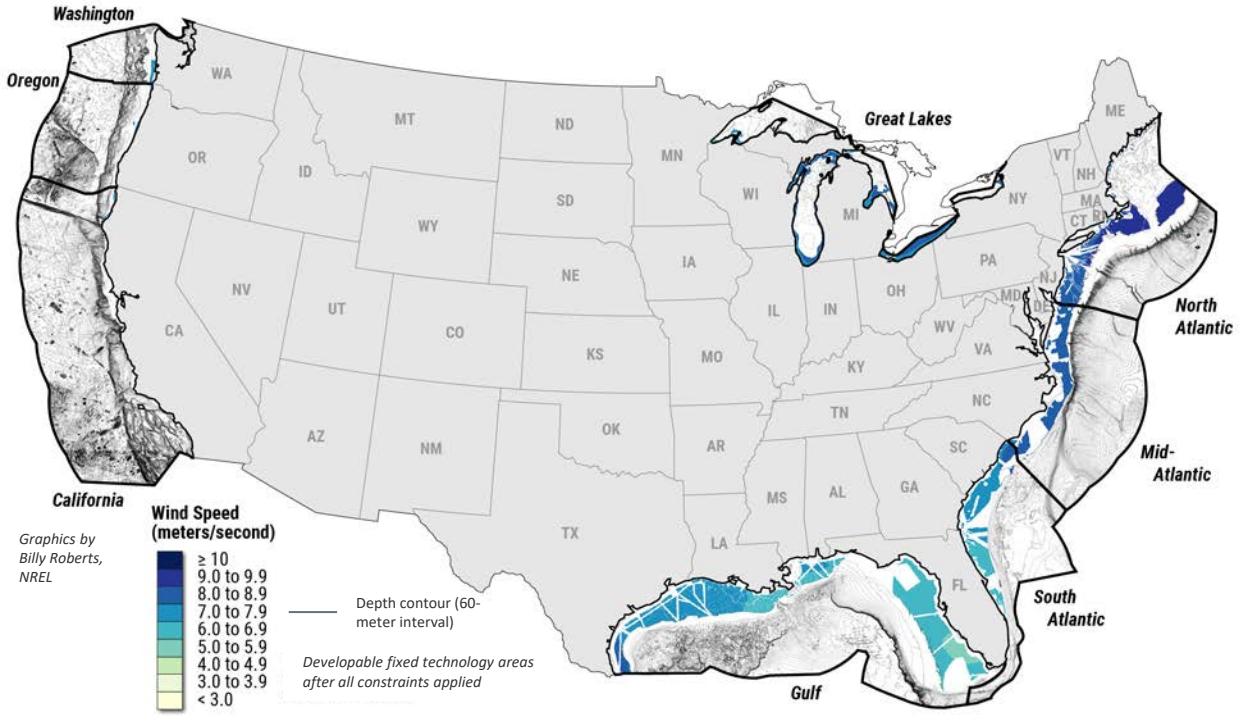
The combination of spatial constraints, bathymetric constraints, and substructure is the basis of OSW energy technical potential estimates. The remaining areas are translated to capacity using a capacity density assumption and modeled to estimate the amount of generation possible given the wind resource.

Limited Access Siting Assumption Differences
(Key Uncertainties in the Primary Spatial Drivers of OSW Energy Potential)

Siting Layer	Exclusion/Setback/Inclusion/Density	Description/Citation
Capacity density	3 MW/km^2	Capacity density is a critical driver of OSW energy technical potential; however, there is large uncertainty in what the realized density will be due to interconnection limits, cable limits, wake impacts including from proximal lease areas, and other site-specific plant design considerations.
Coastal setbacks (viewshed setbacks)	32 km	Coastal setbacks are increased beyond defined state waters to capture uncertainty in the ability to site within coastal viewsheds
Oil/gas pipelines, platforms	122-m, 500-m setback applied	Increased generalized setback
Shipwrecks	100-m setback applied	Increased generalized setback
NOAA chartered submarine cables	1,000-m setback applied	Increased generalize setback
BOEM active oil/gas lease areas	Constraint applied	Assumes oil/gas leases would need to be relinquished before wind energy development

Results

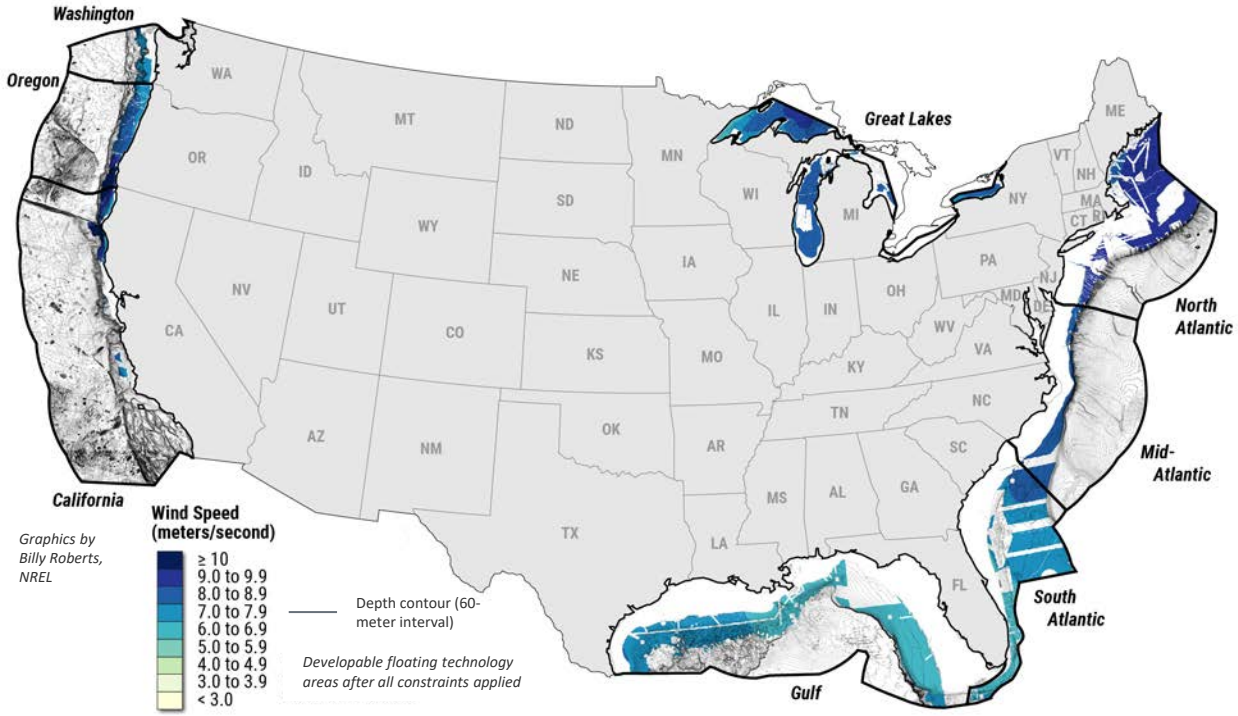
Fixed-Bottom OSW Energy Technology Technical Potential (Open Access)



Region	GW	Terawatt-Hours (TWh)
California	4	10
Great Lakes	160	569
Gulf	696	1,786
Mid-Atlantic	157	584
North Atlantic	264	1,081
Oregon	2	5
South Atlantic	188	544
Washington	5	16
CONUS Total	**1,476**	**4,595**

*values are rounded to closest integer

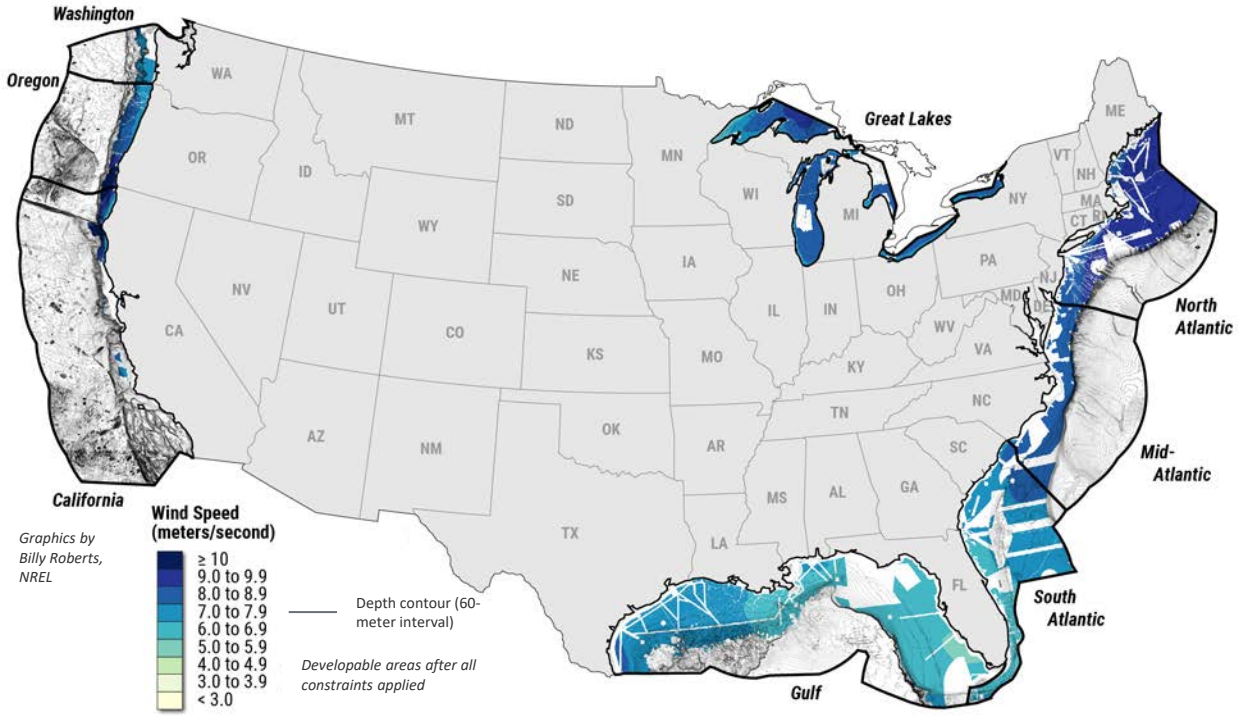
Floating OSW Energy Technology Technical Potential (Open Access)



Region	GW	TWh
California	88	338
Great Lakes	415	1,535
Gulf	867	2,289
Mid Atlantic	166	607
North Atlantic	442	1,843
Oregon	150	544
South Atlantic	586	1,628
Washington	59	188
CONUS Total	**2,773**	**8,972**

*values are rounded to closest integer

Total OSW Energy Technical Capacity Potential (Open Access)



Region	Fixed-Bottom (GW)	Floating (GW)	Fixed-Bottom (%)	Floating (%)
California	4	88	4	96
Great Lakes	160	415	28	72
Gulf	696	867	45	55
Mid-Atlantic	157	166	49	51
North Atlantic	264	442	37	63
Oregon	2	150	1	99
South Atlantic	188	586	24	76
Washington	5	59	8	92
CONUS Total	**1,476**	**2,773**	35	65

*values are rounded to closest integer

Note: DOD-defined wind exclusion areas constitute an area equivalent to an additional 428 GW of California OSW wind energy potential.

Caveats and Future Work

Key Caveats

- This analysis builds on prior OSW energy technical potential assessments by leveraging siting layers used within the marine spatial planning community.
- While this work leverages information from the marine spatial planning community, it is not marine spatial planning and, thus, does not seek to identify specific lease or development opportunities.
- Marine spatial planning is a complex process that requires flexibility to ensure broad and evolving stakeholder considerations are integrated.
- OSW turbine technology is rapidly evolving, and costs are dropping precipitously, which could, in time, open more opportunities for OSW energy development.
- Estimates of renewable energy technical potential, including OSW energy, are dynamic and uncertain and require assumptions and assessment of OSW energy's technical potential to be periodically revisited.
- Sensitivities, such as the forthcoming Limited Access scenario (published in this project's final technical report), will help further inform understanding of the nation's OSW energy technical potential.

Future Work

Specific future work to enhance these estimates includes:

- Integration of additional stakeholder/siting concerns that might not constitute a firm exclusion but could nevertheless impact wind energy development (e.g., fishing, viewsheds)
- Revisions based on or to DOD Wind Compatibility Assessments as necessary. Currently, technical potential in California waters are limited by DOD-defined Wind Exclusion Areas. However, recent efforts among federal agencies have identified co-use areas within the DoD-defined wind exclusion areas.
- Updating capacity density assumptions as necessary (e.g., turbine density under Open Access conditions is empirically derived from Europe but will need to investigate trends in the United States with continued development)
- Regional techno-economic siting assessments to capture local drivers of technology choice, cost, and economic potential
- Refining net generation estimates (in TWh) to better capture losses (e.g., inter/intraplant wake losses).

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