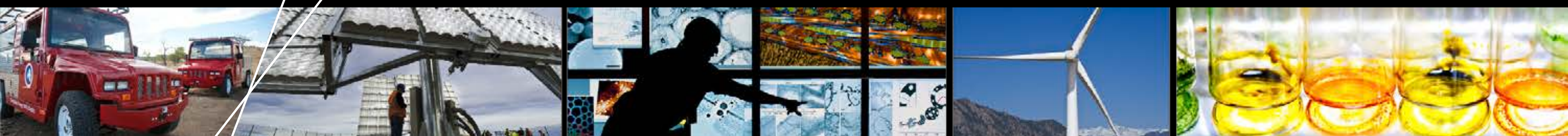
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Proposed Methodology and Preliminary Findings for Maryland Offshore Leasing Zone Delineation



BOEM Maryland Task Force Meeting
Annapolis, Maryland

Walt Musial
NREL Manager Offshore Wind, Principal Engineer

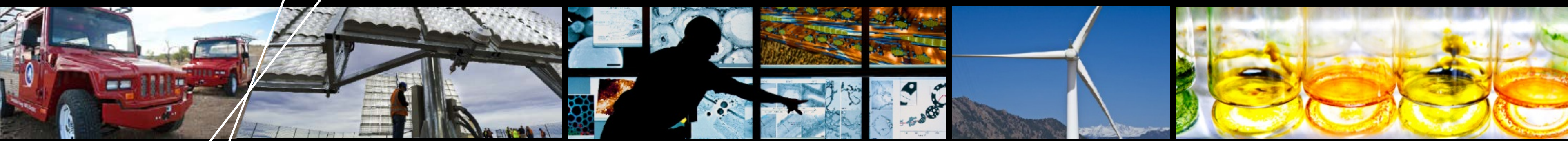
Jason Fields
NREL Senior Engineer

January 29, 2013

NREL Presentation Contents

- **NREL offshore wind technical background**
- **Proposed technical approach for follow-on assessment of delineation zones**
- **Review of Maryland delineation proposal**
- **Schedule and deliverables**
- **Question and answers**

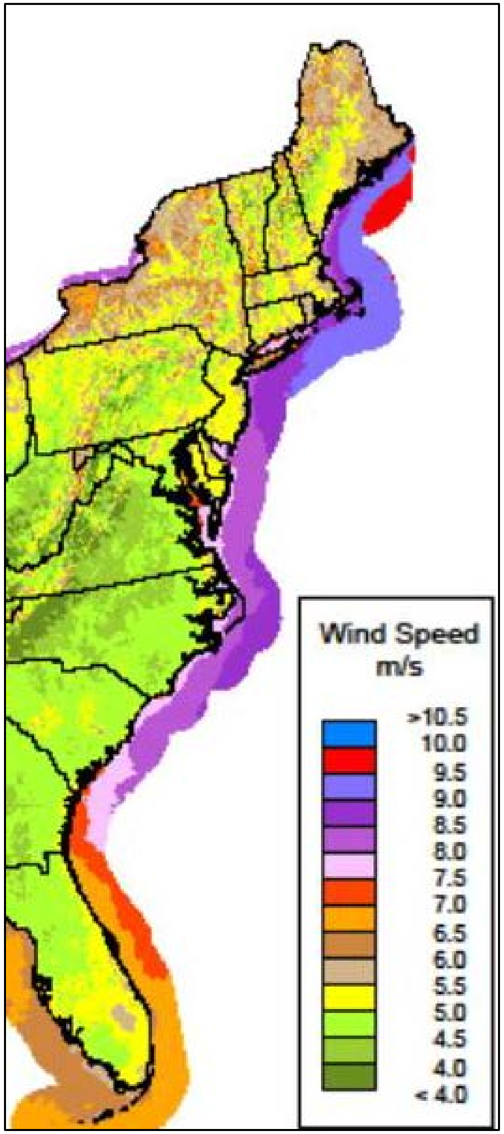
Background



National Renewable Energy Laboratory and Offshore Wind Technology

Project Summary and Background

- **Bureau of Ocean Energy Management (BOEM) requested assistance from the Department of Energy's National Renewable Energy Laboratory (NREL)**
- **NREL will provide technical input to help inform delineation of leasing zones within four BOEM Wind Energy Areas(WEA)**
- **NREL is reviewing Maryland's proposed delineation/methodology and will make recommendations to BOEM**
- **NREL plans to focus on wind resource, assessing buffer zones and maximizing energy potential to produce approximately equal development zones**

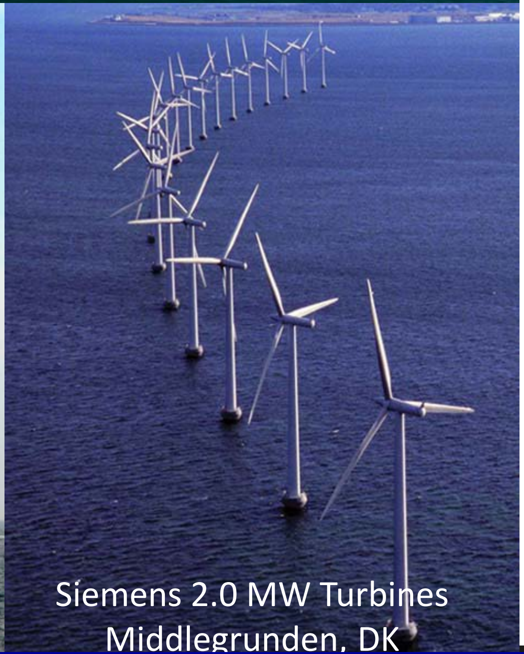


Atlantic Wind Energy Resources

Offshore Wind Technology Status


Horns Rev Wind farm - 160-MW
Courtesy of Vattenfall

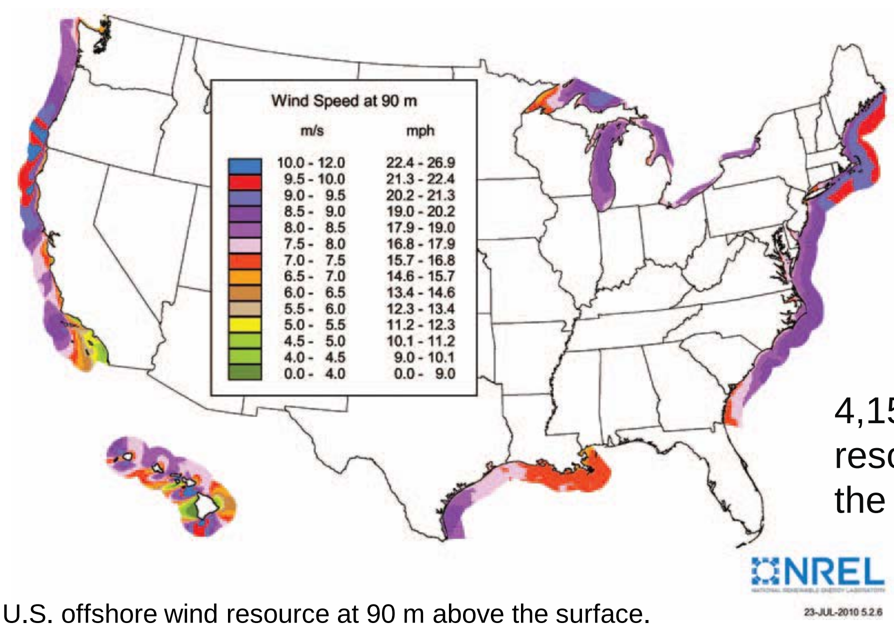

Alpha Ventus – RePower 5-MW Turbine


Siemens 2.0 MW Turbines Middlegrunden, DK

- 51 projects, 3,620 MW installed (end of 2011)
- 49 in shallow water <30meters depth
- 2-6 MW upwind turbines
  (3.8 MW average power)
- 80+ meter towers on monopoles, gravity bases, or truss (jackets)
- Modular geared drivetrains – trending toward direct drive
- Marine technologies
  - Submarine cable technology
  - Oil and gas experience essential
  - Marine operations/ vessels
- Capacity Factors 40% or more
- Higher Cost and O&M have contributed to project risk.

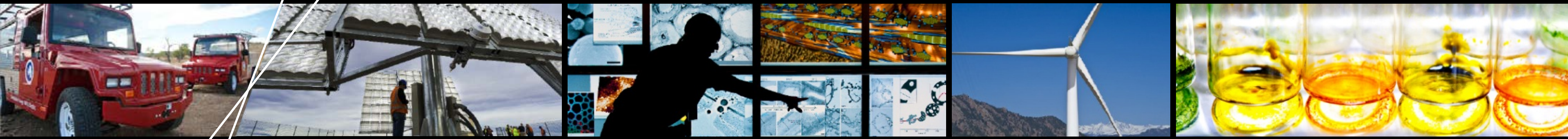
NREL Offshore Wind Program Highlights

- National Offshore Wind Strategic Plan support for DOE
- Published *Assessment of Offshore Wind Energy Resources for the United States*
- Published *Large-Scale Offshore Wind Power in the United States: Assessment of Opportunities and Barriers*
- Service to National Academy of Science committee addressing Offshore Wind Energy Turbine Structural and Operating Safety
- Chaired AWEA Offshore Compliance Recommended Practices (Oct 2012)
- International Standards Development including Hurricane Design



U.S. offshore wind resource at 90 m above the surface.

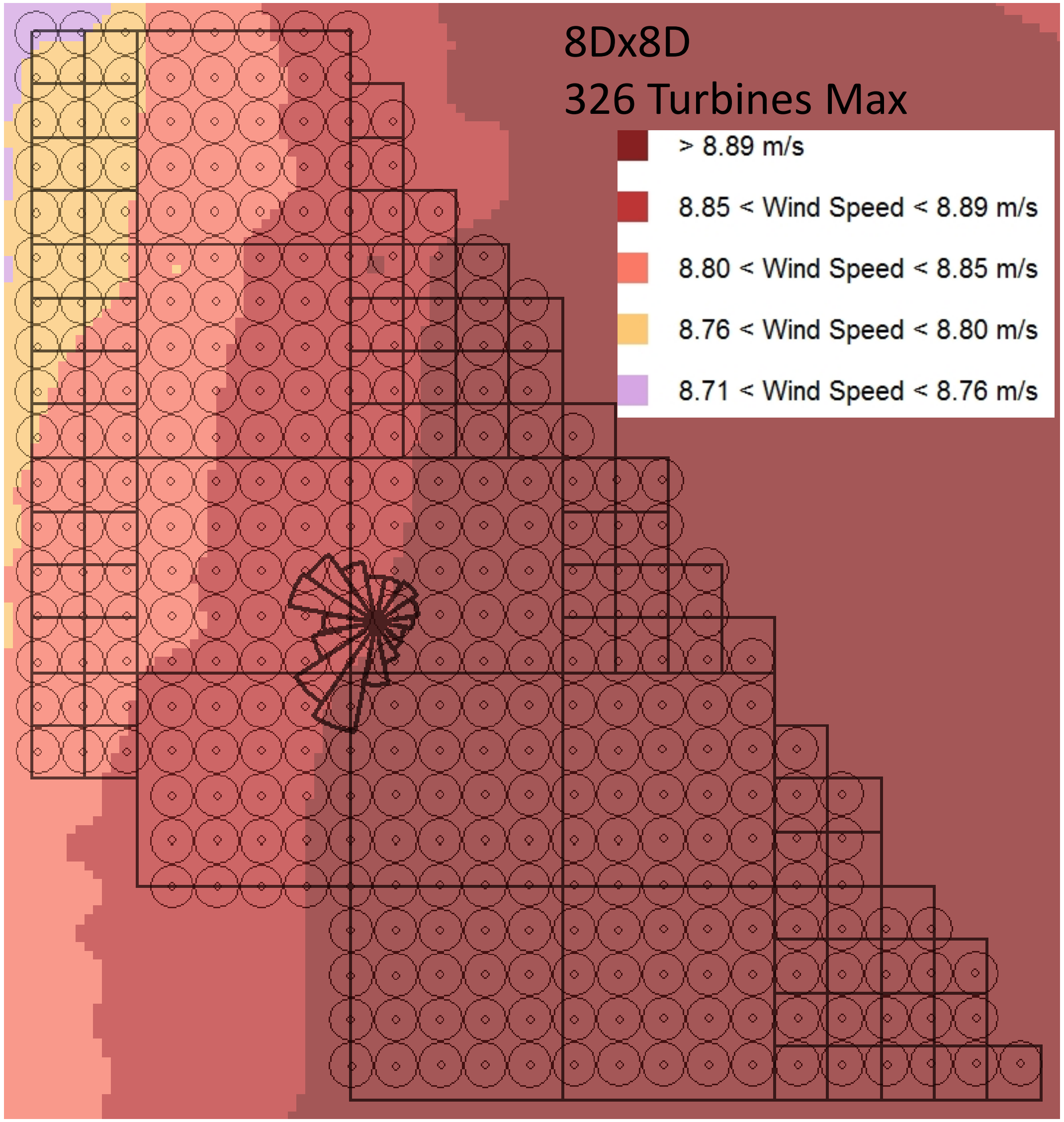
4,150 GW of wind resource potential in the United States



Technical Assessment of Maryland's Proposed Zones and Methodology to Evaluate Alternative Scenarios for MD WEA

NREL's Proposed Technical Approach

- Review Maryland MEA delineation plan (memo 9/13/13)
- Prepare written technical evaluation of proposed MD offshore zones
- Present preliminary findings at 29 Jan 2013 Task force meeting
- Review and incorporate stakeholder input
- Utilize AWS Truepower openWind® Enterprise program to assess merits of offshore leasing zones
- Perform sensitivity analysis on key variables:
  - Wind Resource Variability
  - Turbine Type/Size
  - Wake Model Fidelity
  - Alternative Array Spacing and layouts
- Draft Report in May 2013



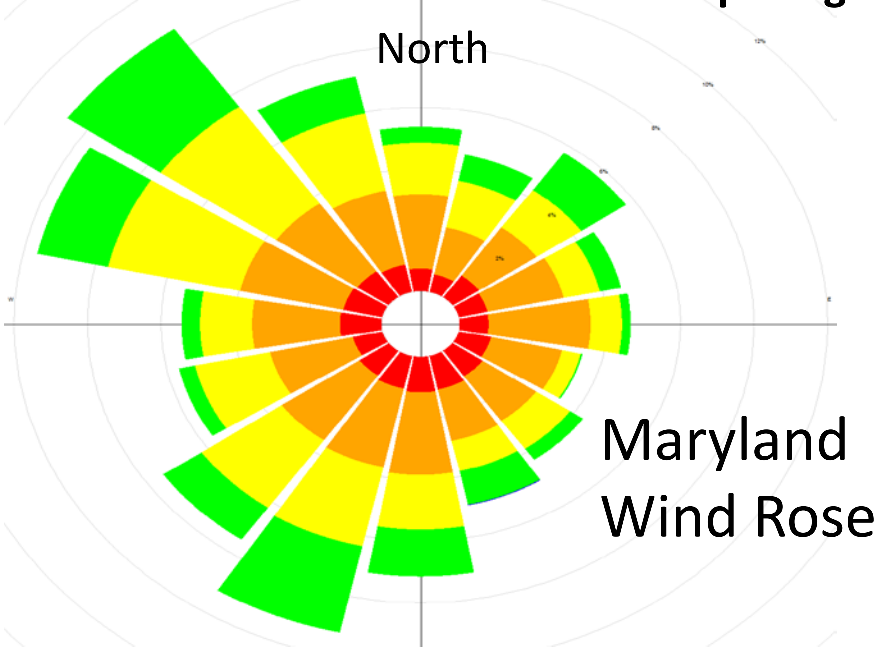
NREL Major Zone Delineation Guiding Principles

- Approximate balance in energy production potential between two development zones
- Minimize wake loss potential between zones when developed
- Maximize developable area in each zone considering buffers

NREL's Major Assumptions for Zone Delineation

- Investigate options for development zones
- Minimum project size – 350 MW
- Baseline turbine size – 5-MW (126-m rotor NREL Reference)
- Baseline array spacing 8D x 8D (approximately 1-km) as used for resource assessment (5 MW/km^2)
- Total MD WEA maximum capacity – ~323 turbines (1615 MW)
- Both zones are built by different developers
- Developers are responsible for planning buffers within their own zones

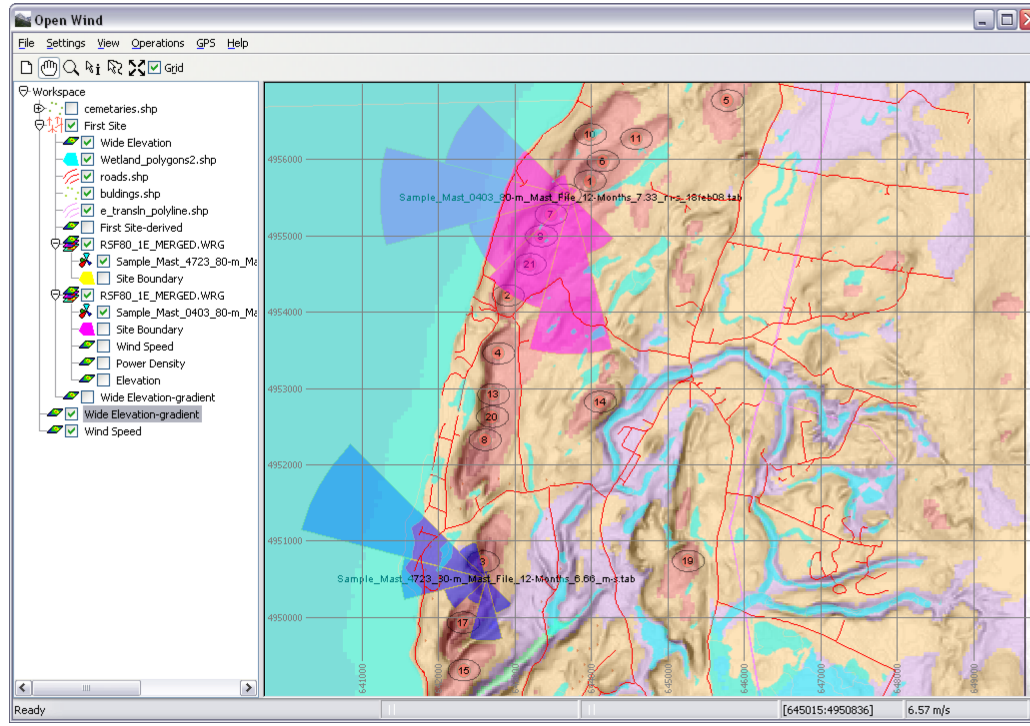
Horns Rev Wind Plant – 7D turbine Spacing



Jonkman, J.; Butterfield, C.P.; Musial, W.; Scott, G. (2009). *Definition of a 5-MW Reference Wind Turbine for Offshore System Development*. NREL/TP-500-38060. Golden, CO: NREL.

Description of openWind® Enterprise Program

- Wind power facility design software program
- Open source software with license for enhanced deep array wake loss model
- Energy computations using standard wind farm design practices
- GIS based architecture
  - o GIS file compatibility
  - o Spatial logic with hierarchical structure
- Deep array offshore wake model for higher fidelity comparison of wake effects

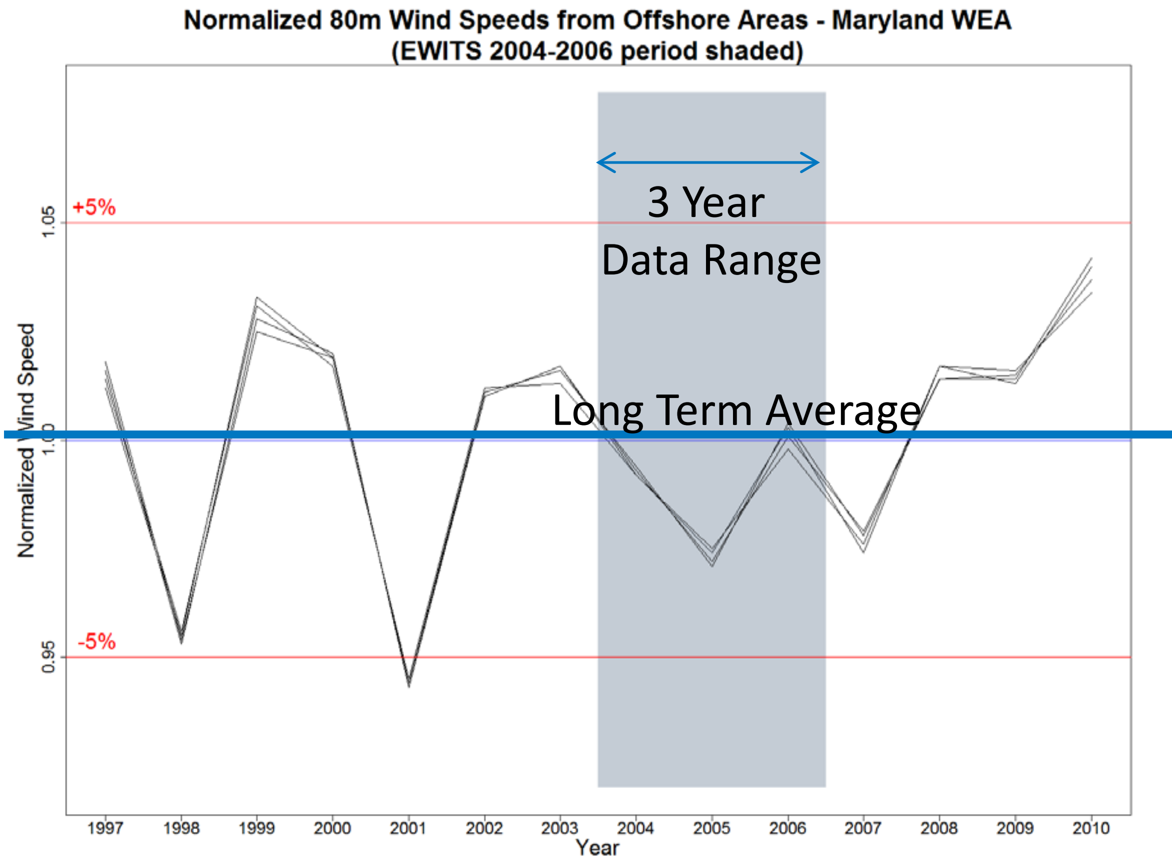


Example of Map Taken from openWind ® Enterprise Tool Showing GIS Layers of Key Parameters

Wind Data Source for NREL Study

- **From available data we selected 3 years of the *Eastern Wind Integration Transmission Study* dataset**

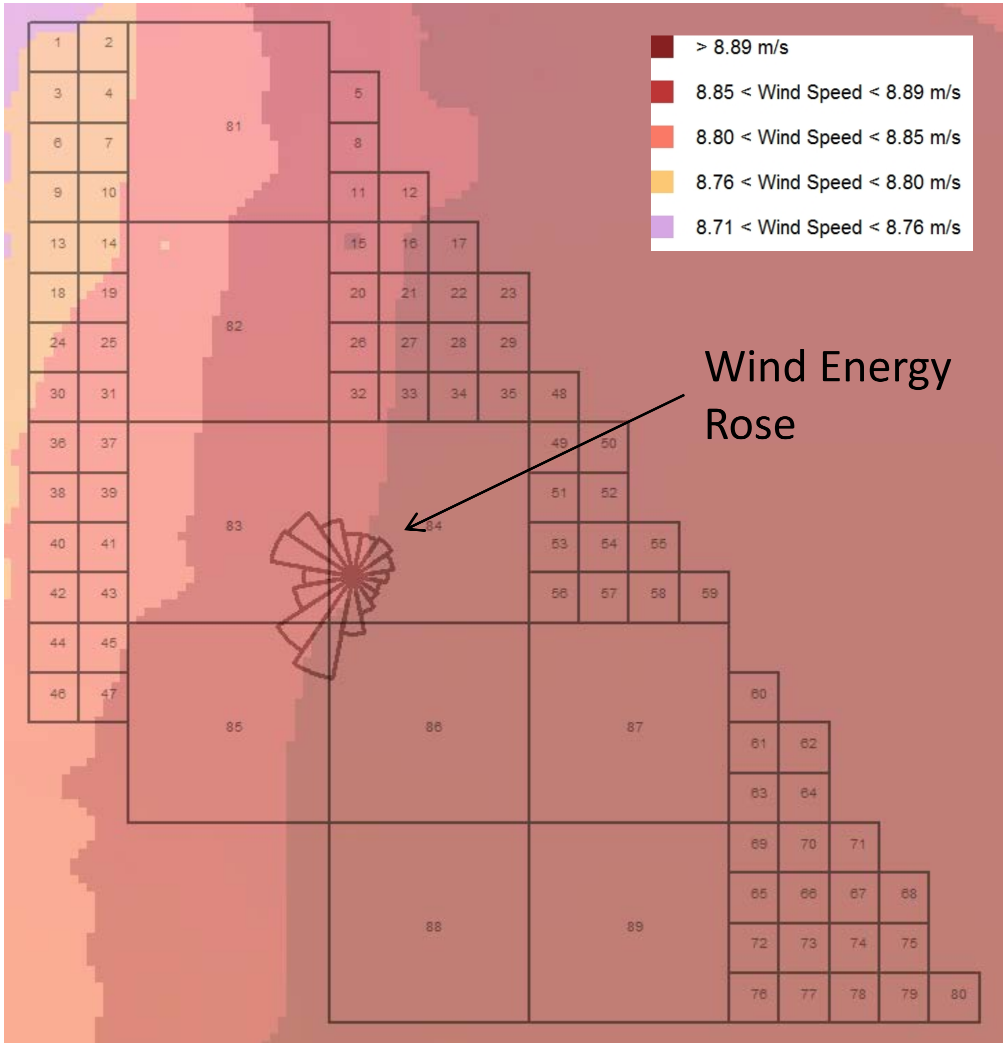
- **Data is within ~1.1% of long term average**



Long Term Representation of EWITS Mean Wind Speeds

Proposed Technical Approach

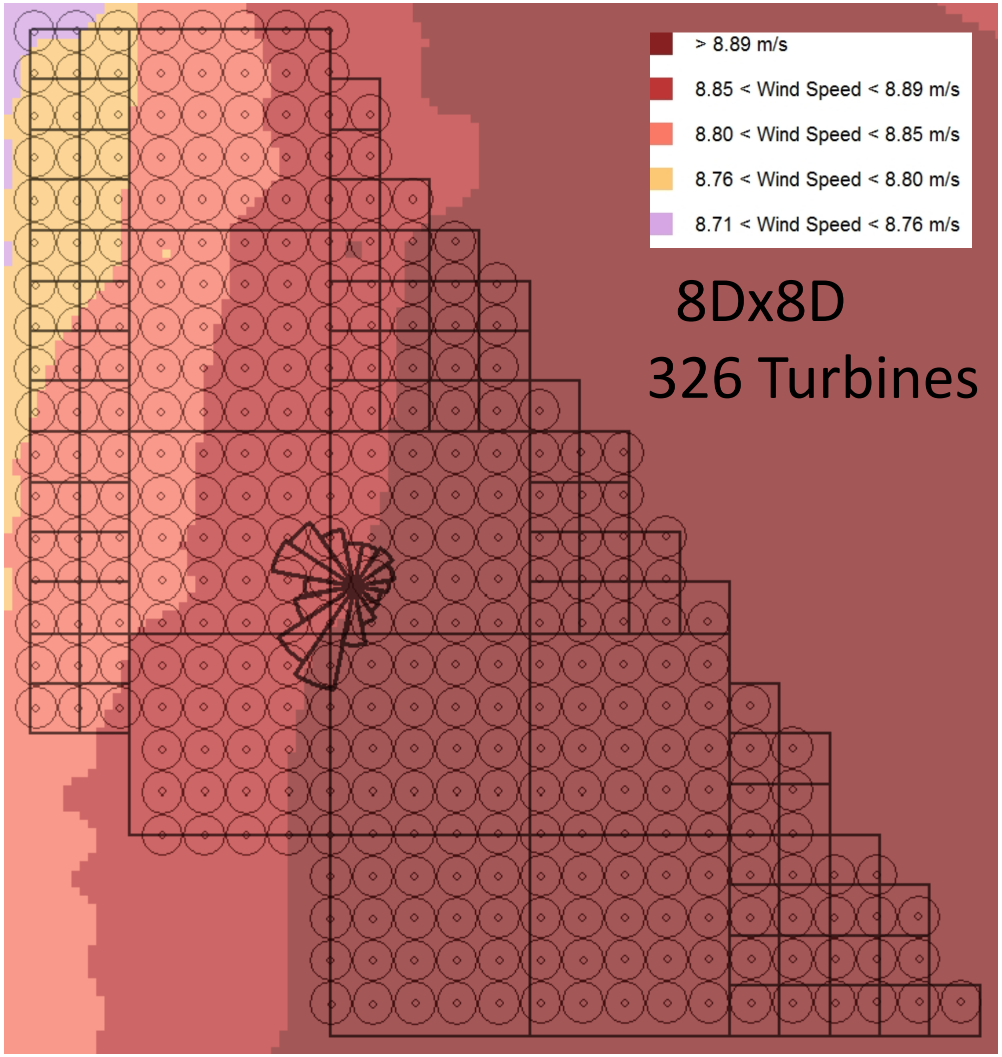
1. Establish spatial and temporal distribution of wind characteristics across MD-WEA
   A. Mean wind speeds
   B. Wind directions
   C. Turbulence intensities
2. Perform detailed analysis of joint wind speed/direction frequency distributions (wind rose) across MD-WEA
3. Model the atmospheric turbulence and stability parameters for wake loss calculations



Example MD-WEA Map of Mean Wind Speeds

Proposed Technical Approach (continued)

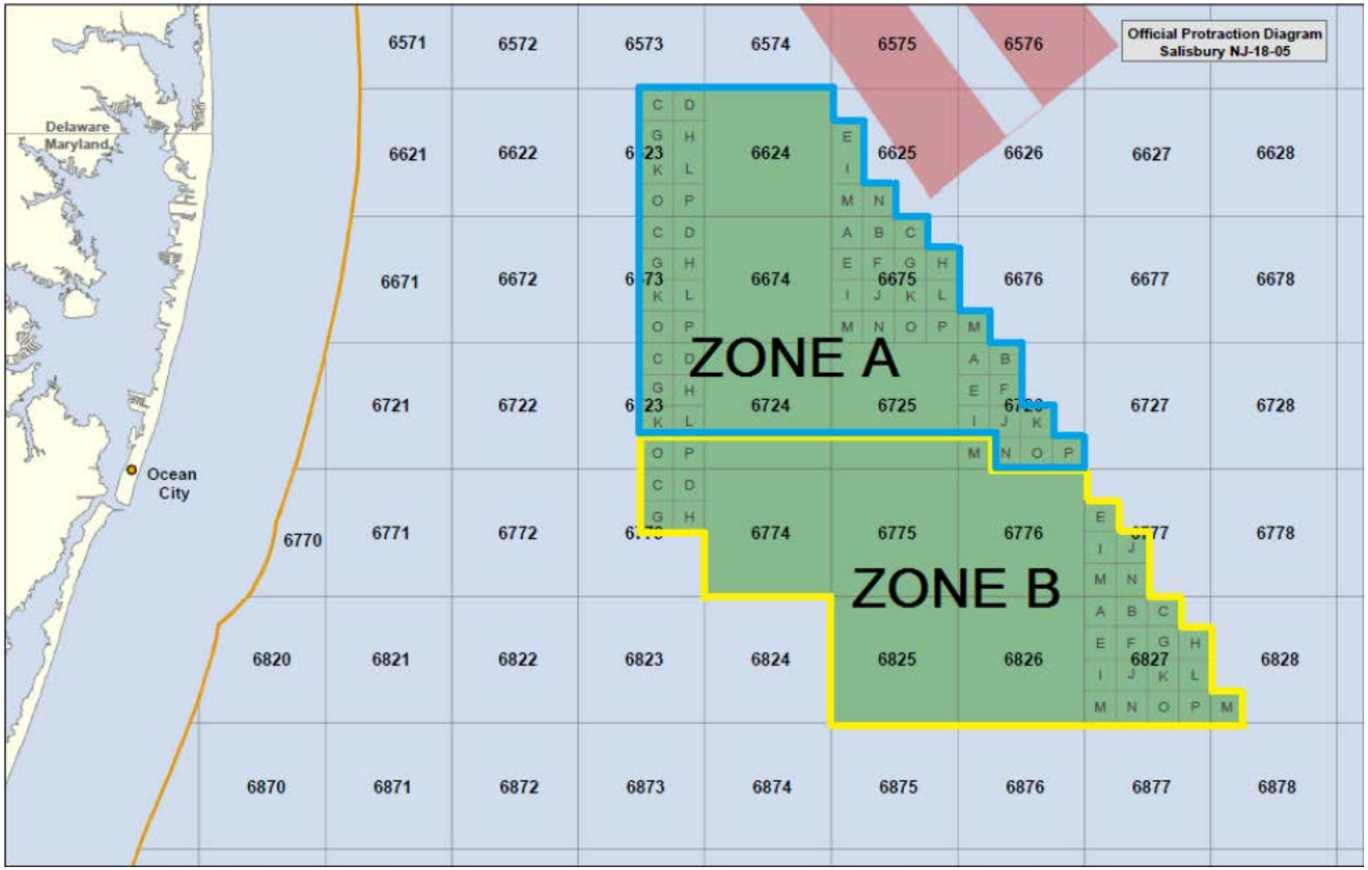
5. Establish various turbine placement options for sensitivity analysis
6. Identify pre-existing buffers due to WEA boundaries
7. Perform analysis to minimize wake losses
8. Identify options to delineate zones and boundaries
9. Vary delineation to generate equitable zones
10. Finalize layout for best energy production scenarios



MD-WEA Map Showing Maximum Turbine Development – Upper Bound

Task 1 Description

Review and evaluate Maryland's proposed lease zones within the BOEM Maryland Wind Energy Area (WEA)



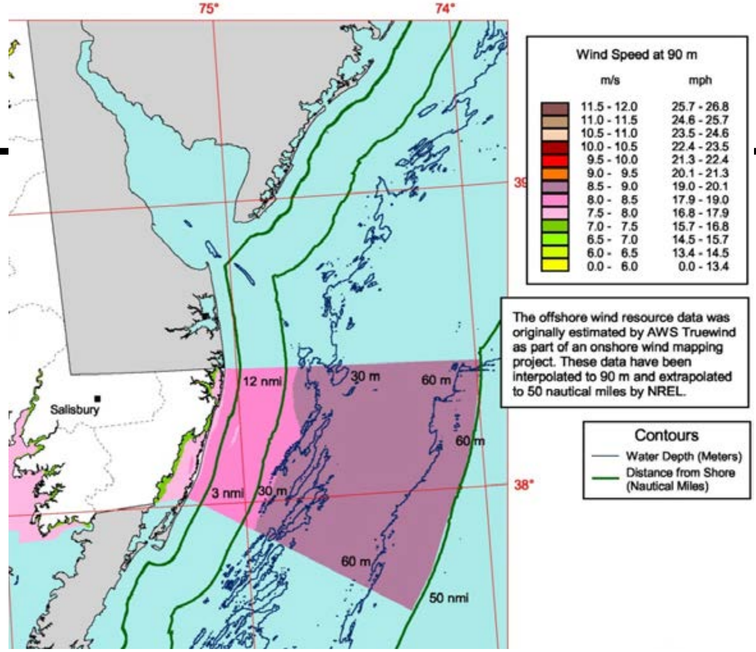
Maryland's WEA Delineation Criteria

1. **Wind Speed**
2. **Prevailing Wind Direction**
3. **Bathymetry**
4. Distance to Shore
5. Transmission Requirements
6. Shipping Lanes and Potential U.S. Coast Guard Requirements
7. **Inter-project Wake Effects and Potential Buffer Requirement**
8. Fisheries Use
9. Military Use
10. Additional Stakeholder Considerations

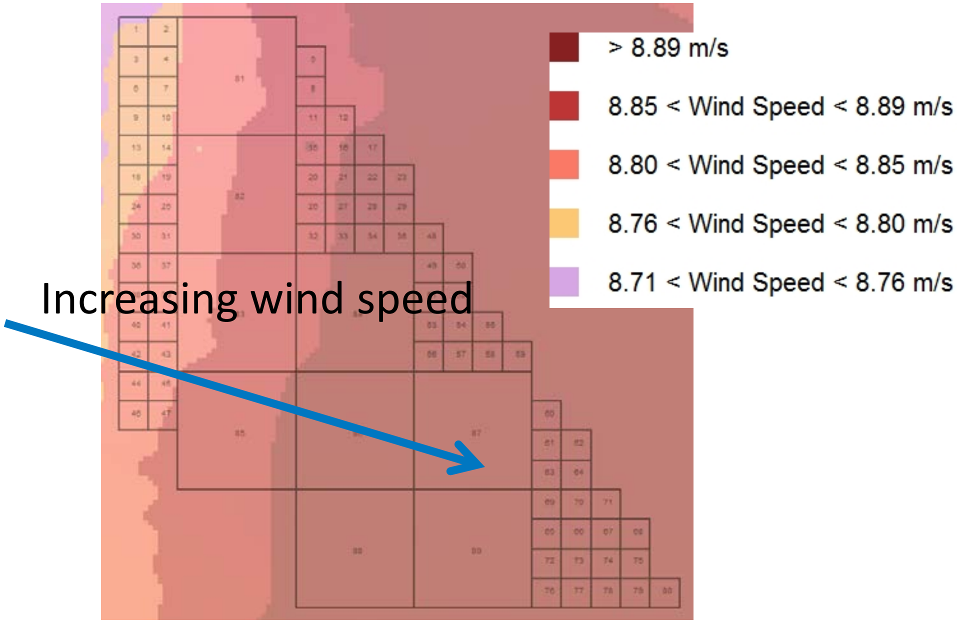
****Bold items are areas of primary focus by NREL in quantitative analysis**

Wind speed

- **Wind speed varies geographically with best wind in the southeast**
- **Wind speed gradients provide better winds further from shore**
- **Maryland's proposed delineation may favor Zone B**



Broad scale map of MD offshore wind resource (Source NREL)

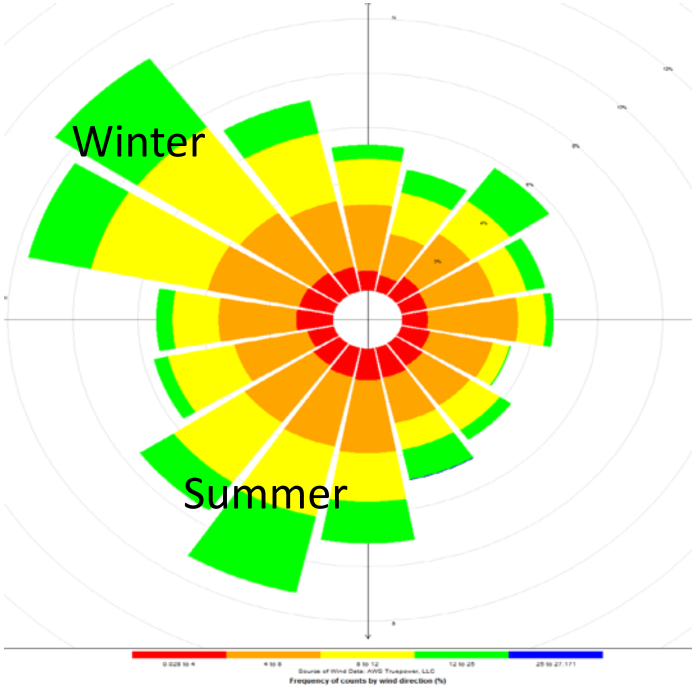


MD WEA Showing Wind Speed Gradients in 0.05 m/s increments (source NREL)

Prevailing Wind Direction

Inter-project Wake Effects and Potential Buffer Requirement

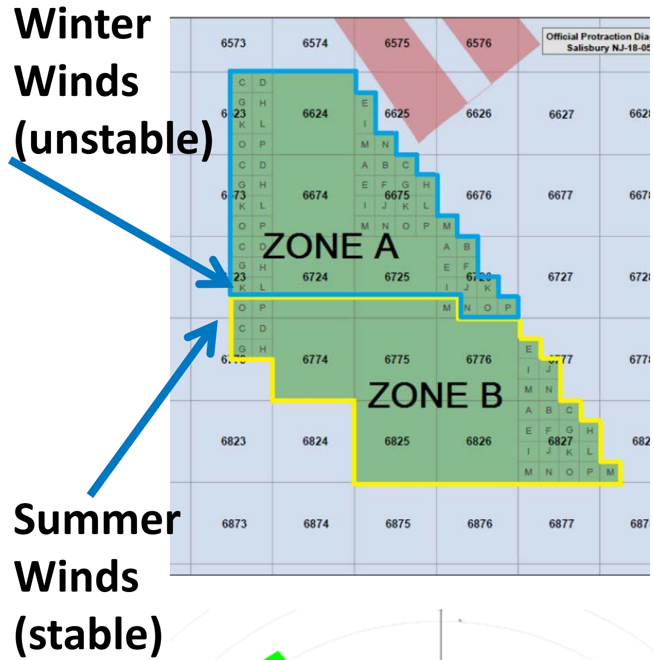
- Prevailing winds are seasonally directed
- Winter winds are NNW and are more likely in unstable atmospheres (natural turbulent mixing)
- Summer winds are SSW and are more likely to occur in unstable atmospheres

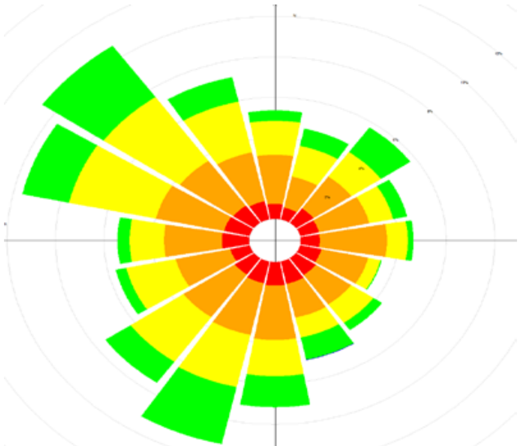


Annual Offshore Wind Rose for Maryland

Wake Losses and Inter-project Buffers

- **The wind in a turbine's wake has lower available energy, higher turbulence, and needs 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



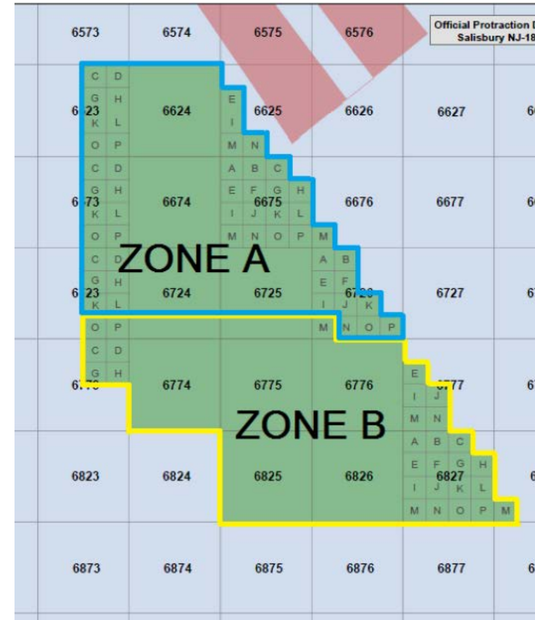


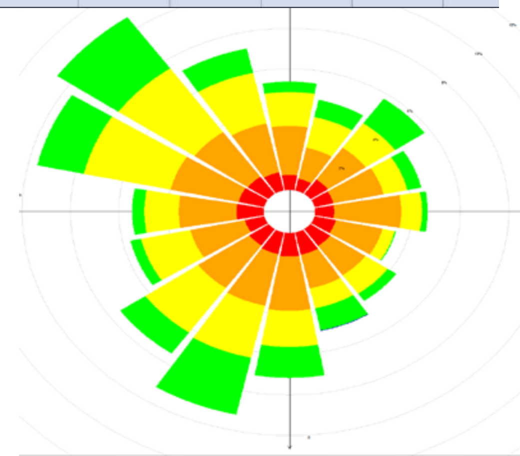
Annual Offshore Wind Rose for Maryland

Preliminary Summary of NREL Analysis

Parameter	MD WEA Zone A	MD WEA Zone B
Total Turbines	153	178
Total Capacity(MW)	765	890
Total Area(km^2)	155.52	167.04
Array Losses(%)	17.01	16.57
Annual Energy Production (GWh)	2746	3240
Capacity Factor(%)	40.95	41.54

Notes: Layout assumes NREL 5 MW baseline turbine and 8Dx8D spacing – max deployment with no additional burdens



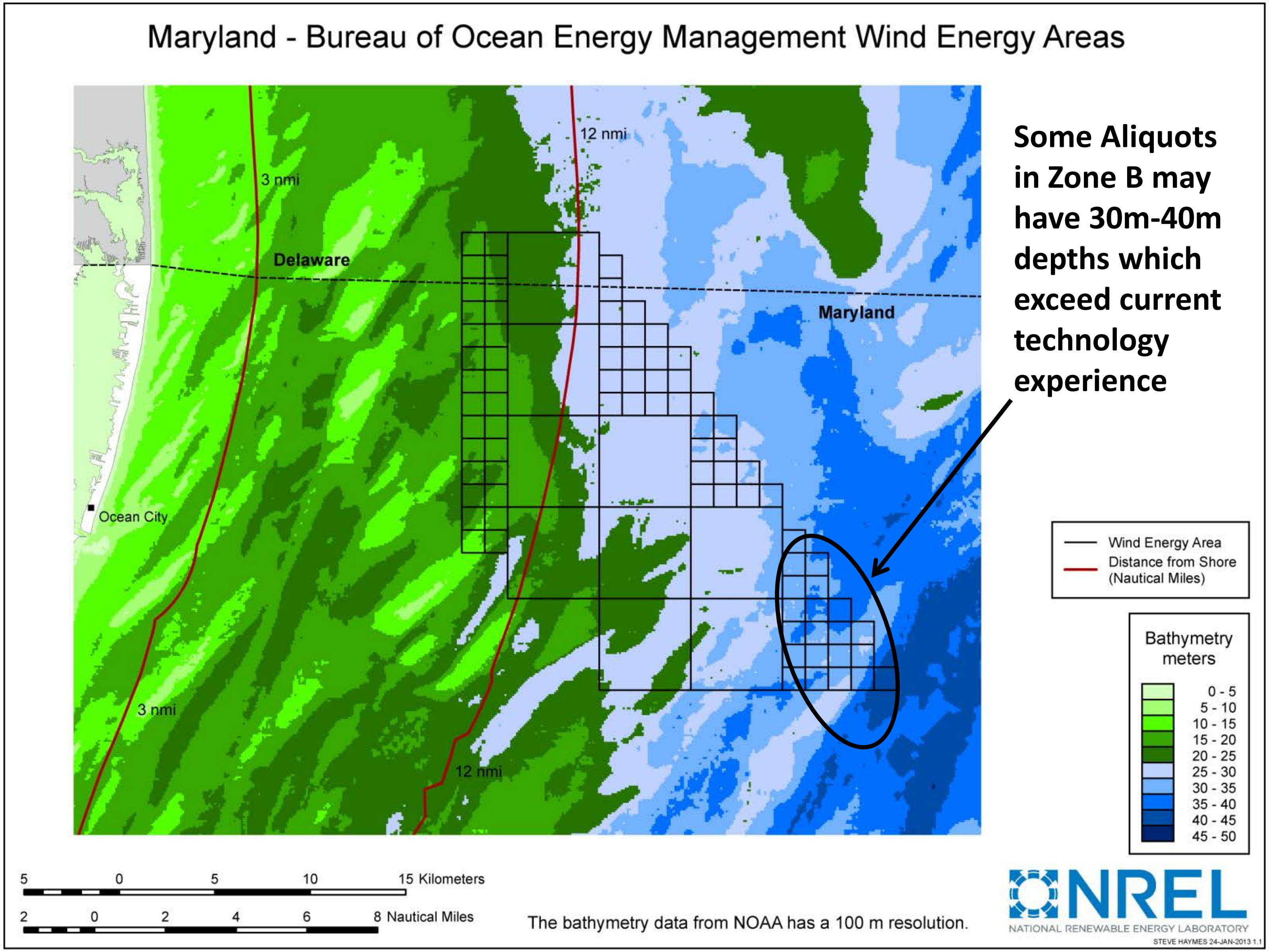


Annual Offshore Wind Rose for Maryland

Wind Zone Buffers

- **Maximum possible project size per zone is between 700MW and 900MW but significant project size reductions are necessary to accommodate wake losses**
- **Wake losses can be mitigated by increased turbine spacing, not developing some areas, or both**
- **Buffer areas are proposed by lessees for BOEM's approval**
- **Developers will create buffer zones for economic purposes in coordination with neighboring zones**

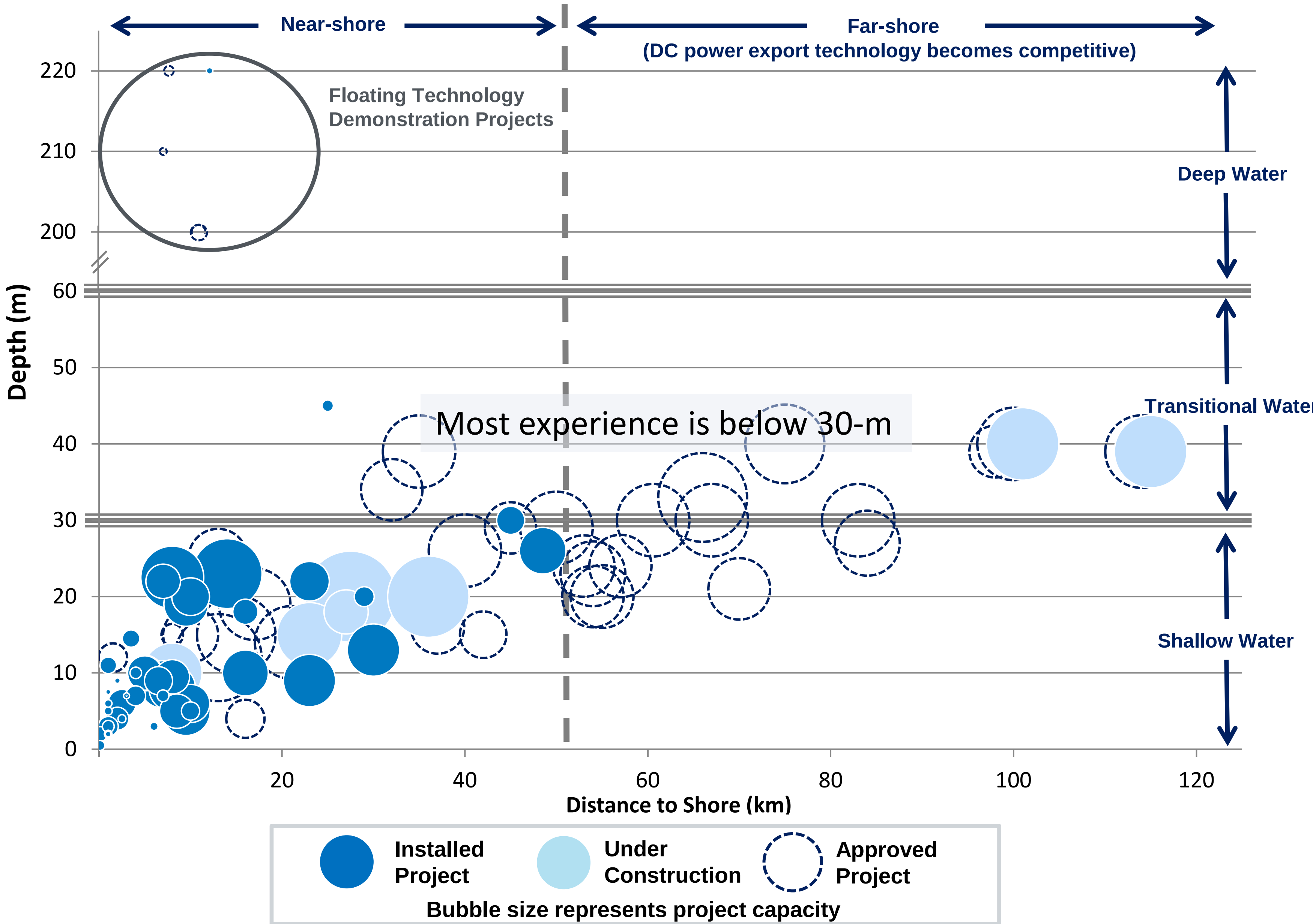
Bathymetry review



Some Aliquots in Zone B may have 30m-40m depths which exceed current technology experience

Offshore Wind Projects – Installed, Under Construction, and Planned

(data current as of Jan 2012)

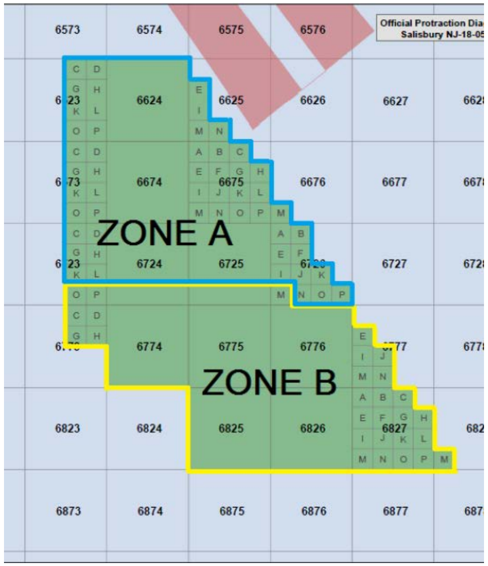


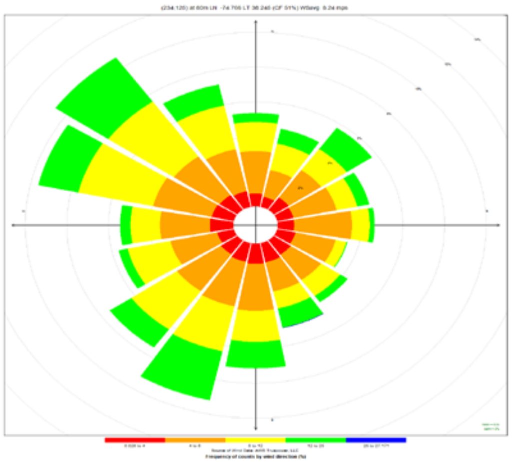
Qualitative Delineation Criteria

- **Transmission and distance to shore**
- **Shipping and navigation uses could impact some areas, especially in Zone B**
- **Fisheries may burden some areas of Zone B more heavily**
- **Military use did not have a significant impact on the delineation.**
- **Additional stakeholder input was received but did not impact the zone delineation outcome substantially**

NREL MD WEA Comparative Summary

Parameter	MD WEA Zone A	MD WEA Zone B
Capacity Factor(%)	40.95	41.54
Total Capacity(MW)	765	890
Total Area (km^2)	155.52	167.04
Potential burden from shipping conflicts	No	Yes
Potential burden from fishing conflicts	No	Yes
Potential burden from additional depth and distance to shore	No	Yes





NREL Conclusions

- **Maryland's proposed delineation provides approximately equal development zones**
  - using comprehensive selection criteria – multiple trade-offs
  - no major issues were found but some findings are subjective
  - Treatment of array effects and bathymetry need some further analysis
- **Zone B is 11 km^2 bigger and would have a 15% higher potential for gross energy yield due to better winds and lower losses**
- **Zone B is more heavily burdened by alternative use conflicts and deeper water**
- **Zone A would have slightly higher array losses**
- **Zone A would have reduced development costs due to shallower water and proximity to shore**
- **Buffer zones and inter-array spacing is key unknown**

Task 2 – NREL Zone Analysis for MD WEA

- **Next steps by NREL will assess:**
  - Optimal turbine placements scenarios, bathymetry, seasonal impacts, and wake losses
  - Alternative delineation scenarios to produce two zone balance to determine sensitivity to key parameters
  - Report on findings

Deliverables to BOEM

- Presentation of methodology and process — Jan 29, 2013
- Evaluation of proposed MD offshore wind zones from a technical resource perspective — Jan 29, 2013
- Draft report detailing: — May 2013
  - Wind resource data and computational models used
  - Assumptions
  - Results and Conclusions
  - Recommendations and next steps

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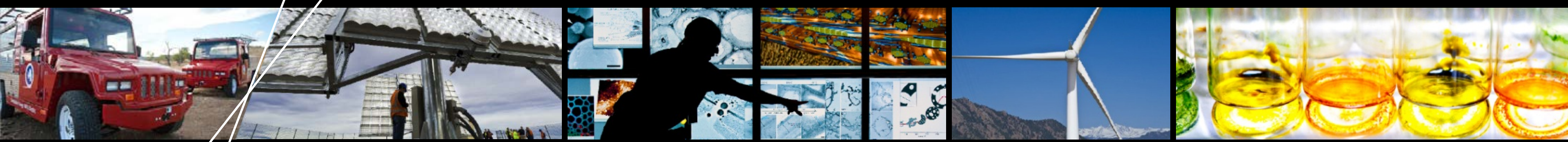

Questions?