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California Offshore Wind Resource and Market Overview

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California Ocean Renewable Energy Conference

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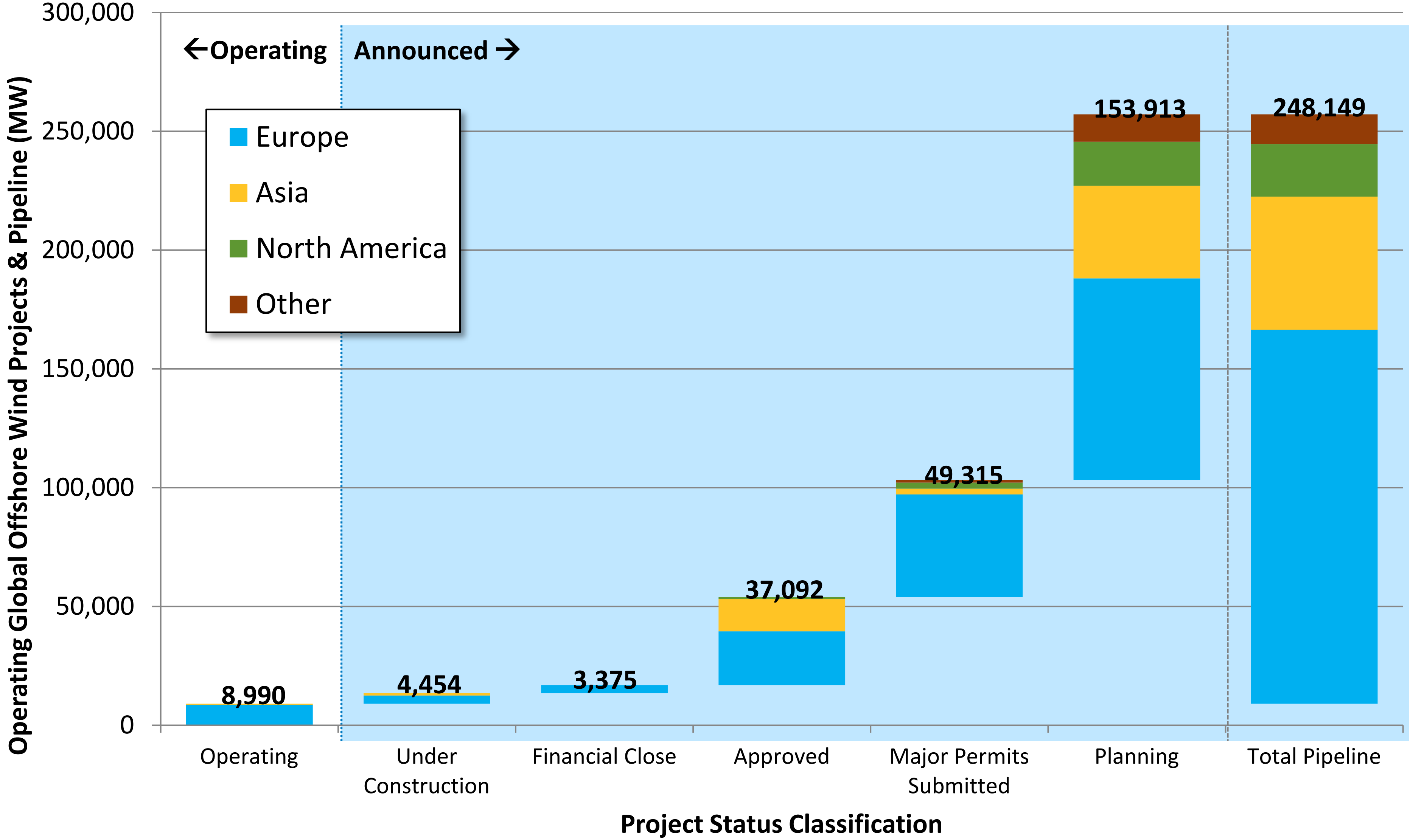
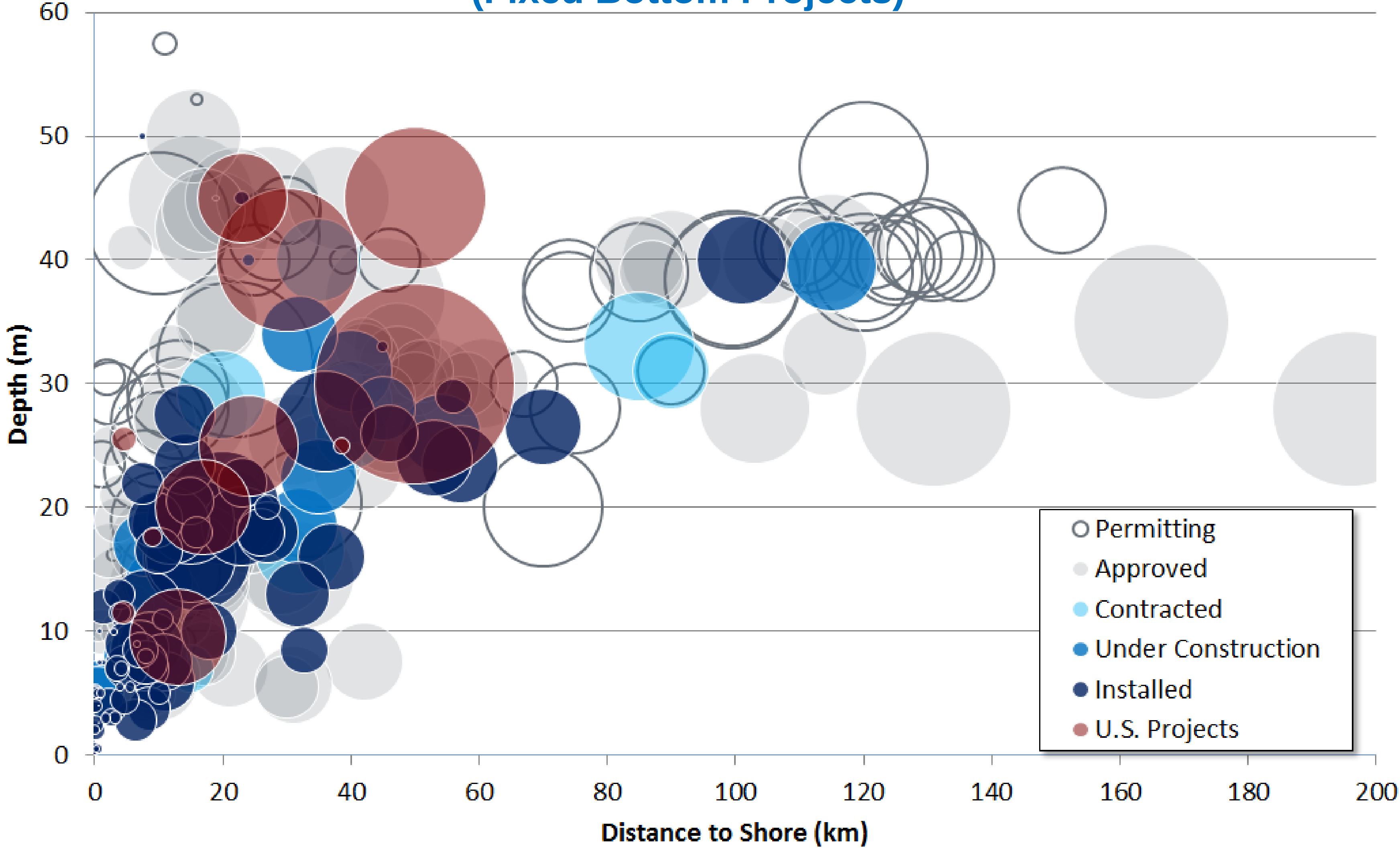
Global Offshore Wind Development Pipeline Totals 248 GW



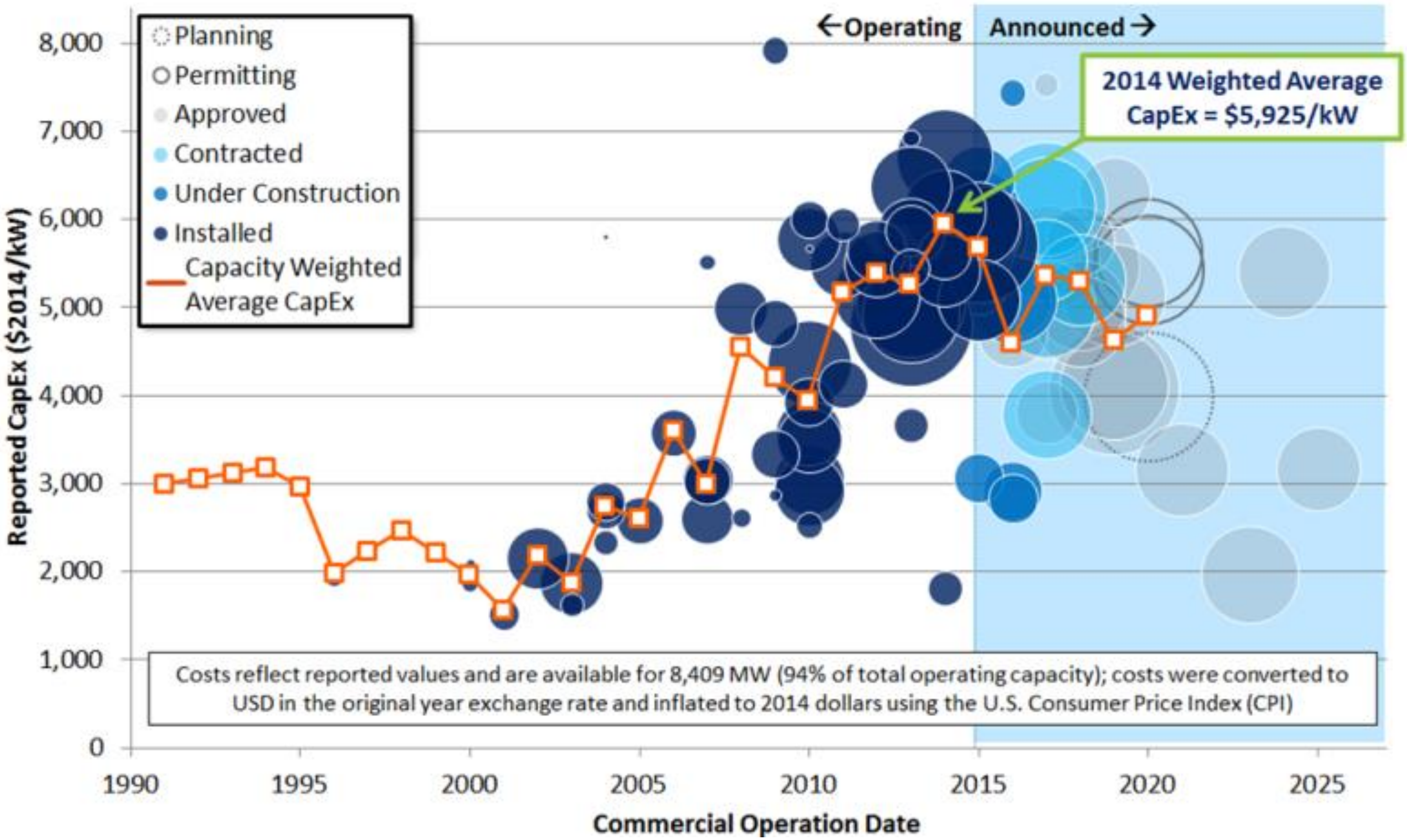
Reference: A. Smith, T. Stehly, and W. Musial; "2014-2015 Offshore Wind Technologies Market Report", Sept 2015, NREL Report, Golden **CO** http://energy.gov/eere/wind/downloads/2014-2015-offshore-wind-technologies-market-report

Global Offshore Wind Projects:
Water Depth and Distance to Shore
(Fixed Bottom Projects)



Reference: A. Smith, T. Stehly, and W. Musial; "2014-2015 Offshore Wind Technologies Market Report", Sept 2015, NREL Report, Golden **CO** http://www.nrel.gov/docs/fy15osti/64283.pdf

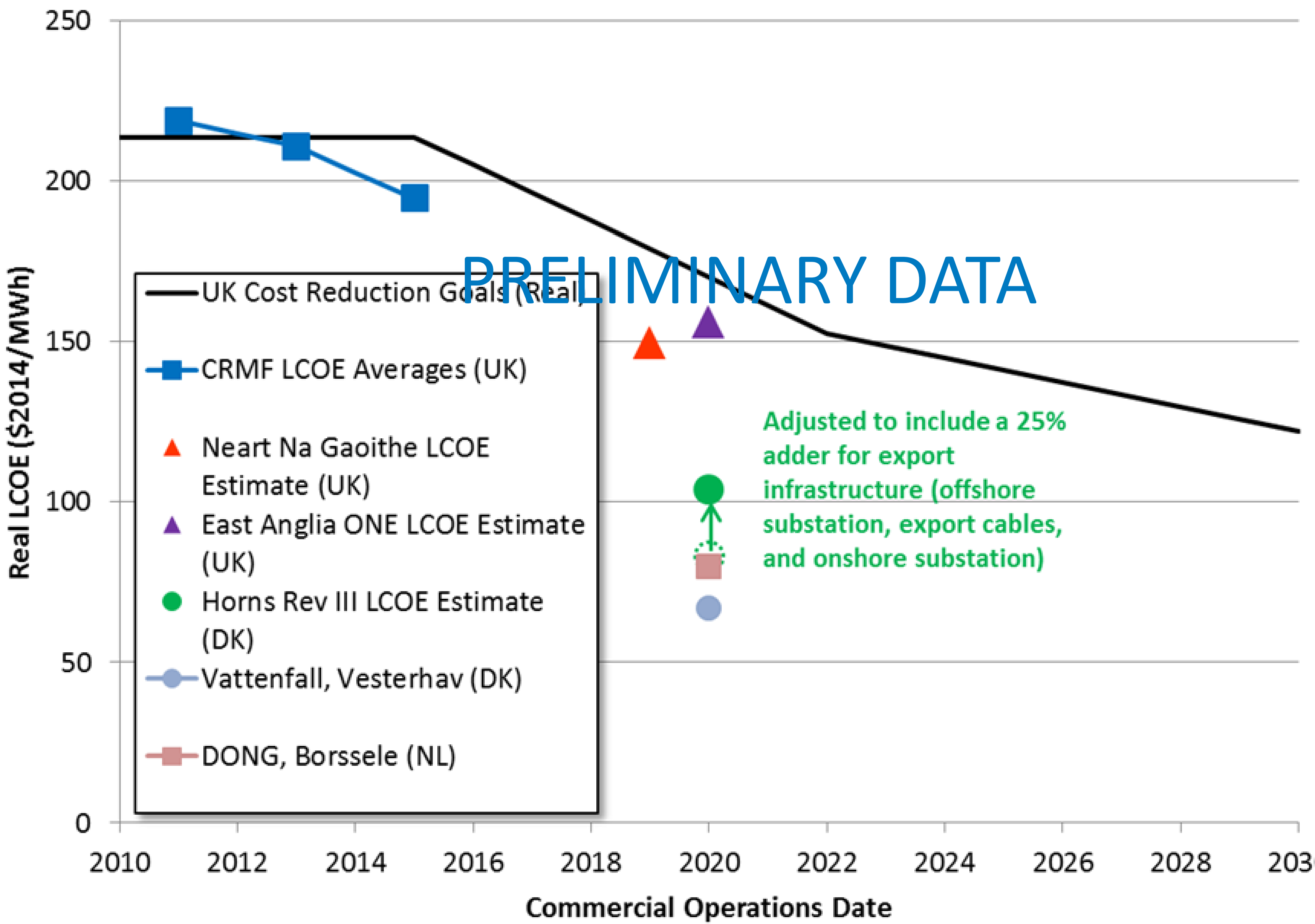
Global Offshore Wind Capital Expenditures At Commercial Operation Date



Reference: A. Smith, T. Stehly, and W. Musial; "2014-2015 Offshore Wind Technologies Market Report", Sept 2015, NREL Report, Golden **CO.** http://www.nrel.gov/docs/fy15osti/64283.pdf

New 6-8 MW Offshore Purpose Designed Machines are Beginning to Drive Down Cost

Preliminary Data Suggest Lower OSW LCOE than Expected

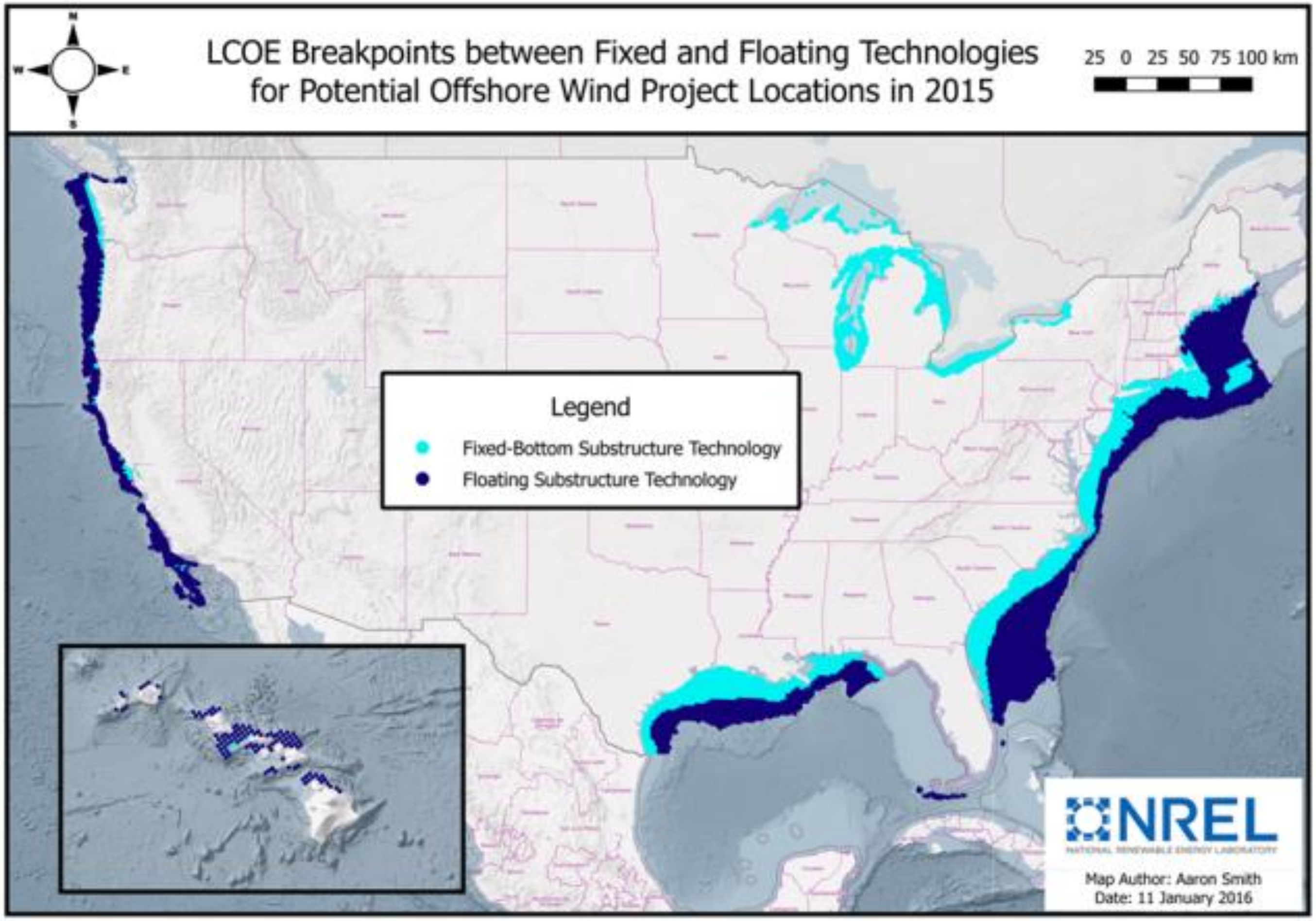


Bathymetry Map of the US Outer Continental Shelf

Source: 2016 Offshore Wind Energy Resource Assessment for the United States.
Link: http://www.nrel.gov/docs/fy16osti/66599.pdf

Map shows greater water depths in Pacific

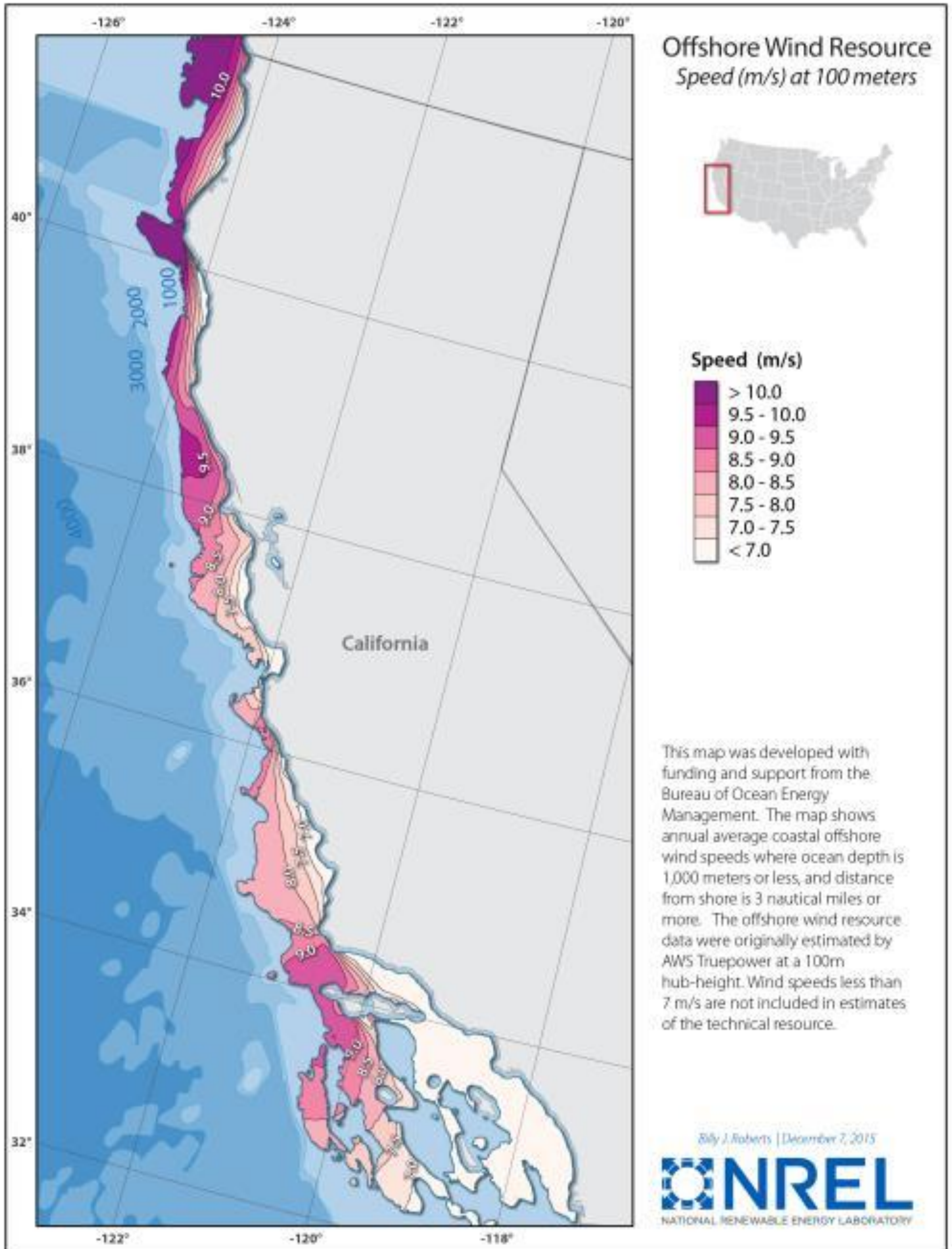
Fixed and Floating Technology – Break Points for LCOE



Beiter et al 2016 http://www.nrel.gov/docs/fy16osti/66579.pdf

Pacific Coast is Best Suited for Floating Offshore Wind Technology

California Offshore Wind Resources



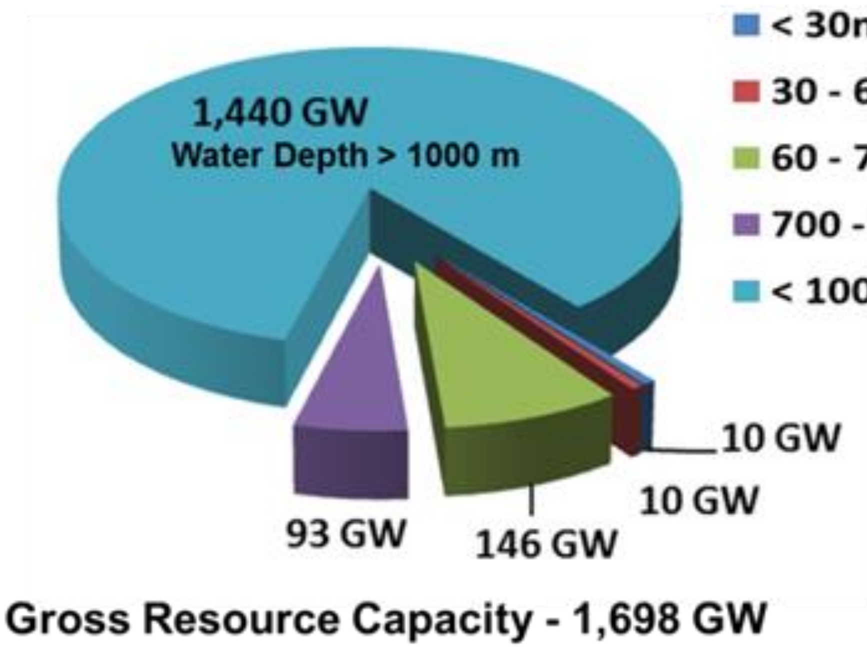
Gross versus Technical Resource Potential in CA

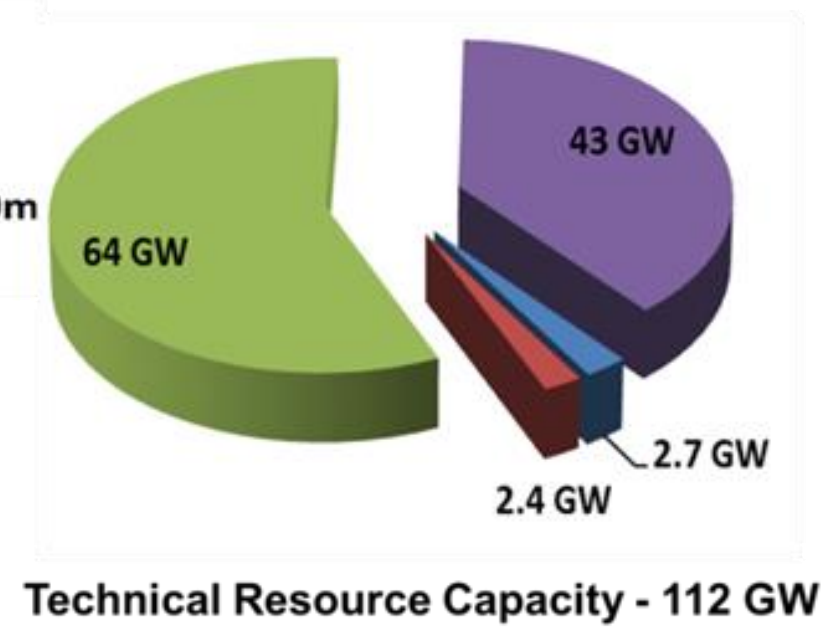
Technology Exclusions

- None
- All area 0 to 200 nm

Technology Exclusions

- >1000 m
- < 7 m/s





Source: 2016 Offshore Wind Energy Resource Assessment for the United States.
Link: http://www.nrel.gov/docs/fy16osti/66599.pdf

Competing Use Exclusions

None

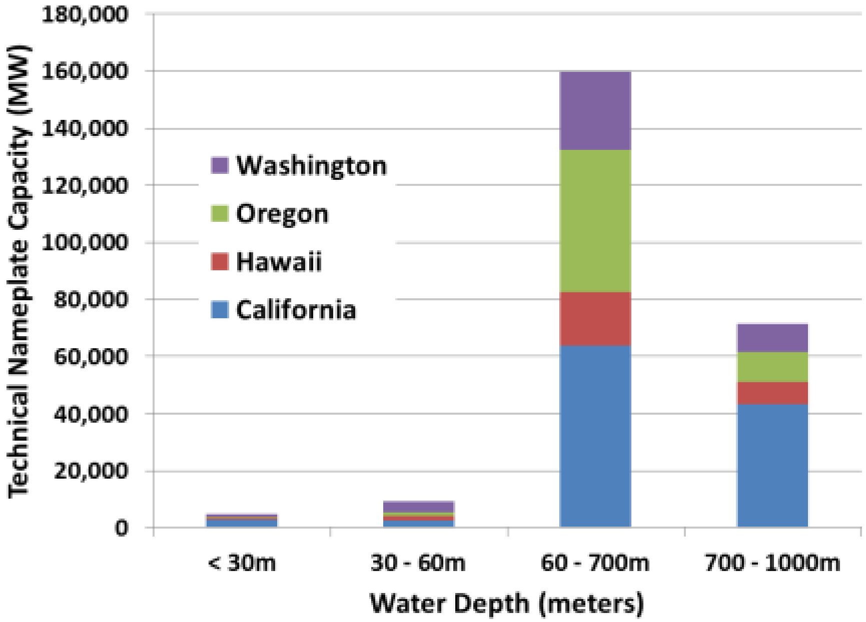
Competing Use Exclusions

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

Pacific States – Technical Resource Offshore Wind Resource by Water Depth (Source: NREL)

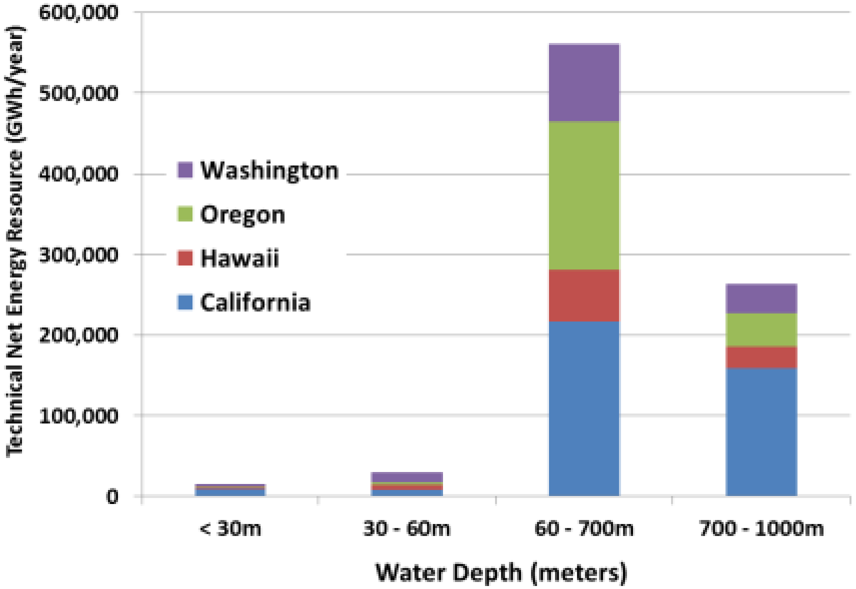
Source: 2016 Offshore Wind Energy Resource Assessment for the United States.
Link: http://www.nrel.gov/docs/fy16osti/66599.pdf

Nameplate Capacity (MW)



State	< 30m	30 - 60m	60 - 700m	700 - 1000m	Grand Total
California	2,769	2,498	63,881	43,307	112,455
Hawaii	617	1,801	18,711	7,802	28,930
Oregon	478	1,187	49,706	10,538	61,910
Washington	1,030	3,624	27,483	9,806	41,944
Total	4,894	9,111	159,780	71,454	245,239

Net Energy Potential (GWh/year)

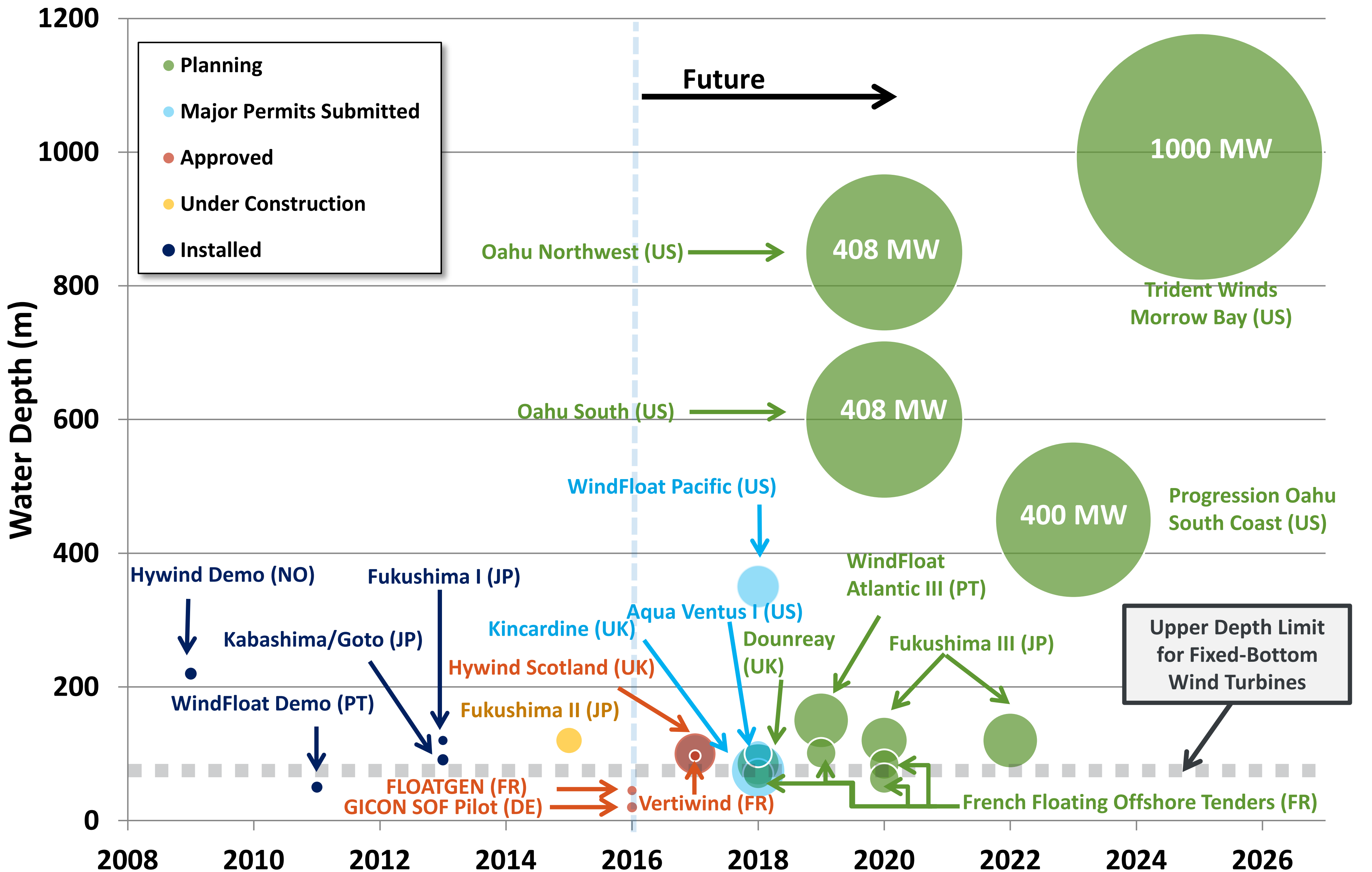


State	< 30m	30 - 60m	60 - 700m	700 - 1000m	Grand Total
California	8,920	8,068	216,579	158,348	391,915
Hawaii	2,049	6,127	64,100	27,608	99,885
Oregon	1,504	3,877	183,961	40,888	230,230
Washington	3,079	11,684	95,889	35,984	146,636
Total	15,552	29,756	560,529	262,828	868,665

Assumptions: Conflicting Use and Environmental Exclusions based in Black and Veatch Study; 0-3 nm 48%, 3-12 nm 38%;12-50nm 21%; Wind speeds at 100 m; water depth ,1000 m; wind speeds > 7m/s; Array power density 3 MW/km^2

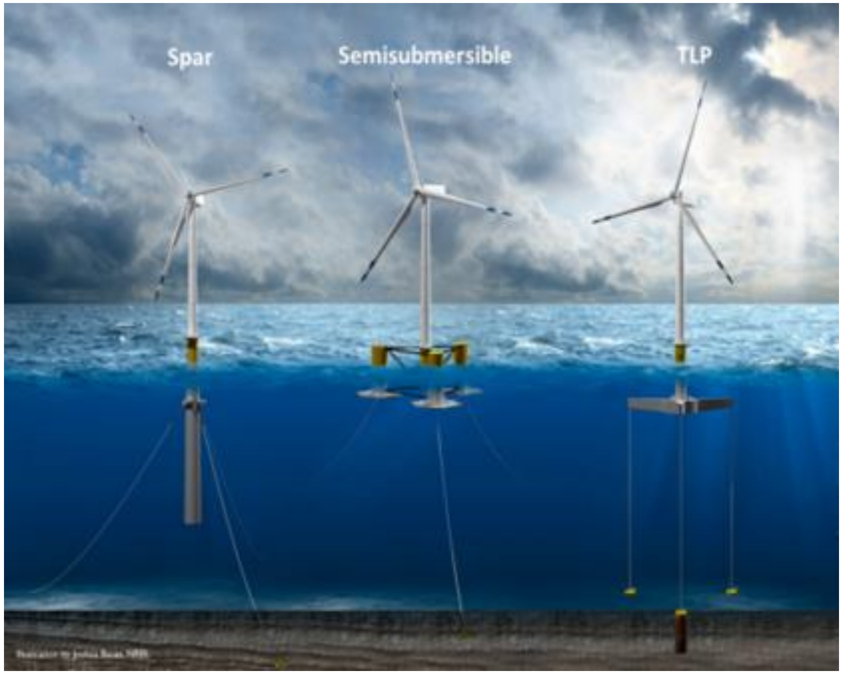
Floating Wind Energy Global Market Timeline

Data Source: NREL



Floating Offshore Wind Technical Challenges

- Reduce levelized cost of energy
- Mature and validate design tools
- Develop floating wind design standards
- Make systems more deployable to minimize large vessel dependence
- Develop dynamic electric cables and mooring/anchor systems
- Overcome higher Pacific sea states with advanced O&M practices
- Establish infrastructure for offshore grid interconnect; ports for service and construction

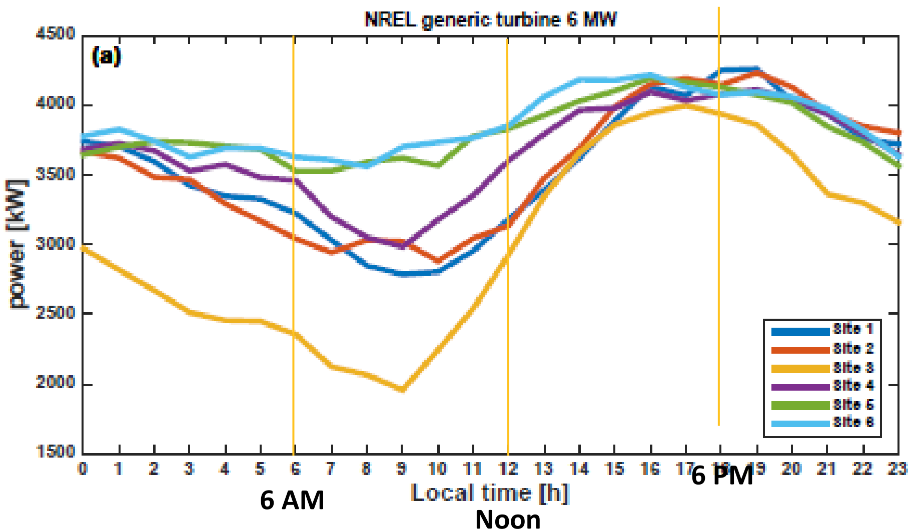


Floating Turbine Configurations (source: NREL)

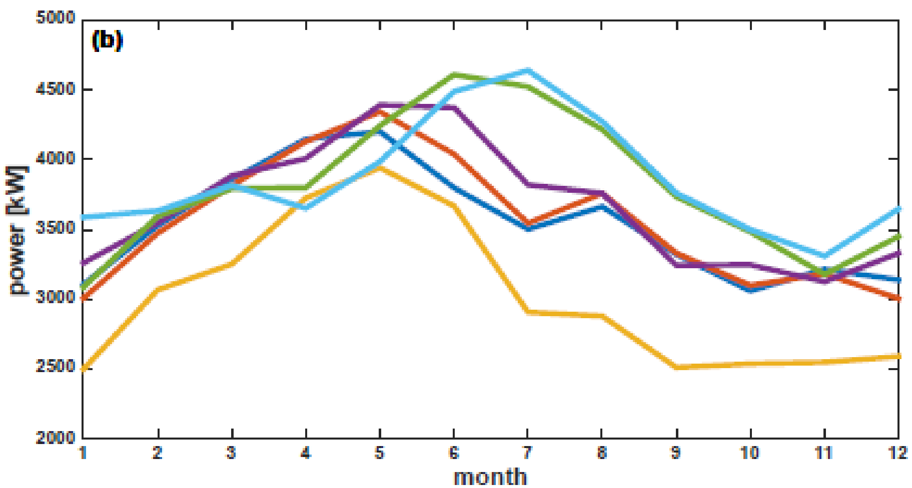
Photos: Left Statoil Hywind I – First offshore wind turbine 2009 Credit NREL PIX 27845

Hourly OSW Power Production: 6 Reference Sites in CA

Note: reference sites are to illustrate behavior of wind resource only



Diurnal Power Characteristics of 6 OSW Sites (March)



Average Monthly Power for 6 OSW Sites (source: NREL)

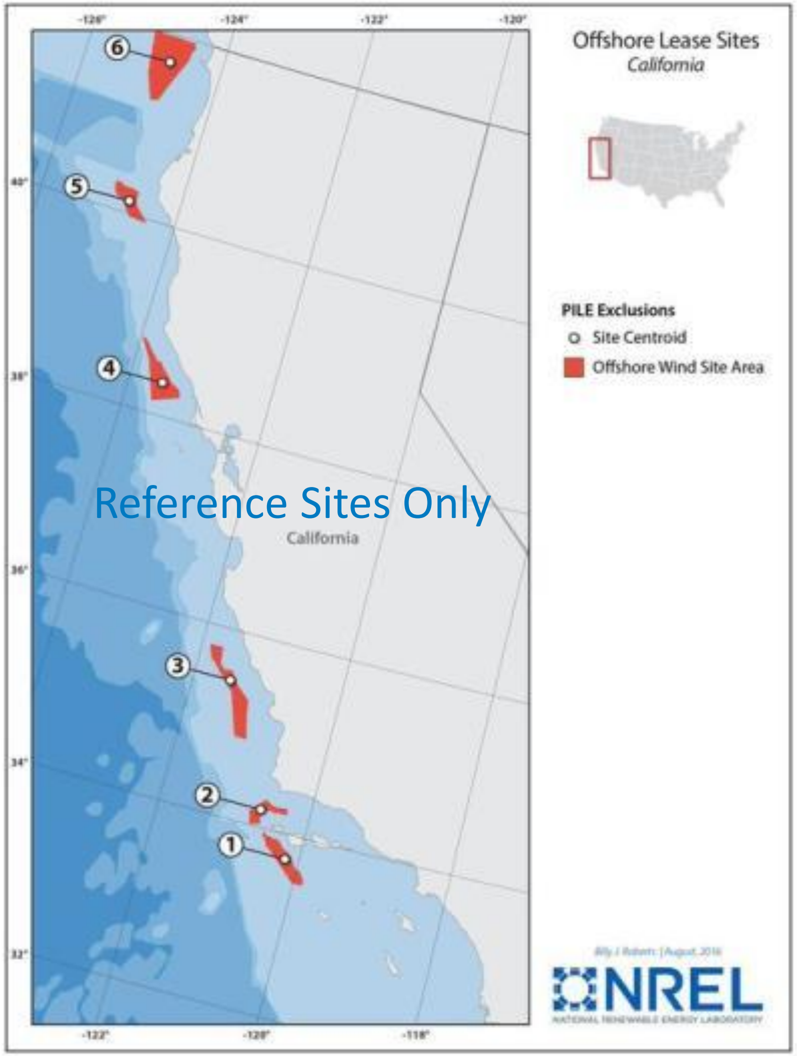
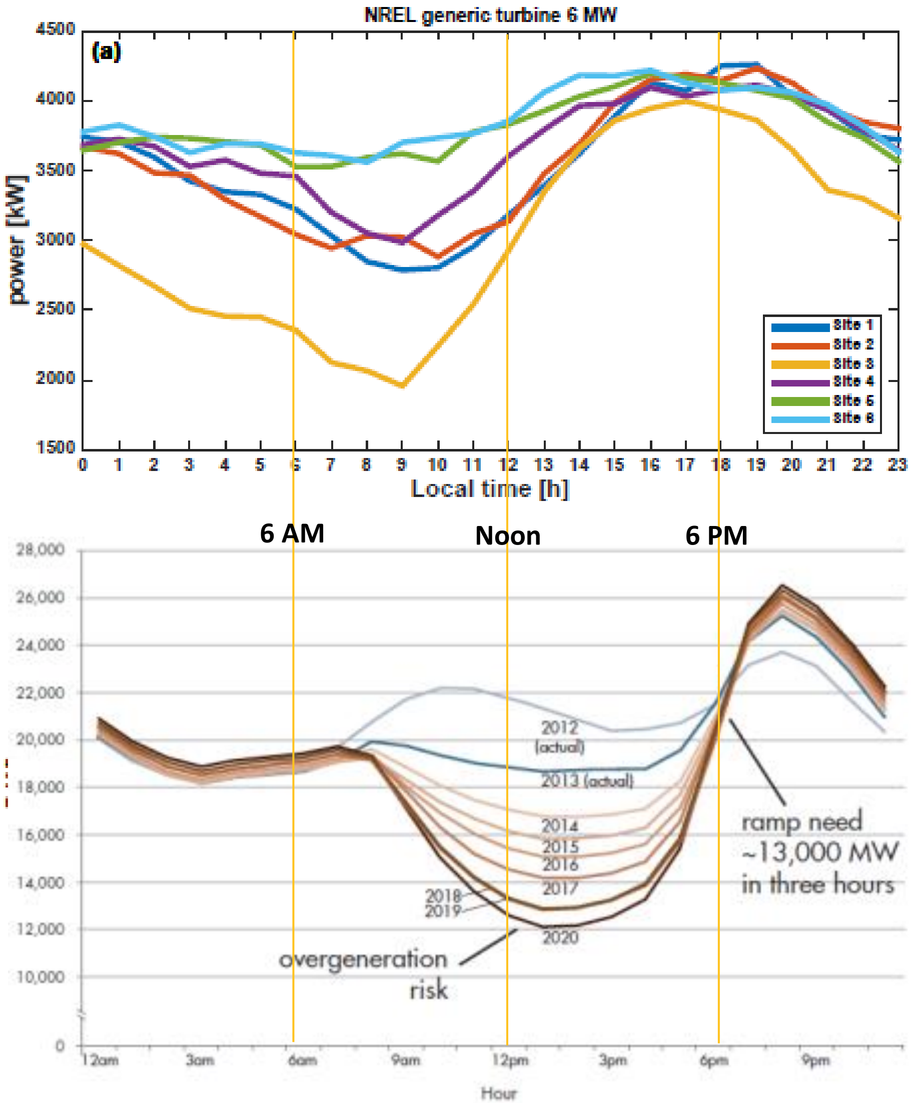


Figure shows six reference site used to calculate offshore wind (Source :NREL)

CA Duck Curve - Preliminary Observations



- All 6 CA reference sites follow similar diurnal patterns for offshore wind from Channel Islands to OR border
- Offshore wind peak may correlate with hourly and seasonal demand
- Offshore wind characteristics may compliment solar to offset curtailment risk

Duck Curve (lower) Compared to Diurnal Power Characteristics of 6 Preliminary OSW Sites Identified (Upper)

Figure Source: NREL (upper) https://www.caiso.com/Documents/FlexibleResourcesHelpRenewables_FastFacts.pdf

Technology Assumptions for Present and Future Offshore Wind Turbines

	2015 Technology	2020 Technology	2025 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	Floating	Floating	Floating

- Turbine size is expected to increase – trend show lower cost with size
- Impact of technology innovation based on DELPHOS tool assumptions for fixed bottom systems out to 2025
- NREL floating model estimated impact of innovations out to 2030.

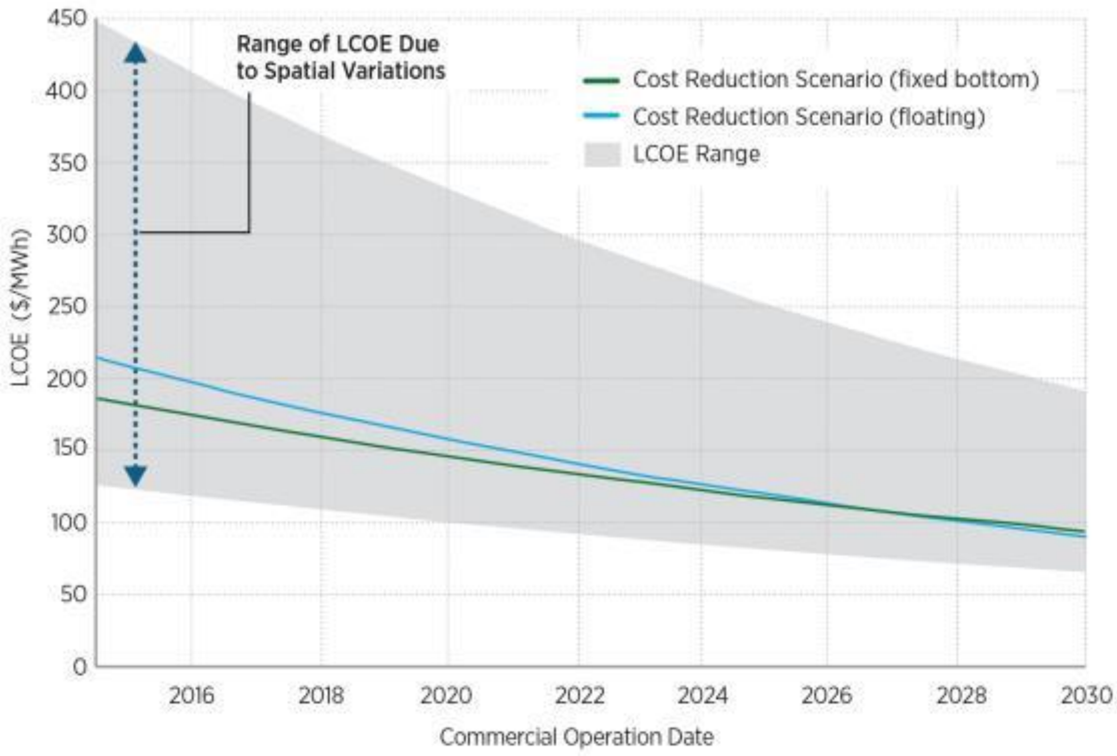
Beiter, P., W. Musial, A. Smith, L. Kilcher, R. Damiani, M. Maness, S. Sirnivas, T. Stehly, V. Gevorgian, M. Mooney, G. Scott. 2016. A Spatial-Economic Cost-Reduction Pathway Analysis for U.S. Offshore Wind Energy Development from 2015-2030. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A20-66579 http://www.nrel.gov/docs/fy16osti/66579.pdf

NREL Geo-spatial Offshore Wind Cost Model

Modeling Approach:

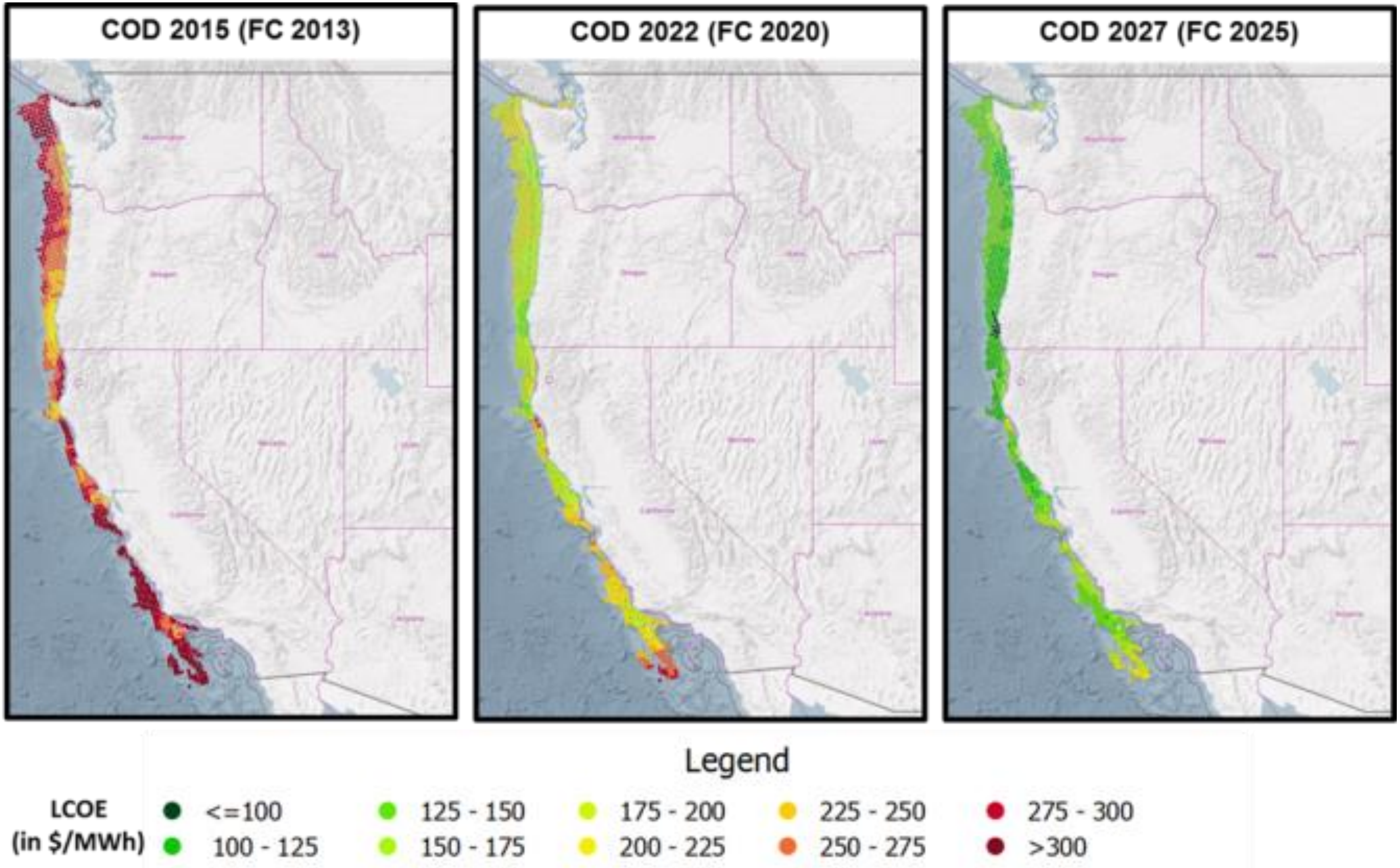
1. Estimate LCOE using NREL Geo-spatial Offshore Wind Cost Model (Beiter et al 2016)
2. Geo-spatial cost variables include water depth, wind resource, substructure type, turbine size, distance to port, distance to cable interconnect, installation method, sea state.
3. Temporal cost variables estimate cost reduction potential through 2030
4. Vet results against literature and industry Data
5. Fixed and Floating Scenarios for Likely Sites Show LCOE Below 100 MWh by 2025 in Some sites

Beiter et al 2016
http://www.nrel.gov/docs/fy16osti/66579.pdf



- Geographic Variations Result in Wide Range of LCOE
- Floating Wind Can Reach Fixed Bottom Costs by 2030
- Results Depend on Supply Chain Growth and Maturity

Estimated LCOE in the Pacific Coast Region



Good Wind Resources – High Sea States Challenge O&M and Availability

Beiter et al 2016 http://www.nrel.gov/docs/fy16osti/66579.pdf

Floating Offshore Wind Summary

- Global fixed bottom markets show about 250 GW in pipeline with cost trending downward
- Floating offshore wind at nascent stage with growing market
- Resource can support multi-GW deployment scale
- Floating offshore wind costs are higher than current fixed LCOE, but has the potential to be economically competitive
- Floating wind has beneficial characteristics that may offset challenges of water depth (lower vessel dependence, siting)
- Preliminary analysis shows offshore wind hourly characteristics may complement solar in CA in high penetration scenarios.

Thank you for your attention!

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Photo Credit : Dennis Schroeder-NREL

Selected References

1. Beiter, P., W. Musial, A. Smith, L. Kilcher, R. Damiani, M. Maness, S. Sirnivas, T. Stehly, V. Gevorgian, M. Mooney, G. Scott. 2016. A Spatial-Economic Cost-Reduction Pathway Analysis for U.S. Offshore Wind Energy Development from 2015-2030. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A20-66579 http://www.nrel.gov/docs/fy16osti/66579.pdf
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4. MERRA: MODERN-ERA RETROSPECTIVE ANALYSIS FOR RESEARCH AND APPLICATIONS, http://gmao.gsfc.nasa.gov/research/merra/
5. Musial et al "2016 Offshore Wind Energy Resource Assessment for the United States" NREL Report Link: http://www.nrel.gov/docs/fy16osti/66599.pdf
6. Rhodri James and Marc Costa Ros, "Floating Offshore Wind: Market and Technology Review" Prepared for the Scottish Government by the Carbon Trust, June 2015 https://www.carbontrust.com/media/670664/floating-offshore-wind-market-technology-review.pdf
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9. Valpy, B. ;English, P.; Martínez, A.; Simonot, E.;"Future renewable energy costs: offshore wind" © KIC InnoEnergy, 2014, ISBN 978-94-92056-00-9 : http://www.kic-innoenergy.com/wp-content/uploads/2014/09/KIC_IE_OffshoreWind_anticipated_innovations_impact1.pdf

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