Offshore Wind Energy Facility Characteristics

Walt Musial
Principal Engineer
Manager of Offshore Wind
National Renewable Energy Laboratory

March 5, 2018

BOEM's Offshore Wind and Maritime Industry Knowledge Exchange Workshop

NREL - 40 Years of Clean Energy Research

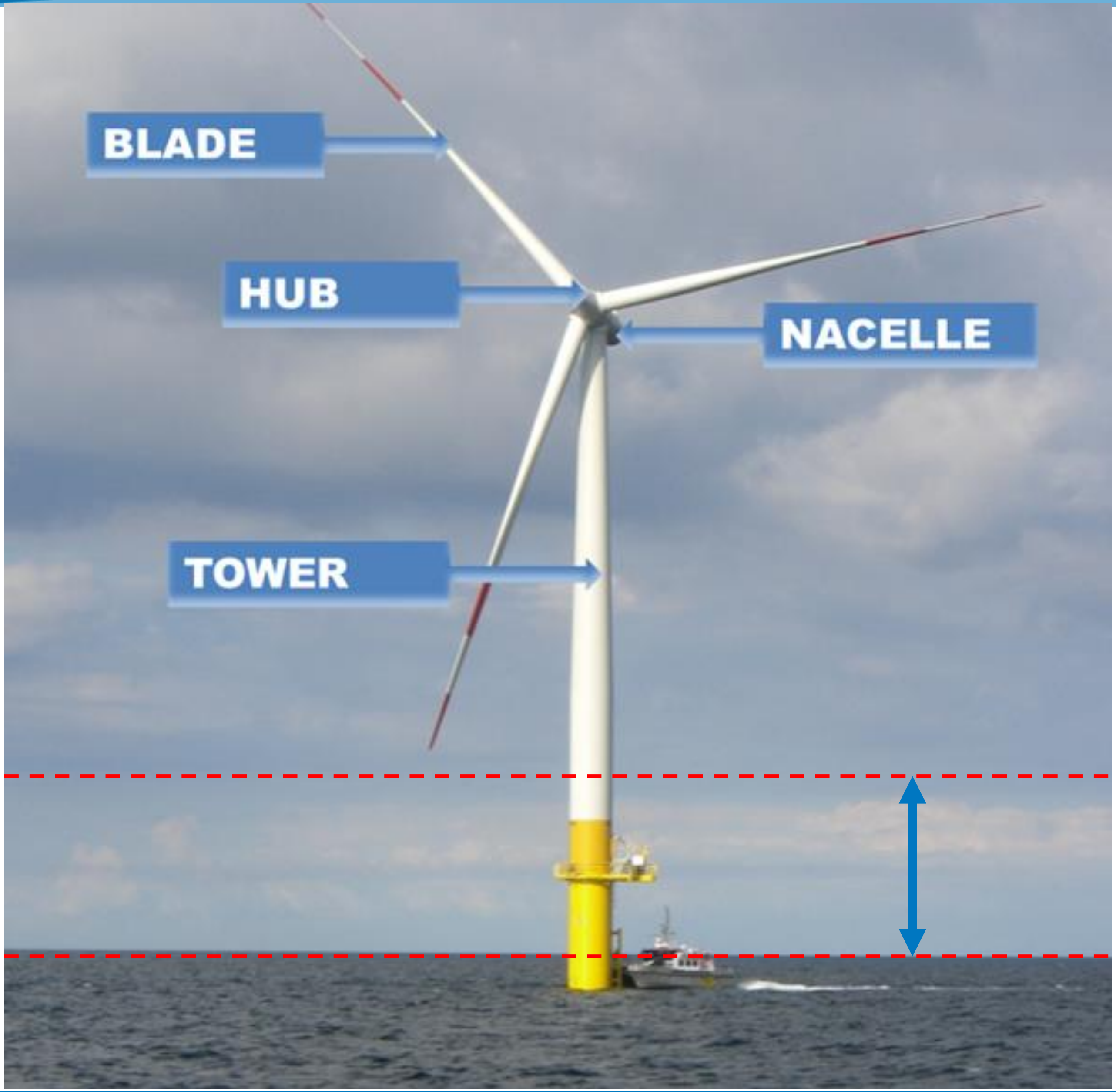
- World-class facilities, renowned technology experts
- Nearly 1,700 employees, including more than 400 early-career researchers and visiting scientists
- Nearly 750 active partnerships
- Campus is a living energy laboratory
- National economic impact of $872M annually

Scope of NREL Mission

Energy Sectors

RENEWABLE POWER	SUSTAINABLE TRANSPORTATION	ENERGY EFFICIENCY	ENERGY SYSTEMS INTEGRATION
Solar	Bioenergy	Buildings	Power Systems Research
Wind	Vehicle Technologies		High-Performance Computing
Geothermal	Hydrogen		Data and Visualizations
Water			

Wind Turbine Basic Terminology



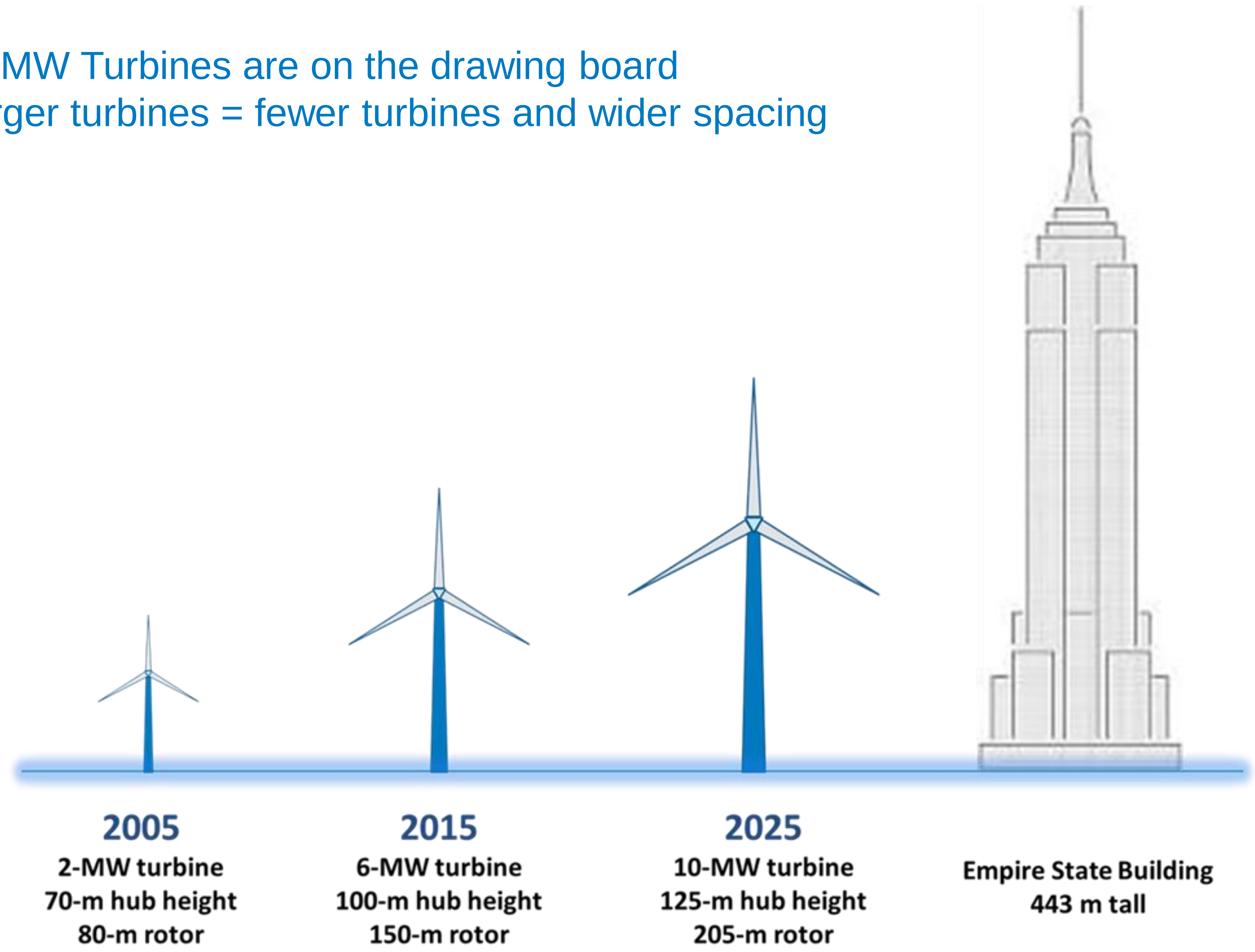
Rotor is the assembly of blades and hub

Nacelle contains the drive train and mechanical to electrical conversion systems

Minimum Tip Clearance
75 ft to 100 ft

Wind Turbine Size- Offshore Wind Growth Continues

15 MW Turbines are on the drawing board
Larger turbines = fewer turbines and wider spacing

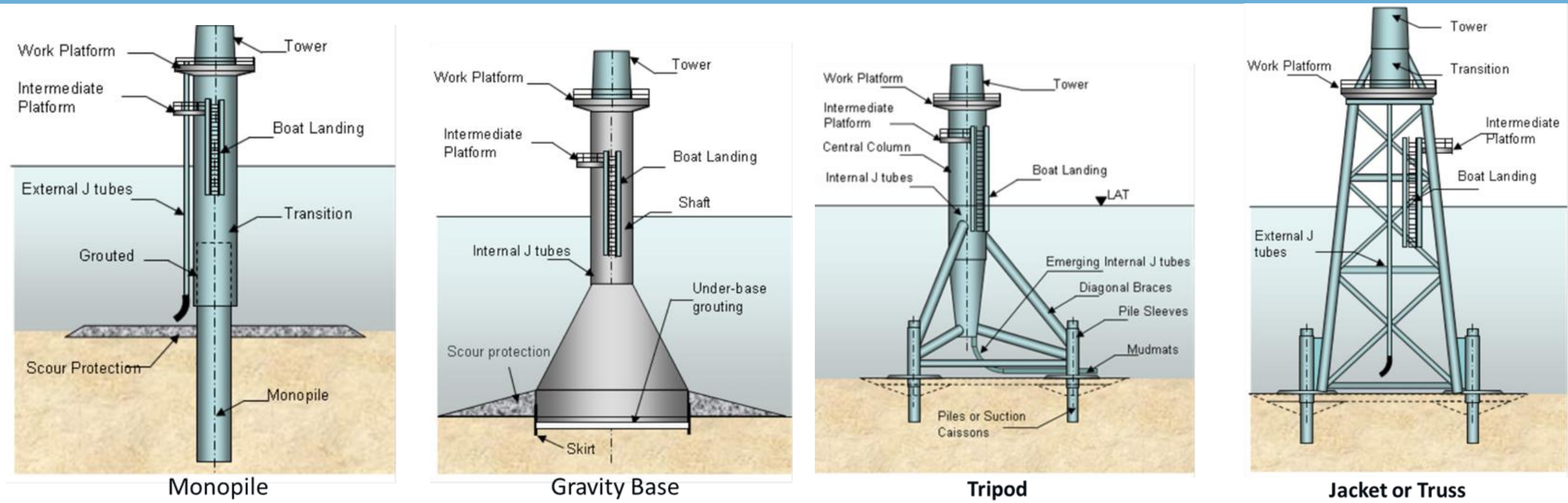


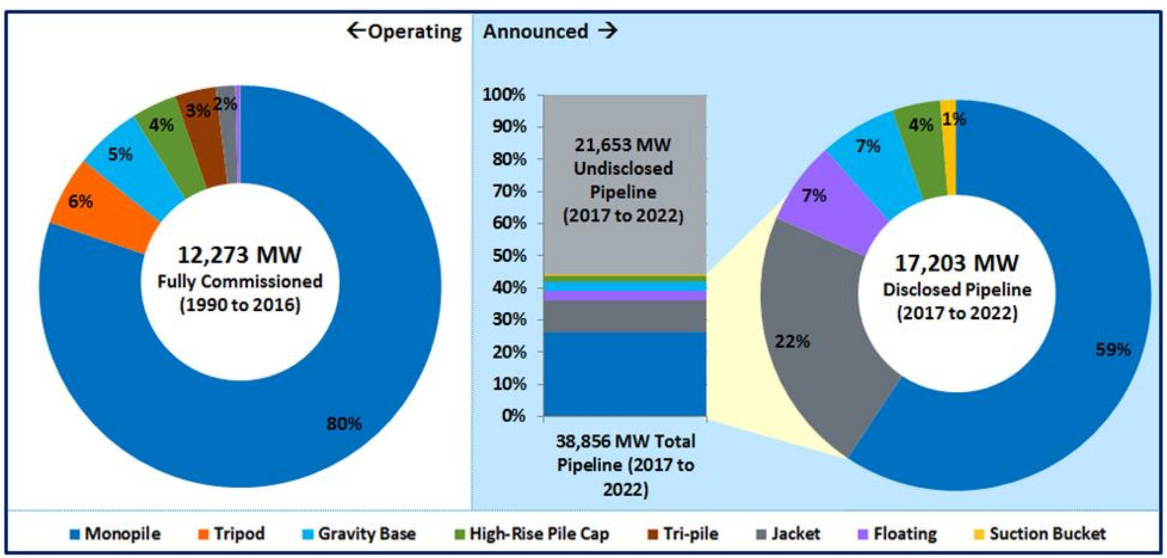
Offshore Wind – Current Technology Status

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

- 111 projects, over 13,000 MW installed (end of 2016)
- 99% are on fixed bottom support structures in shallow water (<50 m)
- Turbine capacity 6-8 MW with upwind rotors – 150 m -180 m diameter
- 90+ meter towers
- Direct drive generators or single stage geared drives with medium speed generators
- Capacity factors 40 to 50 percent
- Capital cost dropping due to experience, competition, technology and lower risk perception
- O&M higher than land-based
- Leverages and expands existing mature marine industries:
  - Offshore Oil and gas
  - Submarine cable

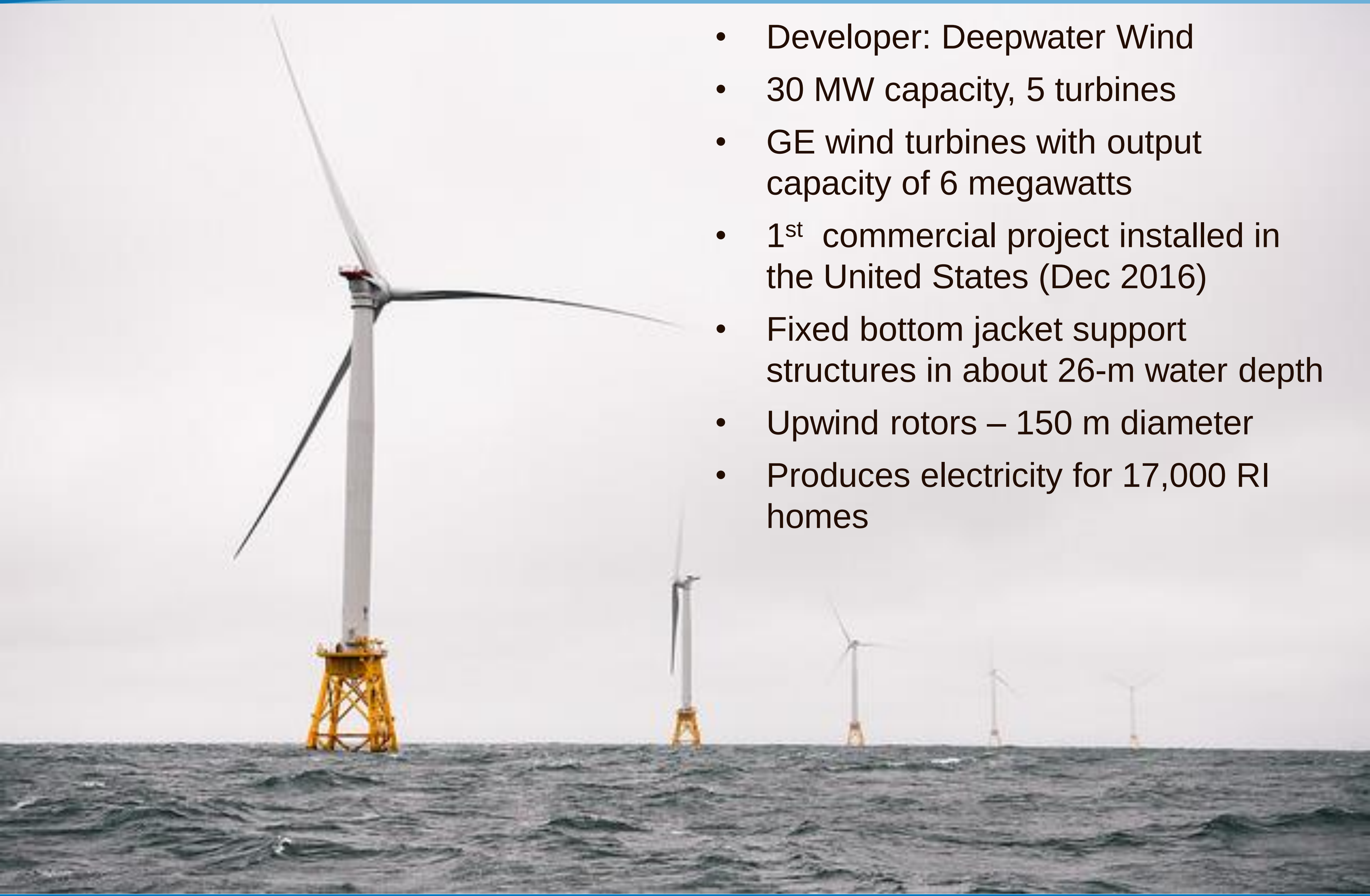
Fixed Bottom Foundation Types





- Fixed bottom support structures are feasible in water depths from 0 to 50-m
- Support structures have been adapted from oil and gas industry
- Monopiles are the most common so far (smallest footprint).

Block Island Wind Farm – Rhode Island



- Developer: Deepwater Wind
- 30 MW capacity, 5 turbines
- GE wind turbines with output capacity of 6 megawatts
- 1st commercial project installed in the United States (Dec 2016)
- Fixed bottom jacket support structures in about 26-m water depth
- Upwind rotors – 150 m diameter
- Produces electricity for 17,000 RI homes

Wind and Wave Resource Measurements

- Fixed MET masts are expensive and are being replaced by floating LIDAR buoys.
- Site specific measurements are needed for:
  - ❑ Resource validation
  - ❑ Power production

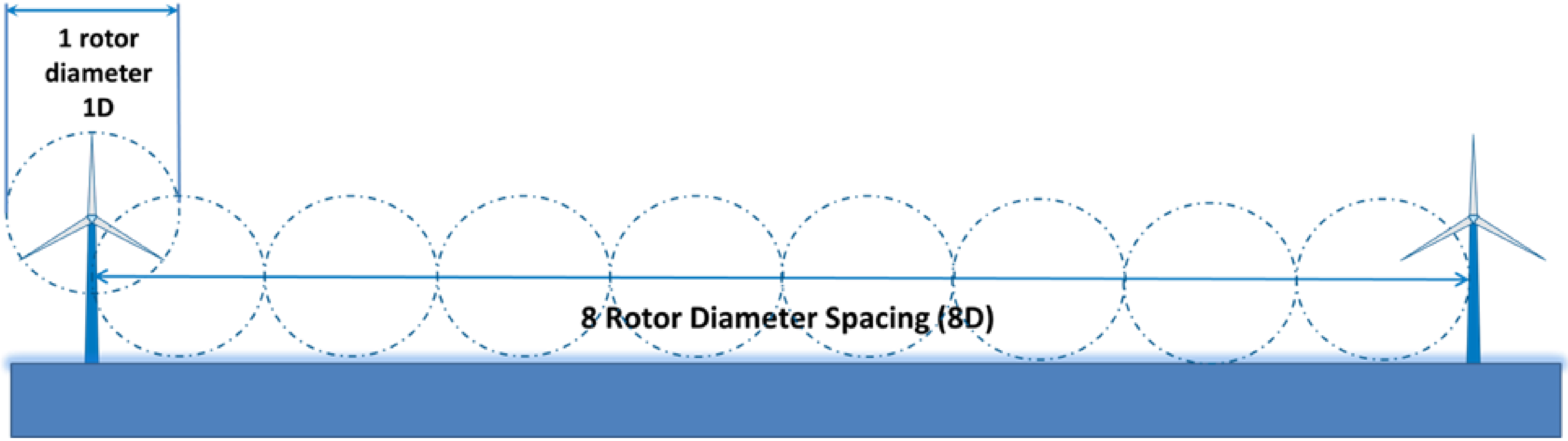
AXYS FLiDAR 6-m buoy typically used for wind and wave assessments installed near a fixed meteorological mast.
Photo courtesy of AXYS Technologies

Wind Plant Rectangular Array – Horns Rev Denmark

Wind Plant Layout Needs to Consider Wake Effects

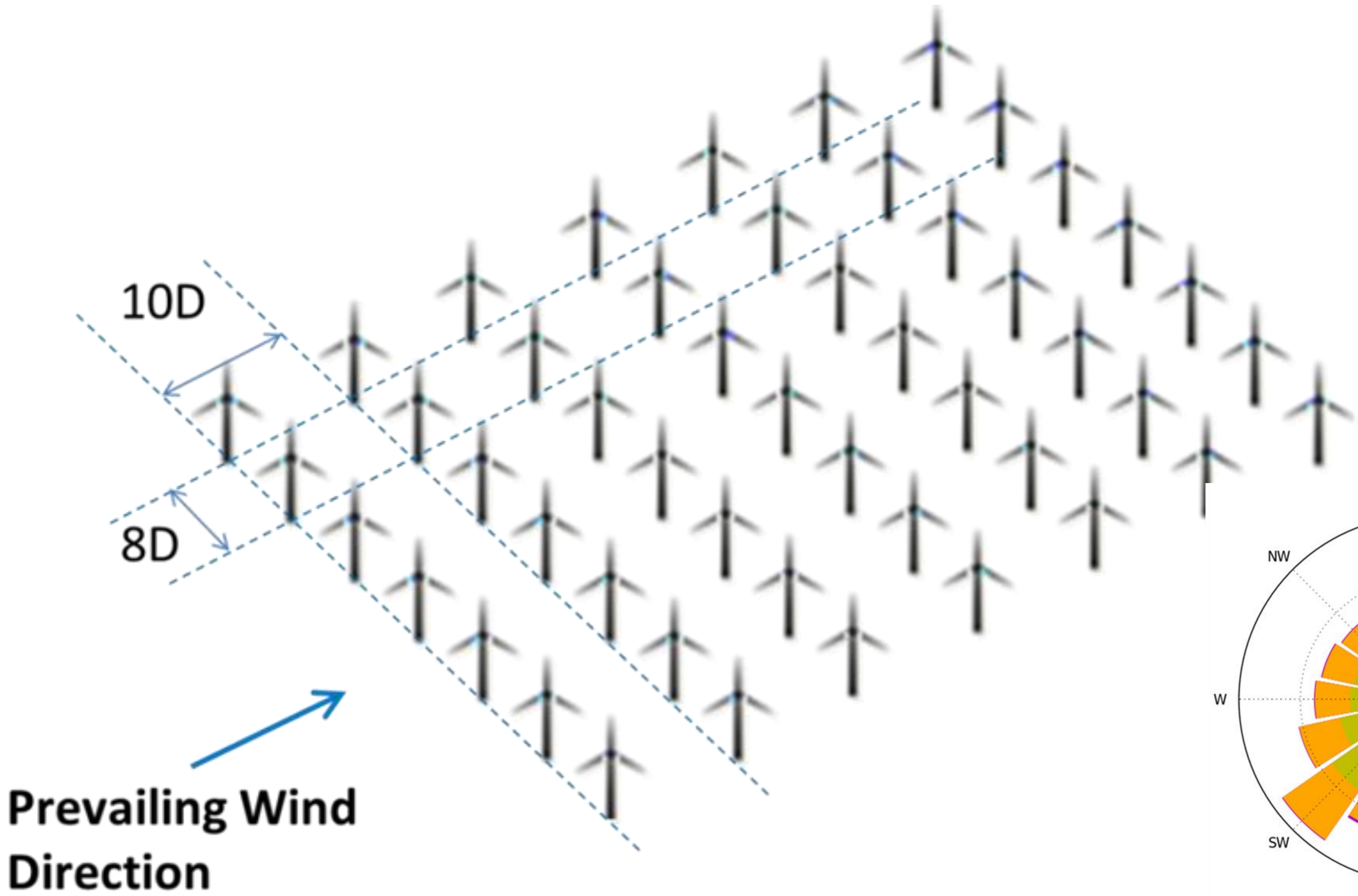
Horns Rev I Offshore Wind Plant
(Source: Vattenfall, *Photo by Christian Steiness*)

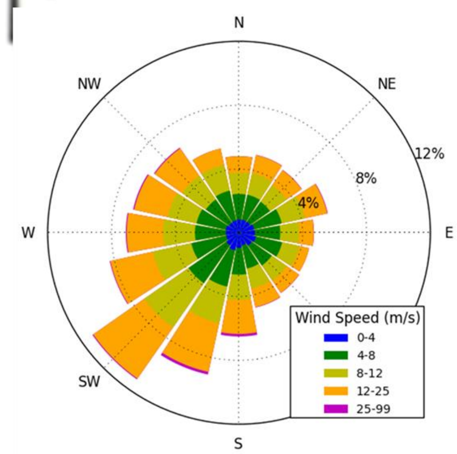
Turbine Spacing is Determined by the Rotor Diameter



- Eight rotor diameter spacing is shown in figure above.
- Distance increases as the diameter of rotor diameter increases
- Generally the number of rotor diameters stays constant as turbines scale up
- Number of diameters used for spacing depends on available site area, cable length (cost), water depth and , and atmospheric conditions.

Wind Plant Layout Considerations

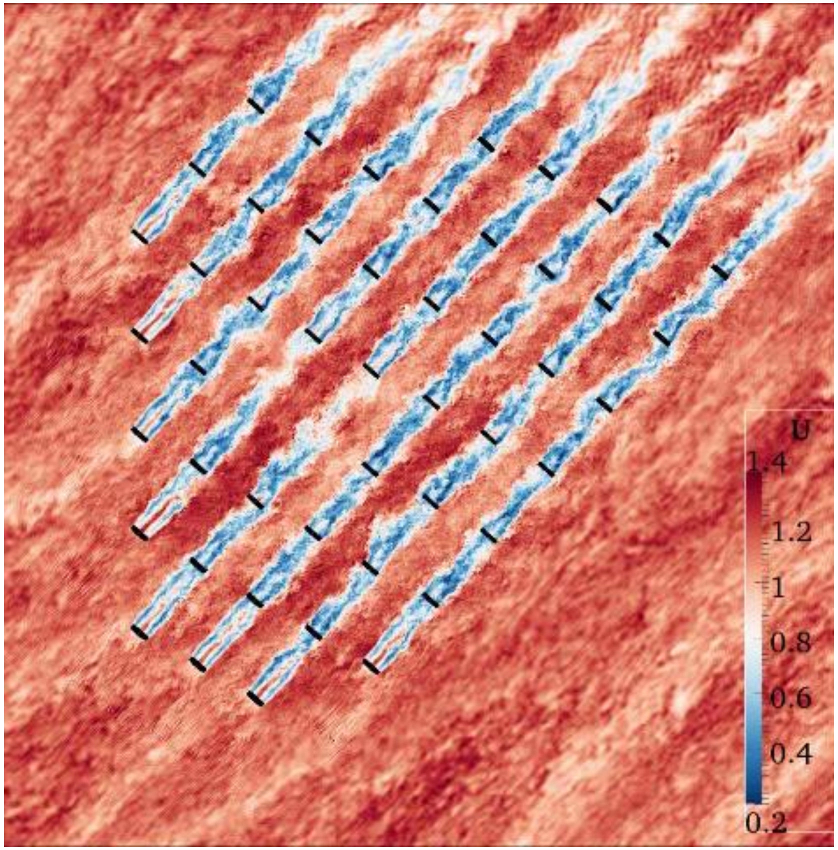




Wind Rose – Indicates the annual average wind direction

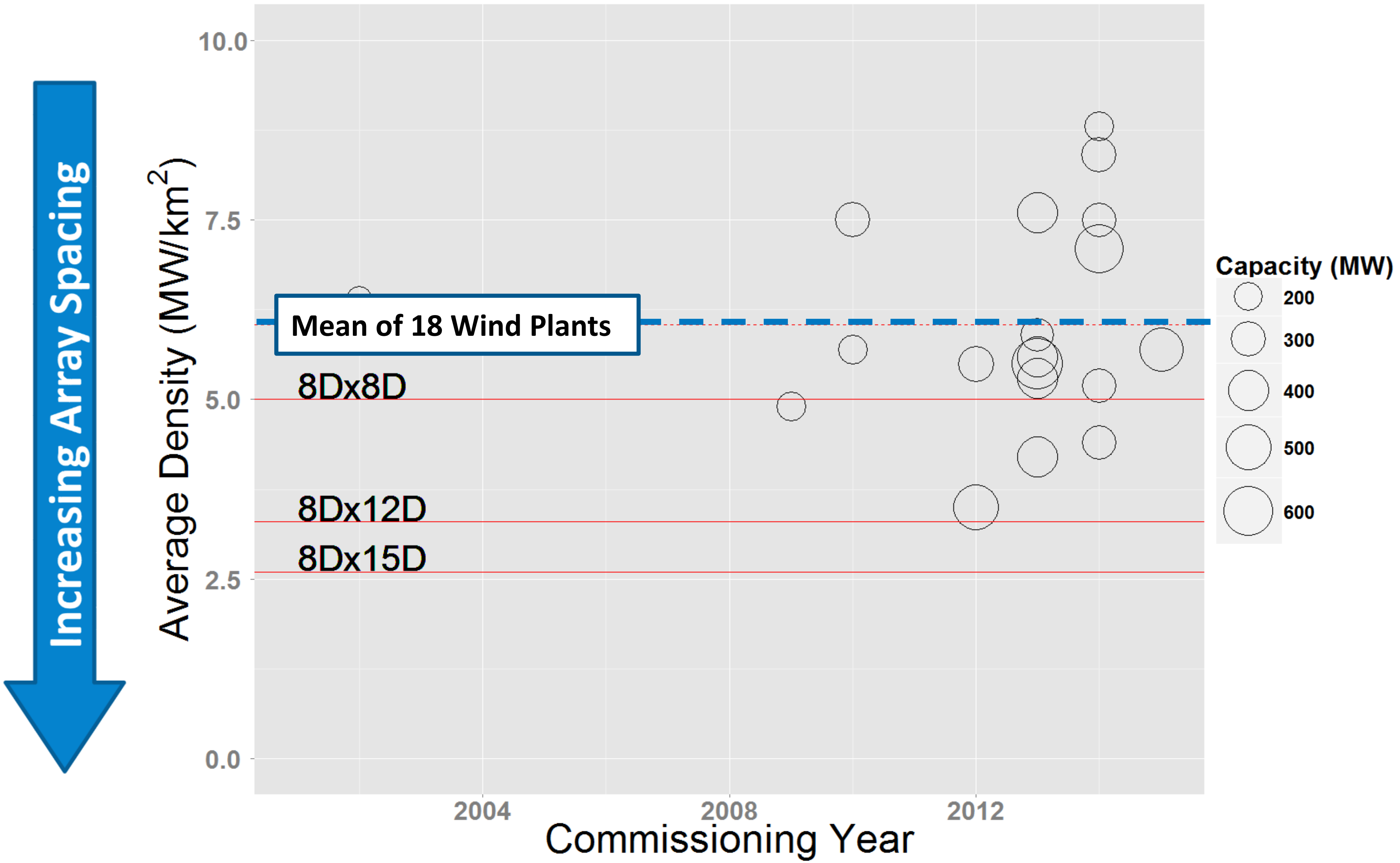
Wake Losses Depend on Atmospheric Stability

- Wind turbines wakes have less energy and higher turbulence.
- Energy is replenished by mixing with adjacent atmospheric layers
- Atmospheric stability conditions dominate the rate of mixing and replenishment
- In **stable atmospheres**, vertical layers are stratified and wake turbulence persists farther downstream
- In **unstable atmospheres**, vertical mixing due to thermal convection helps replenish energy in the wakes more quickly



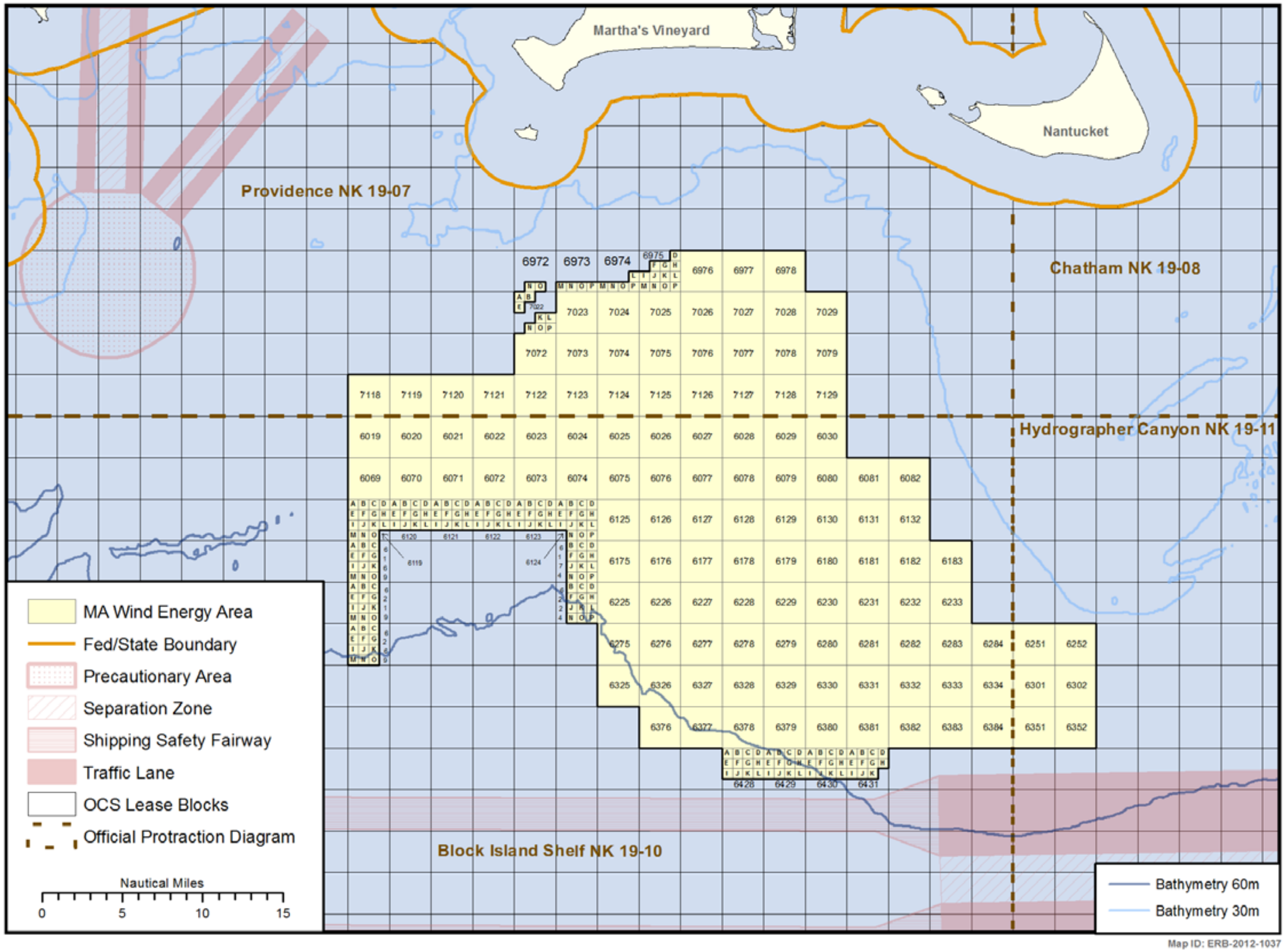
Simulator for Wind Farm Applications showing turbine wake effects (Source: NREL)

Industry Array Spacing: Installed Projects over 200MW Compared to MA WEA Analysis Spacing



Subdividing the Massachusetts WEA

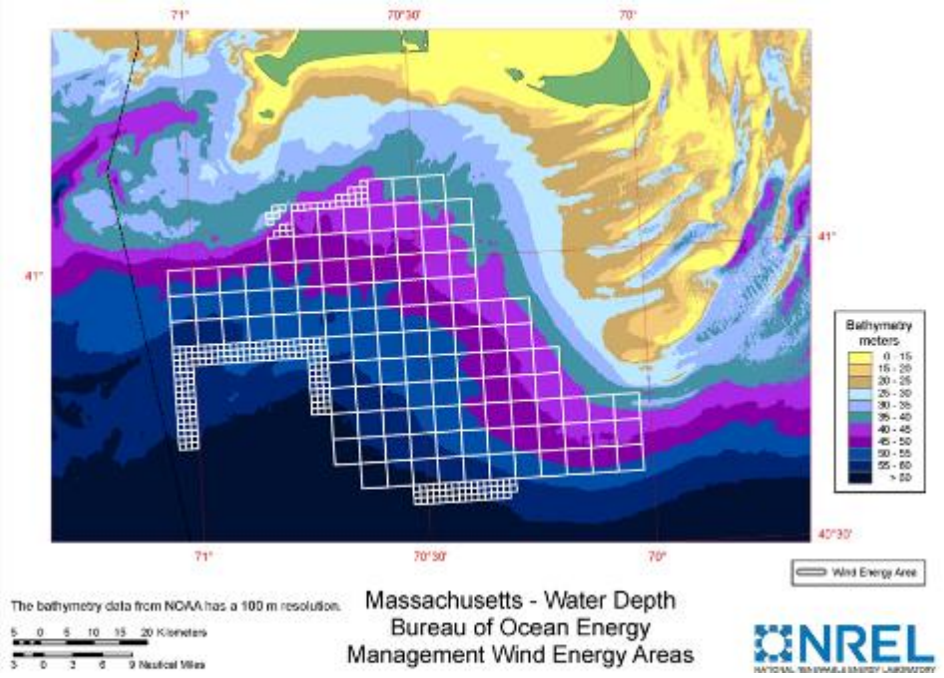
(Source: BOEM 2013)

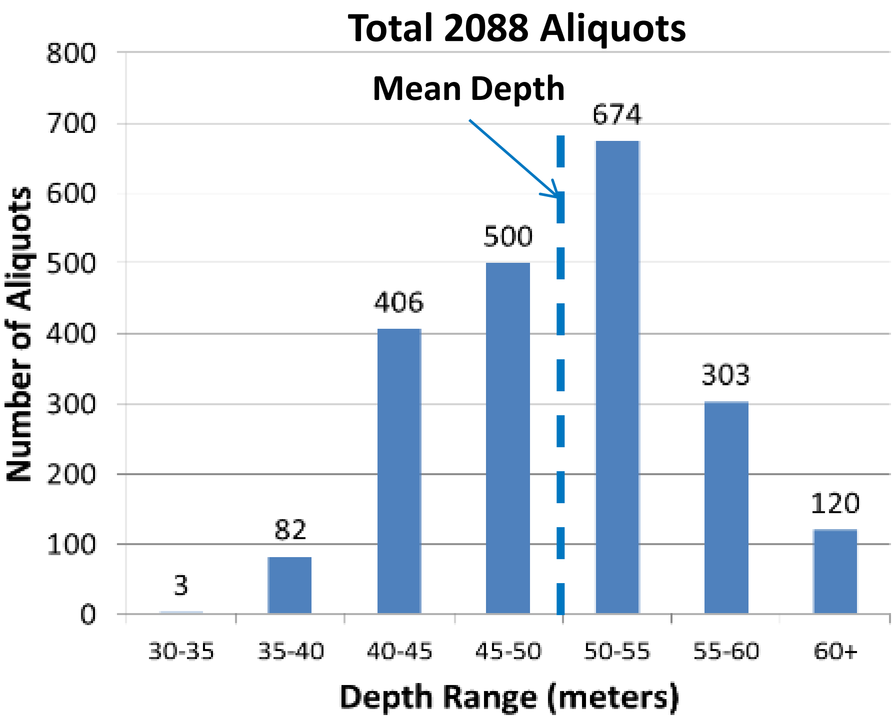


- Current WEA area 742,974 acres, or 3,006.7 square kilometers (km^2)
- About 130 lease blocks, 2088 aliquots

Bathymetry: A Major Factor

Half the area is in water deeper than 50-m



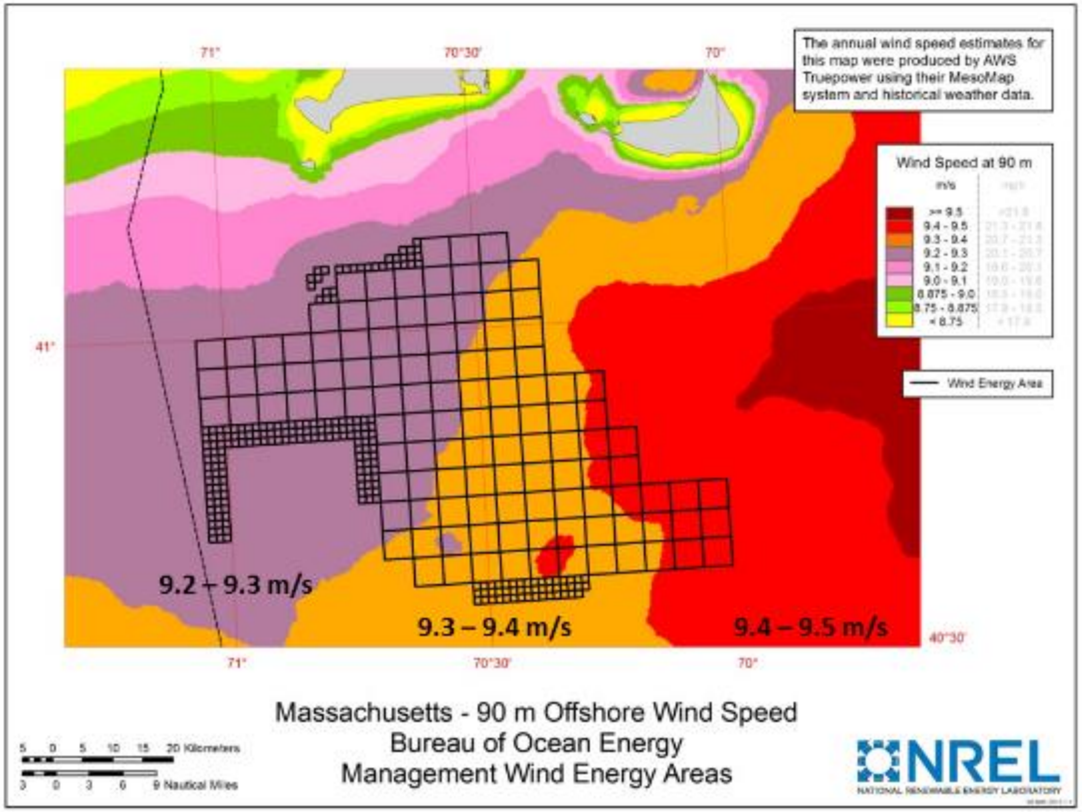


Data Source: NOAA National Geophysical Data Center
http://www.ngdc.noaa.gov/mgg/coastal/crm.html

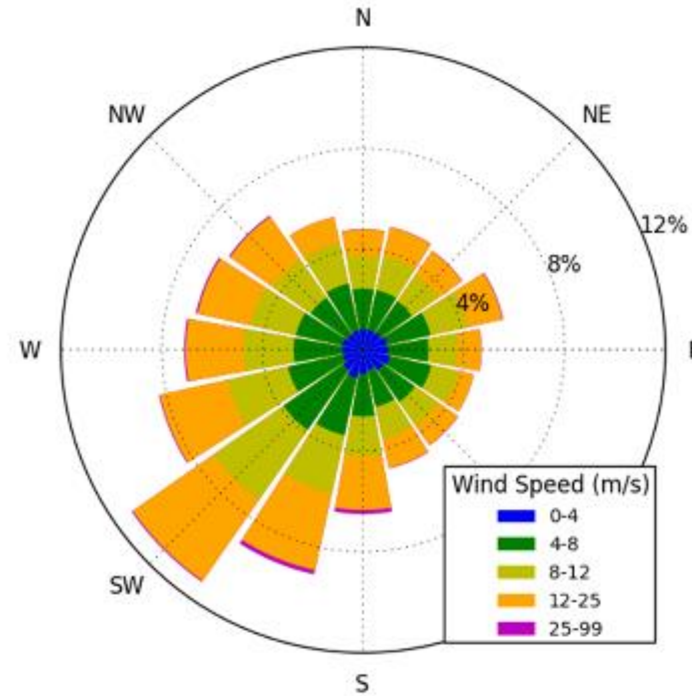
Massachusetts Wind Energy Area - Wind Characteristics

Average Wind Speeds Improve from West to East

Data from AWS Truepower – 14 years hourly data set, mean annual wind resource grid (WRG/B) data containing wind speed, wind direction, and frequency distribution at 90 m.



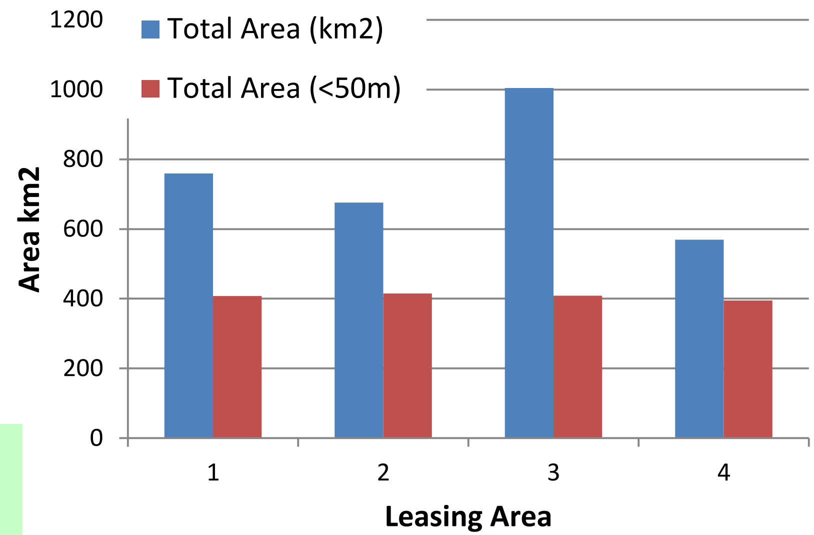
MA WEA showing annual average wind speed between 9.2 m/s and 9.4 m/s

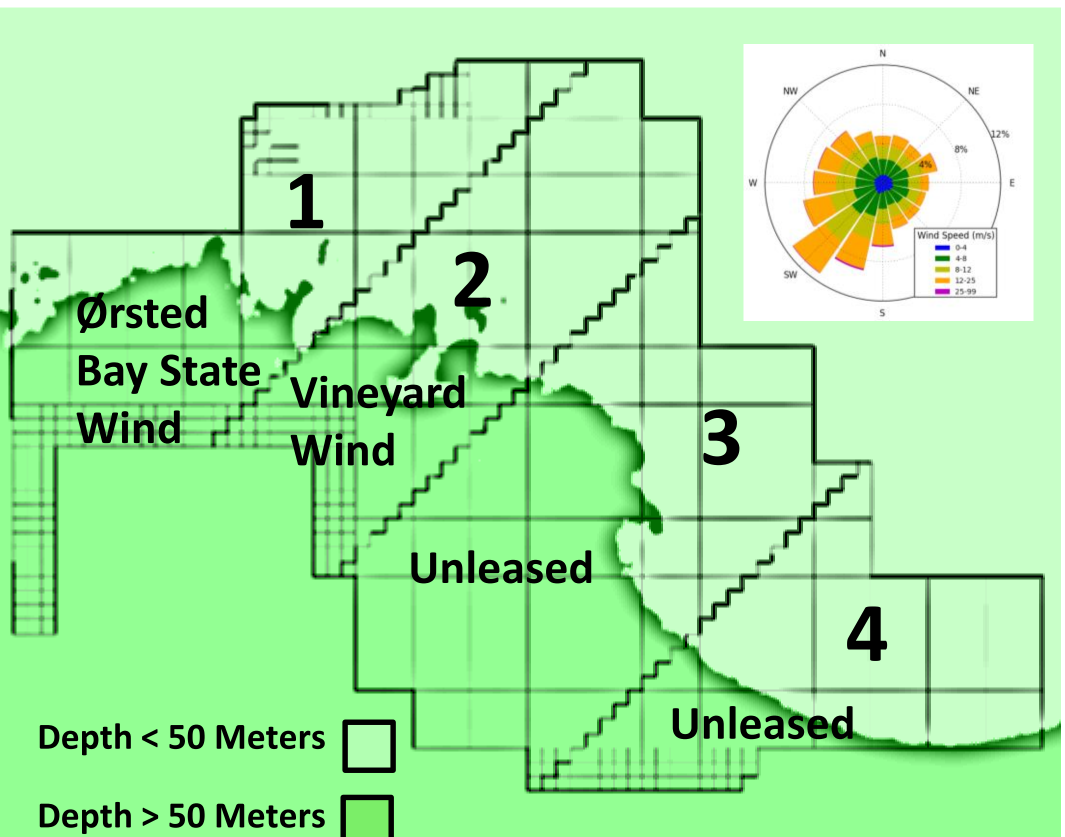


MA WEA annual average wind frequency rose with prevailing southwest

Massachusetts Wind Energy Area - Four Lease Areas

Area less than 50m	
Lease Areas	Area(km²)
Area 1	407.45
Area 2	414.92
Area 3	408.31
Area 4	394.58



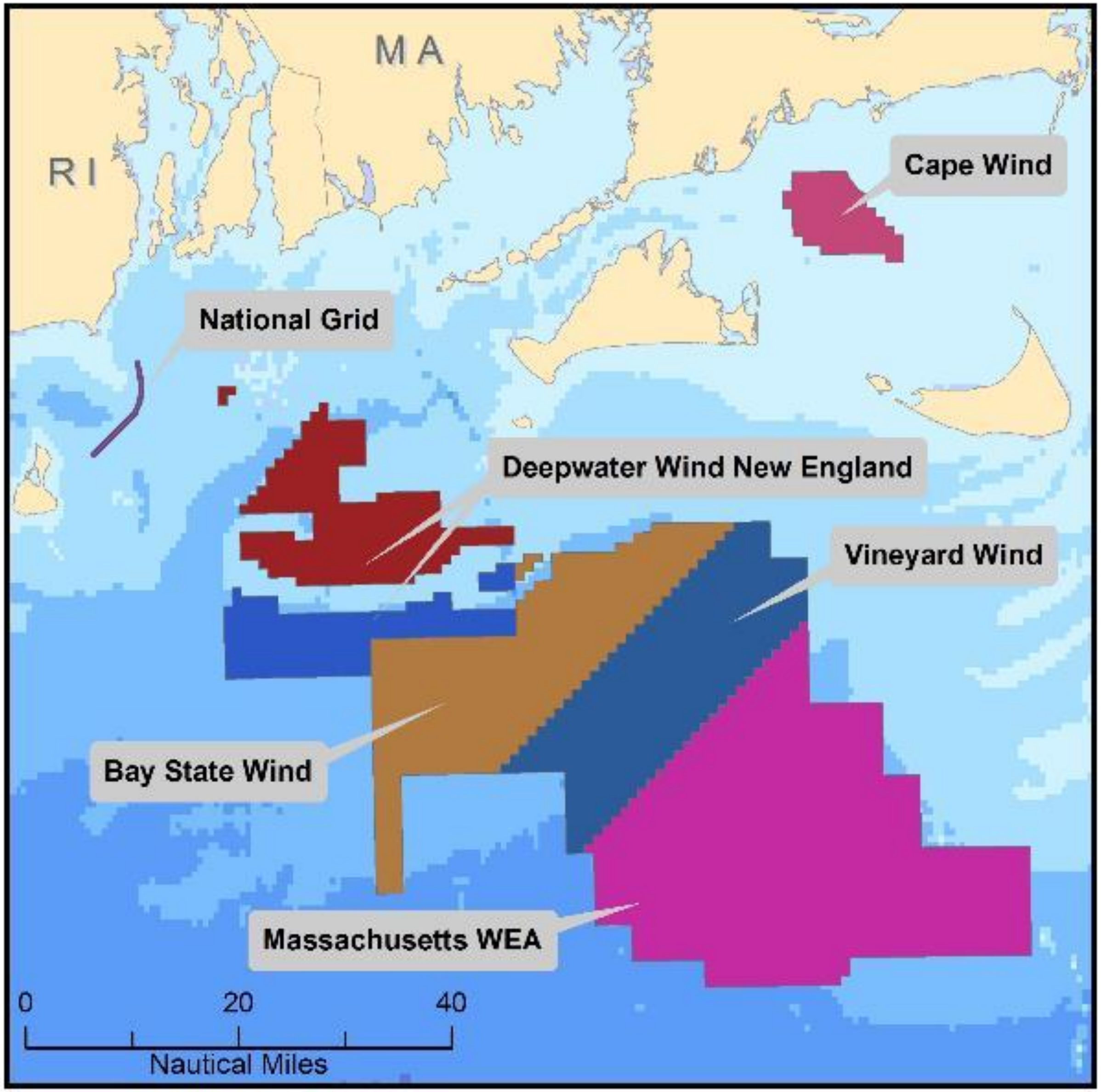


Lease Area Characteristics

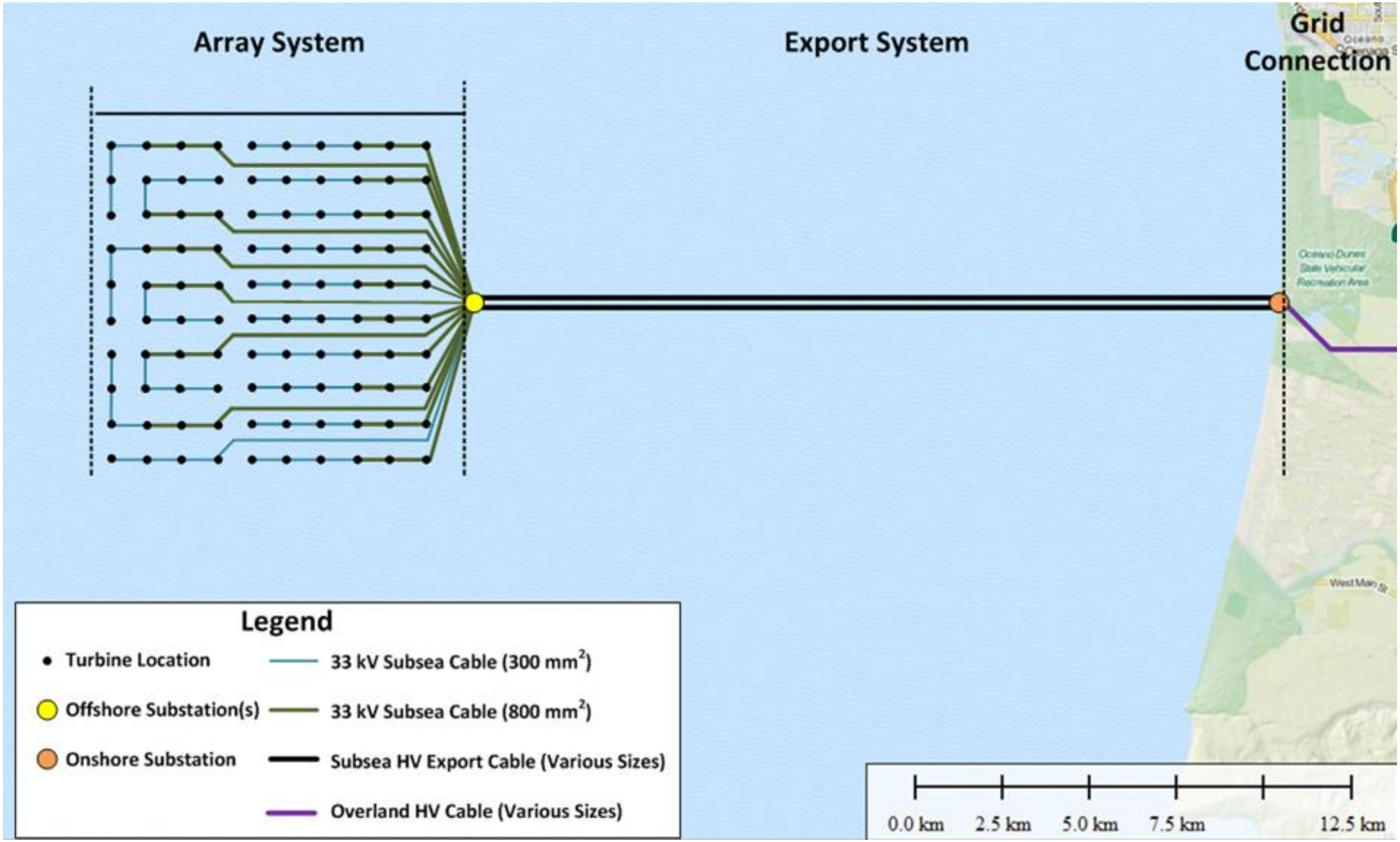
- 4 leasing Areas
- Diagonal delineations minimizes upwind conflicts
- Shallower water less than 50m depth is equal for all areas
- Deeper water may be developed with different technology (e.g. floating)

Massachusetts and RI/MA Wind Energy Areas

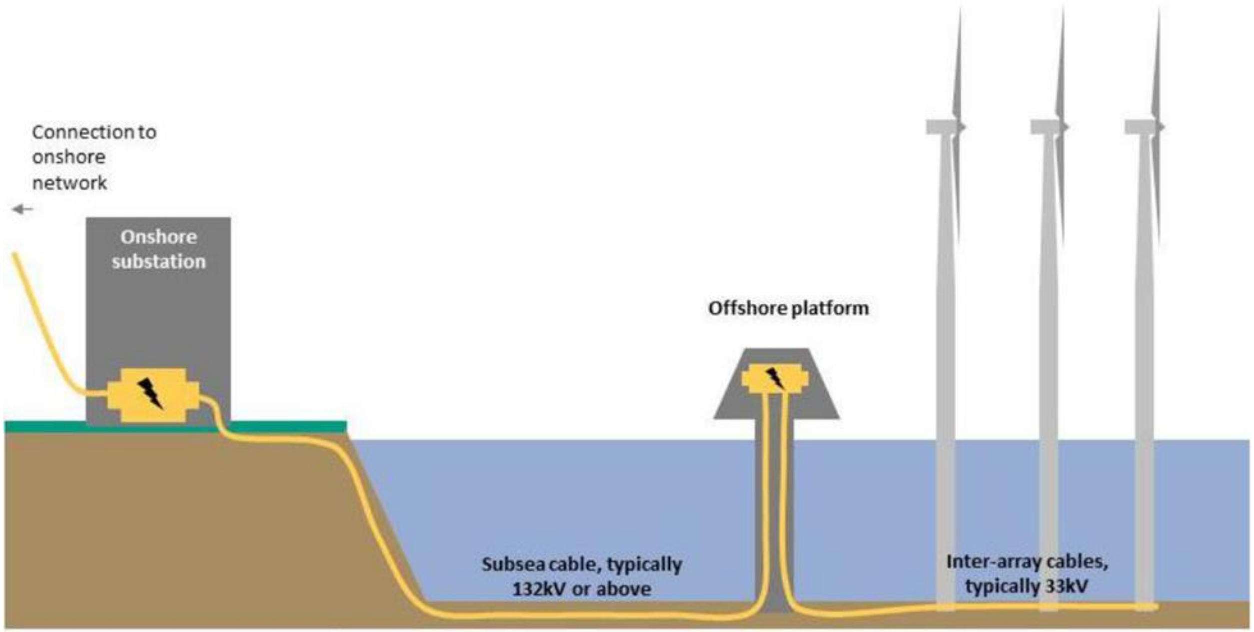
Figure Source:BOEM



Wind Facility Array and Export Cable System



Array and Export Cable Elevation Schematic

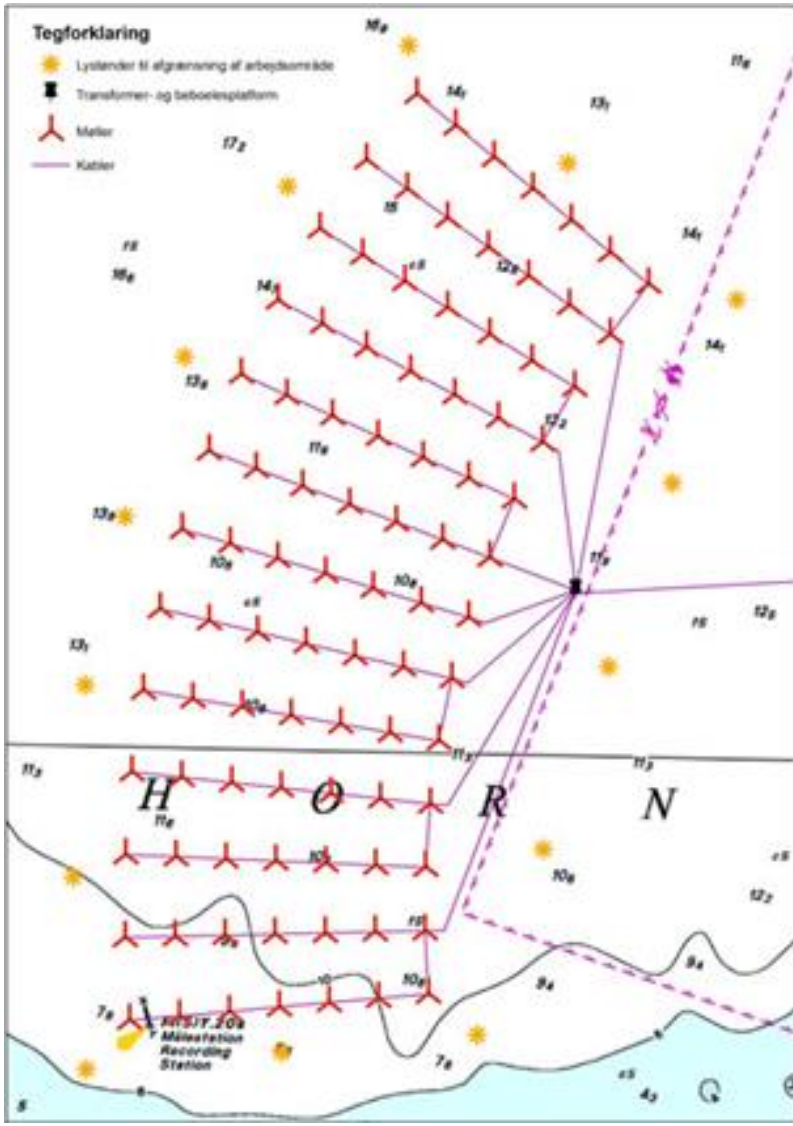


Offshore Wind Electric Cable Schematic from Turbines to On-shore Grid Connection

Offshore Wind Electric Service Platform (Substation)
Photo Credit: Walt Musial

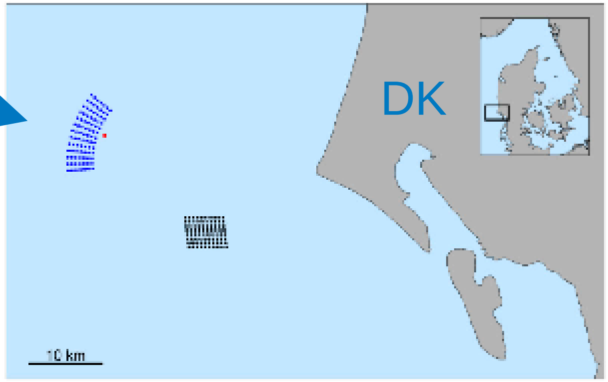
- Cables are typically buried 6 ft below sea bed
- Scour and subsea geology may expose cables over time
- Cables that cannot be buries are protected with mattresses, rock placements, armoring techniques

Alternative Layouts to Reduce Wake Losses



Horns Rev II – Layout

- Alternative layouts can increase energy production and lower cost
- High fidelity wind array models are being developed to optimize energy layout designs
- Wind system array models can minimize
  - Minimize excess turbine loads
  - Maximize power output of existing facilities through advanced controls
  - Optimize layout for most efficient use of wind energy area.



Thank you for your attention!

Walt Musial
Offshore Wind Manager
National Renewable Energy Laboratory
walter.musial@nrel.gov

Photo Credit : Dennis Schroeder-NREL