U.S. Perspectives on Floating Offshore Wind Energy

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Site Visit off Peterhead, Scotland
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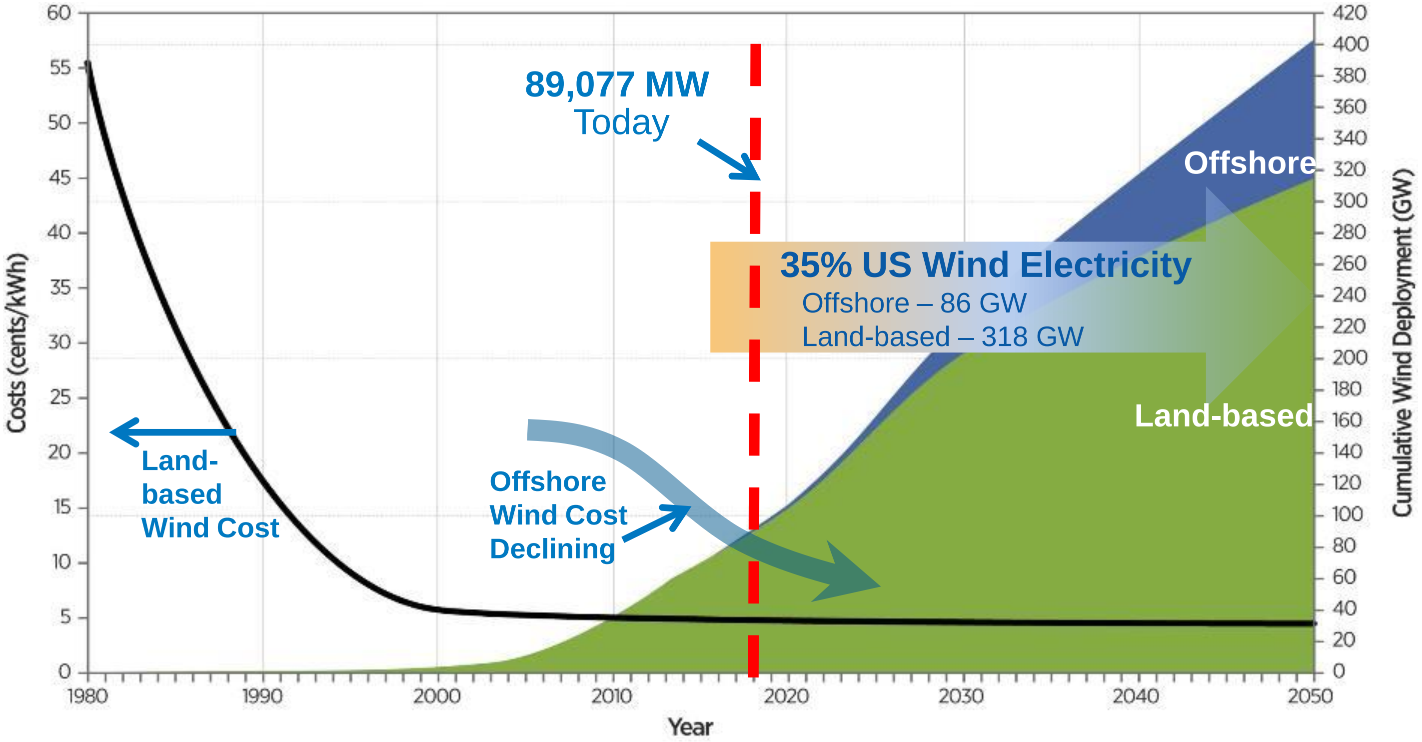
2019 FRENCH AMERICAN INNOVATION DAY BOSTON

Northeastern University
Monday, March 18th

U.S. *Wind Vision* Study - 35% of Electricity From Wind by 2050



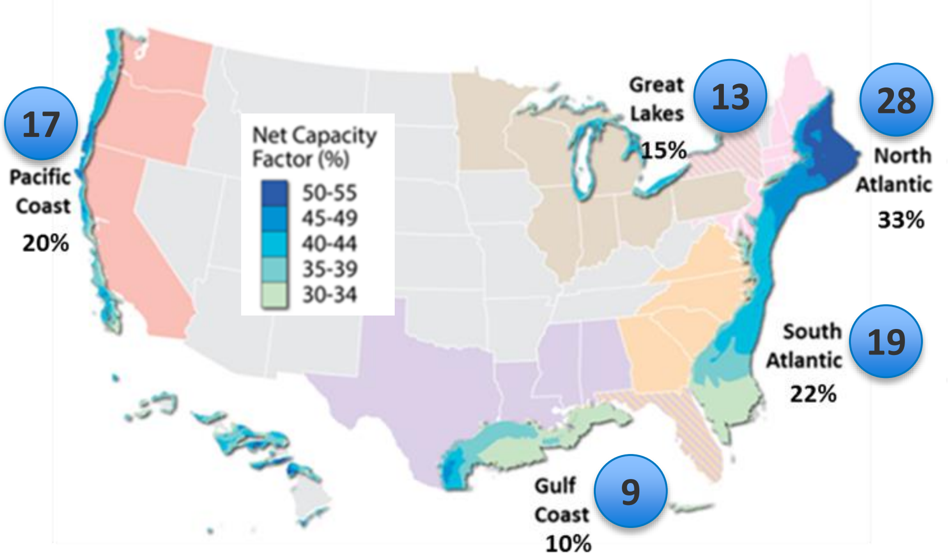
Offshore Wind is 20% of Total U.S. Wind Energy by 2050

U.S. *Wind Vision* Study Scenario Estimates 86 GW from Offshore

DOE. 2015a. *Wind Vision*: A New Era for Wind Power in the United States. U.S. Department of Energy Office of Energy Efficiency and Renewable Energy. DOE/GO-102015-4557. Washington, D.C. Accessed May 2015. http://www.energy.gov/sites/prod/files/WindVision_Report_final.pdf

DOE/DOI Strategy for Offshore Wind

86 GW of Offshore Wind in US by 2050



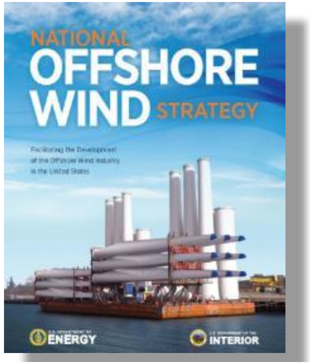
Offshore Wind Regions from Wind Vision showing percentages of the 86 GW scenario for each region. (Percentages and bubbles indicate share of the prescribed 86 GW that each region contributes by 2050.)

- **Assumption:** All regions of the US participate in offshore wind deployment
- Some regions (**Pacific)** can only participate with floating technology
- Some regions may need floating wind achieve sufficient deployment (**Northeast, Great Lakes**)

2015

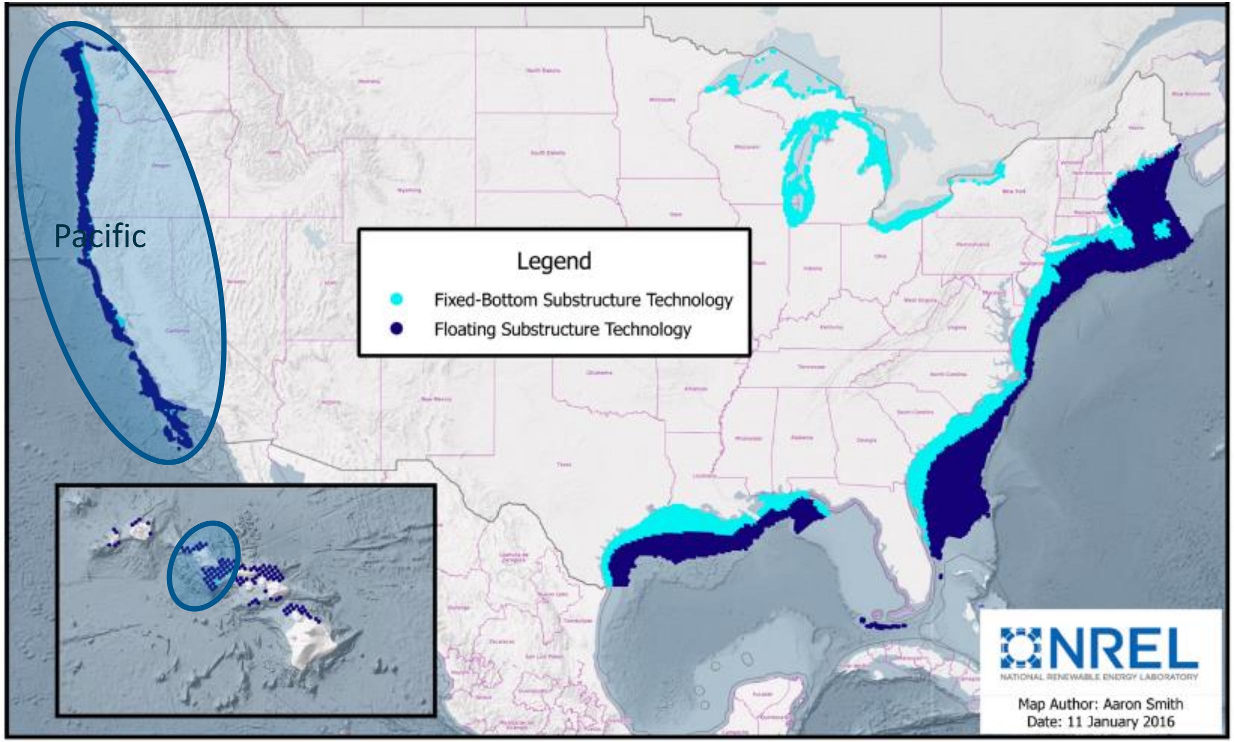
http://energy.gov/eere/wind/downloads/v vision-new-era-wind-power-united-state

2016



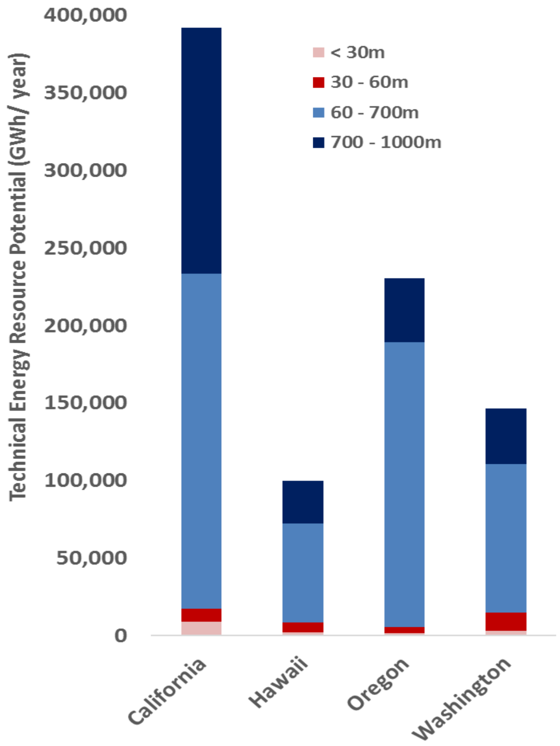
http://energy.gov/sites/prod/files/2016/09/f33/ National-Offshore-Wind-Strategy-report-09082016.pdf

Floating Offshore Wind Technology: Regional Markets



58% of the U.S. offshore wind resource is in water depths greater than 60 m

Pacific Regions: Deep Water Energy Resource

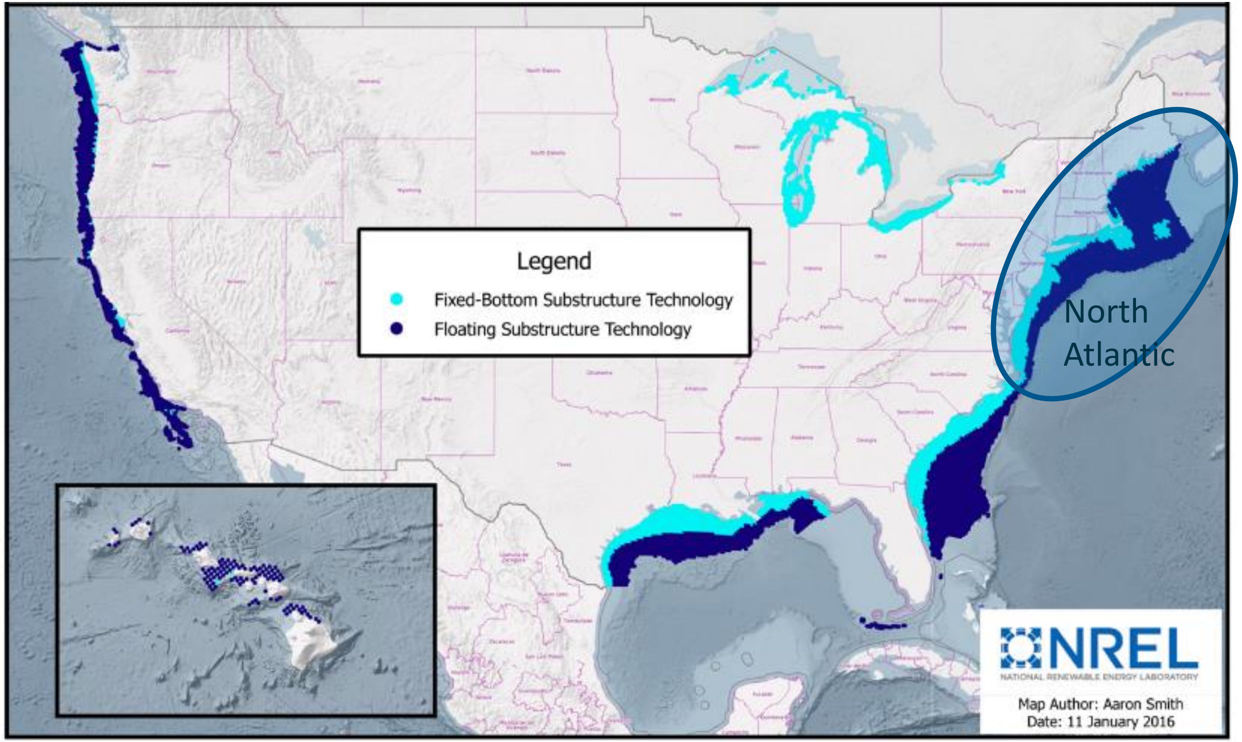


Offshore Wind Resource for Pacific States

- 868 TWh/year total offshore wind technical energy resource
- 95% of the offshore wind energy resource (823 TWh/year) is in water deeper than 60 m
- Key technology challenges:
  - ❑ Minimizing visual impacts while remaining in waters below 1000 meters depth: project sites may be limited to water depths 500 m to 1000 m
  - ❑ High wave climate may require enhanced O&M strategies to increase accessibility

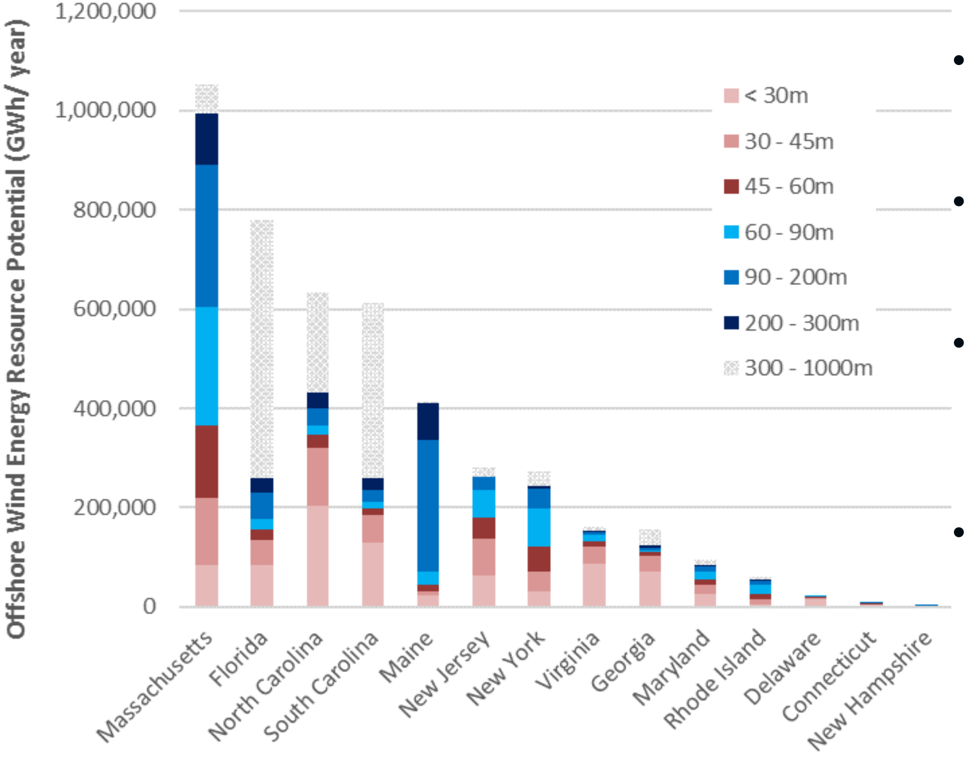
Data Source: Musial, W. et al. ***2016 Offshore Wind Energy Resource Assessment for the United States***. NREL/TP-5000-66599. http://www.nrel.gov/docs/fy16osti/66599.pdf

Floating Offshore Wind Technology: Regional Markets



58% of the U.S. offshore wind resource is in water depths greater than 60m

North Atlantic States: Deep Water Energy Resource

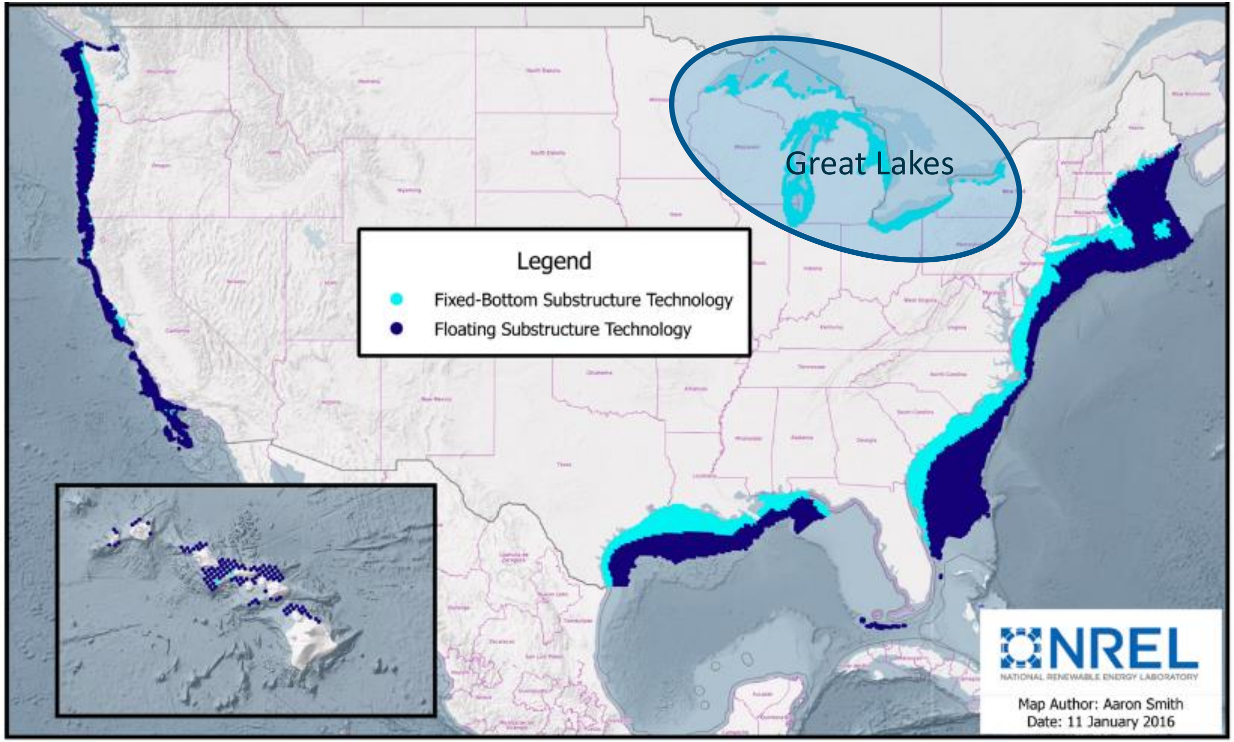


Offshore Wind Resource for Atlantic States

- Eastern states may benefit from fixed bottom AND floating OSW
- 1,543 TWh/year in depths between 60 and 300 meters
- Siting options in the Atlantic coast may be greater in deeper waters in the future
- Key technology challenges: Shallow water moorings, shallow draft substructures

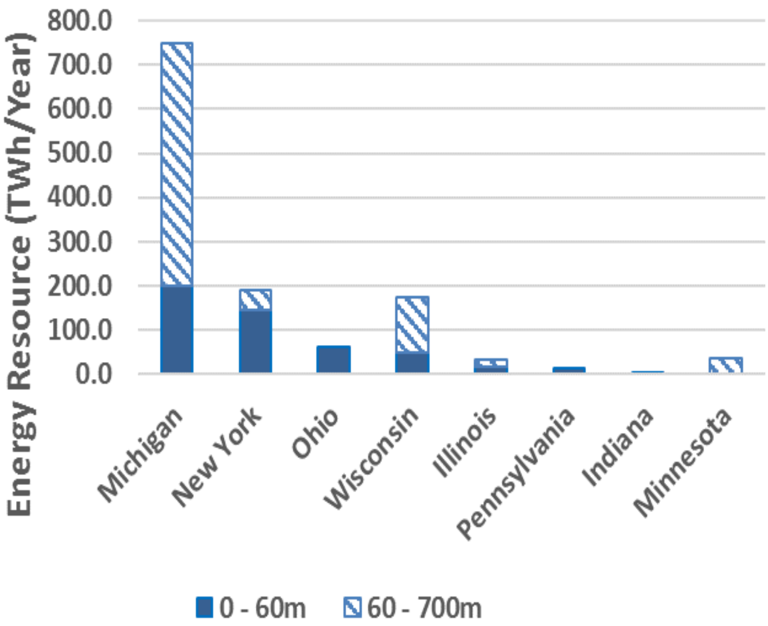
Data Source: Musial, W. et al. ***2016 Offshore Wind Energy Resource Assessment for the United States***. NREL/TP-5000-66599. http://www.nrel.gov/docs/fy16osti/66599.pdf

Floating Offshore Wind Technology: Regional Markets



58% of the U.S. offshore wind resource is in water depths > 60m - floating foundations

Great Lakes: Deep Water Energy Resource



Offshore Wind Resource for Great Lakes States

Data Source: Musial, W. et al. ***2016 Offshore Wind Energy Resource Assessment for the United States***. NREL/TP-5000-66599. http://www.nrel.gov/docs/fy16osti/66599.pdf

- Total Great Lakes energy production potential in water less than 60-m depth is 492 TWh/year
- Total (uncounted) energy resource in water greater than 60-m depth is 771 TWh/year
- Key Technology Challenge: Development of offshore wind floating technology for survival in fresh water ice

Photo to Right: Courtesy of Ken Croasdale

Commercialization Path for Floating Wind Energy

Photo: Equinor Scotland
30 MW 5 Turbines – Credit: Walt Musial

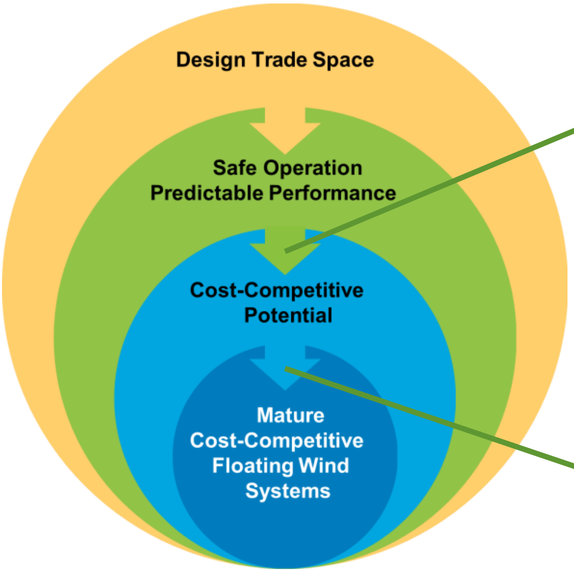
Proof of Concept Phase
2009 to 2016
6 full-scale prototypes totaling about 20-MW
2 - 7 MW turbines

Pre-commercial Phase
2017 to 2023
Multi-turbine commercial arrays
12 – 50 MW projects
11 projects totaling 229-MW

Commercial Floating Arrays
2024 and beyond
400 MW+ arrays proposed
Principle Power – Hawaii/California
Progression - Hawaii
Equinor - TBD
Trident Wind - California
Dyfed/Kantanes – United Kingdom

Next Generation Floating System Design Strategy

Standards do not limit the floating tradespace enough to apply high fidelity design tools



Floating Wind Optimization Strategy

Intelligent Constraints for Cost Reduction

- Minimize operational loading and platform motion
- Platform design standardization (site independence)
- Scalability
- Weight Minimization
- Mooring and anchoring system compatibility
- Manufacturability
- Deployability (stable configuration during tow-out)
- Minimize work at sea
- Maintainability- Corrosion control and prevention
- Decommissioning

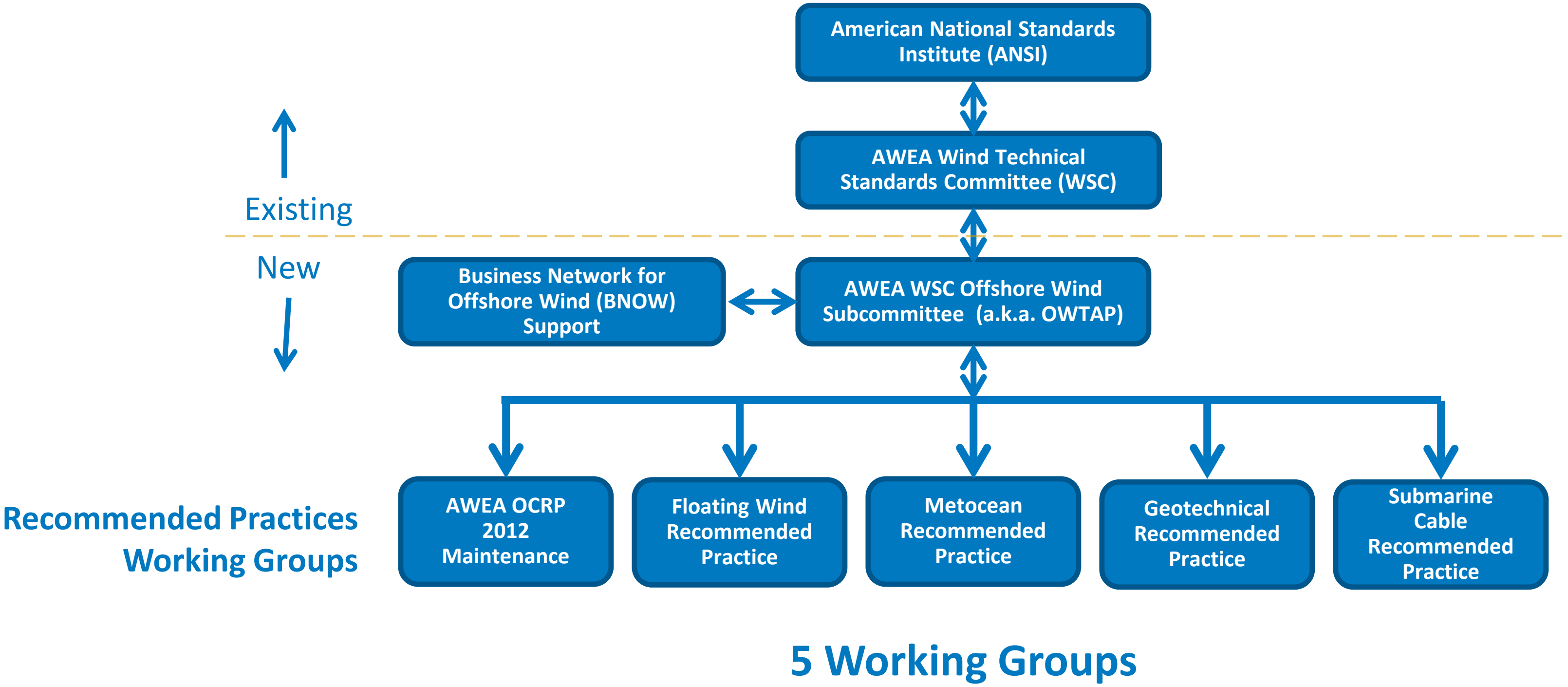
Multi-fidelity Systems Optimization

- Union of all disciplines and costs into a framework of engineering and systems engineering tools
- Multi-fidelity capability and support for uncertainty quantification
- Cost Competitive Floating Wind Systems Design Configurations is end goal

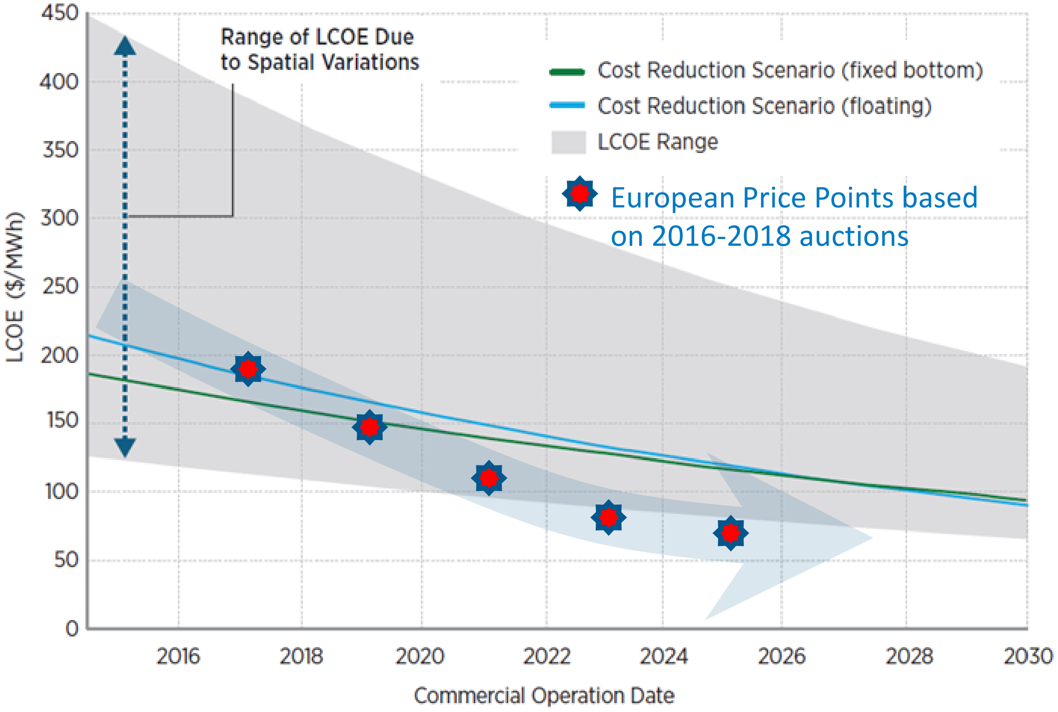
Linking Engineering Design Constraints to Cost Optimization

Offshore Wind Standards Initiative – Leading to Maturity

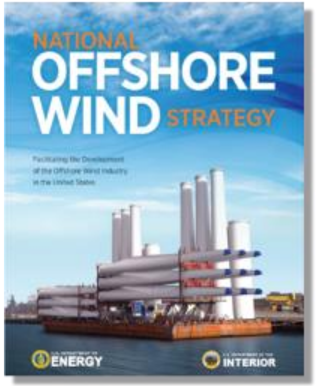
Objective: Develop a comprehensive set of consensus-based roadmaps to navigate the existing standards and guidelines to facilitate safe designs and orderly deployment of U.S. offshore wind energy, and provide DOI with recommended practices that document industry "best practices".



DOE/NREL Strategy Shows Floating Offshore Wind has the Potential for Low Cost



September 2016



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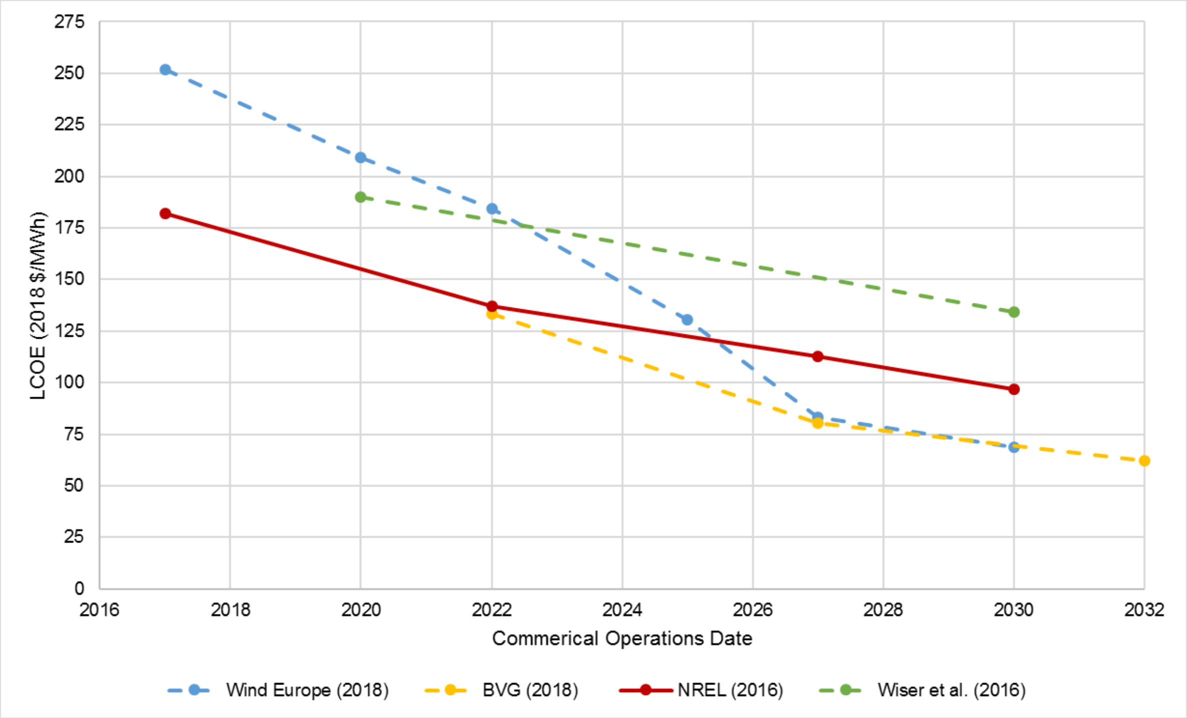
LCOE (unsubsidized) for potential offshore wind power projects from 2015-2030 (COD) for U.S. technical resource area
Reference scenarios from offshore wind strategy show floating LCOE can be lower than fixed bottom

Can European cost reductions be achieved in the United States? Floating?

Dynamic Floating Offshore Costs

Selected Floating Offshore Wind LCOE Trajectories



- Floating cost estimates are declining rapidly as new information is obtained
- NREL (2016) study for CA estimated $100/MWh by 2030
- BVG and Wind Europe (2018) estimate costs near $70/MWh by 2030
- New NREL modeling will deliver similar estimates
- Primary cost drivers:
  - Larger turbines – 12MW to 15 MW
  - Lower turbine prices
  - Lower finance costs
  - Integrated stable substructures
  - Quayside commissioning
  - Reduced cable costs

Business Case for Floating Offshore Wind

- **Resource Abundance:** 58% of U.S. OSW resource is > 60 meters
- **Reduce Siting Conflicts:** Major siting conflicts are likely to be reduced in deeper water, which tends to be farther from shore
- **Wind Vision:** Floating technology may be needed to achieve targets for 86 GW OSW per DOE/DOI strategy (e.g. Pacific)
- **Cost Reduction Potential:** Cost models have shown that floating wind technology has the potential to achieve the same cost (or lower) as fixed bottom OSW by 2030
- **Rapid Global Industry Pace:** The pace of floating technology advancement has been accelerating world-wide
- **Consistent Policy:** Floating OSW, expected to be commercialized within the next decade, can support an "all of the above" U.S. energy policy
- **National Leadership:** There is a significant economic opportunity in establishing national leadership in floating OSW technology

Thank you for listening – questions?

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https://www.nrel.gov/about/nwtc.html

Trip to Block Island Wind Farm – Oct 1, 2016

Photo Credit : Dennis Schroeder-NREL