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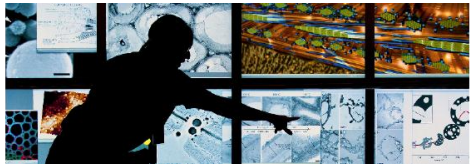
Final Presentation to Massachusetts Renewable Energy Task Force on Leasing Area Delineation Studies

Webinar Sponsored by Bureau of Ocean Energy Management

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January 16, 2014

NREL Presentation Contents

- Technical Background
- Project Scope and Parameters
- BOEM Massachusetts Call for Nominations Summary
- Physical Description of Massachusetts WEA
- Delineation Process and Alternatives
- Massachusetts: Wake Loss and Energy Analysis
- Summary and Recommendations
- Question and Answers

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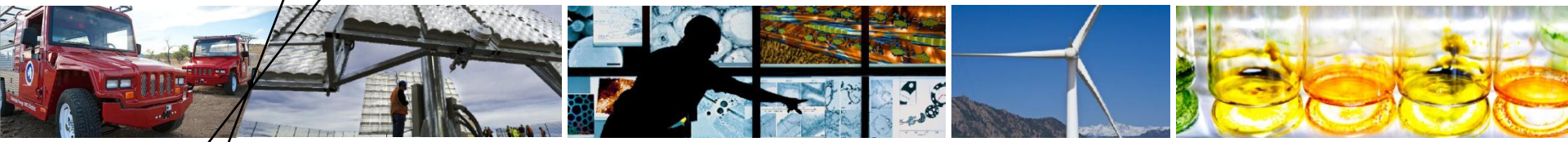
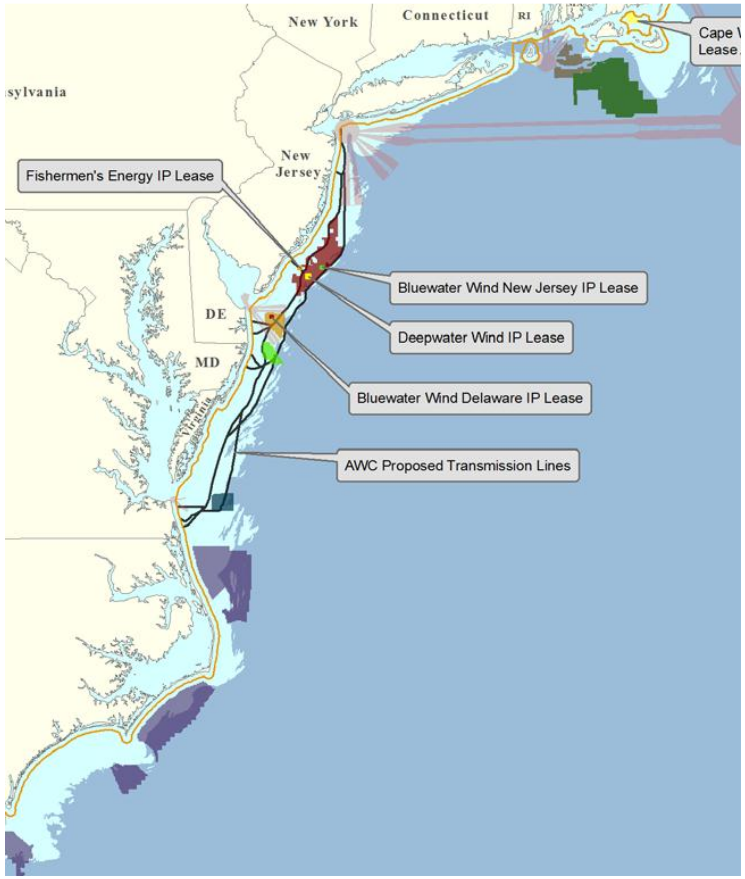


Project Scope and Parameters

Project Summary and Background

- Bureau of Ocean Energy Management (BOEM) requested technical assistance from the Department of Energy's National Renewable Energy Laboratory (NREL) to help inform delineation of leasing areas within four BOEM Wind Energy Areas (WEA)
- NREL evaluated the MA WEA and recommended options to BOEM for delineation into four to five leasing areas
- Focus was on bathymetry, wake effects, wind resource, energy potential, with a goal to produce up to five development zones with similar auction value



BOEM Wind Energy Planning Areas

Project Objectives:

- To evaluate the delineation options for the MA WEA based on physical constraints that may effect offshore wind development
- To identify the benefits and disadvantages of each option
- To make recommendations for delineating the MA WEA

Parameters for MA Offshore Wind Energy Area Analysis

- Investigate best options for 4 to 5 leasing areas
- Use NREL 5-MW reference wind turbine with 126-m rotor diameter
- Assess current WEA area with 742,974 acres, or 3,006.7 square kilometers (km^2)
- Use baseline array spacing of 8D x 12D (3.3 MW/km^2)
- Consider larger (8D x 15D) and smaller (8D x 8D) array densities
- Use 8D setbacks between leasing areas


REpower 5M Alpha Ventus - Germany

Photo Credit: Gary Norton

NREL Task Summary Under BOEM Interagency Agreement

1. **Develop preliminary methodology for delineation of MA WEA and present to MA RE Task Force and MA CEC on May 15, 2013**
2. **Review 8 "RFI" nominations to gather data on proposed development strategies and specific interests in the MA RFI area (Feb 2011)**
3. **Review 10 "Call" nominations to gather data on proposed development strategies and specific interests in the MA WEA (March 2012)**
4. **Perform analysis on delineation options for 4-5 leasing areas using openWind® Enterprise Program based on current MA WEA.**
5. **Modify delineation strategy to equalize shallower water among areas**
6. **Write and publish final report (Dec 20, 2013)**
7. **Present findings and analysis to BOEM/MA Renewable Energy Task Force (January 16, 2014)**

Musial, W.; Parker, Z.; Fields, J.; Elliott, D.; Scott, G. and Draxl, C., "Assessment of Offshore Wind Energy Leasing Areas for the BOEM Massachusetts Wind Energy Area," NREL/TP-5000-60942, December 2013; http://www.nrel.gov/docs/fy14osti/60942.pdf

Criteria Used by NREL to Assess MA WEA

Quantitative Evaluation Criteria	Qualitative Evaluation Criteria
Total area (km^2 and acres)	Distance from shore
Maximum nameplate capacity [megawatts (MW)]	Technology challenges
Bathymetry [meters (m)]	Development cost
Annual average wind speed and direction (m/s)	Interconnection logistics
500-MW phased developments	Development timing
Wake losses (%) and array efficiency	
Array orientation angle (degrees)	
Turbine spacing within array [rotor diameters (D)]	
Capacity factor after wake losses (%)	
Annual energy production [gigawatt-hours (GWh)]	

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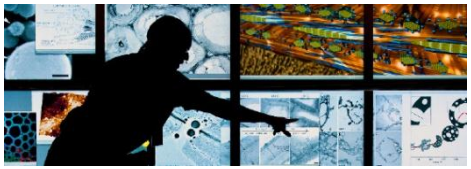
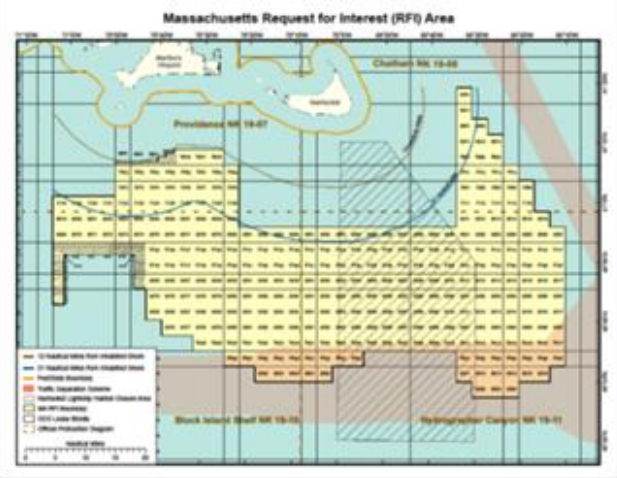


BOEM Massachusetts Request for Informations and Call for Nominations

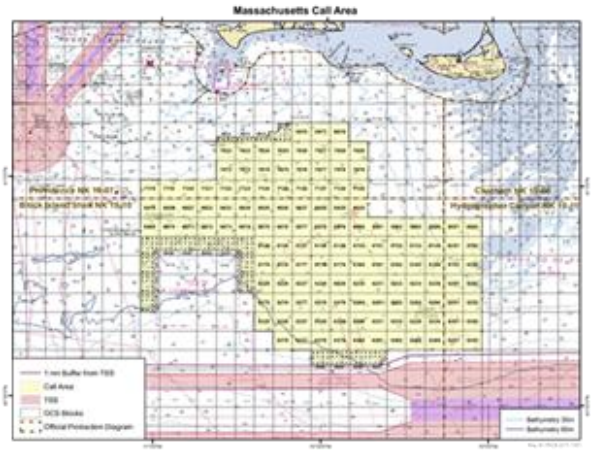
Evolution of MA Wind Energy Area



Request for Interest Area (RFI)

8 responses

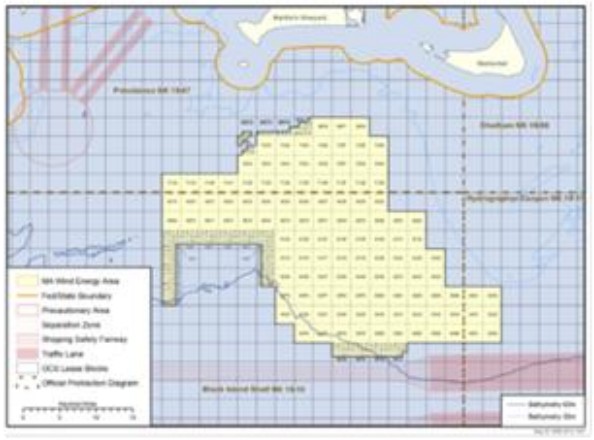
February 2011



Call for Nominations Area

10 responses

March 2012



Current Wind Energy Area

Area of NREL Analysis

Established May 2012

Summary of Input From MA "Call"

Summary of Statistics from 10 BOEM MA Wind Energy Area Nominations (February 2012)

	Average	Maximum	Minimum	NREL Values
Project nameplate capacity (MW)	1,524	3,000	1,000	5,000
Turbine nameplate capacity (MW)	5.63	7.0	5.0	5.0
Wind speed (m/s) at hub height	9.3	9.75	8.8	9.35
Net capacity factor (%)	40	40	40	45–48
Project area (km^2)	1,026	2,004	240	3,006.7
Array power density (MW/km^2)	2.27	4.33	0.54	1.66
Turbine array spacing	8.5 x 10.5	8 x 12	9 x 9	8 x 8; 8 x 12; 8 x 15
Project development time (years)	9.1	16	7	NA

Notes:

- NREL values represent Alternatives 2 and 3 only, the five leasing area delineations
- The net capacity factor reported in the NREL values is the gross capacity factor after subtracting wake losses only (e.g., electrical losses not included)
- NREL used the whole wind energy area

Key Observations from RFI and Call Submissions

- Overlapping developer interest in shallowest areas of MA WEA
- Average array spacing of 8.5D x 10.5D proposed by developers exceeds current practices
- MA developers trended toward larger average project footprint (average 1,112 km^2)
- Project nameplate capacity ranged from 507 MW to 3000 MW (average 1,503 MW)
- Project timelines ranged from 7 to 16 years with multi-phased developments extending development time
- Developers estimated *Net Capacity Factors* at about 40%
- Turbine nameplate capacity was between 3.6MW and 6.0MW

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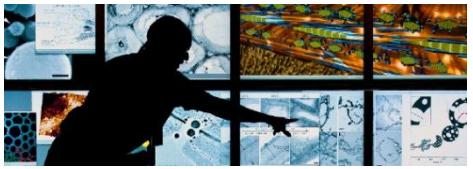
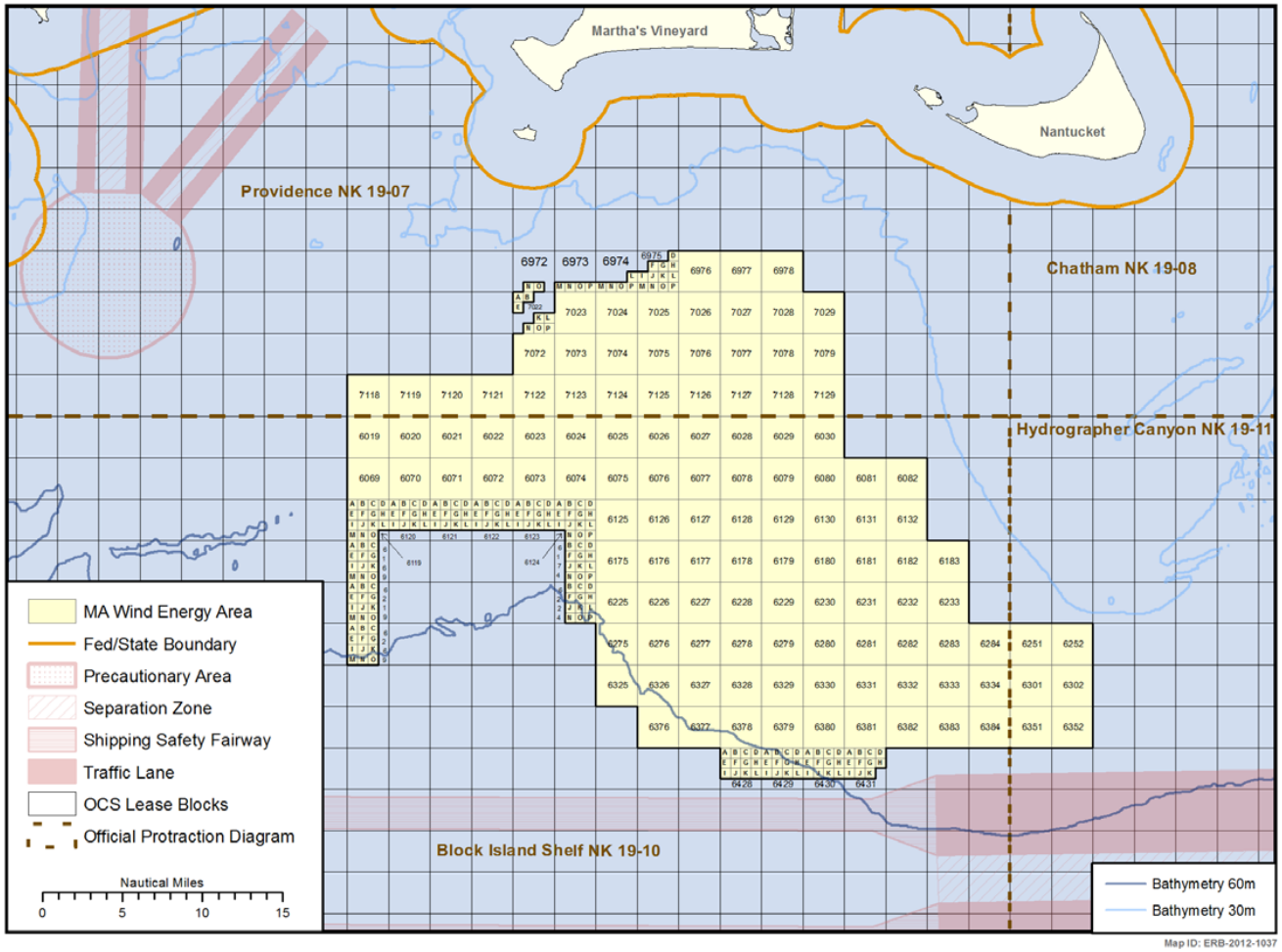


Physical Description of Massachusetts WEA

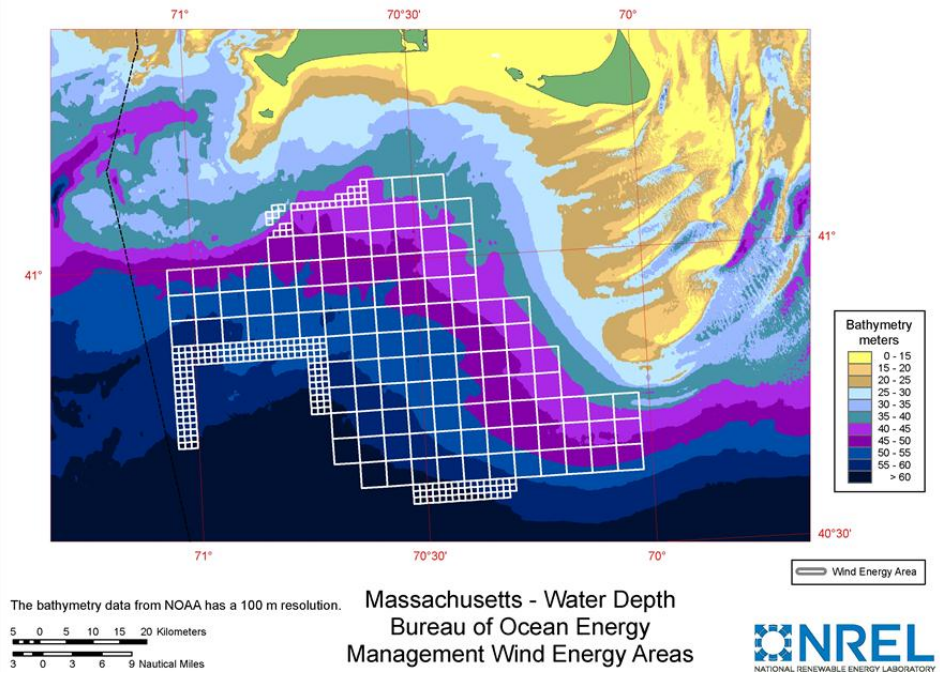
Massachusetts WEA (established May 2012)
(Source: BOEM 2013)

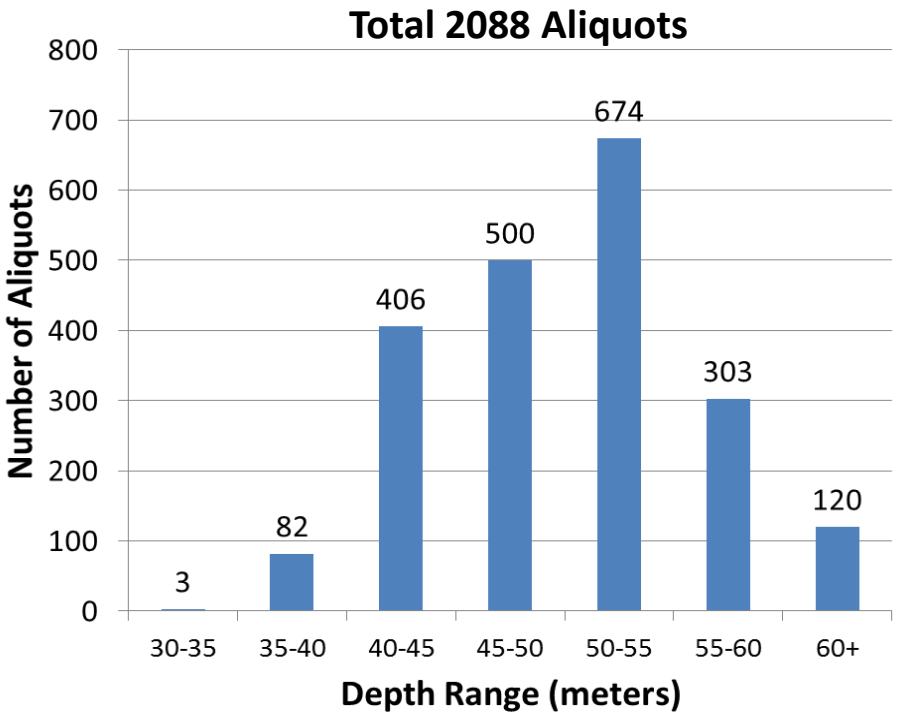


Massachusetts Wind Energy Area
(Source: BOEM)

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

Bathymetry for MA WEA

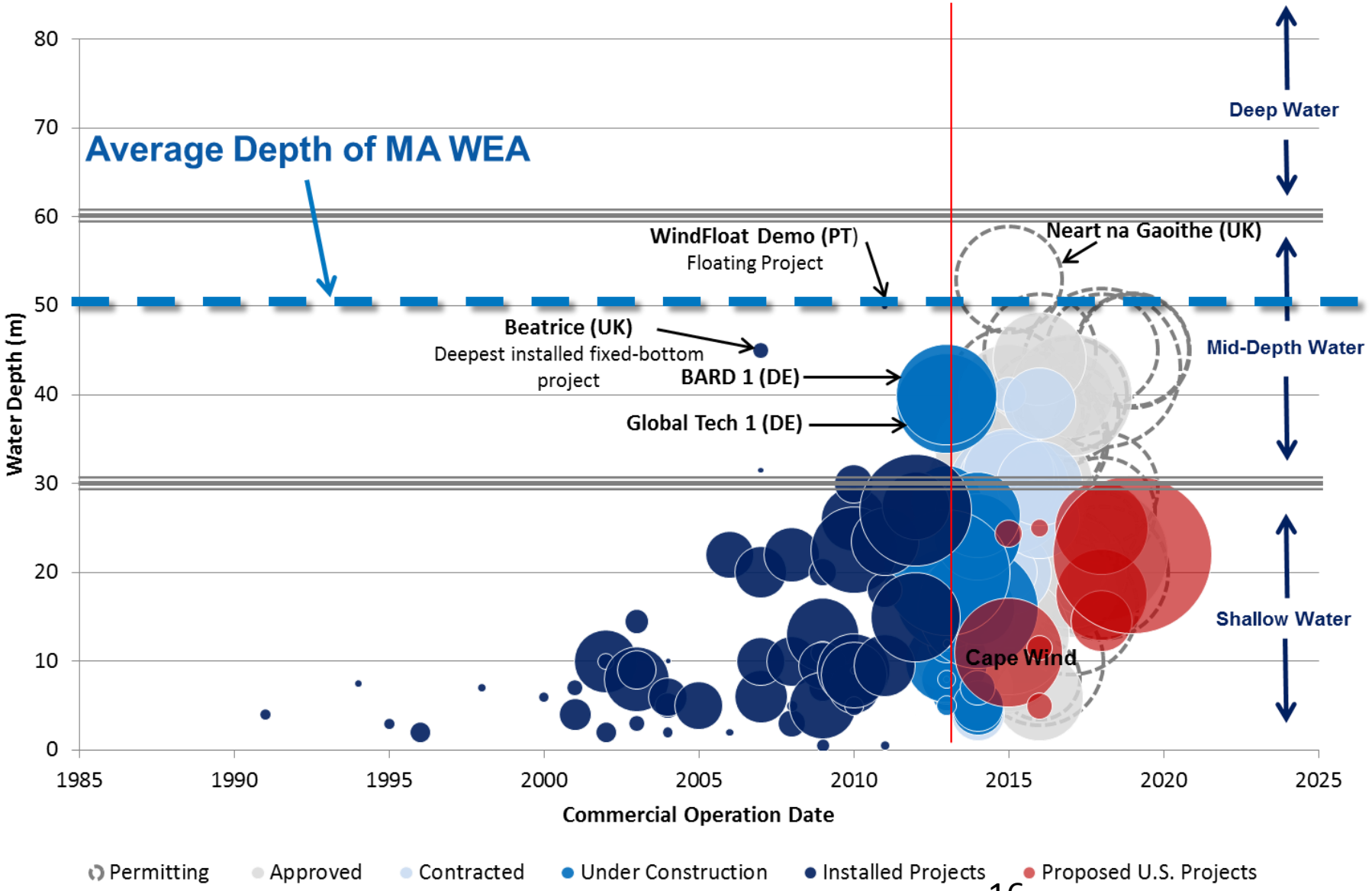




Data Source: NOAA National Geophysical Data Center
http://www.ngdc.noaa.gov/mgg/coastal/crm.html

Future Offshore Wind Projects Expected in Deeper Water

BOEM RFI and Call: Massachusetts Proposed Development Times 6 to 16 years



Wind Data Source for MA WEA Evaluations

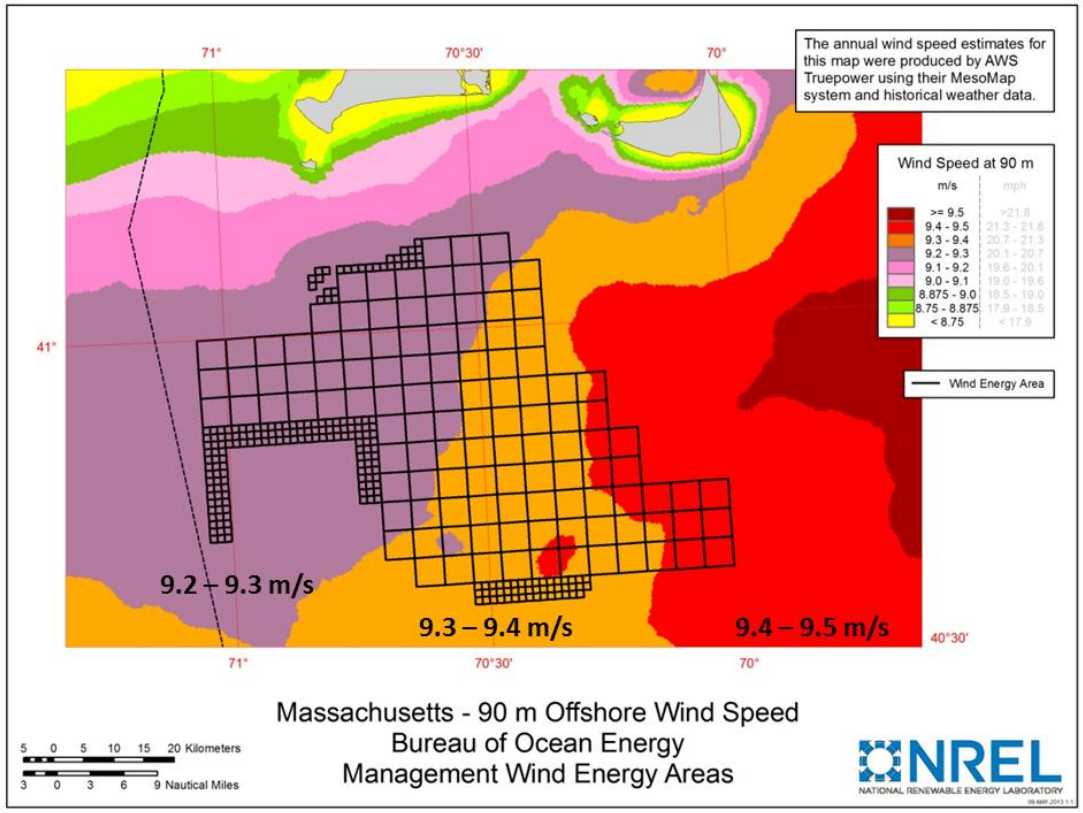
- Wind resource grid (WRG/B) files provided by AWS Truepower[1]
- Data contain wind speed, wind direction, and frequency distribution at a hub height of 90 m
- Mesoscale modeled data at a grid resolution of 20km scaled to 200m grid resolution
- Wind data were selected to provide the spatial highest resolution and longest term record available (14 years)
- Accuracy was validated against surface NOAA buoys 44017 and 44008 closest and MERRA data from NASA[2]

1. AWS Truepower, LLC. (2012). Wind Resource Maps and Data: Methods and Validation. https://windnavigator.com/index.php/content/file/Wind%20Maps-Data_Methods-Validation.pdf

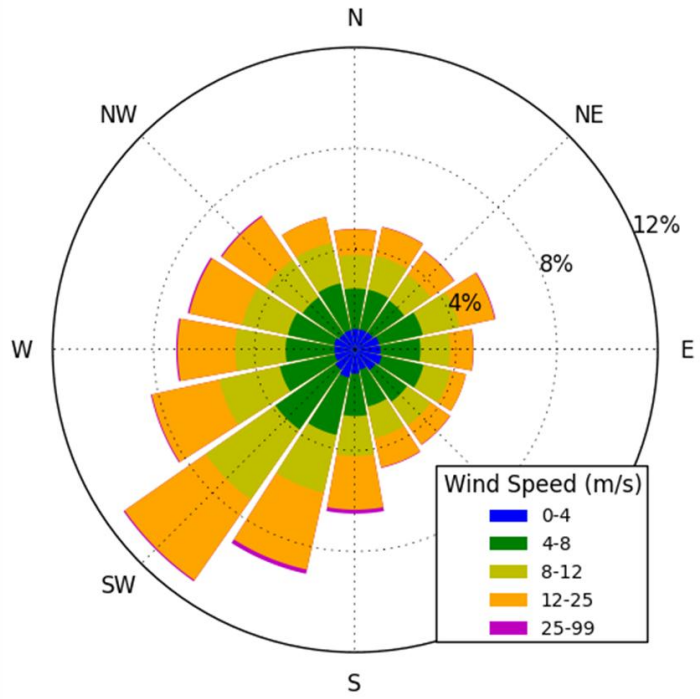
2. National Aeronautics and Space Administration (NASA). (2013). MERRA: Modern-Era Retrospective Analysis for Research and Applications. http://gmao.gsfc.nasa.gov/merra. Accessed April 16, 2013.

Massachusetts Wind Energy Area Wind Resource

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

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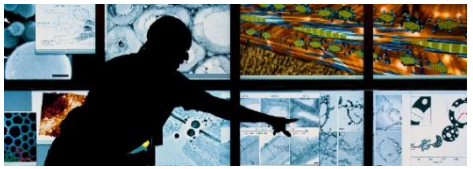


Massachusetts WEA Delineation Process

Major Delineation Criteria for MA WEA

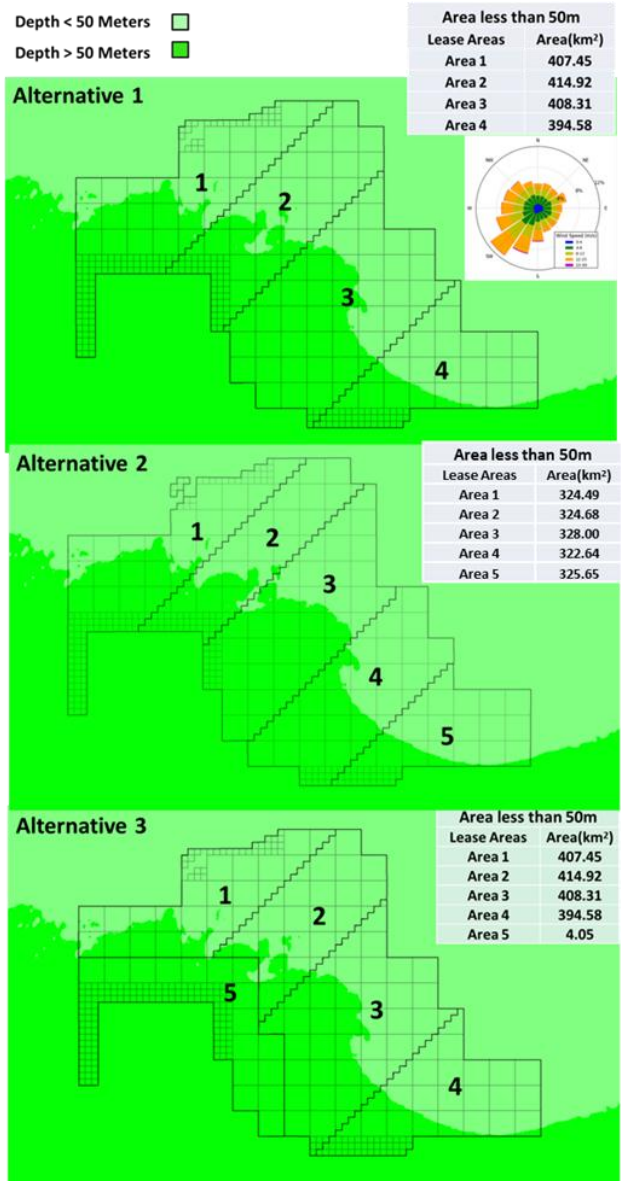
The MA WEA delineations were based on the following major assumptions and constraints:

- Limit of five leasing areas: The leasing process was limited to five non-overlapping leasing areas
- Equalization of the shallower water resource: The delineations equalized the shallower water area below 50m within 5%
- Minimization of external wake effects: 45 degree delineation lines are parallel to the prevailing wind direction to minimize conflicts with neighboring projects
- Wind resource: Wind speed varied only 9.2 m/s and 9.4 m/s across the WEA and did not play a major role in delineation boundary decisions

Three Delineation Alternatives Were Assessed

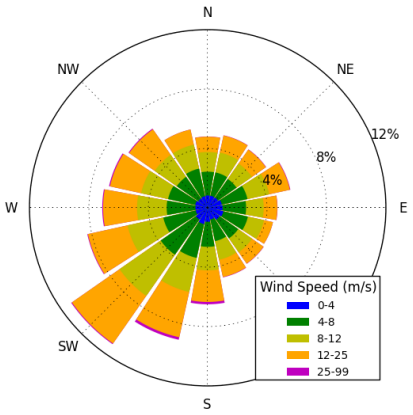
- **Alternative 1**: Four leasing areas with diagonal delineation lines and approximately equal shallow area
- **Alternative 2**: Five leasing areas with diagonal delineation lines and approximately equal shallow area
- **Alternative 3**: Five leasing areas with four areas having approximately equal shallow area and one comprising mostly deep water greater than 50-m.

Any option can be used depending on specific objectives

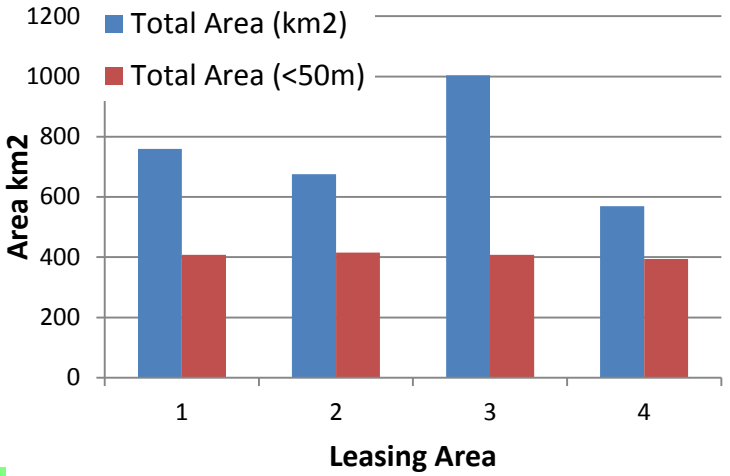


Alternative 1

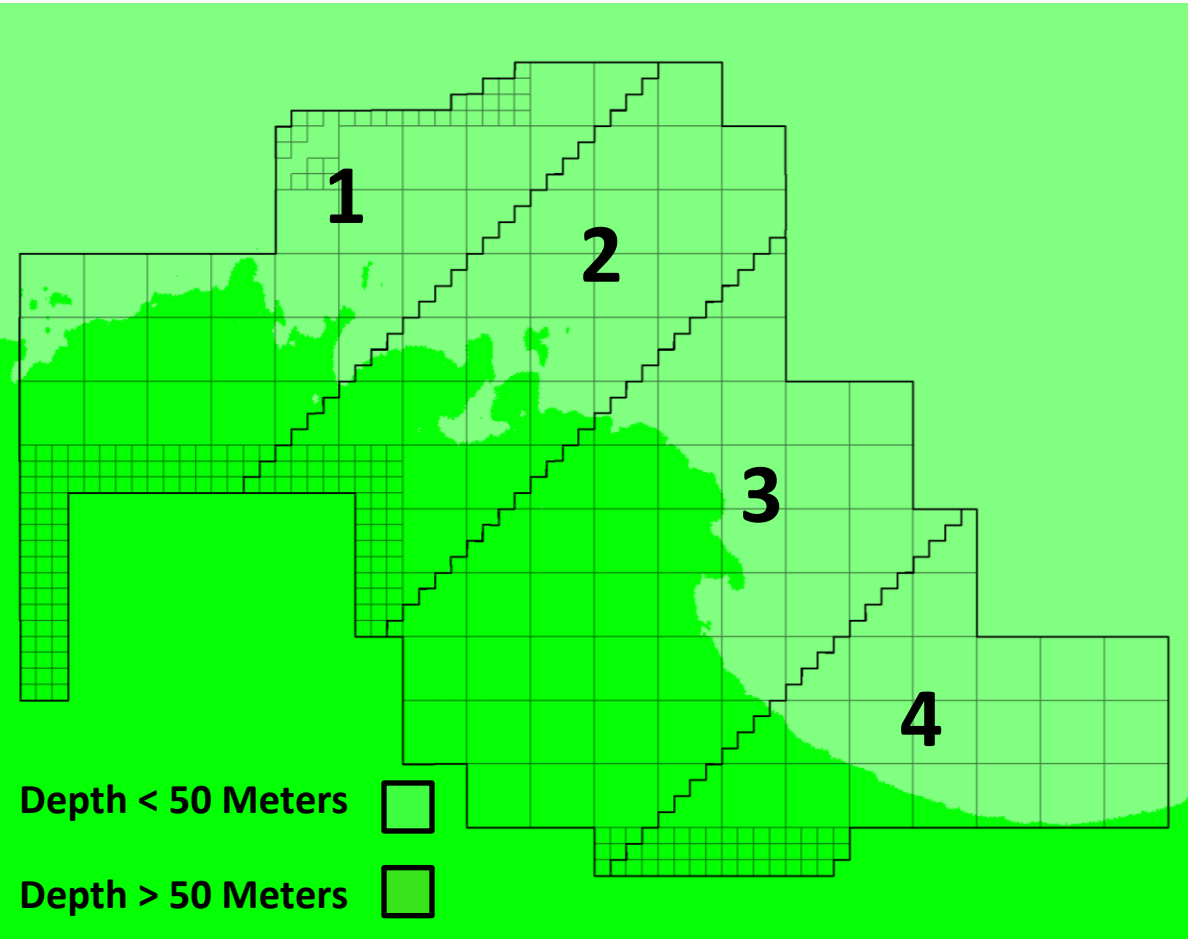
Area less than 50m	
Lease Areas	Area(km²)
Area 1	407.45
Area 2	414.92
Area 3	408.31
Area 4	394.58



MA WEA Wind Direction Rose



Total and Shallower Lease Area for Alt 1

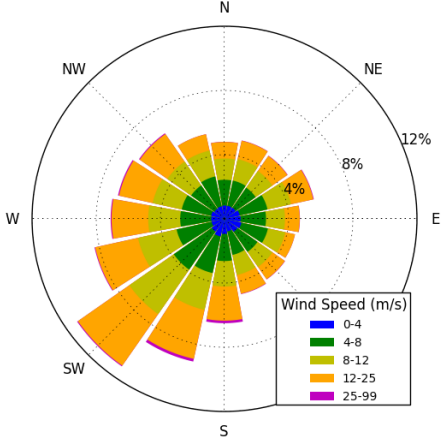


Alternative 1 Characteristics

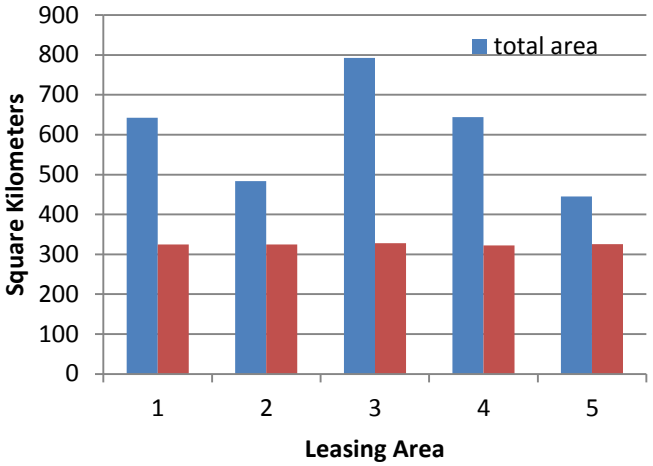
- 4 leasing Areas
- Diagonal delineations minimizes upwind conflicts
- Shallower water <50m equalized
- More shallow per area
- Wider areas enable shallower projects

Alternative 2

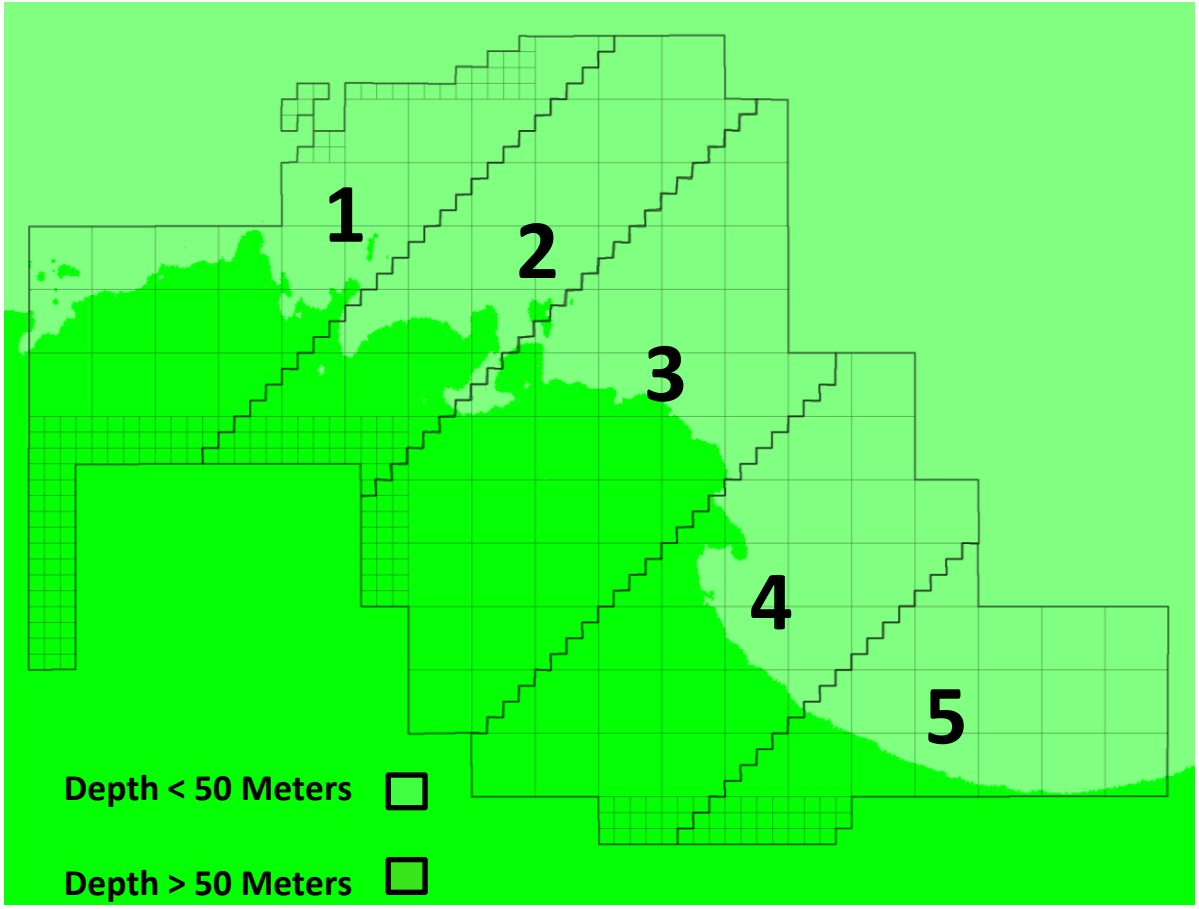
Area less than 50m	
Lease Areas	Area(km²)
Area 1	324.49
Area 2	324.68
Area 3	328.00
Area 4	322.64
Area 5	325.65



MA WEA Wind Direction Rose



Total and Shallower Lease Area for Alt 2

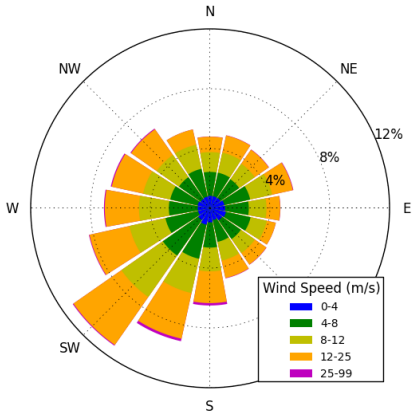


Alternative 2 Characteristics

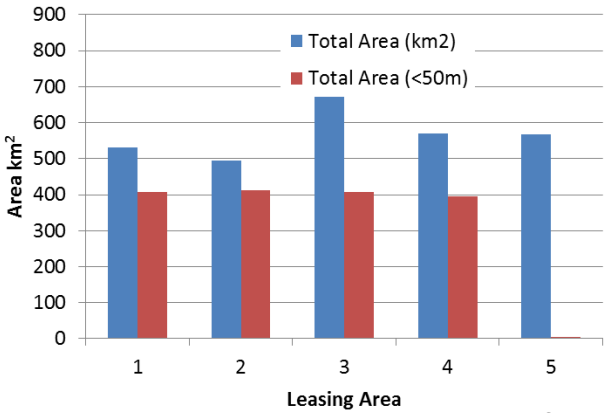
- 5 leasing Areas
- Diagonal delineations minimizes upwind conflicts
- Shallower water <50m equalized
- More areas increase maximum development potential
- Narrower areas may push projects deeper
- NREL preferred method

Alternative 3

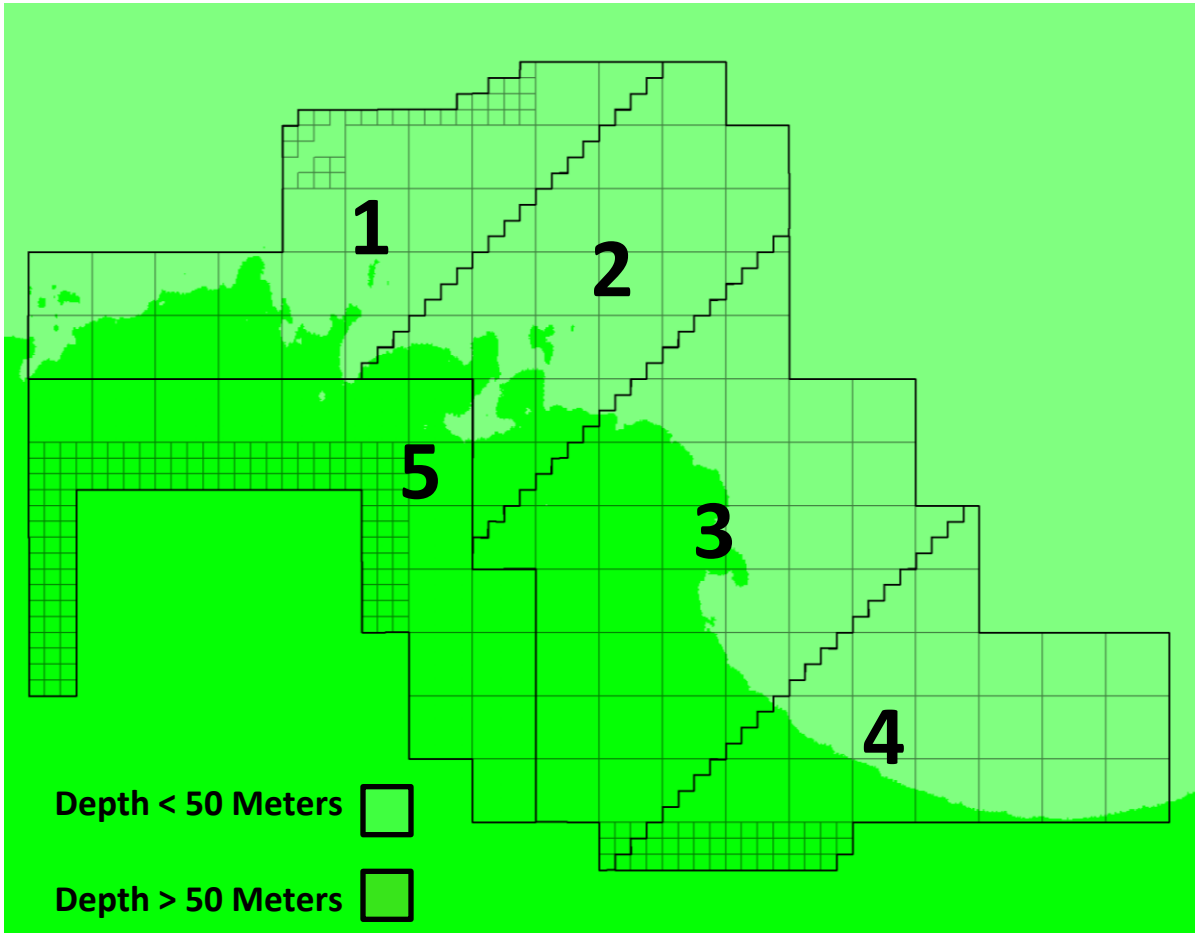
Area less than 50m	
Lease Areas	Area(km²)
Area 1	407.45
Area 2	414.92
Area 3	408.31
Area 4	394.58
Area 5	4.05



MA WEA Wind Direction Rose



Total and Shallower Lease Area for Alt 3



Alternative 3 Characteristics

- 4 leasing Areas from Alt 1 with deep water lease area carved out (area 5)
- Shallower water <50m equalized in areas 1-4
- Maximum near term development potential same as Alt 1 but less burden on deep water
- More shallow per area
- Wider areas enable shallower projects

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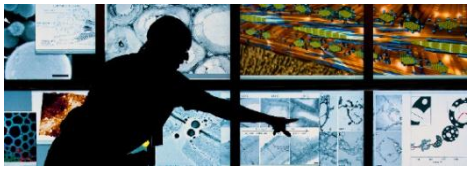


Massachusetts WEA:
Wake Loss and Energy Analysis

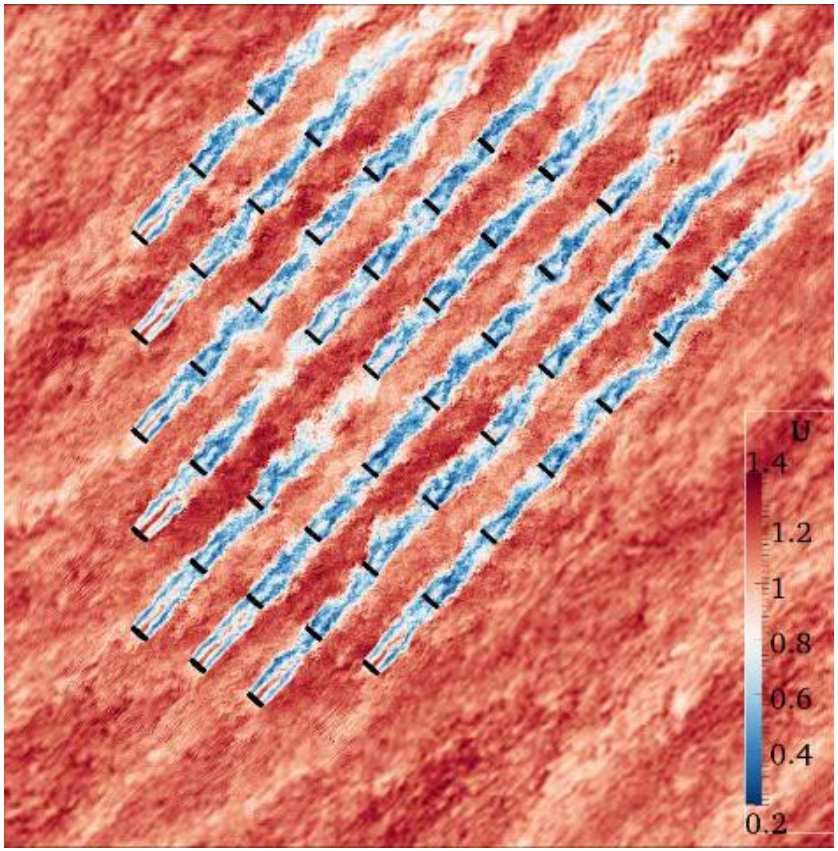
Wind Plant Design Should Consider Wake Effects

Horns Rev I Offshore Wind Plant

(Source: Vattenfall, *Photo by Christian Steiness*)

Wake Losses and Inter-project Buffers - Background

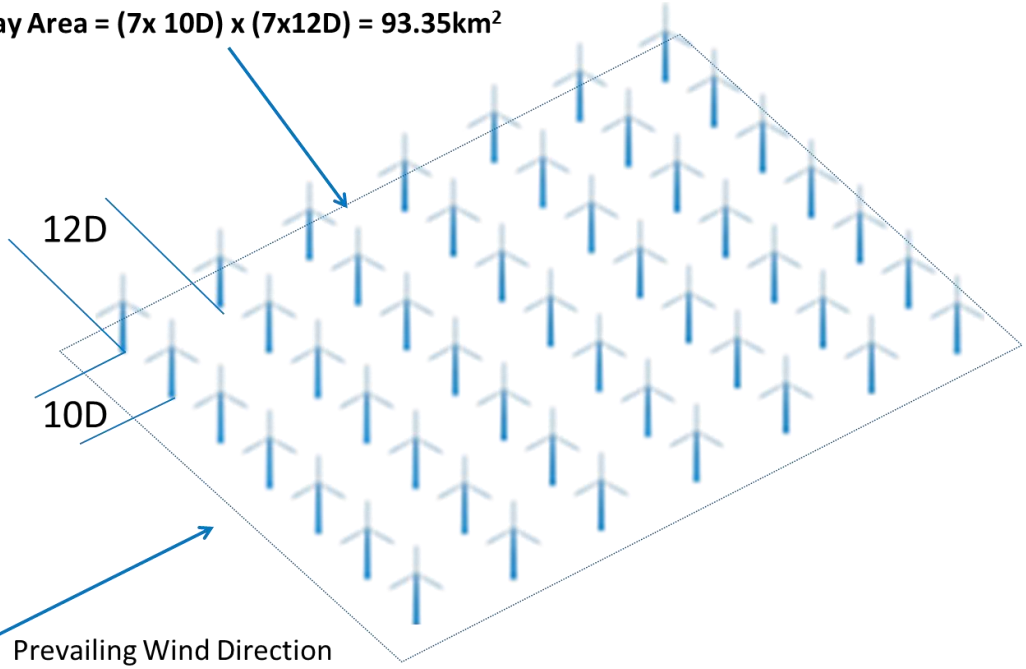
- Wind turbines wakes have lower available energy, higher turbulence, and are replenished by natural atmospheric mixing
- Larger scale atmospheric stability conditions dominate the rate of mixing and replenishment
- Stable atmospheres are stratified and allow wake turbulence to persist farther downstream
- Unstable atmospheres replenish energy in the wakes more quickly with more rapid mixing



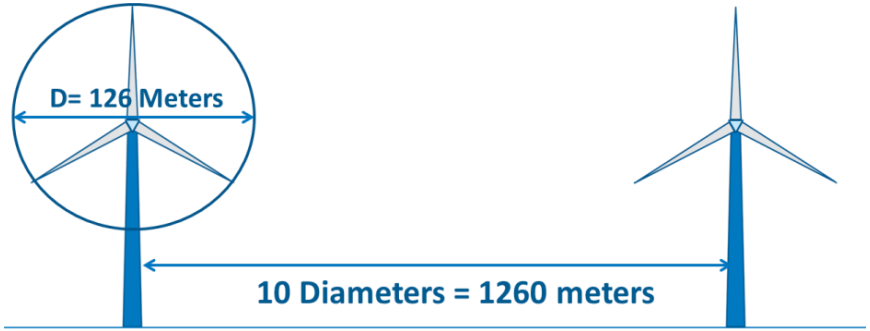
Simulator for Wind Farm Applications showing turbine wake effects (Source: NREL)

Array Spacing Definition

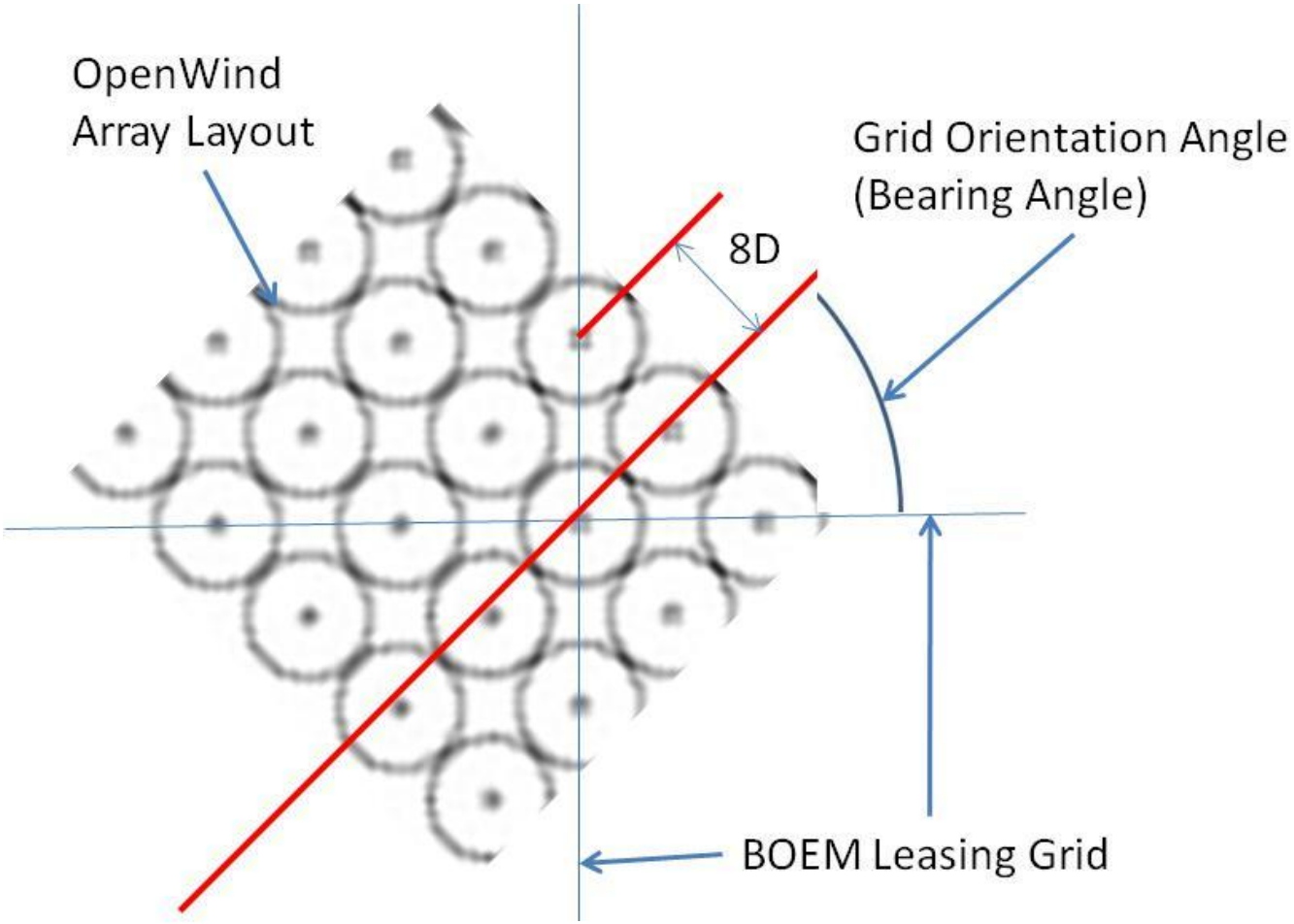
Example: Single Wind Plant with 10D x 12D spacing



5MW per turbine
Rotor Diameter = 126 m
49 turbines
Wind Plant Capacity = 245 MW
Array Area = 93.35 km²
Array Turbine Density = 2.62 MW/km²



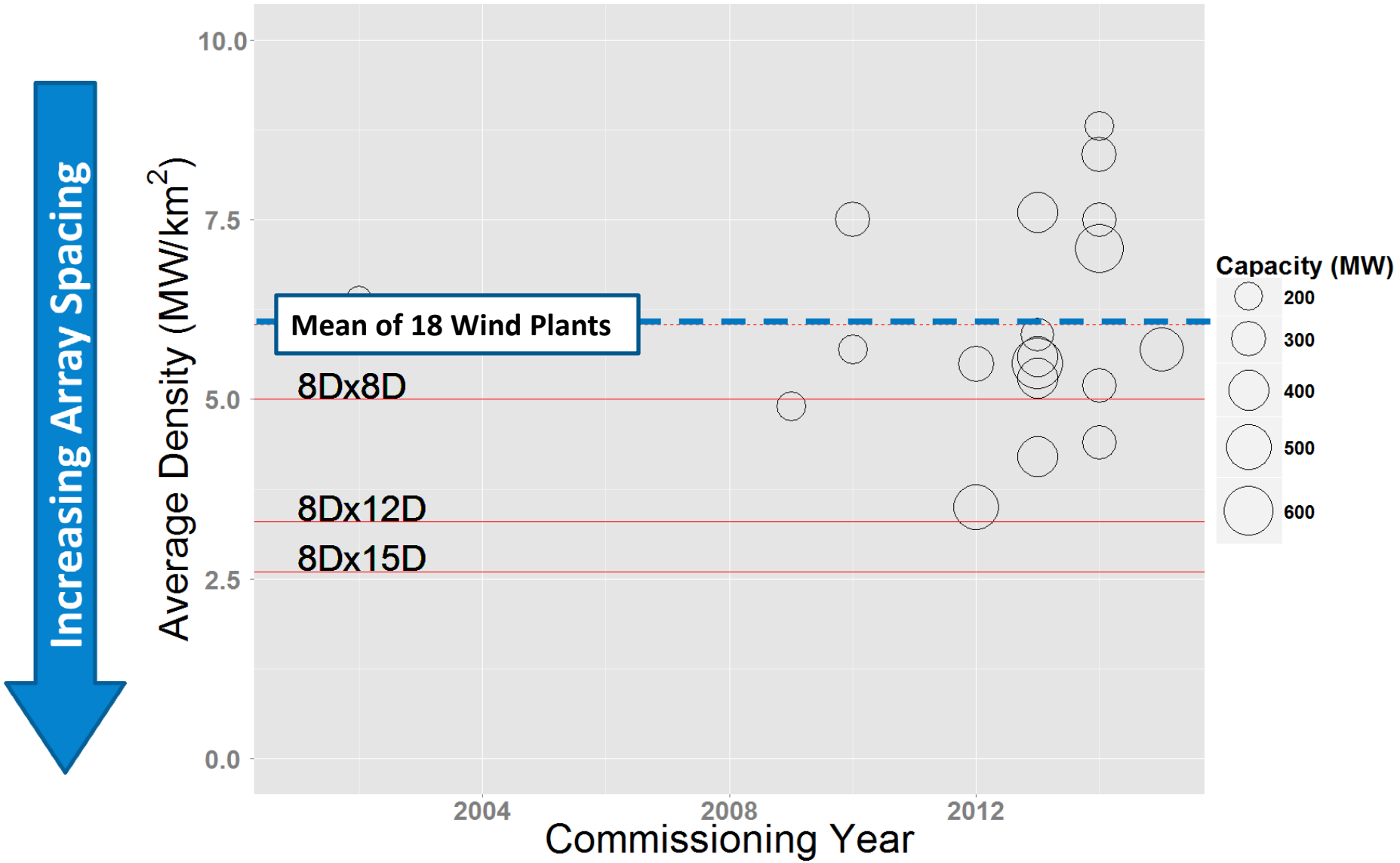
BOEM Leasing Grid is the Reference Frame for the Grid Orientation Angle



Open Wind Output Example with 8D x 8D spacing

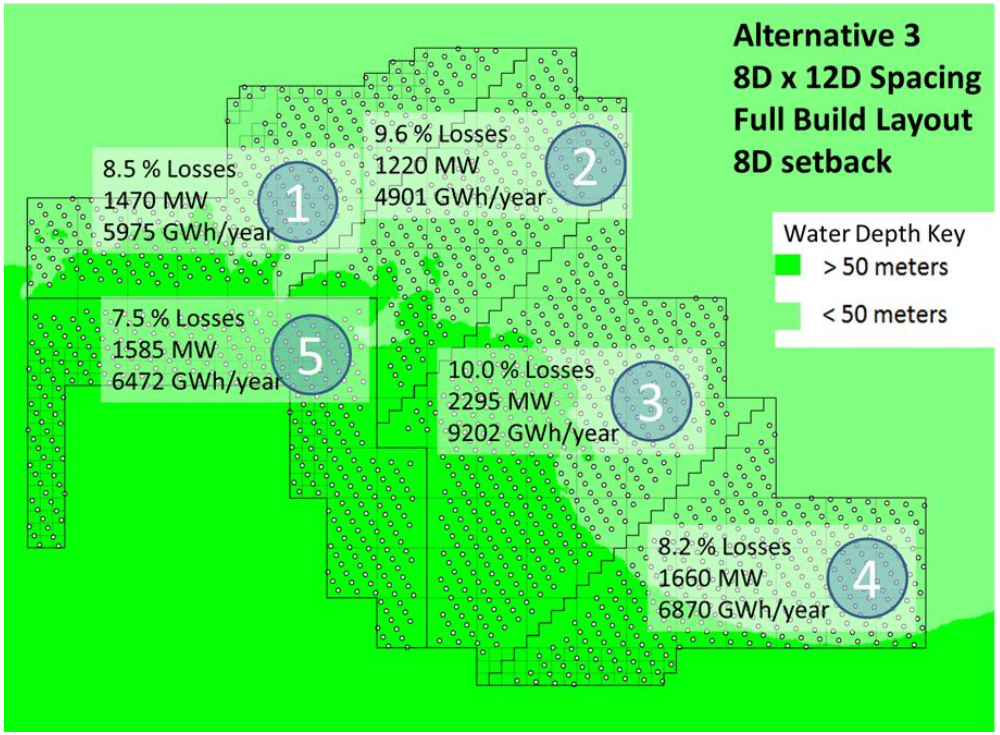
Wake Losses Were Insensitive to Grid Orientation Angle: < 0.1%

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



Description of openWind® Enterprise Program

- Wind power facility design software program
- Open source, but NREL licensed options for deep array wake losses and other features
- GIS based architecture
  - GIS file compatibility
  - Spatial logic with hierarchical structure
- 8D setback from boundaries and 50D between phased projects
- Computations using typical wind plant design practices
- Energy and wake effects assessed
- Default to deep array offshore wake model for higher fidelity

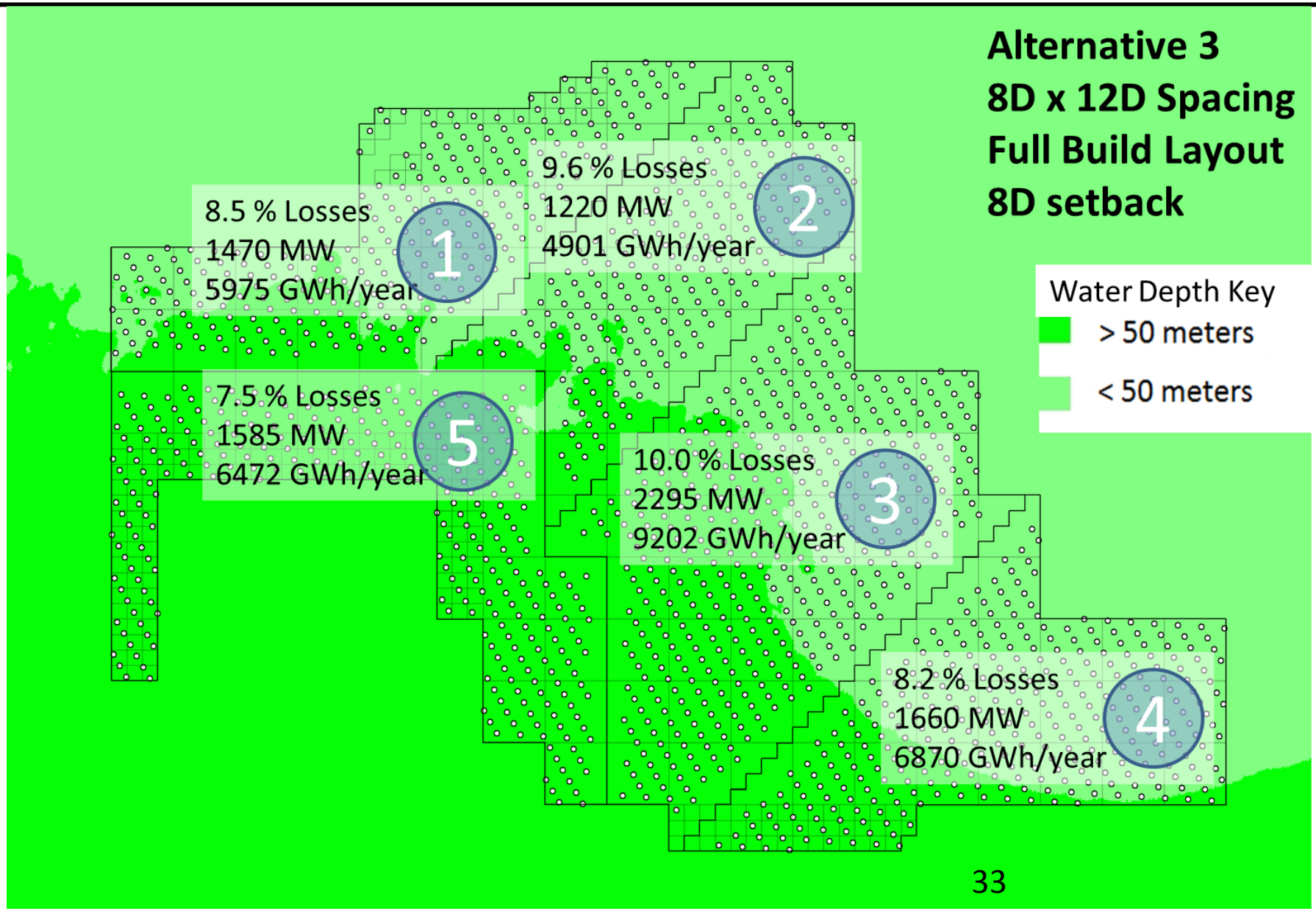


Full Development Scenario: openWind Enterprise Tool arranges turbines inside the Massachusetts Wind Energy Area and computes energy, wake losses and energy performance for Alternative 3– 8D x 12D Spacing and 60 degree orientation angle (Source NREL)

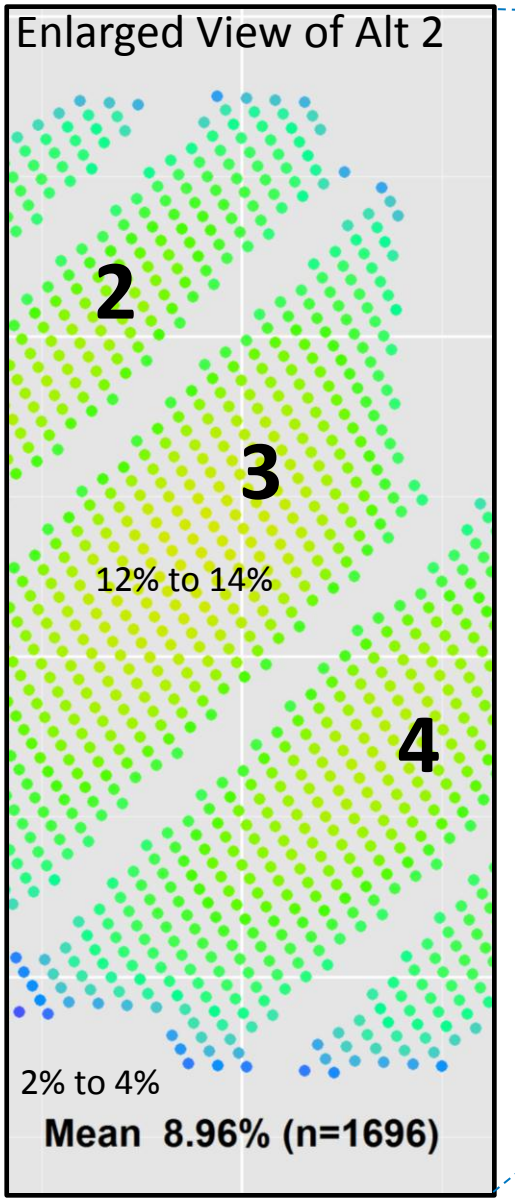
Massachusetts WEA Array Analysis Scenarios

Analysis Performed	Alternative 1: Four Leasing Area Scenario (Diagonal)	Alternative 2: Five Leasing Area Scenario (Diagonal)	Alternative 3: Five Leasing Area Scenario (four shallow and one deep leasing area)	
Full Development Analysis				
8 D x 12 D spacing (max capacity)	✓	✓	✓	**Total Array Power Density Decreases with Spacing**
8 D x 12 D spacing (max capacity)	✓	✓	✓	
8 D x 15 D spacing (max capacity)	✓	✓	✓	
Phased 500-MW Unit Development				
8 D x 8 D 500-MW phased development	✓	✓	✓	**Total Array Power Density Constant for Each Lease Area**
8 D x 12 D 500-MW phased development	✓	✓	✓	
8 D x 15 D 500 MW phased development	✓	✓	✓	

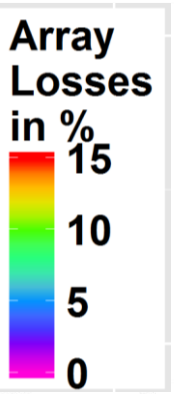
Alternative 3: Full Development Example – 8,230 MW



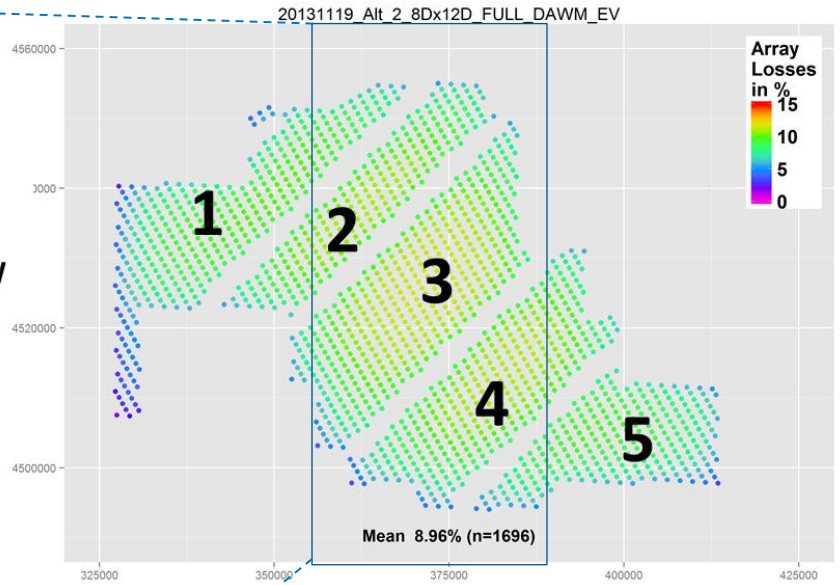
Wake Loss Study for Full Development

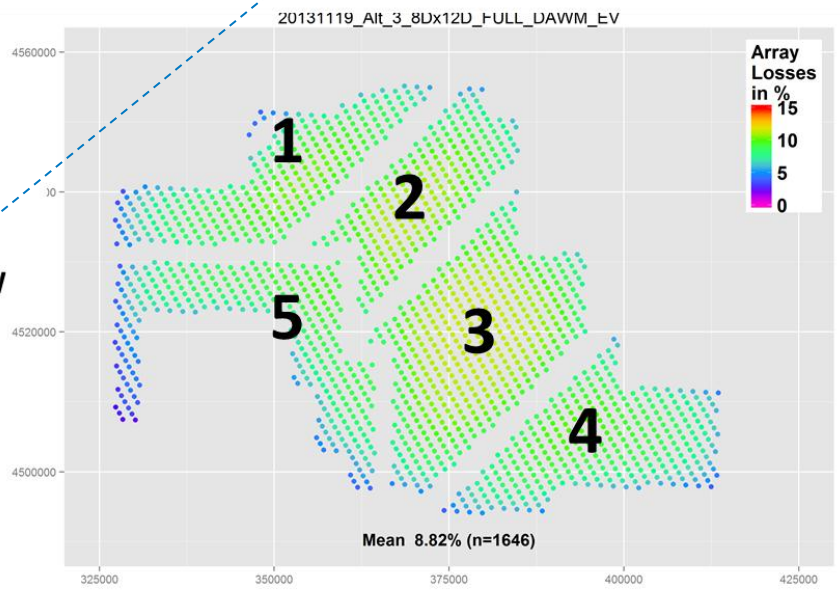


Alternative 2
Full Development
8D x 12D Turbine Spacing
91.1% Array Efficiency
Total Capacity = 8480 MW



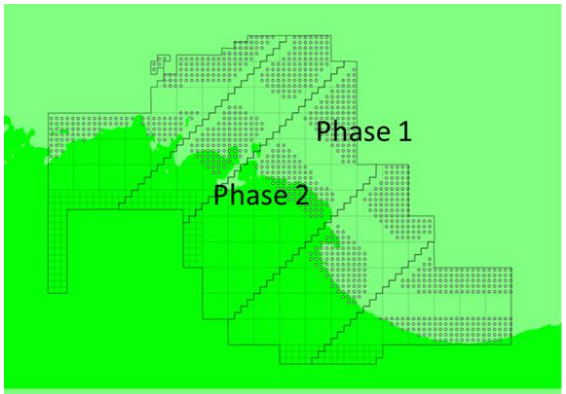
Alternative 3
Full Development
8D x 12D Turbine Spacing
91.2% Array Efficiency
Total Capacity = 8230 MW





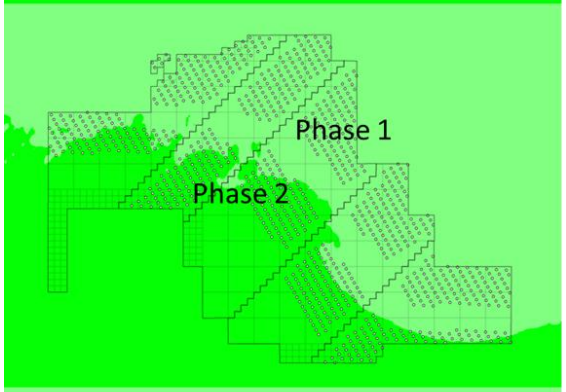
500 MW Phased Developments – Array Spacing and Bathymetry

Wider Spacing Results In Deeper Deployments

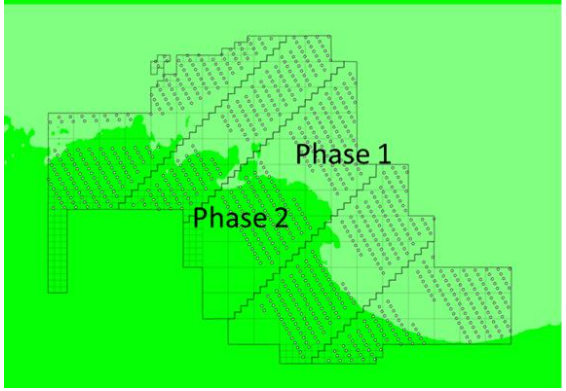


Water Depth Key
> 50 meters
< 50 meters

8D x 8D Array Spacing

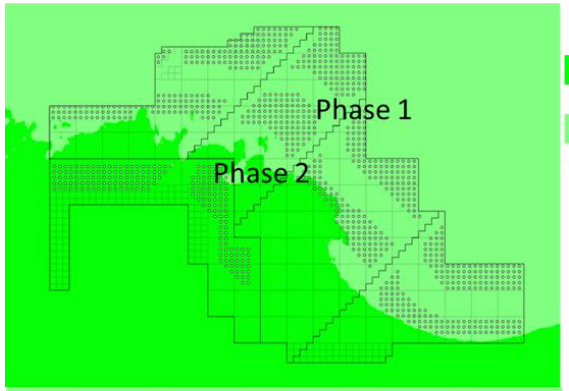


8D x 12D Array Spacing



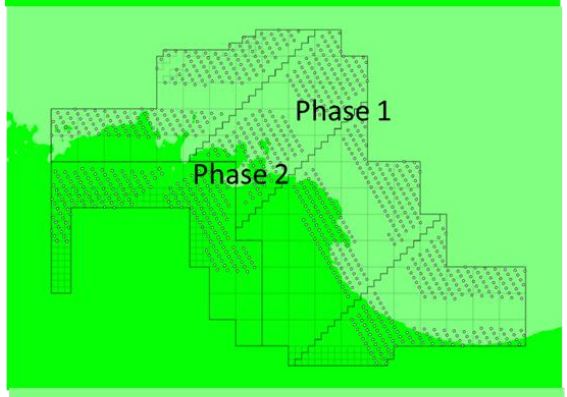
8D x 15D Array Spacing

Alternative 2

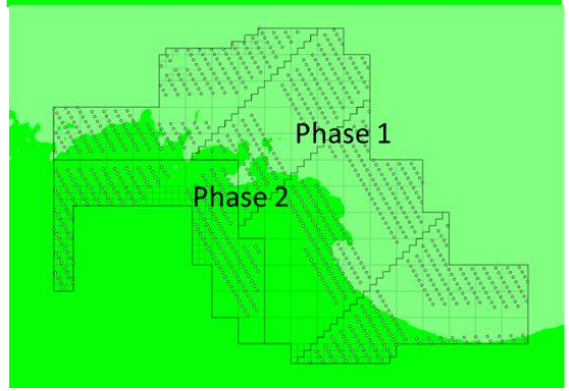


Water Depth Key
> 50 meters
< 50 meters

8D x 8D Array Spacing



8D x 12D Array Spacing

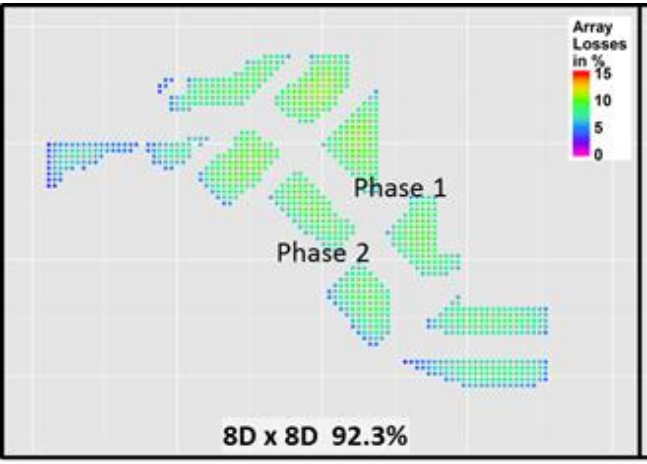


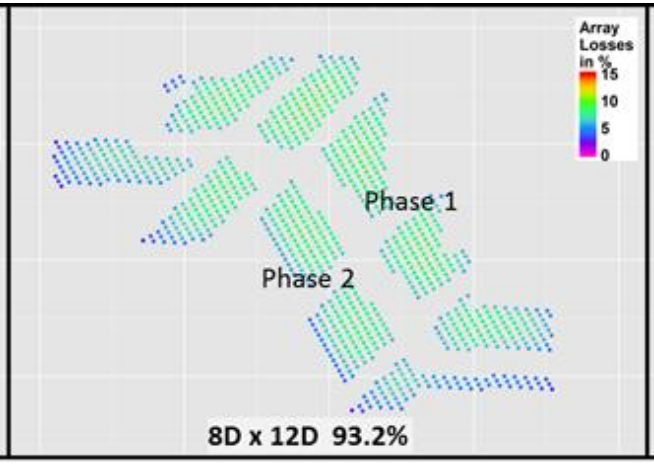
8D x 15D Array Spacing

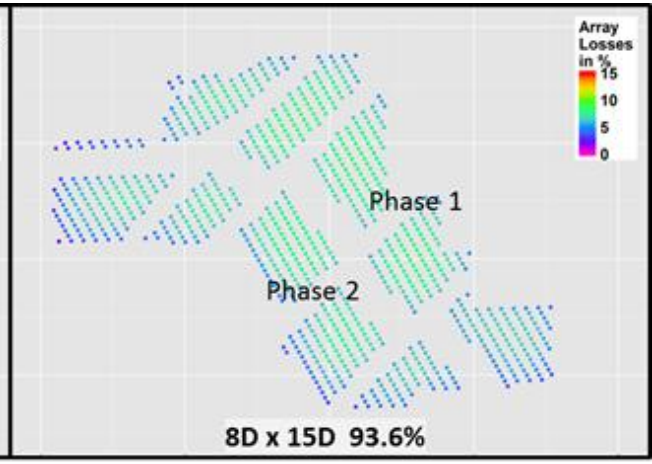
Alternative 3

Alternative 2: Wake Losses for Three Spacing Scenarios

Five Leasing Areas

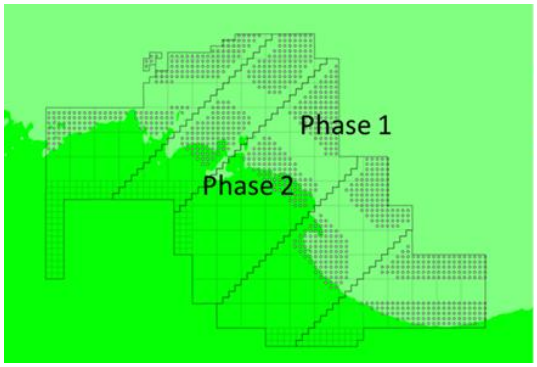


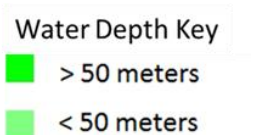




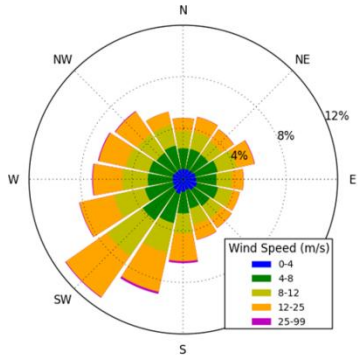
A **B** **C**

MA WEA for Alternative 2 leasing area delineation showing the effect of turbine spacing and buffers on array efficiencies with two 500-MW projects in each leasing area: (A) 8 D x 8 D spacing; (B) 8 D x 12 D spacing; and (C) 8 D x 15 D spacing



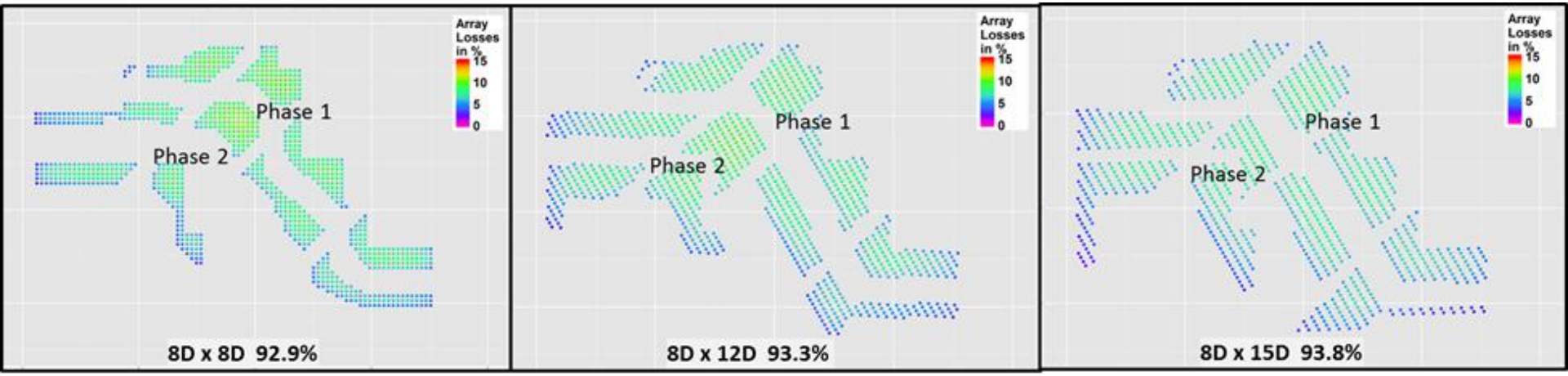


8D x 8D Array Spacing



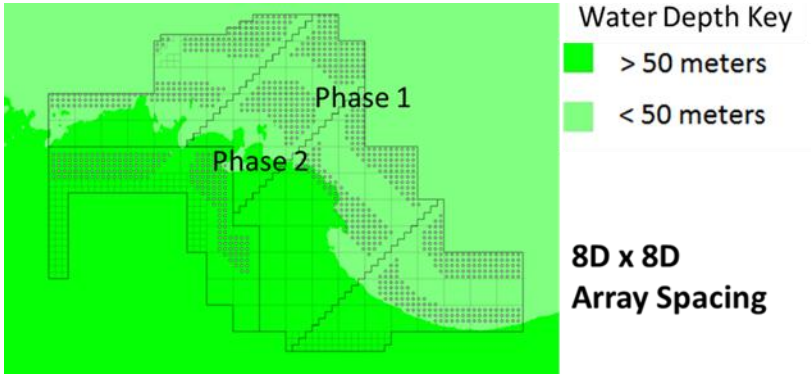
Alternative 3: Wake Losses for Three Spacing Scenarios

1000 MW in Each of Five Leasing Areas



A **B** **C**

MA WEA for Alternative 3 leasing area delineation showing the effect of turbine spacing and buffers on array efficiencies with two 500-MW projects in each leasing area: (A) 8 D x 8 D spacing; (B) 8 D x 12 D spacing; (C) 8 D x 15 D spacing (Source: NREL)



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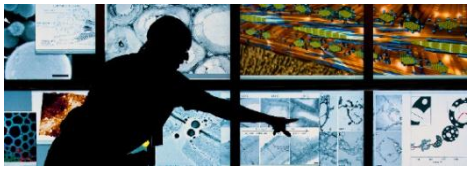

Summary and Recommendations

Summary (1)

1. The MA WEA is relatively large (3,006.7 km^2) and can accommodate at least ten 500-MW wind projects (5,000 MW) using up to five leasing areas.
2. The biggest development challenge in the MA WEA will be water depths that range between 35 and 65 m.
3. The MA WEA can be delineated into four to five leasing areas with equitable divisions of shallower water (less than 50 m), wind resource potential, and exposure to unobstructed free stream prevailing wind
4. Western leasing areas may have an advantage if export cable interconnection points off Cape Cod and the islands are favored. Interconnect access could be a strong driver in appraising leasing area value.
5. The maximum nameplate development capacity per area for Alternatives 2 and 3, ranged from 1,220 MW to 2,295 MW. For Alternative 1, the maximum nameplate development potential ranged from 1,695 MW to 2,955 MW. The shallower water (less than 50 m) is balanced to within 5% for each alternative.

Summary Continued (2)

6. Diagonal delineations to the BOEM leasing grid are the most efficient to equalize depth, and minimize inter-array conflicts
7. The average annual wind speed for the MA WEA ranges from 9.2 m/s to 9.4 m/s, with the highest wind speeds in the east and the lowest wind speeds in the west
8. The range of capacity factors is between 45% and 47% across the WEA (after wake losses only) using 8D x 12D spacing for full development
9. Total wake losses for 8D x 12D spacing in all leasing areas were between 6% and 8% when two 500-MW phases area installed
10. Wake losses in the MA WEA are lower than NJ and MD because higher wind speeds and more unidirectional prevailing winds
11. Array efficiency was insensitive to array orientation angle (<0.1%)
12. Wake losses increased with decreased turbine spacing. For full development in each alternative, wake losses averaged 7.8% for the 8D x 15D spacing and 11.2% for the 8D x 8D spacing. Lower losses are due to fewer turbines with the wider spacing

Summary Continued (3)

13. Wider turbine spacing may have diminishing benefits when multiple large arrays are sited near each other. Benefits of turbine spacing are offset by reductions in the buffers that separate neighboring wind plants.

14. Higher development cost is introduced with wider spacing due to longer cables, deeper water, and farther distances from shore.

Recommendations and Disclaimers

1. NREL prefers Alternative 2 because the development potential of the WEA might be maximized while minimizing the effects of neighboring projects on adjacent wind plants.

2. Any of the alternatives assessed in this report would be feasible and may be preferable to Alternative 2 for a different set of objectives.

3. NREL recommends that BOEM consider methods to discount the deepest aliquots to address the probable time lag in developing deeper water.

4. State or federal regulators should consider options for coordinating cable routing strategies and possible electrical easements among the leasing areas.

5. The analysis in this report is coarse by industry standards. NREL recommends that lessees conduct more rigorous analysis on wake losses before judging the values of these leasing areas which should consider diurnal, seasonal, and annual variations as well as a full cost assessment to examine the additional cost of added cable length. In addition, NREL recommends conducting further analysis on wake losses with respect to atmospheric stability conditions.

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- Massachusetts Office of Coastal Zone Management
- BOEM Massachusetts Renewable Energy Task Force

Thank you for your attention!

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Photo Credit: NREL