U.S. Offshore Wind – Getting Too Big, Too Fast – Where and How Innovation can Help

2019 Marine Board Fall Meeting

Woods Hole, MA

06 November 2019

ODU

Center for Coastal Physical Oceanography

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Marine Board's Most Recent Comprehensive Review of Offshore Wind

TRB TRANSPORTATION RESEARCH BOARD

OF THE NATIONAL ACADEMIES

MARINE BOARD SPRING MEETING

April 27-28, 2011
Washington, D.C.

Selected Presentations

Oil Spills on Ice: Report on Industry Research Effort	A. Steen, Exxon/Mobil P. Velez, Shell Int'l
Offshore Wind Energy Turbine Structural and Operating Safety	K. Michel, Herbert Eng.

Marine Board's Most Recent Comprehensive Review of Offshore Wind

Background

(BOEMRE) is responsible for the orderly, safe, and environmentally responsible development of offshore renewables on the outer continental shelf.

BOEMRE requested that the NRC's Transportation Research Board's Marine Board conduct a study to guide the agency in the regulation and technical oversight of the nascent offshore wind energy industry in the United States.

Marine Board's Most Recent Comprehensive Review of Offshore Wind

Committee

R. Keith Michel, Herbert Engineering Corporation, Alameda, California, *Chair*
Bruce R. Ellingwood, Georgia Institute of Technology, Atlanta
George M. Hagerman, Jr., Virginia Coastal Energy Research Consortium, Virginia Beach
Jan Behrendt Ibsoe, ABS Consulting, Inc., Houston, Texas
Lance Manuel, University of Texas at Austin
Walt Musial, National Renewable Energy Laboratory, Golden, Colorado
Robert E. Sheppard, Energo Engineering, Houston, Texas
Emil Simiu, National Institute of Standards and Technology, Gaithersburg, Maryland
Susan W. Stewart, Pennsylvania State University, State College
David J. Wisch, Chevron Energy Technology Company, Houston, Texas

Staff Madeline G. Woodruff, Study Director

Marine Board's Most Recent Comprehensive Review of Offshore Wind

Scope of Study

- ***TASK 1: Standards and Practices***

The applicability and adequacy of existing standards and practices for the design, fabrication, and installation of offshore wind turbines.

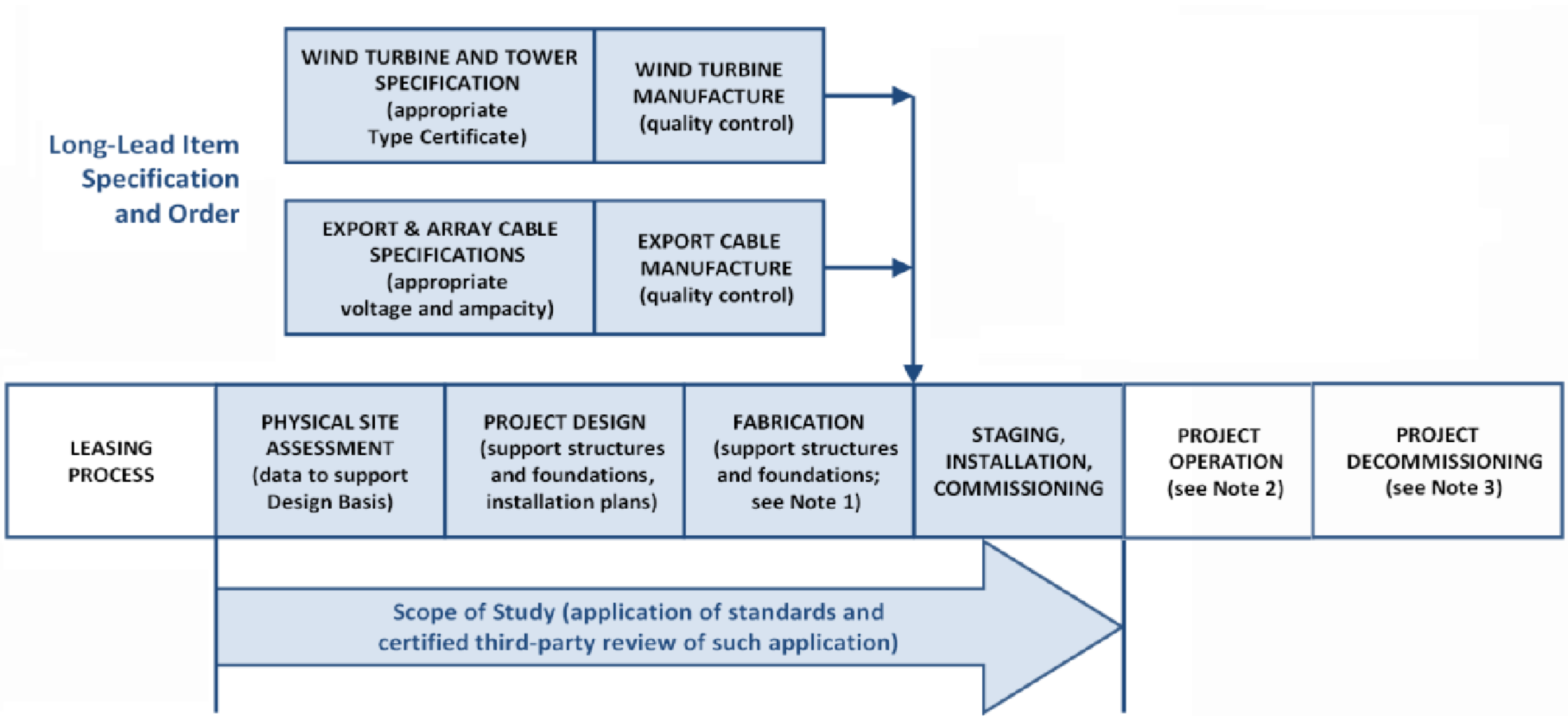
- ***TASK 2: Role of Certified Verification Agents (CVAs)***

The expected role of the CVA in identifying standards to be used and conducting onsite inspections to verify compliance with the standards.

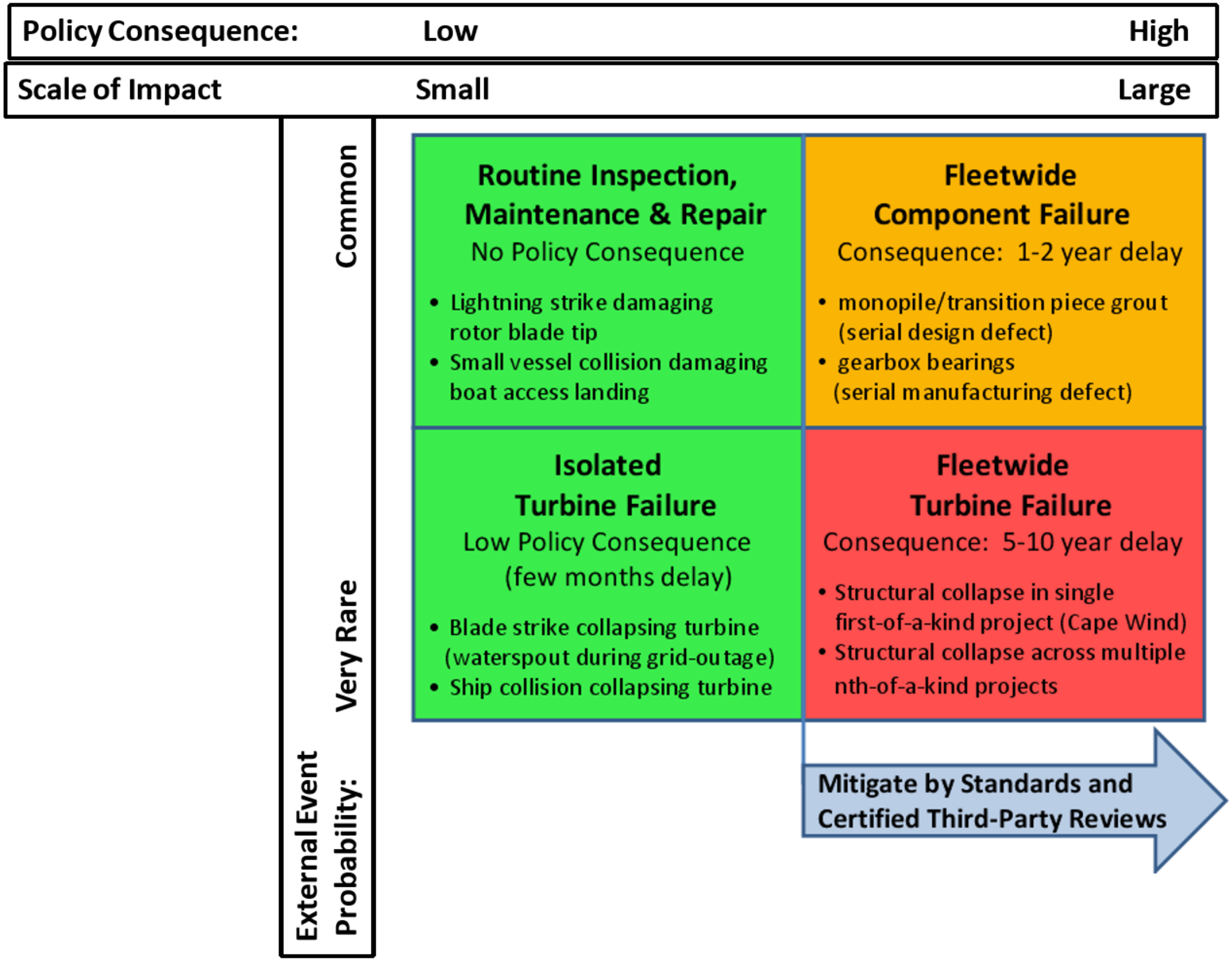
- ***TASK 3: CVA Qualifications***

The experience level, technical skills and capabilities, and support equipment and computer hardware/software needed to be considered a qualified CVA.

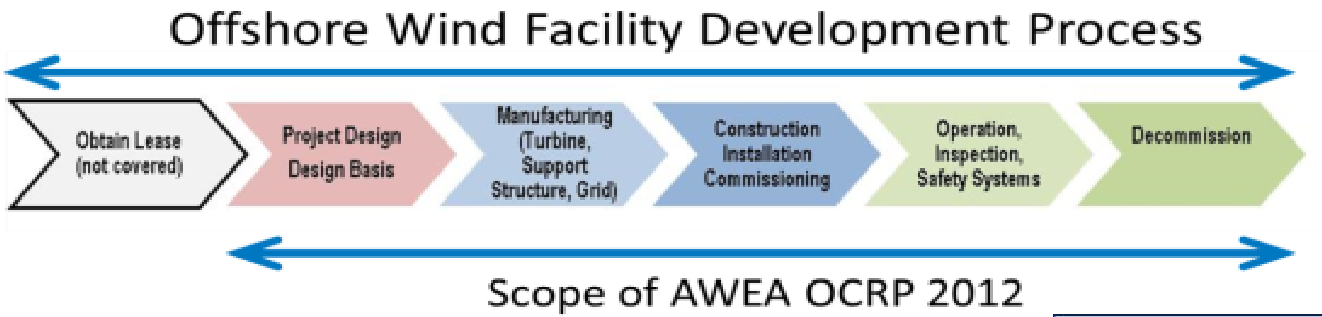
Marine Board's Most Recent Comprehensive Review of Offshore Wind



Marine Board's Most Recent Comprehensive Review of Offshore Wind



Marine Board 2011 Report led to AWEA Offshore Compliance Recommended Practice (OCRP) 2012



Graphic source: NREL

- AWEA OCRP 2012 is structured to mirror BOEM 30 CFR 585 "cradle to grave"
- Dozens of standards and guidelines from various industries and certifying bodies are cited and mapped to development process
- 50+ stakeholders/subject matter experts participated between 2009 and 2012
- AWEA OCRP published in October 2012 as a Recommended Practice


AWEA OCRP 2012 September 16, 2012

AWEA Large Turbine Compliance Guidelines:

AWEA Offshore Compliance Recommended Practices (2012)

Recommended Practices for Design, Deployment, and Operation of Offshore Wind Turbines in the United States

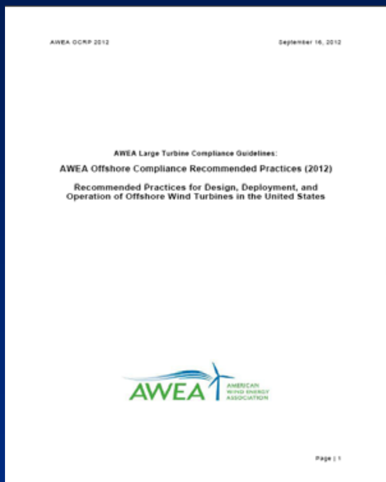
Page | 1

AWEA OCRP 2012 is a roadmap on how to use existing standards

http://awea.files.cms-plus.com/FileDownloads/pdfs/AWEA%20Offshore%20RP2012%20FINAL%202012%20October%2010.pdf

AWEA OCRP 2012 Codes and Standards Hierarchy

ROADMAP


AWEA OCRP 2012
September 16, 2012
AWEA Large Turbine Compliance Guidelines:
AWEA Offshore Compliance Recommended Practices (2012)
Recommended Practices for Design, Deployment, and Operation of Offshore Wind Turbines in the United States
AWEA

AWEA OCRP 2012

LOADS

IEC 61400-3
IEC 61400-1
IEC 61400-22

RESISTANCE


INTERNATIONAL STANDARD
ISO 19902
Petroleum and natural gas industries — Fixed steel offshore structures

ISO 19902

U.S. UNIQUE


Planning, Designing, and Constructing Fixed Offshore Platforms—Working Stress Design
API

API RP2A

AWEA OSW Standards Initiative is replacing OCRP 2012 with five new Recommended Practices

Order of Document Priority

Slide Credit: Rudy Hall – Keystone Engineering

Offshore Wind 101: Energy Resource

Wind Energy is a
Derived Form of Solar Energy

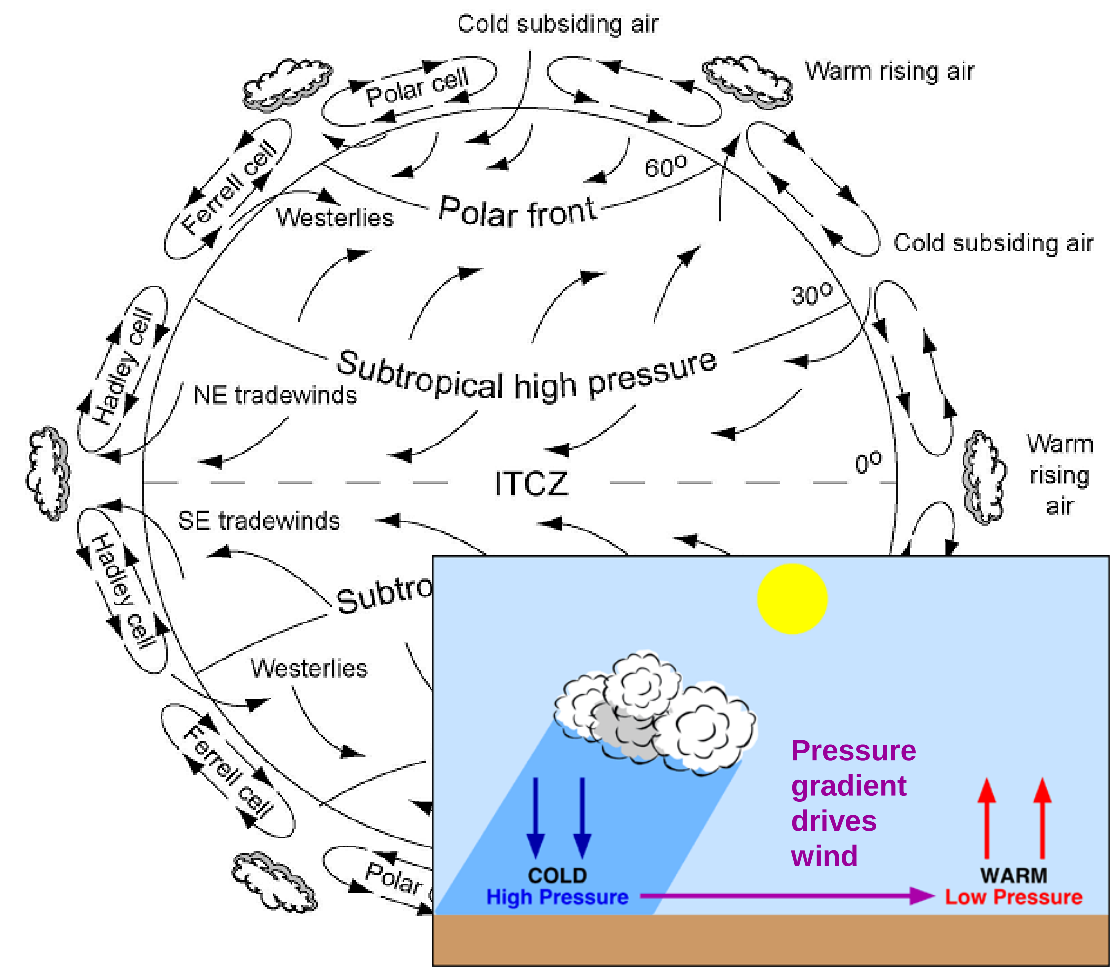
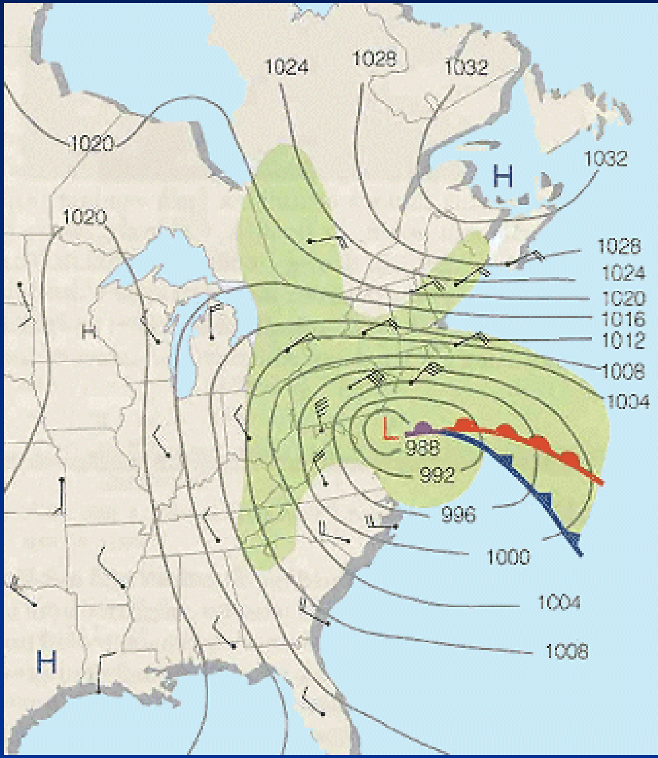
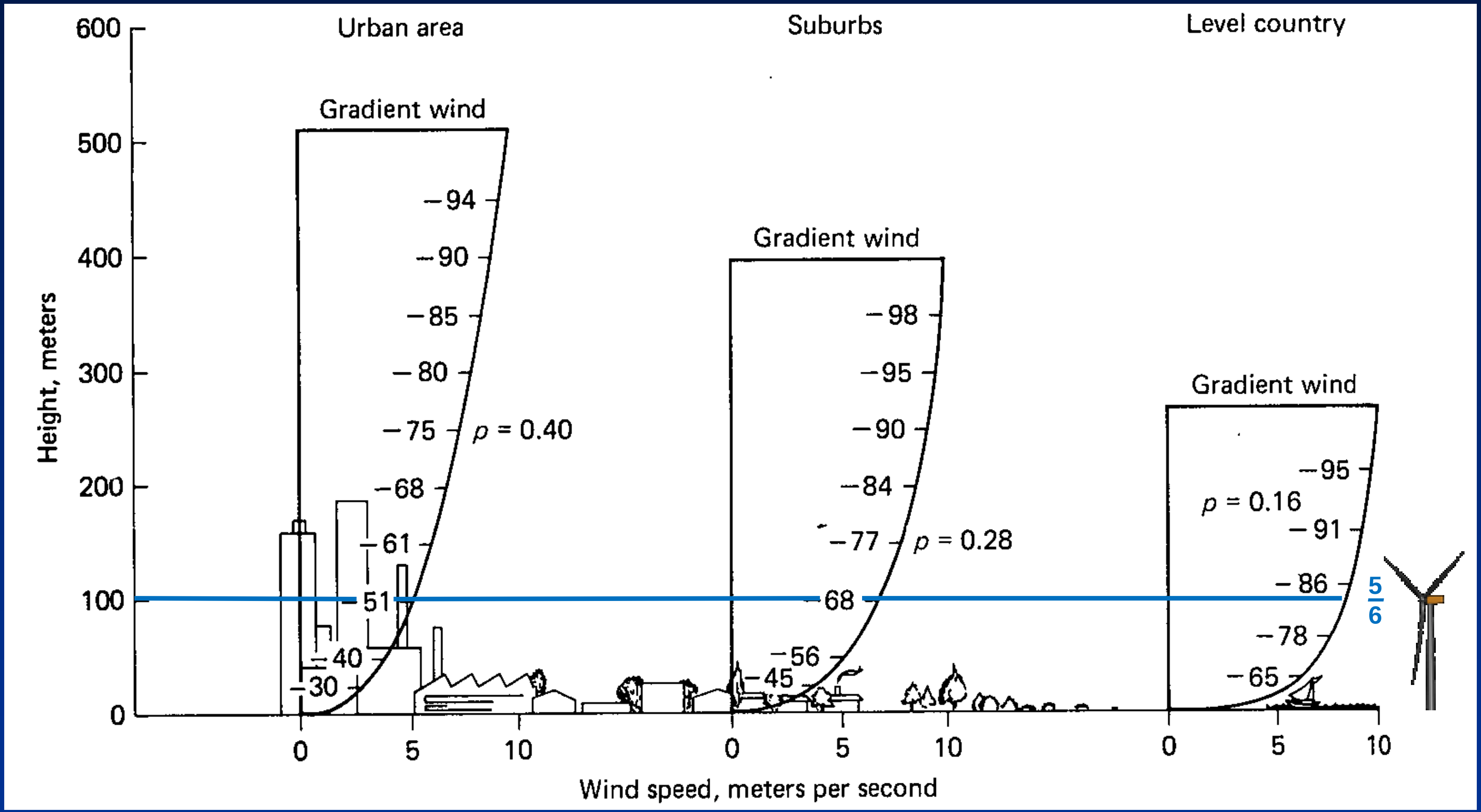


Figure below shows nor'easter forming as cold dry air picks up heat and moisture from ocean



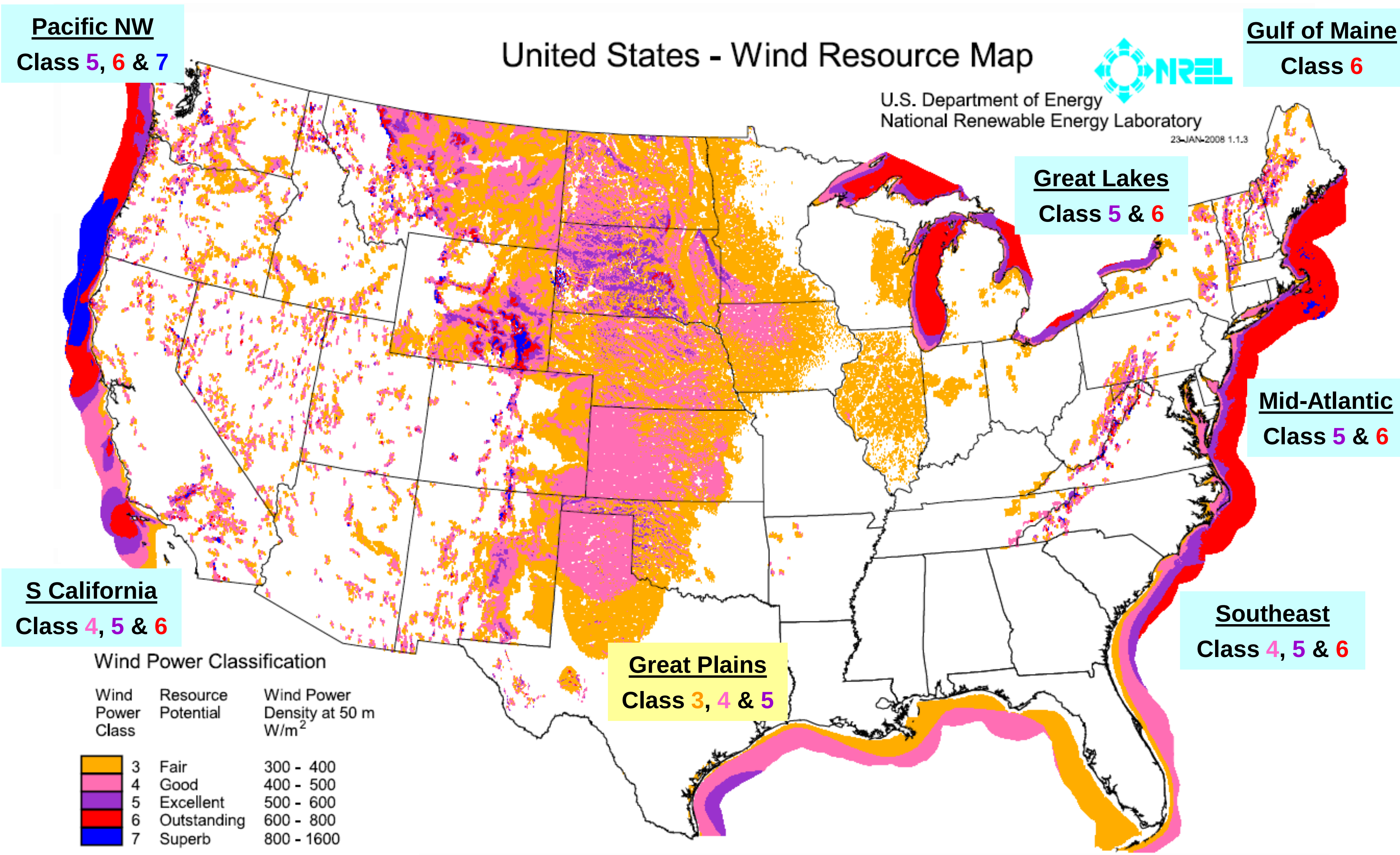
Winds move ~60% of excess equatorial solar energy towards the poles.
Deep-ocean currents move the remaining ~40% (via thermo-haline circulation)

At a Given Turbine Hub Height,
Offshore Wind Speed is Greater than on Land

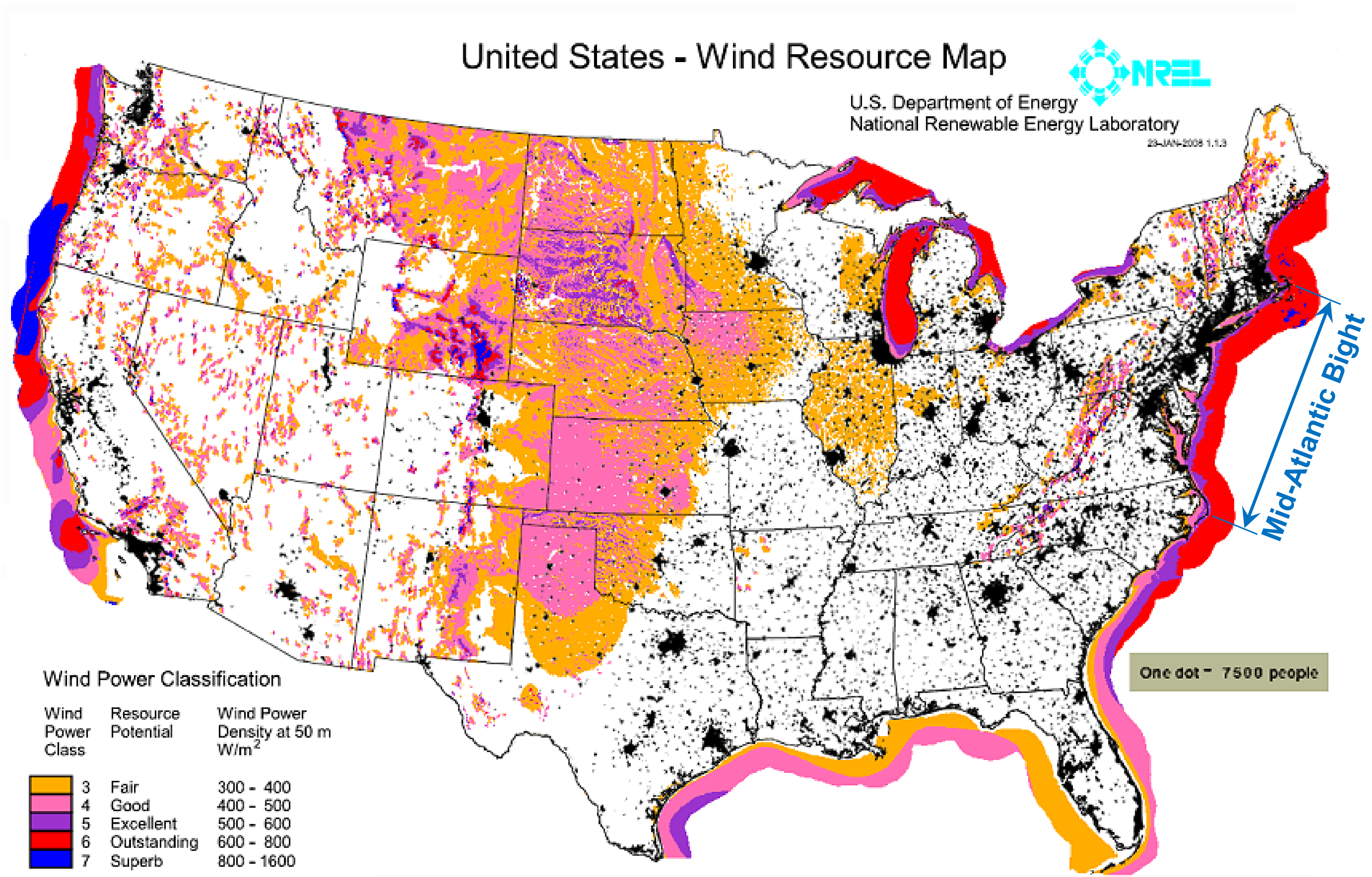


Effect of terrain roughness on wind-speed profiles. Values listed along curves are percentage of gradient wind speed. Because wind power density is proportional to wind speed cubed, wind power densities at a given turbine rotor hub height are much greater over open water.

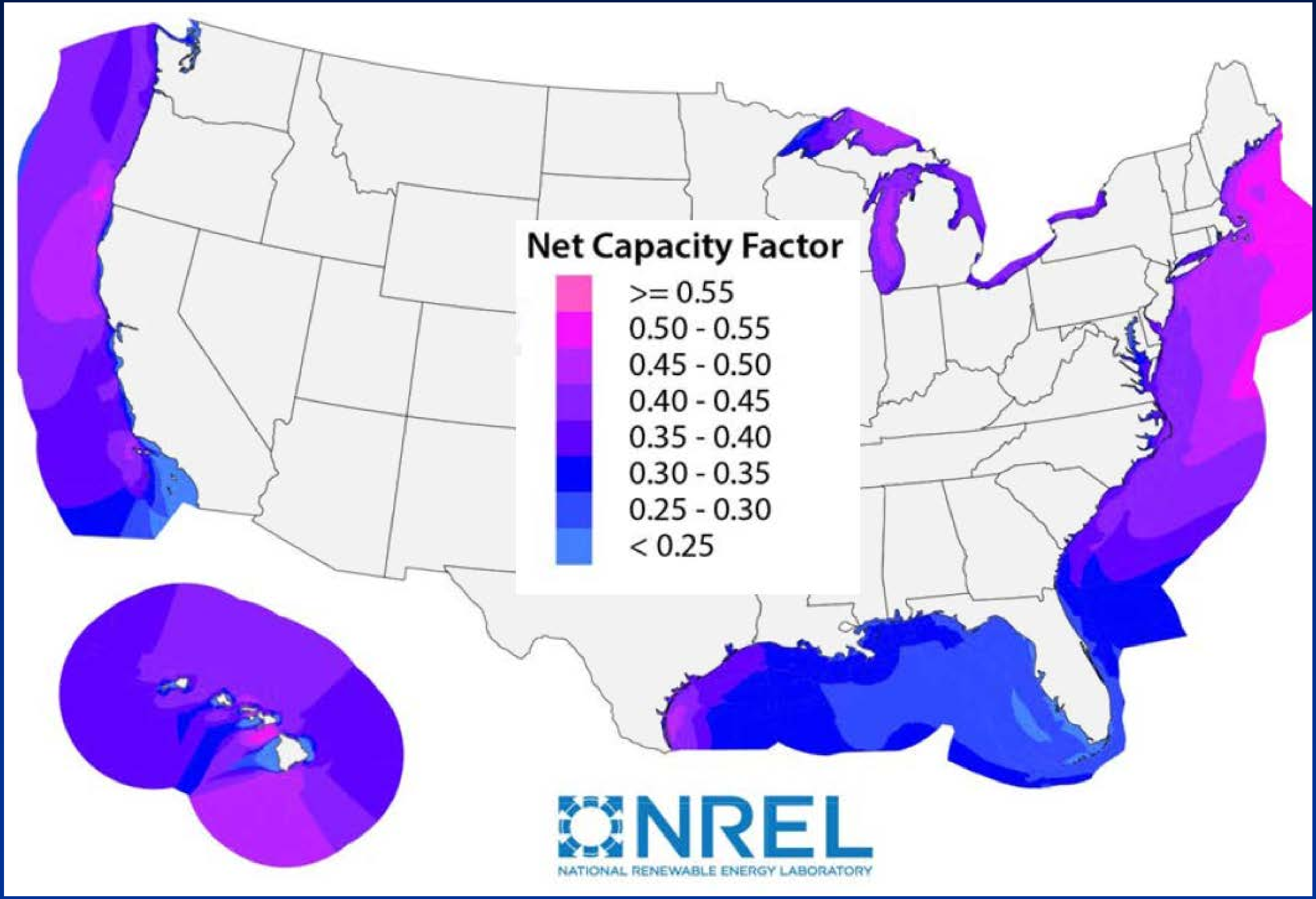
US Offshore and On-Shore Wind Resource Classes



US Offshore Wind Resources are Near Coastal Metropolitan Load Centers



Northeast Business Case Stronger than Southeast



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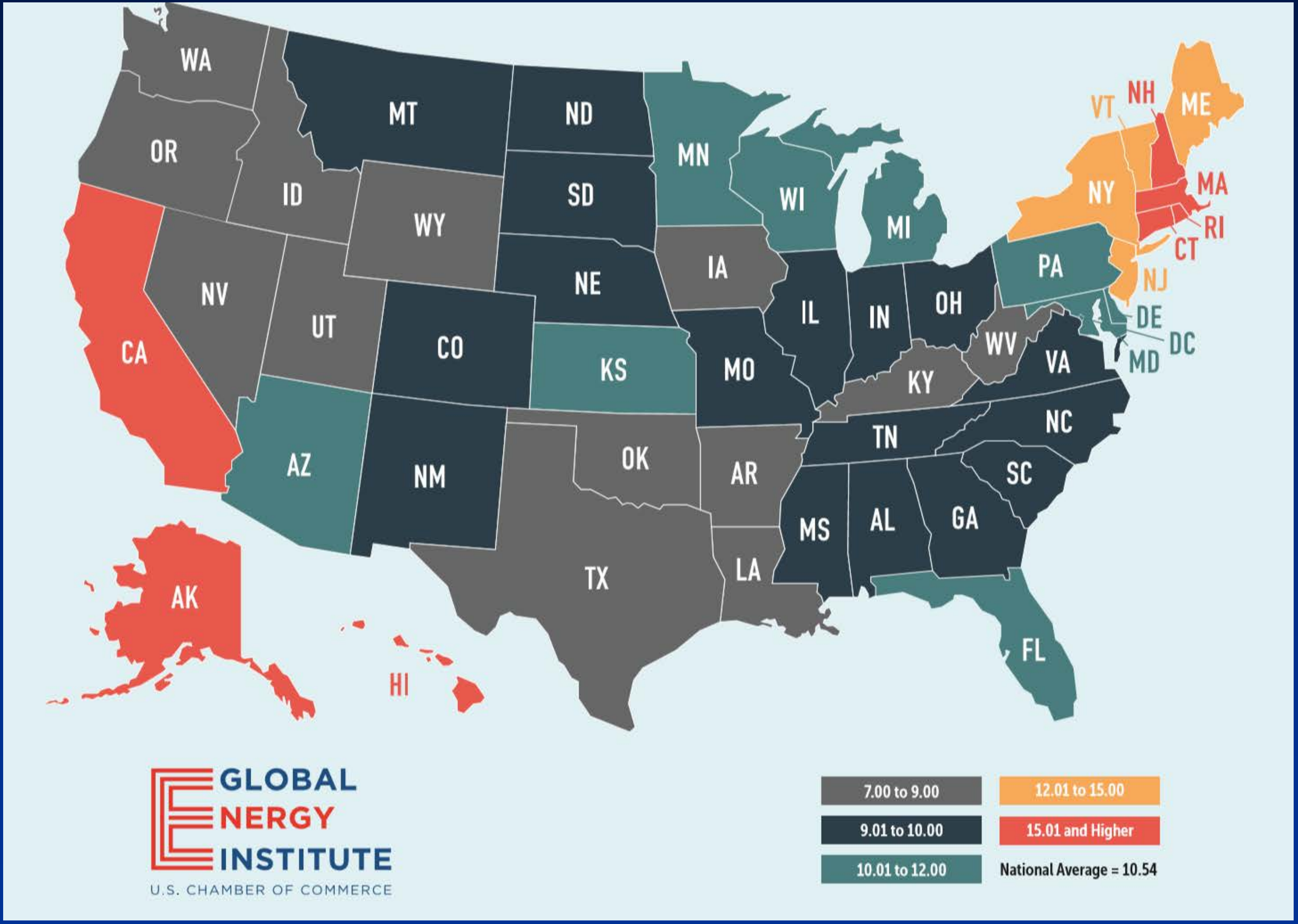
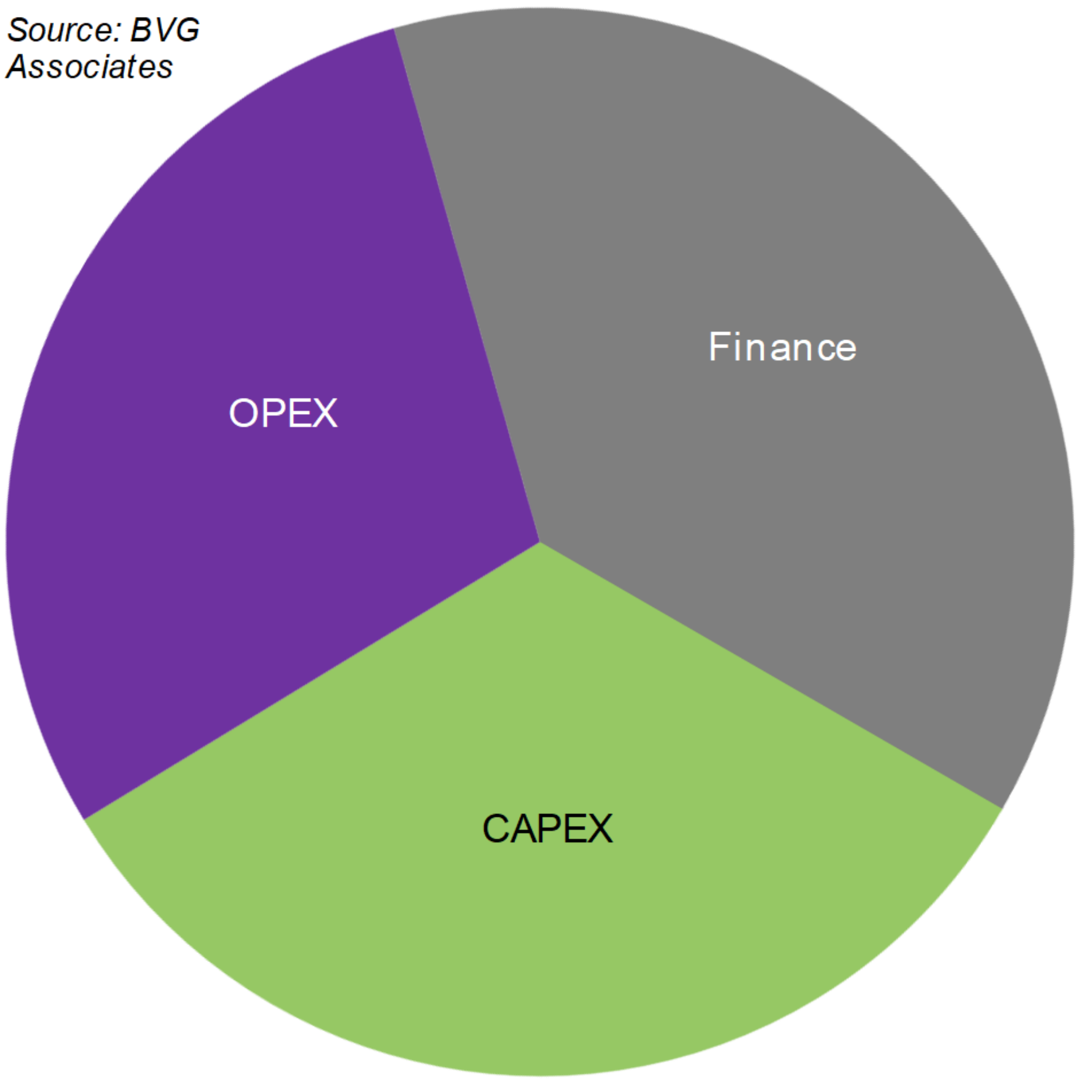


Offshore Wind 101: Economics

Offshore Wind Levelized Cost of Energy Breakdown

Source: BVG Associates



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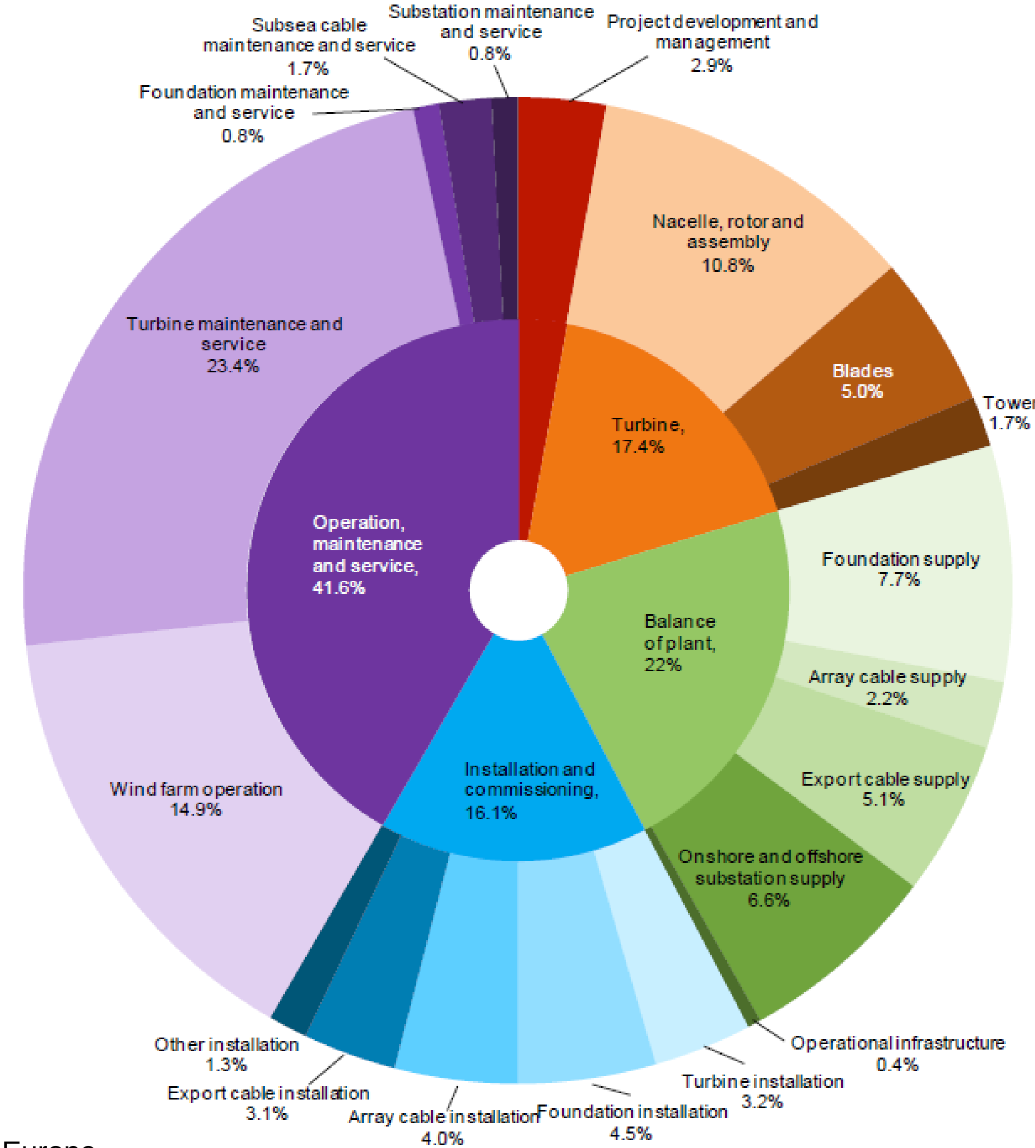
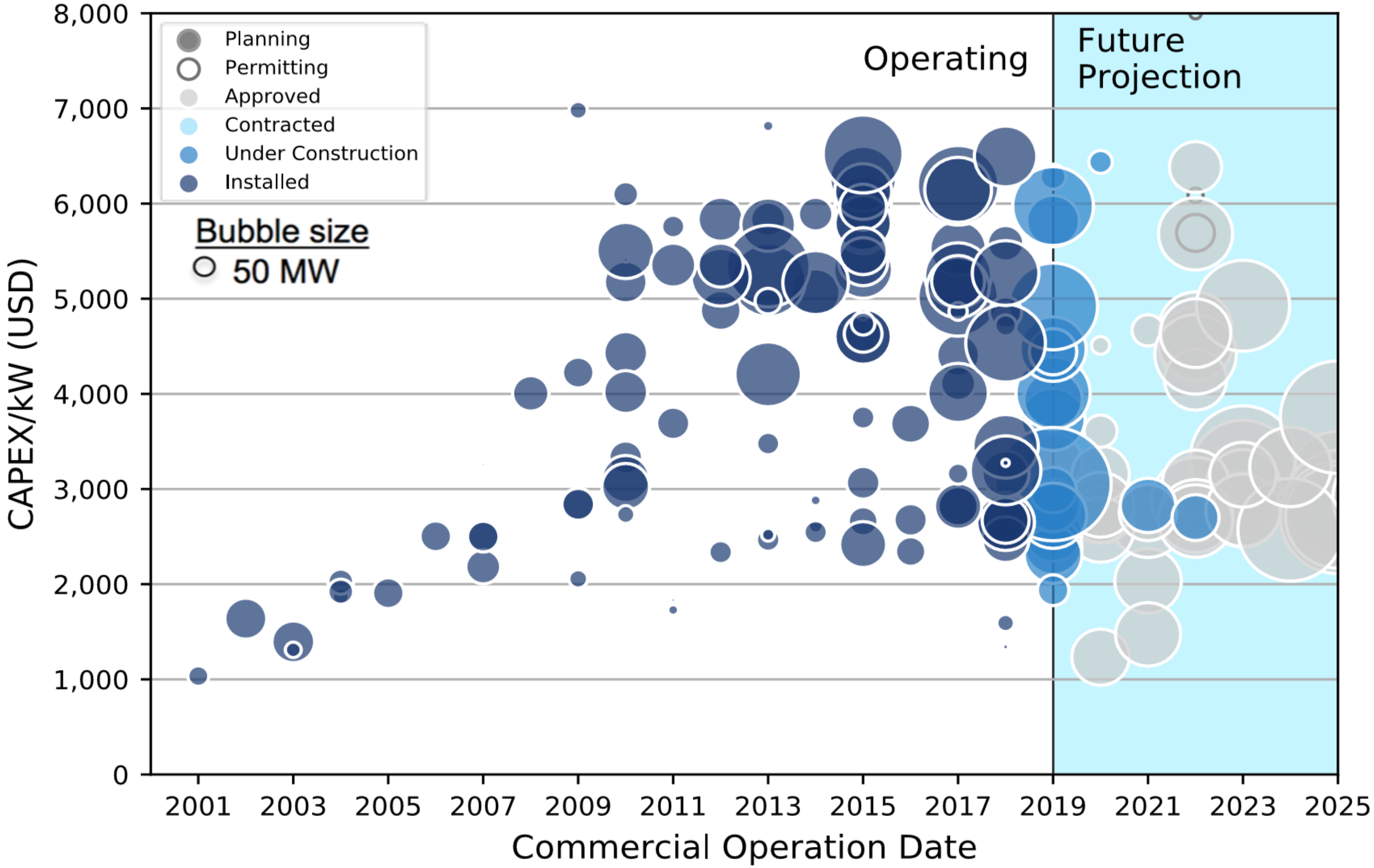


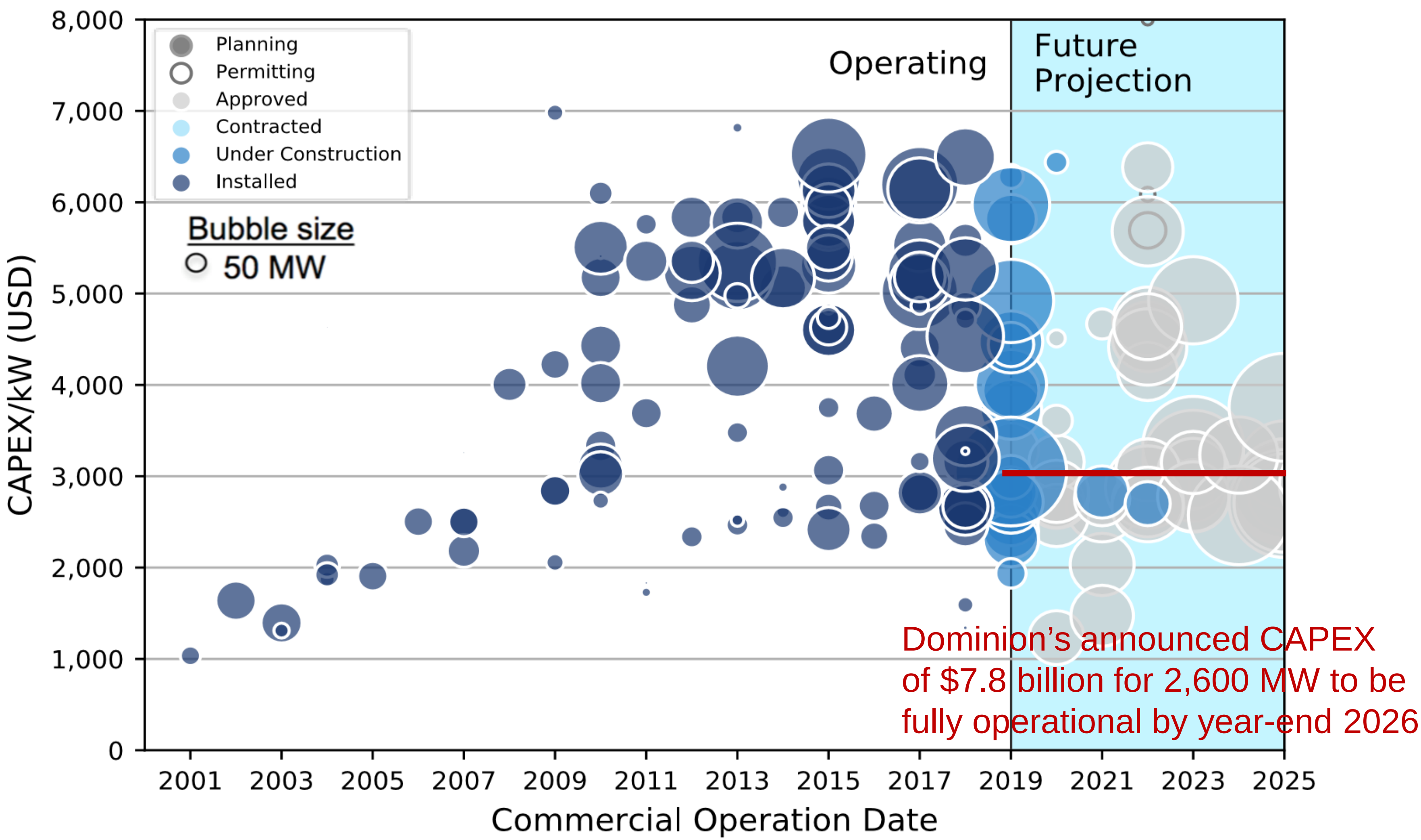
Source: BVG Associates for Wind Europe

Offshore Wind Project CAPEX Trend



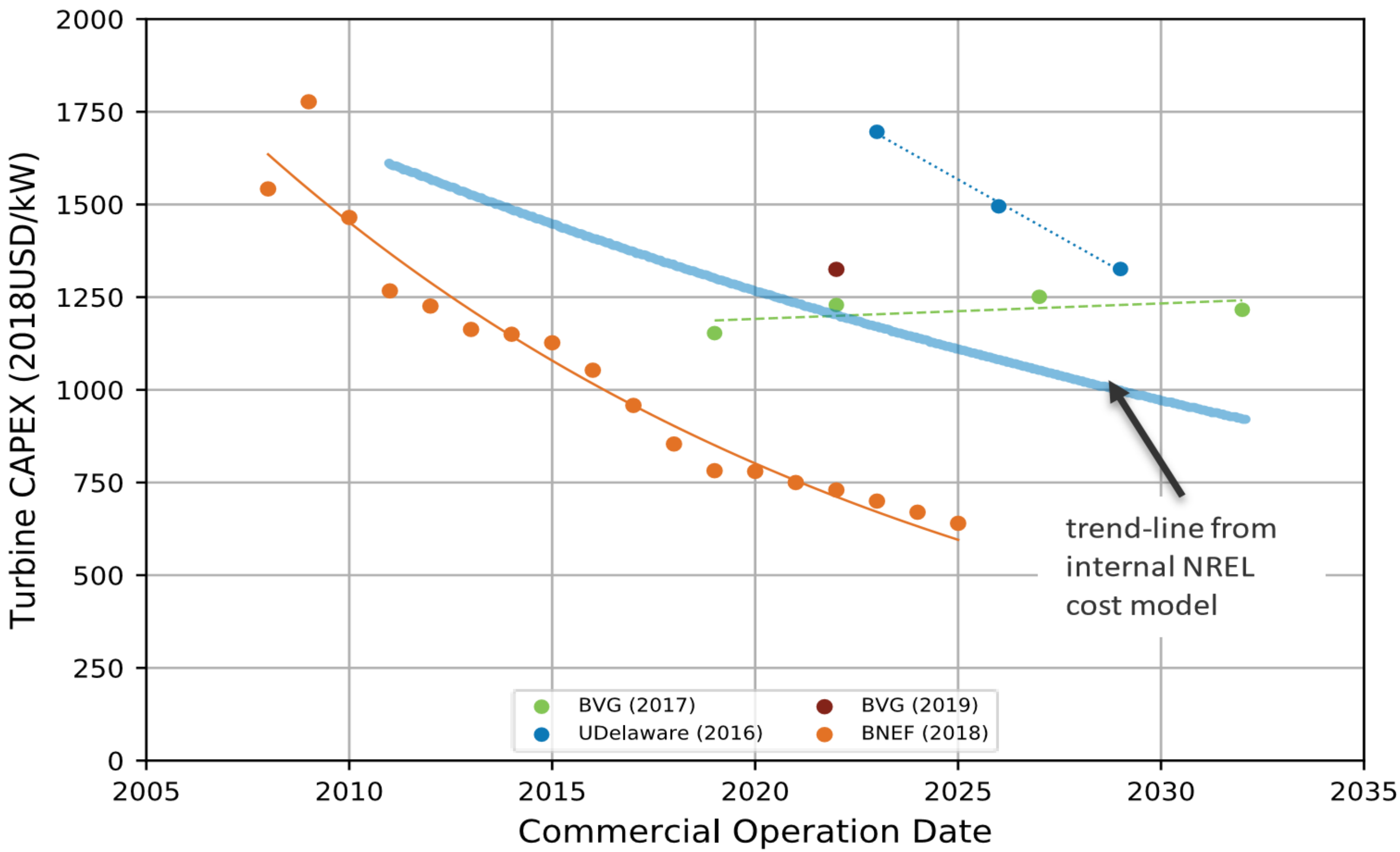
Source: National Renewable Energy Laboratory

Offshore Wind Project CAPEX Trend



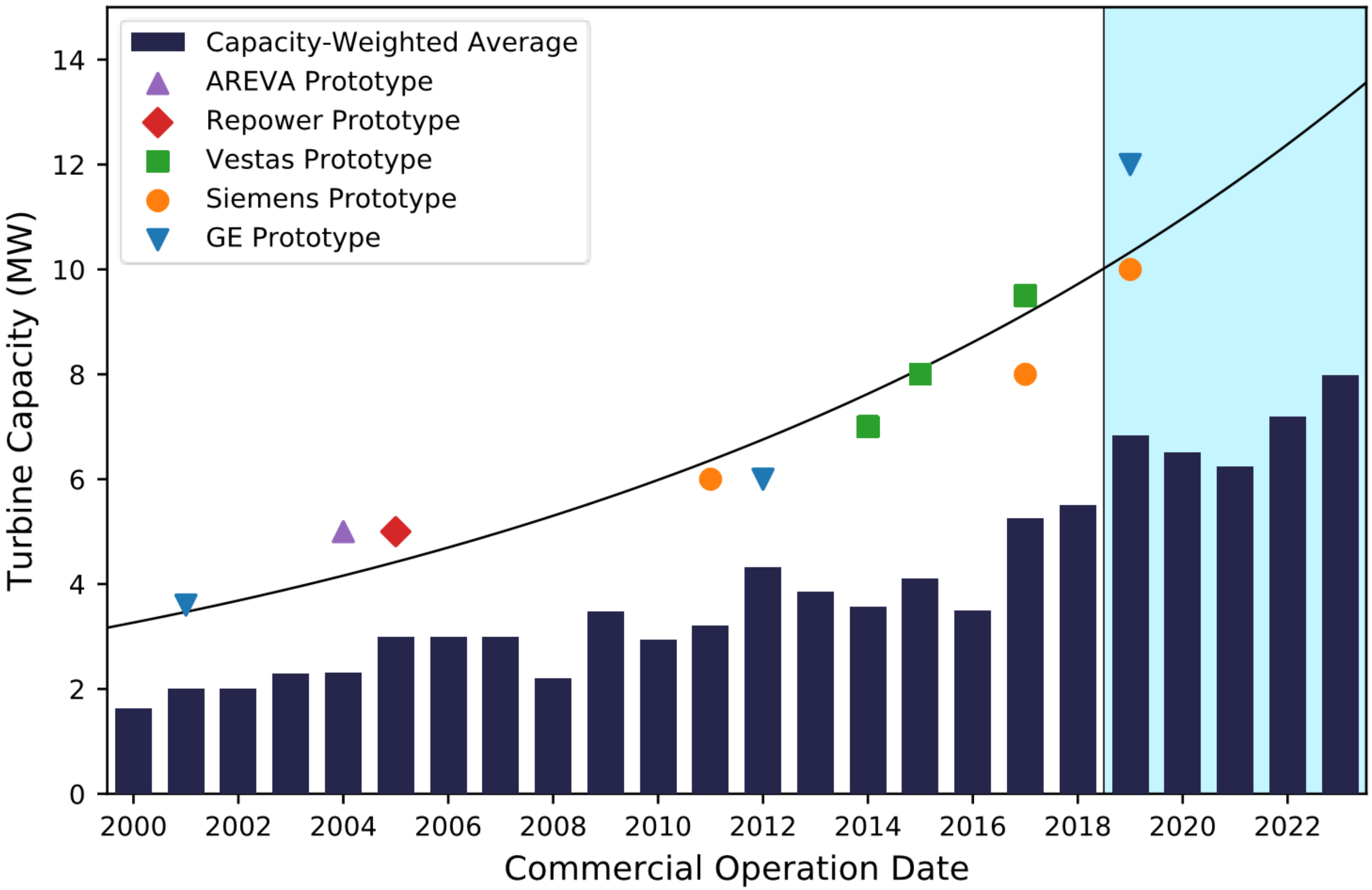
Source: National Renewable Energy Laboratory

Offshore Wind Turbine CAPEX Trend



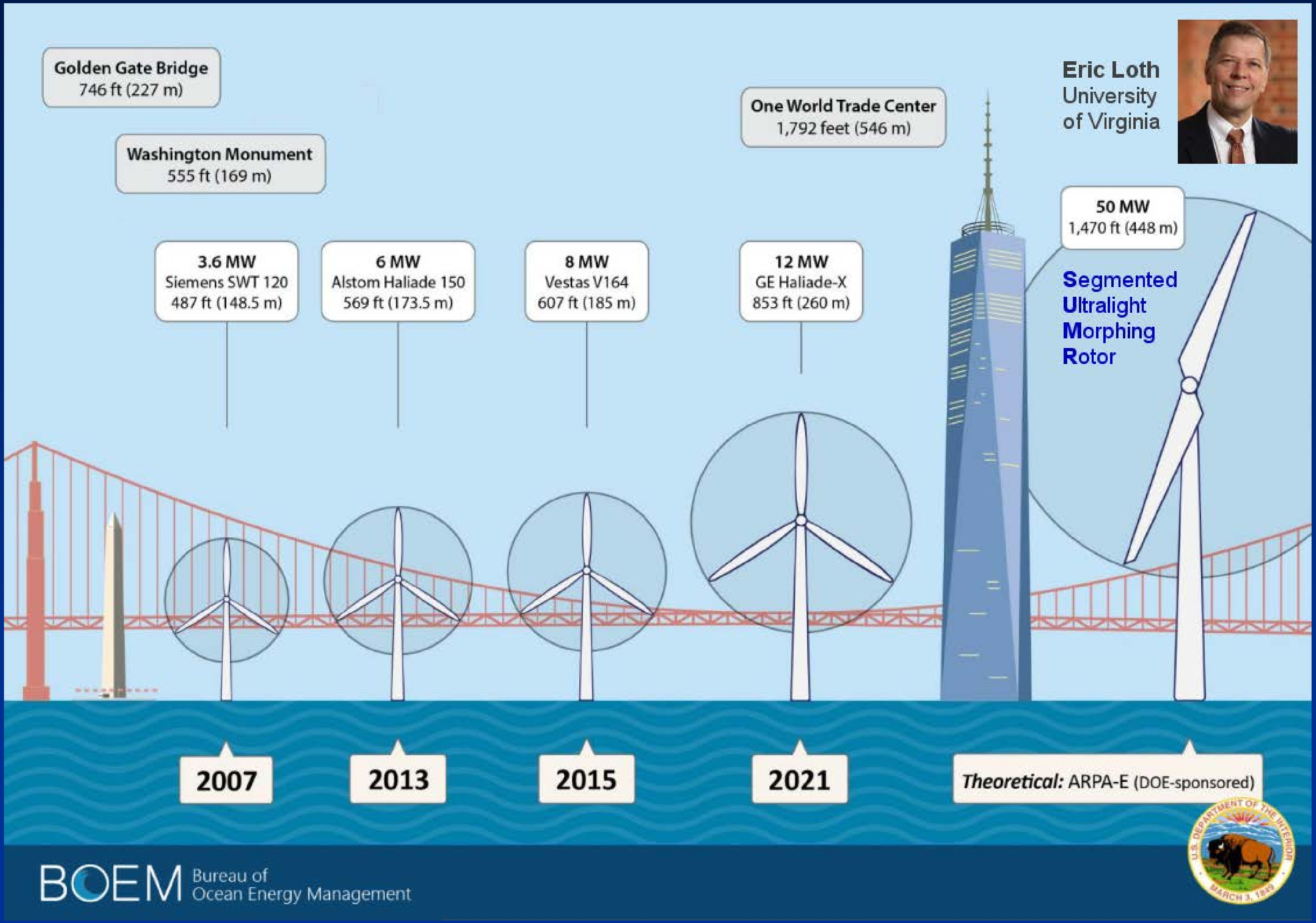
Source: National Renewable Energy Laboratory

Offshore Wind Turbine SIZE Trend
Accelerating Rate of Growth since 2012

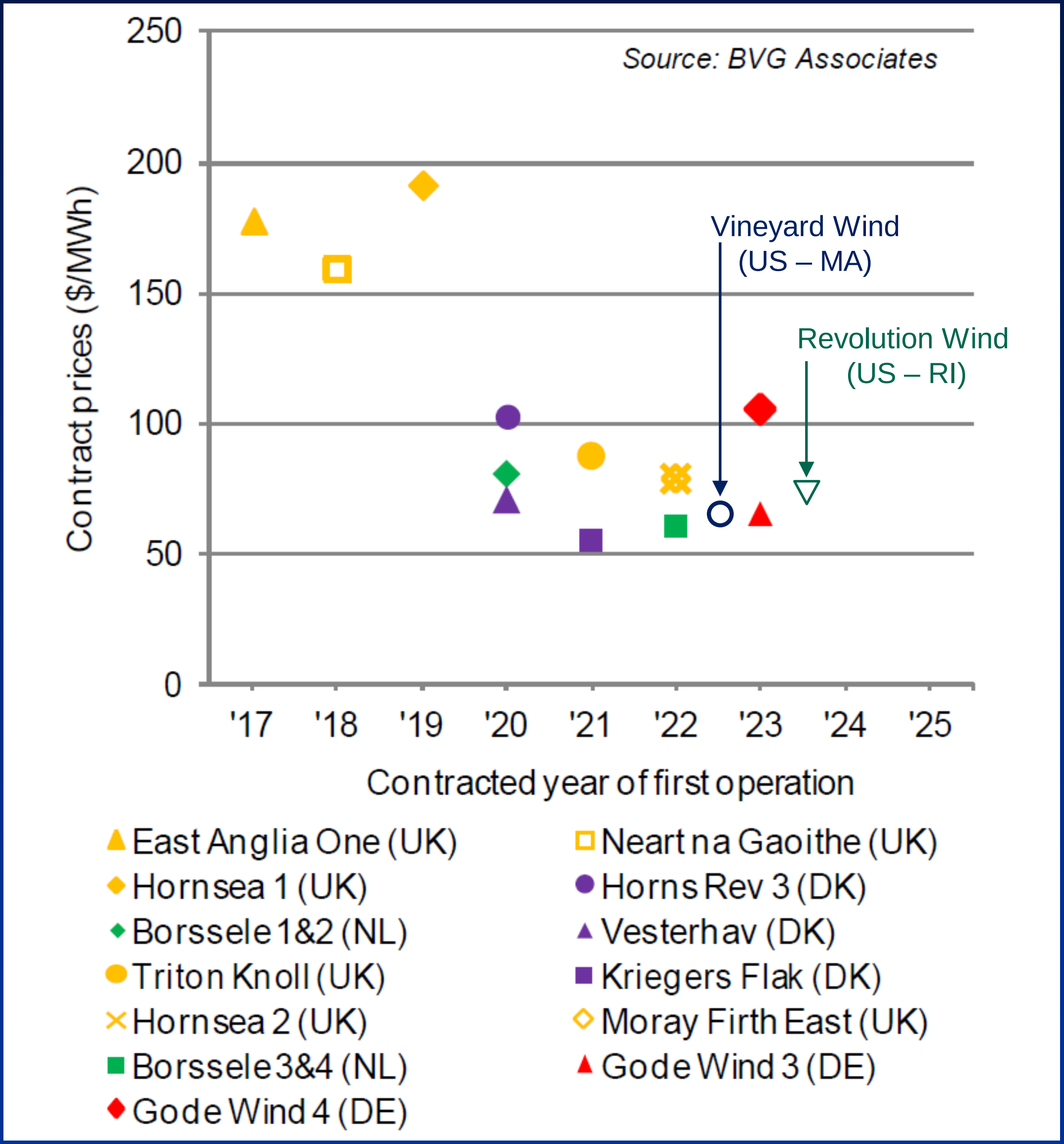


Source: National Renewable Energy Laboratory

Offshore Wind Turbine SIZE Visualization



Power Purchase Price of Offshore Wind Drops Dramatically for Projects in Service After 2019



Graph of European offshore wind power purchase prices for project in-service dates through 2024, based on recent auctions. Only UK projects (yellow) include transmission; NL, DE, and DK projects do not. Prices in 2017 USD; Source: https://files.vasierraclub.org/oswvision.pdf

Sources of US project contract prices:

Vineyard Wind (MA@2x400MW) –
www.windpoweroffshore.com/article/1489414/vineyard-wind-secures-levelised-cost-65-mwh
"The 20-year average cost of the two long-term contracts is $84.23 per MWh in levelised nominal dollar terms. This is equivalent to a levelised net present value price in 2017 dollars of $64.97 per MWh."

Revolution Wind (RI@400MW, CT@304MW) –
www.windpoweroffshore.com/article/1525240/orsted-sells-50-stakes-us-offshore-wind-sites
"Revolution Wind will generate electricity for a levelised cost of energy (LCOE) of $73.68/MWh during its 20-year lifetime, Ørsted confirmed."
www.ripuc.org/eventsactions/docket/4929-NGrid-ScheduleNG-5(REDACTED).pdf
Indicates that LCOE is in 2018 dollars.

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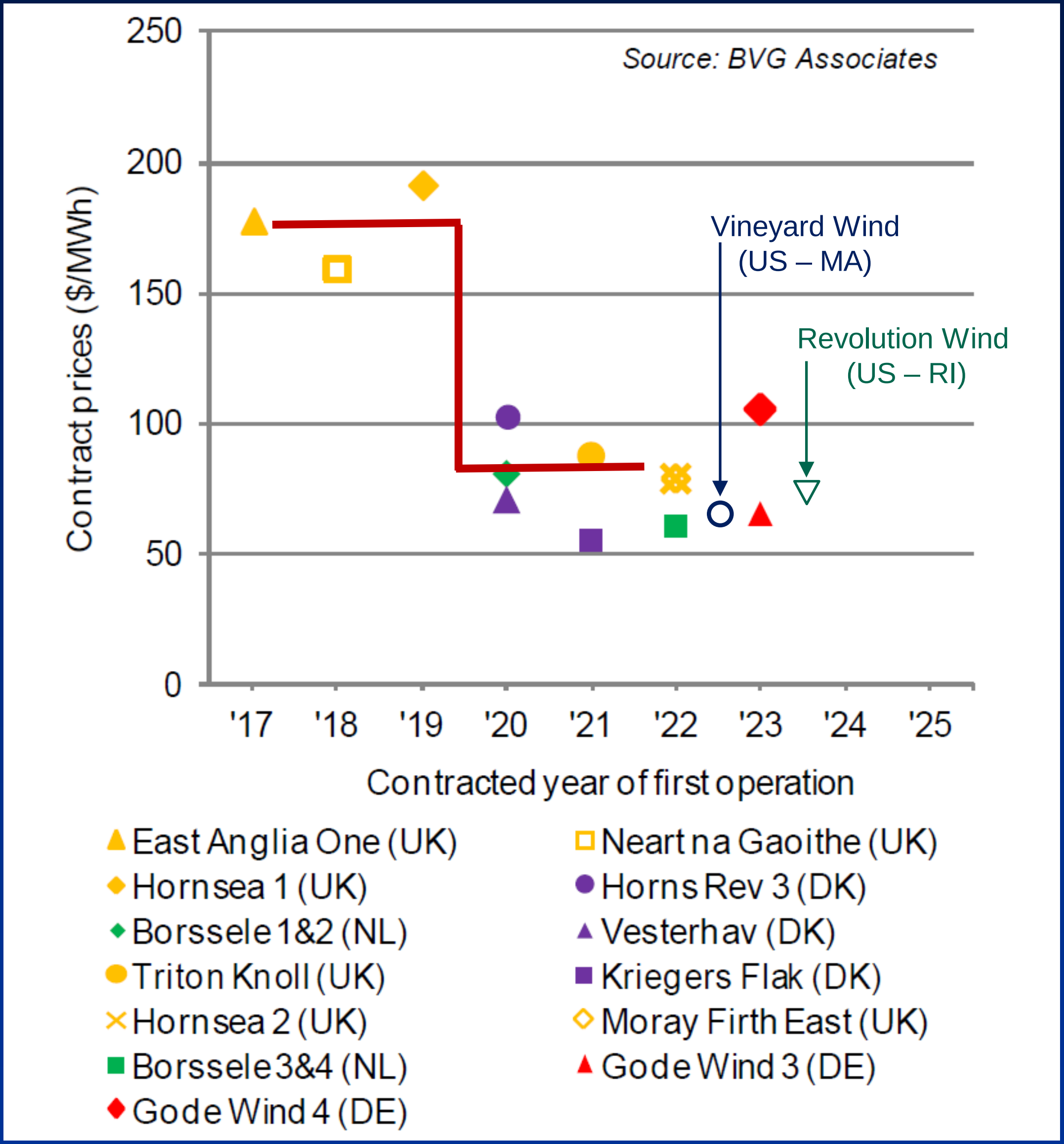

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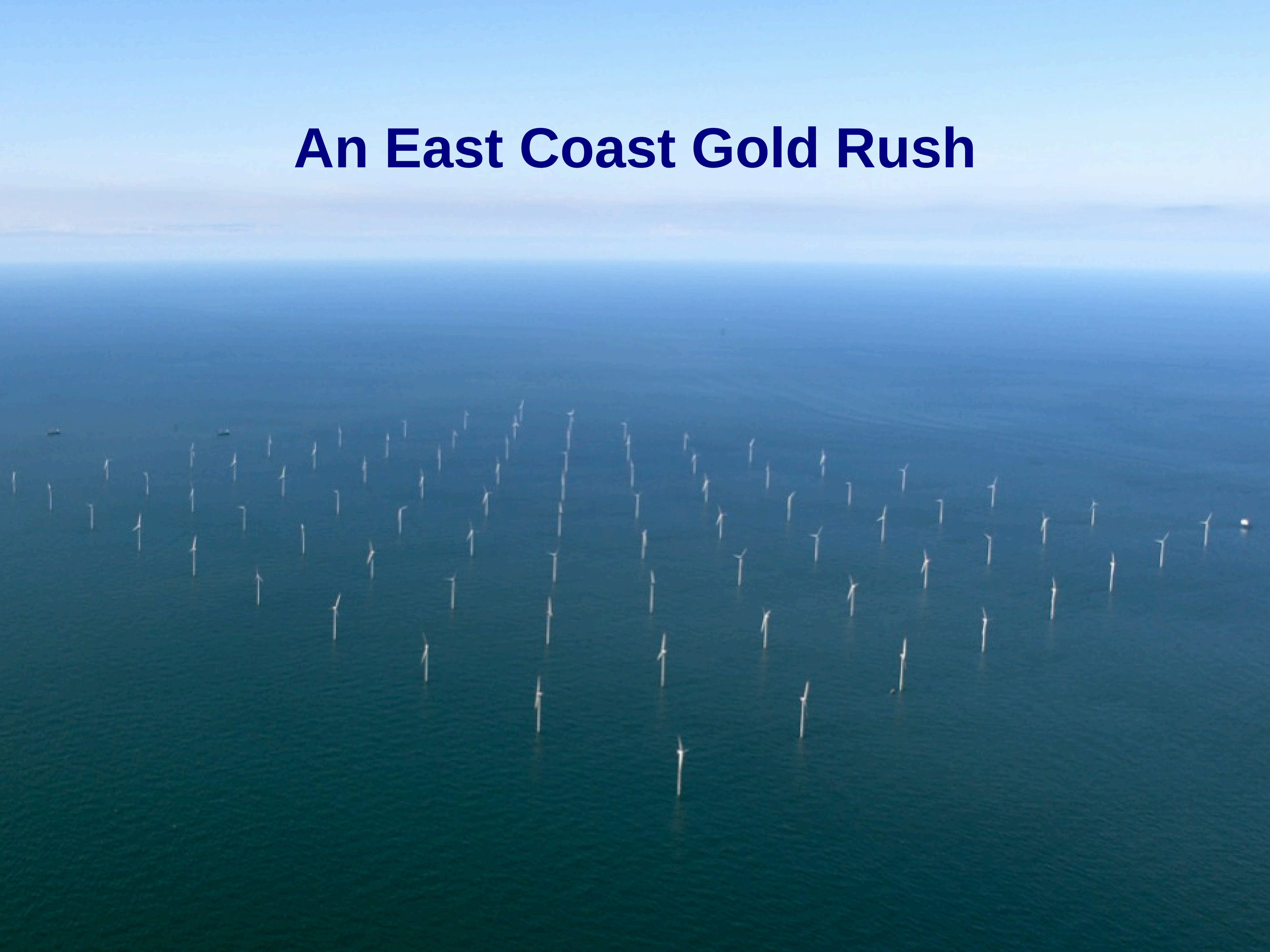
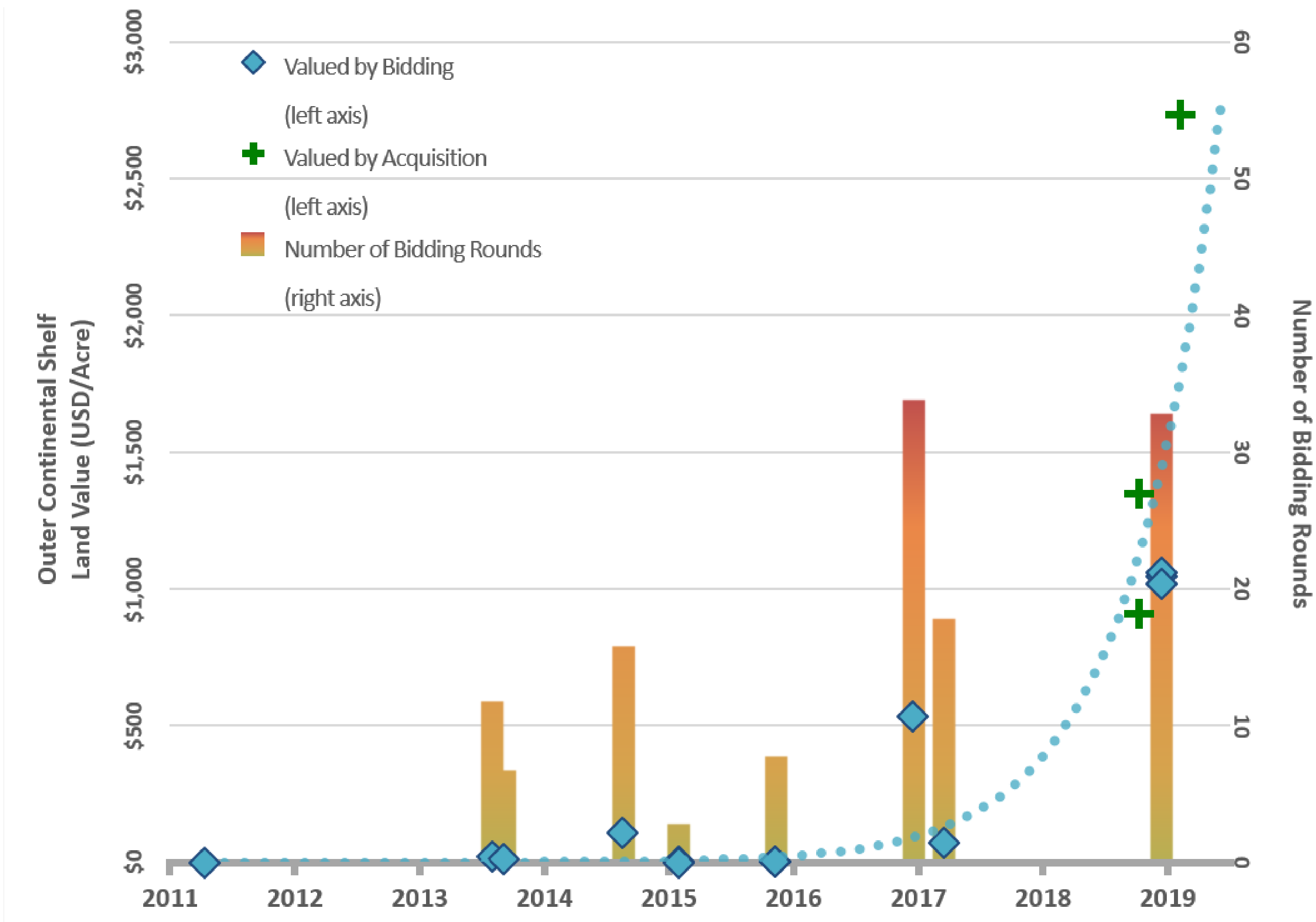
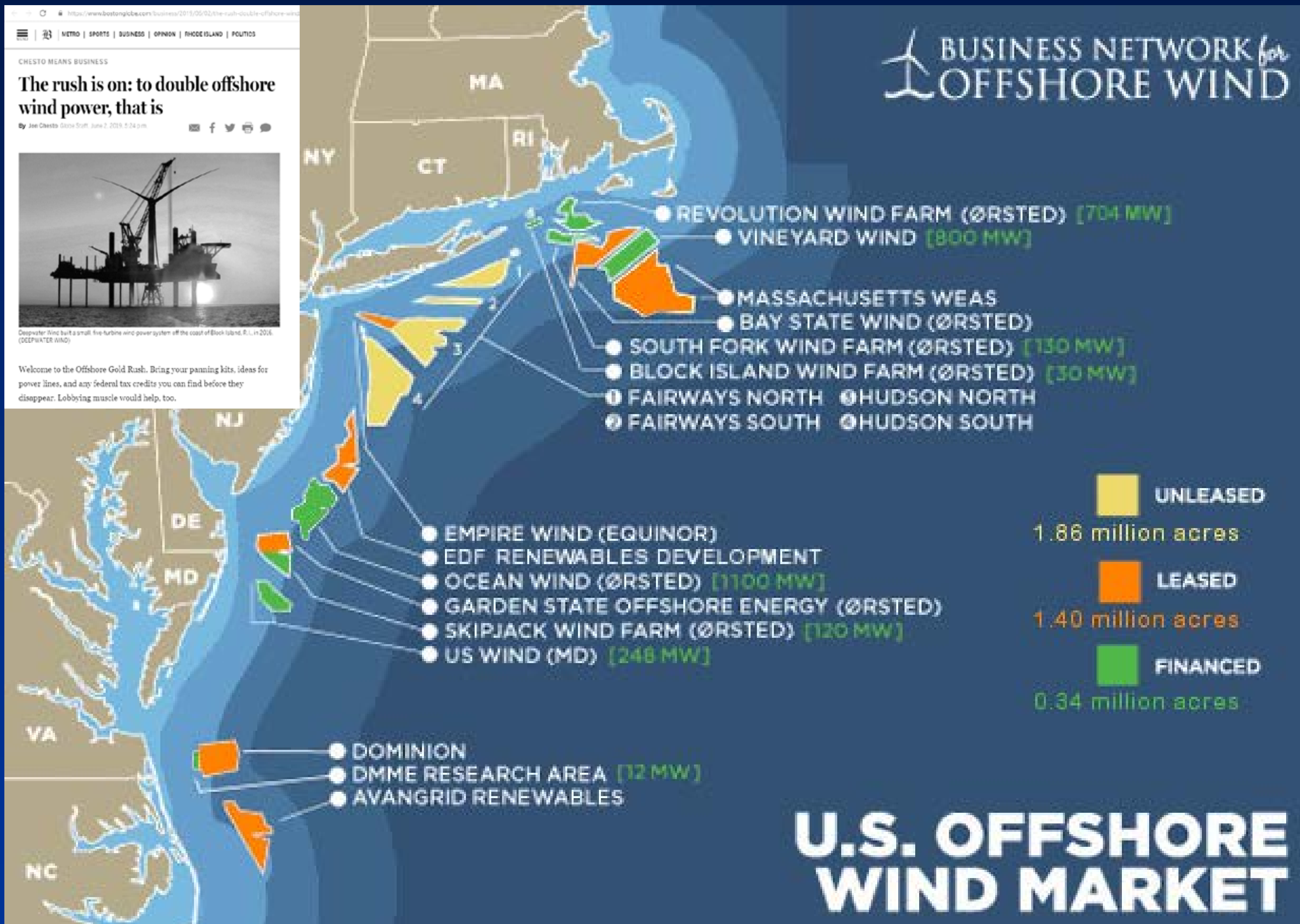
An East Coast Gold Rush



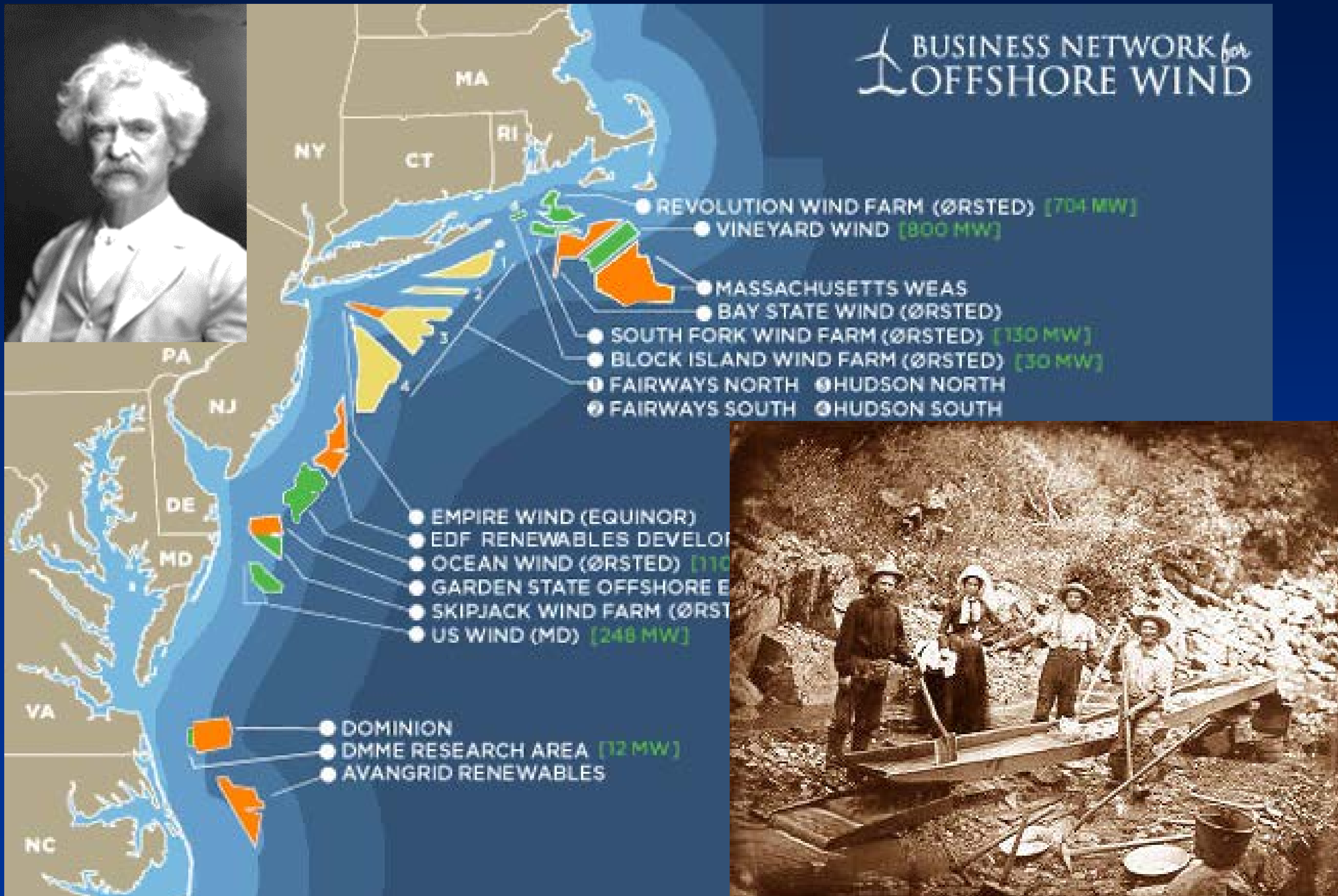
Mid-Atlantic Offshore Wind Lease Auctions and Acquisition Valuation of OCS Lands



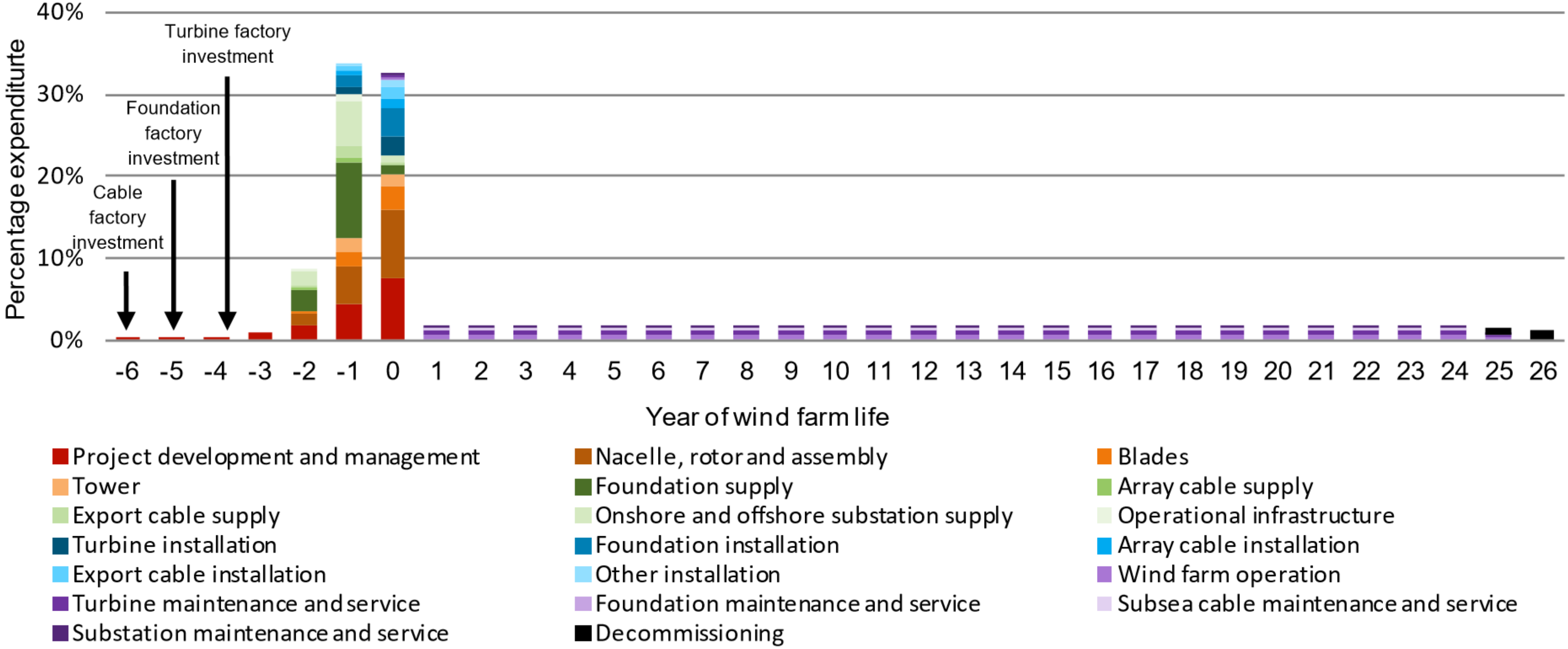
Bureau of Ocean Energy Management's East Coast Offshore Wind Lease Areas Total 1.74 Million Acres



“During the gold rush it’s a good time to be in the pick and shovel business” — Mark Twain

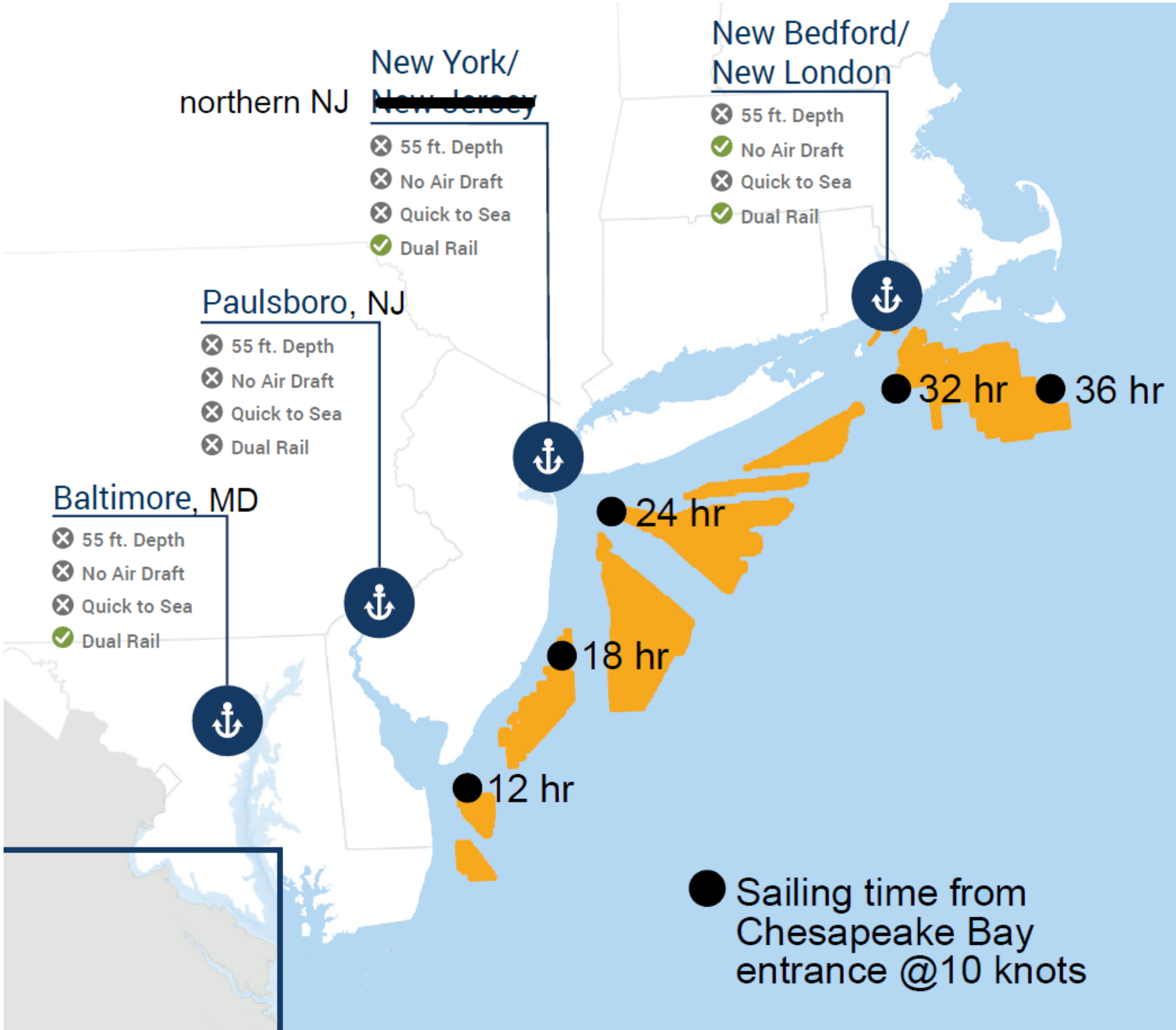


The Pick and Shovel Business of Offshore Wind

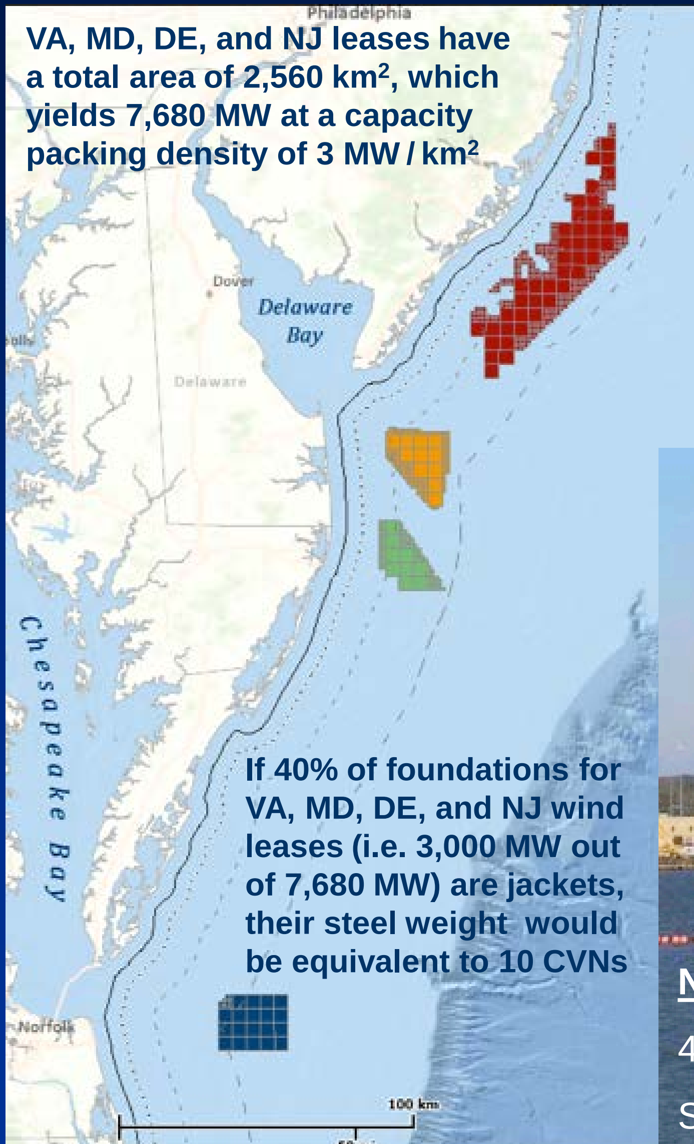


Expenditure profile for a typical offshore wind with the timing of investment decisions for key components

The Pick and Shovel Business of Offshore Wind



40% of VA+MD+DE+NJ Foundations as Jackets would have Steel Weight of 10 Nimitz-class CVNs



VA, MD, DE, and NJ leases have a total area of 2,560 km^2, which yields 7,680 MW at a capacity packing density of 3 MW / km^2

If 40% of foundations for VA, MD, DE, and NJ wind leases (i.e. 3,000 MW out of 7,680 MW) are jackets, their steel weight would be equivalent to 10 CVNs

<u>Total Steel in 300 MW Offshore Wind Project</u>

PIN PILES + PRIMARY STEEL + SECONDARY STEEL
= 800 metric tons per jacket x 60 jackets per project
= 48,000 metric tons (47,240 long tons)

Foundation steel for a 300 MW offshore wind project has the same weight as all of the structural steel in a single Nimitz-class nuclear aircraft carrier (CVN)

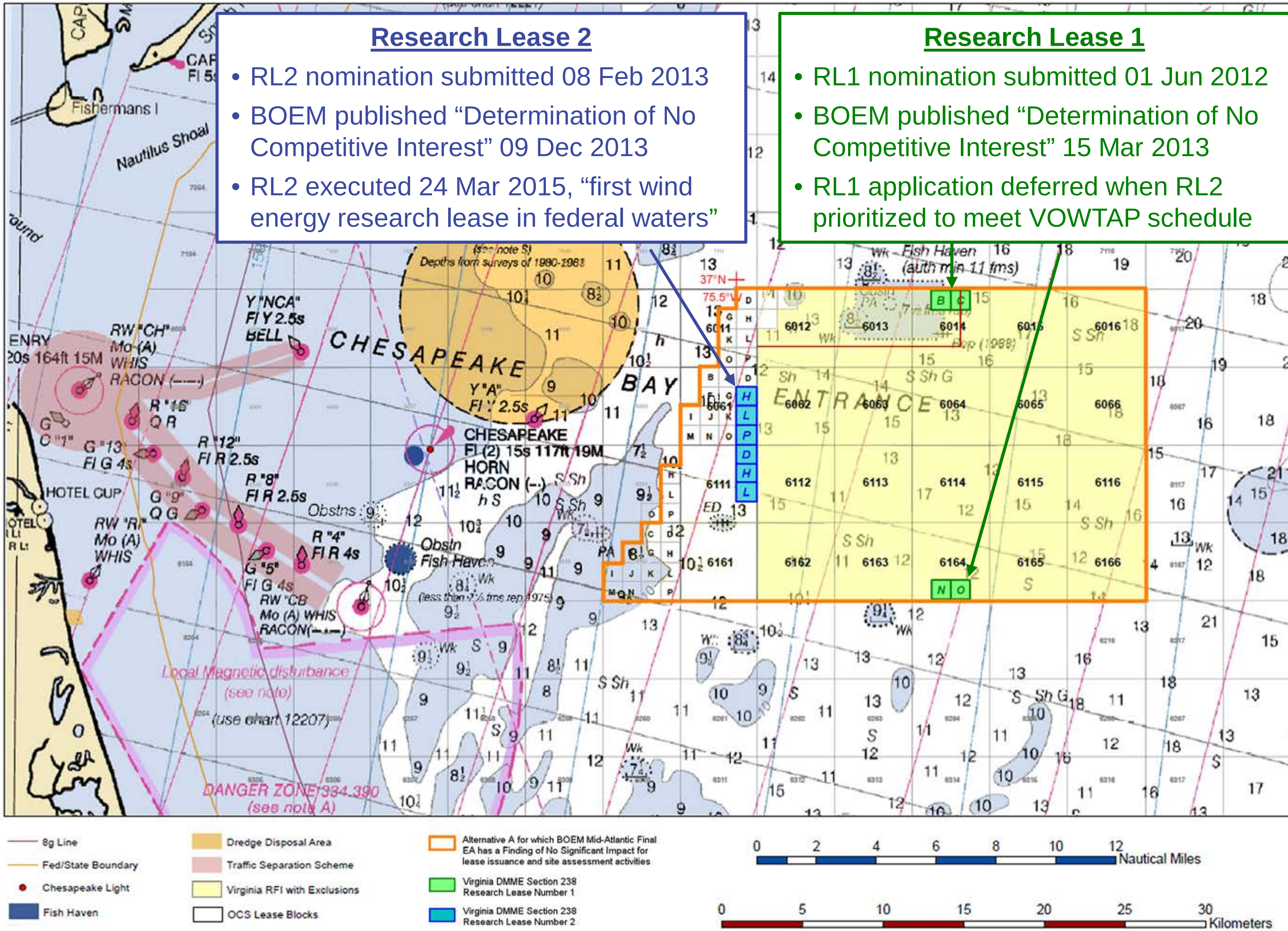
<u>Nimitz-class Nuclear Aircraft Carrier (CVN)</u>

47,000 long tons of structural steel

Source: www.dailypress.com/news/dp-cvn77-01,0,5744629.htmlstory

Demonstrating Technology Innovation

Research Lease Status



Research Lease 2

- RL2 nomination submitted 08 Feb 2013
- BOEM published "Determination of No Competitive Interest" 09 Dec 2013
- RL2 executed 24 Mar 2015, "first wind energy research lease in federal waters"

Research Lease 1

- RL1 nomination submitted 01 Jun 2012
- BOEM published "Determination of No Competitive Interest" 15 Mar 2013
- RL1 application deferred when RL2 prioritized to meet VOWTAP schedule

Major Research Funding Opportunity

National Offshore Wind Research and Development Consortium

Notice of Upcoming Technical Challenges

First Research Pillar: Offshore Wind Plant Technology Assessment | Initial Release Version 1.0 | November 2018

The Consortium will competitively award **~$32 million** in research funding through open solicitations over the **next four years**

NYSERDA solicitation addresses the three research pillars of the US National Offshore Wind Strategy:

- **Pillar #1**: Offshore Wind Plant Technology Advancement
- **Pillar #2**: Offshore Wind Power Resource and Physical Site Characterization
- **Pillar #3**: Installation, Operations and Maintenance, and Supply Chain

First proposals target priority Challenge Areas identified for Pillar #1:

(1) Array Performance and Control Optimization

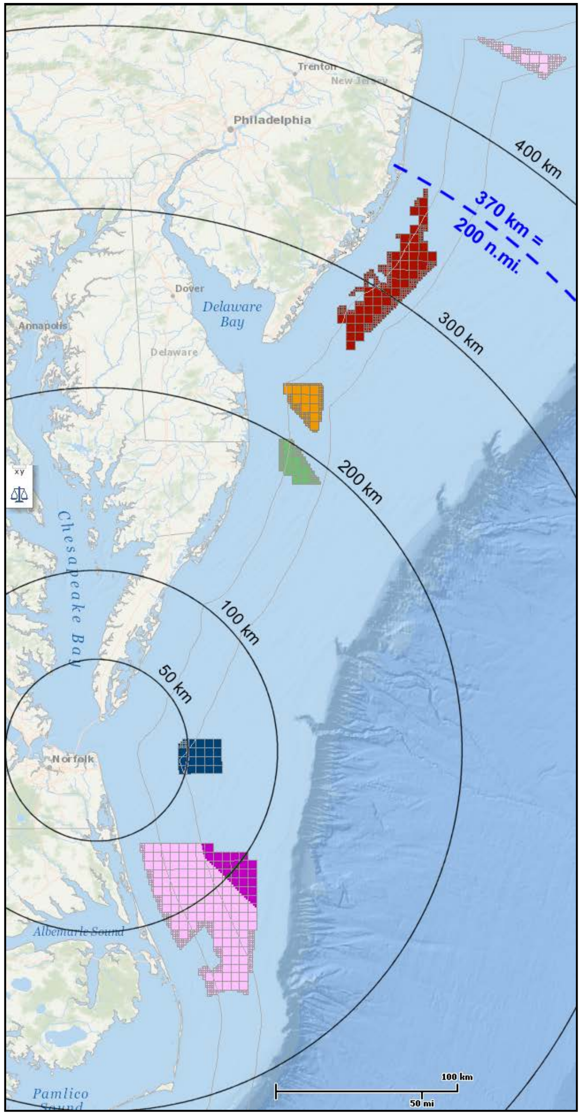
(2) Cost-Reducing Turbine Support Structures

Research Pillar #1 – Challenge Area 1 (CA1)
Array Performance and Control Optimization

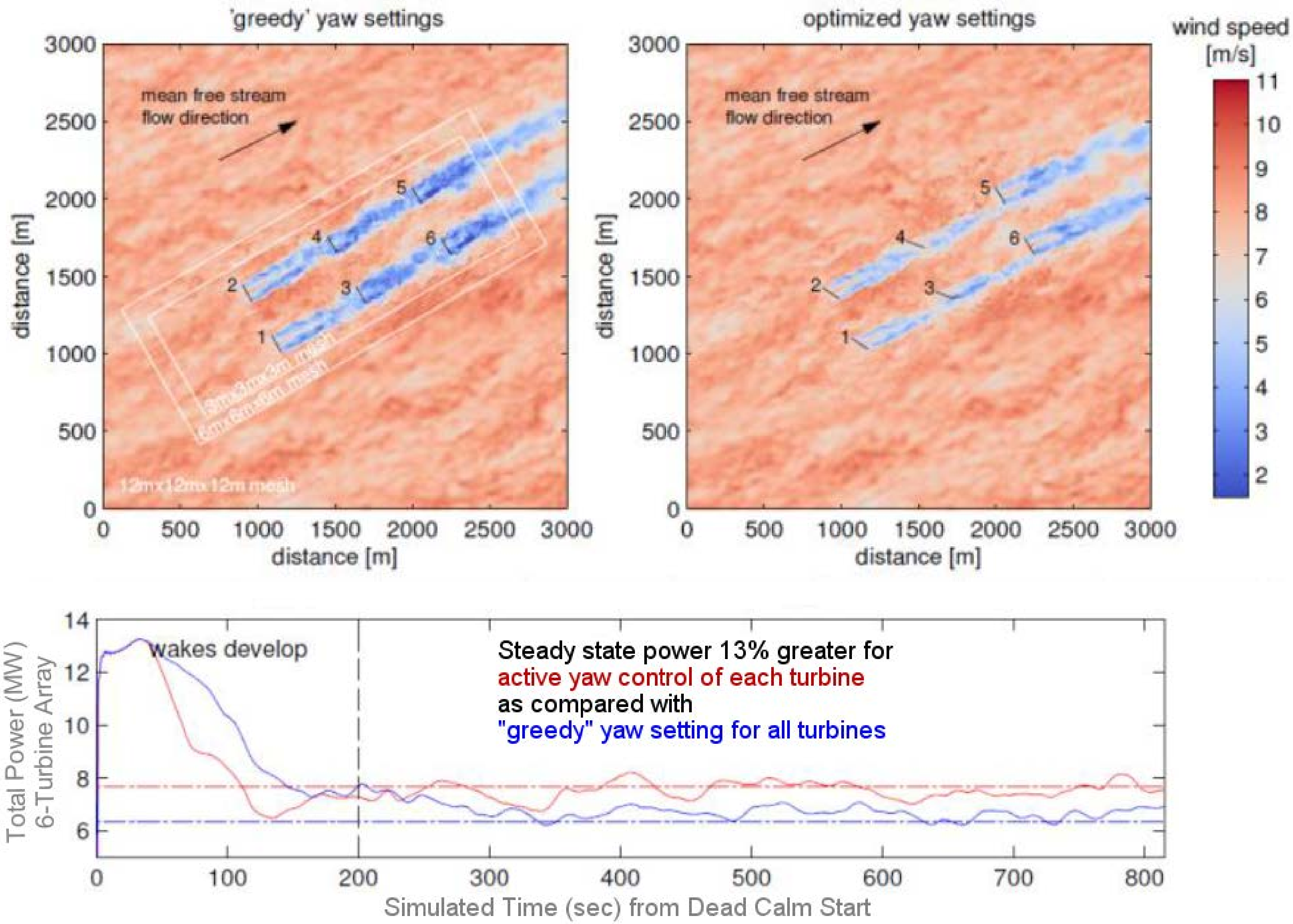
Existing commercial lease project capacity pipeline within a day's sail from Hampton Roads depends on assumed turbine capacity density:

- Commercial leases off NJ, DE, MD, VA, and Kitty Hawk, NC have a total combined area of 3,056 square kilometers
- U.S. National Offshore Wind Strategy assumes a potential installed turbine density of 3 megawatts per square kilometer, or 3.0 MW/km^2, yielding a **9.17 GW pipeline**
- Most recent European resource study (BVGA, June 2017) assumes 5.4 MW/km^2, yielding a **16.5 GW pipeline**
- National Renewable Energy Laboratory studies show that when optimal turbine positioning is combined with wake steering by active yaw control, baseline of 5.4 MW/km^2 can be increased to 8.8 MW/km^2, yielding a **26.9 GW pipeline**

Proving NREL optimization studies would grow the southern Mid-Atlantic project pipeline to the same levels as in Europe, where dramatic cost reductions were possible when pipeline >20 GW



National Renewable Energy Laboratory (NREL) Simulation of Wind Plant Layout & Control



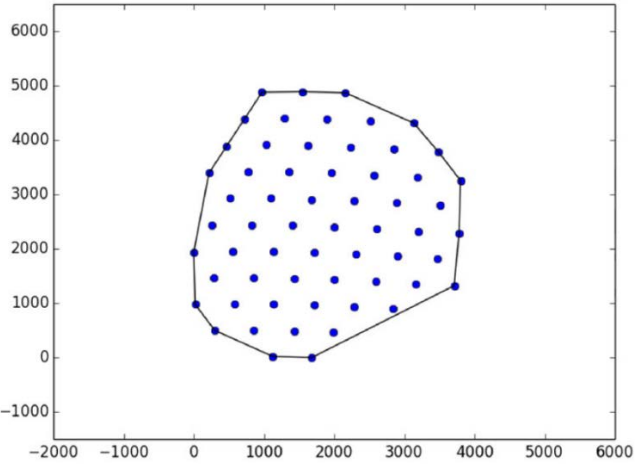
Source: Katherine Dykes, National Renewable Energy Laboratory, 11 Oct 2017

NREL Optimization for Hypothetical Project Yields 5% more Energy 70% more Energy per Unit Area

	Baseline	YawOpt	PosOpt	Combined
Mean power (MW)	78.86	84.91	78.86	78.84
Area (km^2)	14.53	14.53	12.45	8.96
Power density (W/m^2)	5.43	5.84	6.33	8.80
AEP(GWh)	1040.3	1094 (+5.2%)	1055.8 (+1.5%)	1095 (+5.3%)

71.6 GWh per km^2

Baseline Layout



Baseline: fixed (original) turbine positions, turbines all yawed in mean wind direction

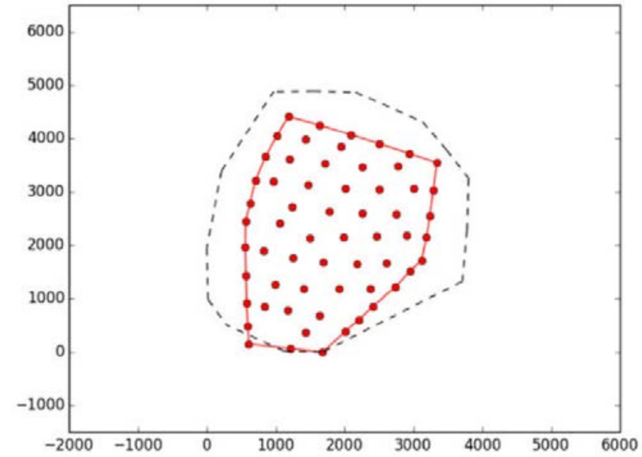
YawOpt: fixed (original) positions, turbines actively yawed for each wind direction

PosOpt: positions optimized, turbines all yawed in mean wind direction

Combined: positions optimized AND turbines actively yawed for each wind direction

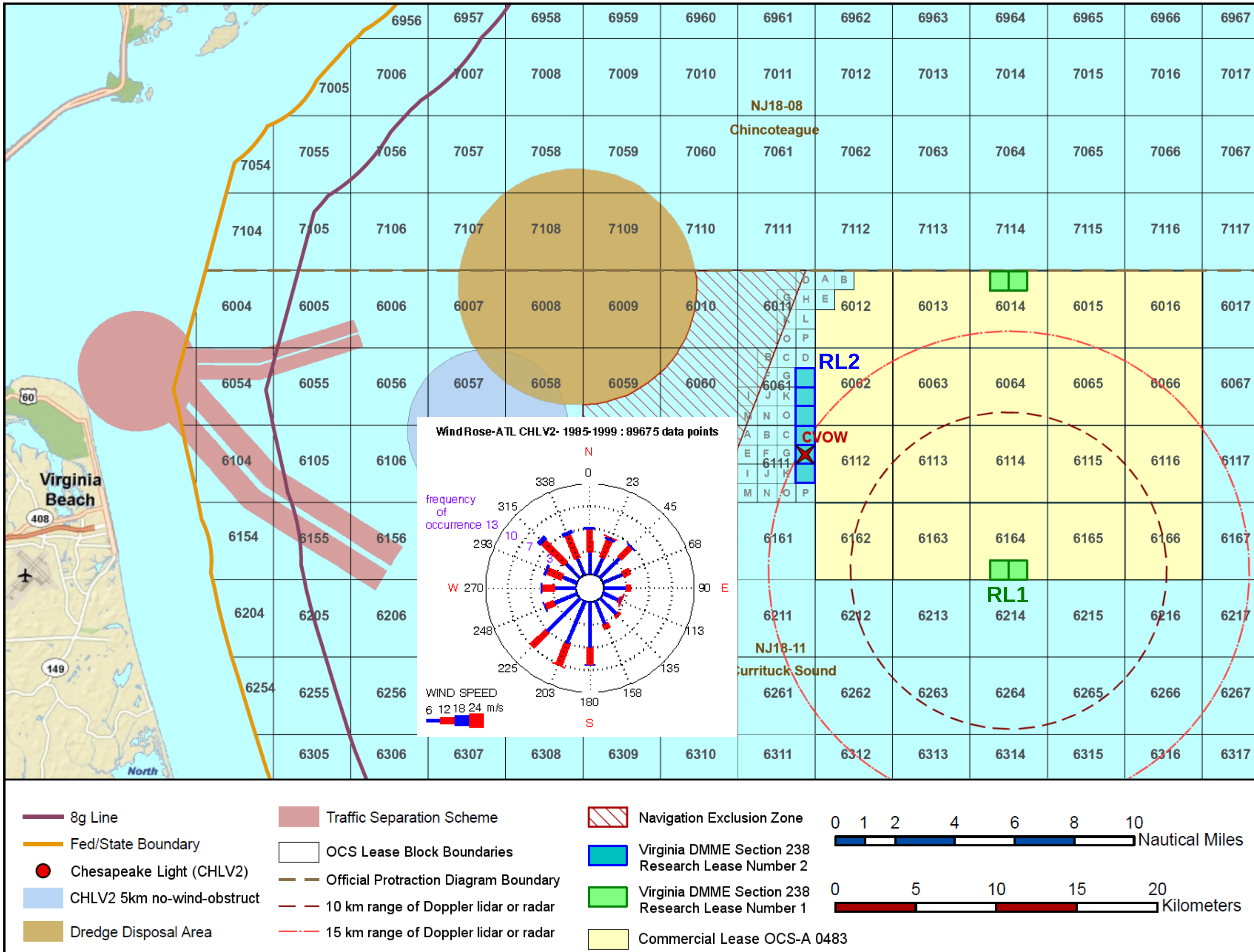
122 GWh per km^2

Combined Layout



Source: Katherine Dykes, National Renewable Energy Laboratory, 11 Oct 2017
See http://onlinelibrary.wiley.com/doi/10.1002/we.1993/abstract for peer-reviewed paper.

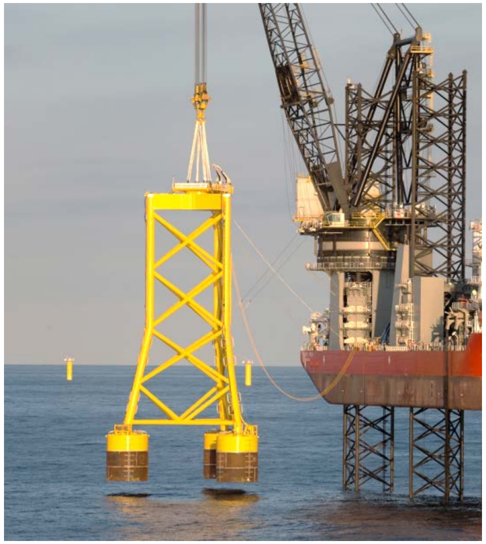
Virginia Research Leases Well-Positioned to Validate Wind Plant Layout & Control Modeling over Water



Research Pillar #1 – Challenge Area 2 (CA2) Cost-Reducing Turbine Support Structures

A fixed platform is required to support a Doppler lidar or radar in RL2, to validate NREL computer simulations, and at the same time, this would demonstrate an innovative suction-bucket jacket foundation that can be fabricated and assembled in Hampton Roads for the entire East Coast market

- Demonstrate foundation installation without pile driving, which greatly expands offshore installation season from summer-only, daytime-only to **year-round, day-and-night**
- Validate jacket transparency to impact of breaking storm waves


First prototype suction-bucket jacket at Borkum Riffgrund I, pioneered by DONG Energy


Breaking wave at FINO-1 platform in 28 m water depth when significant wave height is only 6 m

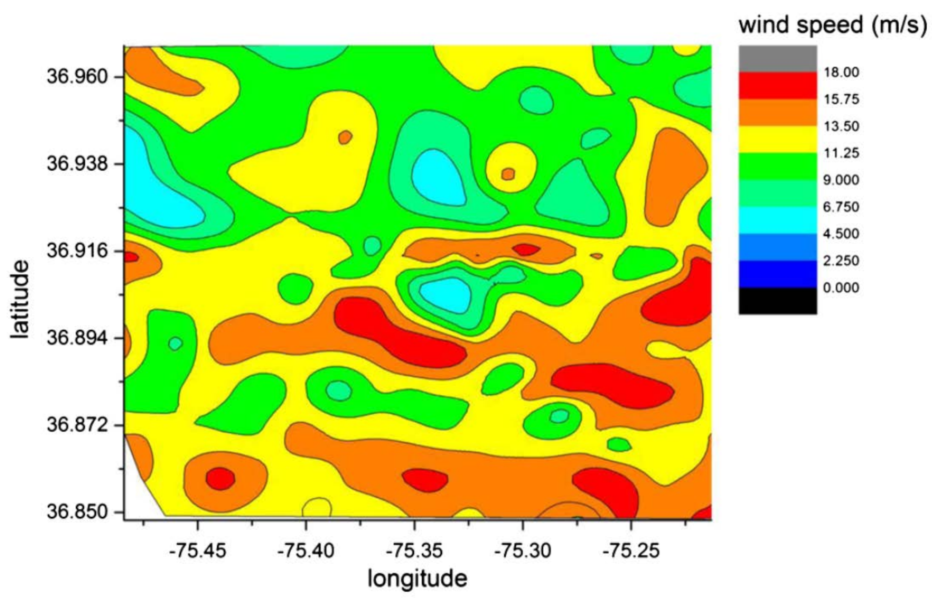

Suction-bucket jacket for European Offshore Wind Deployment Center

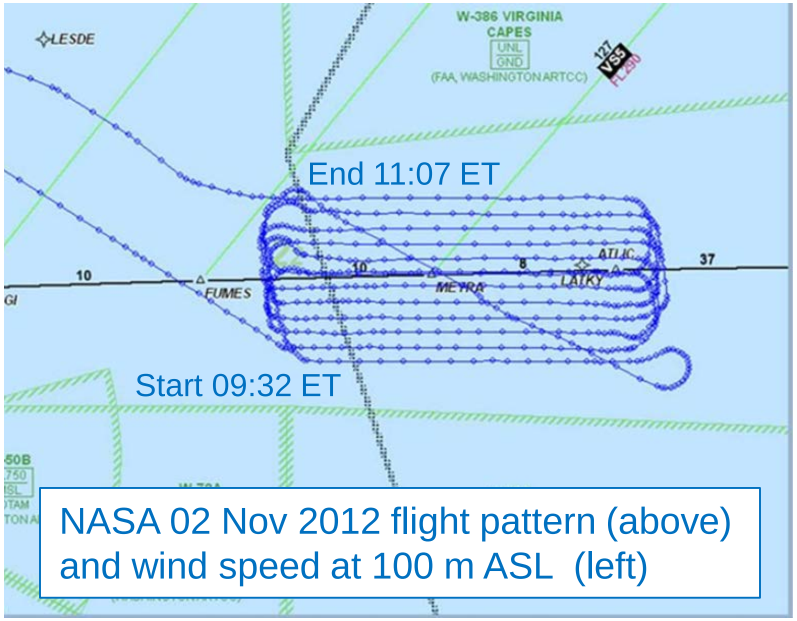
Doppler Lidar or Radar on Fixed Platforms in RL1 Aliquots also can Fully Map Resource

Research Key Question 3)

What innovative products and services can be demonstrated on Virginia's research leases to address wind-resource-related questions?

NASA Langley Research Center airborne Lidar measurements suggest large spatial variability in offshore wind resource across commercial lease area.





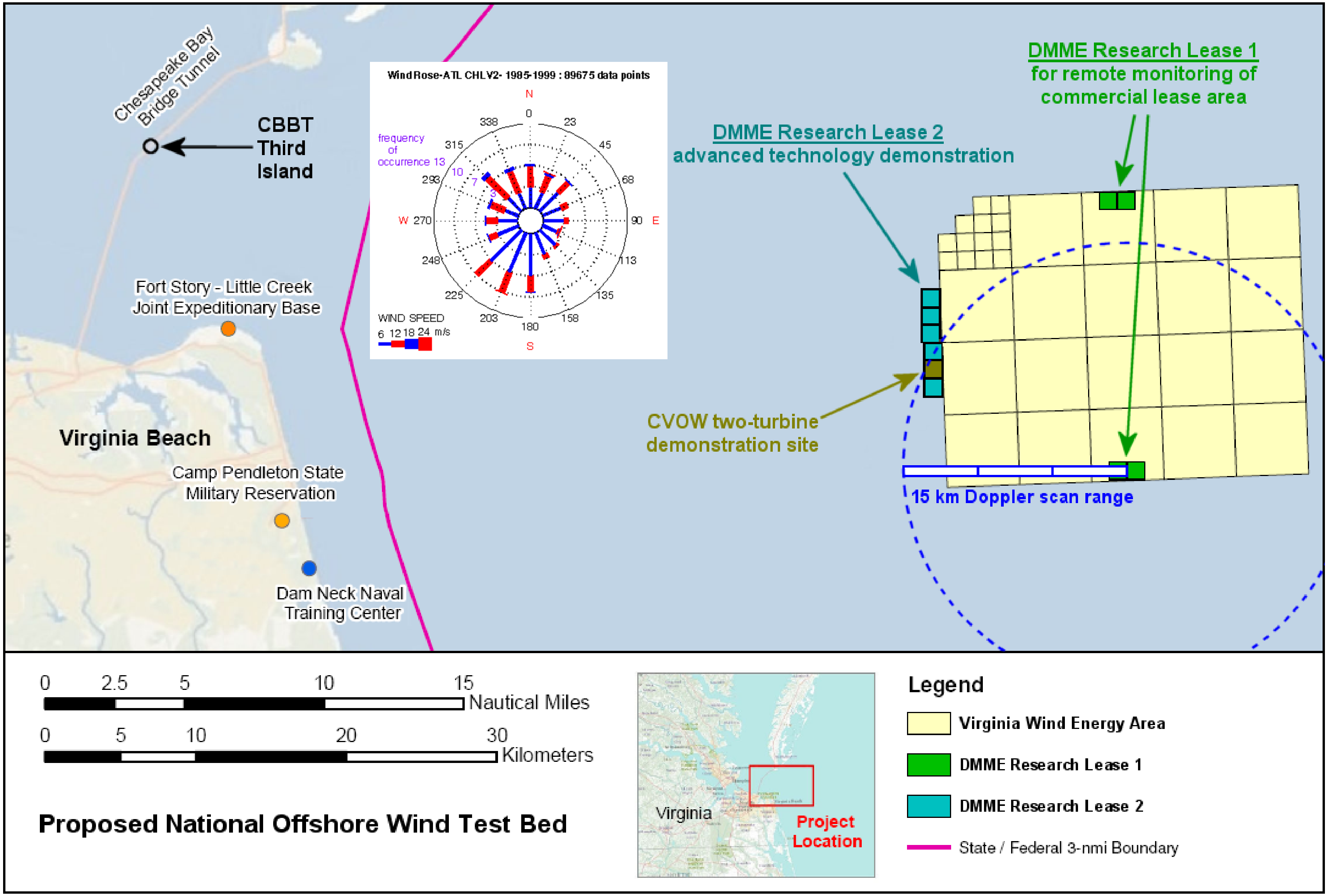
NASA 02 Nov 2012 flight pattern (above) and wind speed at 100 m ASL (left)

Doppler Lidar or Radar Suitability can be Tested at the Chesapeake Bay Entrance

Station Owner		Station Name	Range (km) *
NOS	Q	Chesapeake Bay Bridge Tunnel	8.4
Weatherflow	R	Lynnhaven Pier/Virginia Beach	13.3
NOS	T	Cape Henry	13.7
Weatherflow	S	Cape Henry	14.2
Weatherflow	K	Thimble Shoals/Chesapeake Bay	14.7
Weatherflow	P	Little Creek/Norfolk	14.8
NOS	C	Kiptopeke State Park	16.5
NOS	O	Willoughby Deguassing Station	22.5
Weatherflow	J	Messick Point Poquoson	23.1

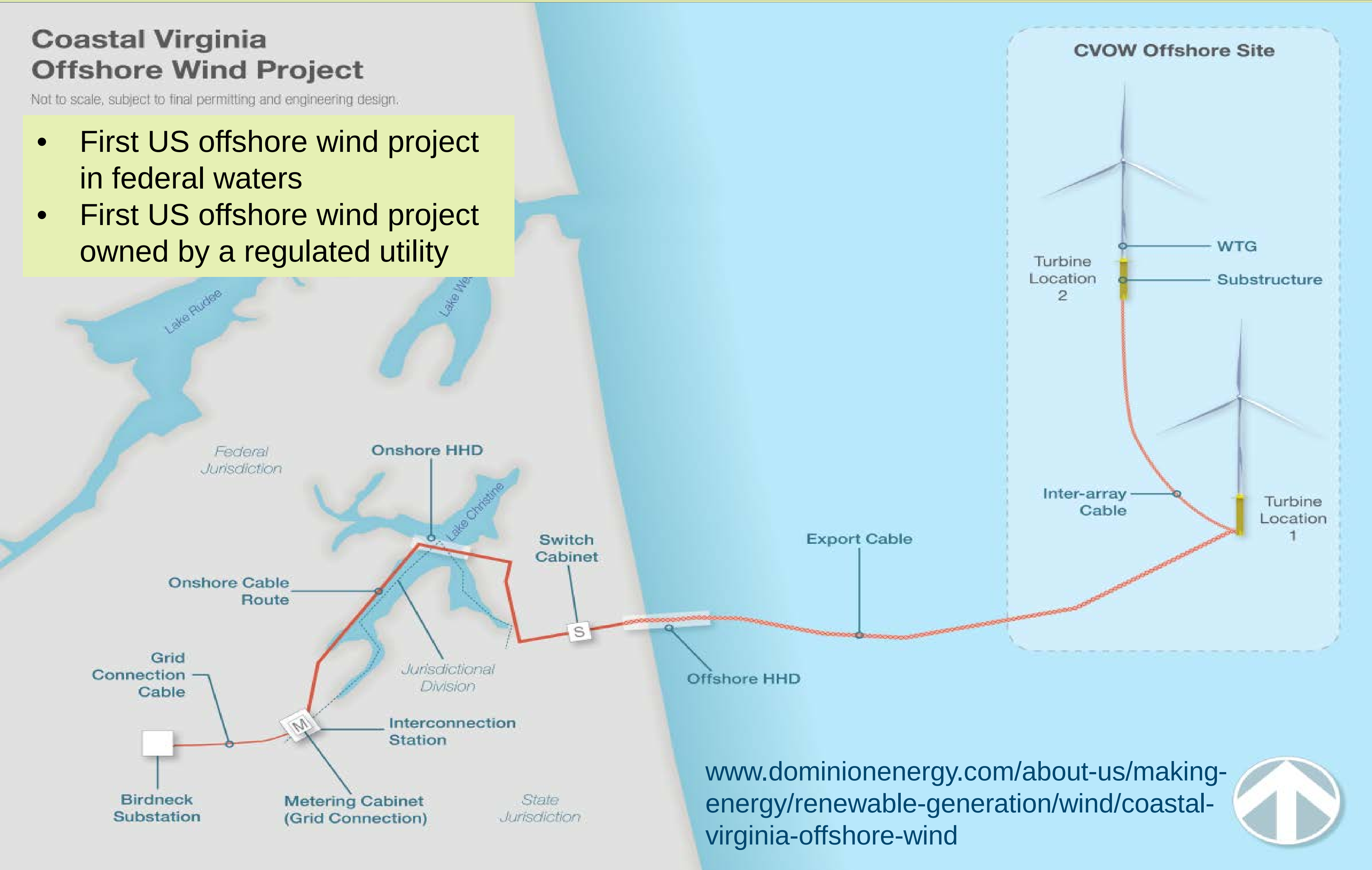
CBBT Third Island (Marker A) can be used to test truck-mounted Doppler lidar or radar signal range against existing coastal met masts before finalizing design and operation for fixed platforms in RL1

Successful CA2 Proposal Lays Groundwork for Reference Metocean Station and Ocean Test Bed



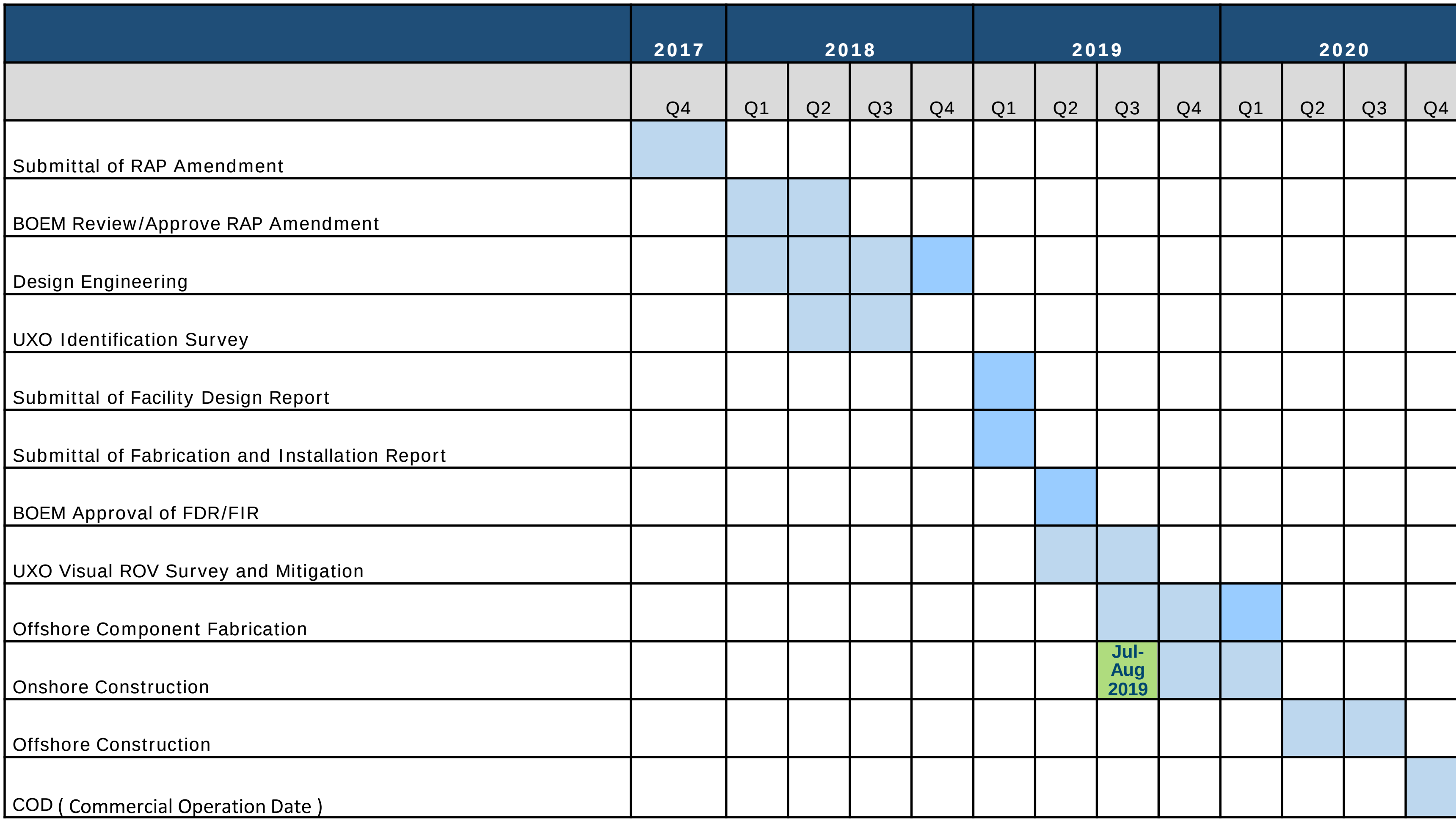
The Coastal Virginia Offshore Wind (CVOW) 12-MW Demonstration Project will be Built in 2020

- First US offshore wind project in federal waters
- First US offshore wind project owned by a regulated utility



www.dominionenergy.com/about-us/making-energy/renewable-generation/wind/coastal-virginia-offshore-wind

The Coastal Virginia Offshore Wind (CVOW) 12-MW Demonstration Project will be Built in 2020



High-Level Project Schedule

Directional drilling and installation of 1 km HDPE conduit for shore crossing of submarine power cable

The Coastal Virginia Offshore Wind (CVOW) 12-MW Demonstration Project will be Built in 2020

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Totally Autonomous Blade Inspection Enables Higher-Fidelity Structural Health Monitoring

Piloted UAV inspection of land-based turbine (left) and offshore oil & gas platform (right)

BENEFITS OF UAV SYSTEM

- Autonomous quad-rotors charged by service power circuit, remotely actuated
- Can afford much more frequent scheduled and "as needed" inspections
- Earlier detection of damage enables timely repair rather than costly replacement
- Eliminates riskiest offshore operation for personnel

Visual inspection by rope technicians will provide commercial standard of service for blades and be used to benchmark UAV performance

BP2	*Plan BP3 – BP5 activities; refine LCOE reduction estimates*
BP3	*Test components; validate visual & IR image interpretation*
BP4	*Integrate components and test on gantry at NASA-WFF*
BP5	*Install and operate a 3-quad system & charging garage on one turbine*

Next Time You Fly through Charlotte