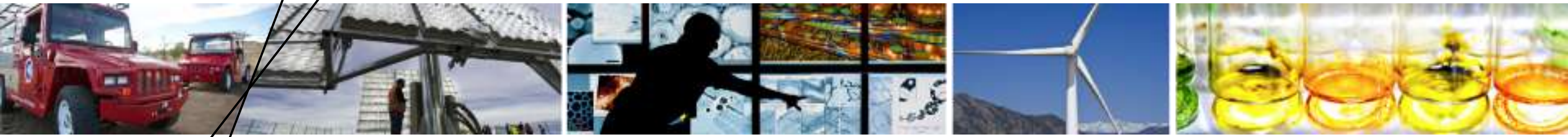
Final Presentation to Maryland Renewable Energy Task Force on WEA Leasing Area Delineation Studies



Webinar Sponsored by Bureau of Ocean Energy Management

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Manager Offshore Wind and Ocean Power Systems

June 27, 2013

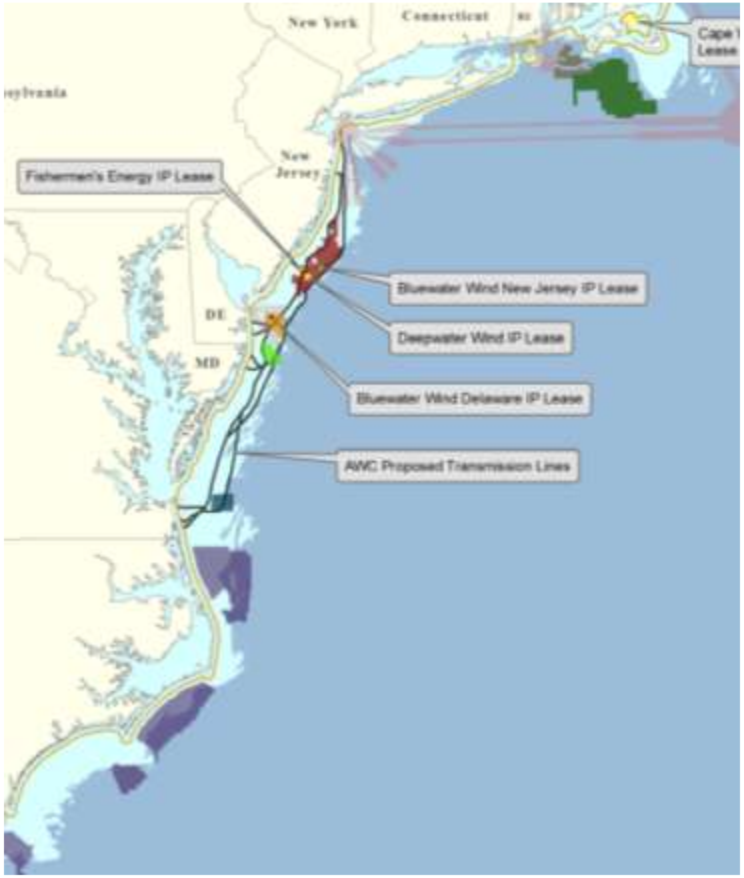
NREL Presentation Contents

- Technical background
- Project Scope and parameters
- Results of analysis
- Summary and recommendations
- Question and answers

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)
- NREL is providing technical input to help inform delineation of leasing areas within four BOEM Wind Energy Areas(WEA)
- NREL evaluated Maryland's wind energy area and will make recommendations to BOEM on options to delineate the area into two leasing areas
- Focus was on wind resource, energy potential, bathymetry and development challenges to to produce approximately equal development zones



BOEM Wind Energy Planning Areas

Project Objectives:

- To evaluate the Maryland Energy Administration (MEA) delineation of the MD WEA and determine if it is technically sound.
- To provide options to MEA's recommendation for the MD WEA.
- To assess two alternative WEAs (one proposed by BOEM and one proposed by the U.S. Coast Guard (USCG)) to address concerns from the USCG about potential conflicts with navigation.

NREL's Tasks for Maryland for BOEM Interagency Agreement

- Reviewed nominations from RFI (Nov 2010) and Call (Feb 2012)
- Assessed MEA methodology for delineating WEA into equitable leasing areas and provide other options
- Presented methodology to Maryland Renewable Energy Task Force (Jan 29, 2013)
- Conducted independent analysis on MD WEA and Alternatives
- Submited draft report (May 2, 2013)
- Published final report (June 25, 2013)

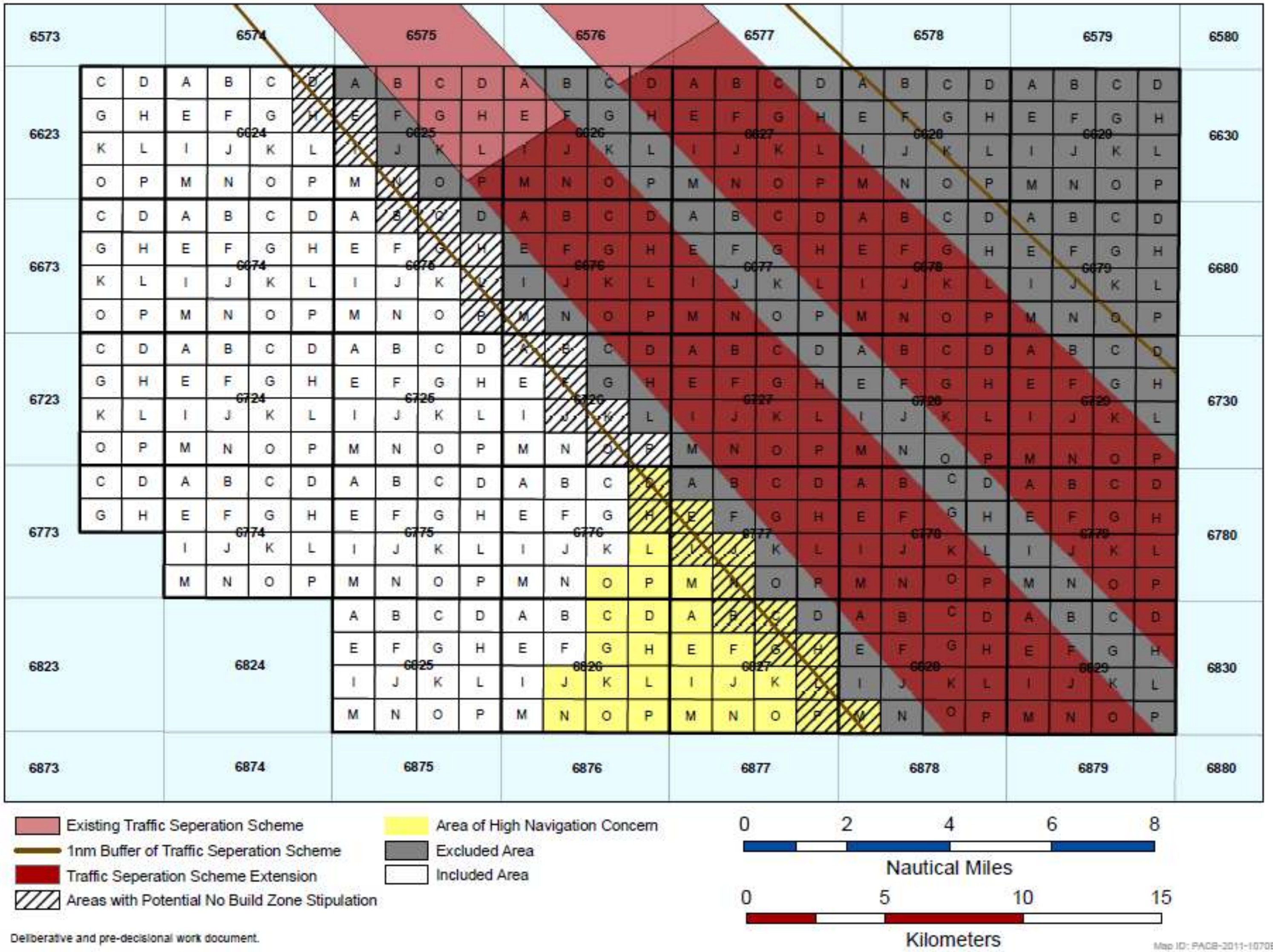
Assumptions for MD Leasing Area Delineation

- Investigate options for 2 leasing areas
- Baseline turbine size – 5-MW (126-m rotor NREL Reference)
- Total area is 79,706 acres (312 km^2)
- Baseline array spacing 8D x 8D as used for resource assessment at NREL (5 MW/km^2)
- Lower array densities: (8D x 12D) were examined
- 8D setbacks between leasing areas are assumed
- No surface occupancy east of TSS setback

REpower 5M Alpha Ventus - Germany

Photo Credit: Gary Norton

Maryland WEA With The Traffic Separation Scheme (TSS) Building Restriction Setback (Source: Walters And Benard 2013)



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General Process for Maryland

1. Review of the State of Maryland's Zone Delineation Recommendation
2. Develop methodology for delineation of MD WEA and present preliminary methodology at meeting Jan 29
3. Read and process RFI responses and Call nominations to gather data on ecological, conflicting use, and development strategies
4. Perform independent analysis on 2 leasing areas delineation options using openWind® Enterprise Program
5. Perform sensitivity analysis on turbine spacing options
6. Repeat analysis for two alternative WEAs
7. Write and publish final report
8. Present findings and analysis to BOEM MD Intergovernmental Task Force

Criteria Used by NREL to Assess MD WEA

Quantitative Evaluation Criteria	Qualitative Evaluation Criteria Considered
Total area [square kilometers (km^2) and acres]	Distance from shore
Potential installed capacity [megawatts (MW)]	Fisheries and competing uses
Bathymetry [meters (m)]	Technology challenges
Annual average wind speed [meters per second (m/s)]	Development cost
Gross capacity factor (%)	
Wake losses (%)	
Annual energy production [gigawatt-hours (GWh)]	
Navigational impacts on WEA	

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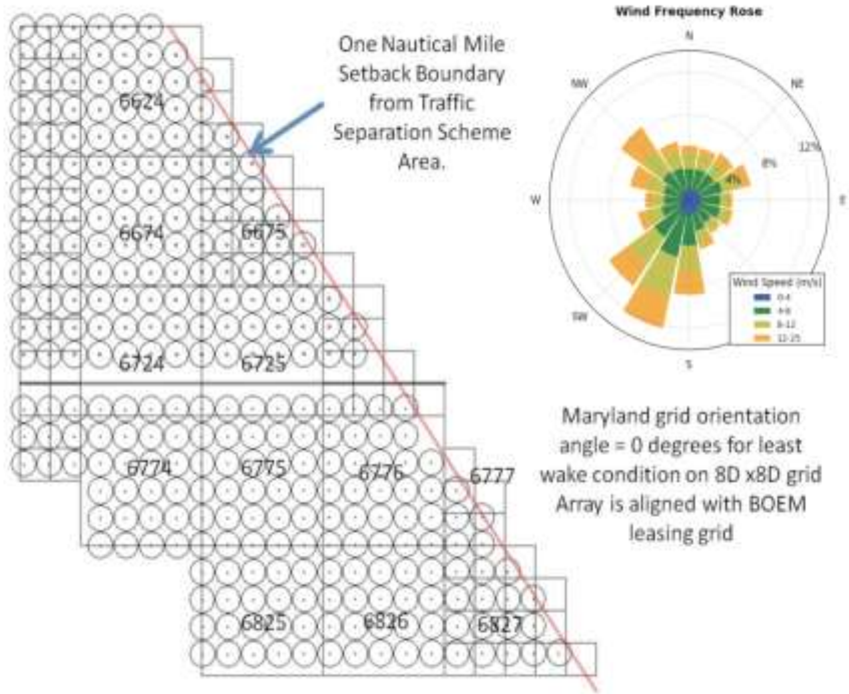
Description of openWind® Enterprise Program

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



Example: OpenWind Enterprise Tool arranges turbines inside Maryland WEA and computes energy, wake losses and power performance (Source NREL)

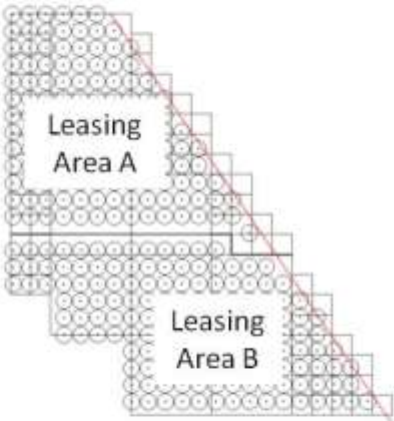
WRG/WRB Wind Data Source for MD WEA Evaluations

- WRG/WRB data was developed by AWS Truepower
- MASS mesoscale modeled data at a grid resolution of 20km and scaled to 200m grid resolution using WindMap (based on NOABL model)
- WRG/WRB wind data provide highest resolution data with long term records (14 years) of wind speed and direction
- Accuracy was validated against local Met towers, surface NOAA buoys and REEMA data from NASA

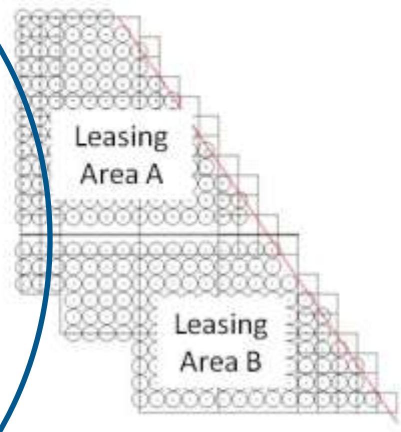
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Results of MD WEA Analysis and Discussion

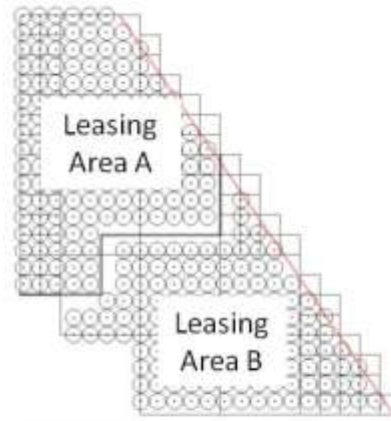
Delineation and WEA Options Investigated



MEA Delineation

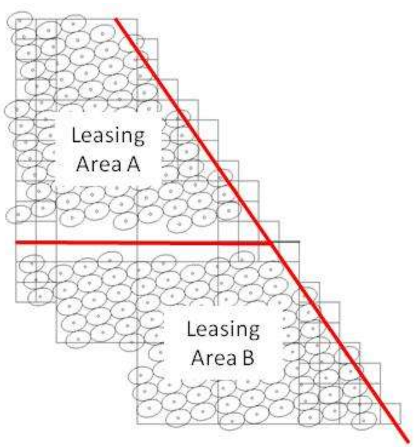


NREL Preferred

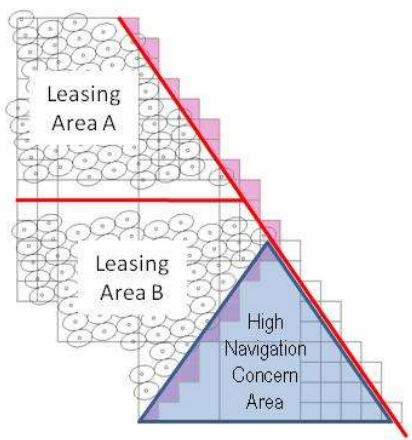


NREL Diagonal

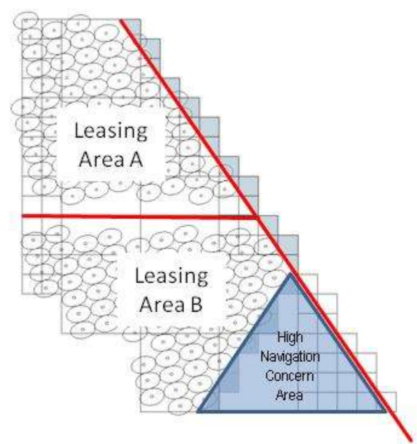
Three Delineation Options



NREL Preferred MD Delineation



Alternative WEA 1



Alternative WEA 2

Three Wind Area Options

Results of Delineation Analysis for MD WEA

Parameter	Proposed MEA Delineation Leasing Area A	Proposed MEA Delineation Leasing Area B	NREL Preferred Delineation Leasing Area A	NREL Preferred Delineation Leasing Area B	NREL Diagonal Delineation Leasing Area A	NREL Diagonal Delineation Leasing Area B
Total area (km²)	155.52	167.04	151.2	171.36	156.96	165.6
Total area (1,000 acres)	38,430	41,276	37,362	42,344	38,786	40,921
Average depth (m)	23	26	23	26	22	27
Bathymetry – depth range (m)	16–29	14–37	16–29	14–37	14–28	17–37
Average wind speed at 90 m (m/s)	8.2	8.3	8.2	8.3	8.2	8.3
8D x 8D - 0 Degree Grid Orientation						
Wake losses (%)	17	16	17	16	17	16
Gross capacity factor (CF) (%)	44	44	44	44	44	44
Gross CF after wake losses (%)	36	37	36	37	36	37
Potential capacity (MW)	675	745	670	760	745	680
Annual energy production (GWh)	2,140	2,407	2,123	2,454	2,372	2,190
8D x 12D - 75 Degree Grid Orientation						
Wake losses (%)	13	12	13	12	12	12
Gross capacity factor (CF) (%)	44	44	44	44	44	44
Gross CF after wake losses (%)	38	39	38	39	38	39
Potential capacity (MW)	405	460	400	475	425	435
Annual energy production (GWh)	1,353	1,559	1,336	1,607	1,427	1,470

Maryland Wind Energy Area – Maryland Energy Administration Delineation Proposal

MEA Delineation of MD WEA

Gohn, A. (2012). Internal memorandum. "Maryland Wind Energy Area Zone Recommendation." September 13, 2012

Key Criteria

- **Wind speed**
- **Prevailing wind direction**
- **Bathymetry**
- **Distance to shore**
- **Transmission requirements**
- **Shipping lanes and potential USCG requirements**
- **Interproject wake effects and potential buffer requirement**
- **Fisheries use**
- **Military use**
- **Additional stakeholder considerations.**

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Assessment of MEA WEA Delineation Proposal

- **MD WEA was logical in terms of achieving economic parity between the two leasing areas**
- **Key criteria were inclusive and considered a wide range of stakeholder inputs – beyond NREL's scope**
- **Bathymetry may not have been adequately weighted**

Summary of Input From RFI and Call

Summary of Nomination Statistics from Nine BOEM Maryland (MD) Wind Energy Area (WEA) Request for Interest (RFI) Responses (Nov 2010)

	Average	Maximum	Minimum	NREL Values
Project nameplate capacity [megawatts (MW)]	865	1,500	285	875–1,430
Turbine nameplate capacity (MW)	4.43	6	3	5
Average wind speed in meters per second (m/s) at 90 meters (m)	8.46	8.75	8.15	8.3
Net capacity factor (%)	36.68	40	33	36–39
Proposed project area (km^2)	363.45	708.48	74.88	322.5
Array spacing in rotor diameters (D)	7.5D x 11D	8D x 12D	5D x 10D	8D x 8D and 8D x 12D
Array power density (MW/km^2)	3.81	6.29	3.28	5.0 and 3.28
Number of turbines	209	328	57	175–286
Maximum depth (m) after traffic separation scheme (TSS) setback	36	48	30	37
Project development time frame (years)	6	7	5	N/A

Summary of Nomination Statistics from Six Responses to BOEM MD WEA Call (Feb 2012)

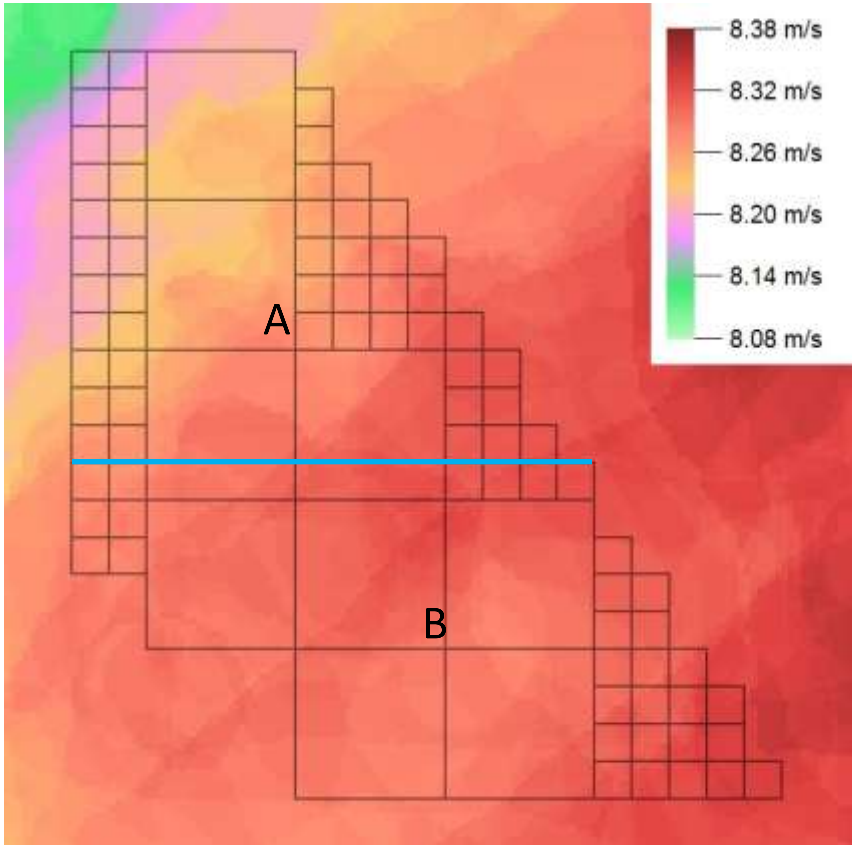
	Average	Maximum	Minimum	NREL Values
Project nameplate capacity (MW)	800	1,000	350	875–1,430
Proposed project area (km^2)	287.76	322.56	213.12	322.5
Array spacing (D)	N/A	N/A	N/A	8D x 8D and 8D x 12D
Array power density (MW/km^2)	2.78	3.10	1.64	5.0 and 3.28
Project development time frame (years)	6.33	7	5	N/A

February 3, 2012 http://www.boem.gov/Renewable-Energy-Program/State-Activities/Maryland.aspx

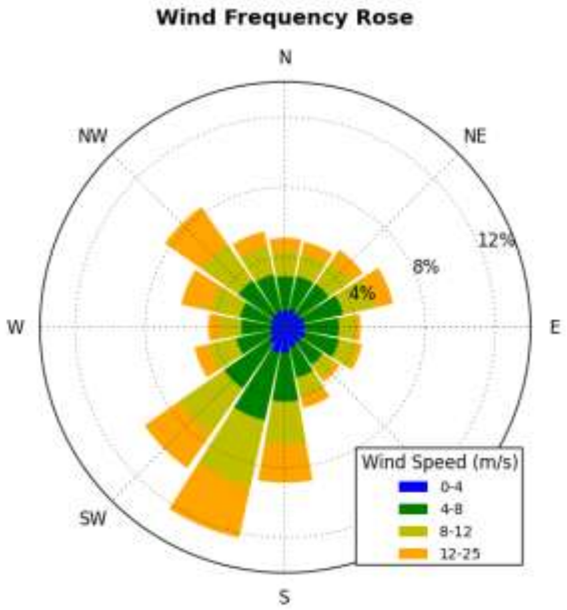
Maryland WEA Wind Resource

Average Annual Wind Speed = 8.3 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.

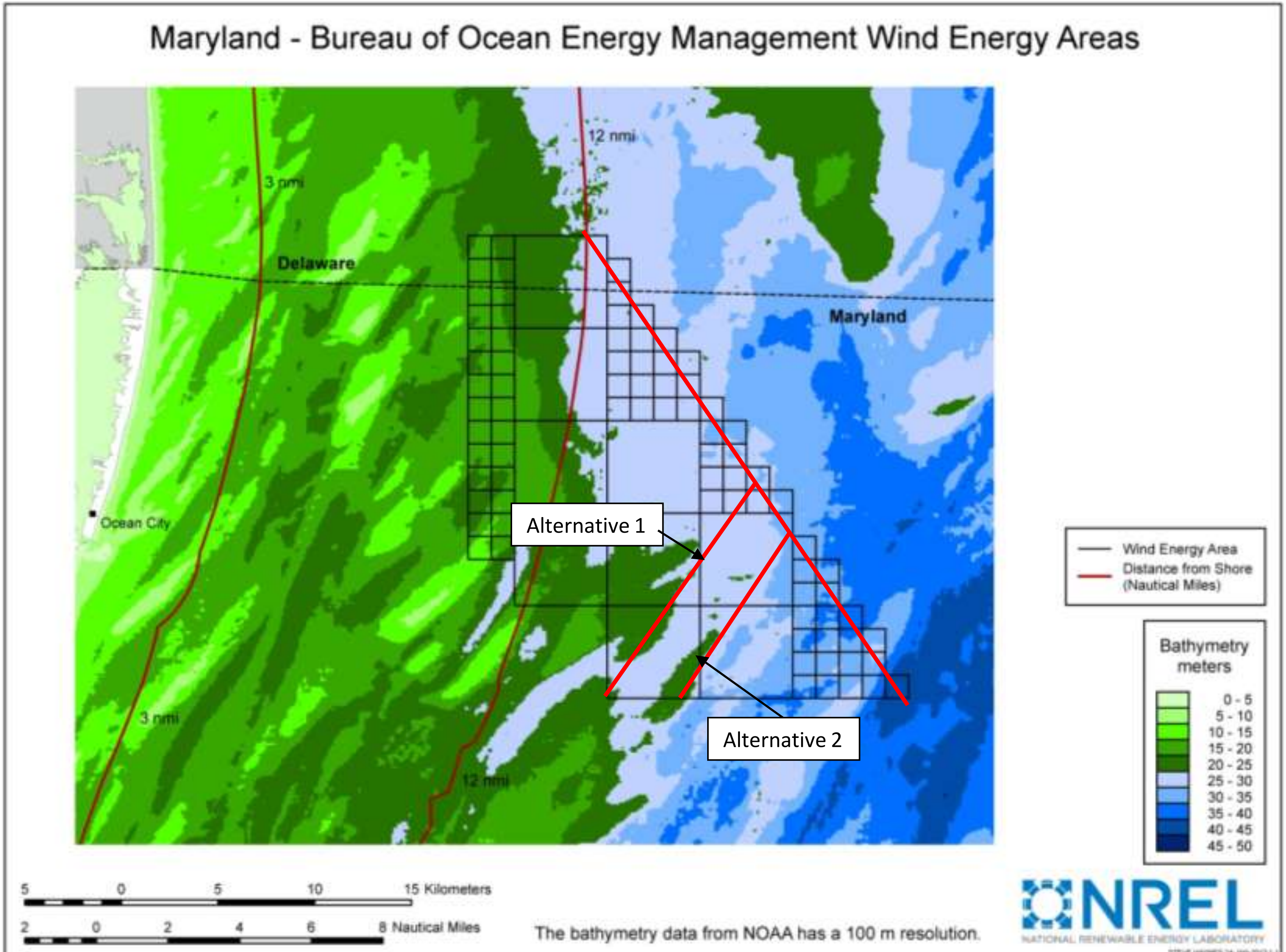


WEA showing annual average wind speed between 8.1 m/s and 8.3 m/s

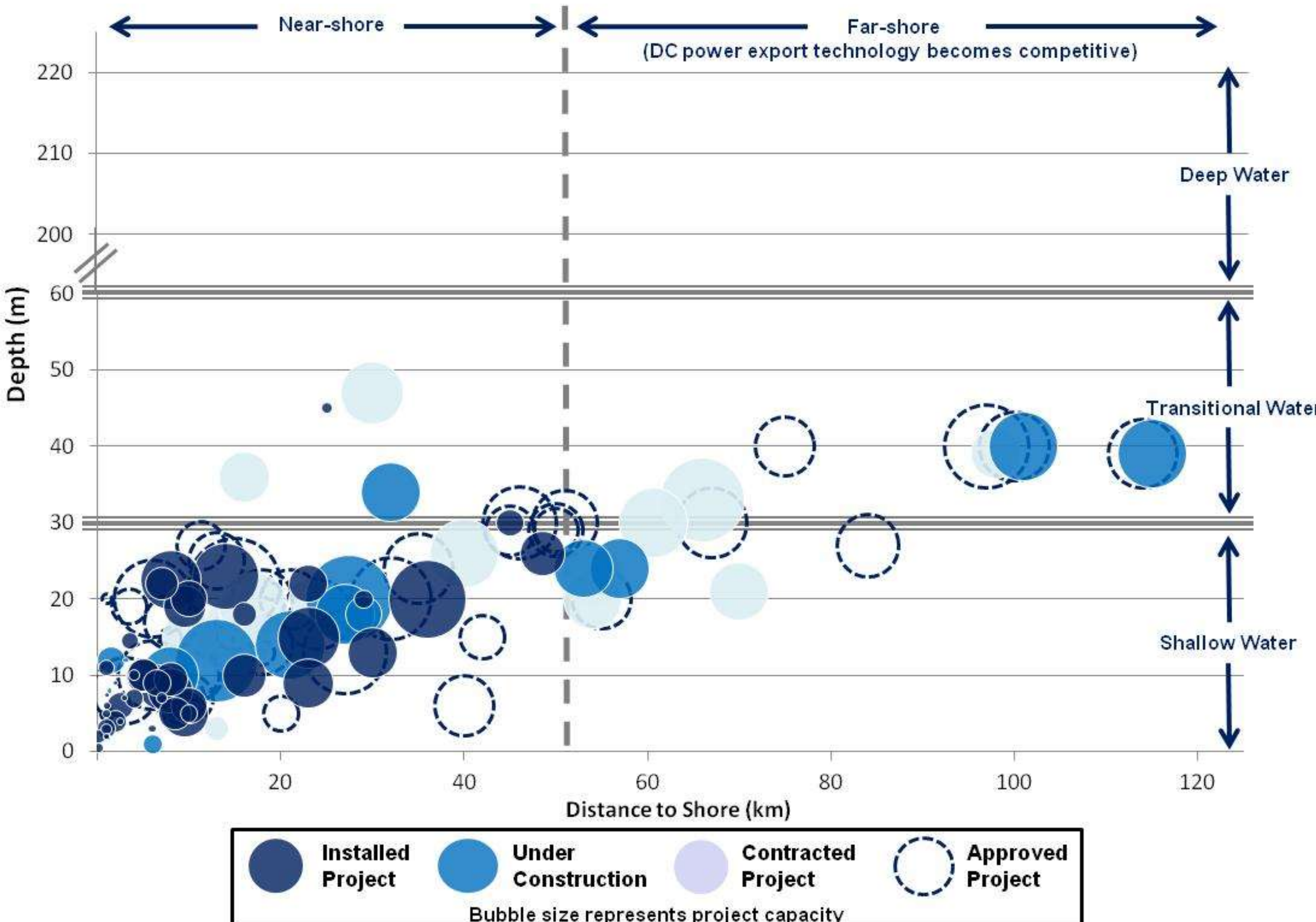


MD WEA annual average wind frequency rose with prevailing south southwest and northwest

Water Depth for MD WEA and Alternatives



Depth of Most Offshore Wind Projects is Less than 30 m



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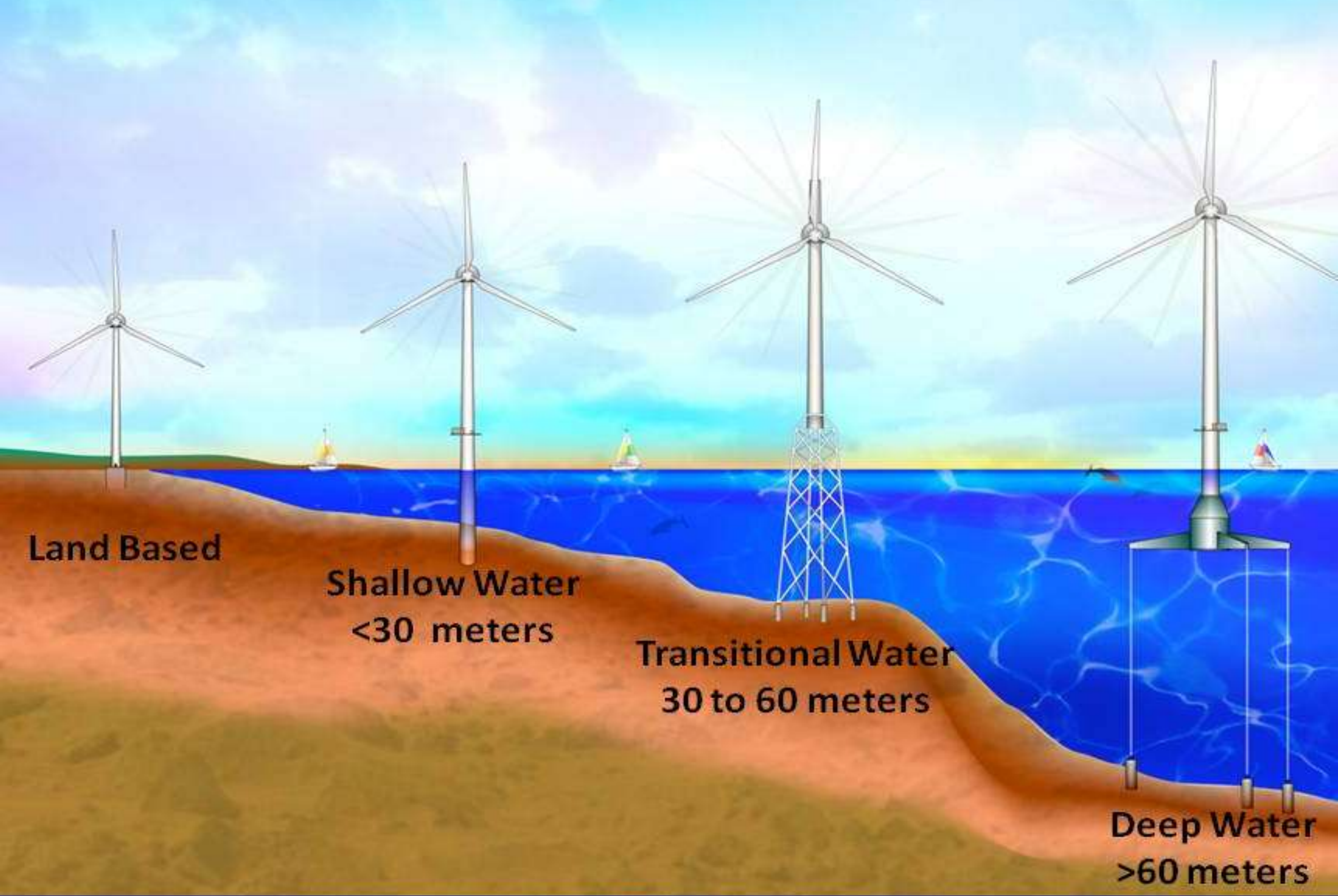
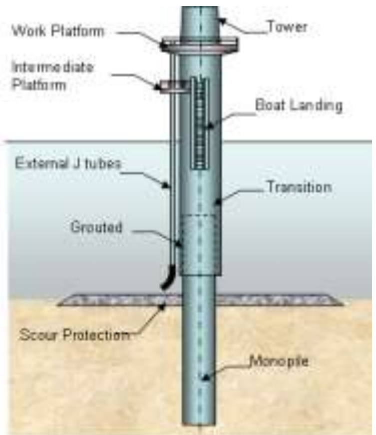
Offshore Wind Technology is Depth Dependent



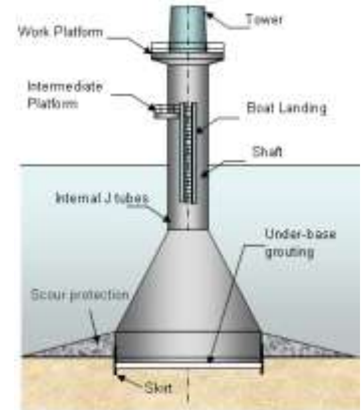
Challenges for Deep Water

Shallow Water (0-30m depths) Foundation Types

Monopile
78% of all
installations

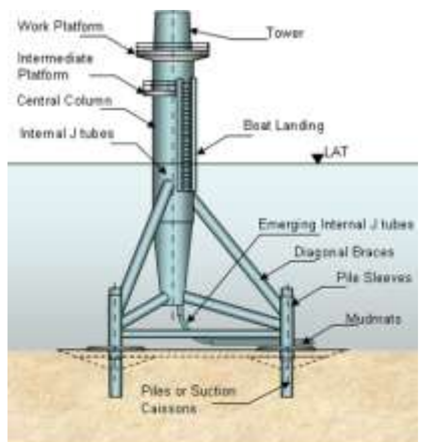


Gravity Base –
17% of all
installations

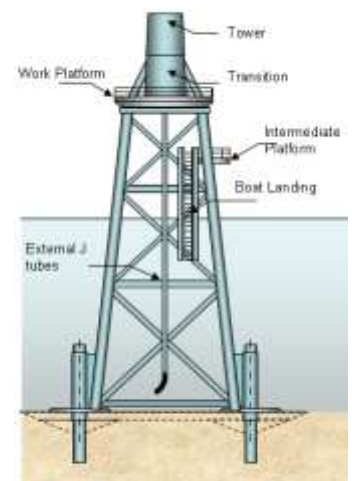


Transitional Water (30-60m depth) Foundation Types

Tripod – 16%
of all planned



Jacket or Truss
– 35% of all
planned



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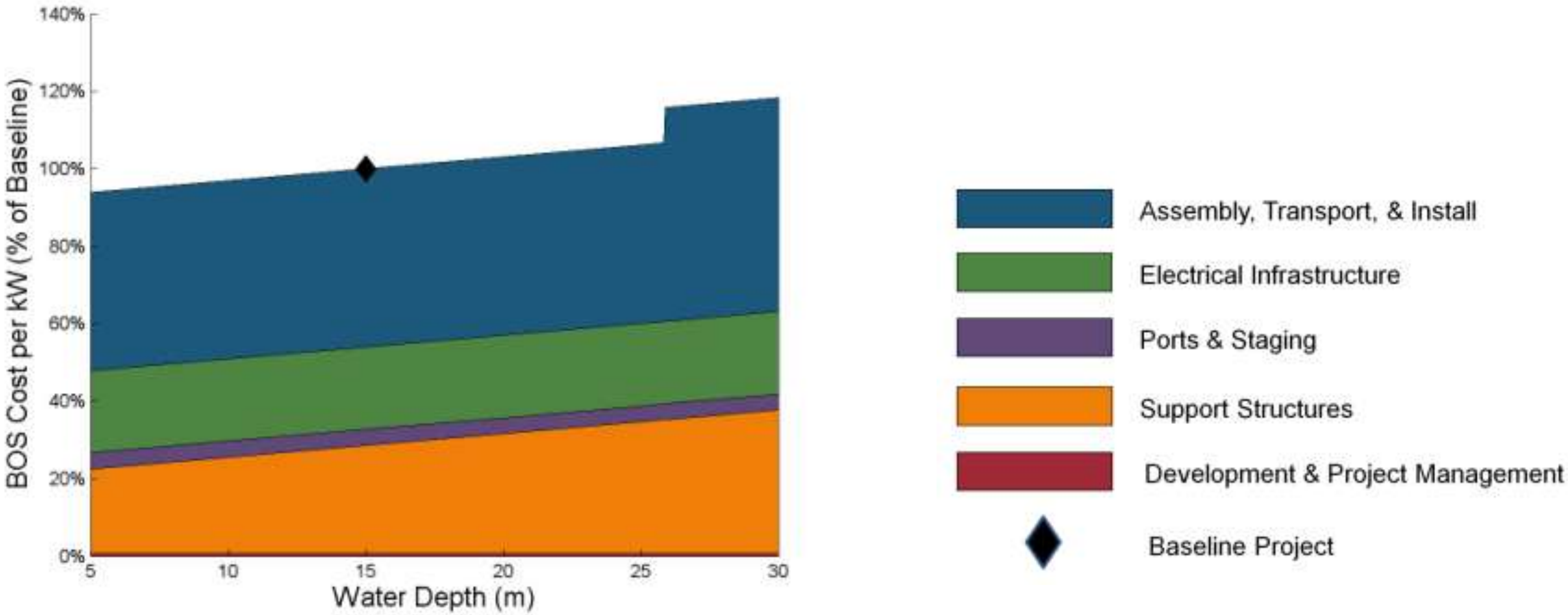
Modeled Sensitivity of Balance of Station to Water Depth



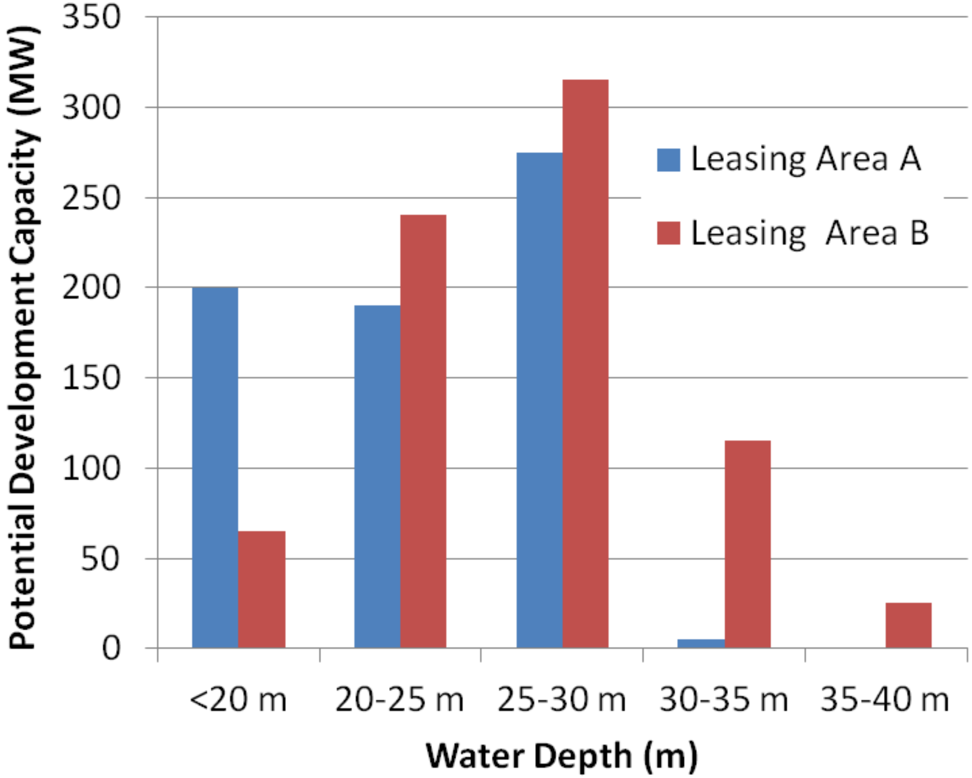
- Support structure cost has the greatest sensitivity to depth
- Larger and more expensive installation vessels cause a step change at about 25 m

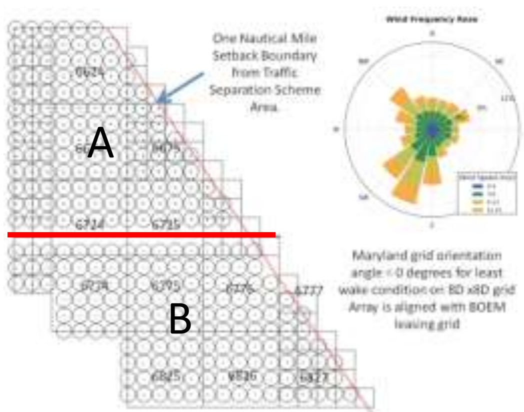
Depths for MD WEA with NREL Preferred Delineation Using 8D x 8D Spacing

Depth Range	Leasing Area A		Leasing Area B		Total Area	
	Capacity (MW)	Turbines	Capacity (MW)	Turbines	Capacity (MW)	Turbines
<20 m	200	40	65	13	265	53
20–25 m	190	38	240	48	430	86
25–30 m	275	55	315	63	590	118
30–35 m	**5**	**1**	**115**	**23**	120	24
35–40 m	**0**	**0**	**25**	**5**	25	5
Total	**670**	**134**	**760**	**152**	**1,430**	**286**

Data Source : NREL

Comparison of Two Leasing Areas for NREL Preferred Delineation

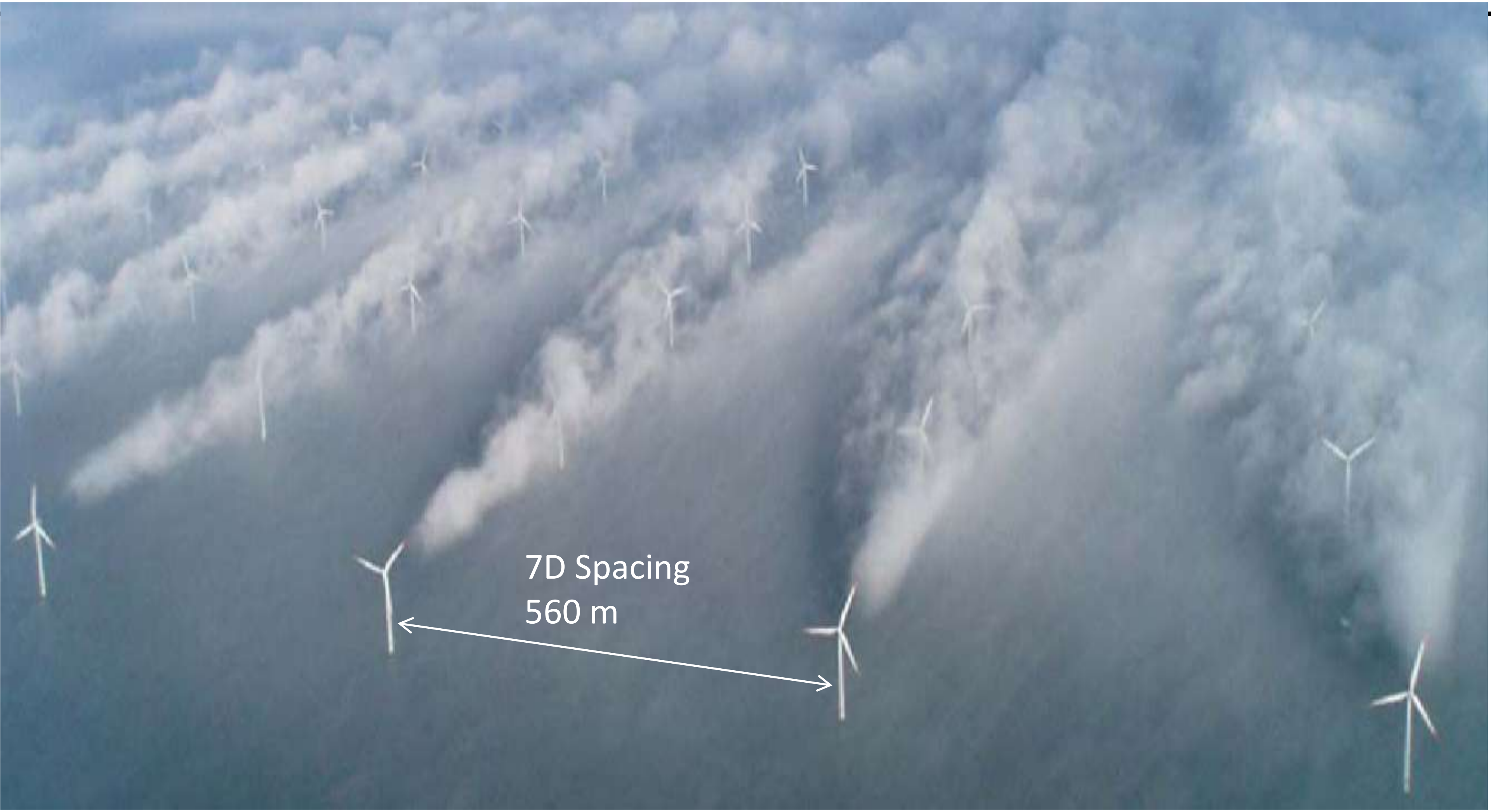




- **Leasing Area A**
  - 151.2 km^2
  - Less than 1% of capacity in water depths greater than 30 m
  - Average Depth 23 m
  - Average Wind Speed 8.2 m/s

- **Leasing Area B**
  - 171.4 km^2
  - 18.4% of capacity in water depths greater than 30 m
  - Average Depth 26 m
  - Average Wind Speed 8.3 m/s

Wake Losses



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

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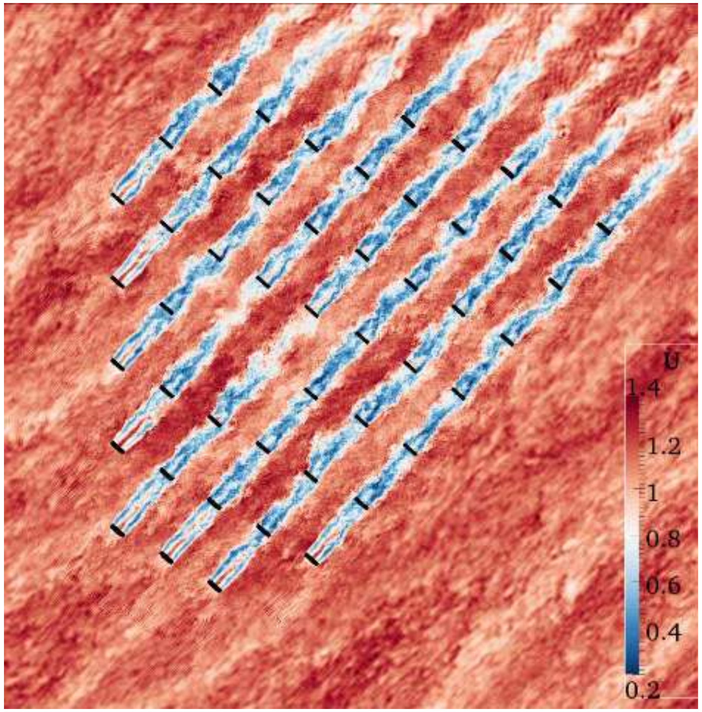
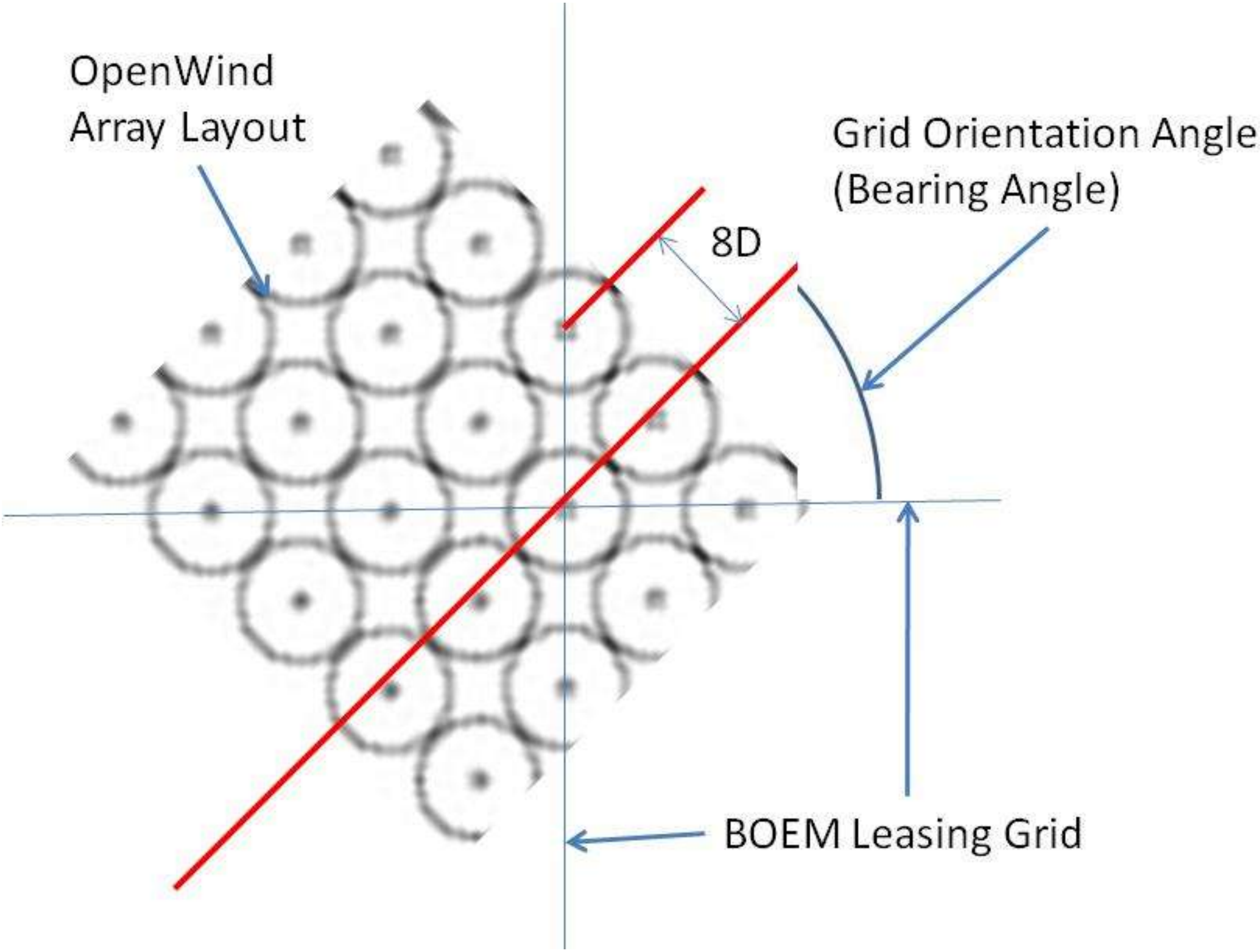
Wake Losses and Inter-project Buffers - Background

- Wind turbines wakes have lower energy available, higher turbulence, and need to be replenished by natural atmospheric mixing
- Atmospheric stability conditions dominate the rate of mixing and replenishment
- Stable atmospheres are stratified and allow turbulence to persist
- Unstable atmospheres replenish energy in the wind more quickly



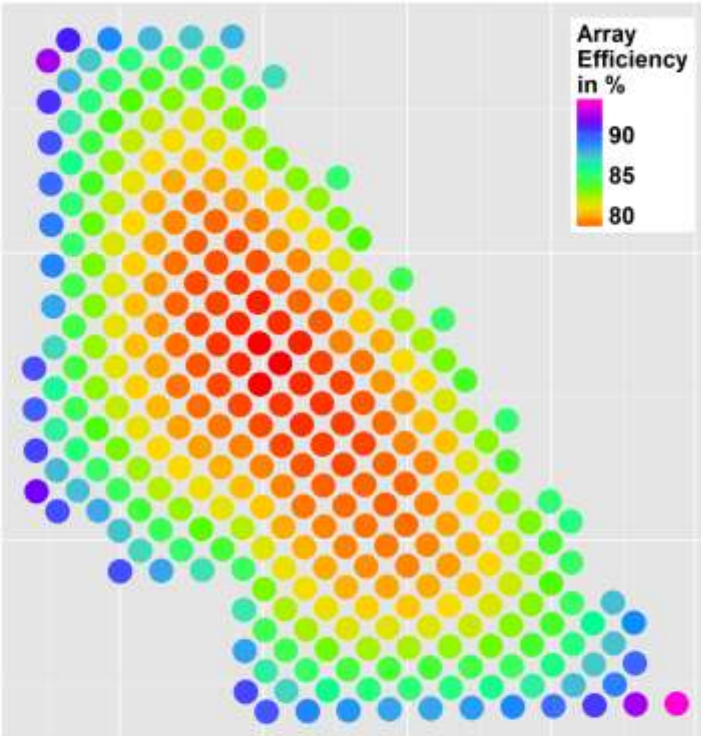
Simulator for Wind Farm Applications showing turbine wake effects (Source: NREL)

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

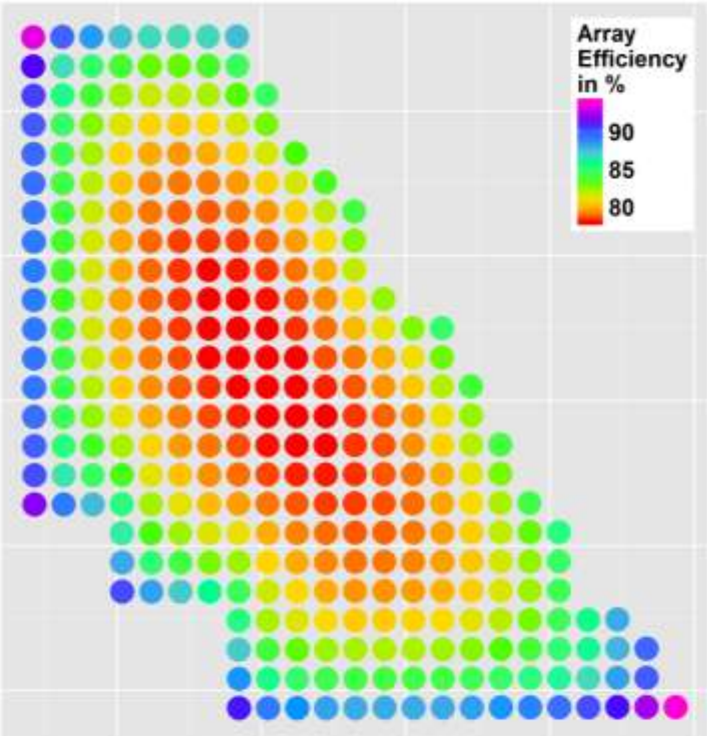


Open Wind Output Example with 8D x 8D spacing

Array Efficiency for 8D x 8D Spacing



45 degree grid angle with 8D x 8D Spacing



0 degree grid angle with 8D x 8D Spacing

- **Deep array losses dominate for all grid orientations – 16% – 17 %**
- **Deep array losses exceed 20% for interior turbines**
- **Most Wake Losses originate in the local array**
- **Some Wake losses originate in neighboring arrays**

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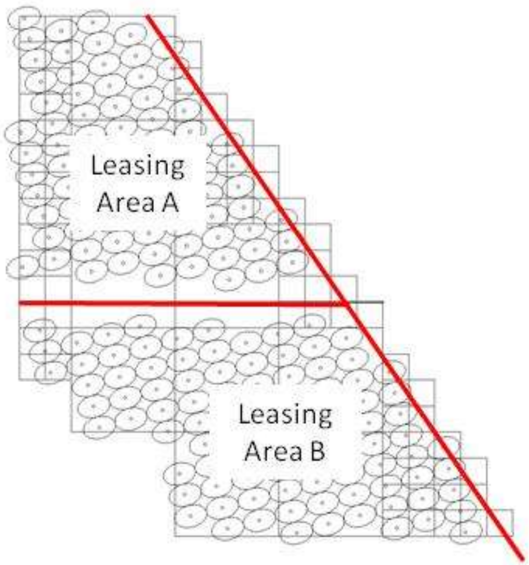
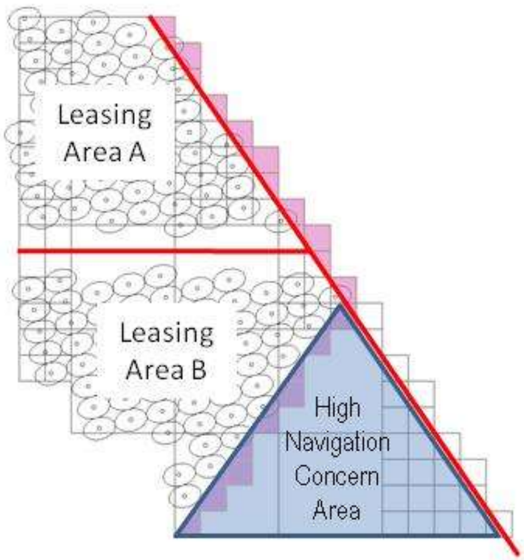
Results of Alternatives Analysis

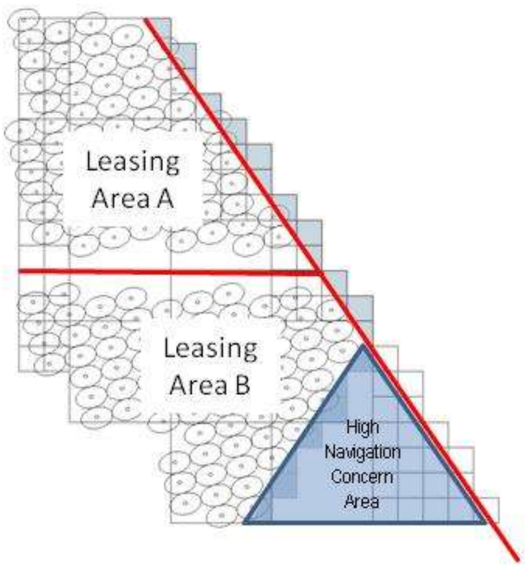
Overview of Alternatives



NREL Preferred MD Delineation



Alternative WEA 1



Alternative WEA 2

Results of Alternative MD WEA Analysis

Parameter	MD WEA - NREL Preferred Delineation		MD WEA Alternate 1		MD WEA Alternate 2	
	Leasing Area A	Leasing Area B	Leasing Area A	Leasing Area B	Leasing Area A	Leasing Area B
Total area (km²)	151.2	171.4	104.5	106.4	120.8	123.5
Total area (1,000 acres)	37.4	42.3	25.8	26.3	29.8	32.0
Average depth (m)	23	26	23	23	23	24
Bathymetry – depth range (m)	16–29	14–37	16–28	14–29	16–29	14–30
Average wind speed at 90 m (m/s)	8.2	8.3	8.2	8.3	8.2	8.3
8D x 8D - 0 Degree Grid Orientation						
Wake losses (%)	17	16	16	15	16	16
Gross capacity factor (CF) (%)	44	44	44	44	44	44
Gross CF after wake losses (%)	36	37	37	37	37	37
Potential capacity (MW)	670	760	465	525	530	610
Annual energy production (GWh)	2,123	2,454	1,496	1,720	1,698	1,983
8D x 12D - 75 Degree Grid Orientation						
Wake losses (%)	13	12	12	11	12	12
Gross capacity factor (CF) (%)	44	44	44	44	44	44
Gross CF after wake losses (%)	38	39	38	39	38	39
Potential capacity (MW)	400	475	300	315	350	370
Annual energy production (GWh)	1,336	1,607	1,010	1,079	1,173	1,258

Trend in European offshore wind project size

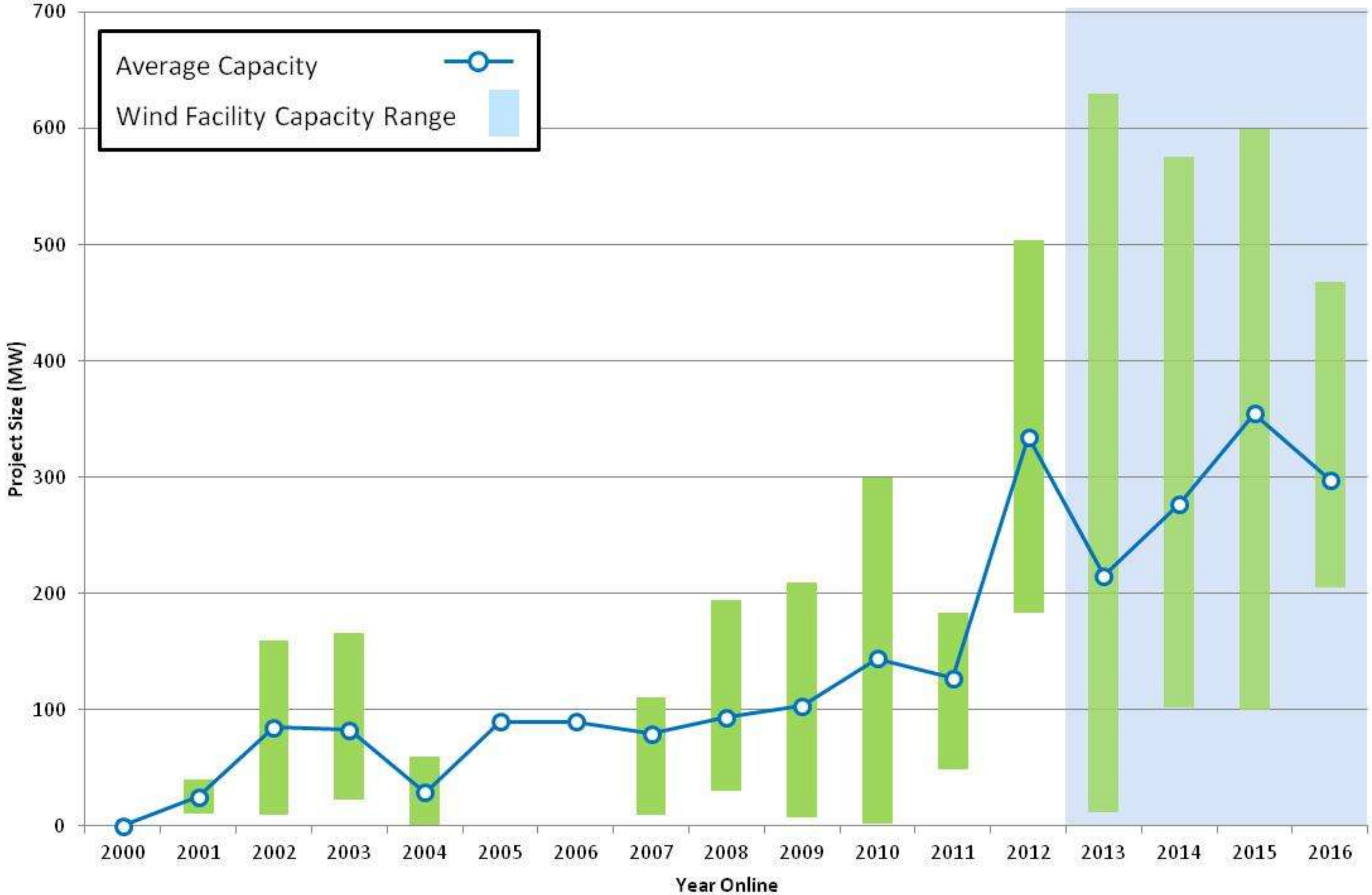
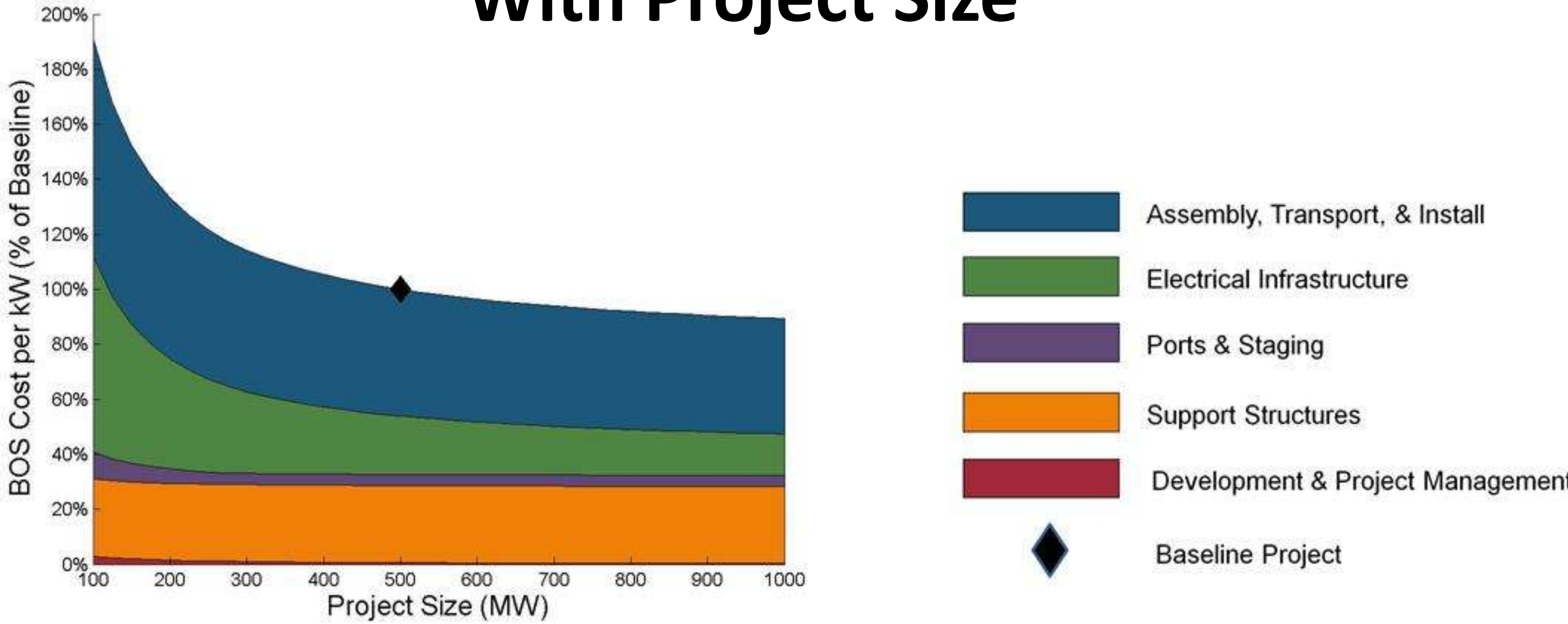


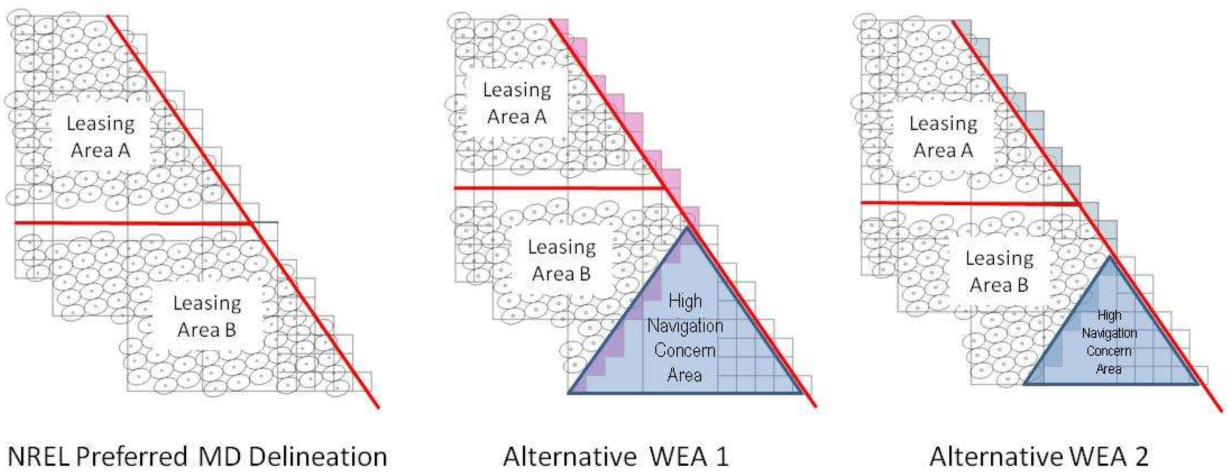
Chart included installed projects and projects under construction as of Jan 2013

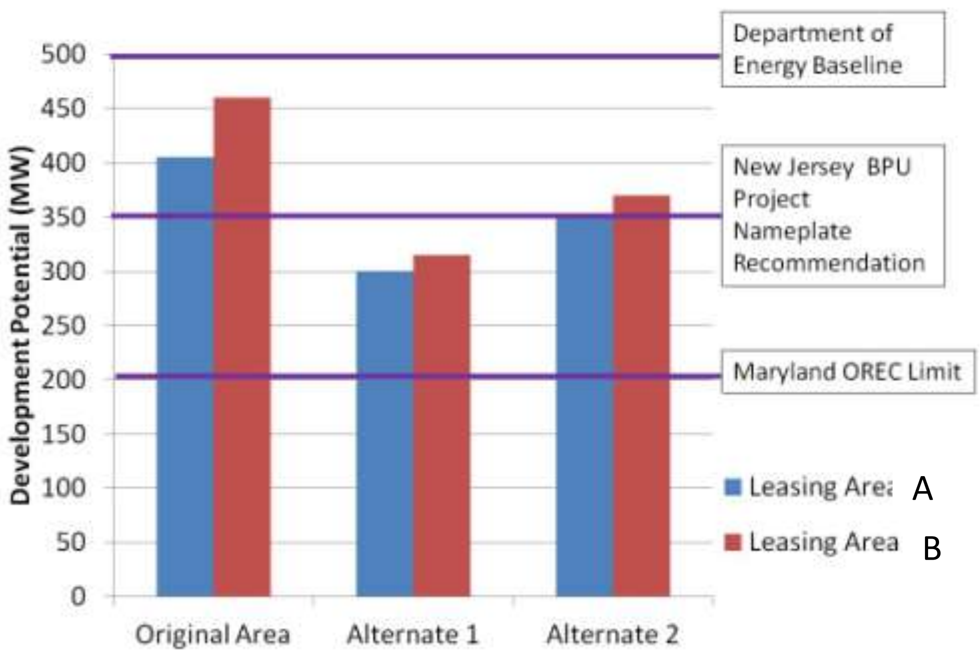
Analysis Shows Balance of Station Cost Decreases With Project Size



- Fixed costs such as vessel mobilization, export cable landfall operations increase $/kW for smaller projects
- Cost reductions come from economies of scale
- The electrical costs can become prohibitive for small projects

Development Potential for MD WEA Alternatives





Comparison of the development nameplate potential for the three alternative MD WEAs delineated into two leasing areas using 8D x 12D turbine array spacing

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Summary and Recommendations

Summary

- The MEA analysis provided a logical approach to delineating the MD WEA and is similar to NREL's preferred option
- A diagonal delineation showed low sensitivity to delineation strategy
- Wake losses in the overall WEA were more pronounced (16% and 17% for 8D x 8D spacing and 12% and 13% for 8D x 12D spacing) than between leasing areas (<1%)
- Leasing area B is larger, the wind speeds are higher (about 0.1 m/s), and it has better exposure to dominant south-southwest winds. These positive factors are expected to be offset by approximately equal negative factors because of deeper water in area B.

Summary Continued

- The MD WEA can support 600 MW wind plants using 8D x 8D spacing, and 400 MW for the 8D x 12D spacing.
- The bimodal wind direction and lower average wind speed may cause higher wake losses and hinders layout optimization
- Capacity potential for the MD WEAs is low due to its relatively small size, and there is little additional siting flexibility
- Alternative 1 has a development potential of about 300 MW and 315 MW for the two leasing areas; near the lower end of typical project sizes
- Alternative 2 has a development potential of 350 MW and 370 MW for the two leasing areas; near the current project size range

Recommendations

- NREL recommends a straight west-east line similar to the MEA approach that approximately balances the development potential of the two leasing areas, by taking into account the challenges caused by deeper bathymetry (NREL Preferred)
- Turbine spacing greater than 8D x 8D and additional buffers may be required in the MD WEA.
- Prospective lessees are strongly encouraged to conduct more rigorous analysis on wake losses before judging the values of the leasing areas. This analysis should consider diurnal, seasonal, and annual wind variations and cost tradeoffs between spacing and cable length.
- Deep array performance and fatigue loading analysis with respect to atmospheric stability conditions is recommended

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)
- Maryland Energy Administration
- Maryland Department of Natural Resources
- BOEM Maryland Renewable Energy Task Force

Citation for Maryland Report and Key References

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Thank you for your attention!

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