Oregon Offshore Wind Site Feasibility and Cost Study

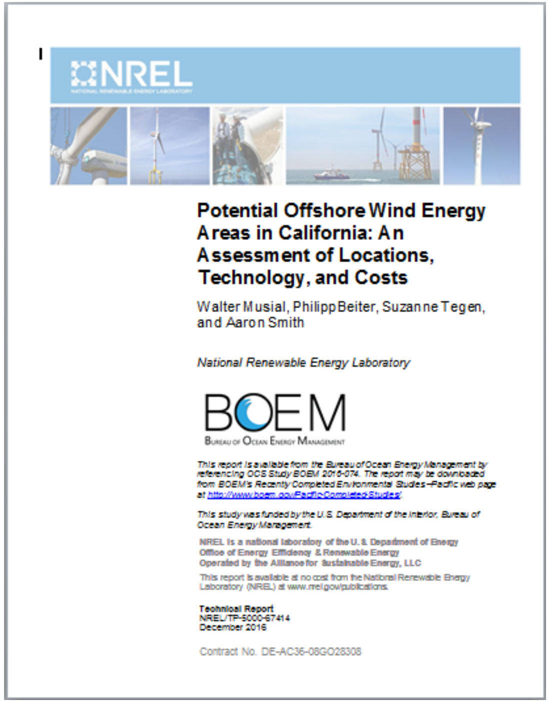
November 2019

Walt Musial, Philipp Beiter, Jake Nunemaker,
Donna Heimiller, Paul Spitsen, Jason Busch, and Josh Ahmann

Overview

- Introductions and Recognitions
- Project Background
- Site Selection and Description
- Cost Model
- Results
- Summary

Background – Bureau of Ocean Energy Management Sponsorship


NREL
NATIONAL RENEWABLE ENERGY LABORATORY

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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Office of Energy Efficiency & Renewable Energy
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Technical Report
NREL/TP-5000-67414
December 2016

Contract No. DE-AC36-08GO28308

- Studies conducted by the National Renewable Energy Laboratory (NREL) and Parametrix
- Sponsored by the Bureau of Ocean Energy Management (BOEM) under interagency agreement M14PG00038/IAG-14-1944 between BOEM and NREL
- Purpose to inform Oregon state energy planning
- Oregon study builds on 2016 NREL/BOEM study for California (Musial et al. 2016)
- This cost study is not a marine-spatial planning effort.

BOEM Project Managers:
Necy Sumait, Sara Guiltinan, Whitney Hauer

Musial et al. (2016): Walter Musial, Philipp Beiter, Suzanne Tegen, and Aaron Smith. 2016. *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.

Advisory Committee

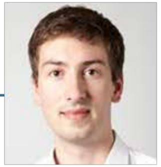
- Jason Busch – POET – Advisory Committee Chairman
- Adam Schultz – Oregon Department of Energy
- Andy Lanier – Department of Land Conservation and Development
- Bryson Robertson – Pacific Marine Energy Center, Oregon State University
- Crystal Ball – Bonneville Power Administration
- John Schaad – Bonneville Power Administration
- Jimmy Lindsay – Portland General Electric
- Mike Starrett – Northwest Power and Conservation Council (NPCC)
- Rebecca O'Neil – Pacific Northwest National Laboratory

THANK YOU ALL FOR YOUR SUPPORT !

Study Team

- Walt Musial - NREL

- Philipp Beiter - NREL



- Jake Nunemaker - NREL

- Paul Spitsen - DOE

- Tiffany Byrne - NREL

- Jason Busch - POET

- Josh Ahmann - Parametrix

Other Contributors:
Donna Heimiller (NREL):

- Maps and GIS

Special thanks to John Schaad at BPA and Mike Starrett at Northeast Power and Conservation Council for gathering information on load characteristics.

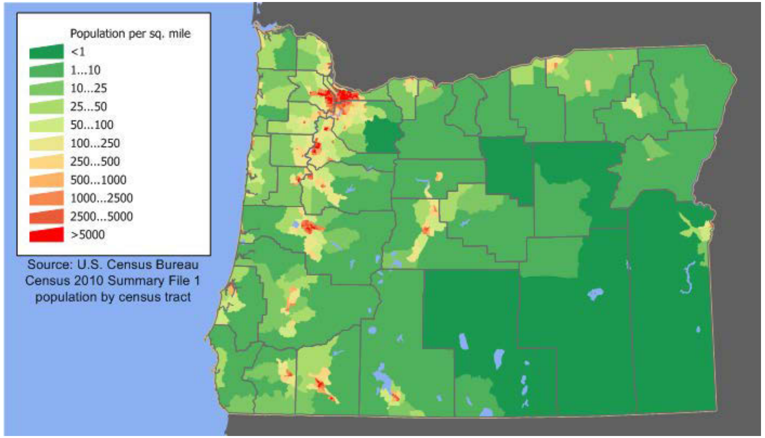
Project Objectives

- To reflect current floating wind technology trends and industry market data in cost models.

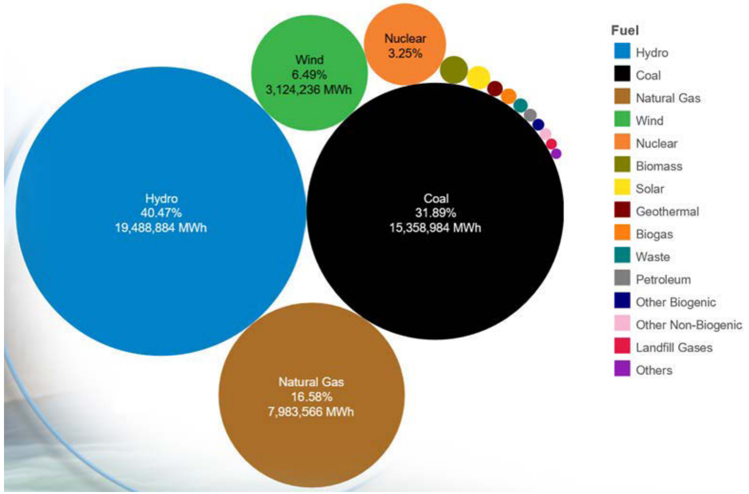
- To provide cost analysis in support of Oregon state energy planners considering floating offshore wind’s potential contribution to future state energy supplies.

Regional Description

- 48,157 gigawatt-hours per year (GWh/yr) Oregon electric consumption between 2014 and 2016
- ~50% of energy consumption is currently carbon-free (hydro, wind, nuclear)
- Population centers inland, east of coastal range
- Electric-generating plants near high population areas
- Power flows east to west to serve coastal communities.



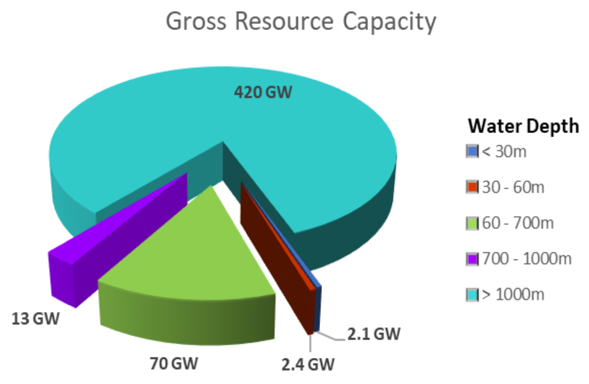
Oregon Population Distribution – U.S. Census (2010)

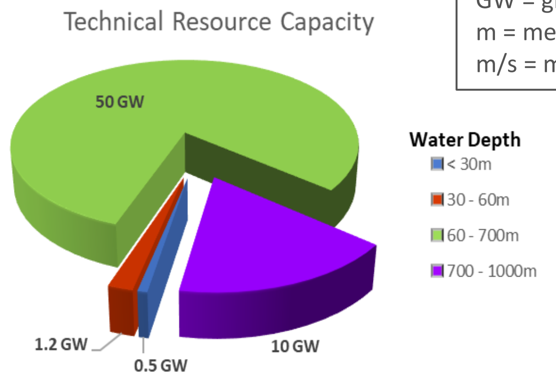


Oregon Electricity Use Profile
Oregon Department of Energy (2019)

Offshore Wind Resource in Oregon

GW = gigawatts
m = meters
m/s = meters per second





Gross Resource Capacity – 508 GW

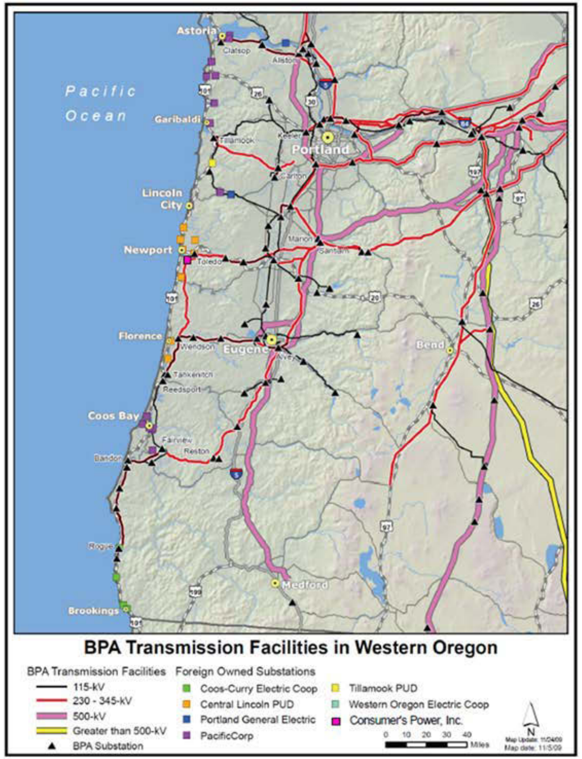
Technical Resource Capacity – 62 GW

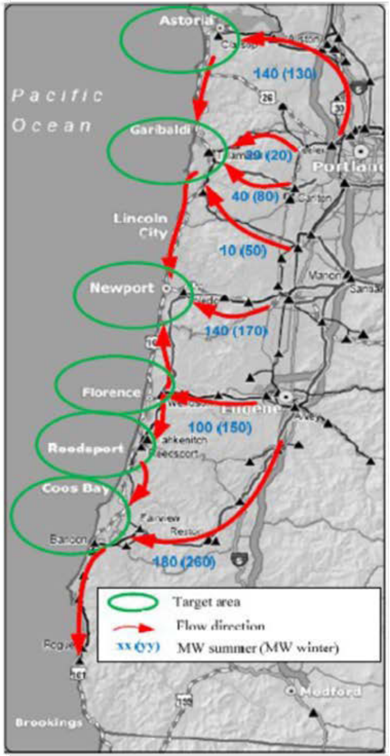
Exclusions

Gross	Technical
None	Greater than 1,000 m
	Less than 7 m/s average windspeed
Possible use conflicts	48% between 0 and 3 nautical miles 38% between 3 and 12 nautical miles 21% between 12 and 50 nautical miles

Source: Musial, W., D. Heimiller, P. Beiter, G. Scott, and C. Draxl. 2016. *2016 Offshore Wind Energy Resource Assessment for the United States* (Technical Report). NREL/TP-5000-66599. National Renewable Energy Laboratory, Golden, CO (US). http://www.nrel.gov/docs/fy16osti/66599.pdf.

Electric Transmission System



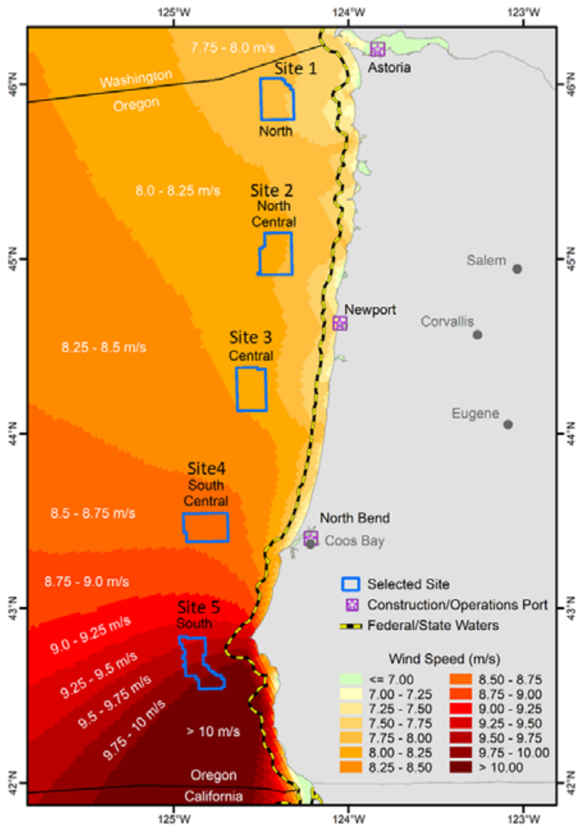


- Managed regionally by the Bonneville Power Administration (BPA)
- Net power flow from east, toward coastal communities
- Offshore wind plants could reverse power direction
- Future work may investigate possible benefits to land-based transmission system.

Source: BPA

Site Selection

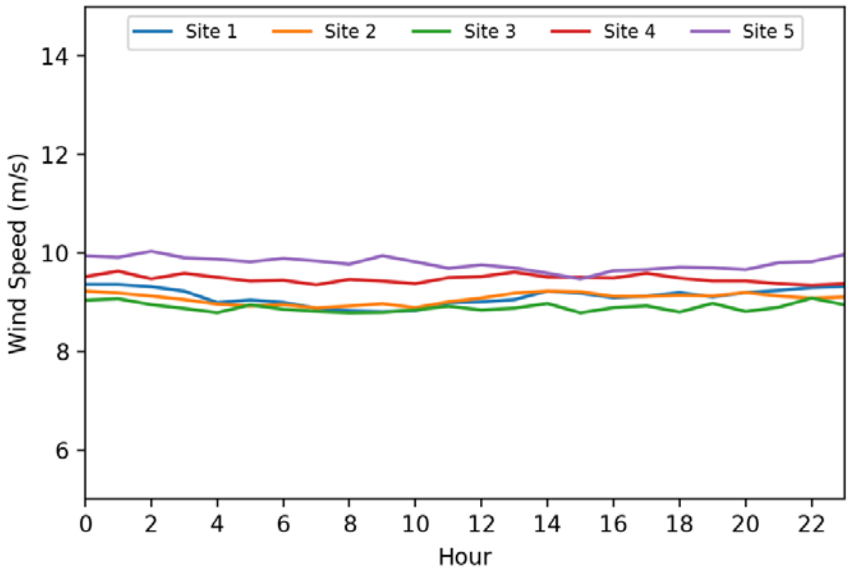
Average Annual Wind Speeds



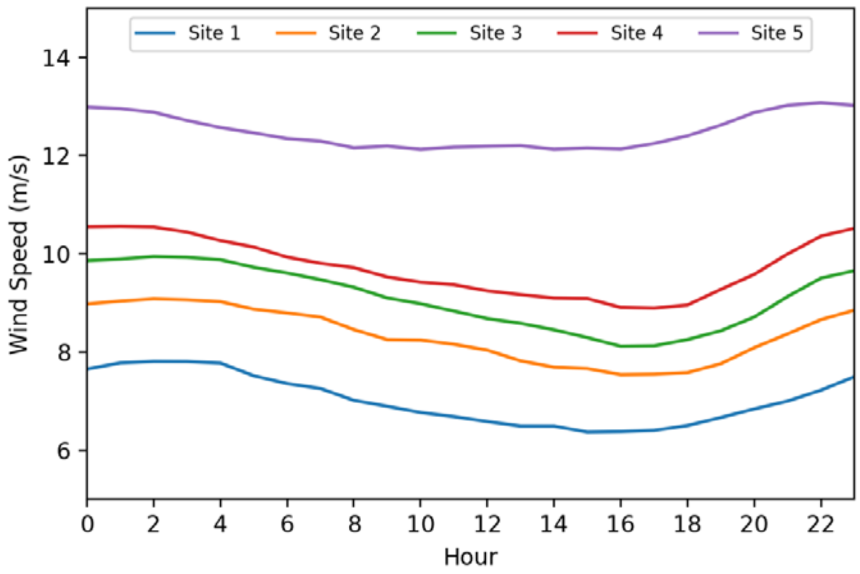
Note: Modeled at 100-m elevation.
NREL (2019)

- Parametrix (under POET subcontract) mapped options for five geographically dispersed study sites where commercial-scale projects are technically viable
- NREL and BOEM provided guidance on technical criteria and minimum site size
- Technical site selection criteria:
  - Annual average wind speed greater than 7 m/s
  - Water depths shallower than 1,000 m
  - Access to land-based transmission interconnect
  - Suitable ports for installation and service
  - Minimum distance from shore 10 nautical miles (nm)
  - Area can support a 1,000-MW wind plant (350 km^2)
- Sites were reviewed by advisory committee
- Site selection was for cost modeling purposes; not an effort to create wind energy areas under BOEM's leasing process
- Wind speeds at 100 m range from 7.8 m/s to 9.8 m/s
- Strong north-south wind speed gradient.

Winter/Summer Diurnal Variation in Wind Speed



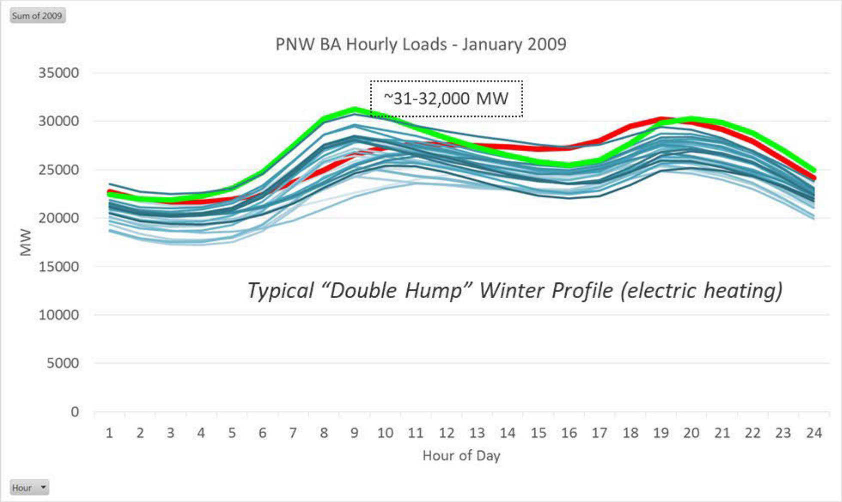
January



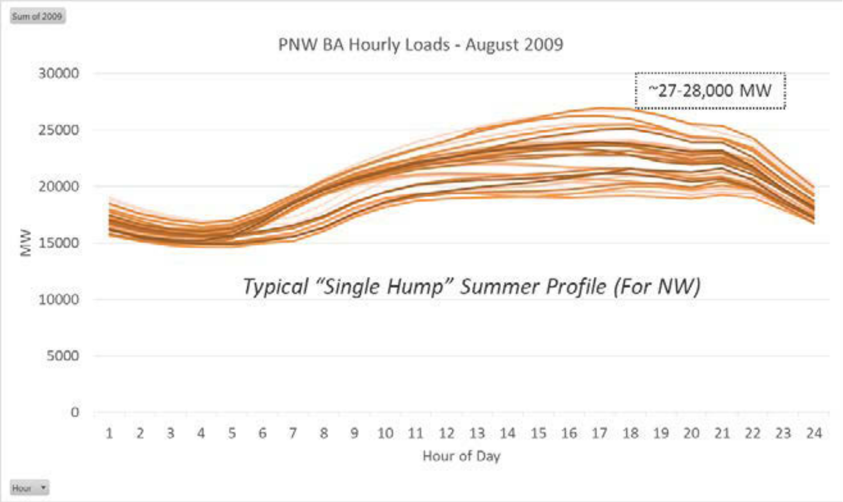
July

Note: 0 = midnight

Winter/Summer Diurnal Load Characteristics



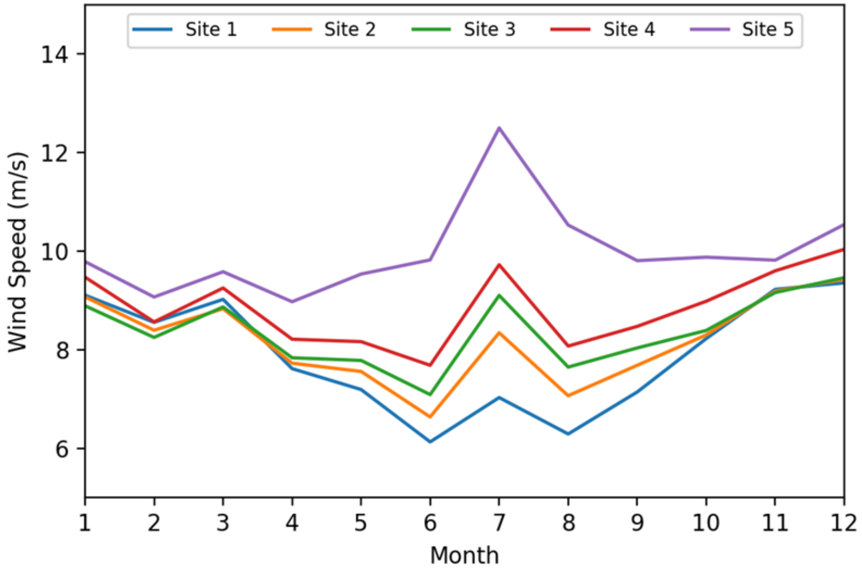
Daily Winter Profiles



Daily Summer Profiles

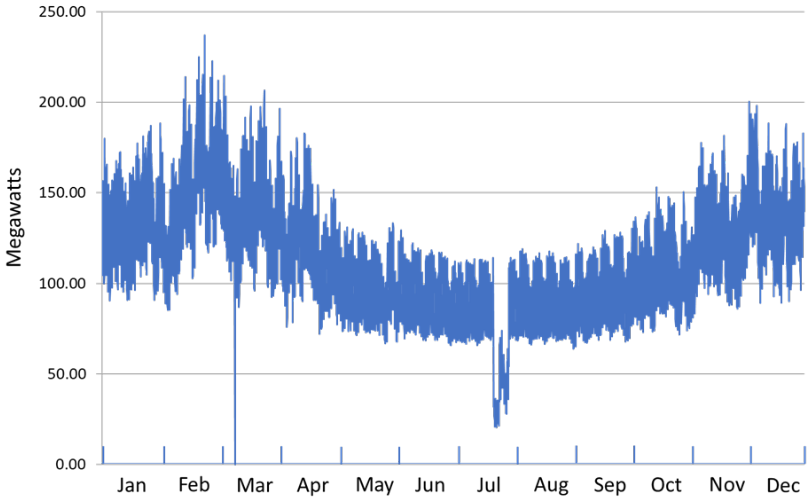
Source: NPCC

Monthly Wind Speed and Load Variations



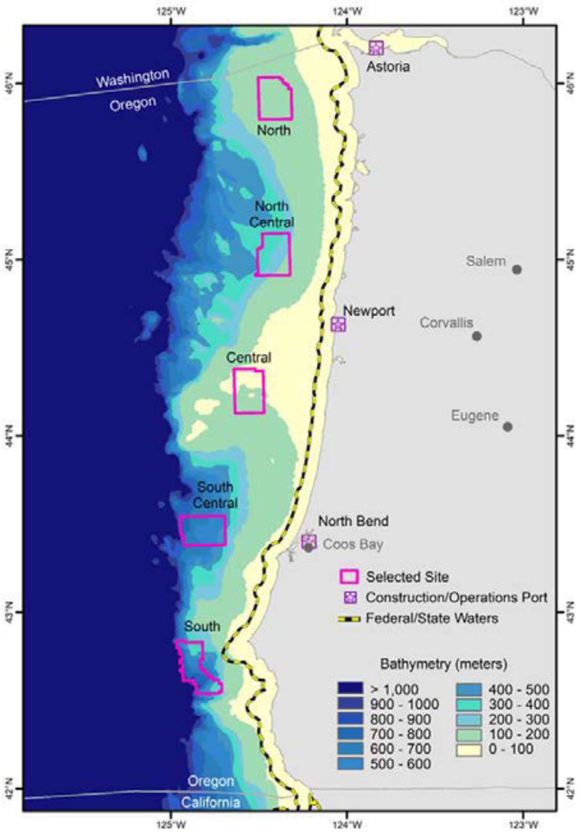
Average Monthly Wind Speed

Note: January = 1



Hourly Load for Southwest Region of Oregon (vicinity of site 5)

Oregon's Ocean Bathymetry



Ocean bathymetry

- Site water depths range from 85 m (site 3 - Central) to 1,013 m (site 5 - South)
- Steep continental shelf favors projects near shore
- 90% of gross offshore wind resource eliminated because of depth limits.

Site-Specific Data

		1 - North	2 - North Central	3 - Central	4 - South Central	5 - South
Location	Distance to shore[a] (km)	26 - 40	23 - 38	28 - 42	25 - 50	21 - 36
	Mean wind speed (m/s)	7.80	8.03	8.17	8.65	9.84
	Average significant wave height (m)	2.52	2.53	2.52	2.57	2.58
	Mean water depth (m)	147	279	101	595	602
	Area < 1,000 m depth (km^2)	360	360	360	360	359
	Total potential capacity (MW)	1,081	1,081	1,081	1,080	1,076
Logistics	Construction port	Astoria	Newport	Newport	North Bend	North Bend
	Distance to construction port[b] (km)	62	55	58	57	95
	O&M port	Astoria	Newport	Newport	North Bend	North Bend
	Distance to O&M port[b] (km)	62	55	58	57	95
Grid infrastructure	Interconnection point	Cannon Beach	Devil's Lake	Florence	Empire	Gold Beach
	Distance to cable landfall[b] (km)	36	32	48	44	33
	Distance to interconnect (km)	1.0	0.6	5.4	1.0	1.4

[a] Straight line distance.
[b] Avoids land for distance calculation.
Notes: Distances calculated from site centroid; the total area of the study sites comprises approximately 7.7% of the technical resource area.

Technology Assumptions

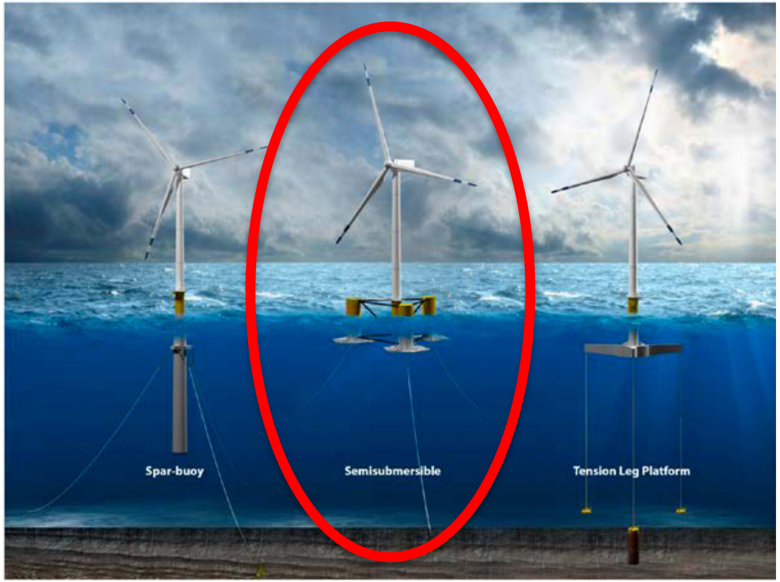
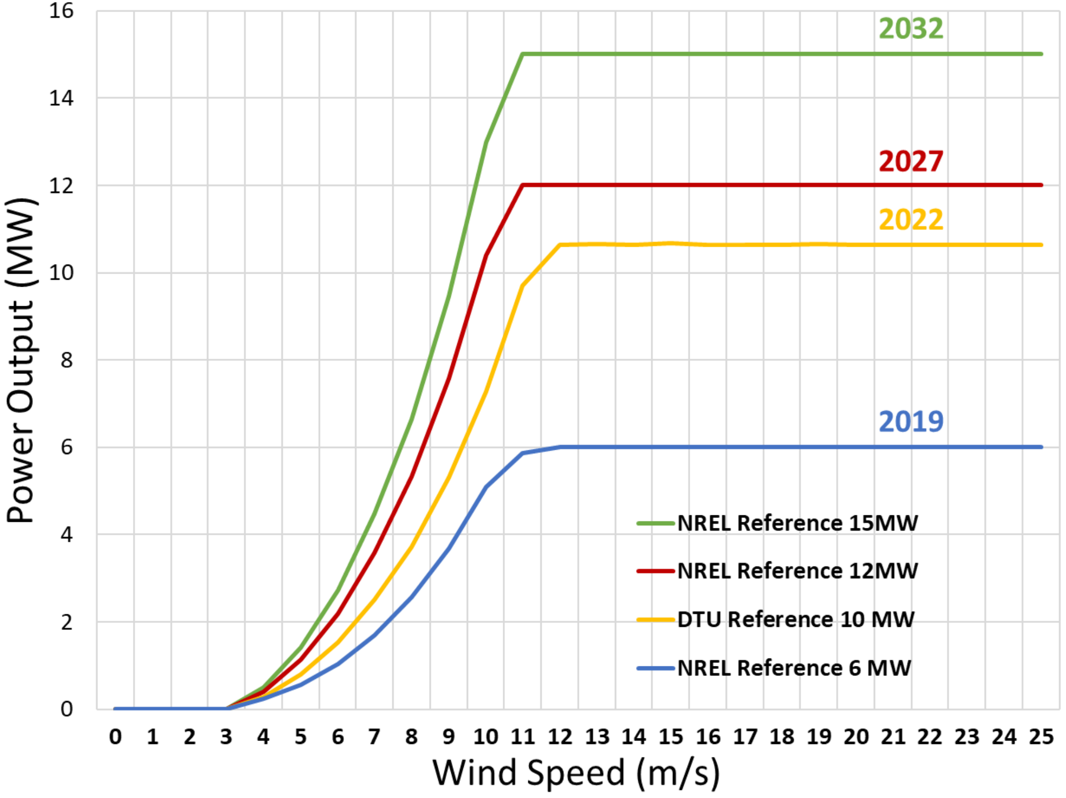


Illustration by NREL

Commercial Operations Date	2019	2022	2027	2032
Turbine Rated Power (MW)	6	10	12	15
Turbine Rotor Diameter (m)	155	178	222	248
Turbine Hub Height (m)	100	114	136	149
Turbine Specific Power (W/m^2)	318	401	310	311
Substructure Technology	Semisubmersible	Semisubmersible	Semisubmersible	Semisubmersible

Power Curves Assumptions

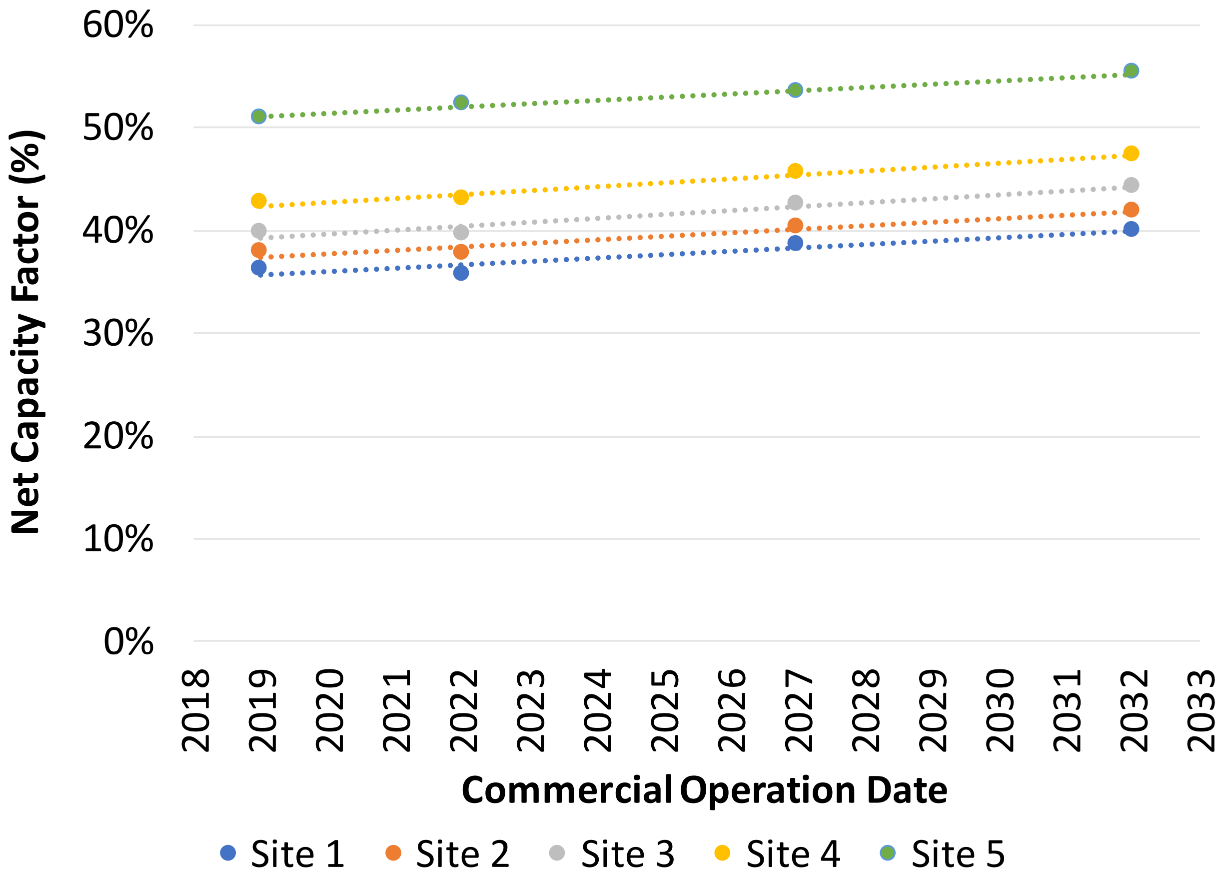


- Larger turbines enable multiple cost reductions
- New technology is introduced according to NREL research based on the year it is likely to become available to market
- 6-MW turbine rating reflects obsolete technology
- 2022 turbine assumptions reflect what could be available by 2020 (e.g., DTU 10 MW is similar to the Vestas 10 MW – 176-m rotor)
- Technology such as the GE 12-MW 220-m rotor, announced last year, is assumed for 2027.

Modeled Energy Production Results

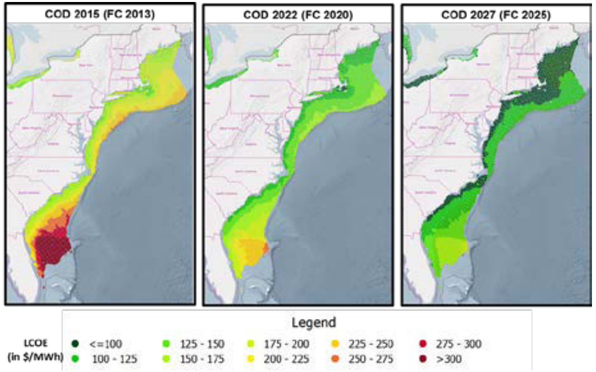
6 MW 2019					
100-m Hub Height	Site 1	Site 2	Site 3	Site 4	Site 5
Gross Capacity Factor	43.48%	46.26%	47.20%	50.68%	59.74%
Total Losses	16.78%	18.09%	15.91%	15.73%	14.71%
Net Capacity Factor	36.18%	37.89%	39.69%	42.71%	50.95%
AEP_{net} (GWh)	1,902	1,991	2,086	2,245	2,678
10 MW 2022					
114-m Hub Height	Site 1	Site 2	Site 3	Site 4	Site 5
Gross Capacity Factor	42.85%	45.90%	47.08%	50.98%	61.12%
Total Losses	16.63%	17.93%	15.77%	15.59%	14.58%
Net Capacity Factor	35.72%	37.67%	39.65%	43.03%	52.21%
AEP_{net} (GWh)	1,877	1,980	2,084	2,262	2,744
12 MW 2027					
136-m Hub Height	Site 1	Site 2	Site 3	Site 4	Site 5
Gross Capacity Factor	46.15%	49.10%	50.39%	53.94%	62.49%
Total Losses	16.58%	17.88%	15.72%	15.54%	14.53%
Net Capacity Factor	38.50%	40.32%	42.47%	45.55%	53.41%
AEP_{net} (GWh)	2,023	2,119	2,232	2,394	2,807
15 MW 2032					
149-m Hub Height	Site 1	Site 2	Site 3	Site 4	Site 5
Gross Capacity Factor	47.77%	50.82%	52.28%	55.87%	64.54%
Total Losses	16.32%	17.60%	15.47%	15.30%	14.30%
Net Capacity Factor	39.97%	41.88%	44.19%	47.32%	55.31%
AEP_{net} (GWh)	2,101	2,201	2,323	2,487	2,907

Estimated Net Capacity Factors



Cost Model Description

- Offshore Regional Cost Analysis Tool (ORCA) quantifies the impact from a variety of spatial characteristics and technology on the levelized cost of energy (LCOE) for a 600-MW project between 2019 and 2032 for:
    - Fixed-bottom foundations (monopile, jacket)
    - Floating foundations (spar, semisubmersible)
- A cost reduction trajectory was derived from an expert elicitation study conducted by BVG Associates (Hundleby et al. 2017)
- Several caveats apply related to domestic supply chain, data availability, technology assumptions, policy, and so on
- Model has been used for various studies, such as:
    - DOE/DOI National Offshore Wind Strategy (Gilman et al. 2016)
    - “Potential Offshore Wind Energy Areas in California” (Musial et al. 2016a)
    - “An Assessment of the Economic Potential of Offshore Wind” (Beiter et al. 2017).



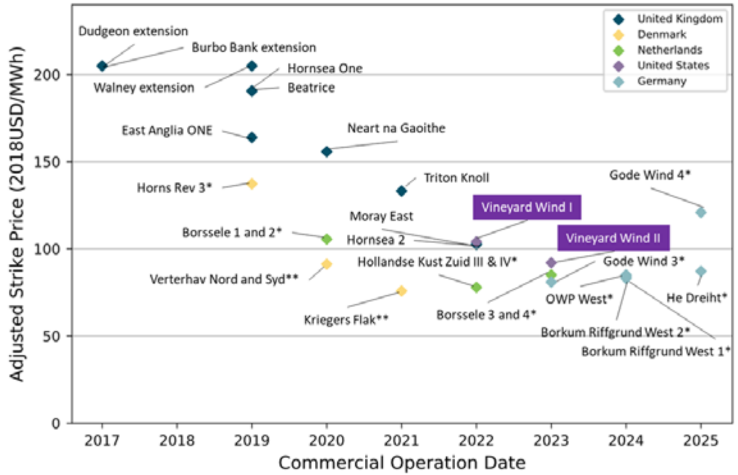
LCOE estimated by ORCA in the Atlantic Coast region (Beiter et al. 2016)

Cost Model Description

Analysis of the Vineyard Wind power purchase agreement (Beiter et al. 2019) and the latest technology trends (Musial et al. 2019) have informed this study. Compared to earlier NREL cost studies in 2016–2018:

- **No significant cost premium** because of less mature U.S. supply chains compared to European projects
- **Lower finance costs** (nominal weighted average cost of capital of 5.4%)
- Turbine power capacity **growth to 15 MW** by 2032 (General Electric 2018; Hundleby et al. 2017)
- **Turbine $/kW lowered** ($1,300/kW) (Bloomberg New Energy Finance 2018)
- **Cost impact of turbine scaling reduced**
- New floating **platform designs promise lower unit cost** and reduced labor at sea (Villaespesa et al. 2015; Melis et al. 2016)
- **Lease costs** implemented ($50 million).

Adjusted strike prices from European offshore wind auctions



Source: Beiter et al. (2019)

TetraSpar

SBM Tension Leg Platform

Fixed and Floating Cost Crossover

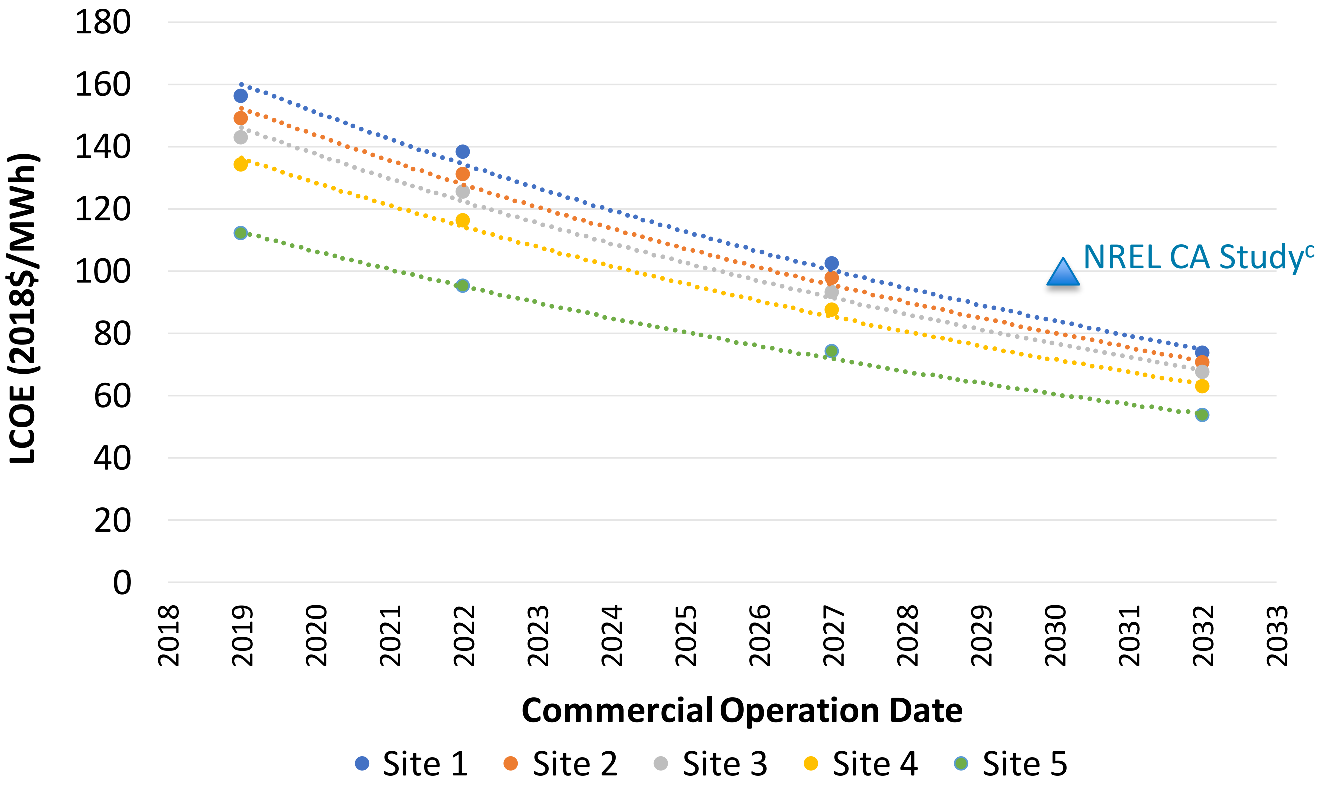
Common LCOE Elements between Commercial-Scale Fixed-Bottom and Floating Offshore Wind Systems

Category	Major Cost Element	Common Cost Elements
Turbine	Turbine	Common
Balance of System	Development and Project Management	Common
	Substructure	Floating-specific
	Foundations	Floating-specific
	Port, Staging, Logistics, and Transport	Floating-specific
	Turbine Installation	Floating-specific
	Substructure Installation	Floating-specific
	Array Cable	Floating-specific
	Export Cable	Common
	Offshore Substation	Common
	Onshore Grid Connection	Common
Soft Costs	Soft Costs (Insurance, Contingencies, Construction Finance)	Common
Financing	Financing Terms	Common
Energy Production	Capacity Factor	Common
Operation & Maintenance	Operations	Common
	Maintenance	Floating-specific

- Common cost elements were derived from fixed-bottom data points
- Cost elements specific to floating were informed by industry consultation (e.g., substructure, moorings/anchors, installation costs)
- Turbine costs are based on multiple inputs from original equipment manufacturers, developers, and literature.

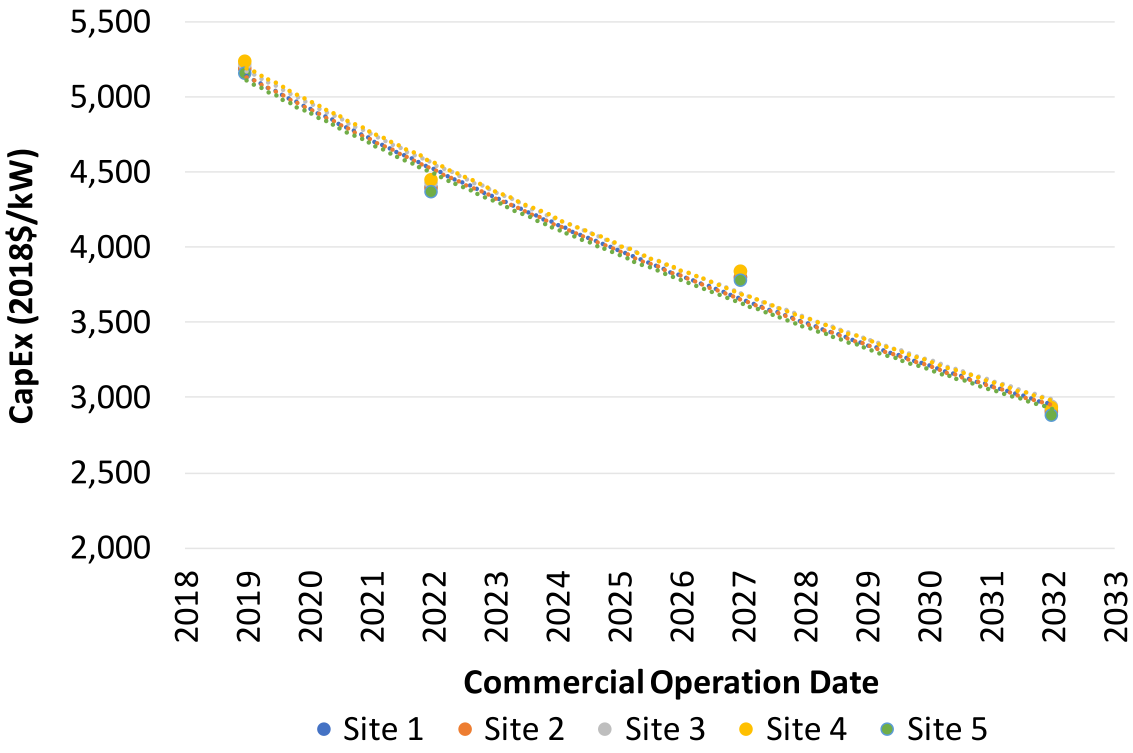
Oregon Cost Results

Levelized Cost of Energy 2019 - 2032

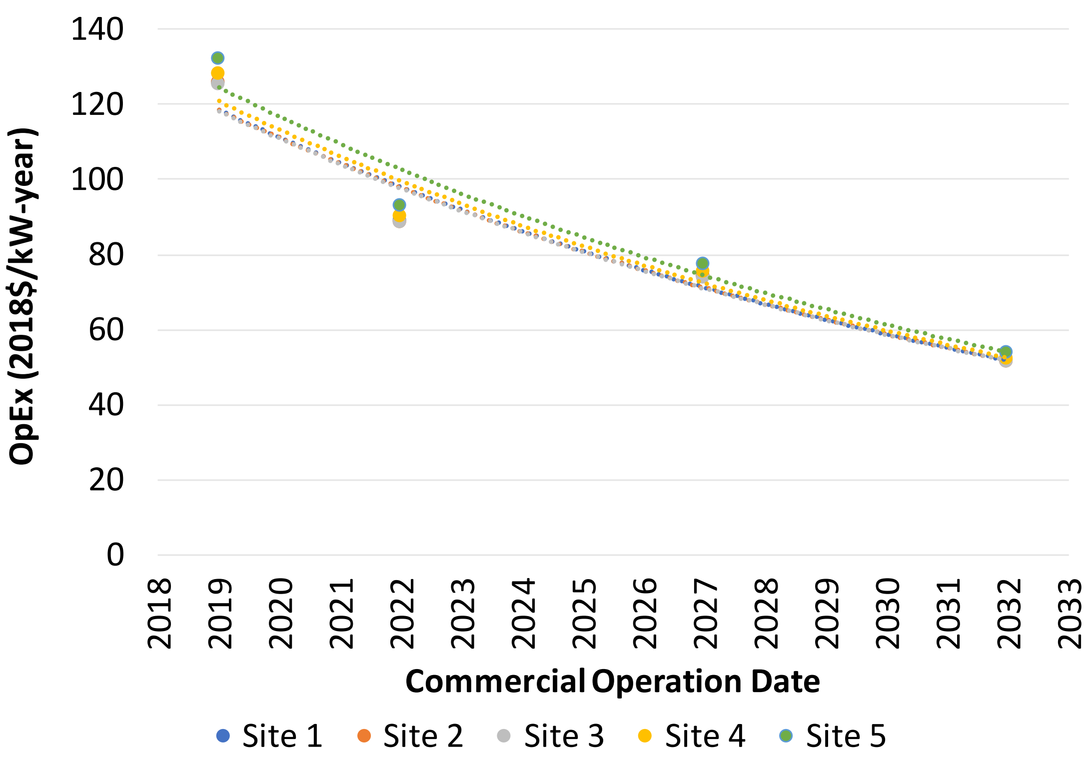


Source: [c] Musial et al. (2016a)

Capital Expenditures 2019–2032



Operational Expenditures 2019–2032



Oregon Cost Results

LCOE ($/MWh)

Commercial Operation Date (COD)	Site 1	Site 2	Site 3	Site 4	Site 5
2019	156	149	143	134	112
2022	138	131	125	116	95
2027	102	97	93	87	74
2032	74	70	67	63	53

Capital Expenditures ($/kW)

COD	Site 1	Site 2	Site 3	Site 4	Site 5
2019	5,180	5,177	5,213	5,229	5,150
2022	4,388	4,383	4,424	4,437	4,358
2027	3,797	3,792	3,833	3,836	3,769
2032	2,901	2,897	2,936	2,924	2,877

Operational Expenditures ($/kW/year)

COD	Site 1	Site 2	Site 3	Site 4	Site 5
2019	126	126	125	128	132
2022	89	89	89	90	93
2027	74	74	74	75	78
2032	52	52	52	52	54

Net Capacity Factor (%)

COD	Site 1	Site 2	Site 3	Site 4	Site 5
2019	36%	38%	40%	43%	51%
2022	36%	38%	40%	43%	52%
2027	38%	40%	42%	46%	53%
2032	40%	42%	44%	47%	55%

Principle Power Project Scaling Analysis

PPI prototype being towed to its station off Portugal in 2011

- Principle Power, Inc. (PPI) proposed a 24-MW Advanced Technology Demonstration (ATD) pilot project sponsored by the U.S. Department of Energy (DOE) off Coos Bay, OR in 2014
- The project was not approved because of high costs
- Commercial-scale projects are 20-30 times larger and can lower unit energy cost by spreading fixed costs over the entire project
- This cost study compared costs for Coos Bay demo project at 24 MW to a full-scale 600-MW commercial project cost.

Project-Scale Impact Findings

- LCOE comparison shows a 3x lower cost for a 600-MW plant compared to a 24-MW plant in 2032: $183/MWh vs. $63/MWh
- Cost-reduction benefits also introduced by turbine size and industry maturity
- New technology is difficult to finance at large scale—cost modeling may be the only method to demonstrate commercial feasibility.

	Project size / *Unit*	600 MW Project Size / $/kW	24 MW Project Size / $/kW	% Difference
1	Tower	182	250	-27%
2	RNA	839	1,536	-45%
TURBINE SUPPLY		1,021	1,786	-43%
3	Substructure	577	1,265	-54%
4	Foundation[1]	-	-	0%
SUPPORT STRUCTURE		577	1,265	-54%
5	Port, Staging, Logistics and Transport	44	868	-95%
6	Turbine Install	-	-	0%
7	Substructure Install[2]	164	300	-45%
TOTAL INSTALLATION		208	1,169	-82%
8	Array Cabling	181	181	0%
9	Export Cable	253	1,574	-84%
10	Grid Connection	7	7	0%
TOTAL ELECTRIC SYSTEM		441	1,762	-75%
11	Development	79	974	-92%
12	Lease Price	88	88	0%
13	Project Management	45	168	-73%
BALANCE OF SYSTEM		1,438	5,426	-73%
14	Insurance During Construction	28	72	-61%
15	Project Completion	28	72	-61%
16	Decommissioning	28	175	-84%
17	Procurement Contingency	132	302	-56%
18	Install Contingency	57	351	-84%
19	Construction Financing	118	686	-83%
TOTAL SOFT CAPEX		391	1,658	-76%
TOTAL CAPEX		**2,924**	**8,870**	**-67%**

		$/kW-year	$/kW-year	% Difference
1	Operations	19	64	-70%
2	Maintenance	33	109	-70%
TOTAL OPEX		**52**	**172**	**-70%**

		%	%	% Difference
1	Net Capacity Factor	47%	47%	0%
NET CAPACITY FACTOR		**47%**	**47%**	**0%**

		%	%	% Difference
1	WACC (nominal)	5.4%	5.4%	0%
FIXED CHARGE RATE (nominal)		**7.11%**	**7.11%**	**0%**

	$/MWh	$/MWh	% Difference
LCOE	**63**	**183**	**-68%**

Summary

- NREL analyzed floating wind costs at five Oregon study sites using an upgraded version of the ORCA model
- Modeled LCOE at Oregon study sites ranged from **$53/MWh to $74/MWh for floating wind technology by 2032** commercial operation date
- Because of European price declines and new market information, these floating costs assessed for Oregon are lower than previous assessments made for California by NREL in 2016
- Full-scale 600-MW project costs in Oregon were found to be three times lower than the 24-MW pilot-scale project PPI proposed in 2014 in Oregon.

Thank you for your attention!

Walt Musial
Principal Engineer
Offshore Wind Manager
National Renewable Energy Laboratory
walter.musial@nrel.gov

NREL/PR-5000-75348

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