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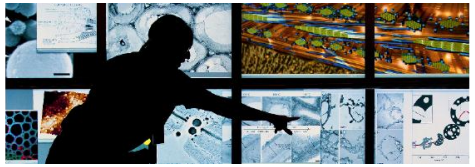
Final Presentation to New Jersey Renewable Energy Task Force on Leasing Area Delineation Studies

Webinar Sponsored by Bureau of Ocean Energy Management

Walt Musial

National Renewable Energy Laboratory

Principal Engineer and Manager Offshore Wind

January 28, 2013

NREL Presentation Contents

- Project scope and parameters
- BOEM New Jersey Call for Nominations summary
- Physical description of New Jersey WEA, Area of Analysis, and delineation process
- New Jersey Area of Analysis: Wake loss and energy analysis
- Summary and recommendations
- Question and answers

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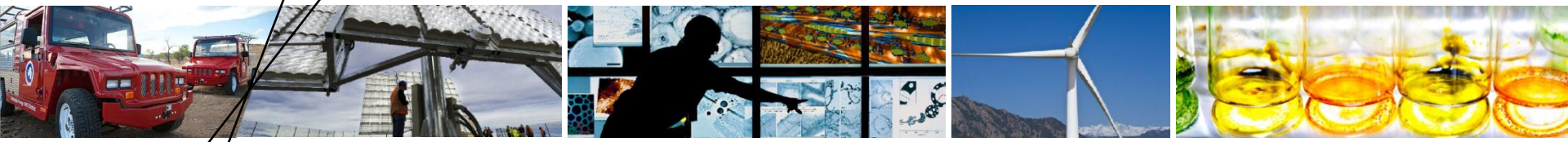
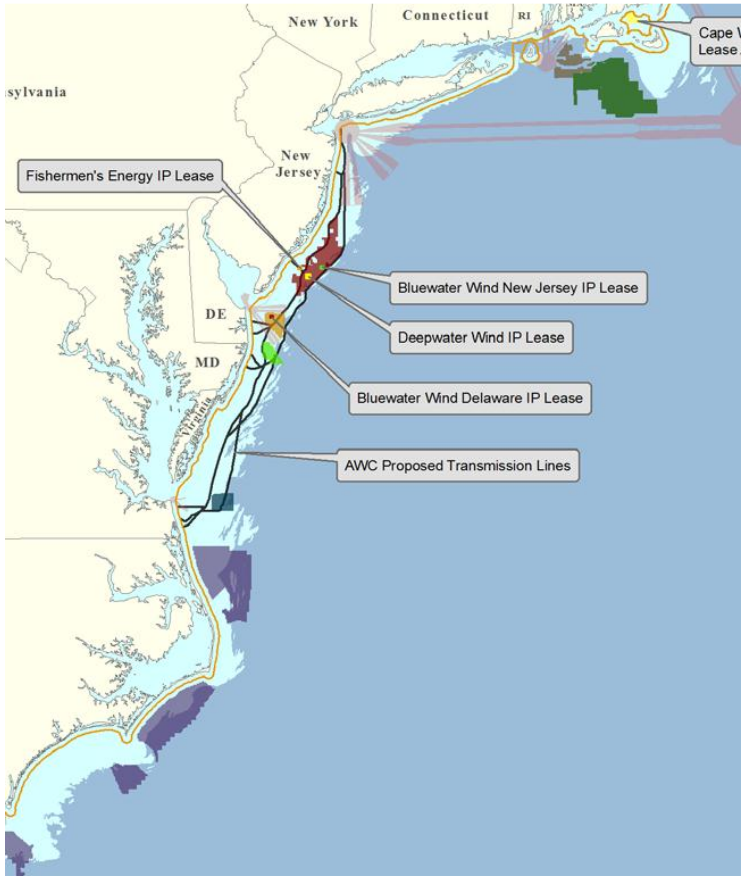


Project Scope and Parameters

Project Summary and Background

- Bureau of Ocean Energy Management (BOEM) requested assistance from the Department of Energy's National Renewable Energy Laboratory (NREL) to provide technical input to inform the delineation of leasing areas within four BOEM Wind Energy Areas(WEA)
- NREL evaluated New Jersey's wind energy area and made recommendations to BOEM on options to delineate the area into two to four leasing areas
- Focus was on wind resource, energy potential, bathymetry, and wake effects with a goal to produce development zones with similar value



BOEM Wind Energy Planning Areas

Project Objectives:

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

Major Parameters for NJ Offshore Wind Analysis

- Investigate best options for 2 to 4 leasing areas
- Assess NJ Area of Analysis 1,359.3 km^2 which is 5.2% smaller than “Call Area” 1,433.7 km^2
- Assess NJ Area of Analysis with baseline array spacing of 10D x 12D (2.62 MW/km^2)
- Examine larger (10D x 15D) and smaller (8D x 8D) array spacing
- Use 8D setbacks between leasing areas
- Use NREL 5-MW reference wind turbine with 126-m rotor diameter


REpower 5M Alpha Ventus - Germany

Photo Credit: Gary Norton

Tasks for NREL/BOEM Interagency Agreement

1. **Develop preliminary methodology for delineation of NJ WEA and present to NJ BPU and RE Task Force on Dec 18, 2012**
2. **Review 11 "Call" nominations to gather data on proposed development strategies and specific interests in the NJ WEA**
3. **Perform analysis on delineation options for 3-5 leasing areas using openWind® Enterprise Program based on "Call" WEA.**
4. **Modify area of analysis based on Feedback from BOEM and BPU; Revised area of analysis eliminated certain high traffic areas and cable routes**
5. **Change array spacing, and assess 2-4 leasing areas**
6. **Write and publish draft and final report – Oct 3, 2013**
7. **Present findings and analysis to BOEM/NJ BPU and Renewable Energy Task Force (January 28, 2014)**

Assessment of Offshore Wind Energy Leasing Areas for the BOEM New Jersey Wind Energy Area, W. Musial, D. Elliott, J. Fields, Z. Parker, G. Scott, and C. Draxl
http://www.nrel.gov/docs/fy13osti/60403.pdf (PDF 4.1 MB)

Parameters Assessed in NJ Area of Analysis

Quantitative Evaluation Criteria	Qualitative Evaluation Criteria
Total area (km^2 and acres)	Distance from shore
Maximum installed capacity [megawatts (MW)]	Technology challenges
Bathymetry [meters (m)]	Development cost
Annual average wind resource [meters per second (m/s)]	
Gross capacity factor (%)	
Wake losses (%)	
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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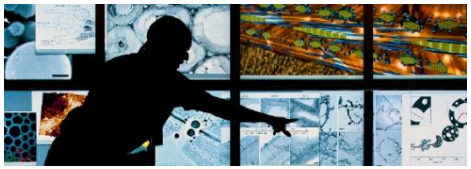
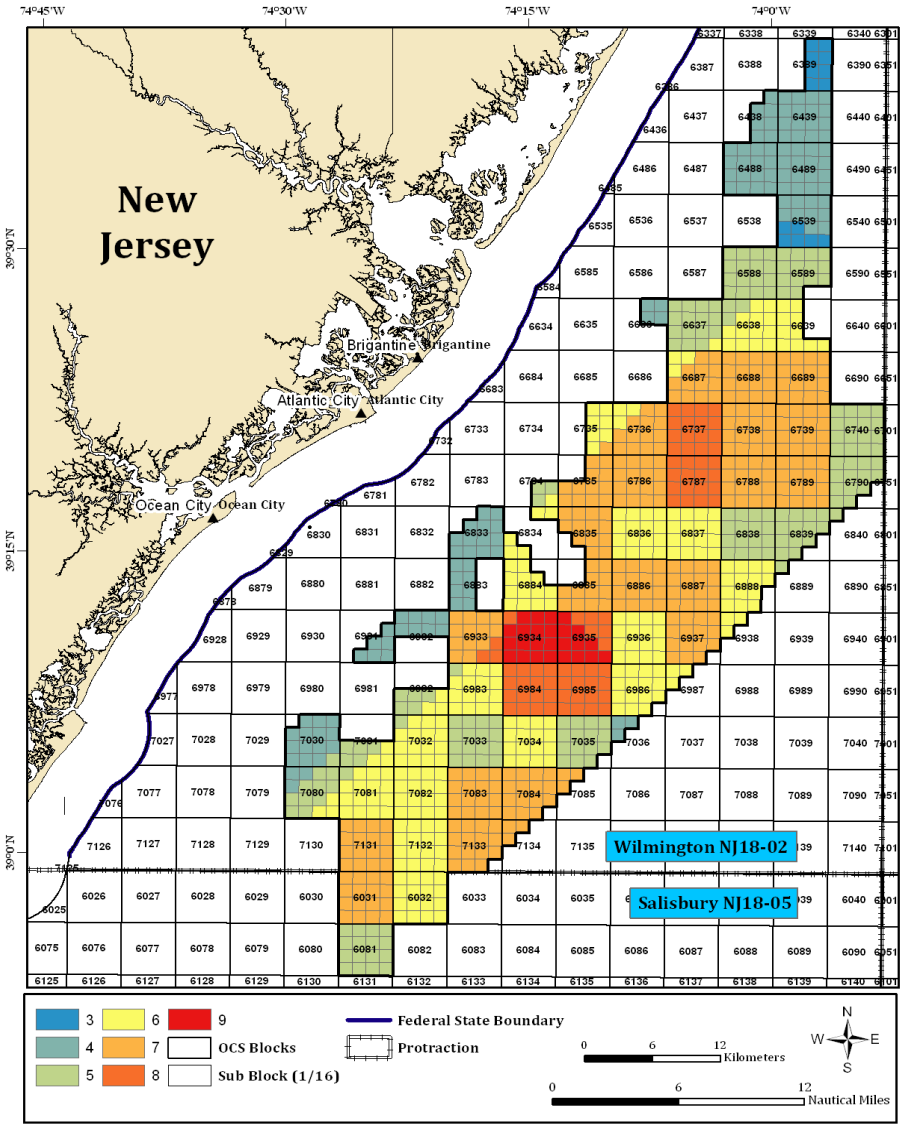


BOEM New Jersey Call for Nominations Summary

Call Nominations – Areas of Development Interest



Key Observations from Call Nominations

- Overlapping interest in center of WEA
- Array spacing of 10D x 11D average from developers exceeds current practices
- Average project footprint 262 km^2 to 1280 km^2
- Average project nameplate capacity ranged from 350 MW to 1,568 MW.
- Developers were not in agreement about wind speed, capacity factor
- Developer interest was not bounded by leasing areas restrictions: project sizes ranged from 18% to 89% of entire “Call” area.

Summary of Nominations From NJ "Call"

Summary of Data from 11 BOEM NJ Wind Energy Area (WEA) Nominations (April 20, 2011)

	Average	Maximum	Minimum	NREL Values
Project nameplate capacity [megawatts (MW)]	1,568	3,900	350	3,095
Turbine nameplate capacity (MW)	5	8	3	5
Average wind speed in meters per second (m/s) at 90 meters (m)	8.5	9.5	7.5	8.5
Net capacity factor (%)	38.3	42.3	34.4	42.2
Proposed project area (km^2)	593.9	1,280.1	262.2	1,359.3
Array spacing in rotor diameters (D)	10 D x 11 D	15 D x 15 D	7D x 10D	10D x 12D
Array turbine density (MW/km^2)	3.0	4.6	1.4	2.6
Number of turbines	325	650	70	619
Maximum depth (m)	34	43	30	38
Project development time frame (years)	9.75	19	6.5	N/A

Notes:

1. NREL used the NJ area of analysis from December 18, 2012, for its analysis, which differs from the original WEA considered by developers during the Call.
2. NREL's array turbine density computation assumes the NREL reference turbine 5-MW nameplate power capacity and 126-m rotor diameter (Jonkman et al. 2009).
3. NREL's net capacity factor is the gross capacity factor after wake losses only.

New Jersey Federal Register Call for Nominations, April 2011
http://www.gpo.gov/fdsys/pkg/FR-2011-04-20/html/2011-9545.htm

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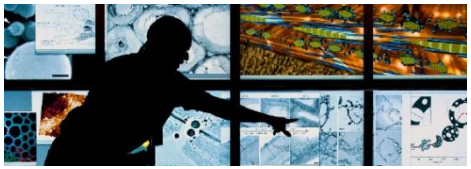
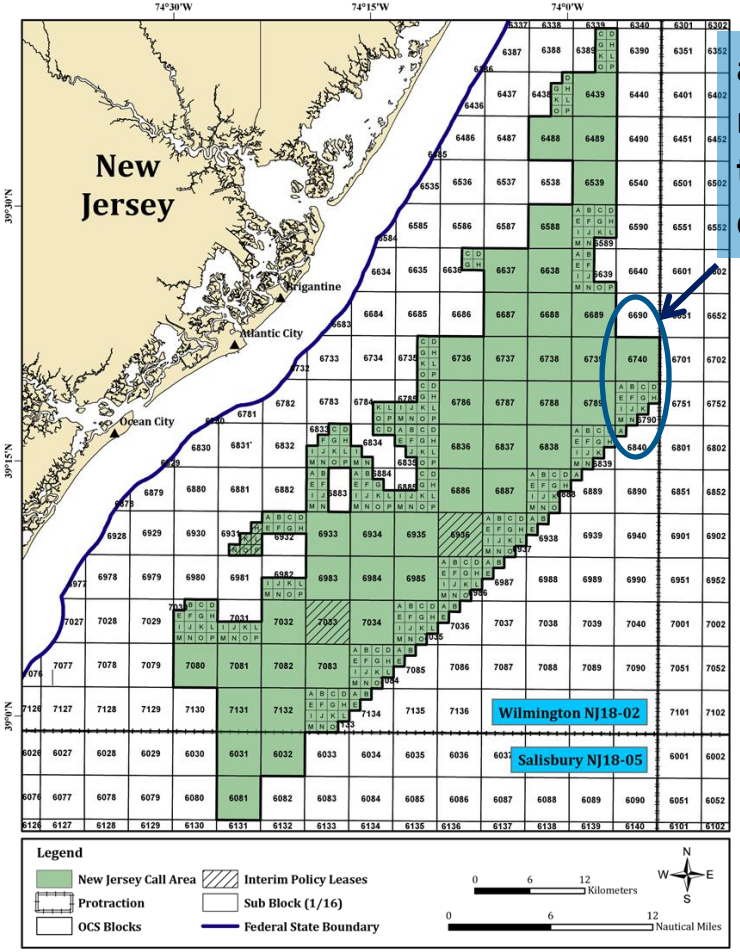


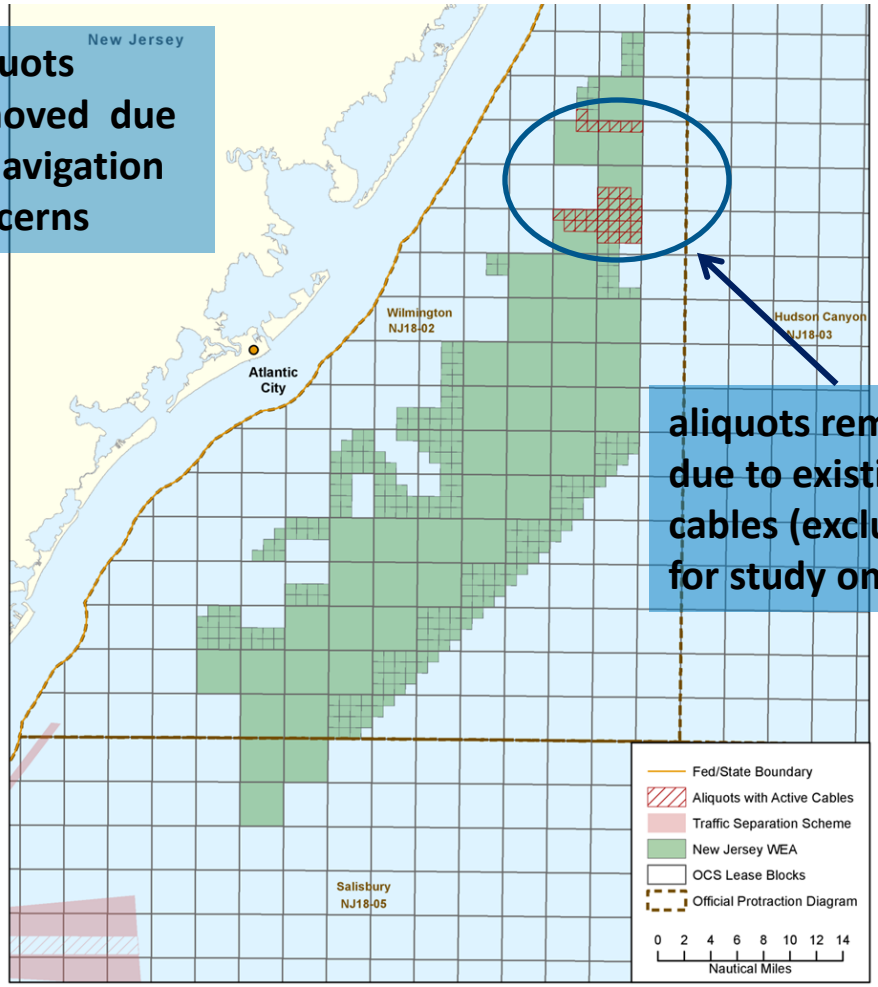
Physical Description of New Jersey WEA, Area of Analysis, and Delineation Process

New Jersey WEA Call Area and New Jersey Area of Analysis
(Source: BOEM 2013)



New Jersey Call area (Source: BOEM)

aliquots removed due to navigation concerns



aliquots removed due to existing cables (exclusions for study only)

New Jersey "Area of Analysis" (Source: BOEM)

Wind Data Source for New Jersey Evaluations

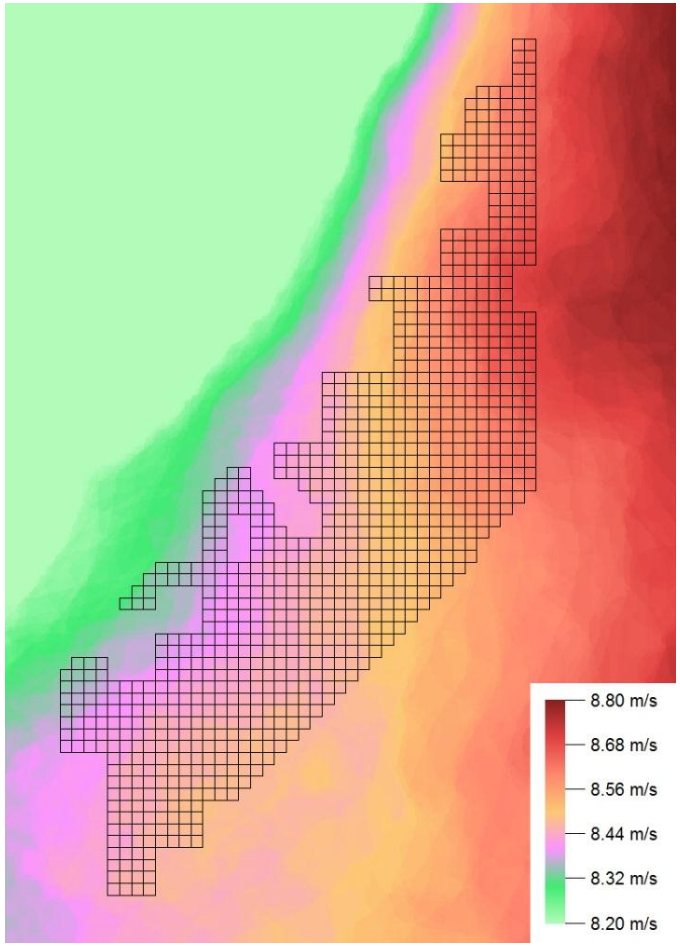
- Wind resource grid (WRG/B) files provided by AWS Truepower[1]
- Data contain wind speed, wind direction, and frequency distribution at a hub height of 90 m
- Mesoscale modeled data at a grid resolution of 20km scaled to 200m grid resolution
- Wind data were selected to provide the highest spatial resolution and longest term record available (14 years)
- Accuracy was validated against surface NOAA buoy (44009 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.

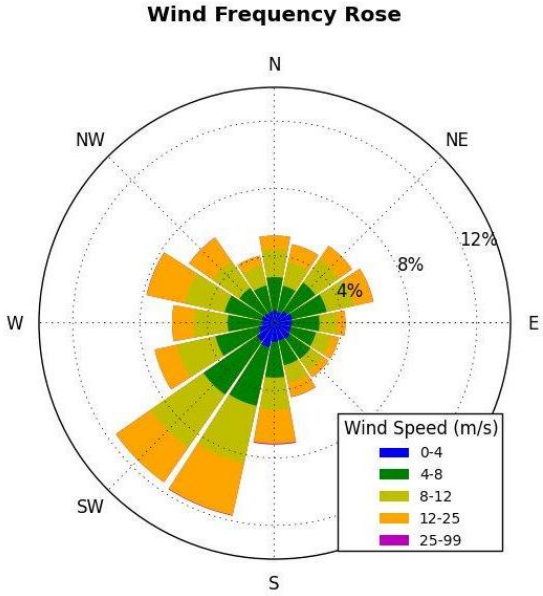
New Jersey “Area of Analysis” Wind Resource

Average Annual Wind Speed = 8.5 m/s



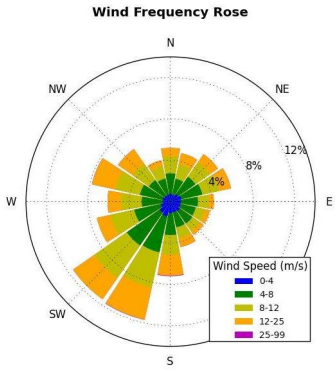
NJ Area of Analysis showing annual average wind speed between 8.4 m/s and 8.6 m/s

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.

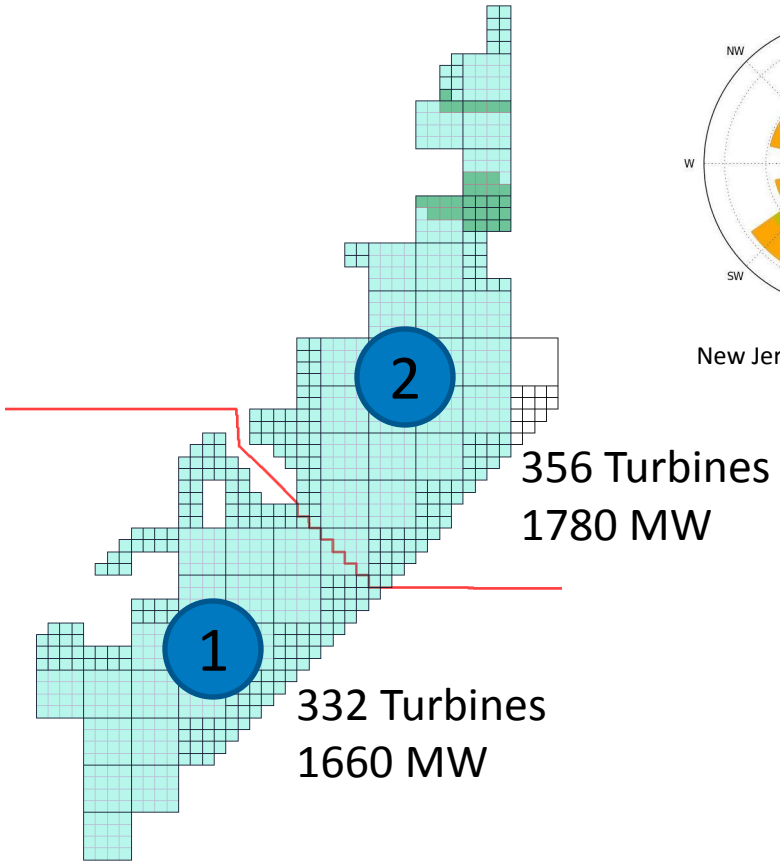


NJ Area of Analysis annual average wind frequency rose with prevailing southwest

2 Leasing Area Delineation Options for NJ WEA



New Jersey WEA Wind Rose



356 Turbines
1780 MW

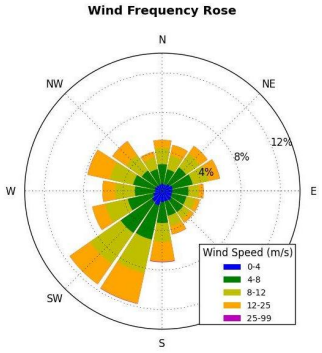
332 Turbines
1660 MW

341 Turbines
1705 MW

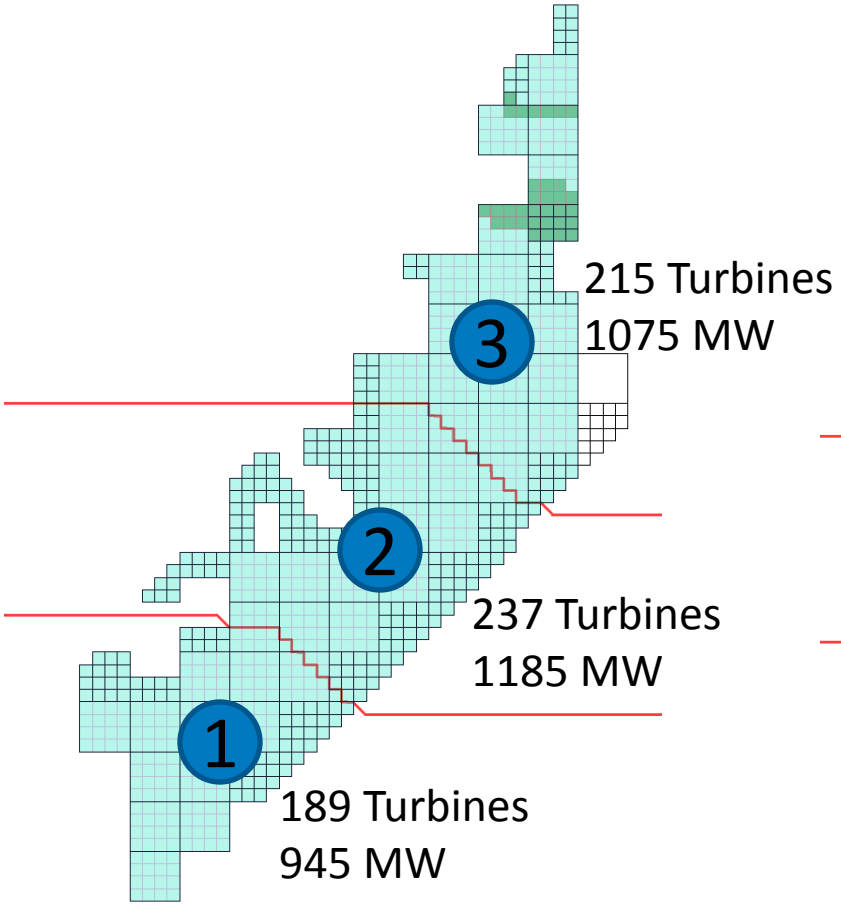
336 Turbines
1680 MW

All calculations assume 10D x 12D spacing and a 5 MW wind turbine with a 126 m diameter rotor

3 Leasing Area Delineation Options for NJ WEA



New Jersey WEA Wind Rose



215 Turbines
1075 MW

237 Turbines
1185 MW

189 Turbines
945 MW

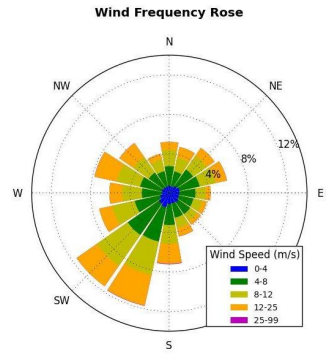
210 Turbines
1050 MW

220 Turbines
1100 MW

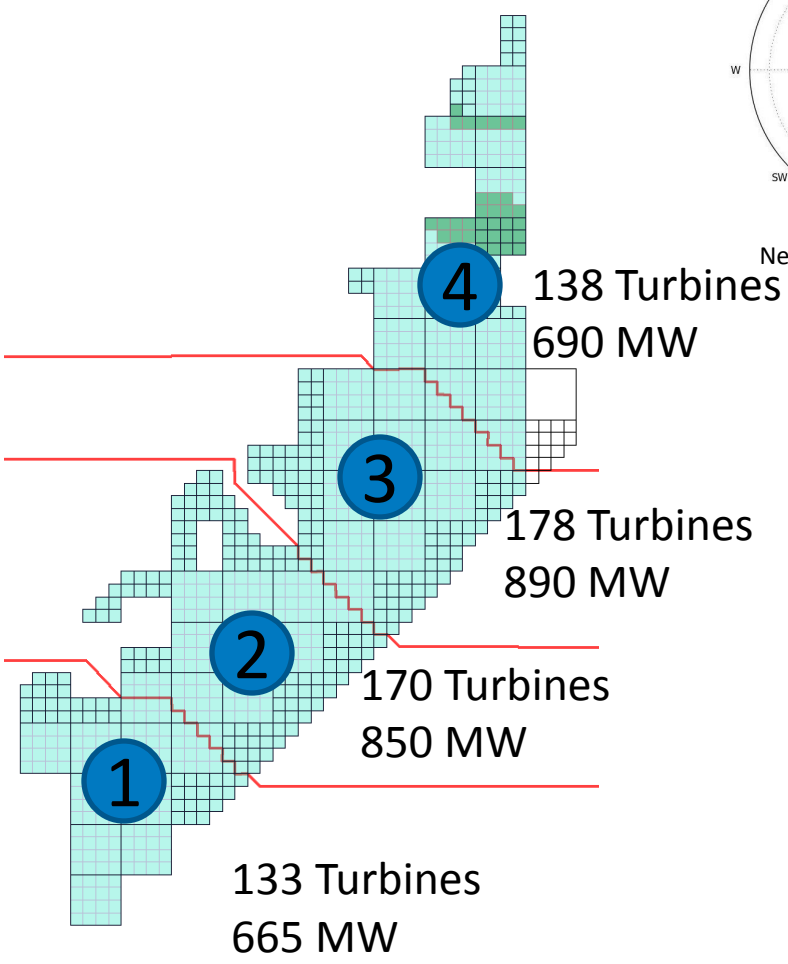
201 Turbines
1005 MW

All calculations assume 10D x 12D spacing and a 5 MW wind turbine with a 126 m diameter rotor

4 Leasing Area Delineation Options for NJ WEA



New Jersey WEA Wind Rose

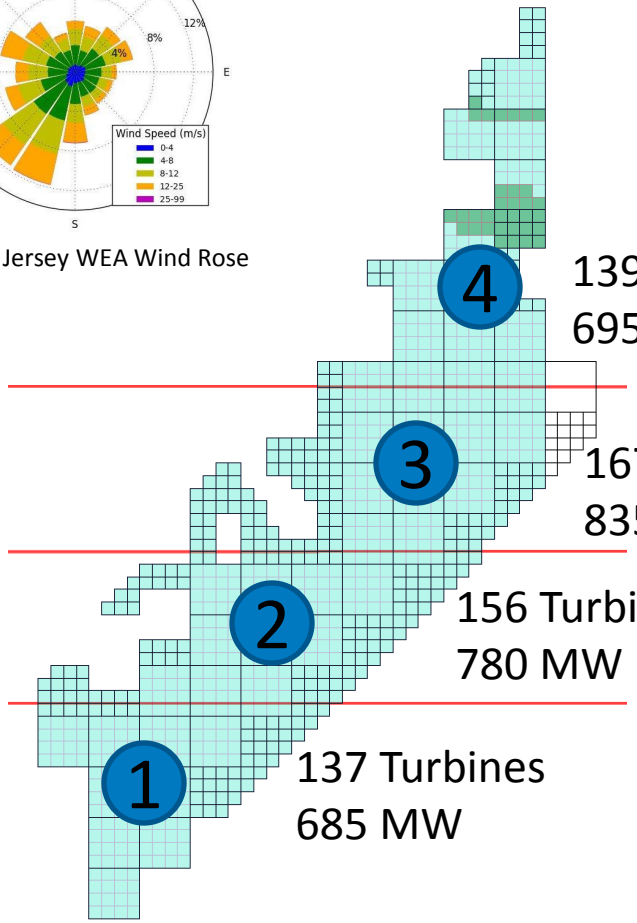


138 Turbines
690 MW

178 Turbines
890 MW

170 Turbines
850 MW

133 Turbines
665 MW



139 Turbines
695 MW

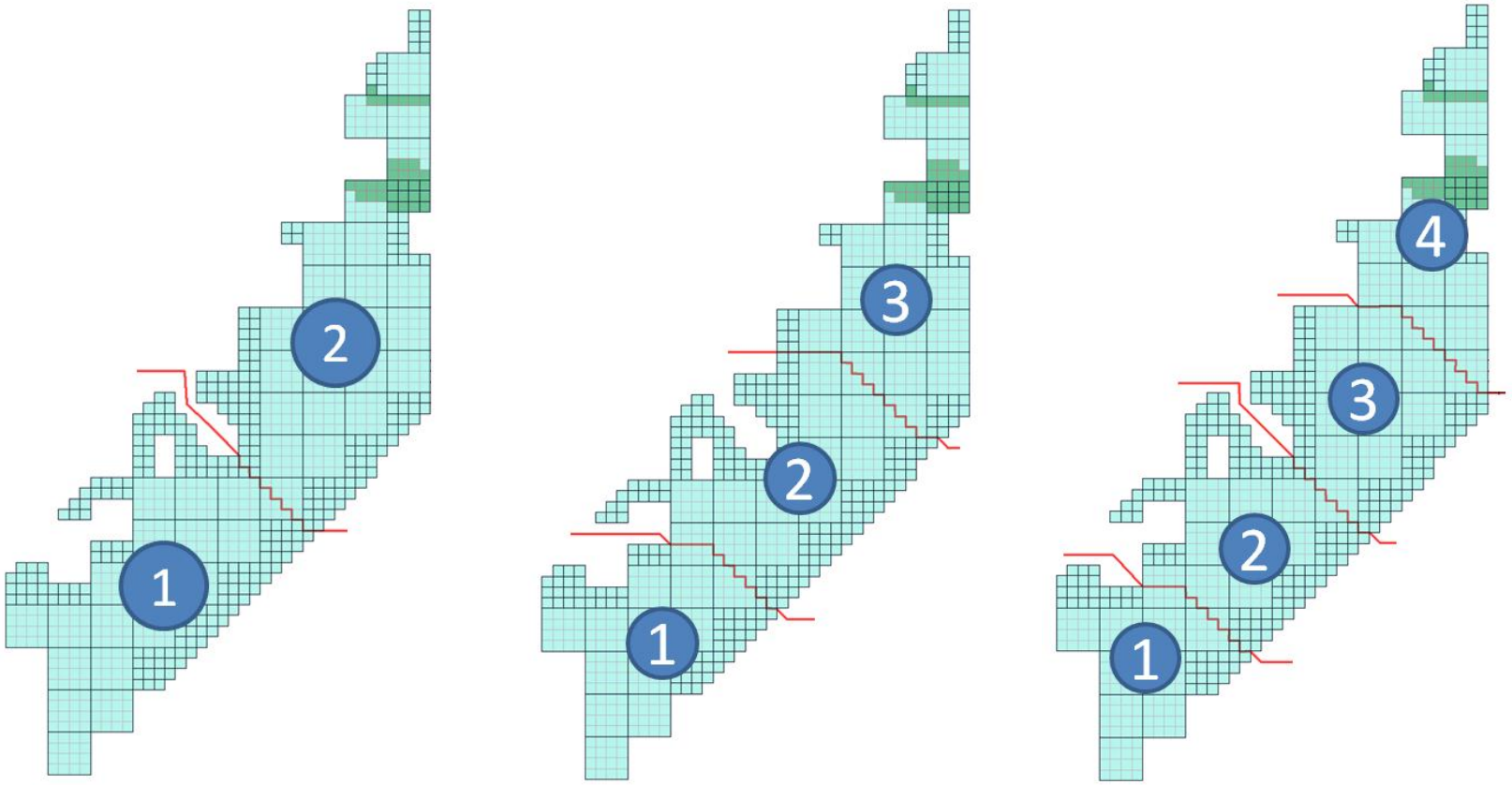
167 Turbines
835 MW

156 Turbines
780 MW

137 Turbines
685 MW

All calculations assume 10D x 12D spacing and a 5 MW wind turbine with a 126 m diameter rotor

Diagonal Delineation Options Were Most Efficient



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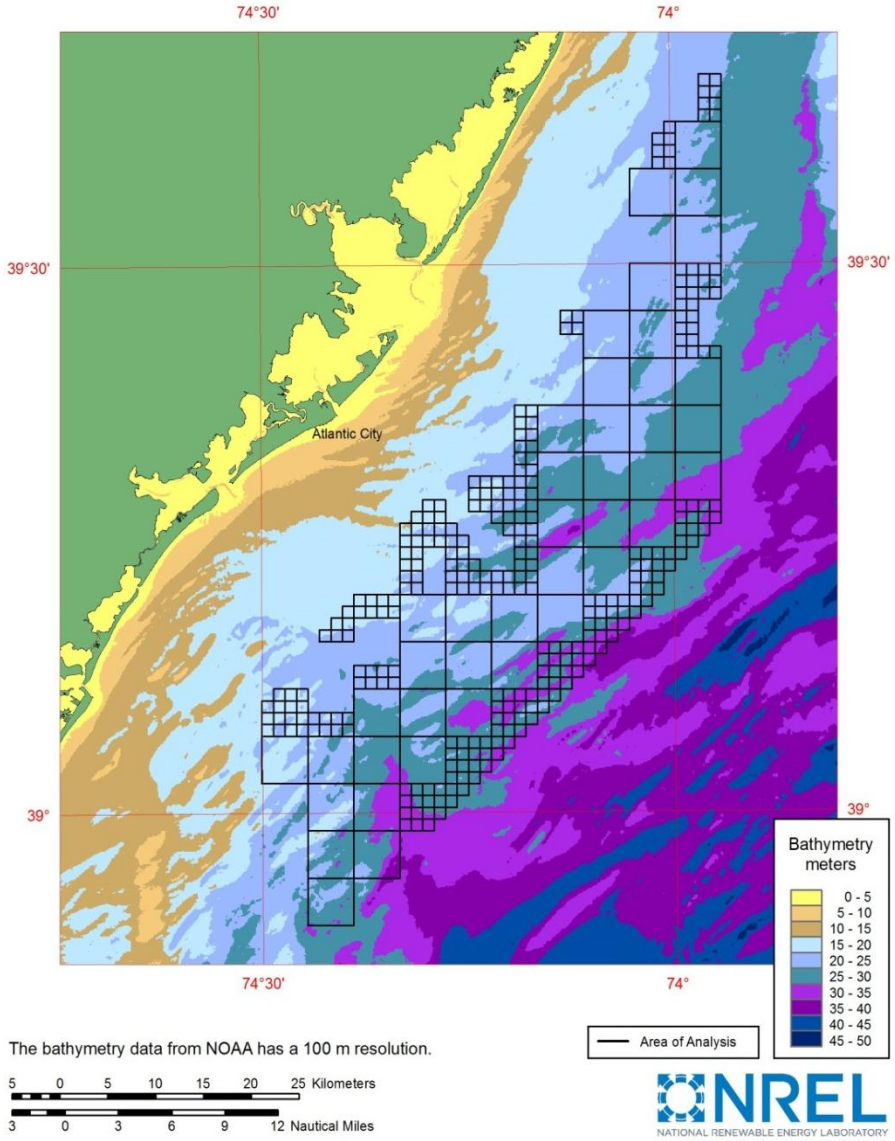
Three Delineation Options for NJ Area of Analysis

Water Depth for NJ Area of Analysis

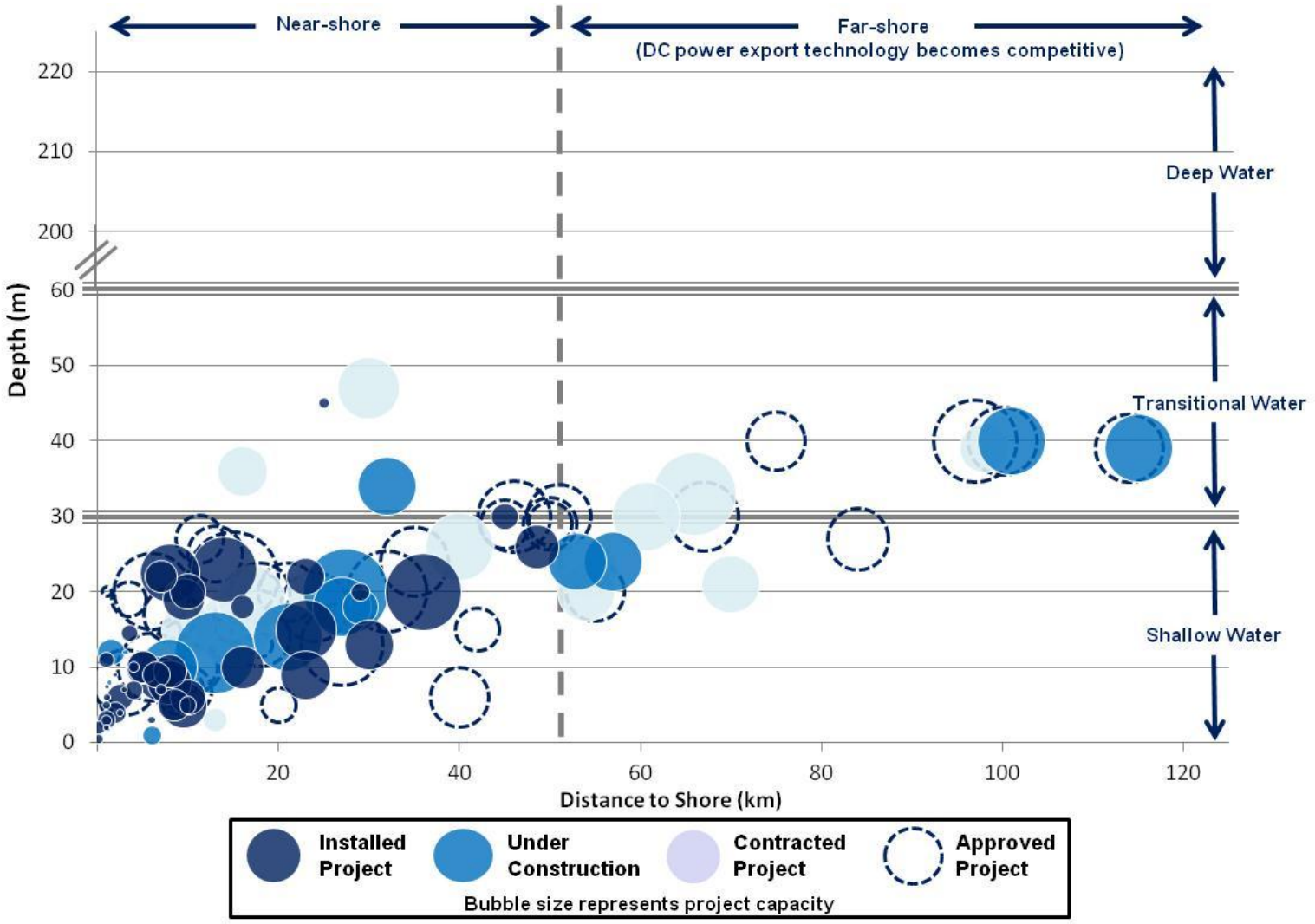


Bathymetry Chart for NJ Area of Analysis
(source NREL)

NJ Area of Analysis Depth Observations:

- Percentage of deep water above 30 m (purple shaded) represents less than 10% of the total area in most of the NJ leasing areas
- Generally, the NJ Area of Analysis is shallow enough to support large projects in all leasing areas without adding excessive development cost

Installed, Under Construction, and Planned Offshore Wind Projects



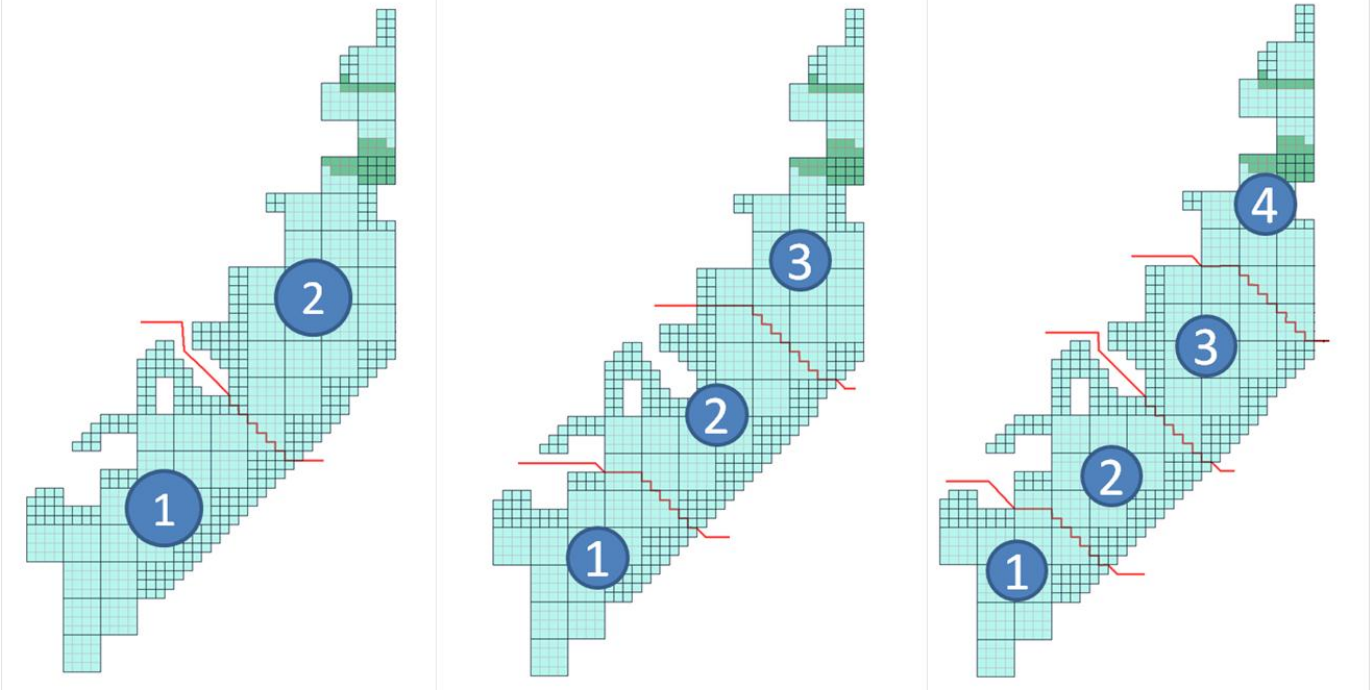
Depth of most offshore wind projects is less than 30 m

Depths for New Jersey Analysis Area

Data Source : NREL

10D x 12D Spacing

	Two Leasing area Delineation (MW)		Three Leasing area Delineation (MW)			Four Leasing area Delineation (MW)			
DEPTH m	Zone 1	Zone 2	Zone 1	Zone 2	Zone 3	Zone 1	Zone 2	Zone 3	Zone 4
0-15m	0	0	0	0	0	0	0	0	0
15-20m	325	145	130	265	90	135	220	75	60
20-25m	625	940	310	450	675	195	300	340	495
25-30m	550	580	415	355	260	250	240	410	130
30-35m	155	115	85	115	50	70	90	65	5
35-40m	5	0	5	0	0	15	0	0	0
TOTAL (MW)	1660	1780	945	1185	1075	665	850	890	690



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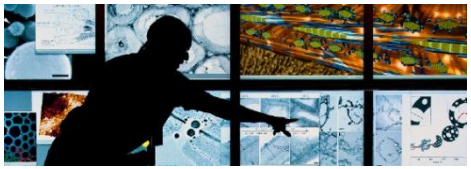


New Jersey Area of Analysis: Wake Loss and Energy Analysis

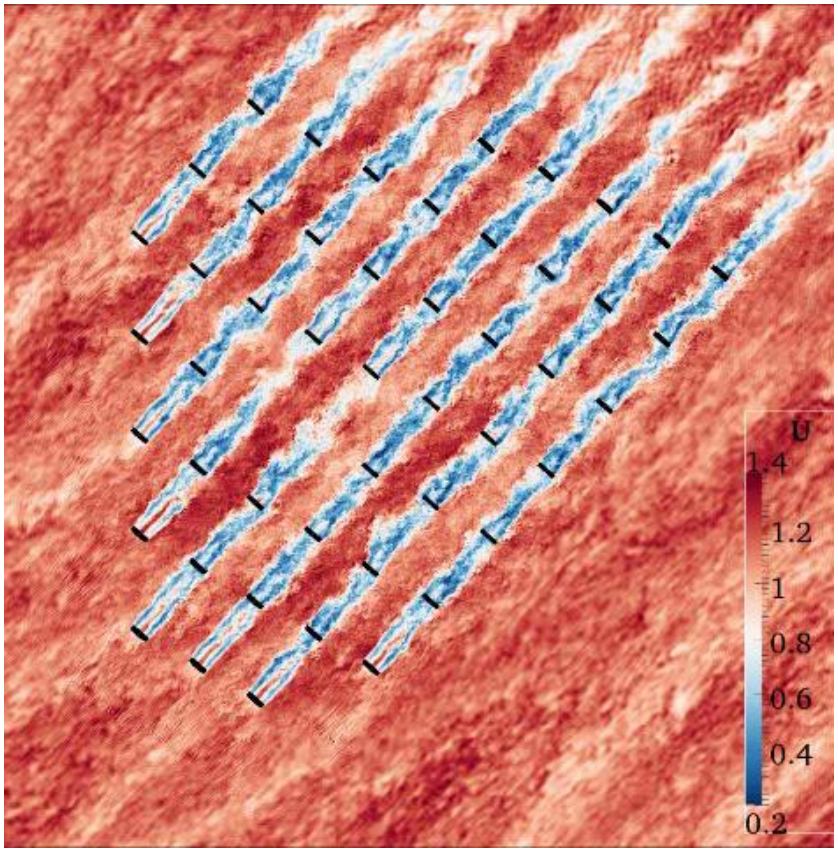
Wind Plant Design Should Consider Wake Effects

Horns Rev I Offshore Wind Plant

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

Wake Losses and Inter-project Buffers - Background

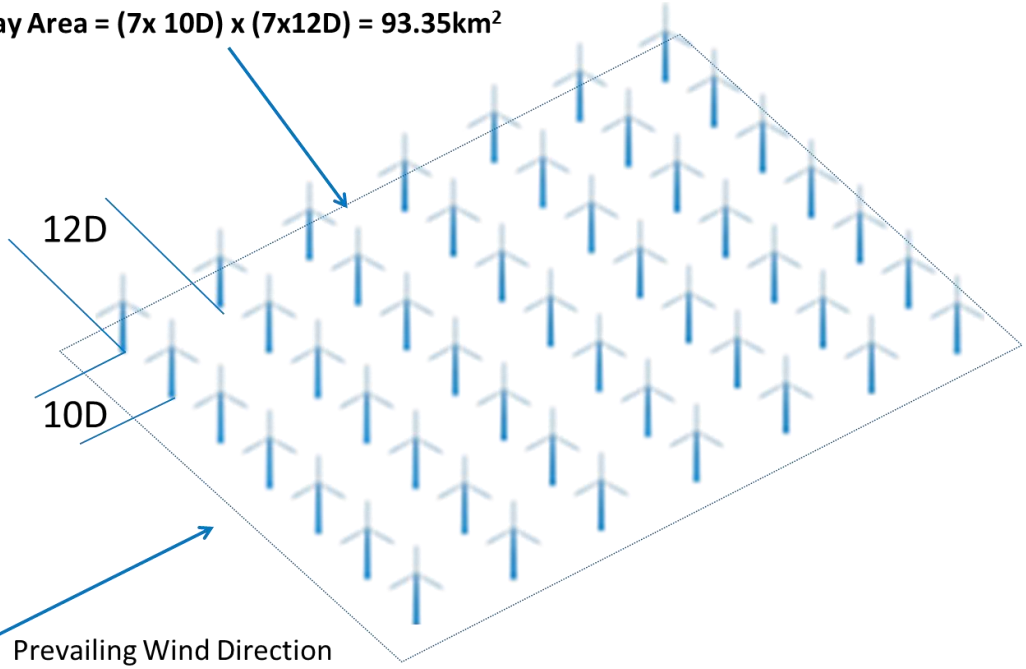
- Wind turbines wakes have lower available energy, higher turbulence, and are replenished by natural atmospheric mixing
- Larger scale atmospheric stability conditions dominate the rate of mixing and replenishment
- Stable atmospheres are stratified and allow wake turbulence to persist farther downstream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



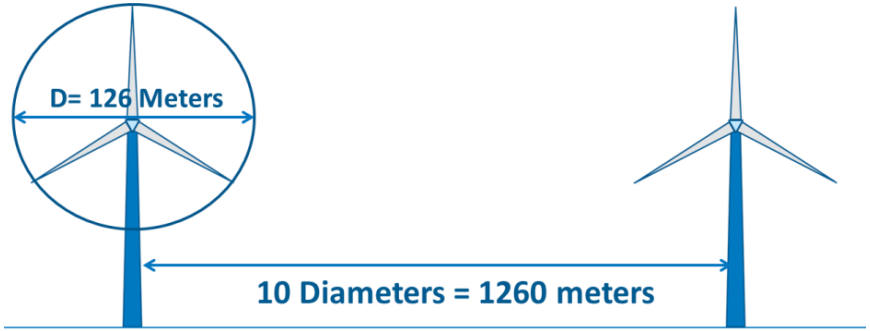
Simulator for Wind Farm Applications showing turbine wake effects (Source: NREL)

Array Spacing Definition

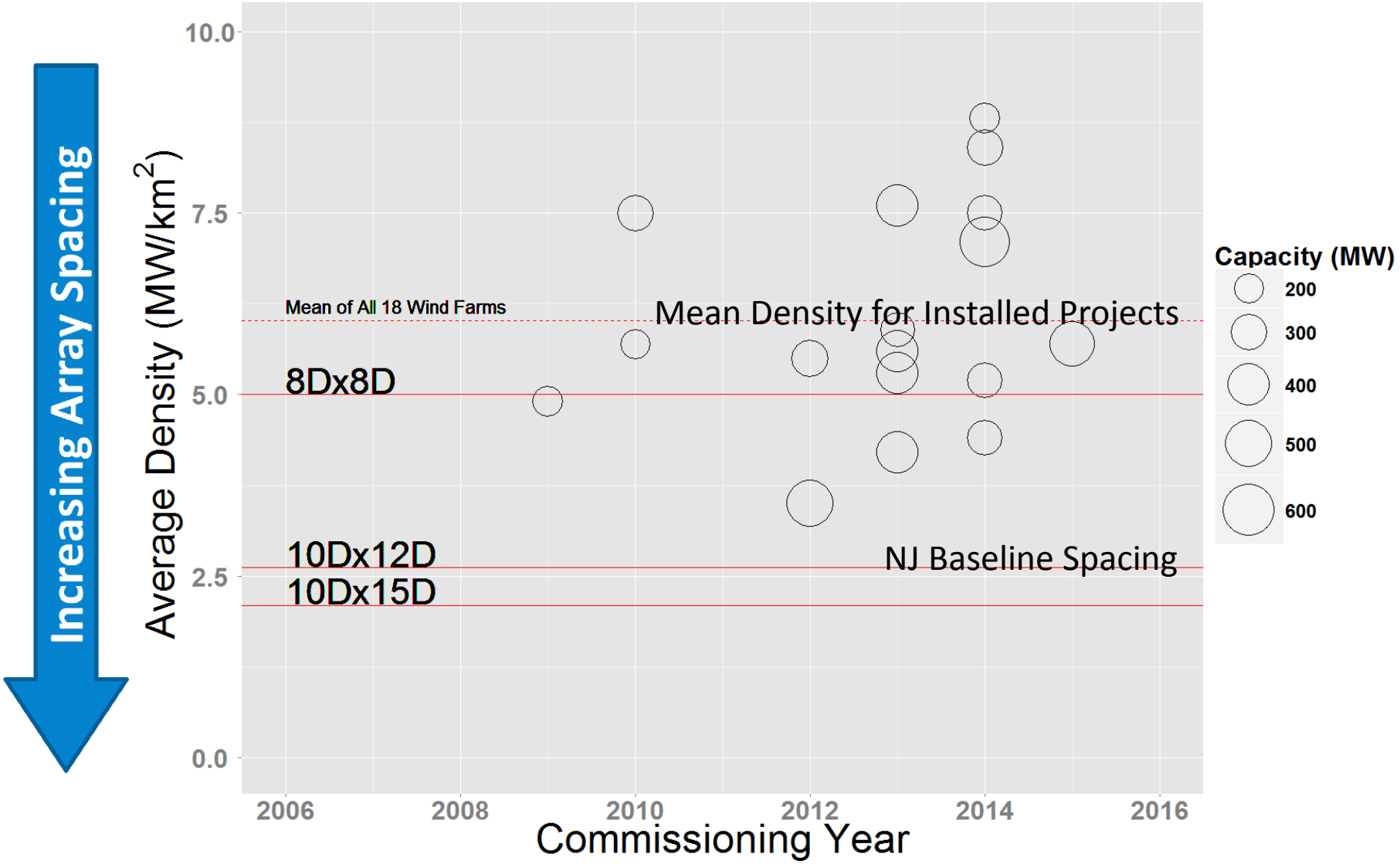
Example: Single Wind Plant with 10D x 12D spacing



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

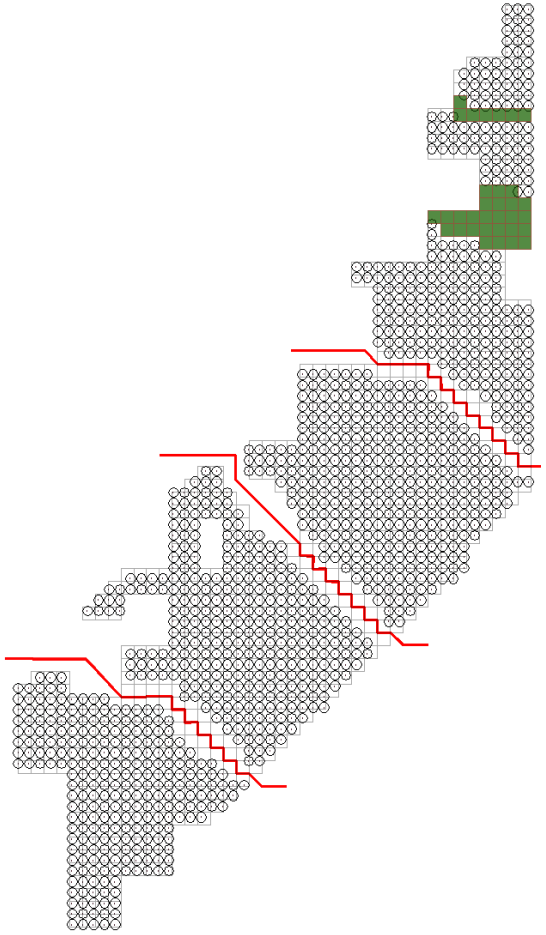


Industry Array Spacing: Installed Projects over 200MW



Description of openWind® Enterprise Program

- Wind power facility design software program
- Open source software with NREL licensed options for deep array wake losses and other features
- GIS based architecture
  - GIS file compatibility
  - Spatial logic with hierarchical structure
- Energy computations using typical wind plant design practices
- Energy and wake effects were studied with openWind.
- Default to deep array offshore wake model for higher fidelity

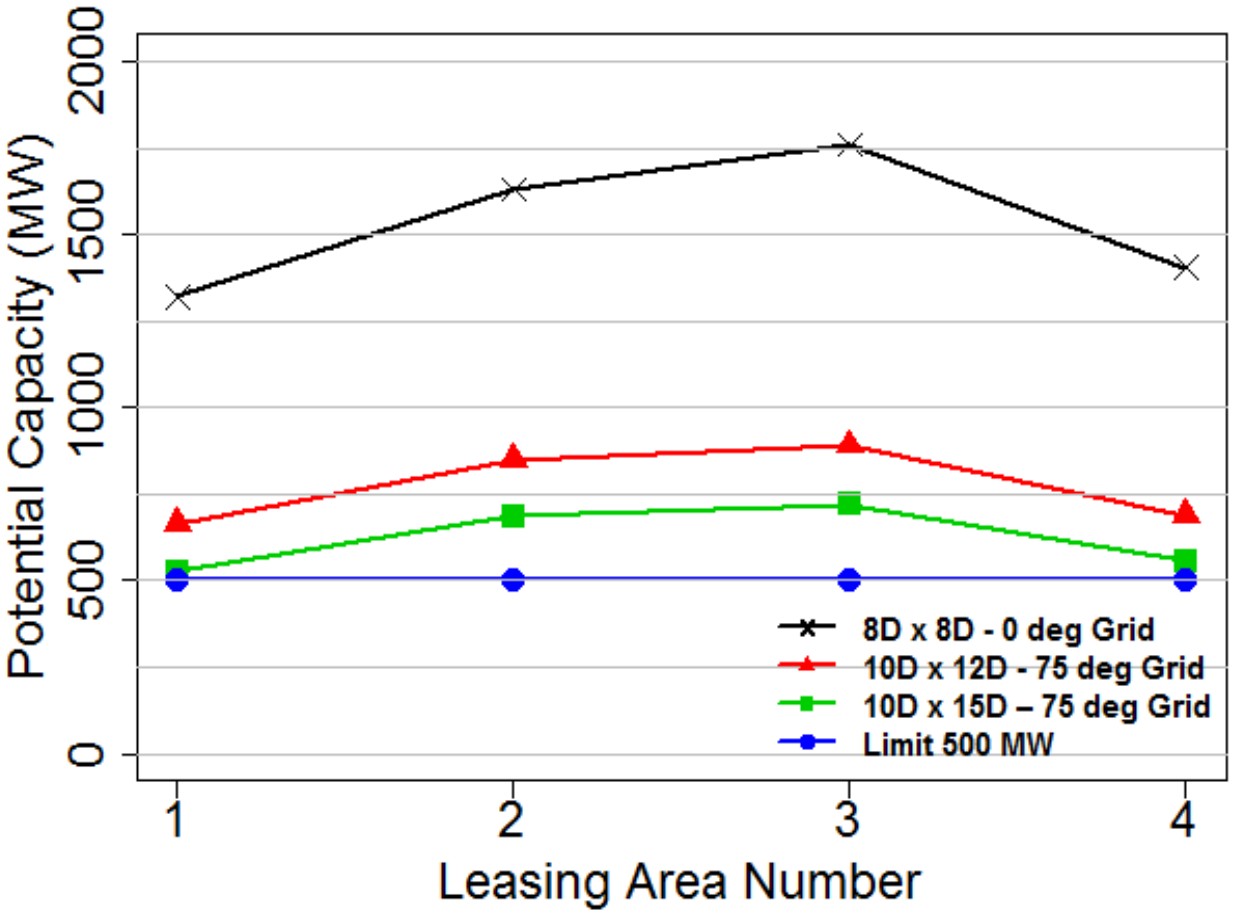


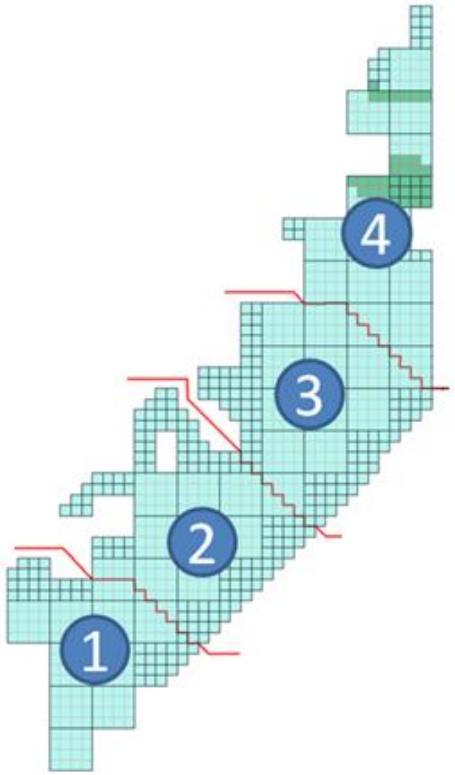
Example: openWind Enterprise Tool arranges turbines inside the New Jersey Area of Analysis and computes energy, wake losses and power performance – 8D x 8D Spacing and 0 degree orientation angle (Source NREL)

Array Spacing: NJ Analysis Scenarios

Scenario	Array Spacing	Turbine Array Density (MW/km^2)	Full Build	500 MW Limit
Nominal Industry Average	**8 D x 8 D**	5.08	✓	✓
New Jersey Baseline	**10 D x 12 D**	2.62	✓	✓
New Jersey Wide Spacing	**10 D x 15 D**	2.09	✓	
New Jersey "Call" Average	**10 D x 11 D**	2.86		

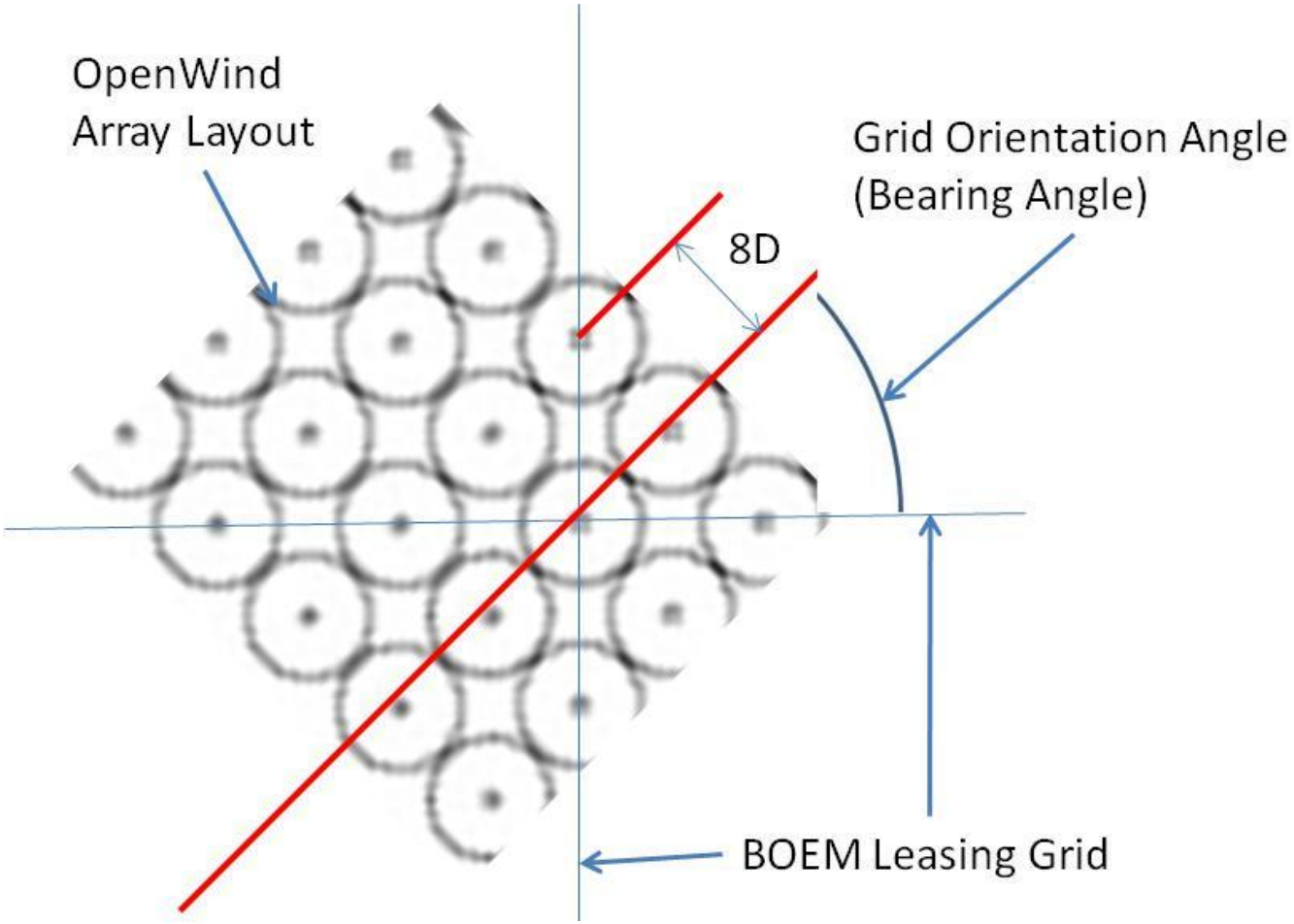
Development Potential Decreases with Increased Turbine Spacing





Maximum development potential for the four leasing area delineation strategy of the New Jersey area of analysis with three different turbine spacing options and the 500 MW limit (Source: NREL)

BOEM leasing grid is the reference frame for the grid orientation angle

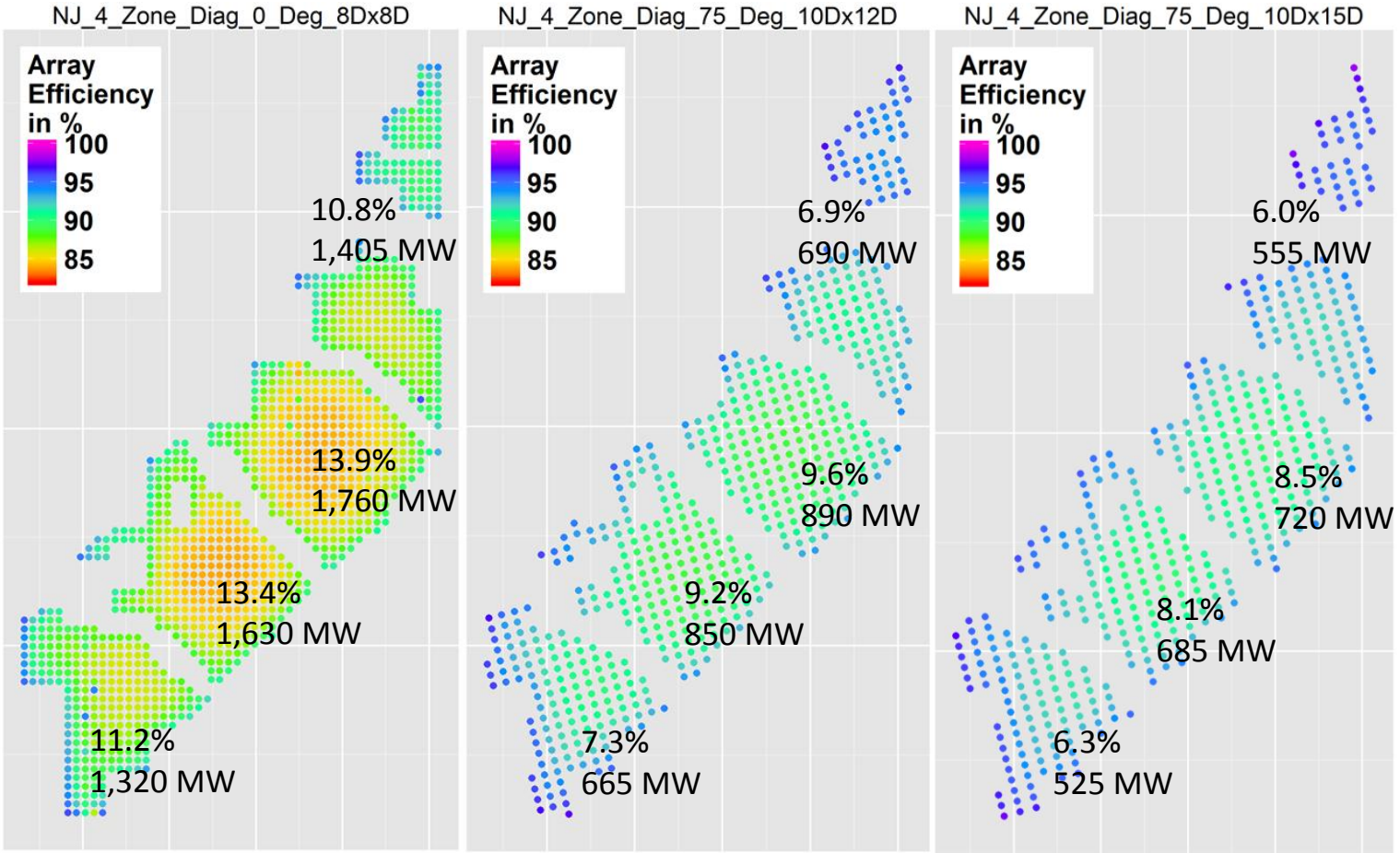


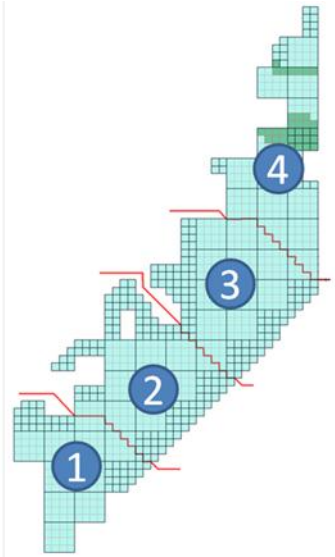
Open Wind Output Example with 8D x 8D spacing

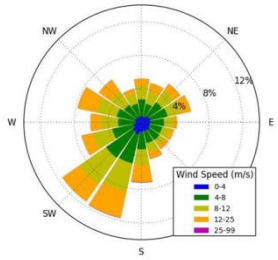
Wake Losses Were Insensitive to Grid Orientation Angle: < 0.1%

Array Efficiency for Three Spacing Scenarios

Four Leasing Area Delineation







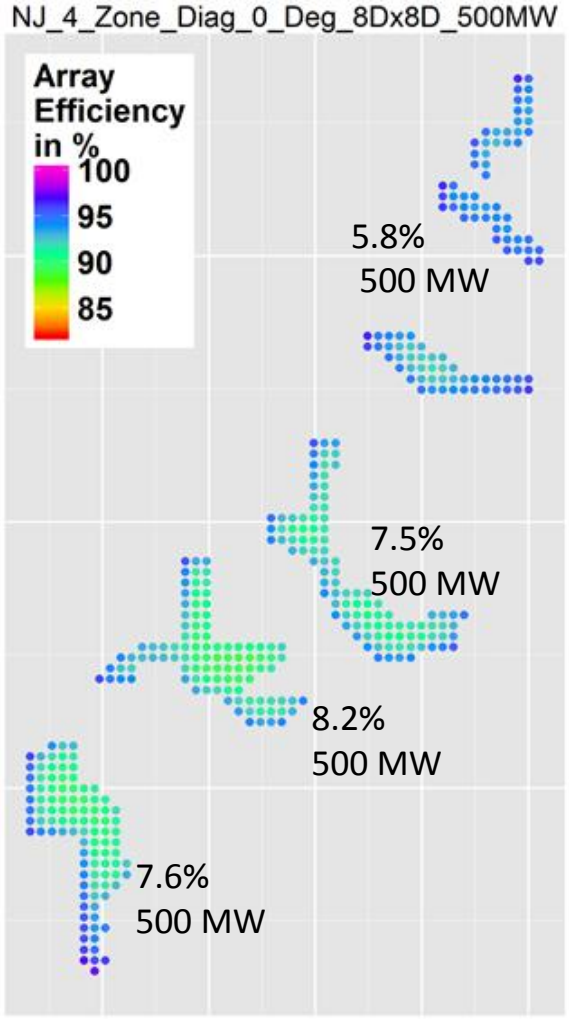
8D x 8D **10D x 12D** **10D x 15D**

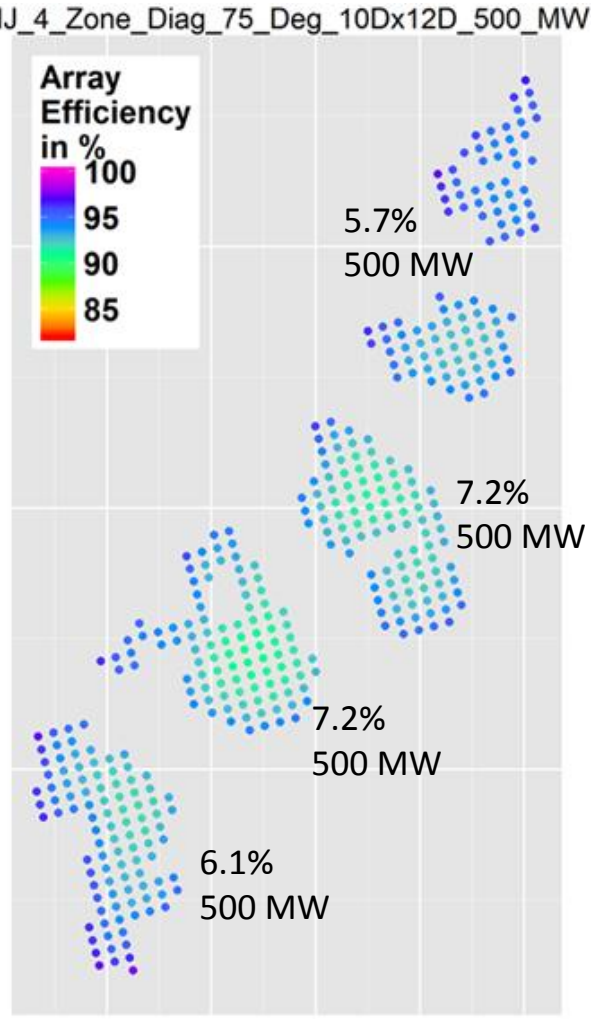
Array losses shown as percent decrease from ideal energy Production capacity based on full build-out

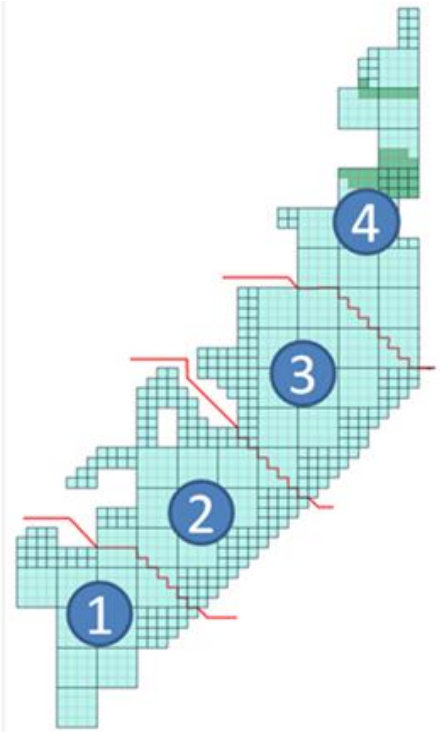
(Source NREL)

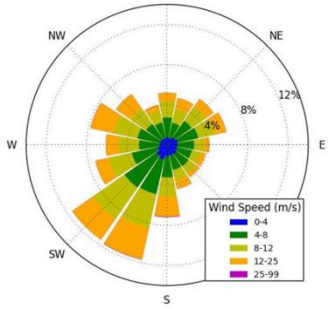
Array Efficiency for 500 MW Project Size Limit

Two Spacing Scenarios - Four Leasing Area Delineation





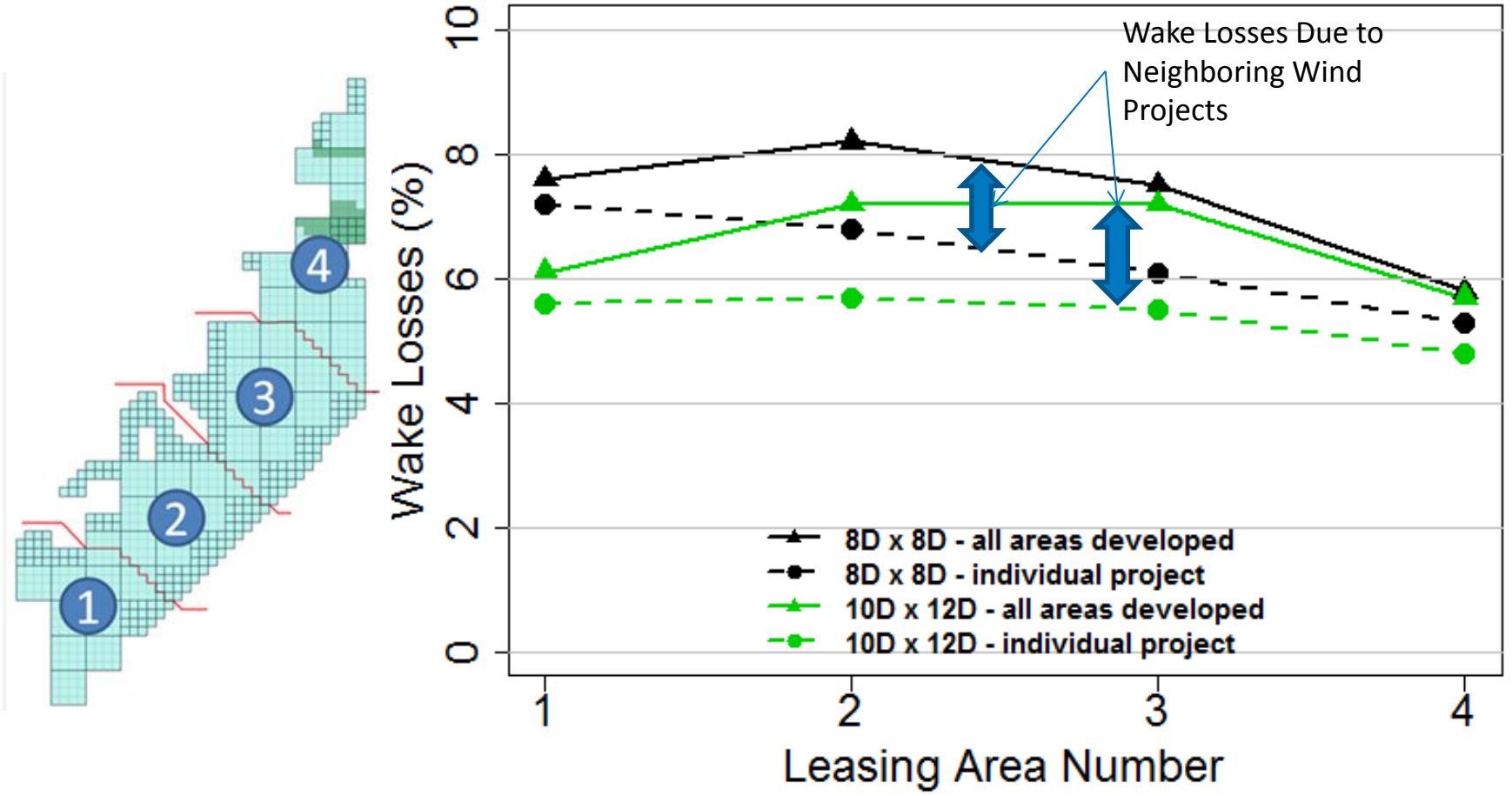




8D x 8D

10D x 12D

External Array Losses Less than 25%



Comparison of wake losses for individual versus full development of 500-MW projects with 8 D x 8 D and 10 D x 12 D spacing. The wake losses with all four leasing areas developed are contrasted to the wake losses without the neighboring leasing areas developed

(Source: NREL)

Wake and Array Loss Observations

- Internal deep array losses dominate for all grid orientations
- Grid orientation angle plays a small role (+/- 0.1%) in wake losses compared to other parameters such as spacing and buffers
- Full build array losses range from 10.8% to 13.9% for the 8D x 8D spacing to 6.0% to 8.5% for the 10D x 15D spacing
- Most wake losses originate in the local array but a significant fraction originate in neighboring arrays
- Deep array losses can exceed 20% for interior turbines with 8D spacing
- Middle (inside) lease areas have 2.5% to 3% higher array losses which are mitigated by larger areas
- Wake losses from neighboring wind plants can contribute 25% additional array losses for 500 MW wind plant scenario

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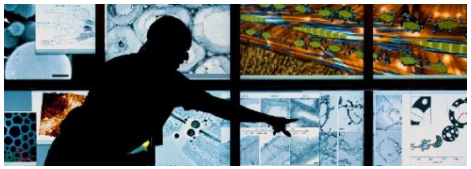

Summary and Recommendations

Summary

- Diagonal delineations proved to be the most efficient strategy for dividing the NJ area of analysis because they resulted in the shortest delineation boundaries which maximized the developable area.
- Average annual wind speed for the NJ area of analysis ranged from 8.4 m/s to 8.6 m/s in all leasing areas assessed. This corresponds to a small range of gross capacity factors between 45.4% and 47.0%.
- The maximum capacity of the NJ area of analysis, using 10 D x 12 D spacing was found to be between 3,100 MW and 3,400 MW.
- The NJ area of analysis can support four leasing areas with at least 500 MW per area.
- Bathymetry of the NJ area of analysis is shallow enough in all leasing areas, with most leasing areas having over 90% of the depths less than 30 meters.
- Higher potential wake losses in the middle leasing areas were compensated for by adding additional area to allow for greater flexibility when placing internal buffers.

Summary Continued

- Total losses from wake effects (10 D x 12 D spacing, four leasing areas) decreased from 7% to 10% to 5% to 7% for 500 MW projects.
- The grid orientation angle no significant impact on array efficiency (~0.1%).
- Wake losses increased with decreasing turbine spacing. With a full build of four leasing areas, wake losses averaged 6.0% to 8.5% for 10D x 15D spacing, 6.9% to 9.6% for 10D x 12D spacing, and 10.8% to 13.9% for 8D x 8D spacing. For all spacing scenarios, the highest wake losses were in the middle areas.
- If the projects are limited to 500 MW each in four leasing areas, wake losses are significantly reduced. The average wake losses for the area of analysis are 6.6% for 10D x 12D spacing and 7.3% for 8D x 8D spacing. However, the area required for an 8D x 8D project is only about half that for a 10D x 12D project.
- Wake losses from neighboring wind projects within the NJ area of analysis were less than 30% of the total array losses. Most wake losses are generated internally to a given project.

Recommendations and Disclaimers

- The four leasing area option provides the best development potential with four commercial-scale projects.
- More leasing areas provide greater diversity of developers with higher potential for concurrent development of the entire WEA.
- The wake analysis in this report is coarse by industry standards and prospective lessees should investigate wake losses more rigorously before judging the values of these leasing areas. An enhanced analysis should consider diurnal, seasonal, and annual variations as well as a full cost assessment to examine the additional cost due to added cable length. In addition, further analysis on wake losses with respect to atmospheric stability conditions is recommended.
- This report does not attempt to account for New Jersey offshore wind legislation and initiatives.

Acknowledgements

- Authors: Walt Musial, Dennis Elliott, Jason Fields, Zach Parker, George Scott, and Caroline Draxl
- Peer Reviewers and contributors: Sheri Anstedt, Ian Baring-Gould, Fort Felker, Robert Hawsey, Pat Moriarty, Brian Smith, and Suzanne Tegen
- Bureau of Ocean Energy Management (BOEM)
- New Jersey Board of Public Utilities
- BOEM New Jersey Renewable Energy Task Force

Thank you for your attention!

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

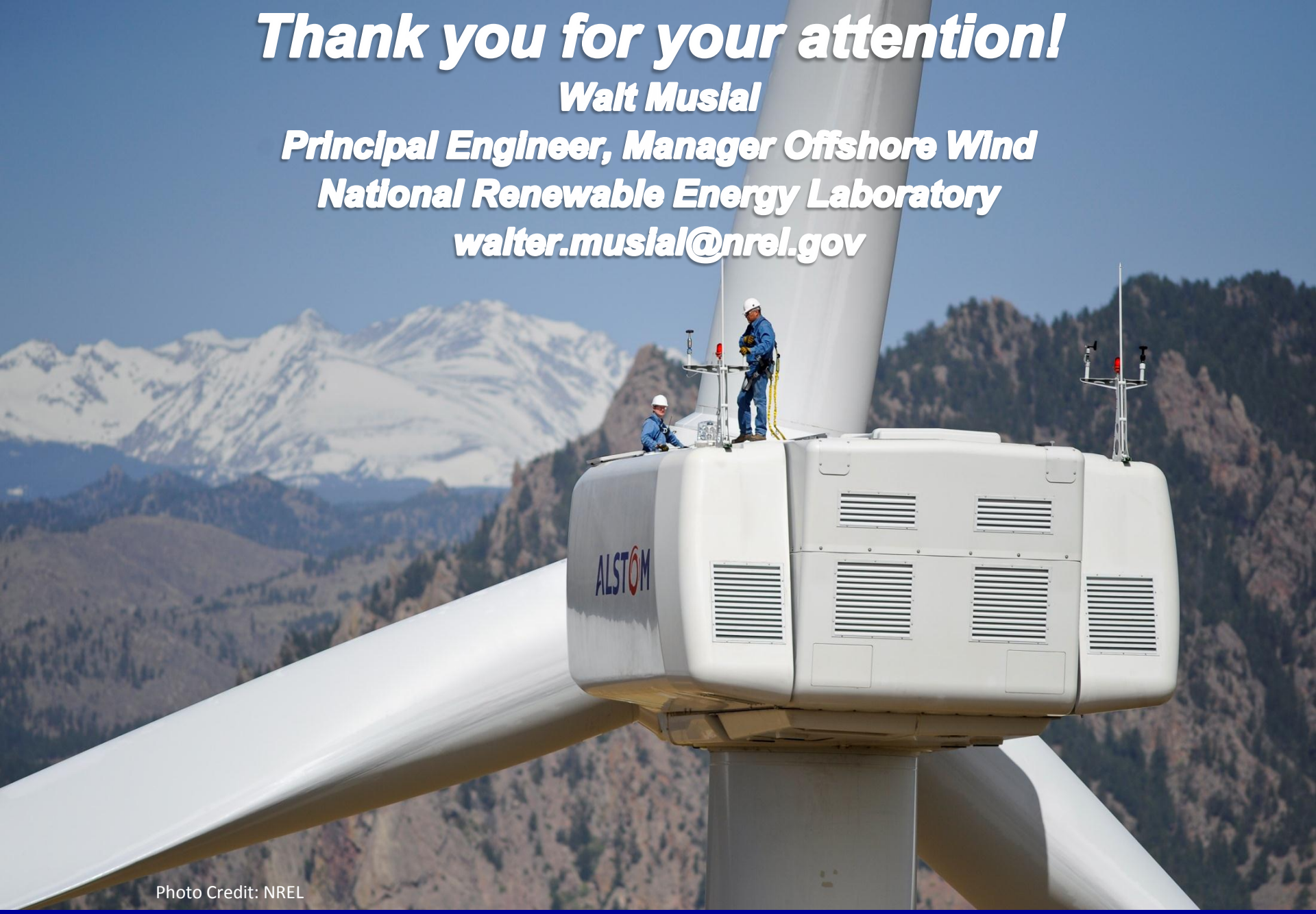

Photo Credit: NREL