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The Current State of R&D and Commercialization in U.S. Offshore Wind

Sandia National Laboratories

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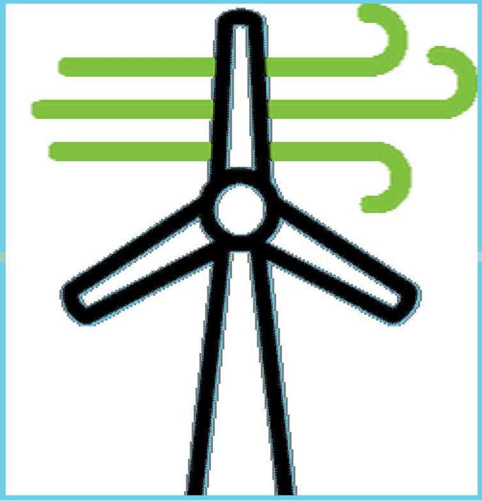
on behalf of the National Offshore Wind R&D Consortium



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Current State of Commercialization

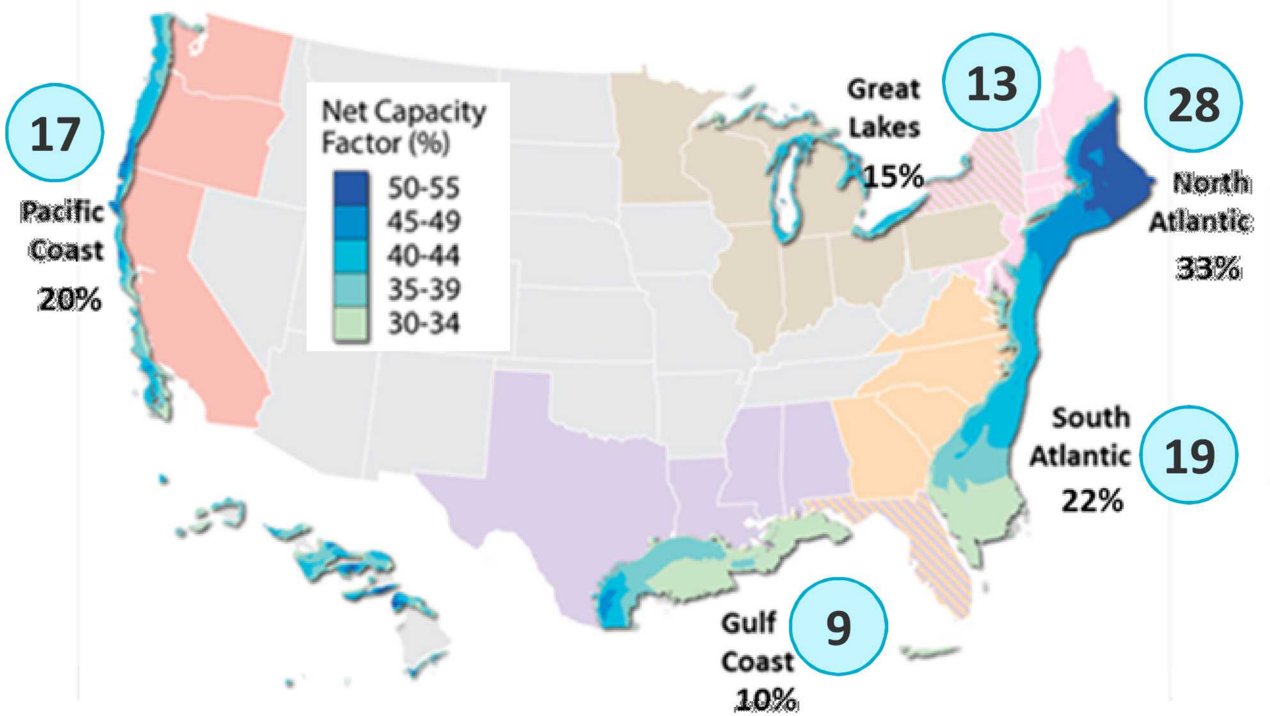
Offshore Wind – Global Industry Status

GE-Haliade 6 MW Turbines 30 MW Block Island Wind Farm Rhode Island

- 176 projects, over 22,592 MW installed (end 2018)
- Typically fixed bottom support structures in shallow water (<50 m)
- Current Turbine capacity 6.0 – 9.5 MW
- Upwind rotors – 150 m -170 m diameter
- Tower height – 25-m plus rotor radius (min)
- Drivetrain – Direct drive or geared with medium speed generators
- Capacity factors 40 to 55 percent
- **Capital cost $4,350/kW in 2018, declining to below $3,000/kW by 2030**
- O&M cost higher than land-based
- Leverages and expands opportunities for existing mature marine industries:
  - Offshore oil and gas
  - Submarine cable
  - Marine operations

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.)*

All regions of the US participate in offshore wind deployment

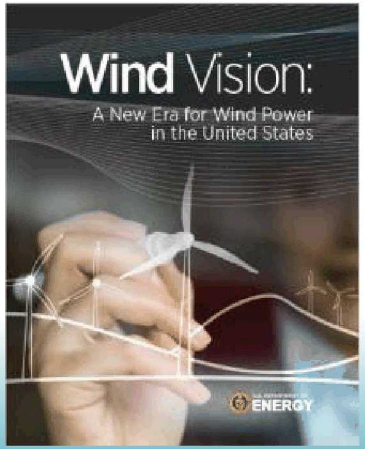
Pacific can only participate with floating technology.

Northeast, Great Lakes may need floating wind and fix-bottom wind

Great Lakes will require new technology for floating ice resistance

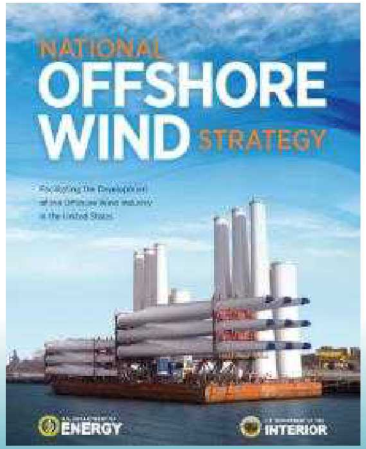
Gulf of Mexico and South Atlantic will need hurricane resistant designs

2015



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

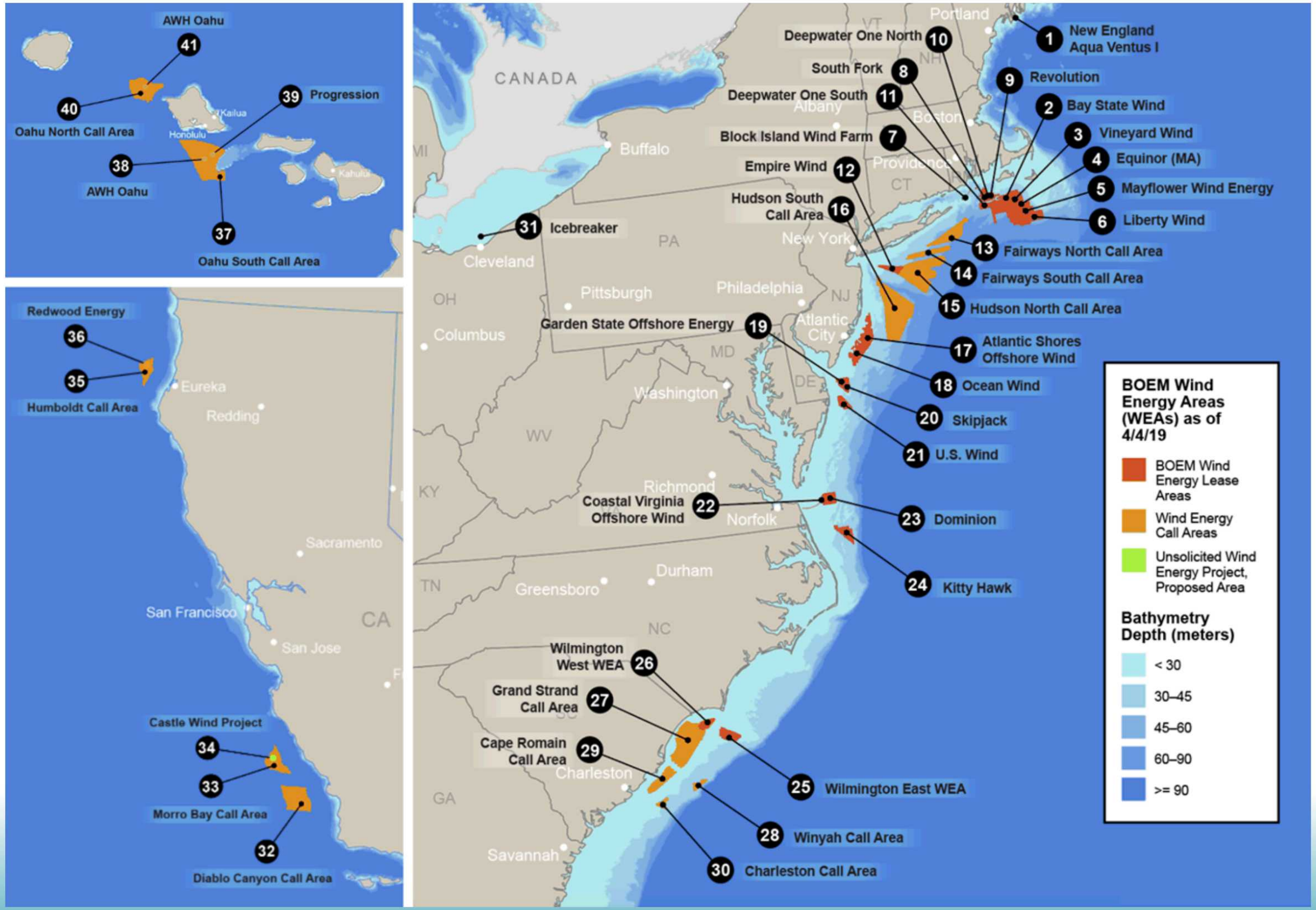
2016



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

U.S. Offshore Wind Industry Regulatory Activity

- Bureau of Ocean Energy Management (BOEM) given authority under EPAct 2005
- 30 CFR 585 released in 2009 provides regulatory framework for federal waters
- Offshore Wind lease sales begin in 2011
- BOEM works with state task forces prior to lease area designation
- 16 lease areas have been sold in public auctions (about 21 GW)
- **Call areas (13)** are nascent ocean tracts under consideration for possible leasing



U.S. State Offshore Wind Policy Commitments

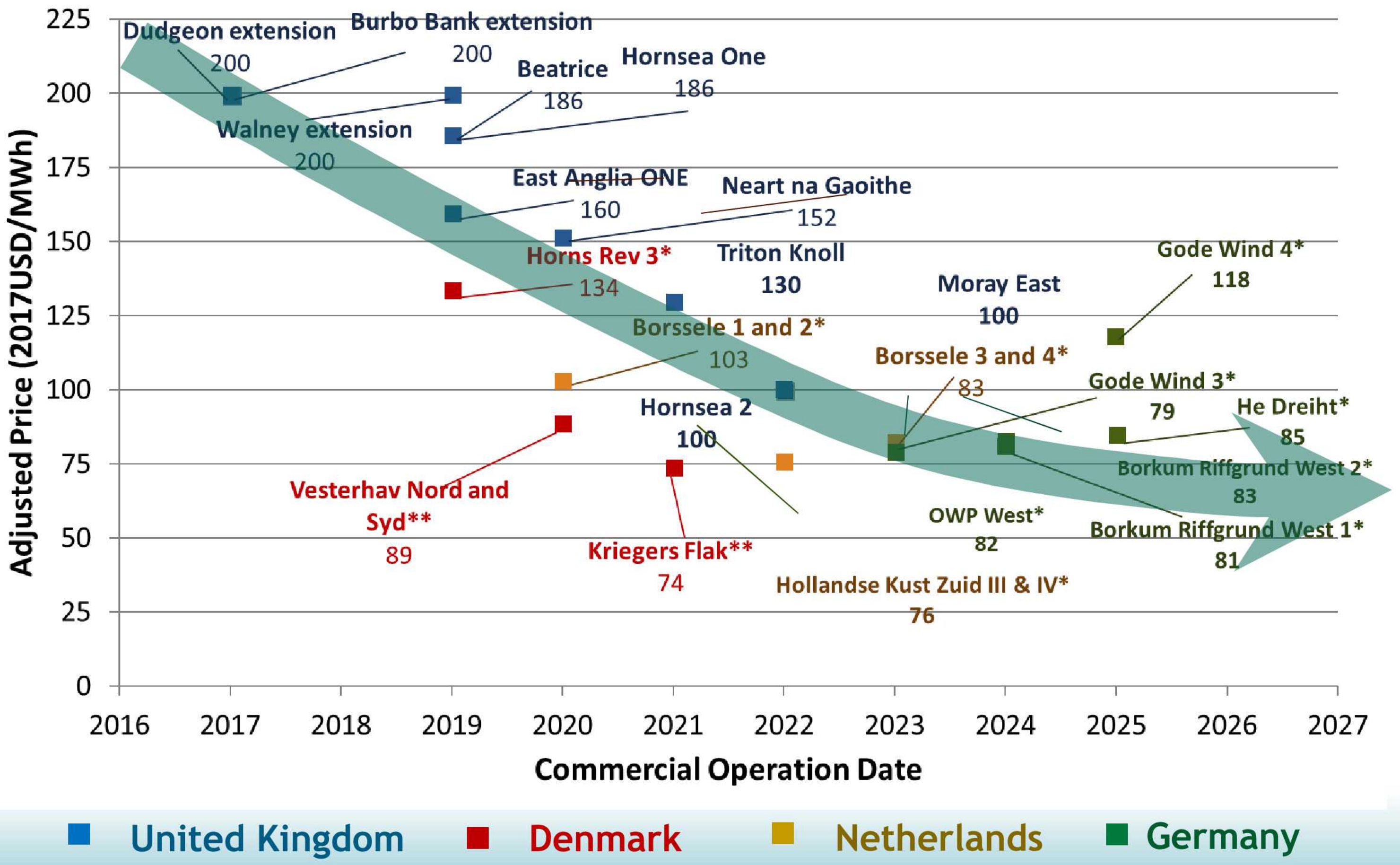
- 26,480 MW* committed by 2035
- 13,956 MW* committed by 2030
- 8 States
- $80 Billion in gross revenue possible
- Global forecasts predict 154 to 193 GW of Offshore Wind by 2030 and 500 GW by 2050
- Regulatory project pipeline for U.S. is calculated at 25,824 MW

*increased by 2,5000 MW from August market report after VA Gov. Northham's Executive Order in Sept. 2019

Why are prices coming down?

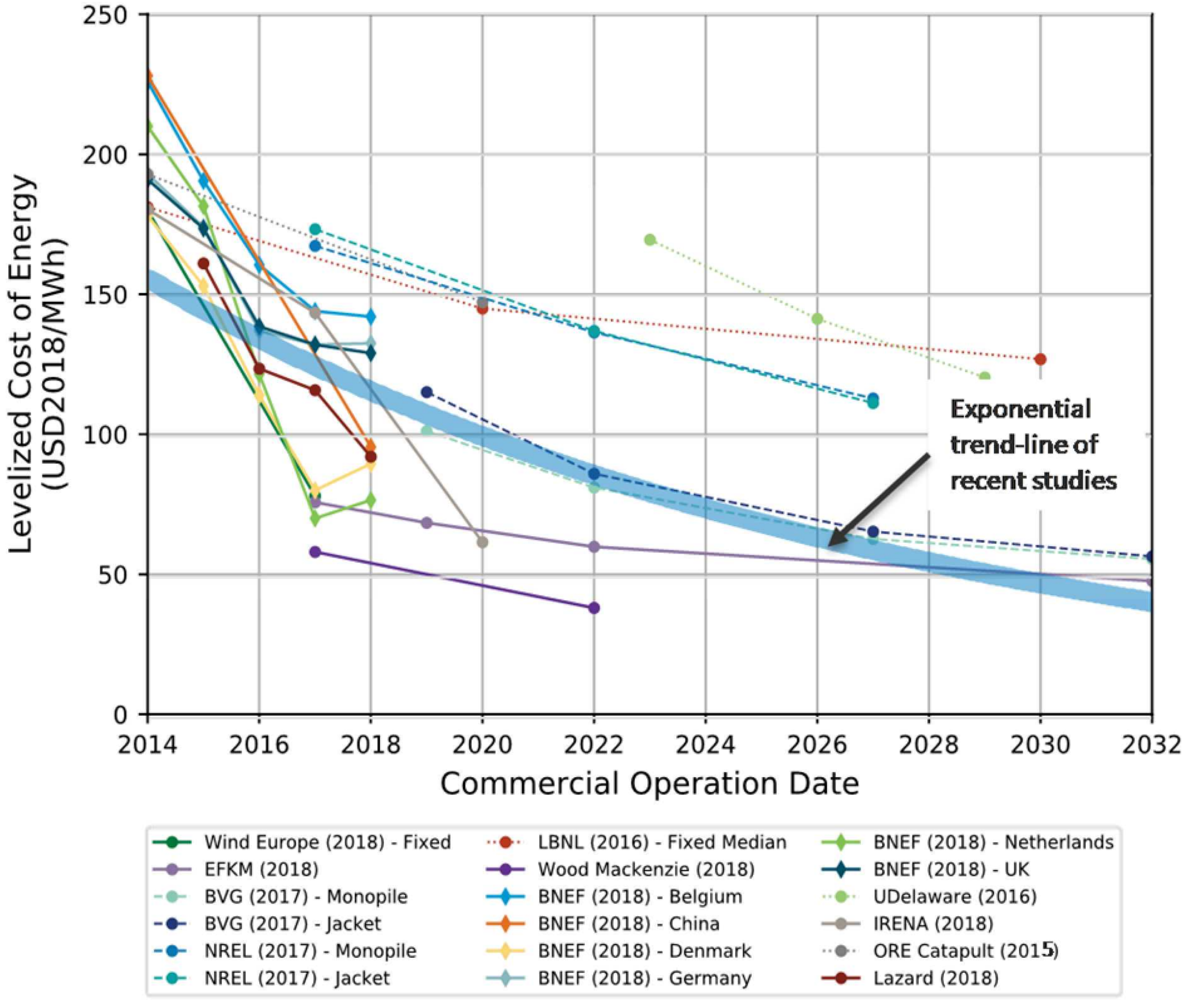
Date reflect estimated levelized revenue based on winning bids and expected wholesale power market revenues

- Technology Improvements
- Lower Risk
- Maturing Supply Chains
- Increased Competition



Notes: *Grid and development costs added; **Grid costs added and contract length adjusted
Sources: NREL Spatial Cost Model; BNEF 2017 (German price projections); PBL Netherlands Environmental Assessment Agency (2018) (Dutch price projections)

Fixed-Bottom LCOE Forecasted to Decline to $50/MWh by 2030

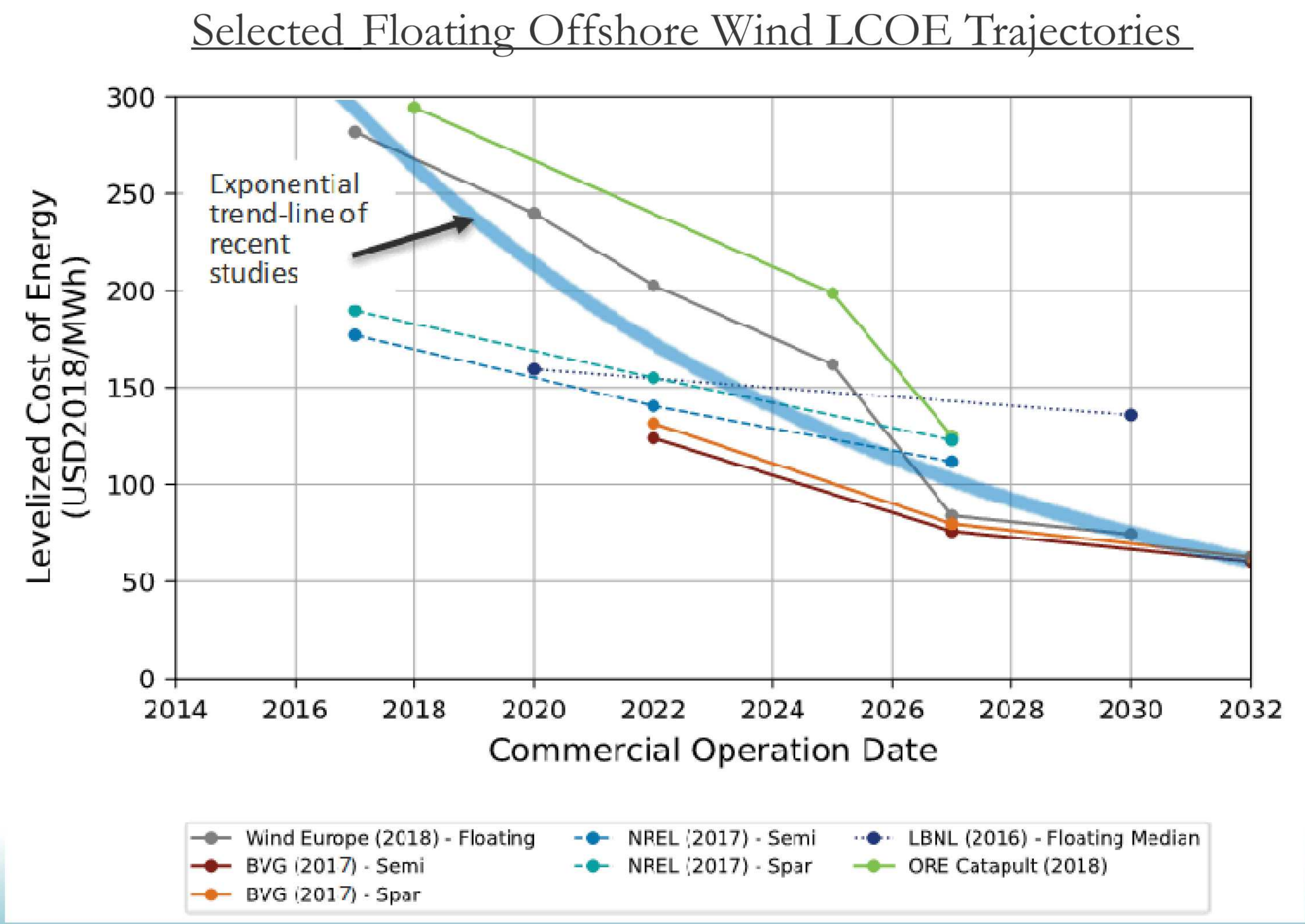


Analysts generally agree the cost reduction trend for fixed-bottom projects will continue globally and in the United States.

Levelized cost of energy projections (LCOE) from the most recent studies suggest a decrease from $120/MWh in 2018 to $50/MWh by 2030.

Sources: WindEurope (2018), Danish Ministry of Energy, Utilities and Climate (2018), Valpy et al. (2017), Beiter et al. (2017), Wiser et al. (2016), Barla (2018), BNEF (2018b, 2018c), Kempton et al. (2016), IRENA (2018), ORE Catapult (2015), and Lazard (2018)

Current Floating Offshore Costs



- Floating cost estimates are declining rapidly as new information is obtained
- NREL (2019) study for OR estimated $60/MWh by 2032
- BVG and Wind Europe (2018) estimate costs near $70/MWh by 2030
- New NREL modeling will deliver similar estimates

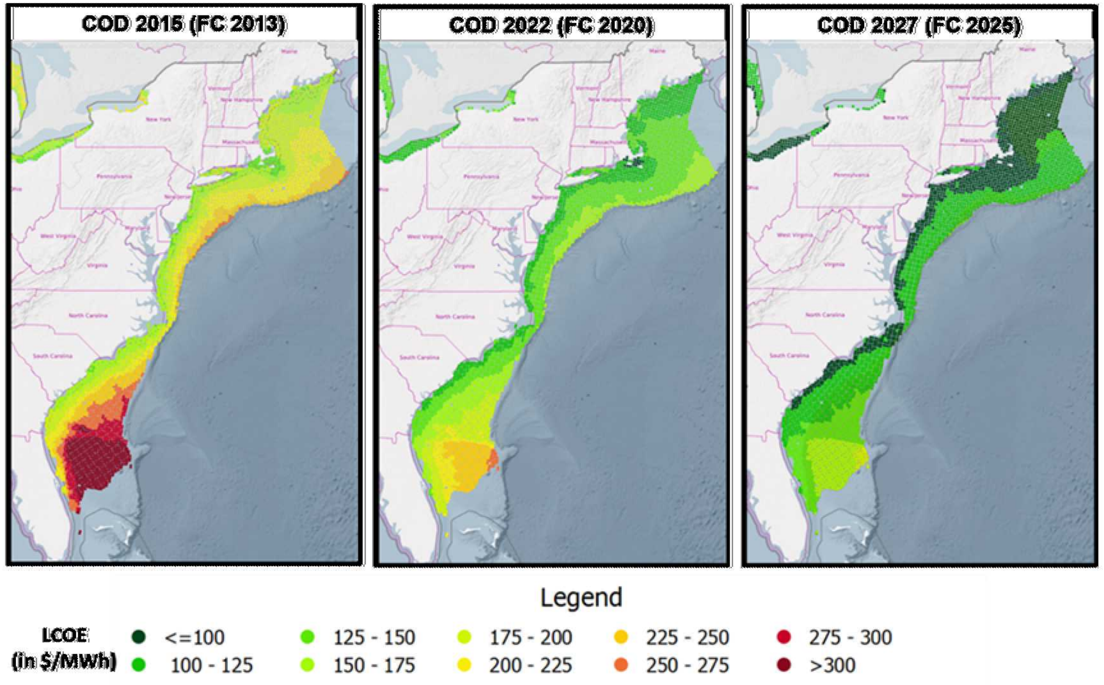
Musial, W; Beiter, P., Spitsen, p., Nunemaker, J., Gevorgian, V. 2019. “2018 Offshore Wind Technologies Market Report”, U.S. Department of Energy Report, August 2019. https://www.energy.gov/eere/wind/2018-wind-market-reports#offshore

NREL's Offshore Regional Analyzer: Recent Updates

Analysis of the Vineyard Wind Power Purchase Agreement (PPA)a and the latest technology trends[b] have informed model upgrades compared to earlier NREL cost studies

Key Model Updates Assume:

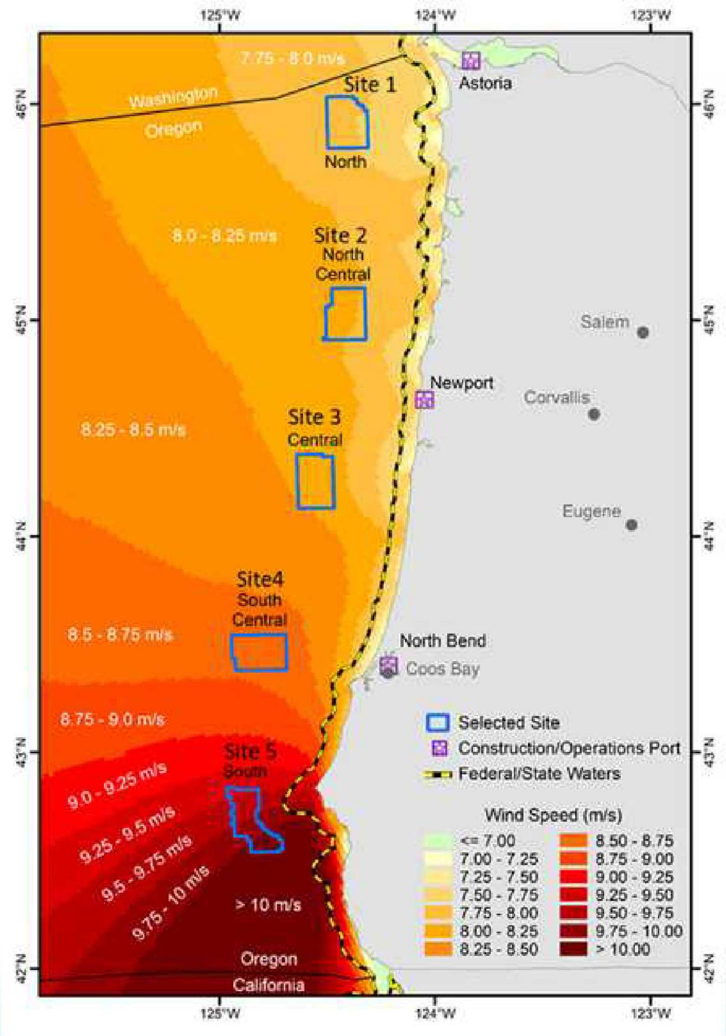
- **No significant cost premium due** to less mature U.S. supply chains compared to European projects
- **Lower finance costs**
- Turbine power capacity **growth to 15 MW** by 2032[c,d]
- **Baseline turbine cost ($/kW) lowered** ($1,300/kW)[e]
- **Cost impact of turbine scaling reduced**
- New floating **platform designs promising lower unit cost** and reduced labor at sea[f,g]
- **Lease area costs** implemented ($50 million)



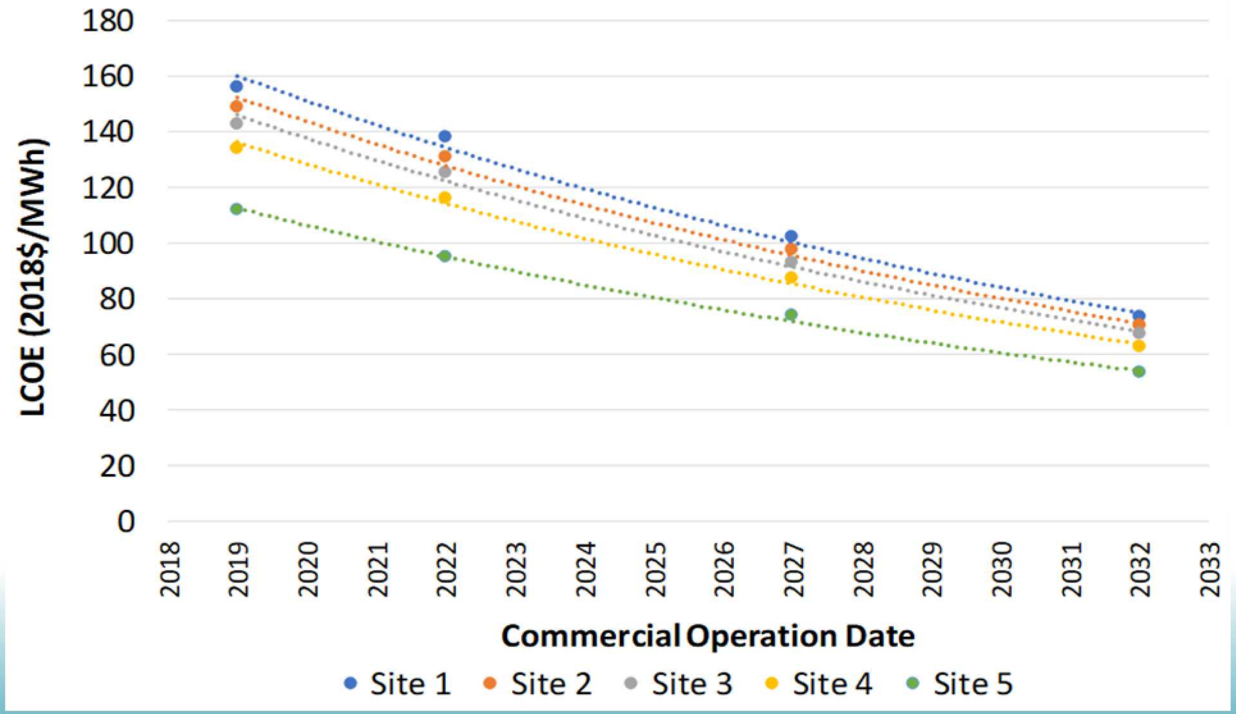
LCOE estimated by ORCA (Beiter et al., 2016)

Sources: [a] Beiter et al. (2019); [b] Musial et al. (2019); [c] General Electric (2018); [d] Hundleby et al. (2017); [e] BNEF (2018); [f] Villaespesa et al. 2015; [g] Melis et al. (2016).
Notes: * Weighted Average Cost of Capital (WACC).

Oregon Cost Study Results – Sept 2019



- Funded by the Bureau of Ocean Energy Management
- Hypothetical sites have not been vetted by ocean user communities
- Only cost and geo-spatial factors were considered
- By 2032 – costs may drop below $60/MWh in some locations



Musial W., Beiter P., Nunemaker J., Heimiller D. , Ahmann J., and Busch J. “Oregon Offshore Wind Site Feasibility and Cost Study” NREL September 2019

Current State of R&D: DOE's National Offshore Wind R&D Consortium

National Offshore Wind R&D Consortium

Announced in 2017 by DOE **to address technological barriers and lower the costs and risks of offshore wind** in the United States

DOE and the Department of the Interior identified 3 research areas to facilitate the development of the U.S. offshore wind industry:

- **Wind plant technology advancement.**
- **Wind resource and physical site characterization.**
- **Installation, operations and maintenance, and supply chain technology solutions.**

In June 2018, **DOE selected the New York State Energy Research and Development Authority** (NYSERDA) as administrator of the National Offshore Wind R&D Consortium. Founding members included 9 leading project developers (Deepwater Wind, Shell, and Ørsted, and the Carbon Trust, Renewables Consulting Group, and DOE's National Renewable Energy Laboratory (NREL).

NYSERDA committed to matching DOE's funds, resulting in a **$41 million R&D consortium**. In January 2019, 6 new members joined (Maryland, Massachusetts, and Virginia plus Vineyard Wind, EnBW North America, and Anbaric Development.)

Operating under an **R&D Roadmap**, published in October 2018 and updated in 2019. 1st rfp was issued in Spring 2019 and the **1st project funded** was $300,000 to improve the economic feasibility of floating offshore wind plants by **researching shared mooring systems** that require fewer anchors and cables (NREL)

NATIONAL OFFSHORE WIND
RESEARCH & DEVELOPMENT CONSORTIUM

NOWRDC Awards

Operating under an **R&D Roadmap**, published in October 2018 and updated in 2019. 1st rfp issued in Spring 2019. 8 projects selected for award ($6.9M):

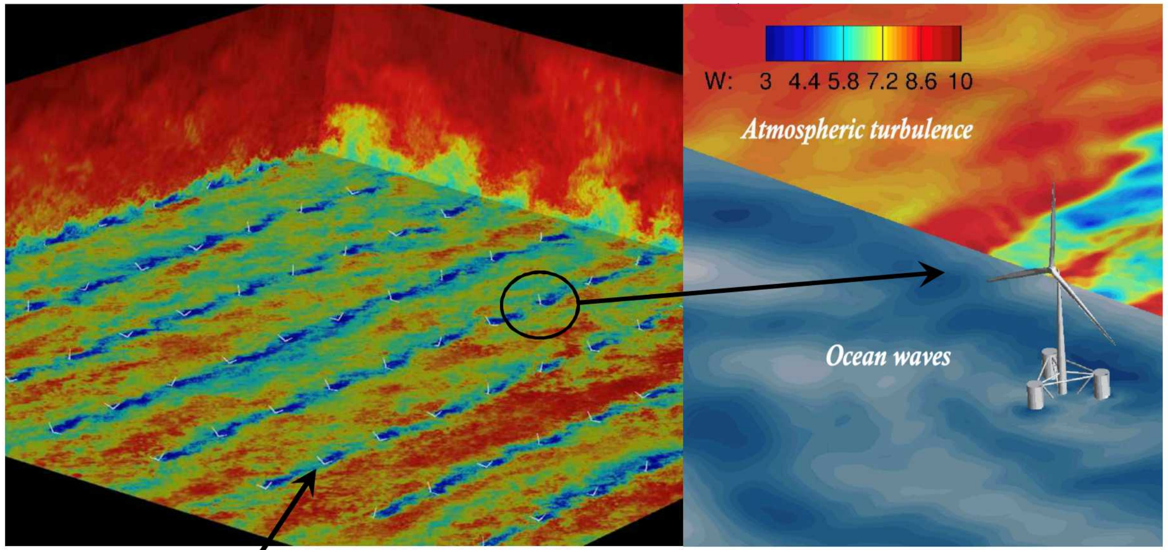
National Renewable Energy Lab (NREL)	Validated National Offshore Wind Resource Dataset w/ Uncertainty Quantification
NREL	**Shared Mooring Systems** for Deep-Water Floating Wind Farms
RCAM Technologies	A low-cost **modular concrete support structure** and heavy lift vessel alternative
Principle Power Inc.	Innovative **Deepwater Mooring Systems** for Floating Wind Farms (DeepFarm)
Stony Brook University	**Computational Control Co-design Approach** for Offshore Wind Farm Optimization
General Electric Research	**Impact of Low Level Jets** on Atlantic Coast Offshore Wind Farm Performance
Cornell University	Reducing LCOE from offshore wind by **multiscale wake modeling**
NREL	**Wind Farm Control and Layout Optimization for U.S. Offshore Wind Farms**

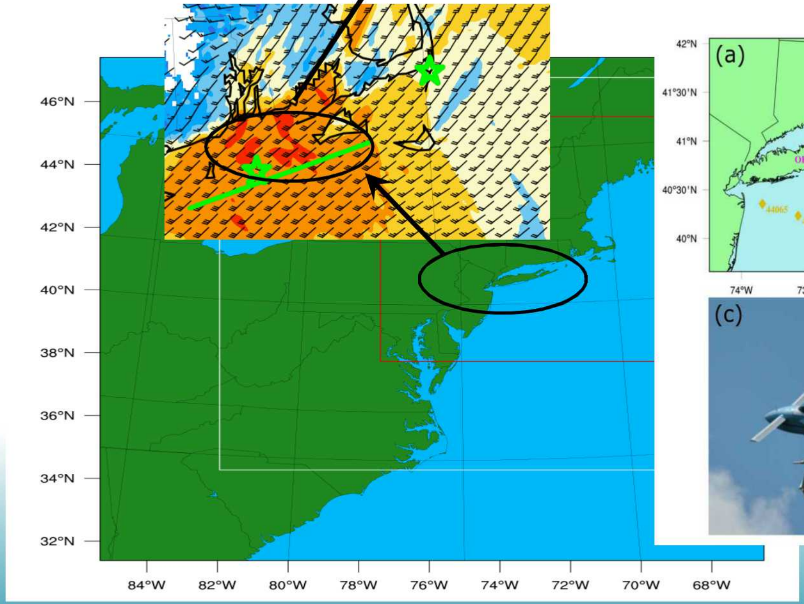
Current R&D from NOWRDC R&D Advisory Group Members

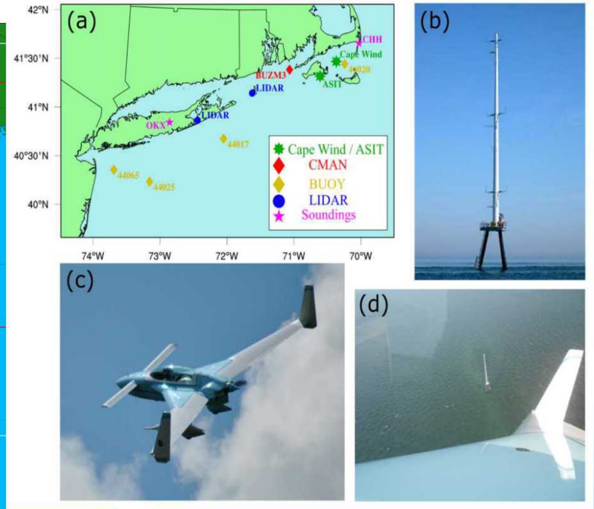
Offshore Wind Energy R&D at Stony Brook

Contact: Fotis.Sotiropoulos@stonybrook.edu, Dean, College of Engineering & Applied Sciences

- Unique blend of marine, atmospheric sciences (**School of Marine & Atmospheric Sciences**), engineering and policy (**College of Science and Engineering**) research
- Engagement with industry and industry-relevant research (**Advanced Energy Research and Technology Center**)
- Research expertise relevant to offshore wind energy:
- Wind resource assessment, wind farm controls and optimization, advanced floating systems design
- Cutting-edge high performance multi-scale computing simulation tools for offshore wind
- State-of-the-art remote sensing and field measurements of atmosphere-ocean interactions
- Impacts on aquatic environment and marine ecosystems
- Energy storage and battery technologies
- Energy policy and socio-economic research





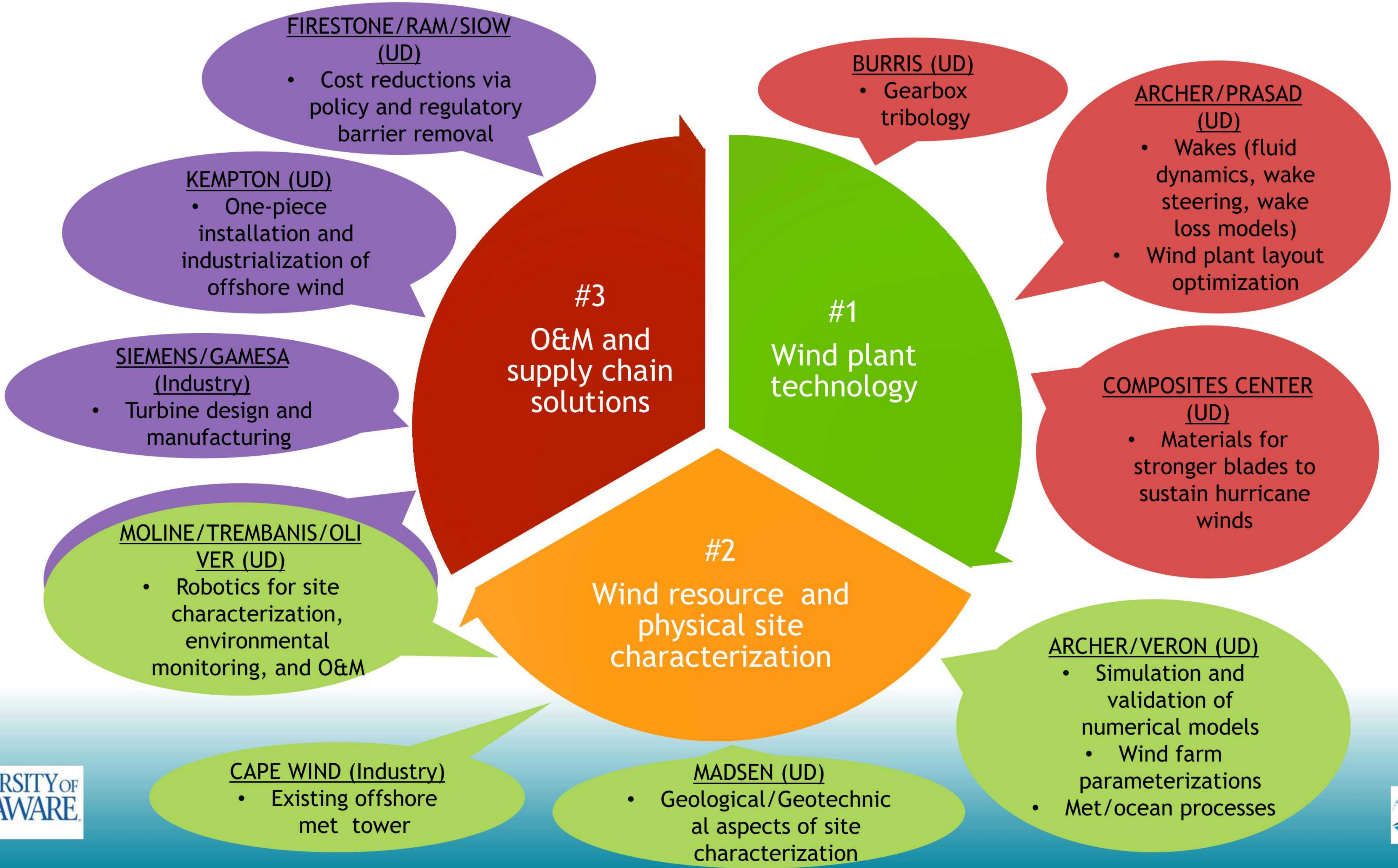


ADVANCED ENERGY™ Research and Technology Center AT STONY BROOK UNIVERSITY

Stony Brook University College of Engineering and Applied Sciences
MAKING SCIENCE FICTION COME TO LIFE

Stony Brook University School of Marine and Atmospheric Sciences

University of Delaware Expertise



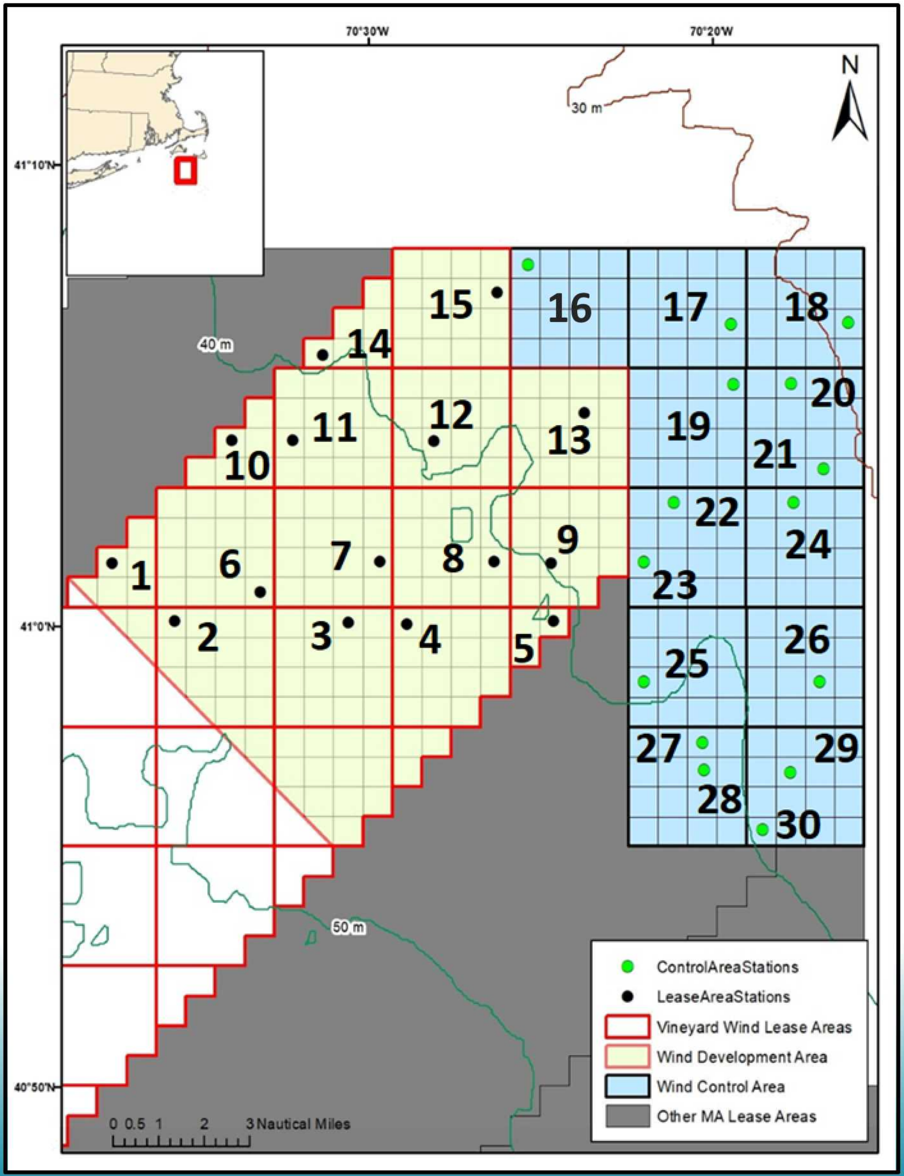
UNIVERSITY OF DELAWARE

CReW Center for Research in Wind

UMass Dartmouth School of Marine Science and Technology

Ventless Trap, Larval Lobster, and Black Sea Bass Survey
Before-After-Control-Impact (BACI) Analyses

Area	Lobsters (n)	Carapace (mm)	Lobster Larvae (n)	Sea Bass (n)
Impact	214	91.3 ±2.38	13	165
Control	137	90.8 ± 2.15	10	99



UMass Dartmouth

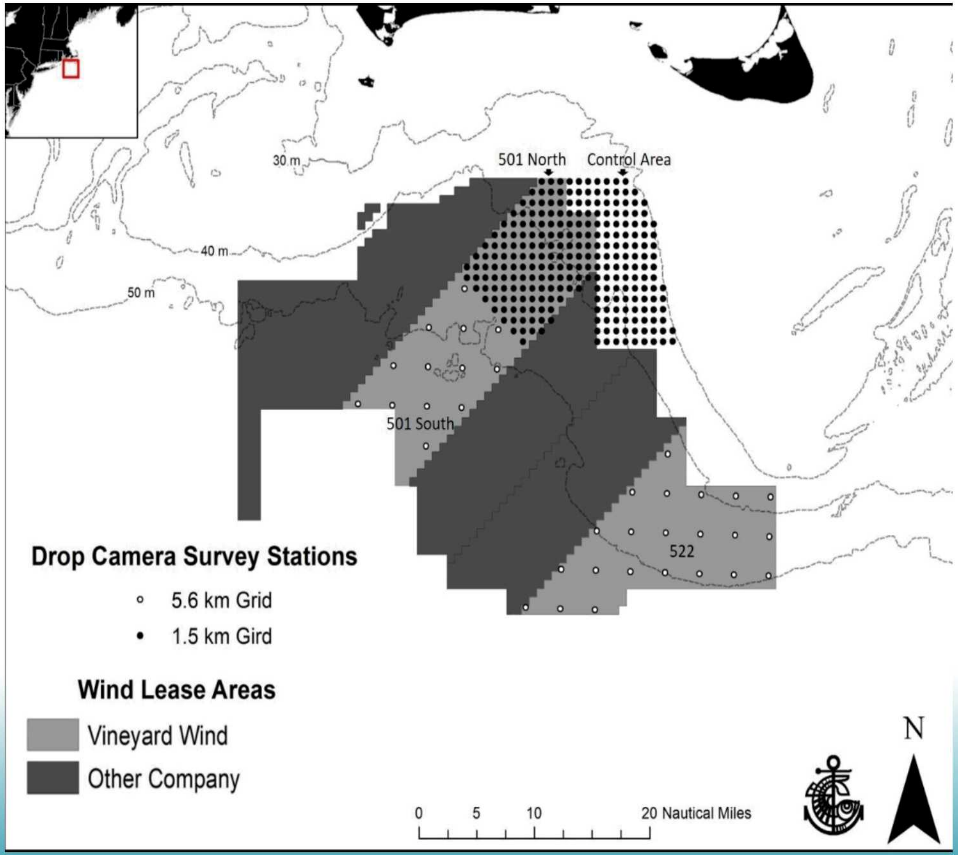
UMass Dartmouth School for Marine Science and Technology

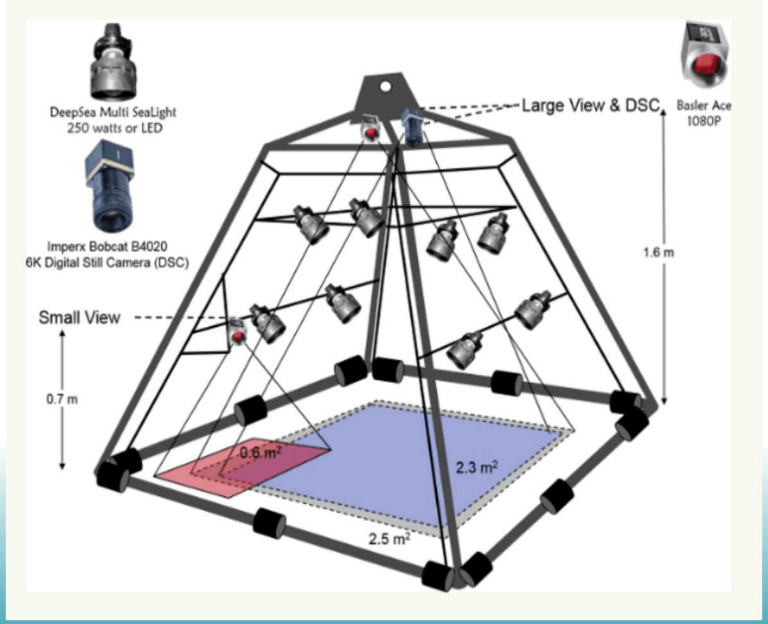
UMass Dartmouth

SMAST Drop Camera Survey

- Baseline Benthic Community and Habitat Assessment of the Vineyard Wind Lease Areas

	July		October	
Animal Group	Quadrats Present	Counts	Quadrats Present	Counts
Anemones	217		0	
Crab	49	49	0	0
Flounder	21	21	0	0
Hermit Crabs	380	380	0	0
Red hake	65	67	3	3
Sand Dollars	485		61	
Scallop	6	6	1	1
Skate	66	66	44	44
Quadrats Sampled	1032		736	





Contacts: Kevin Stokesbury, N. David Bethoney

Cornell University

Offshore Wind R&D Activities

- High-fidelity modeling:
  - Wind resource/wind profiles (mesoscale)
  - Within array & between array wake effects (micro-to meso-scale)
- Measurements for wakes & resources:
  - Remote sensing (scanning & vertically pointing lidar, ceilometer)
  - In situ atmospheric properties
- Recent Results
  - Demonstrated 20% of electricity from wind feasible/has minimal environmental impact (https://www.nature.com/articles/s41598-019-57371-1)
  - New methods to simulate array-array interactions (doi: 10.1175/JAMC-D-19-0235.1)
  - New methods for wake detection with lidar (https://www.atmos-meas-tech.net/12/3463/2019/amt-12-3463-2019.pdf)

Contacts:
Prof. R.J. Barthelmie (rb737@cornell.edu)
Prof. S.C. Pryor (sp2279@cornell.edu)

NREL Offshore Wind Capabilities

- Resource Assessment and Characterization
- Wind Plant Optimization
- Wind Technology Innovation
- Advanced Manufacturing and Materials
- Grid Systems Integration
- Research Laboratories and Facilities
- Energy and Economic Analysis
- Marine Environmental Science and Siting
- STEM Workforce Development
- Stakeholder Engagement

Contacts: Walt Musial, Walter.Musial@nrel.gov
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NREL Flatiron's Campus

NREL's wind energy research at the National Wind Technology Center (NWTC), located on the Flatirons Campus, has pioneered wind turbine components, systems, and modeling methods that have driven the industry's acceleration over the past 40 years.

- Field research validation sites with six wind turbines and four meteorological towers
- Three dynamometers for assessing wind turbine drivetrains and water power-take-off systems
- Structural research facilities, which verify blades and components
- The Controllable Grid Interface, which provides grid operators with valuable performance information
- Integrated Energy System at Scale, which addresses the challenge of designing integrated regulation strategies of overall energy systems
- Composites Manufacturing Education and Technology (CoMET), which enables NREL to lead composite research
- High Performance Computing, features state-of-the-art computational modeling and predictive simulations that reduce the risks and uncertainty of adopting new and innovative energy technologies.

Sandia National Labs Offshore Wind R&D

- **Radar Interference** – Sandia leads coordination of the interagency Wind Turbine Radar Interference Mitigation (WTRIM) working group. Research opportunities are starting to be evaluated by WTRIM for understanding offshore radar impacts from wind turbines and potential mitigation efforts.

- **Big Adaptive Rotor Project** – Multi-lab effort to design larger land-based low specific power rotor, with a focus on design optimization and novel carbon fiber composites. Results from this research can translate into offshore turbine design.

- **ARPA-E Atlantis** – Controls co-design for a new floating offshore vertical axis wind turbine/platform design will kick off February 2020.

- **Leading Edge Erosion** – Side-by-side comparison of land-based wind turbines with existing eroded blades and repaired blades. SCADA data will be used to develop insight and methods for reducing erosion.

Recent Results

- **The radar pilot mitigation project at Travis AFB demonstrated infill radar capabilities can work with existing military air traffic control radar. Relationships developed with DOE, DoD and the wind industry will continue to advance a collaborative approach at addressing potential offshore radar interference.**

Scaled Wind Farm Technology Facility (SWiFT): An Ideal Facility for Offshore Wind R&D in Lubbock, TX

- **Three open-source wind turbines and two metrological towers, all highly instrumented and time synchronized through a fiber-optic data acquisition system**
- **Flat terrain without significant vegetation; predominant wind direction from the south, enabling the study of wake impacts within a wind plant**

- **Established uncertainty quantification methods on measurements and derived quantities of interest for baseline site instrumentation**
- **SWiFT wake steering data used for verification and validation of high-fidelity Nalu-WIND CFD code**
- **Extreme load detection and structural health monitoring – capability for rotor sensing to monitor blade loading and damage**

- **Hub height atmospheric inflow conditions are commonly representative of offshore sites with turbulence intensity values < 5% and low wind shear**
- **High resolution temporal and spatial sake characterization and analysis using DTU SpinnerLidar, Windar 4-beam, and Pentalum SpiDAR lidar**

Contact: Geoff Klise – gklise@sandia.gov

Leverage Texas Tech University assets, including adjacent wind tunnel, Ka-band and X-band radar; GroupNIRE/DNV GL LiDAR calibration tower

Thanks to my Co-Authors

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