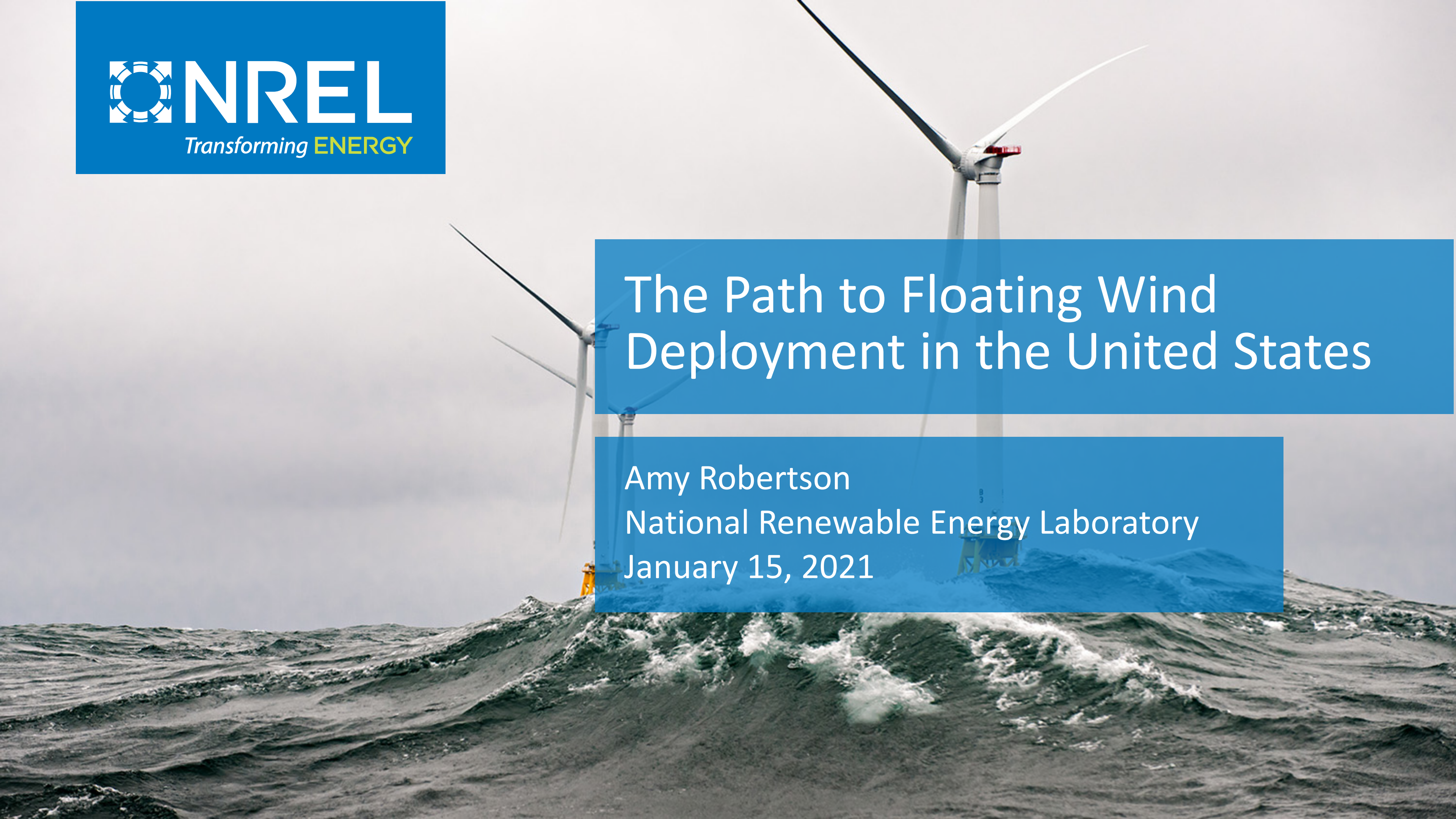


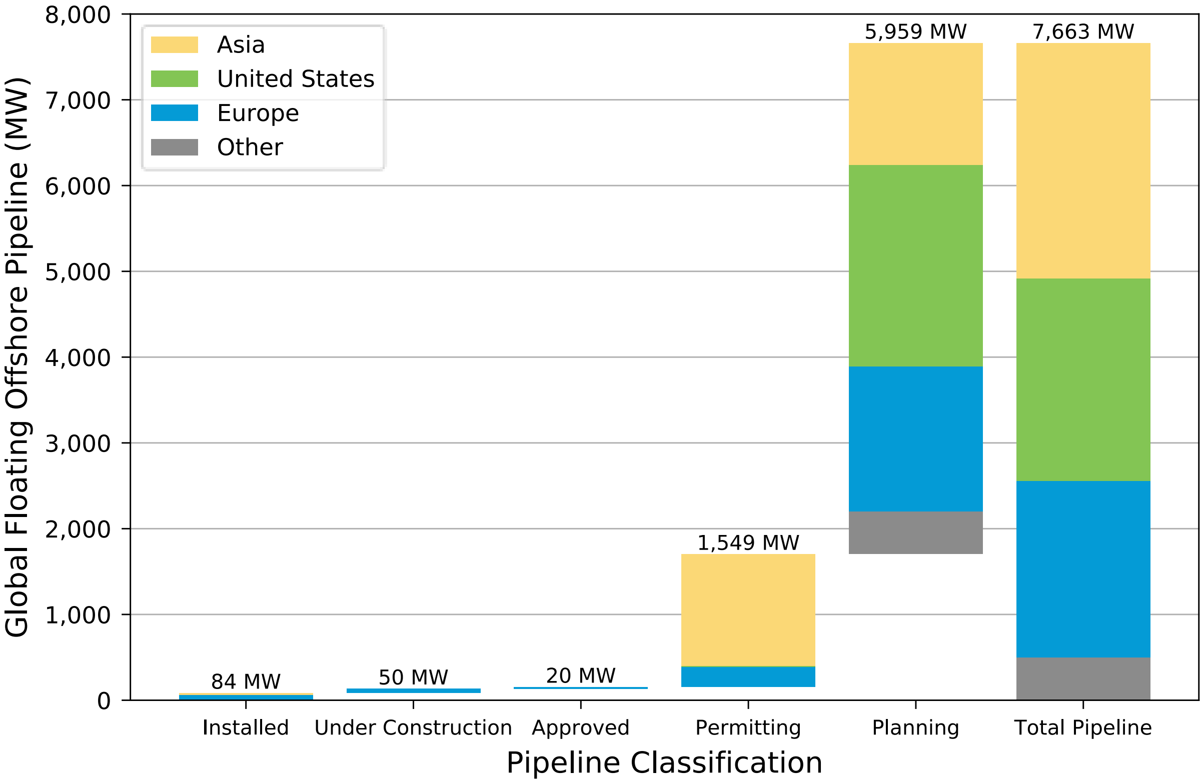
NREL
Transforming ENERGY

The Path to Floating Wind Deployment in the United States

Amy Robertson
National Renewable Energy Laboratory
January 15, 2021

US Floating Wind Status

Global Floating Offshore Wind Pipeline



- The total global floating offshore wind pipeline was 7,663 MW at the end of 2019, based on projects that have announced their planned capacity.
- 1,549 MW of floating offshore wind has reached the permitting stage.
- The 25.2-MW WindFloat Atlantic, the second floating project in Europe, became fully operational in 2020.
- The primary driver for pipeline expansion is the movement toward commercial-scale projects developing in Asia.

Floating Offshore Wind Pipeline

Region	Country	Installed (MW)	Under Construction (MW)	Approved (MW)	Permitting (MW)	Planning (MW)	Totals (MW)
Asia	China	0	0	0	0	16	**16**
	Japan	22.06	0	0	0	0	**22.06**
	South Korea	0	0	0	1,300	406	**1,706**
	Taiwan	0	0	0	0	1,000	**1,000**
Middle East	Saudi Arabia	0	0	0	0	500	**500**
Europe	France	2	0	10	108.5	256	**376.5**
	Germany	0	0	0	0	2.3	**2.3**
	Ireland	0	0	0	0	706	**706**
	Norway	2.9	0	10	101.6	0	**114.5**
	Portugal	25	0	0	0	0	**25**
	Spain	2.2	0	0.03	27	216.23	**245.46**
	Sweden	0.03	0	0	0	1	**1.03**
	United Kingdom	30	50	0	0	506	**586**
North America	United States	0	0	0	12	2,350	**2,362**
	Totals	**84.19**	**50**	**20.03**	**1,549.1**	**5,959.5**	**7,663**

Note: Values are estimated on developer's announced plant capacity and only include projects with specified CODs.

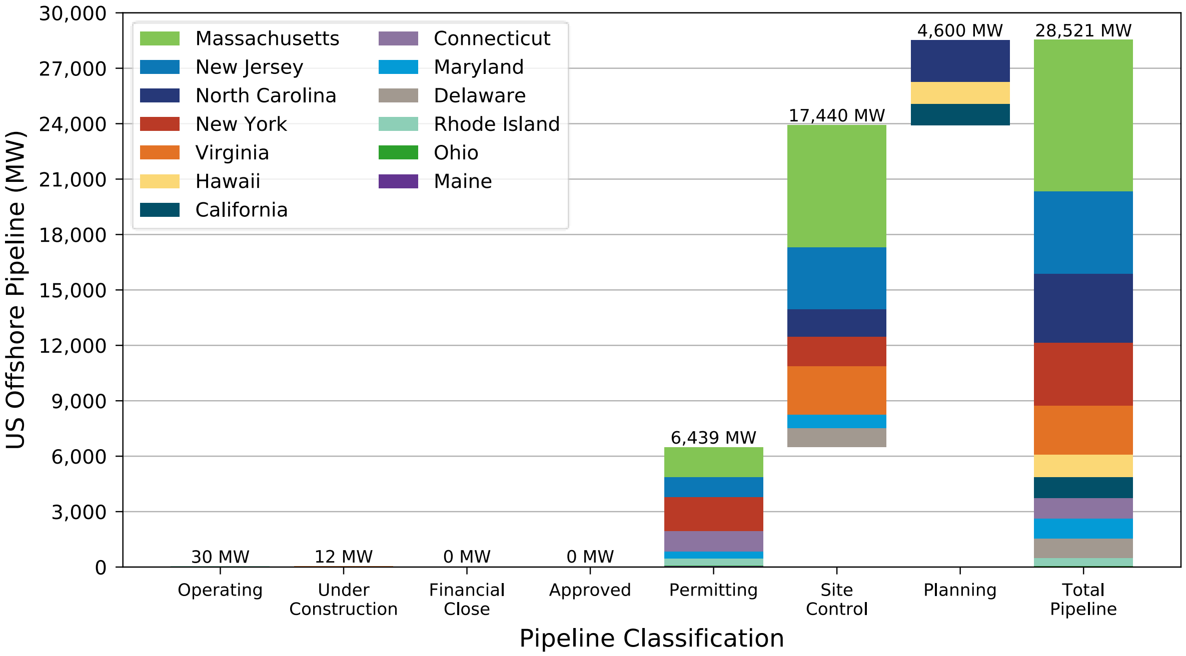
Block Island Windfarm

- Only offshore wind project in the U.S.
- Located off east coast of U.S. in Atlantic ocean.
- 3.8 miles from Block Island, Rhode Island
- Five Alstom Haliade 150-6MW turbines
- Operation launched in Dec. 2016

Block Island WindFarm

By Ionna22 - Own work, CC BY-SA 4.0,
https://commons.wikimedia.org/w/index.php?curid=60655658

2019 U.S. Offshore Wind Pipeline



- The U.S. offshore wind pipeline grew by 2,697 MW in 2019 to a total capacity of 28,521 MW.
- The U.S. offshore wind pipeline is broken down as follows:
  - 30 MW is operating, which was unchanged in 2019
  - 12 MW is under construction
  - 6,439 MW is in the permitting stage
  - 17,440 MW is under site control
  - 4,600 MW is in planning.

U.S. Offshore Fixed/Floating Regions

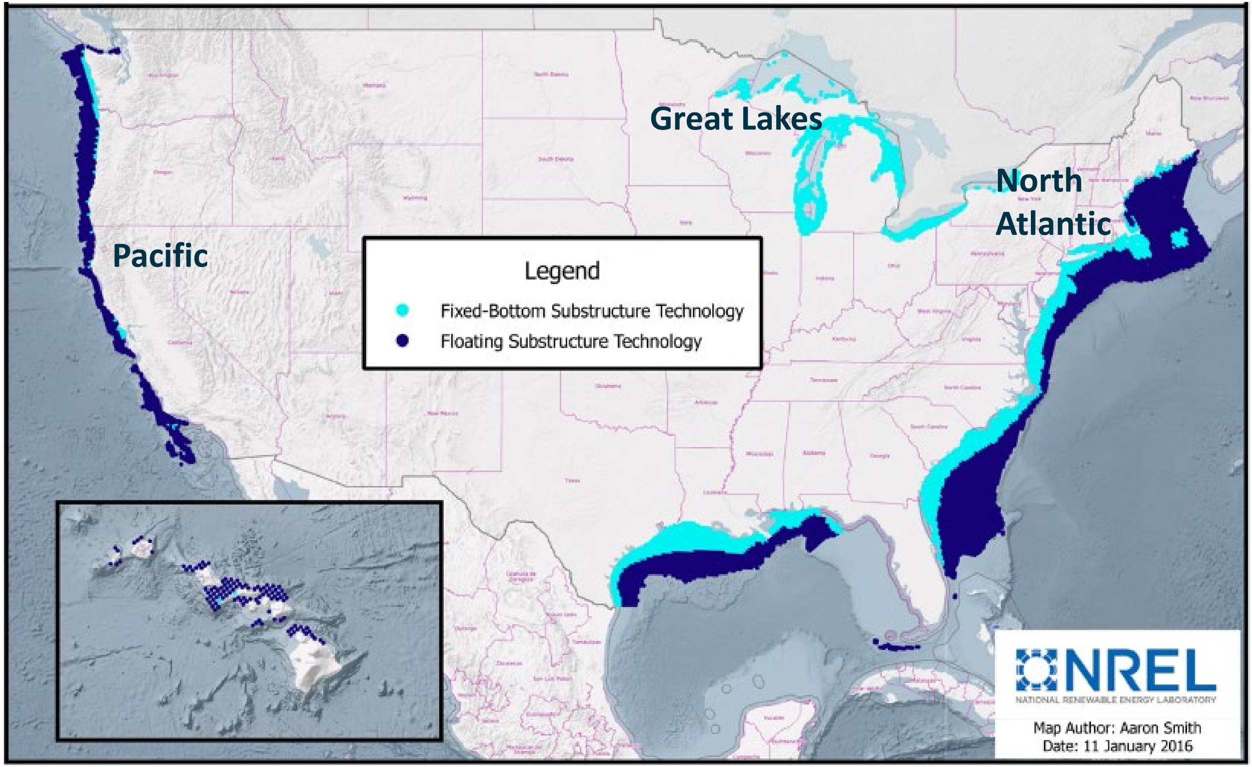
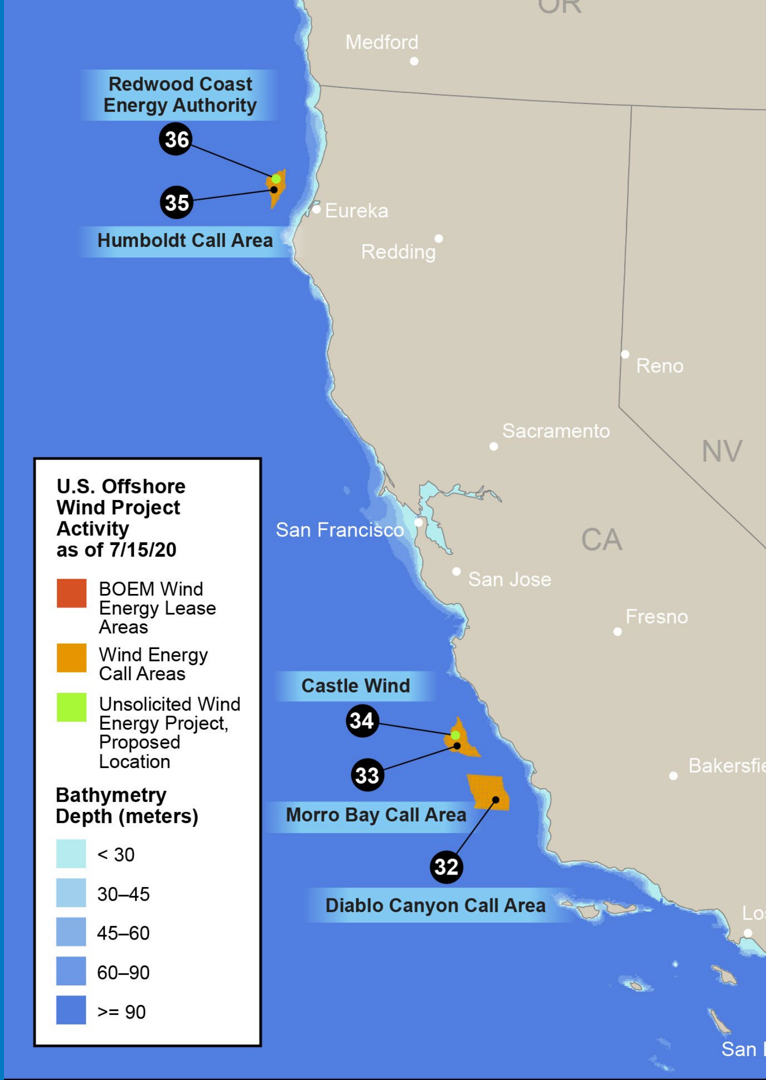


Figure credit: NREL

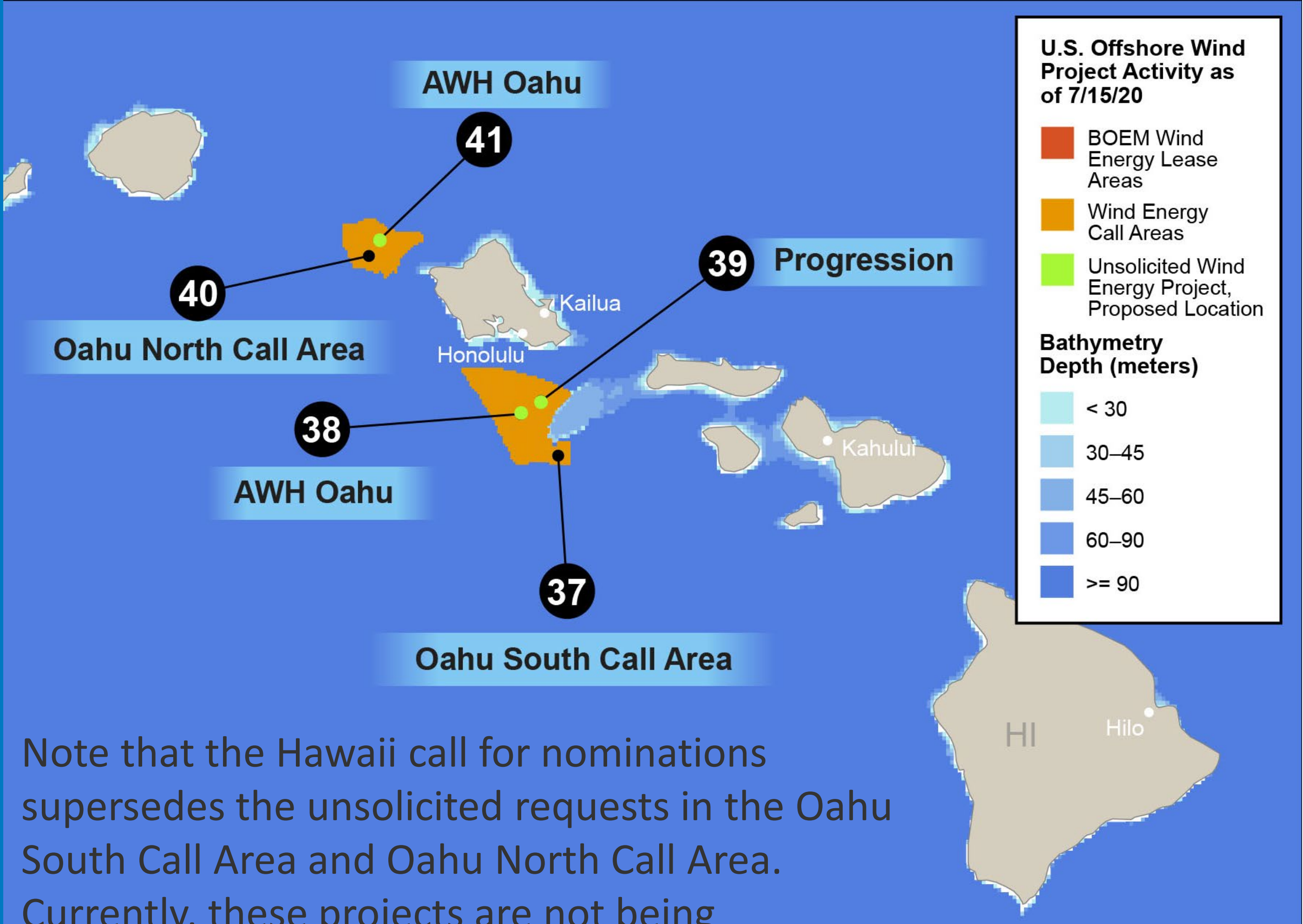
- 58% of the U.S. offshore wind resource is in water depths > 60m - floating foundations
- Floating wind will first be developed in Pacific and North Atlantic due to limited shallow-water locations
- Only one project in permitting stage – New England Aqua Ventus I

Locations of U.S. West Coast Offshore Wind Pipeline Activity and Call Areas as of July 2020

Note that the call for nominations supersedes the unsolicited requests in Morro Bay and Humboldt. Currently, these projects are not being processed by BOEM.



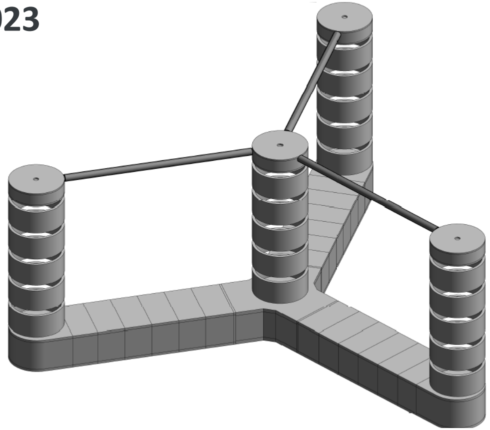
Locations of Hawaiian Offshore Wind Pipeline Activity and Call Areas as of July 2020



Note that the Hawaii call for nominations supersedes the unsolicited requests in the Oahu South Call Area and Oahu North Call Area. Currently, these projects are not being processed by BOEM.

New England Aqua Ventus I

- University of Maine VolturnUS Concrete semisubmersible design, has 55 patents
- US DOE Advanced Technology Demonstration Program for Offshore Wind
- RWE & Mitsubishi-DGC to invest $100 m
- Monhegan Island, Maine
- PPA contract signed 2020
- **Start construction 2022, COD 2023**



Locally produced VolturnUS segmental concrete hull

NREL – Floating Wind Research

Floating Offshore Wind Systems

- Building wind plants in water depths greater than 60 meters offers tremendous opportunity for wind deployment, including almost the entire west coast of the United States
- The deep offshore opportunity requires floating solutions that stretch the capabilities for system design and optimization
- NREL's offshore wind turbine research capabilities focus on the short-term and long-term needs of the industry

Research Focus Areas:

- Design Tools and Methods
- Technology Innovation
- Adoption

- *20 Awards Total, $17.3M in Funding*
- *7 of 20 projects awarded focused on floating wind*
- *NREL involved in 12 out of 20 projects*

Pillar 1:

OW Plant and Technology Advancement

1.1 Wind Farm Control and Layout Optimization

1.3 Advanced Moorings

1.4 Grid Stability Impacts

Pillar 2:

OSW Power Resource and Physical Site Characterization

2.1 National Offshore Wind Resource Dataset

2.2 Metocean Reference Site

Pillar 3:

Installation, O&M, and Supply Chain Solutions

3.2 Digital Twins

3.3 Supply Chain Roadmap

Impact:

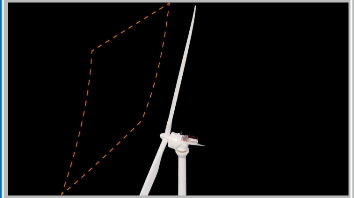
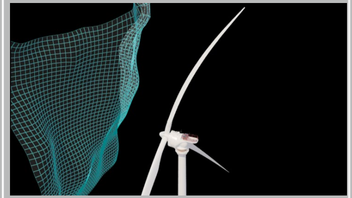
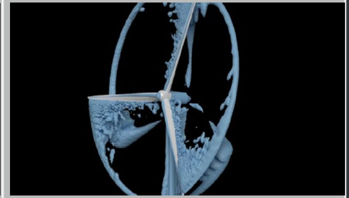
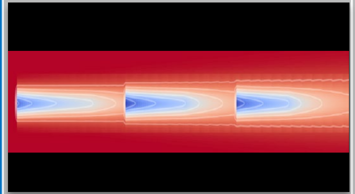
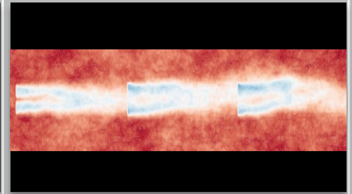
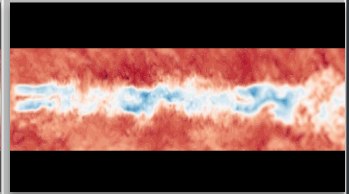
- *Produce innovations that directly respond to technical and supply chain barriers*
- *Build strong networks connecting technology innovators, investors, and industry*
- *Increase U.S. content and job opportunities*

Design Tools and Methods

- Metocean Characterization
- Loads/Performance
- Techno-Economic
- Design Optimization
- Verification & Validation
- Experimental Methods and Measurements

Loads/Performance Toolset

Model Fidelity →

Application	Design Exploration	Detailed Design	Highly Resolving
Single Turbine Performance and Loads	WISDEM 	OpenFAST 	SOWFA/ExaWind 
Full Wind-Plant Performance and Loads	FLORIS 	FAST.Farm, WindSE 	SOWFA/ExaWind 

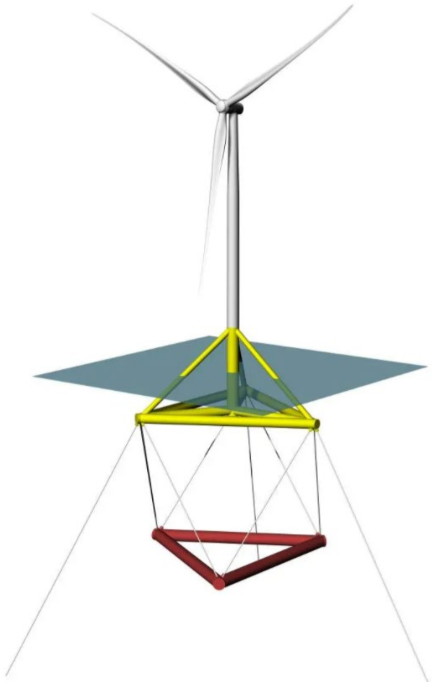
Advanced FOWT Modeling Capabilities

CHALLENGE

Innovative floating designs are sought to provide significant cost-reduction pathways that do not rely on overly robust offshore oil and gas production solutions. To find these innovative solutions, modeling capabilities are needed that can accurately represent their novel design components—to assess their feasibility and impact.

APPROACH

- Upgrade OpenFAST to compute floating substructure flexibility and member-level loads -> critical to enable design of floating substructures that are streamlined, flexible, and cost-effective
- Include new types of members and joints to represent novel FOWT design components

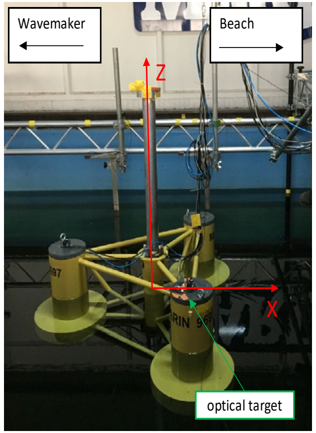


Stiesdal TetraSpar

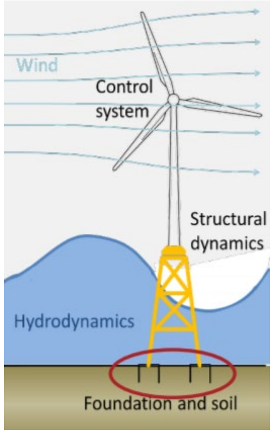
OC6 Project – Offshore Modeling Tool Validation

Objective: Verify and validate engineering-level, coupled modeling tools used to design offshore wind systems.

- **More focused validation projects**
  - Based on issues identified in previous OC3-OC5 projects
  - Focus on aerodynamics, hydrodynamics separately; as well as combined
- **Three-way validation** performed between engineering-level tools, CFD, and measurement data
  - Goal is to use CFD to understand reason for inaccuracies in engineering tools
  - Engineering tools improved based on findings from comparison to CFD
  - Prescription for methodology for using CFD to tune engineering models
- **Also serve as a validation of CFD for offshore wind**



Phase I:
Nonlinear Hydrodynamics
Jan 2019 – Dec 2019
Jan 2019 – Feb 2020
(OWN TESTING)



Phase II:
Soil/Structure Interaction
Jan 2020 – June 2020
Mar 2020 – Feb 2021
(REDWIN)

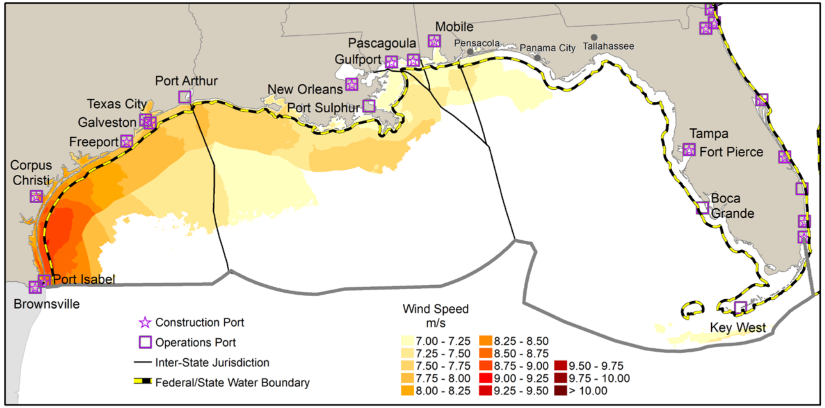
Phase III:
Aerodynamics under Motion
Mar 2021 – Mar 2022
(UNAFLOW)

Phase IV:
Hydrodynamic Challenges
Mar 2022 – Mar 2023
(STIESDAL)

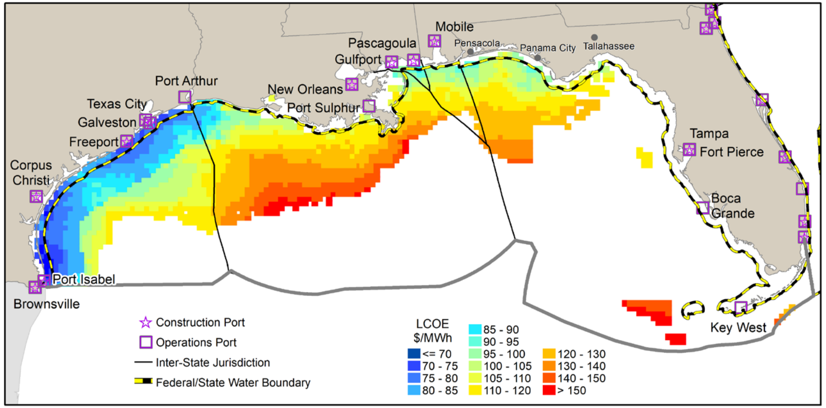
IEA Task 30 (OC6): Jan 2019 – Jan 2023

Offshore Regional Cost Analyzer (ORCA)

- Costs analysis to demonstrate commercial competitiveness for fixed and floating in all U.S. regions
- NREL's techno-economic modeling capability (offshore regional cost analyzer [ORCA])is undergoing continuous upgrades – FY 19: temporal enhancements to 2032, upgrades to 15 MW turbines, improved floating technology.
- Recent Activities
  - DOE/DOI Offshore Wind Strategy - 2016
  - Floating commercial technology in Maine (2014 – 2019)
  - Vineyard Wind Assessment– Subsidized Price and Revenue Streams Accounting
  - California floating cost study 2016
  - Oregon floating cost study 2019
  - Gulf of Mexico economic analysis for 2030 fixed turbines (2017 – 2019)



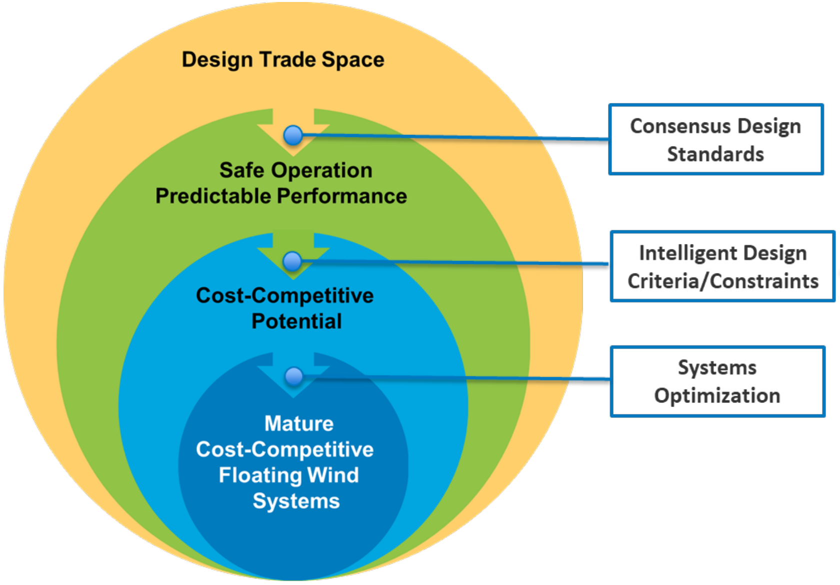
Gulf of Mexico – Offshore Wind Resource



Gulf of Mexico – Offshore Wind Levelized Cost of Energy

A Systems Engineering Vision For Floating Offshore Wind Cost Optimization

How do we narrow the design options to achieve potentially cost competitive designs?



- Minimize platform motion
- Site Independence – Universal design
- Manufacturability
- Deployability
- Maintainability
- Scalability
- Weight minimization/low CG
- Decommissioning

REF: https://www.sciencedirect.com/science/article/abs/pii/S1755008420300132

ARPA-E ATLANTIS Program

13 Awards, 2 years, $26M Funding

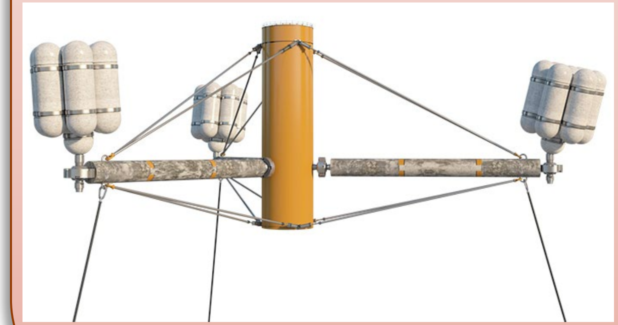
Use a controls co-design (CCD) approach to achieve more optimized FOWT designs

NREL-led projects:

TA1: New Designs

***USFLOWT** – Use CCD to drastically reduce size, mass, and cost of a novel floating support structure*

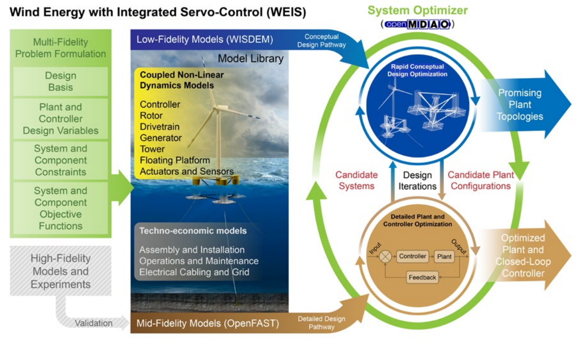
PI: Senu Sirnivas



TA2: Software Tools

***WEIS** – Revolutionary open-source toolset for floating wind controls co-design*

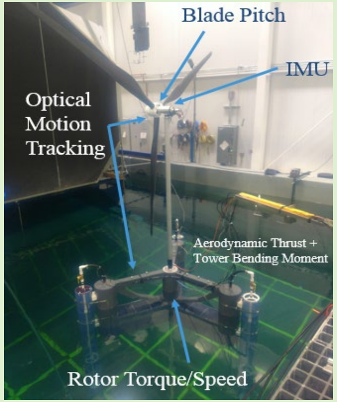
PI: Alan Wright



TA3: Experiments

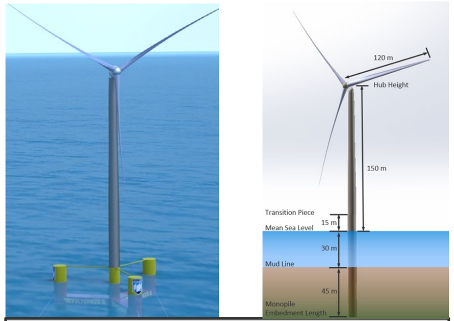
***FOCAL** – Four campaigns to validate floating control methods for turbine and platform*

PI: Amy Robertson

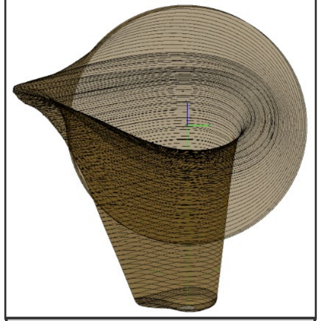


International Energy Agency (IEA) Wind 15-MW Reference Wind Turbine

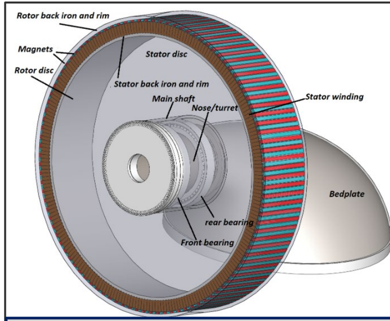
SYSTEMS ENGINEERING AND OPTIMIZATION



Monopile and Semisubmersible Support Structures



Detailed Blade Design



PMDD Generator Design

CHALLENGE

Wind energy researchers and engineers need openly defined reference wind turbines (RWTs) as the platforms on which to publicly demonstrate and share advances in modeling and design. The existing slate of RWTs has not kept pace with the power-rating growth of commercial wind turbines.

APPROACH

Under coordination of IEA Wind Task 37, NREL led the design effort of a new, modern, 15-MW RWT featuring both fixed-bottom and floating-support structures; the RWT is completely open and documented.

IMPACT

Enables collaboration with industry without sharing intellectual property, provides a common baseline model for which research teams around the world can demonstrate research advances, and establishes an education resource for understanding the fundamentals of wind turbine design.

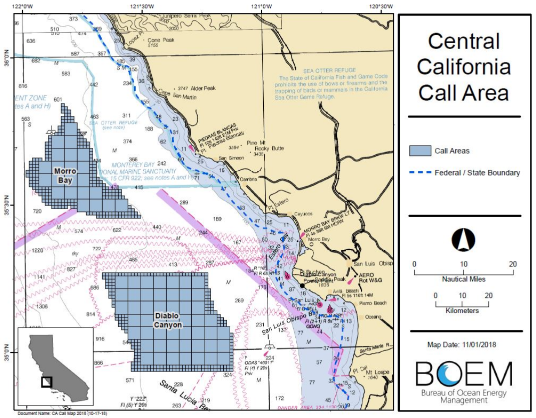
Offshore Metocean Characterization

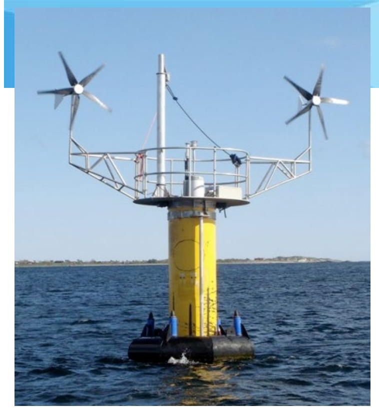
Challenges

- Marine boundary layer (wind shear, stability, and turbulence) is not well characterized in US
- External design conditions not fully understood
- Resource assessments rely on single ensemble set-ups and sparse measurements for validation
- Standard protocols do not exist

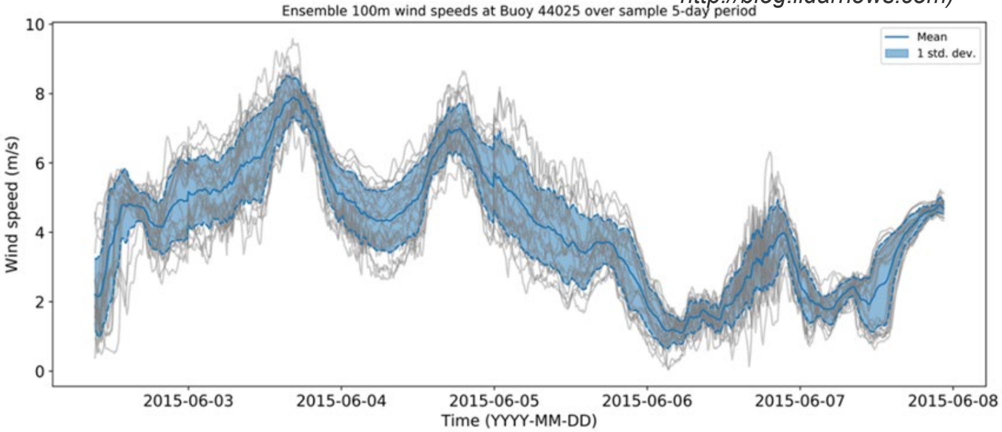
New Research for Metocean Characterization:

- New U.S. Mesoscale Resource Analysis (WRF) with ensemble averaging at all temporal scales – National Study beginning 2020
- Measurements needed to validate metocean conditions at hub height (LIDAR)
- Methodology to extrapolate buoy data and integrate multiple data sources for validation (e.g. satellites, met towers) and correct bias
- U.S. standard protocols for offshore wind (OCRP-3)





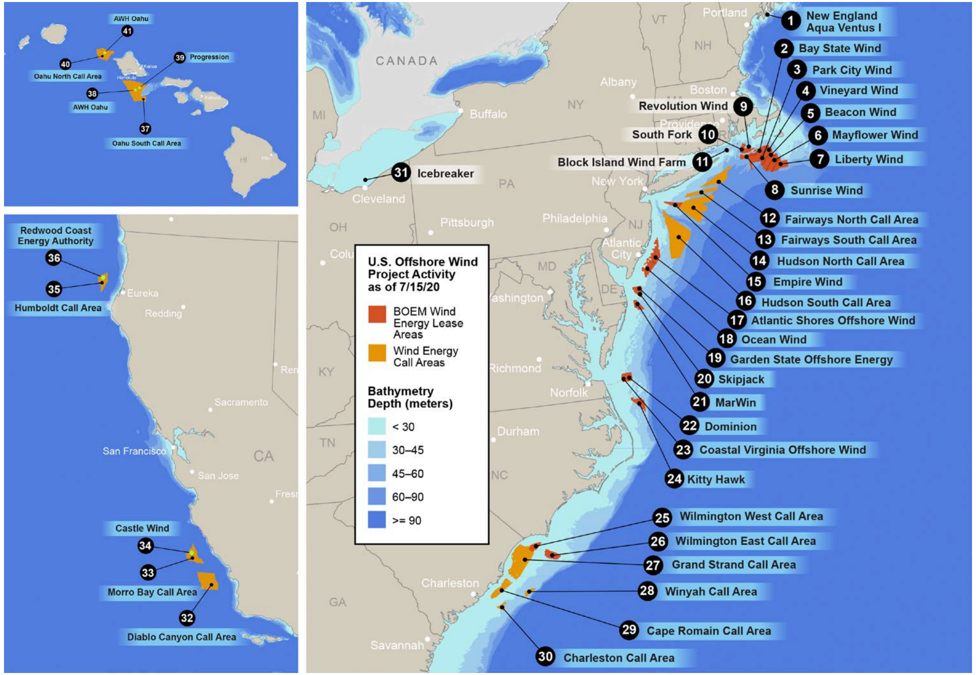
Floating wind LIDAR; The Natural Power Sea ZephIR (from http://blog.lidarnews.com)

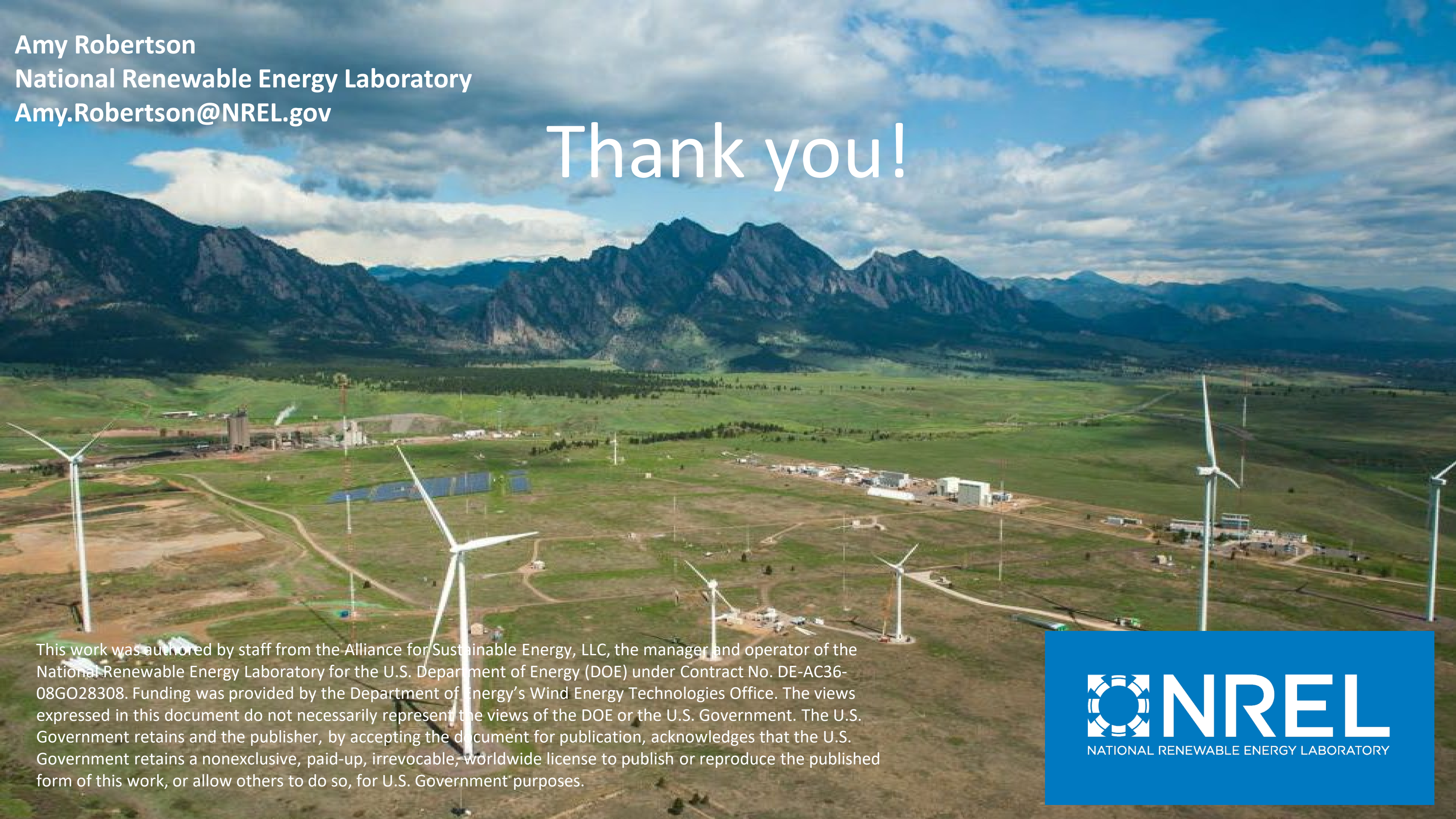


Rutgers Collaboration: Multiple ensembles of WRF generated wind speed data at 100 meters, plotted over a six-day period at NDBC Buoy 44025 off the coast of New Jersey.

Developing a National Strategy for Offshore Wind Grid Integration

- **Objective**: Coordinate, develop and vet a strategy for expanding the funding base of research and use of NREL ARIES facilities specific to the grid integration (GI) needs of the rapidly expanding offshore wind sector (OSW) in the U.S.
- **Justification:** OSW is rapidly expanding in the US and known GI challenges need to be tackled
  - Need to develop strategic solutions for OSW grid integration (GI) throughout the US.
  - OSW GI challenges and solutions vary among US OSW regions (East Coast, West Coast, Gulf of Mexico, Hawaii, and Great Lakes).
  - Need to investigate a range of scenarios across these two approaches to develop a long- term strategy to solve GI challenges in various regions.





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