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Potential Offshore Wind Energy Areas in California: An Assessment of Locations, Technology, and Costs

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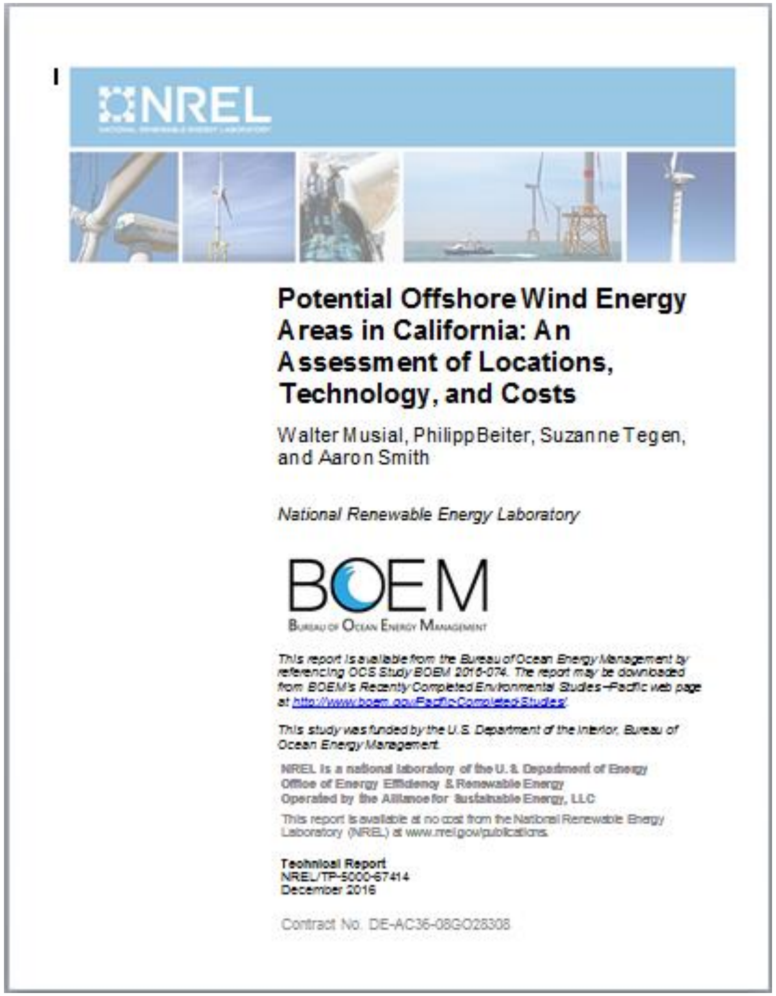
California Energy Commission Workshop on Offshore Renewable Energy
Friday, March 3, 2017

About the Study



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Potential Offshore Wind Energy Areas in California: An Assessment of Locations, Technology, and Costs

Walter Musial, Philipp Beiter, Suzanne Tegen, and Aaron Smith

National Renewable Energy Laboratory

BOEM
Bureau of Ocean Energy Management

This report is available from the Bureau of Ocean Energy Management by referencing OCS Study BOEM 2016-074. The report may be downloaded from BOEM's Recently Completed Environmental Studies–Pacific web page at http://www.boem.gov/Pacific-Completed-Studies/.

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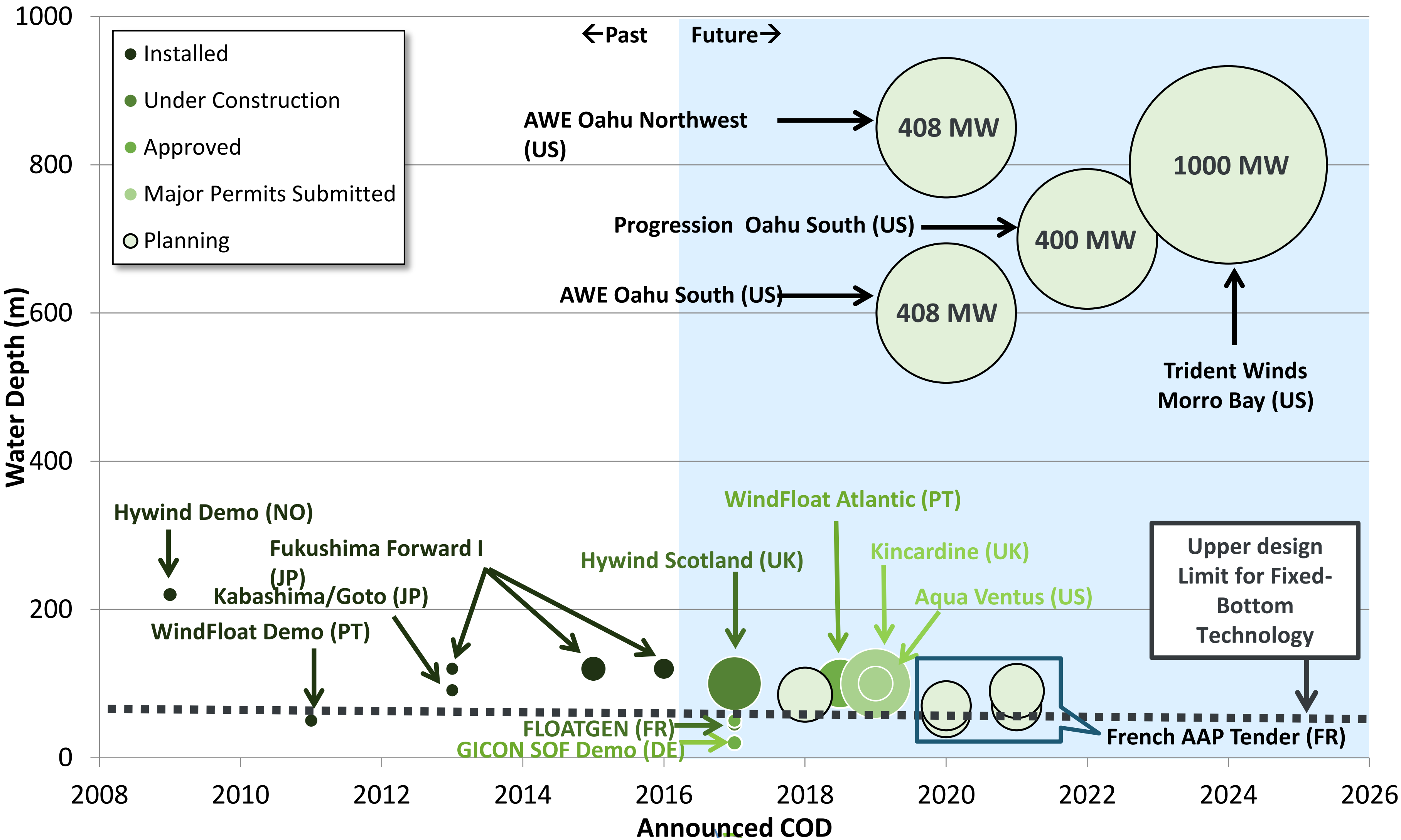
Technical Report
NREL/TP-5000-67414
December 2016

Contract No. DE-AC36-08GO28308

- Conducted by the National Renewable Energy Laboratory
- Work began in July 2015
  Report was published Dec 2016
- Sponsored by BOEM to inform CA state energy planning
- Extensive peer review with over 160 comments
- All comments were resolved and documented

Musial et al 2016 - Walter Musial, Philipp Beiter, Suzanne Tegen, and Aaron Smith; *Potential Offshore Wind Energy Areas in California: An Assessment of Locations, Technology, and Costs:* National Renewable Energy Laboratory; Technical Report: NREL/TP-5000-67414, December 2016; http://www.nrel.gov/docs/fy17osti/67414.pdf

Floating Wind Energy Market Data



Source: NREL

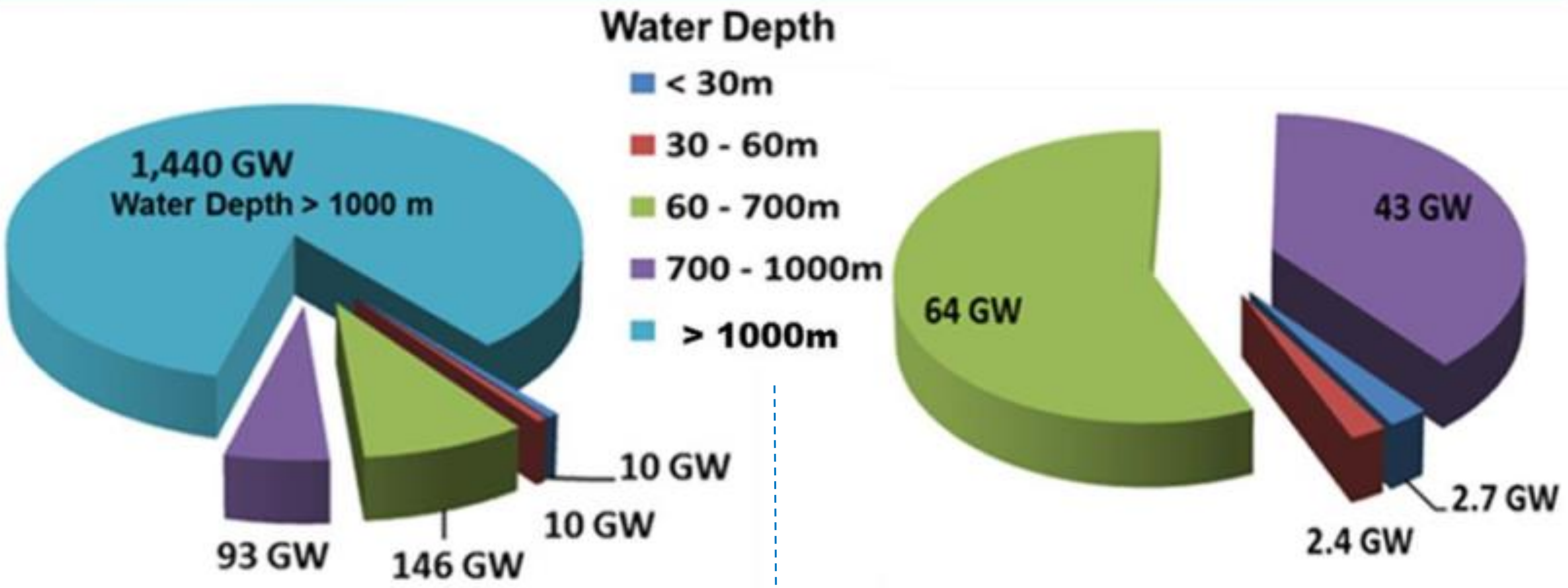
California Offshore Wind Resource

Gross Resource Capacity – 1,698 GW | **Technical Resource Capacity – 112 GW**

Technology Exclusions

Gross:
- None
- All area 0 to 200 nm

Technical:
- >1000 m
- < 7 m/s



No Competing Use Exclusions

Competing Use Exclusions

0 – 3nm	48%
3nm – 12nm	38%
12nm – 50 nm	21%

96% of California's offshore wind resource is deeper than 60 m, indicating site conditions for floating wind.

Site Selection Criteria

Siting Objective: Find representative sites that could potentially support future offshore wind for indicative cost analysis

Site selection criteria:

- Annual average wind speed greater than 7 m/s
- Water depths shallower than 1,000 m
- Suitable distance from shore (subjective)
- Lowest use conflicts (using Black and Veatch data circa 2010)
- Access to transmission on land (not required but evaluated)
- Suitable ports for installation and service (does not consider required improvements)

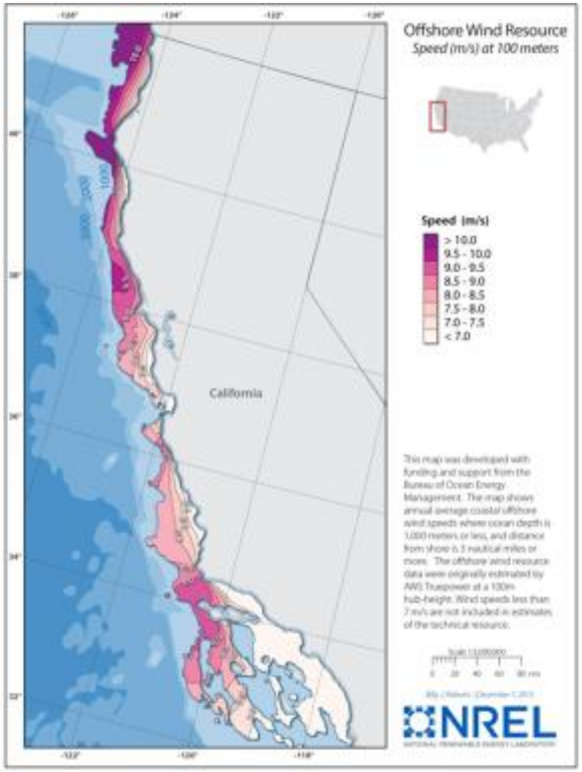
Study is not intended to be a prescreening exercise for future offshore wind development.

Site Selection Process

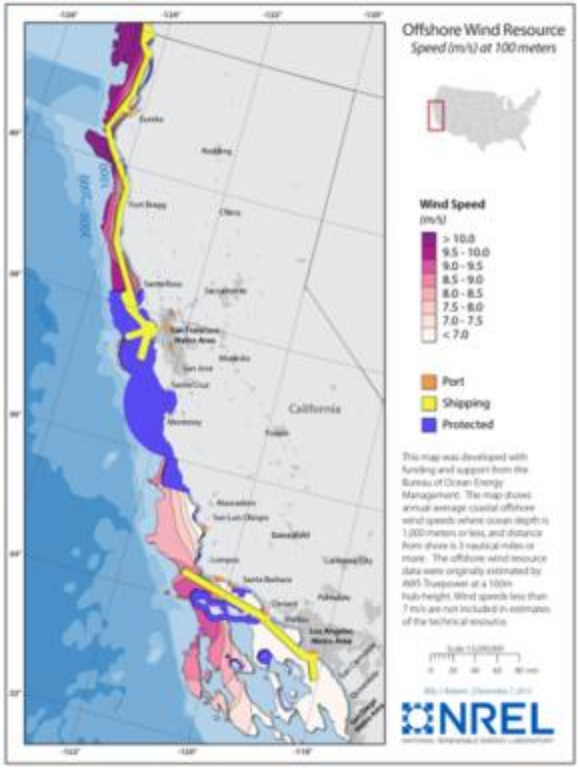
Filtered technical resource area

Overlaid Black and Veatch exclusions

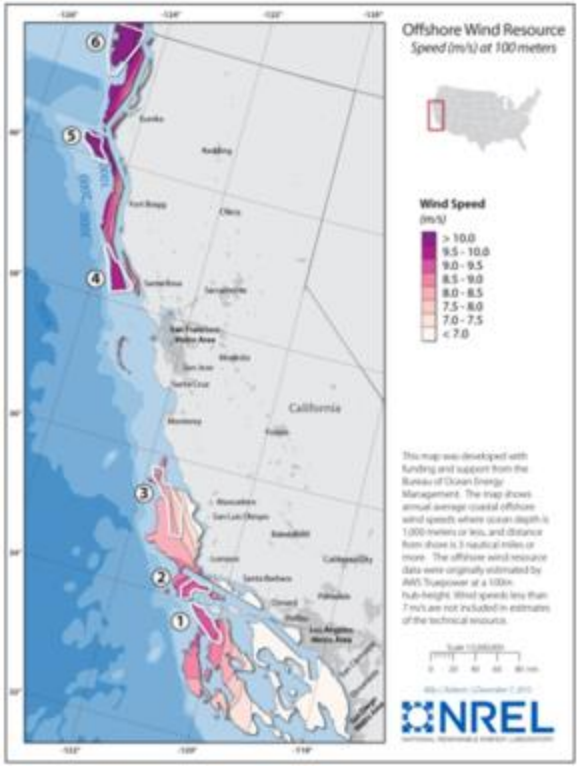
Subtracted excluded area and selected high wind areas for analysis



Technical offshore wind resource



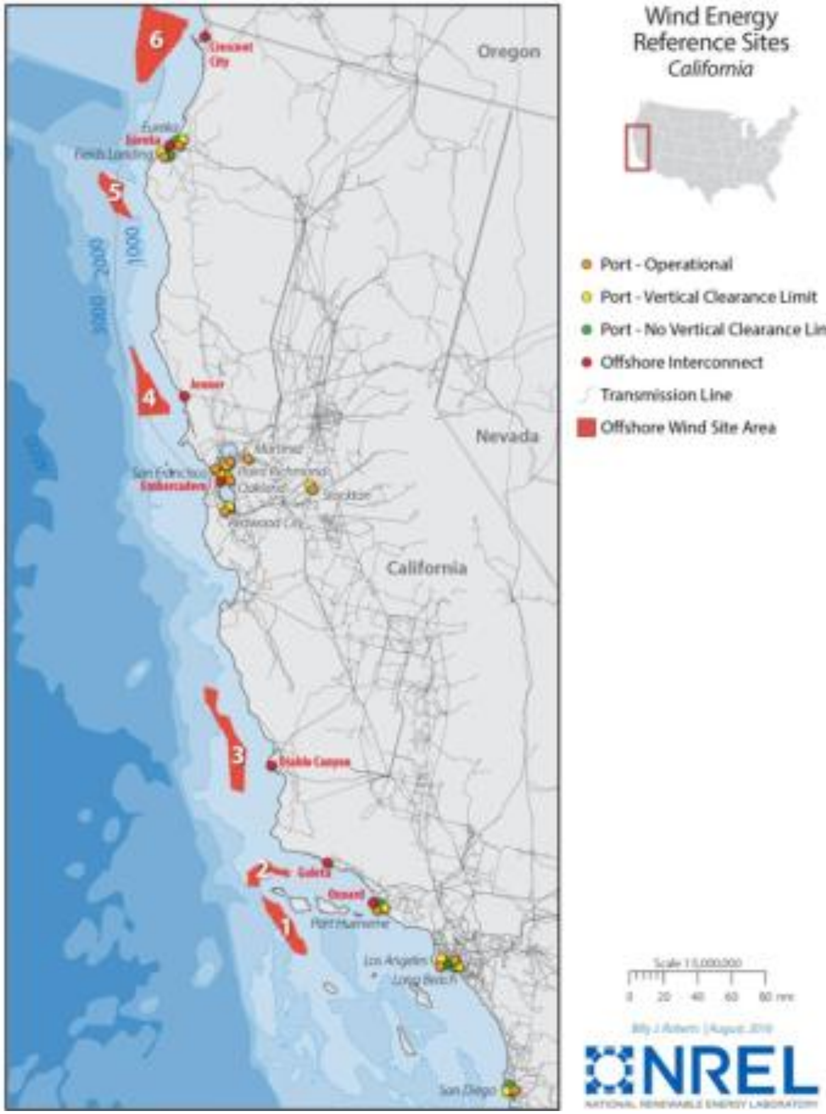
Technical offshore wind resource and Black and Veatch exclusion data layer



Technical offshore wind resource with lower conflicts showing reference sites

Final Six Representative Sites Used for Cost Analysis

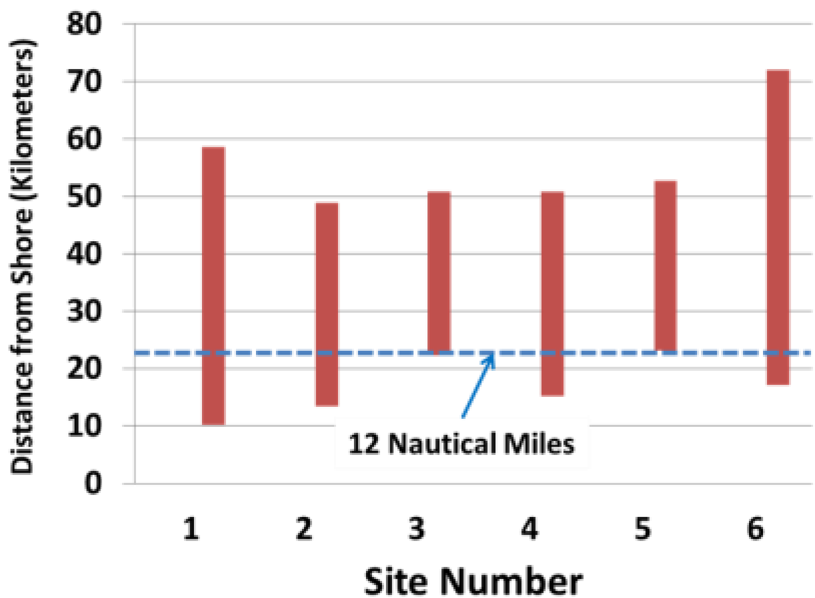
- For each site:
  - Distance from shore
  - Hourly diurnal characteristics
  - Geo-spatial assessment of cost variables including depth; distance from electric interconnect, construction and service; wave climate, wind resource
  - Time varying cost projection applying current technology trends
  - Annual energy and deployment capacity



California Offshore Wind Reference Sites Identified in Musial et al 2016

Musial et al 2016 - Walter Musial, Philipp Beiter, Suzanne Tegen, and Aaron Smith; *Potential Offshore Wind Energy Areas in California: An Assessment of Locations, Technology, and Costs:* National Renewable Energy Laboratory; Technical Report: NREL/TP-5000-67414, December 2016; http://www.nrel.gov/docs/fy17osti/67414.pdf

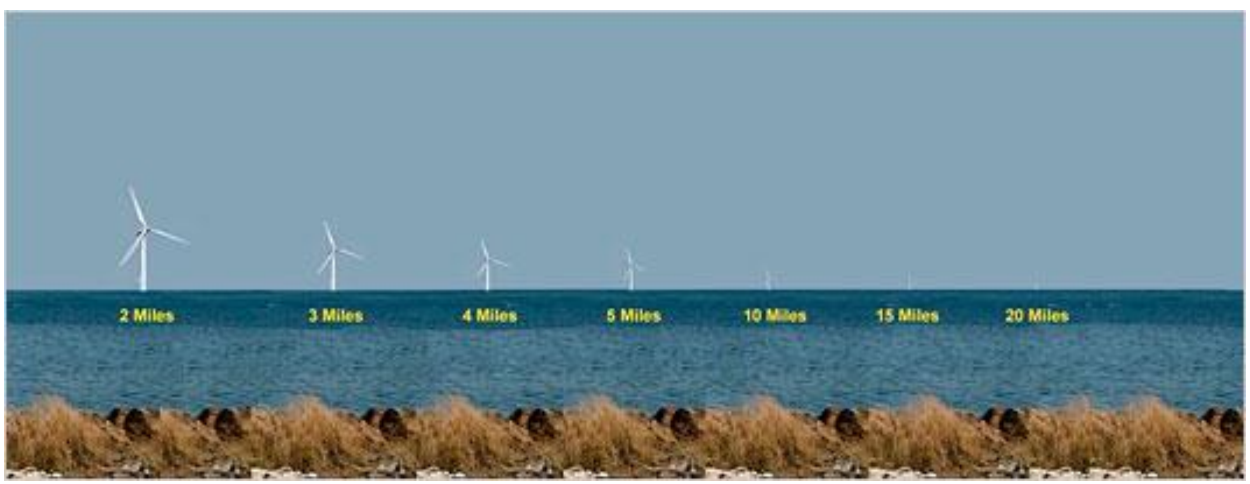
Site Distance from Shore - Viewshed



Distance from shore for California six reference sites

Distance from Shore: A primary siting factor

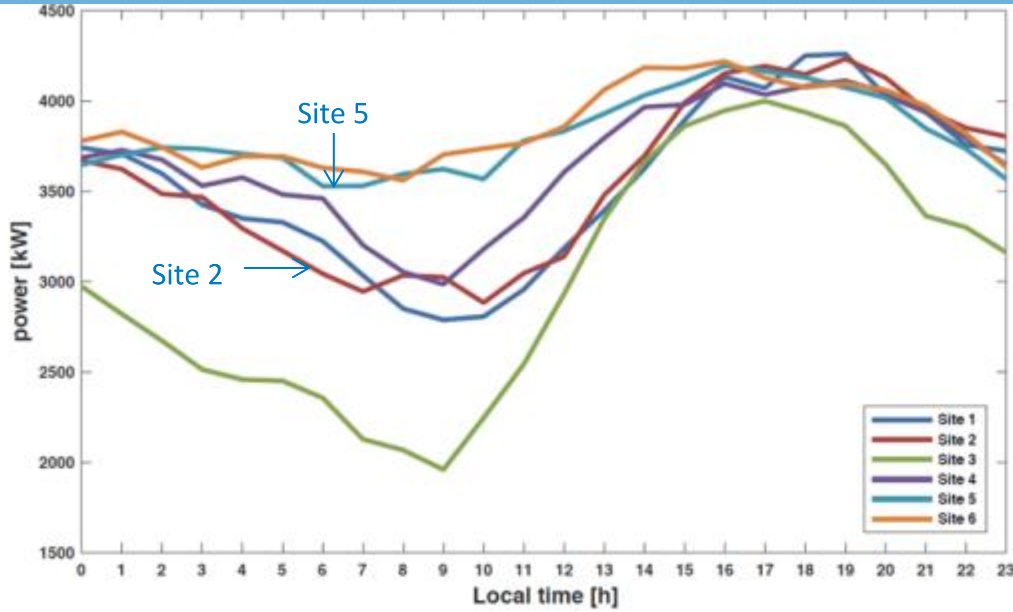
- No established quantitative cut-off criterion
- All sites have significant developable area >30 km (18 miles).

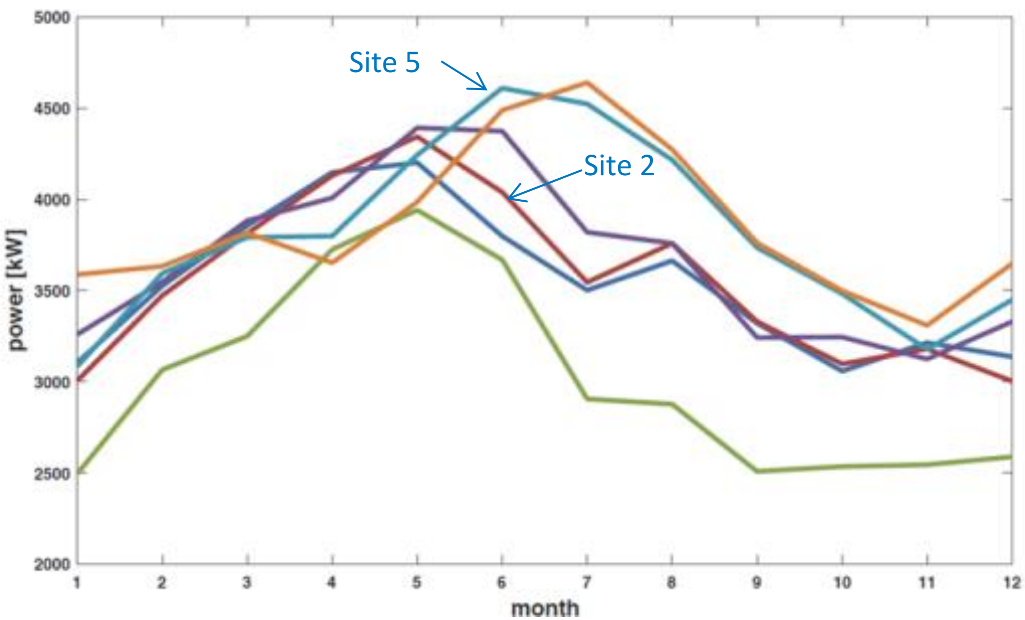


What wind turbines would look like at varying distances from the shore. (Illustration: P.S.E.G.)

https://green.blogs.nytimes.com/2008/10/03/offshore-wind-farm-approved-in-new-jersey/?_r=0

Diurnal and Monthly Power Output for Six Offshore Wind Reference Sites





Figures: Diurnal and monthly single 6 MW turbine output for six California floating wind reference sites (top left Diurnal) and (Bottom left – monthly average)

- Diurnal Characteristics
  - Pattern is consistent from south to north
  - Peak power from 17:00 to 19:00
  - Low power around 9:00
- Monthly Characteristics
  - Southern sites peak in May
  - Northern sites peak in July

Site 2 and Site 5 were selected to represent southern and northern California coastal regions respectively

Representative Sites – Site 2 and 5

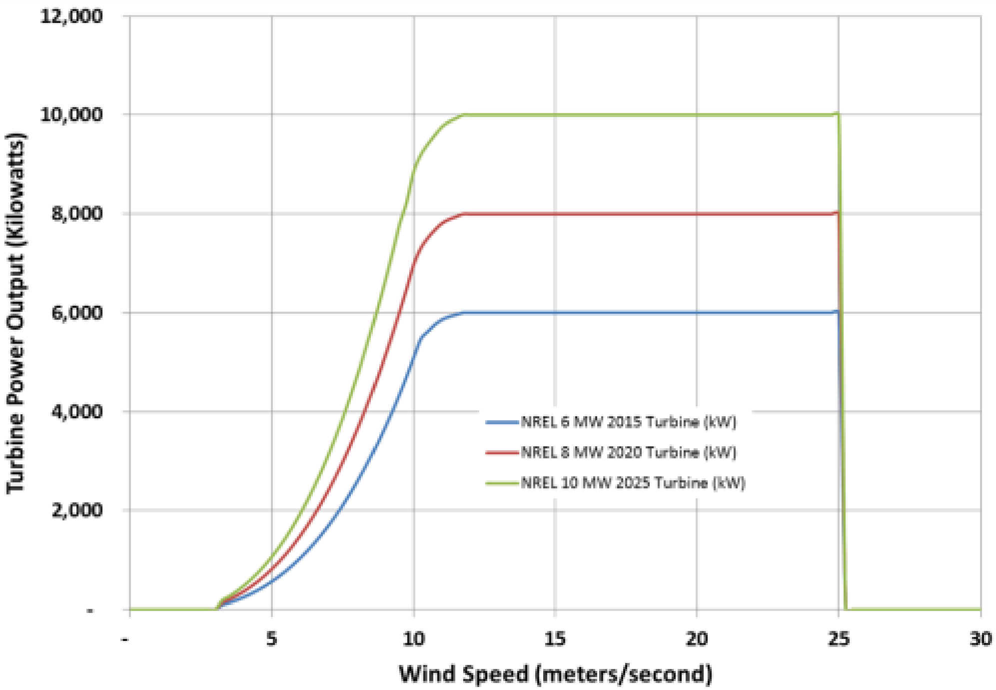
Offshore Wind Reference Area	2 - Channel Islands North	5 – Humboldt Bay Area
Mean Wind Speed (m/s) at 100-m hub height	8.86	9.73
Min, Mean, Max Significant Wave Height (m)	1.8/2.3/2.5	2.7/2.7/2.8
Min, Mean, Max Depth (m)	198/575/774	592/870/994
Construction Port	Port Hueneme	Fields Landing
O&M Port	Port Hueneme	Fields Landing
Distance to O&M Port (Straight Line –km)	127	78
Distance to O&M Port (Avoids Land–km)	127	87
Interconnection Point	Goleta, CA	Eureka, CA
Distance to Interconnection (Offshore Until Landfall) (Straight Line–km)	69	80
Distance to Interconnection (Offshore Until Landfall) (Avoids Land–km)	69	87
Distance Cable Landfall to Interconnect (km)	6	5
Area (km^2) <1,000-m depth	445	431
Total Potential Capacity (MW)	1,335	1,293

California Technology Assumptions 2015 to 2027

Generic Semi-submersible floating platform

California Floating Wind Technology Assumptions 2015 to 2027

	2015 Technology	2022 Technology	2027 Technology
Turbine Rated Power (MW)	6	8	10
Turbine Rotor Diameter (m)	155	180	205
Turbine Hub Height (m)	100	112	125
Turbine Specific Power (W/m^2)	318	314	303
Substructure Technology	Semisubmersible	Semisubmersible	Semisubmersible



Generic power curves used to calculate Annual Energy Production (AEP)

Trends Indicate Continued Turbine Growth to 10 MW – Largest Turbines will be Selected

Levelized Cost of Energy – Primary Source

$$\mathrm{LCOE} = \frac{(FCR*CapEx) + OpEx}{AEP_{net}}$$

where:

FCR	=	fixed charge rate (%)
CapEx	=	capital expenditures ($/kW)
AEP_{net}	=	net average annual energy production (kWh/yr)
OpEx	=	average annual operational expenditures ($/kW/yr).

Beiter, P. et al . ***A Spatial-Economic Cost Reduction Pathway for U.S. Offshore Wind Energy Development from 2015–2030*** , NREL/TP-6A20-66579. http://www.nrel.gov/docs/fy16osti/66579.pdf

NREL

A Spatial-Economic Cost-Reduction Pathway Analysis for U.S. Offshore Wind Energy Development from 2015–2030

Philipp Beiter, Walter Musial, Aaron Smith, Levi Kilcher, Rick Damiani, Michael Maness, Senu Sirnivas, Tyler Stehly, Vahan Gevorgian, Meghan Mooney, and George Scott
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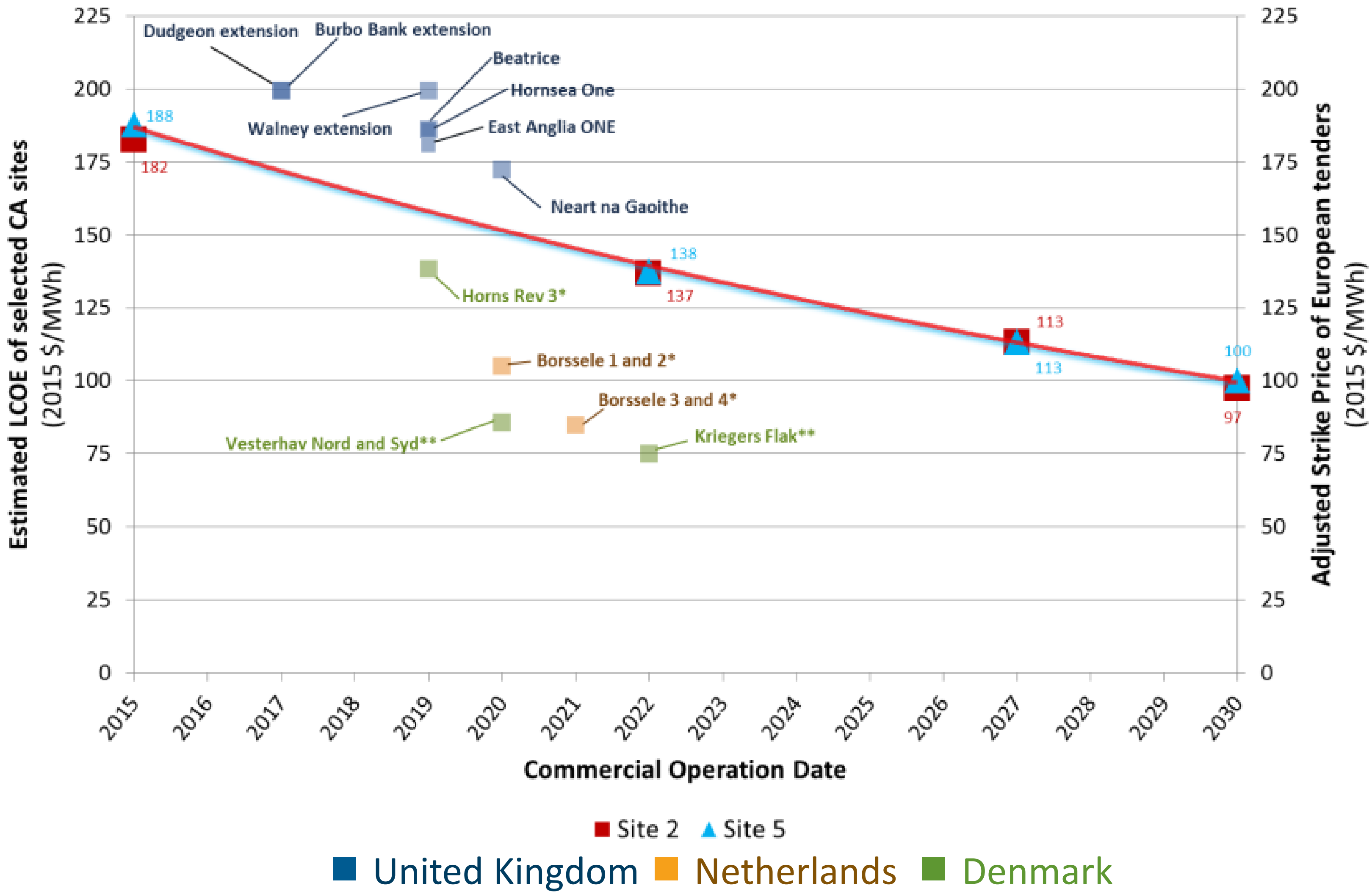
Technical Report
NREL/TP-6A20-66579
September 2016

Contract No. DE-AC36-08GO28308

Primary Source Document from 2016 DOE Offshore Wind Strategy

California LCOE Estimates and Adjusted European Strike Prices



* Grid and development costs added

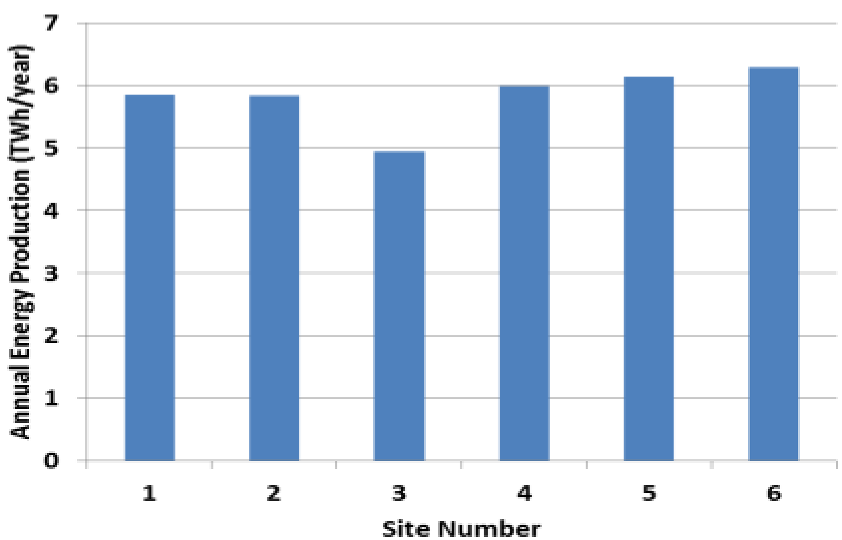
** Grid costs added and contract length adjusted

Source: Data derived from Garlick et al. (4COffshore) (2017)

Fixed-bottom strike prices from 2016 European bids indicate rapid price declines.

Example Deployment Scenario: 2- 600MW per site (7.2 GW)

- Site utilization 23% to 93% per site
- 400 km^2 per site (Array density 3 MW/ km^2)
- 35 TWh/year total energy production
- Approximately 13.5% of California's 2014 electric energy demand



Annual Energy Production (AEP) by site with 1200 MW deployed on each site

Reference Site map

Future offshore wind can potentially contribute at multi-GW scale in California.

Conclusions

- CA technical offshore wind resource is 112 GW or 392 TWh/year; about 1.5x CA electric use
- 96% of OSW resource is deeper than 60 m, indicating site conditions suitable for floating wind
- Floating wind may be commercially ready by 2025
- Offshore wind can contribute at multi-GW scale in CA
- Onshore infrastructure is more abundant in southern California
- More severe wave climate results in higher LCOE
- Site similarities result in small LCOE variations.
  - Site 2 potential reduction from \$182/MWh to \$97/MWh
  - Site 5 potential reduction from \$188/MWh to \$100/MWh

Limitations and Caveats

- Economic potential is dependent on the level of policy support, technology attributes, the value of other market factors, and the prevailing electricity prices.
- Floating baseline cost ($187/MWh for 2015 floating wind) has higher uncertainty than fixed-bottom due to limited deployments.
- Cost declines assume that a mature supply chain develops.
- Sharp declines in fixed offshore wind cost and increasing floating wind innovation globally support the possibility of lower offshore wind costs over time.

Thank you for your attention!

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Photo Credit : Dennis Schroeder-NREL

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