Floating Offshore Wind Technology and Oregon Offshore Wind Energy Studies

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Presentation Outline

1. Industry Overview
2. Cost Model
3. Technology Assumptions
4. Physical Site Assessment
5. Grid Study Results
6. Cost Study Results
7. Conclusions and References

Background

- The projects presented were funded by the Bureau of Ocean Energy Management(BOEM) under an interagency agreement M19PG00025 with the DOE National Renewable Energy Laboratory.
- The work builds on a 2019 National Renewable Energy Laboratory (NREL) floating offshore wind power cost study in Oregon (Musial et al. 2019) and a recent NREL California cost analysis (Beiter et al. 2020).
- The cost study* (published Oct 4, 2021) provides heat maps showing updated estimates of the levelized cost of energy (LCOE) for floating offshore wind energy off the coast of Oregon.
- The grid study** "Evaluating the Grid Impact of Oregon Offshore Wind" (published Oct 19, 2021) investigates the robustness in Oregon OSW's value and grid operations impact for the western interconnection.
- The studies do not prioritize specific sites or make judgments about marine spatial planning viability.

* https://www.nrel.gov/docs/fy22osti/80908.pdf

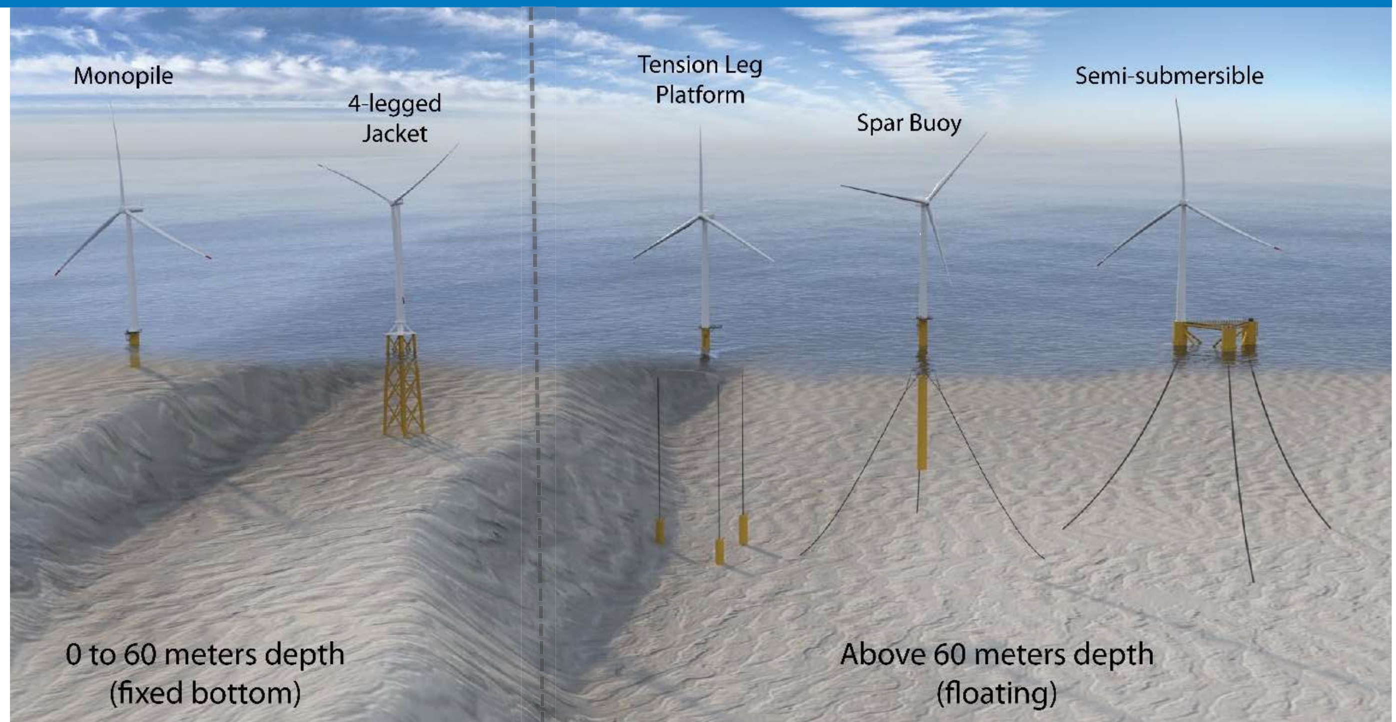
** https://www.nrel.gov/docs/fy22osti/81244.pdf

Most Offshore Wind Deployment has been on Fixed-bottom Support Structures

Leading Offshore Wind Countries
(Installed Capacity)
5,519 MW added in 2020

United Kingdom	9222 MW
China	8181 MW
Germany	7756 MW
Netherlands	2639 MW
Belgium	2262 MW
Denmark	1935 MW
Sweden	196 MW

Figures current as of 31Dec 2020



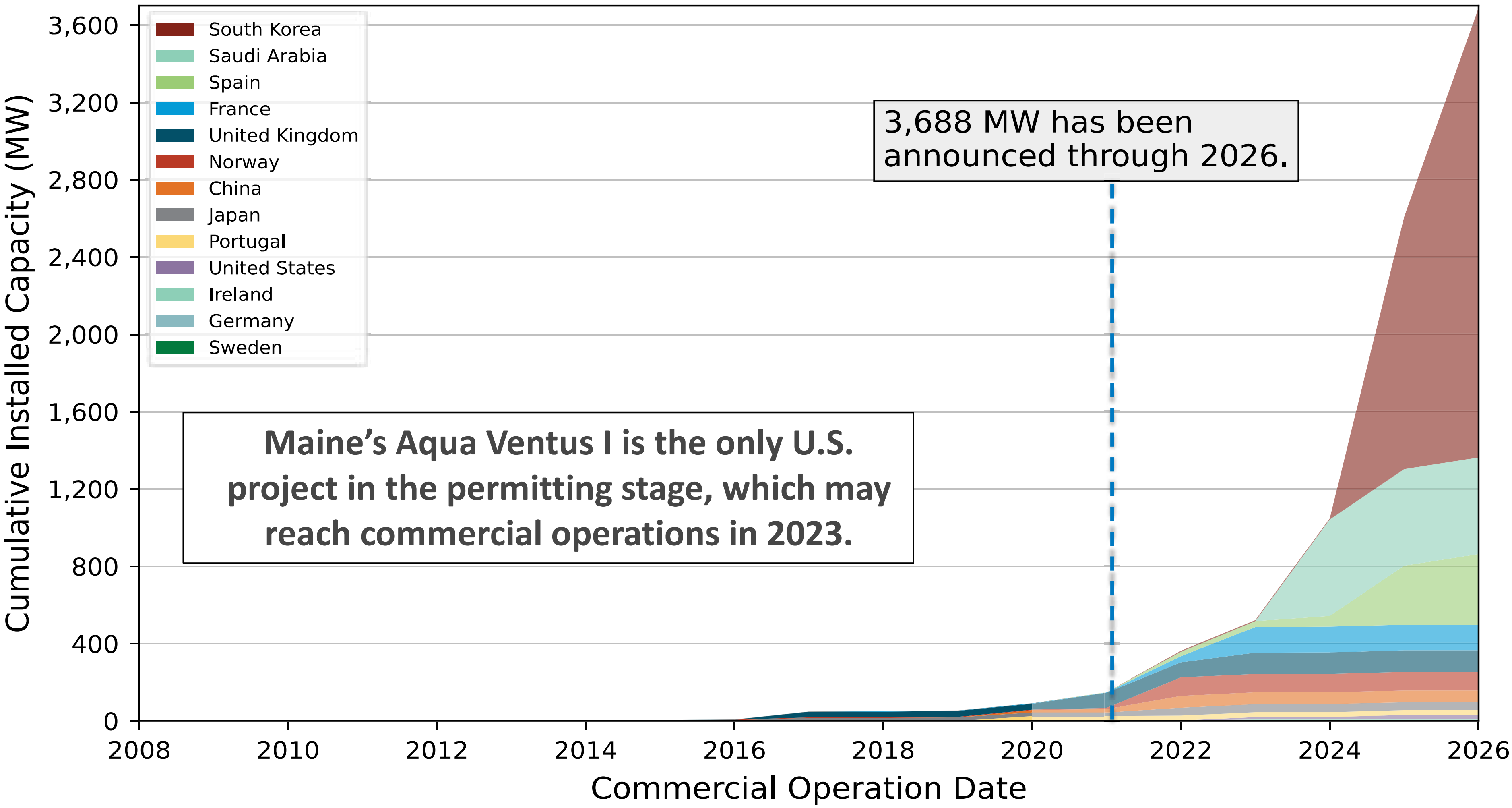
Offshore Turbine Substructure Type Depends on Water Depth

Fixed Bottom
32,906 MW Installed

Floating Offshore Wind
79 MW Installed

The future floating wind energy market may be bigger than the fixed-bottom market

Projected Floating Offshore Wind Capacity



World's Largest Floating Wind Plant: 50-MW Kincardine

- Kincardine floating wind farm was completed in 2021.
- Five, 9.5-MW Vestas turbines mounted on steel semi-submersibles substructures – Principle Power Inc.
- Located 15-kilometers off Aberdeen, Scotland.

Kincardine 50-MW Floating Offshore Wind Plant

Photo: courtesy of Principle Power Inc.

Cost Modeling and Technology Assumptions

Focus: Floating Levelized Cost of Energy

LCOE is the cost to produce one unit of electricity in megawatt-hours (MWh) for an offshore wind energy project averaged over the 25-year life cycle of the project.

$$LCOE = \frac{FCR(C_{turbine} + C_{BOS}) + C_{O\&M}}{AEP}$$

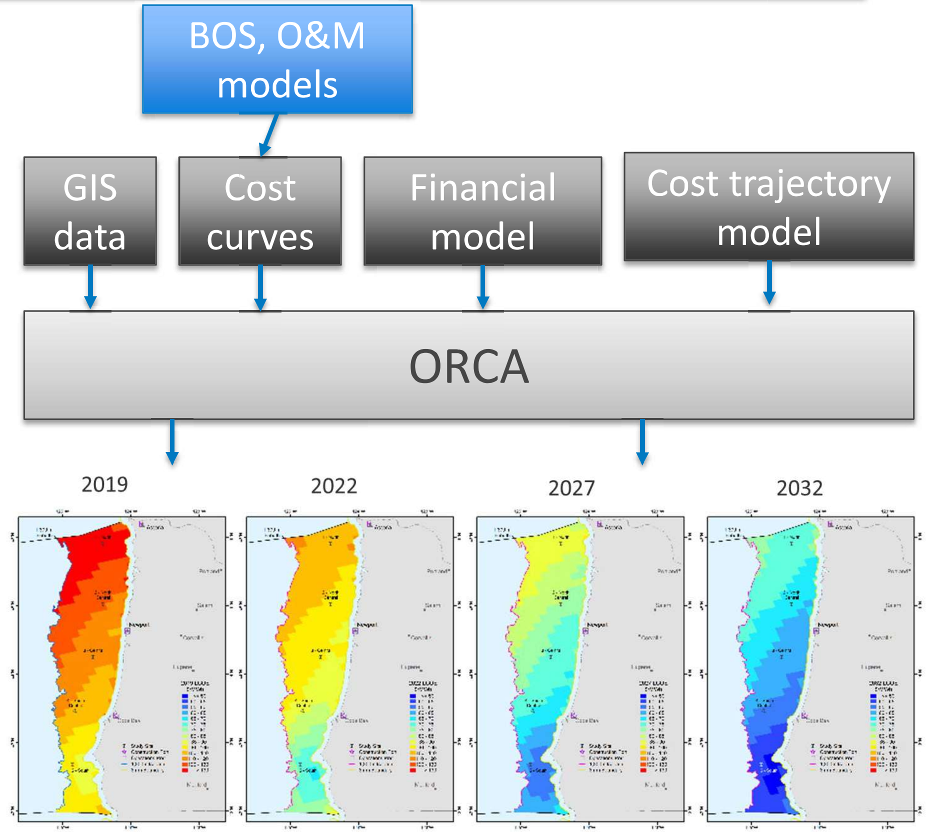
- LCOE: $/megawatt-hour (MWh)
- FCR: Fixed charge rate
- $C_{turbine}$: Turbine capital expenditures, $/kilowatt (KW)
- C_{BOS}: Balance of system (BOS) capital expenditures, $/KW
- $C_{O\&M}$: Operation and maintenance (O&M) annualized costs, $/KW/year
- AEP: Annual energy production, MWh.

LCOE is helpful to compare projects/technologies with <u>different cash flow profiles and over time.</u>
LCOE does <u>not</u> capture the locational and time <u>value</u> of the generated energy and other services.

Description of ORCA Model: Offshore Regional Cost Analyzer

Techno-economic model calculates the spatial and temporal variation of offshore wind costs.

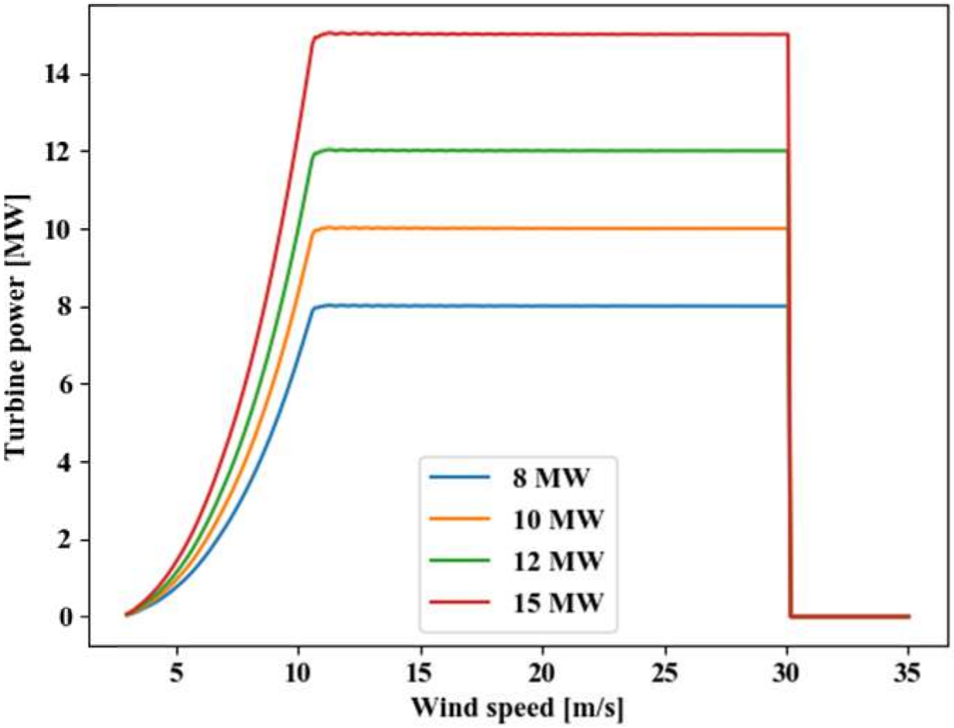
- The bottom-up model uses current cost and wind resource data.
- The **geospatial** cost variables help assess potential offshore wind energy sites on the Outer Continental Shelf (OCS); e.g., depth, distance, resource.
- The **temporal** model estimates the future costs for operation dates up to 2032 based on technology timelines and learning curve.
- The model evaluates the impact of technological, financial, and O&M decisions on LCOE.
- The model is continuously updated to reflect changing market conditions.



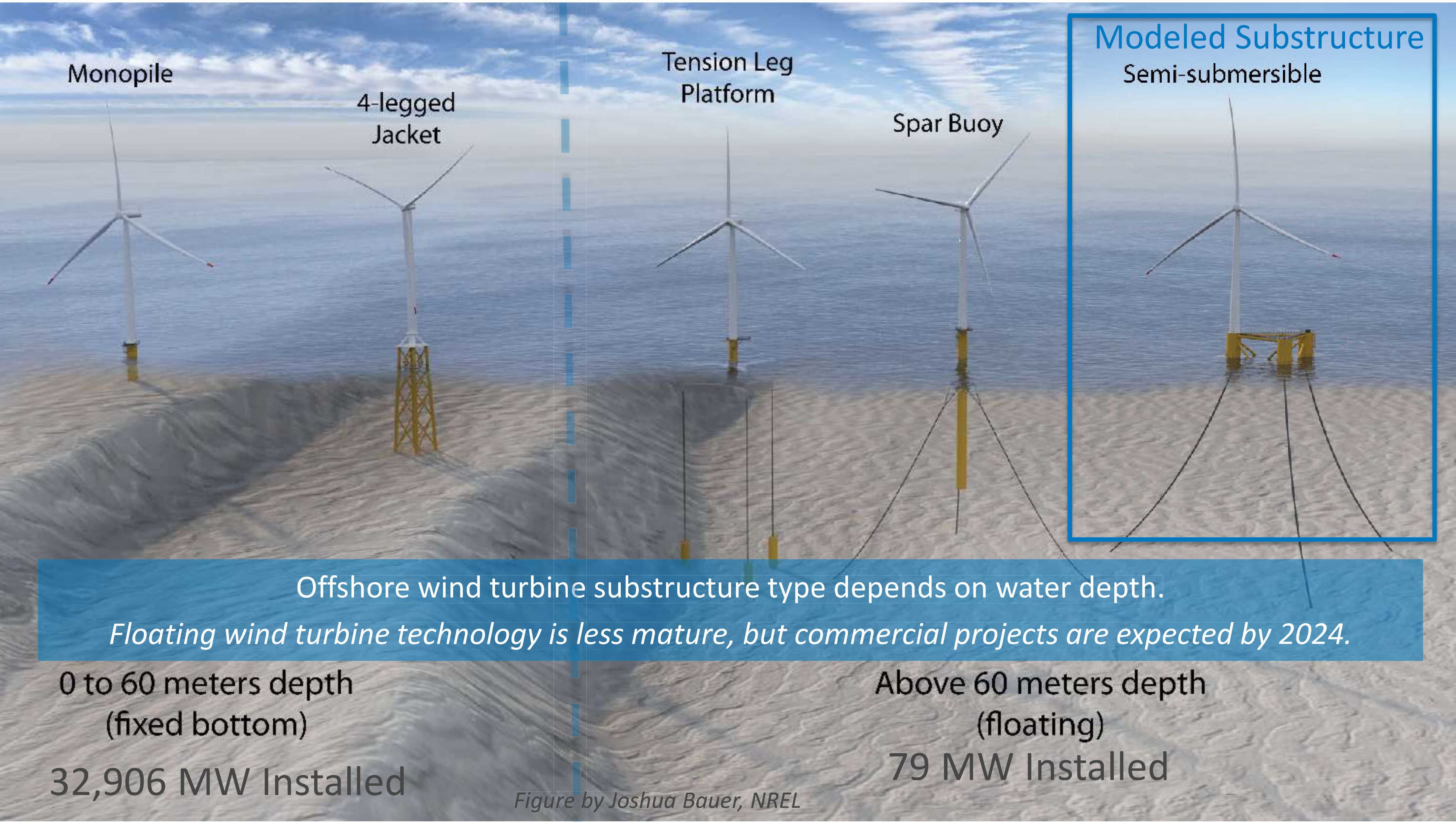
Spatial and temporal LCOE results

Offshore Wind Technology Assumptions

- All wind turbines in the model are based on the International Energy Agency (IEA) Wind 15-MW offshore reference turbine (Gaertner et al. 2020).
- Turbine capacities are assumed to increase over time from 8 MW to 15 MW based on market trends:
  - 8 MW (2019)
  - 10 MW (2022)
  - 12 MW (2027)
  - 15 MW (2032)
- Cut-out wind speed was increased from 25 meters/second (m/s) to 30 m/s in all turbines to account for the higher wind speeds in southern Oregon.

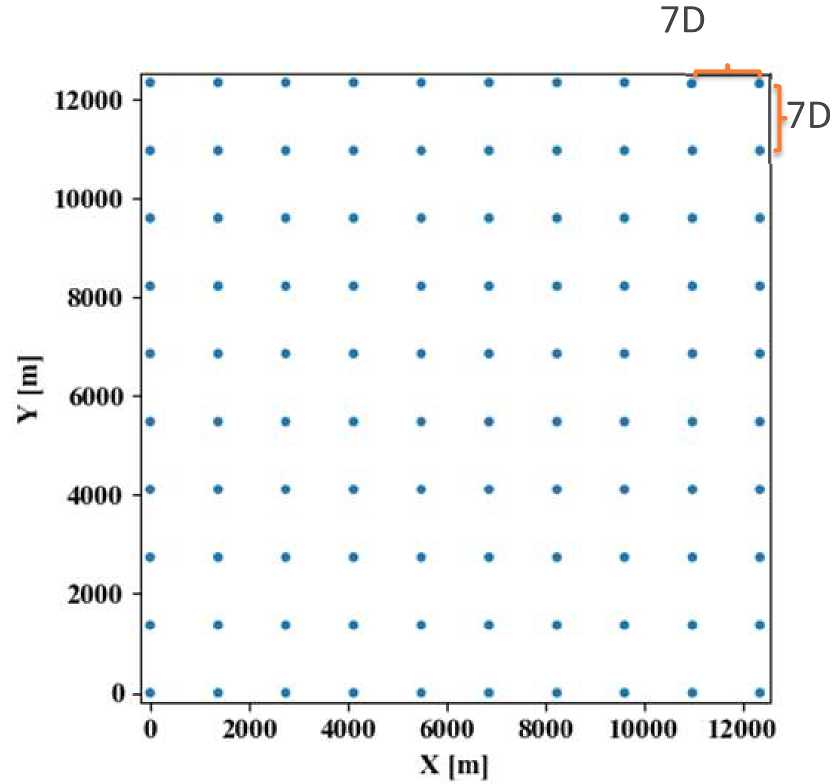


Offshore wind turbine power curves correspond to 2019, 2022, 2027, and 2032


Monopile
4-legged Jacket
Tension Leg Platform
Spar Buoy
Modeled Substructure
Semi-submersible
Offshore wind turbine substructure type depends on water depth.
Floating wind turbine technology is less mature, but commercial projects are expected by 2024.
0 to 60 meters depth
(fixed bottom)
32,906 MW Installed
Above 60 meters depth
(floating)
79 MW Installed
Figure by Joshua Bauer, NREL

Wind Power Plant Assumptions

- A nominal wind plant capacity of 1,000 MW is assumed.
  - Actual plant capacity varies due to integer wind turbine capacity in the commercial operation date (COD):
    - 2019: 1,000 MW (125 x 8 MW)
    - 2022: 1,000 MW (100 x 10 MW)
    - 2027: 1,008 MW (84 x 12 MW)
    - 2032: 1,005 MW (67 x 15 MW)
- Turbines are laid out on a square grid with 7-rotor-diameter (7D) spacing (see figure).*
- AEP and wake losses are calculated using NREL's wake modeling toolbox, FLORIS (NREL 2021).
- Export cable costs include the cost of a 3-kilometer (km), land-based spur line after landfall (likely not a full accounting of interconnection costs).

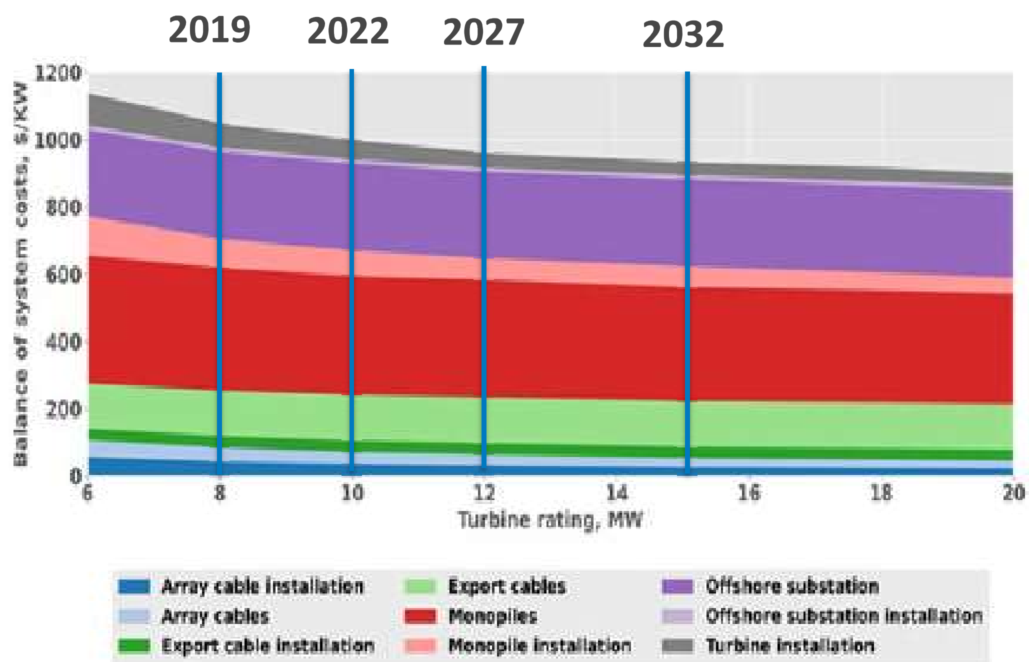


Plant layout for COD 2022 (10-MW wind turbines) has a dot radius representing a 1-rotor diameter.

* Note that 7D spacing is not recommended from this analysis as a layout option for Oregon. The spacing was a conservative layout option chosen to calculate the wake losses. A site optimization of projects in Oregon will likely show lower wake losses.

Main Capital Expenditure Drivers

- Turbine upscaling is a primary driver for BOS cost reduction (see figure).
- Increasing plant size has a large cost benefit due to economies of scale.
- Substructure costs are based on proprietary developer vendor quotes for 1,000-MW projects.
- Lower BOS costs have a cascading effect on soft costs (calculated as percent of BOS).
- Port and bulk transmission upgrade costs are not included in the LCOE or CapEx numbers.



This graph shows the impact of turbine size from Offshore Renewables Balance-of-System and Installation Tool (ORBIT). ***Graph from Shields et al. (2021)***

Note: Labor cost multipliers are not used in this study.

Local Port Requirements for a Viable Floating Offshore Wind Energy Industry in Oregon

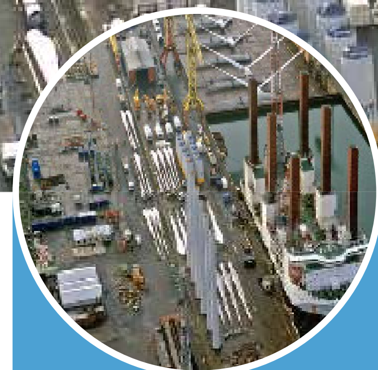
Image by Harland and Wolff Heavy Industries

Wharf

Serial turbine, substructure assembly, and component port delivery due to depth, waves off coast.

Navigation Channel and Wet Storage

Storage and wet tow-out of assembled turbines with year-round access. Width/depth varies by substructure design.



Upland Yard

50- to 100-acre storage and staging of blades, nacelles, and towers and possible fabrication of floating substructures.

Crane

Minimum 600-ton lift capacity at 500 feet height to attach components.

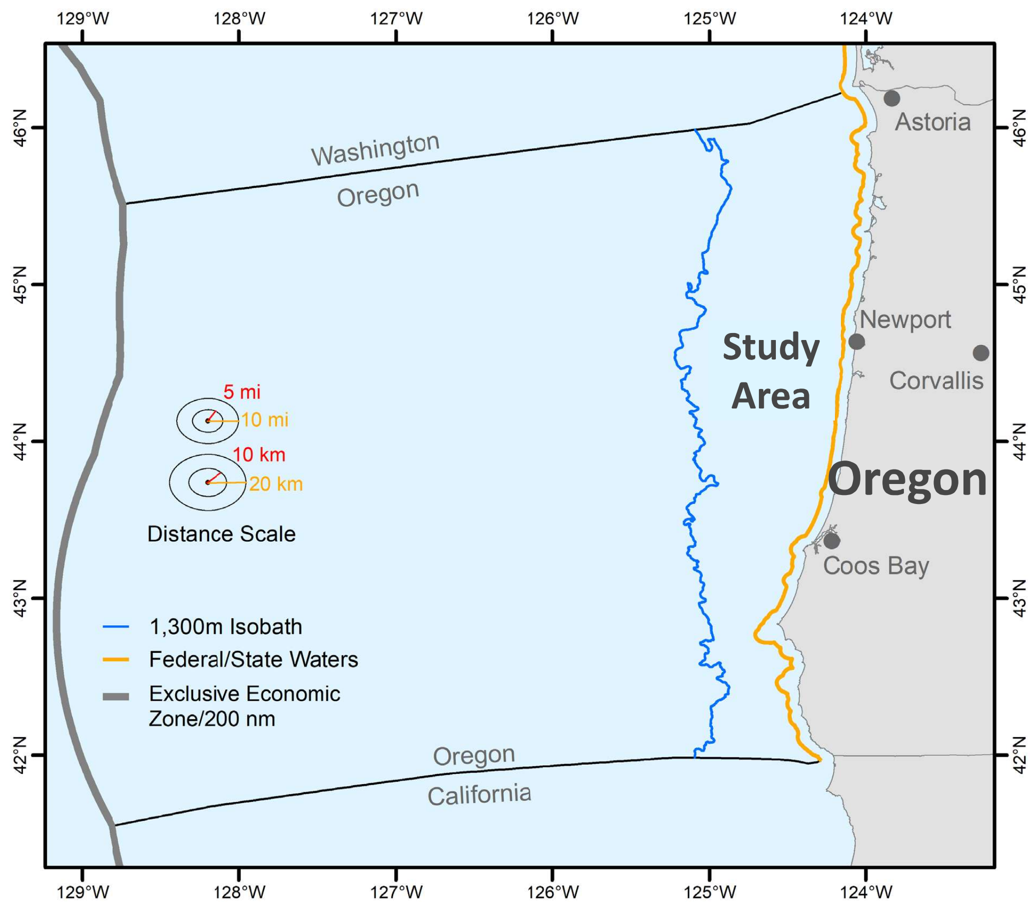
Crew Access & Maintenance

Moorage for crew access vessels. O&M berth for major repairs of full system.

Physical Site Characteristics

Oregon Study Area

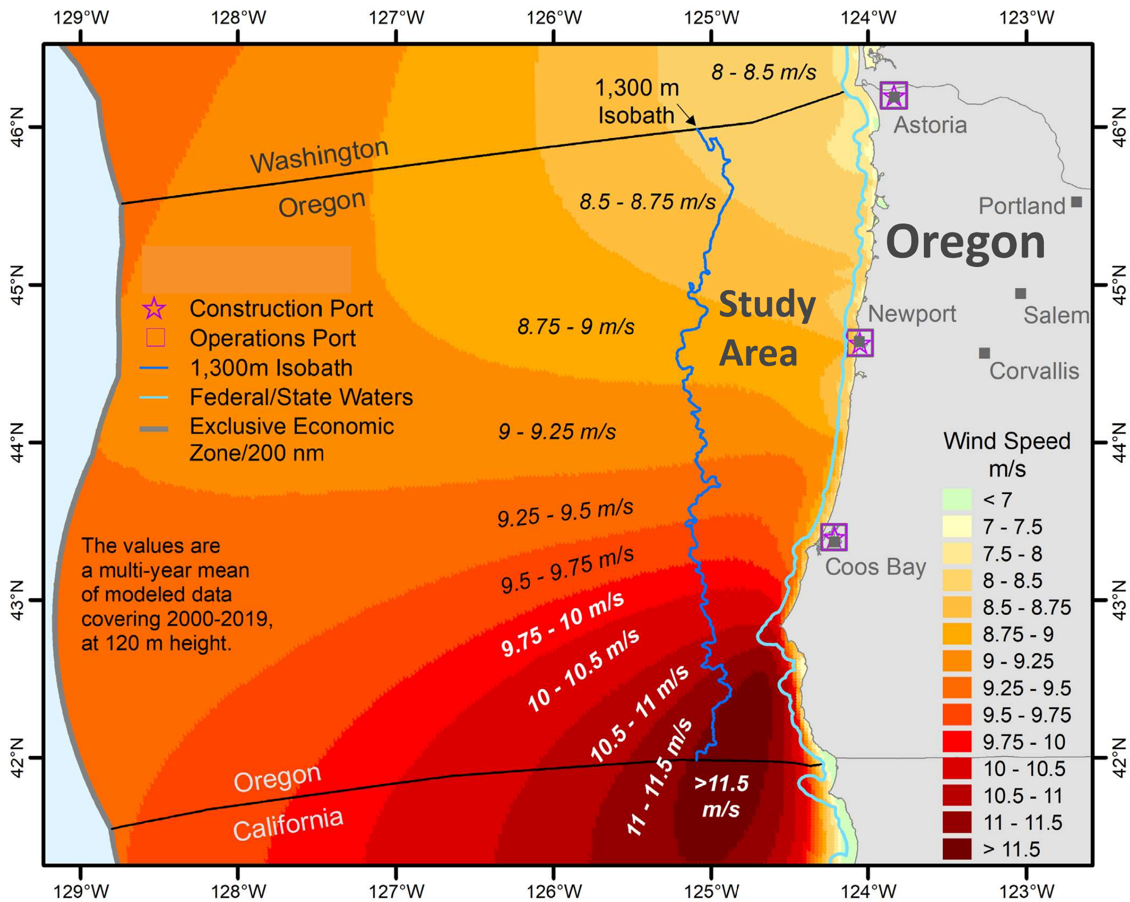
- Study area is bounded by:
  - A 1,300-m isobath to the west, based on present technology limits
  - Washington and California state borders to the north and south
  - 3 nautical miles (nm) federal/state water boundary to the east.
- All ocean space has at least a 7-m/s annual average wind speed.
- No additional areas were excluded (e.g., for conflicting use or environmental reasons).
- Note: the study is not intended to address marine spatial planning or stakeholder concerns; those will be part of a later public review.



This map shows the study area used. Map created by *NREL*

New Oregon Offshore Wind Resource Dataset

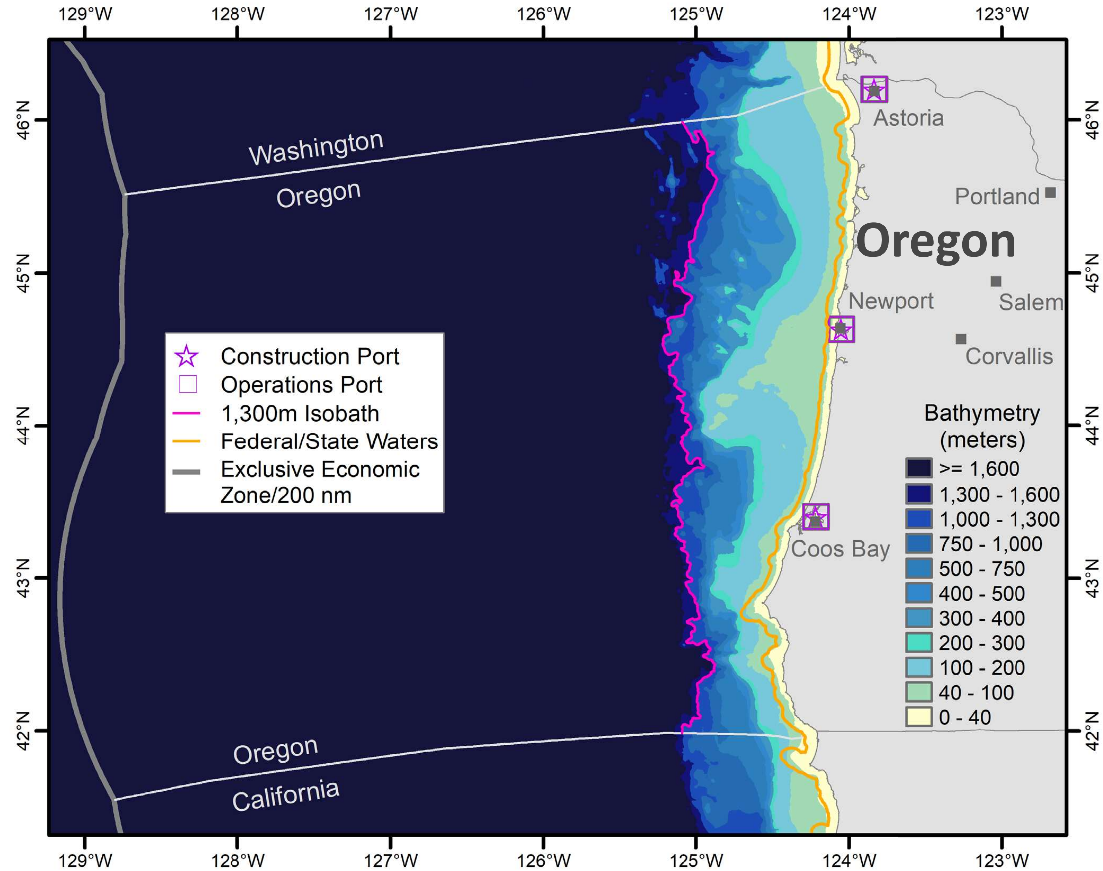
- New OR-WA20 offshore wind dataset produced a 120-m wind resource map (see figure) using 20 years of data.
- This is the best assessment of offshore wind resources in the Pacific Northwest to date.
- The study indicates higher wind speeds than the earlier WIND Toolkit in most regions (by up to 1.8 m/s; see figure).
- The data shows a strong north/south gradient (8 m/s to 11 m/s), with the best wind resources being in the south.



Wind Resource Offshore Oregon – source NREL

Bathymetry Offshore Oregon

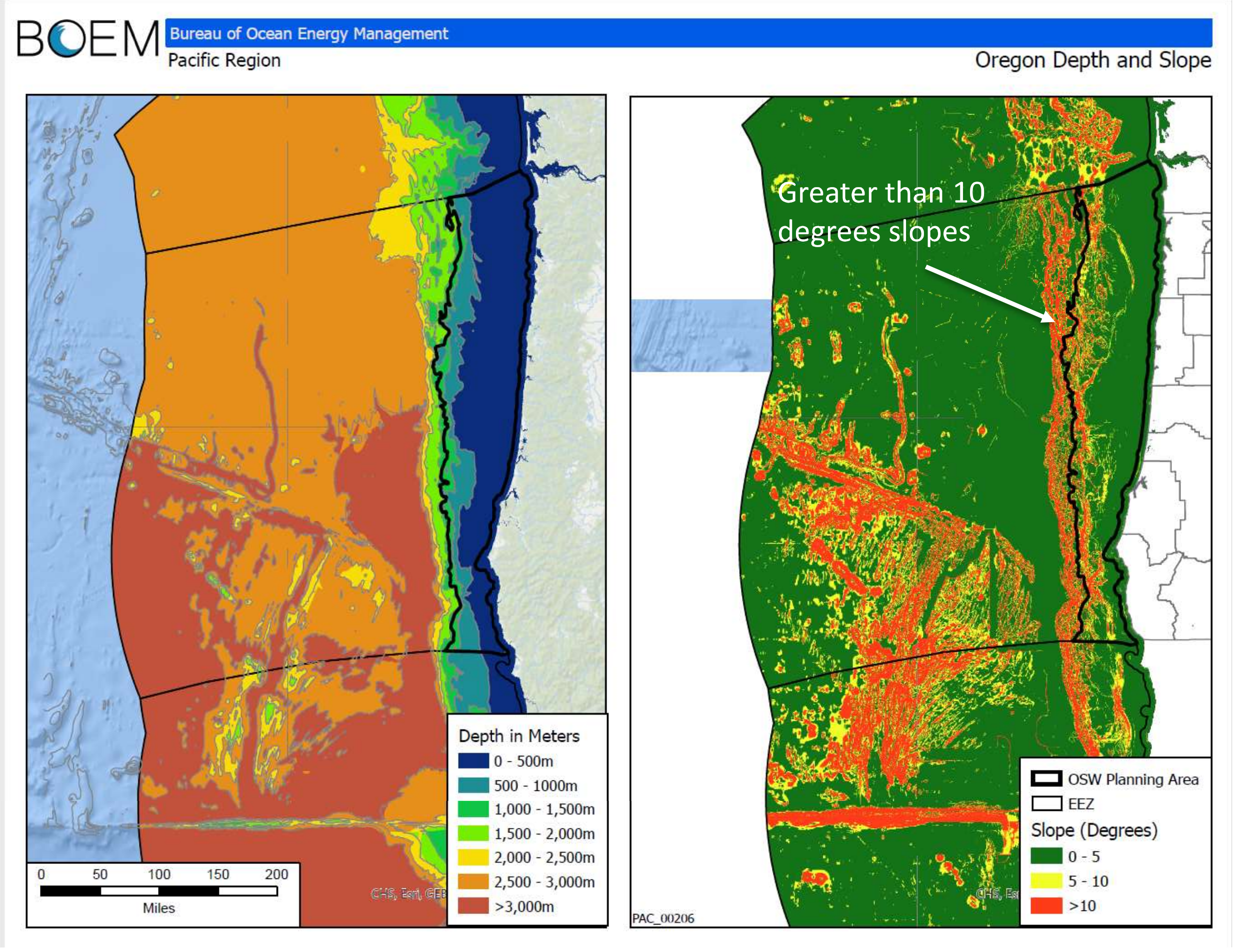
- 97% of the waters on the OCS off the state of Oregon are greater than 60 m in depth, indicating a need for floating wind turbine foundations.
- Most of the technical resource area is less than 30 miles from the shore due to steep slopes on the OCS near the 1300-m isobath.



Bathymetry Offshore Oregon – source NREL

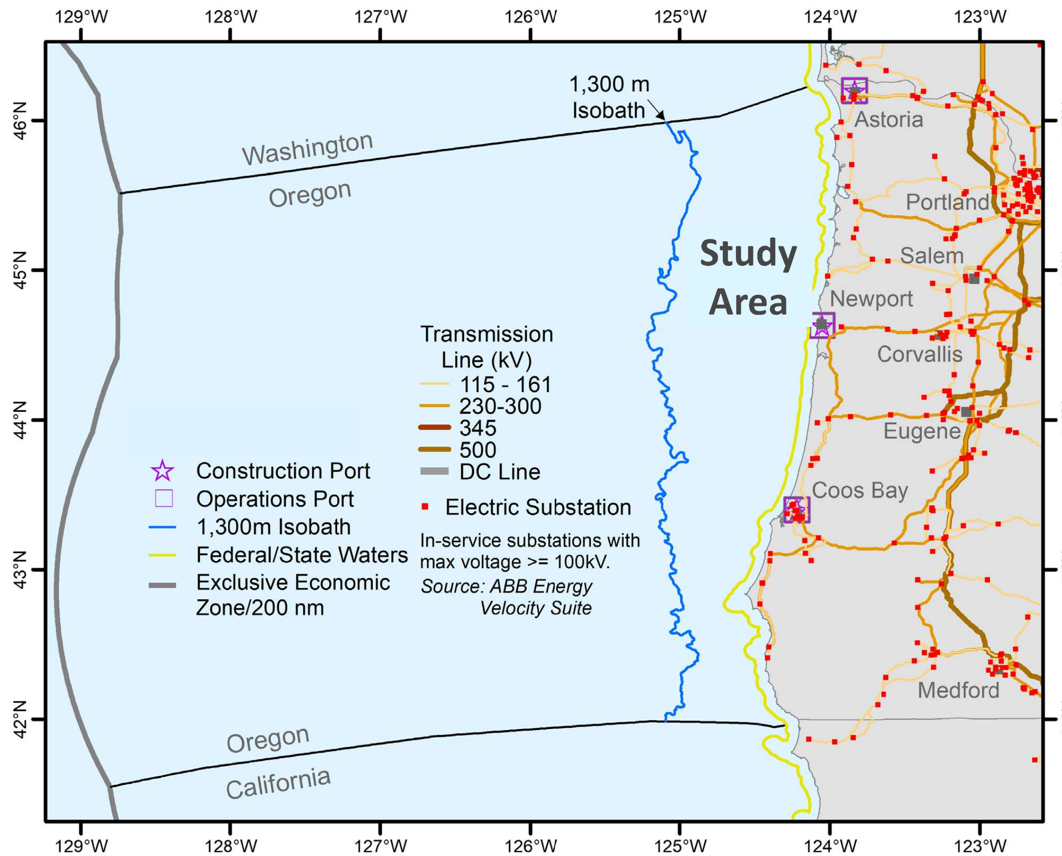
Water Depth and Bottom Slope Steepness Considerations

- Deeper waters beyond the 1300-m study area cut off yield very little additional resource area.
- Steeper slopes are found between the 1000-m and 2000-m isobaths that would make offshore wind development difficult.



Coastal Oregon Electrical Infrastructure

- Almost all power generation in Oregon is currently inland.
- Electric power flows from the east to the west to serve the coastal communities.
- Offshore wind would reverse the direction of power flow and reduce impacts on inland grids.
- NREL OR grid study (Novacheck and Schwartz. 2021) assessed potential impacts of offshore wind to the Oregon power grid.



Electric Infrastructure in Oregon Relative to Study Site – source NREL

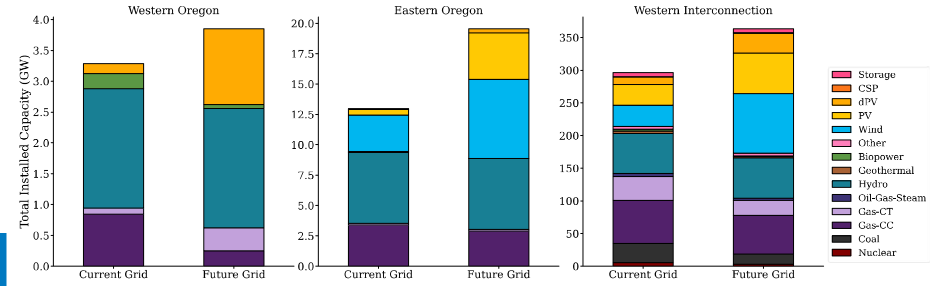
NREL Oregon Grid Study Objective

Investigate the robustness in Oregon OSW's value and grid operations impact across a range of scenarios using a detailed production cost model of the Western Interconnection.

Five scenario dimensions

1. **Offshore wind penetration**: Base (0-GW), Mid (2.6-GW), or High (5-GW)
2. **Western Electricity Coordinating Council (WECC) infrastructure year**: Current grid (21% Wind/Solar), or future system (46% Wind/Solar).
3. **Trans-coastal transmission expansion**: no expansion, or expansion along trans-coastal corridors to avoid congestion with 5 GW of offshore wind.
4. **Co-located energy storage**: no storage, or co-located storage at the onshore point of interconnection.
5. **Historical year:** 7 historical weather years (2007-2013) for three select scenario combinations.

Installed Generation Capacity by Type for both Infrastructure Scenarios



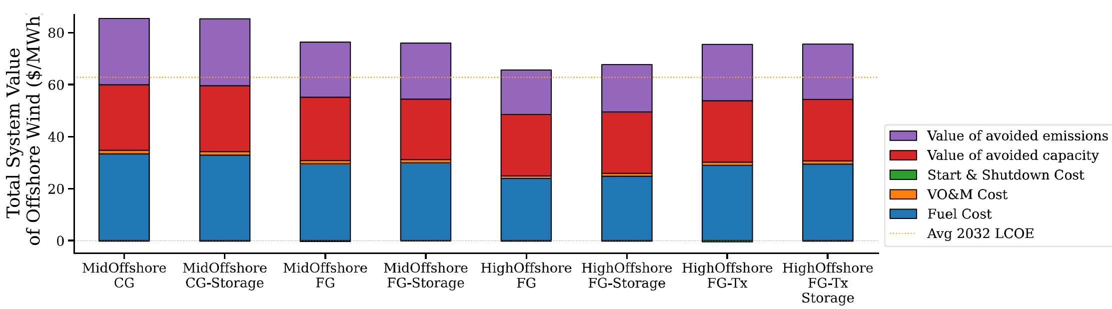
Offshore Wind Capacity in the Mid Scenario

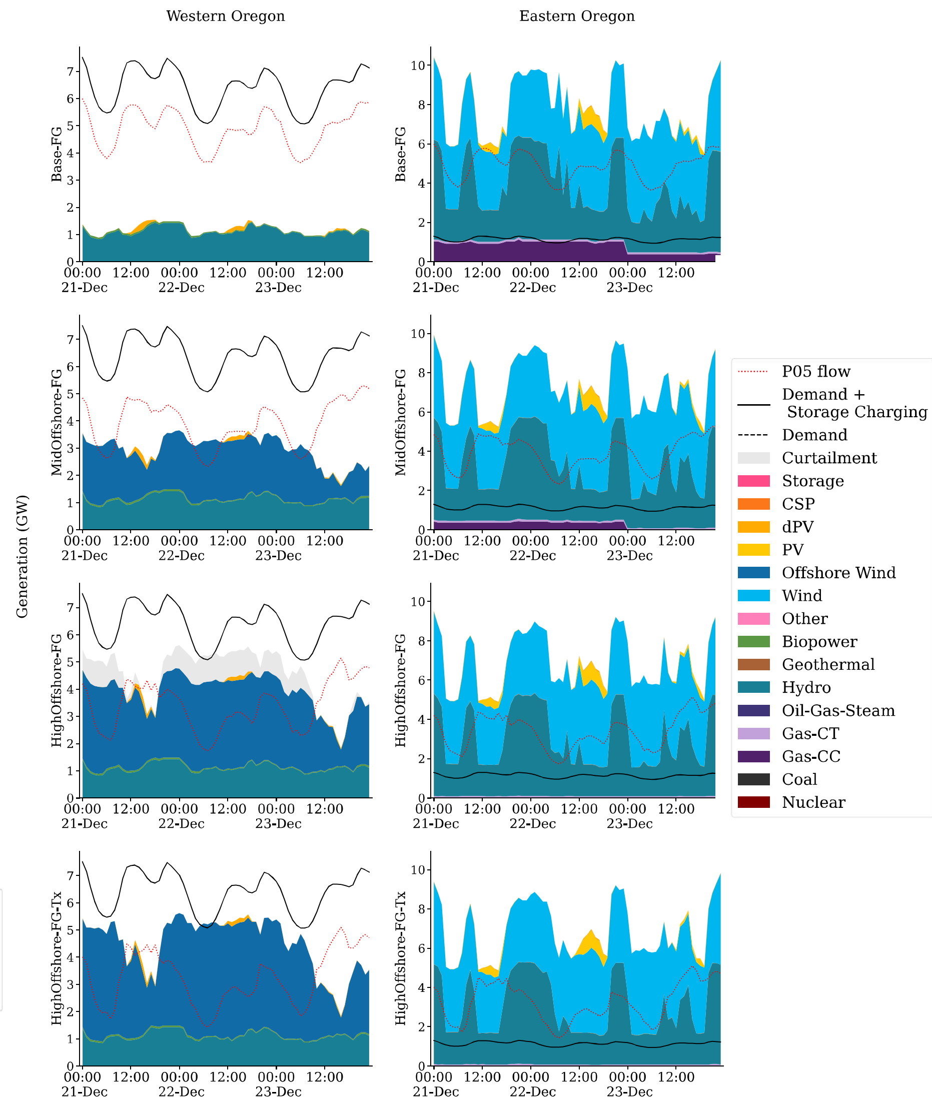
Offshore Wind Point of Interconnection	Max Nameplate Capacity (MW)	Max Injected power* (MW)
Clatsop (1-North)	361	301
Tillamook (2-North Central)	553	461
Toledo (3-Central)	156	130
Wendson (4-South Central)	613	512
Fairview (5-South)	941	785
Total	**2625**	**2189**

*Due to internal loses, max injected power is 83.4% of nameplate

Key Grid Study Findings

1. Existing system can support up to 2.6 GW of Offshore Wind (OSW).
2. Trans-coastal transmission congestion is the main driver of Offshore Wind curtailment.
3. The system value of OSW ranges between $65/MWh - $85/MWh.
4. East/West cross-Cascade power flow reduces 500-550 MW for every 1000 MW of OSW output but does not eliminate high flow periods.
5. OSW can serve over 84% of hourly coastal Oregon loads.
6. OSW allows for more optimal hydropower dispatch, while hydro availability (i.e., wet vs dry year) has little impact on OSW system value.
7. OSW increases contributes to serving evening net load peak in California (i.e., duck curve), but further contribution limited by congestion.
8. Co-located storage could be a “non-wires” alternative to increase OSW capacity beyond 2.6 GW.





Oregon Offshore Wind Levelized Cost of Energy: Heat Map Analysis

Oregon Offshore Wind Capital Expenditures

- CapEx heat maps show strong dependence on distance from shore but little north-south variations.
- CapEx values drop below $3,000/KW in many areas by 2032.

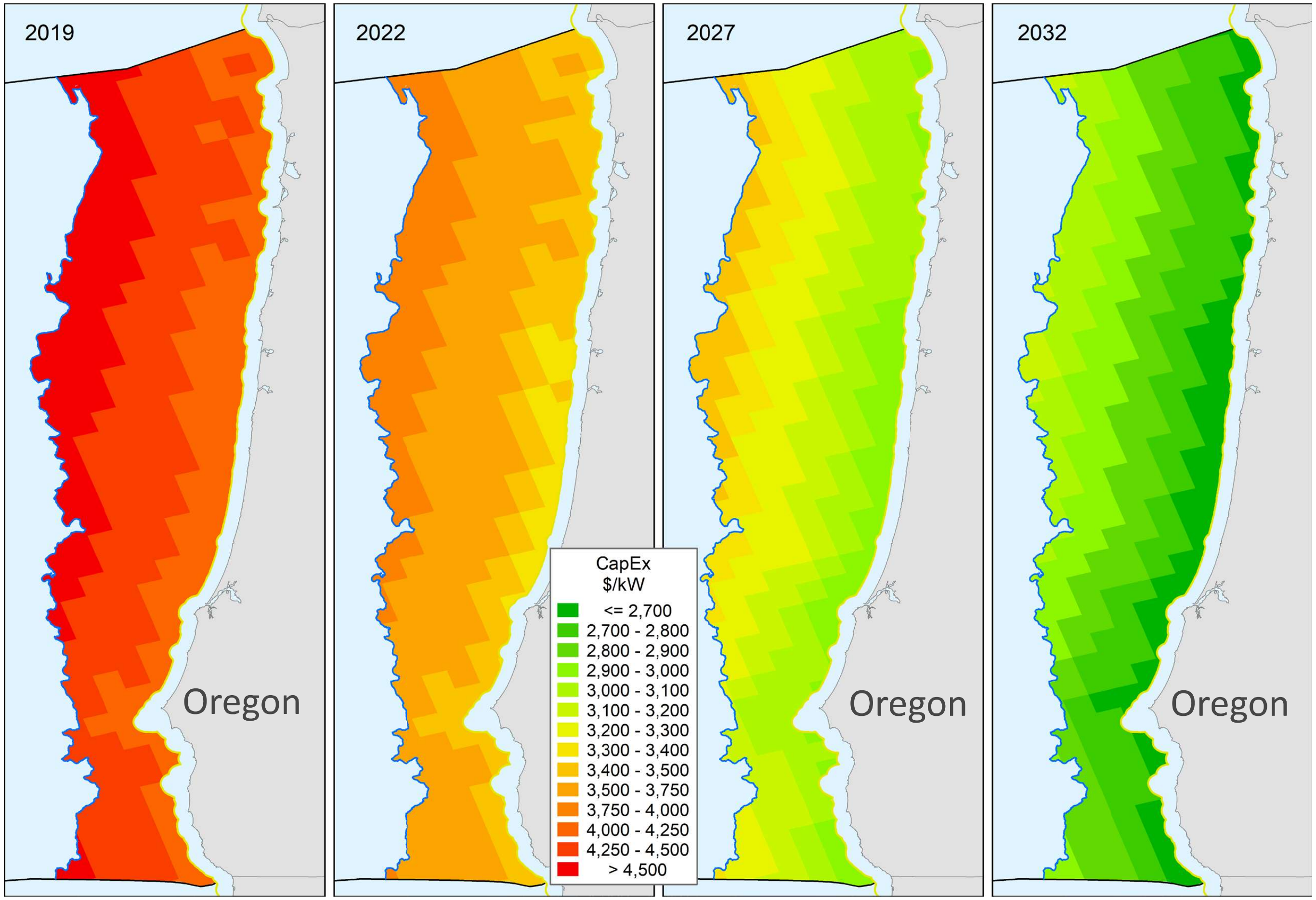


Image source NREL

Oregon Offshore Wind Operating Expenditures

- Operating expenditures (OpEx) heat maps show strong dependence on distance from shore but little north-south variations.

- OpEx costs will drop below $55/kW/year by 2032 in many regions.

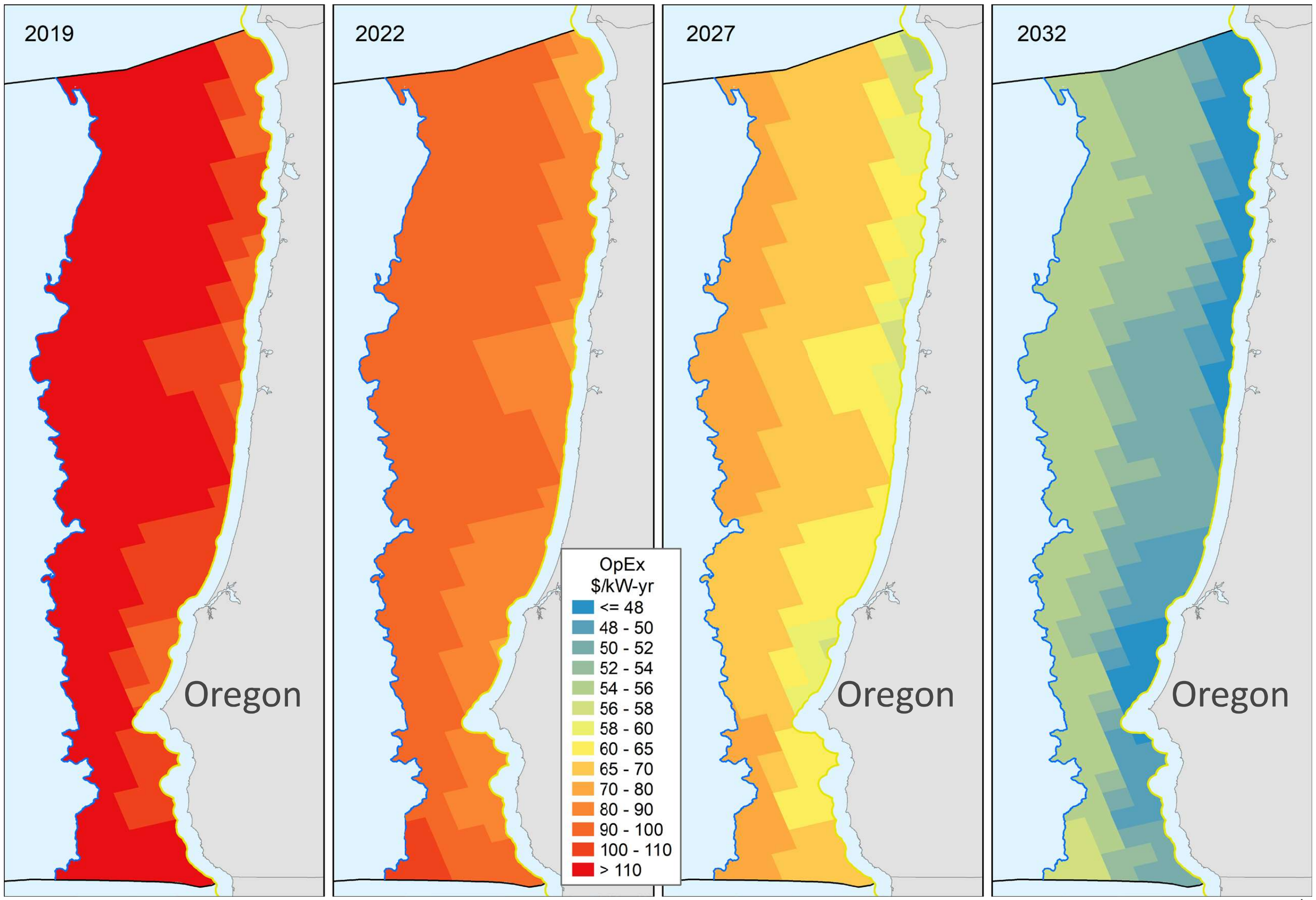


Image source NREL

Oregon Offshore Wind Net Capacity Factor

- Net capacity factor (NCF) heat maps show strong north-south variations, which are mostly due to wind resources.
- NCF values are expected to range between 39% (in the north) and 57% (in the south) by 2032.

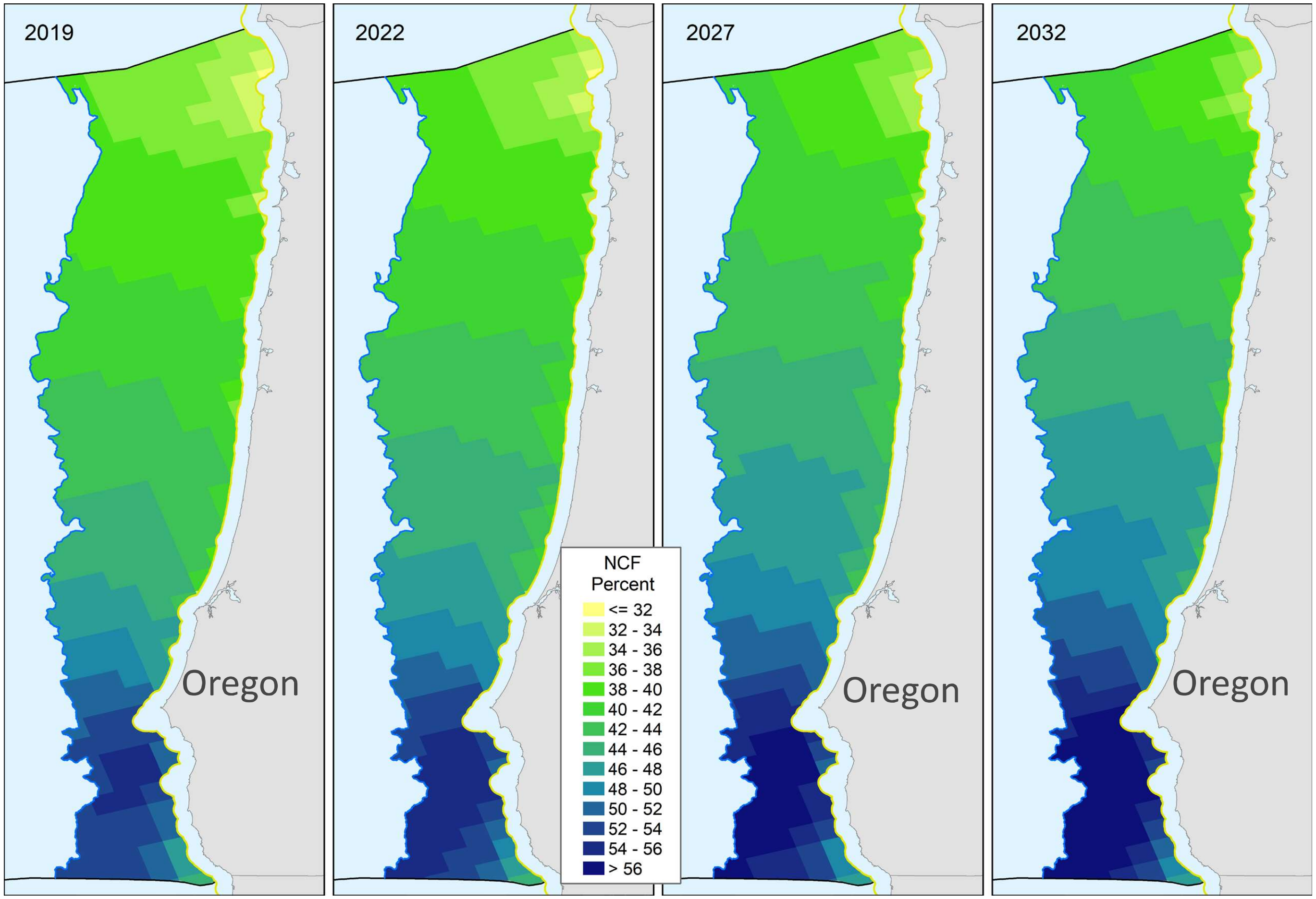


Image source NREL

Oregon Offshore Wind – Levelized Cost of Energy

- LCOE heat maps show strong north-south variations and dependence on distance from shore.
- LCOE geographic variations are mostly due to wind speed.
- By 2032, LCOE is expected to range between $75/MWh in the north to as low as $50/MWh in the south.

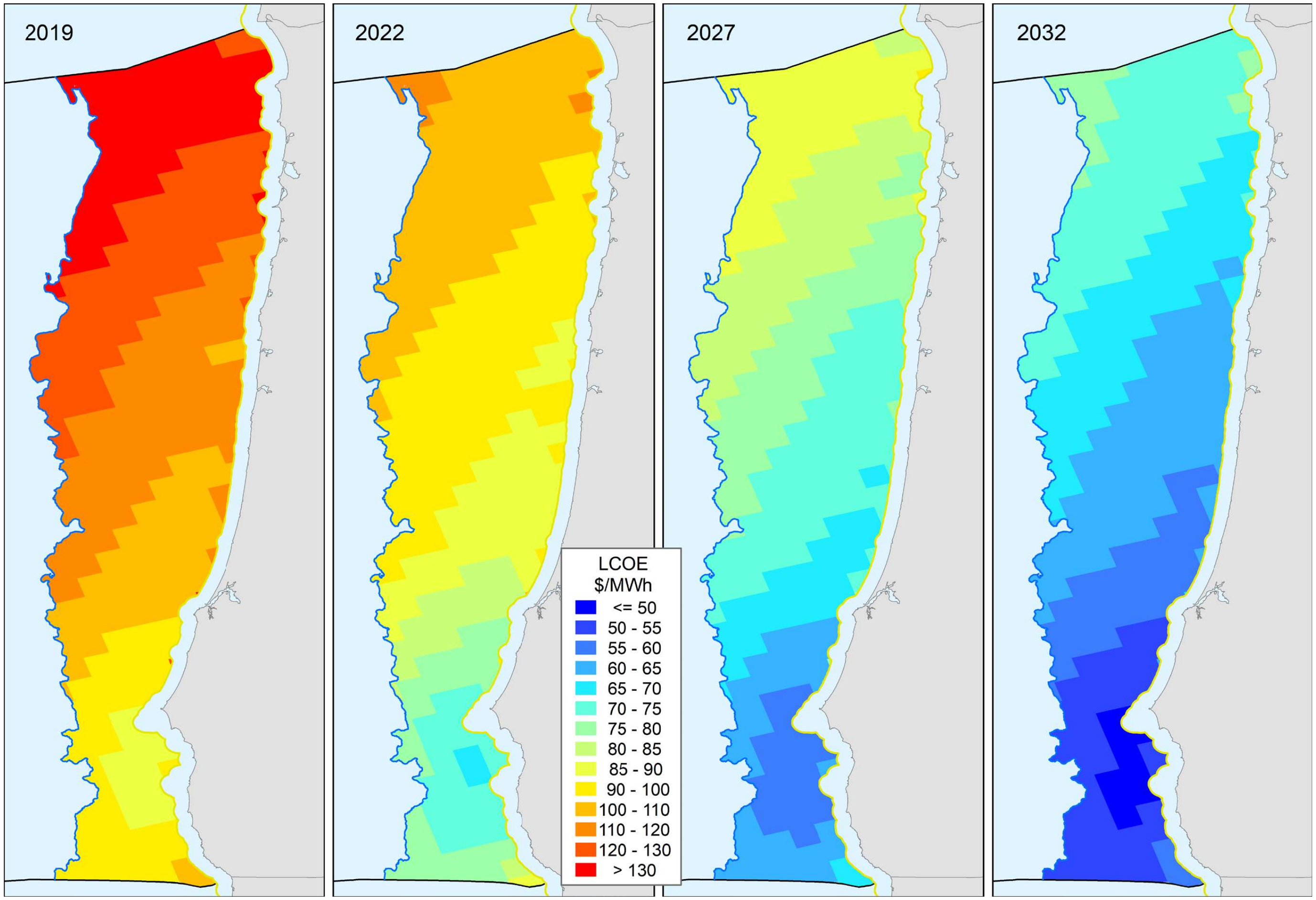


Image source: NREL

Possible Economic Benefits of Offshore Wind Energy in Oregon

- The development of offshore wind energy in Oregon would create a new, industrial economy comprising new ports and infrastructure for project construction, manufacturing, turbine assembly, and services.
- The electric grid study found that 2,600 MW (Mid scenario) of offshore wind power could be installed without the need for major grid upgrades (Novacheck and Schwarz. 2021).
- 2,600 MW of offshore wind power would require revenues of $8–$10 billion, much of which would flow through the state's economy.
- 2,600 MW of offshore wind energy would generate enough electricity to power over 1 million Oregon homes, significantly reducing the state's carbon footprint.

Key Takeaways

- Floating wind is needed for offshore wind in Oregon, and global industry is expected to enter a commercial phase by 2024.
- OR Grid study (Novacheck et al. 2021) identified significant possible benefits for the OR transmission infrastructure and indicated "no-wires" alternatives were possible from offshore wind in Oregon.
- The cost study indicated that LCOE for floating offshore wind in Oregon could range from \$75/MWh in the north to \$50/MWh in the south.
- A marshalling port to serve offshore wind deployment and service the wind farms would likely be needed.
- Significant economic benefits may be available with Oregon offshore wind energy.

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