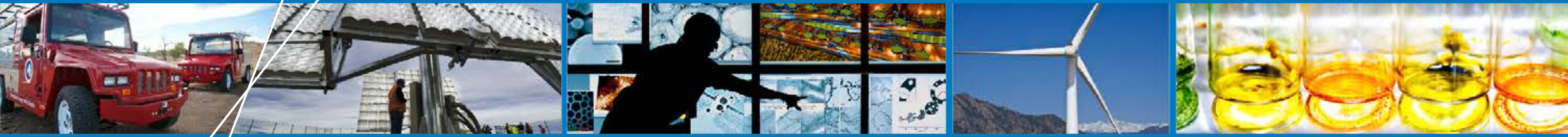
BOEM Offshore Renewable Energy Workshop:

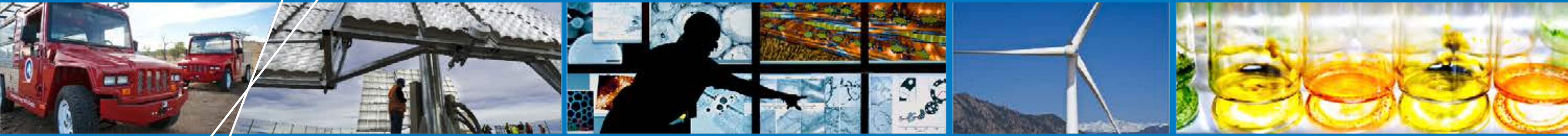
Day 1 - Offshore Wind



BOEM Offshore Renewable Energy Workshop
Hyatt Regency Sacramento
1209 L Street
Sacramento California 95814
July 29-30, 2014

Sponsor: Bureau of Ocean Energy Management
Training Coordinator: National Renewable Energy Laboratory

BOEM Offshore Renewable Energy Workshop: Opening Session



Walt Musial, NREL

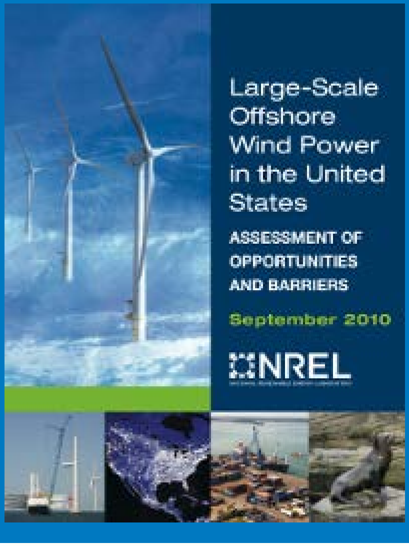
Jean Thurston, BOEM

July 29, 2014

DOI and DOE Collaborate on Energy Strategy

On June 29, 2010, the U.S. Department of Energy (DOE) and the U.S. Department of the Interior signed an MOU entitled the “Coordinated Deployment of Offshore Wind and Marine Hydrokinetic Technologies on the United States Outer Continental Shelf.”

DOE and DOI jointly announce *A National Offshore Wind Strategy* and over $200M in Funding Opportunities

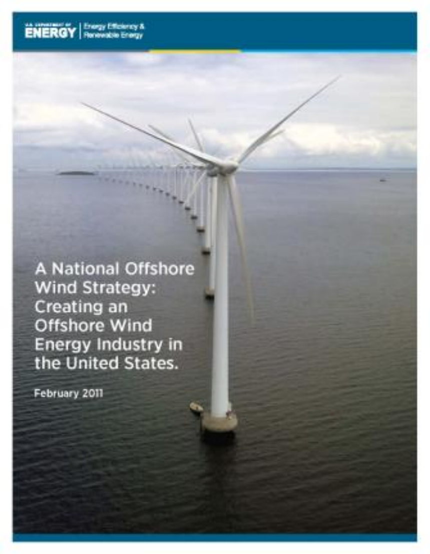


Large-Scale Offshore Wind Power in the United States

ASSESSMENT OF OPPORTUNITIES AND BARRIERS

September 2010

NREL



U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

A National Offshore Wind Strategy: Creating an Offshore Wind Energy Industry in the United States.

February 2011

National Renewable Energy Laboratory

DOE's National Wind Technology Center Overview

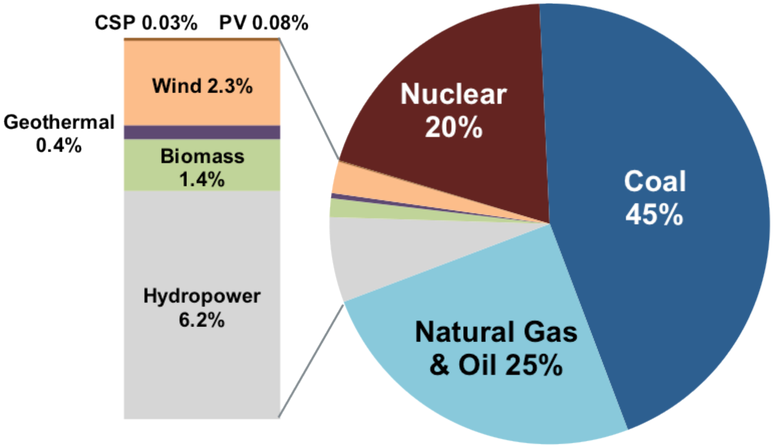
- Primary wind technology center inside the National Renewable Energy Laboratory (NREL)
- Established in1977
- Approx. 150 staff on-site
- Budget approx. $40M
- Partnerships with industry
- Wind and Marine Hydrokinetic Technology

- Modern utility-scale turbines
- Pioneers in wind component testing
  - Blade Testing
  - Dynamometer drivetrain testing
  - Controls research turbines (CART)
- Leadership roles for international standards
- Leading development of design and analysis codes

Why Renewables?

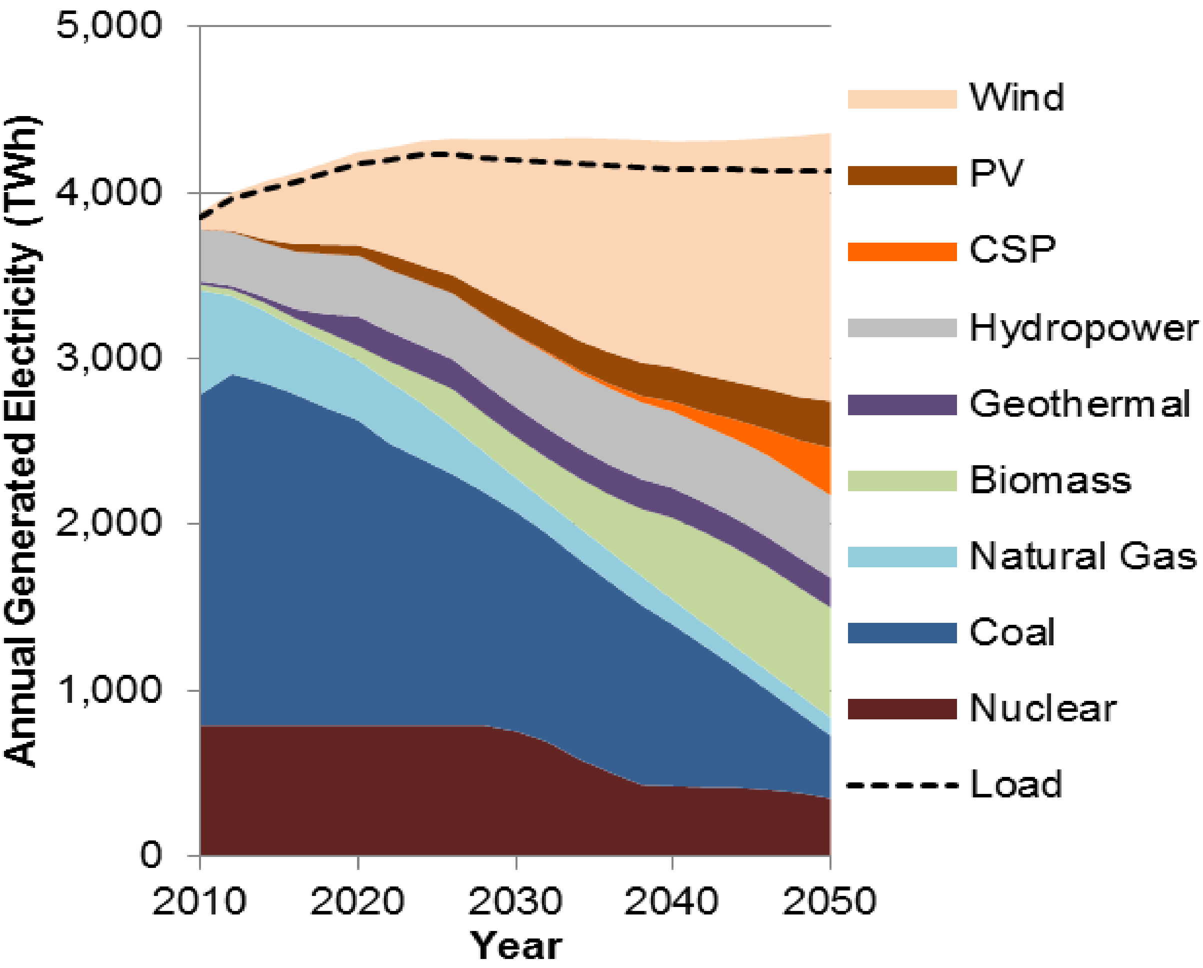
- Energy security and diversifying the domestic portfolio
- Clean energy and public health
- Regional economic development and jobs
- Carbon reduction and climate change mitigation
- Reduction in water use

2010 Electricity Generation Mix



Source: Renewable Electricity Futures (2012)

NREL: Renewable generation resources could adequately supply 80% of total U.S. electricity generation by 2050



- Significant adoption of **energy efficiency**
- Some **shift in transportation energy away from petroleum** and toward electric vehicles
- **Enhanced grid flexibility** in the way electricity is generated and used
- **Expanded transmission** infrastructure and improved access
- **Standard land-ocean use exclusions** for project siting and permitting for renewable electricity development and transmission expansion

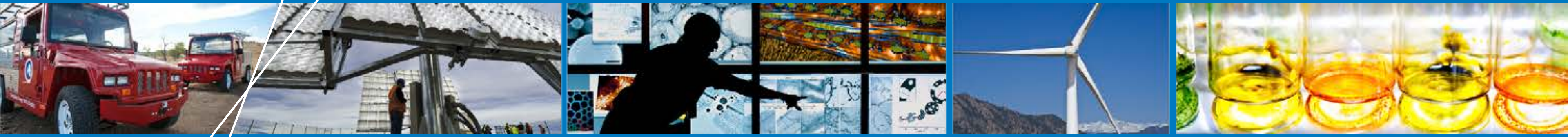
Renewable Electricity Futures Study , National Renewable Energy Laboratory. (2012). Renewable Electricity Futures Study. Hand, M.M.; Baldwin, S.; DeMeo, E.; Reilly, J.M.; Mai, T.; Arent, D.; Porro, G.; Meshek, M.; Sandor, D. eds. 4 vols. NREL/TP-6A20-52409. Golden, CO: National Renewable Energy Laboratory. http://www.nrel.gov/analysis/re_futures/.

Meeting Goals and Objectives

- **Provide technical information on offshore renewables**
  - Offshore Wind- Day 1
  - Ocean Energy - Day 2
- **Questions and discussion are encouraged**

BOEM Offshore Renewable Energy Workshop:

Offshore Wind Technology Overview



Walt Musial, NREL

July 29, 2014

Wind Energy: A California Legacy

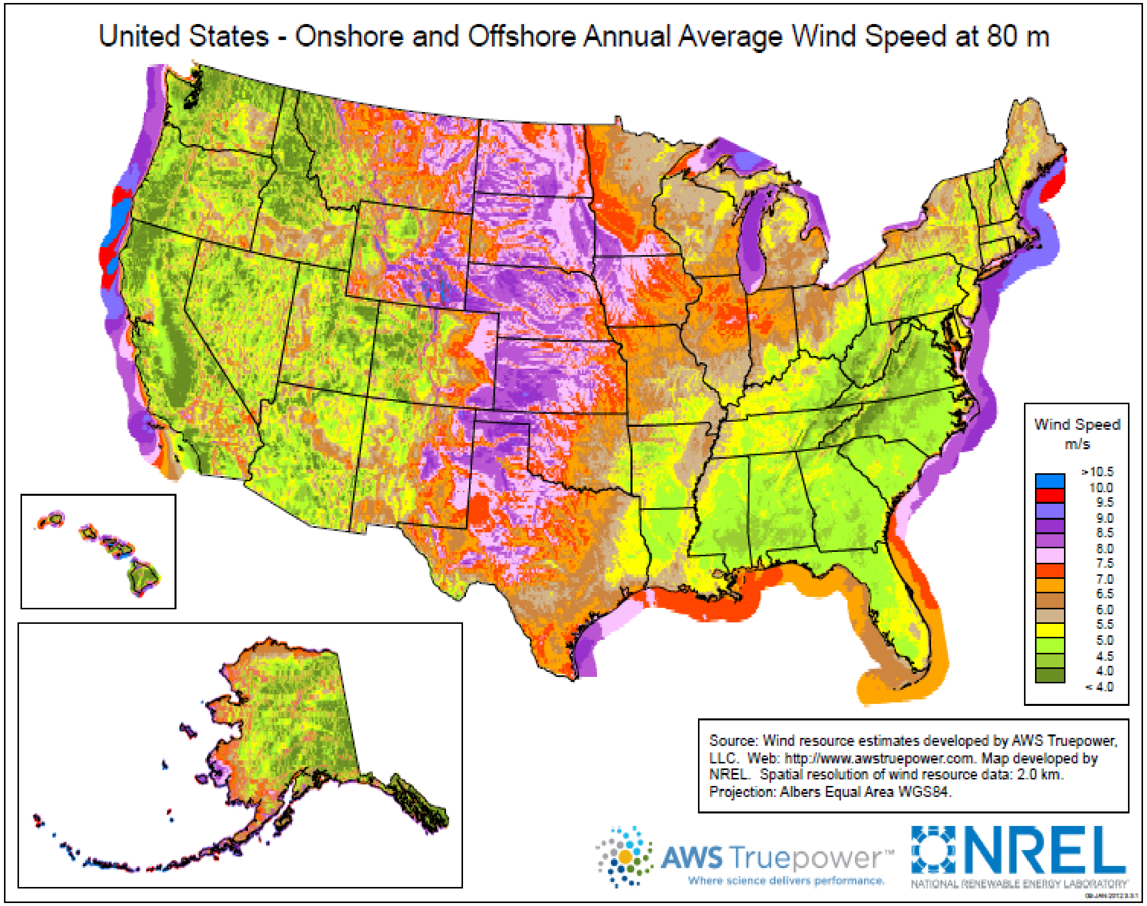
Above: US Windpower 56-100 Wind Turbines Circa 1985

Right: Energy Sciences ESI-80 Installation Team Tehachapi Pass December 31, 1984

- Global wind energy industry began in California
- The policies of Governor Brown and President Carter created today's wind turbines
- Over 10,000 wind turbines were installed in California between 1981 and 1985
- In 1985, 90% of all wind turbines in the world were in California!

Why Offshore Wind?

US Energy Potential: ***Land: 9,000 GW*** **|** ***Offshore: 4,000 GW***



Wind Resource Map of the United States: Graphic Source: NREL

- ✓ Stronger winds
- ✓ Generation close to large coastal populations
- ✓ Diversify energy generation portfolio
- ✓ Offshore wind can have higher capacity value
- ✓ Can contribute to lower grid congestion and market price suppression
- ✓ Positive job benefits
- ✓ Revitalizes ports and domestic manufacturing
- ✓ Transportation and construction are less constrained

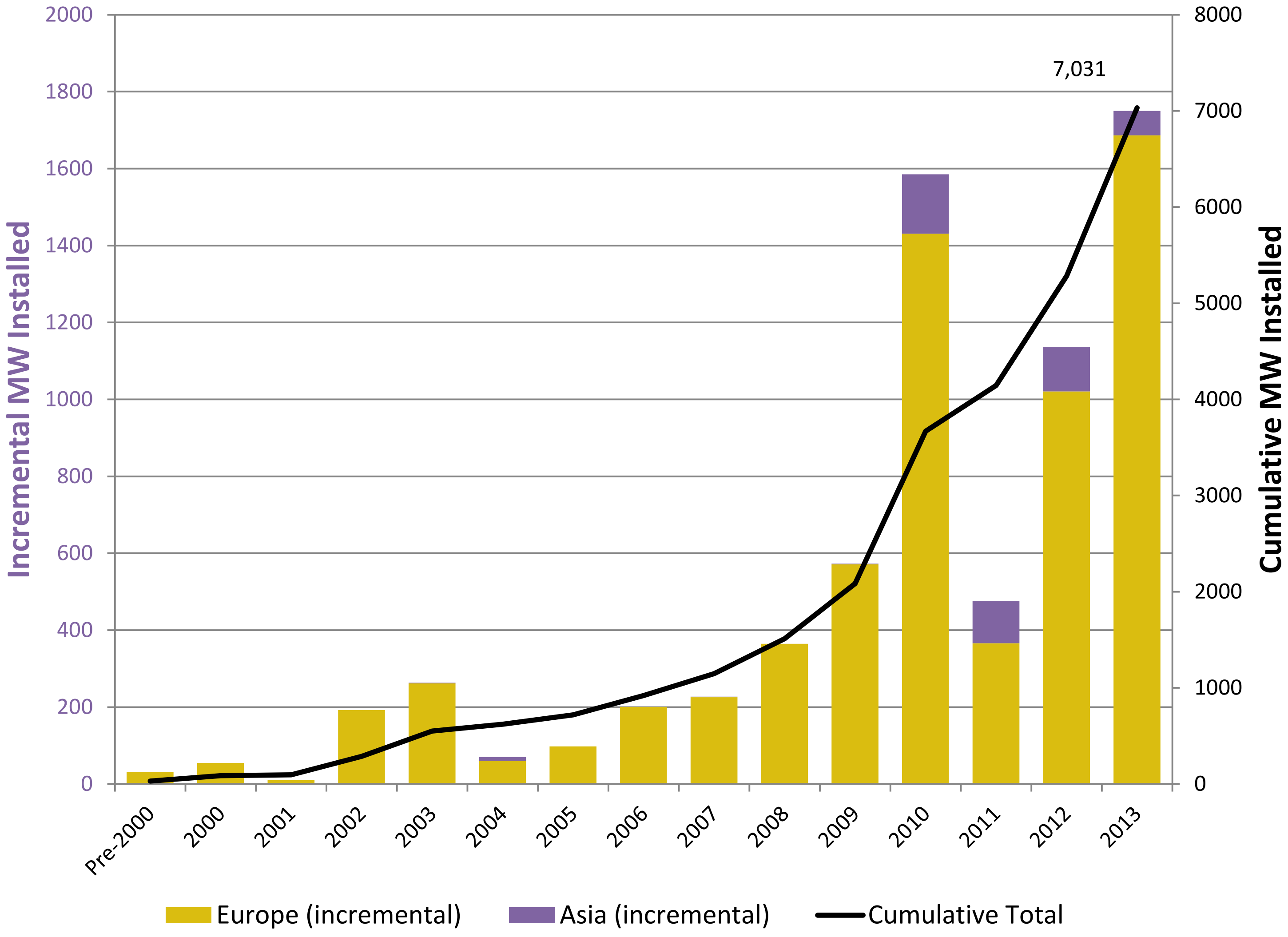
Offshore Wind Technology Status

Alpha Ventus – RePower 5-MW Turbine

Siemens 2.0 MW Turbines Middlegrunden, DK

- **104 operating projects, 7,031 MW installed (end of 2013)**
- **About 100 are on fixed bottom support structures in shallow or mid-depth water**
- **Average turbine capacity 3.94 MW (2 – 8 MW turbines upwind rotors)**
- **80+ meter towers**
- **Modular geared drive trains >> direct drive generators coming**
- **Higher capacity factors 40% +**
- **Higher cost initially**
- **Challenging O&M**
- **Mature marine industries leveraged:**
  - **Offshore Oil and gas**
  - **Submarine cable**

Global Offshore Wind Installations



All Offshore Wind Projects are in Europe and Asia

Region	Country	Number of Operational Projects	Total Capacity (MW)	Total Number of Turbines Installed
Asia	China	15	404	158
	Japan	9	50	27
	South Korea	2	5	2
Europe	Belgium	6	571	135
	Denmark	17	1,274	517
	Finland	3	32	11
	Germany	8	516	115
	Ireland	1	25	7
	Netherlands	4	247	128
	Norway	1	2	1
	Portugal	1	2	1
	Spain	1	5	1
	Sweden	6	212	91
	United Kingdom	30	3,686	1,083
	Total	104	7,031	2,277

Graphic Source: NREL

Total capacity in the offshore wind project regulatory pipeline (end of 2012) exceeds 200 GWs worldwide

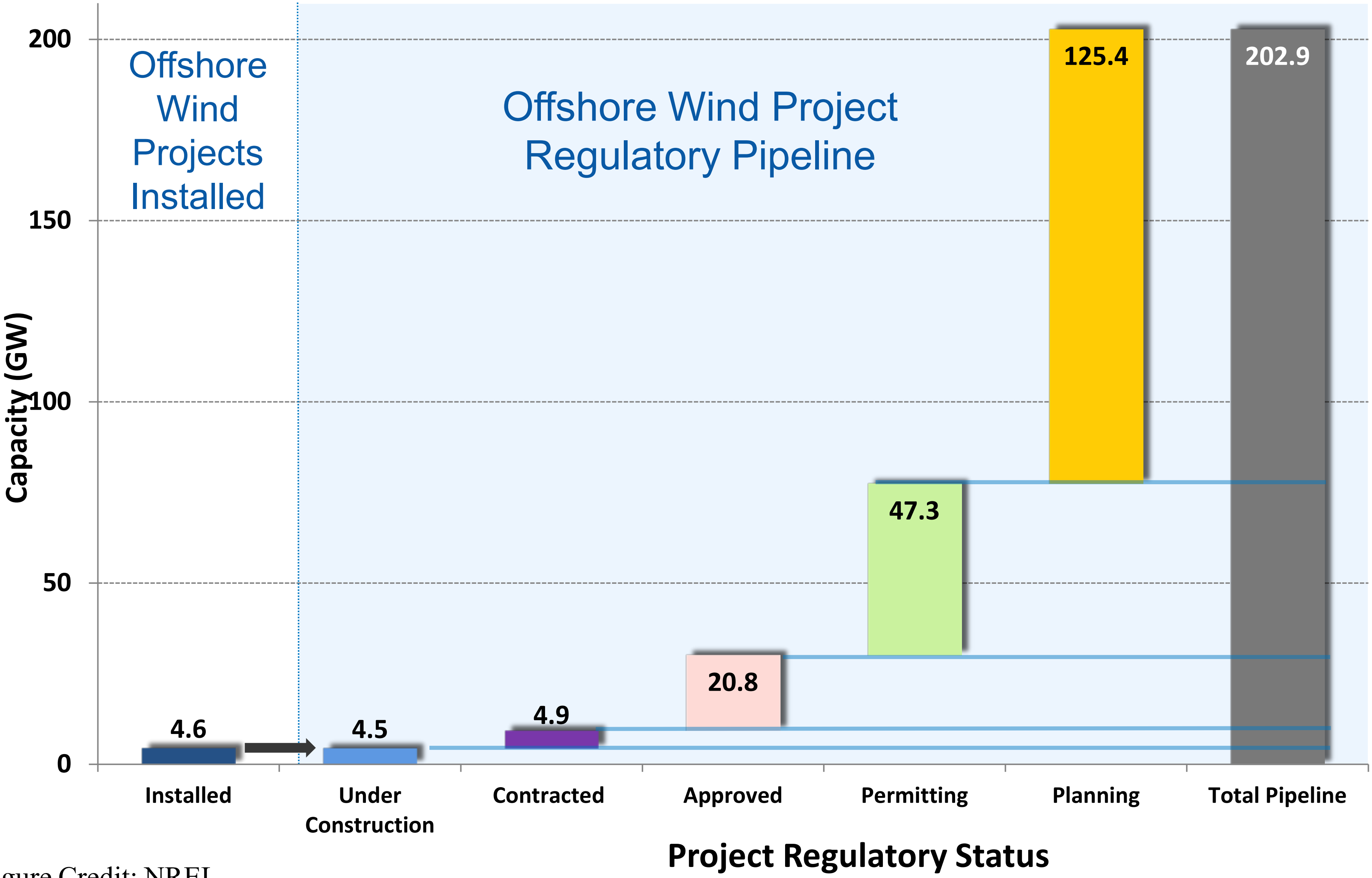
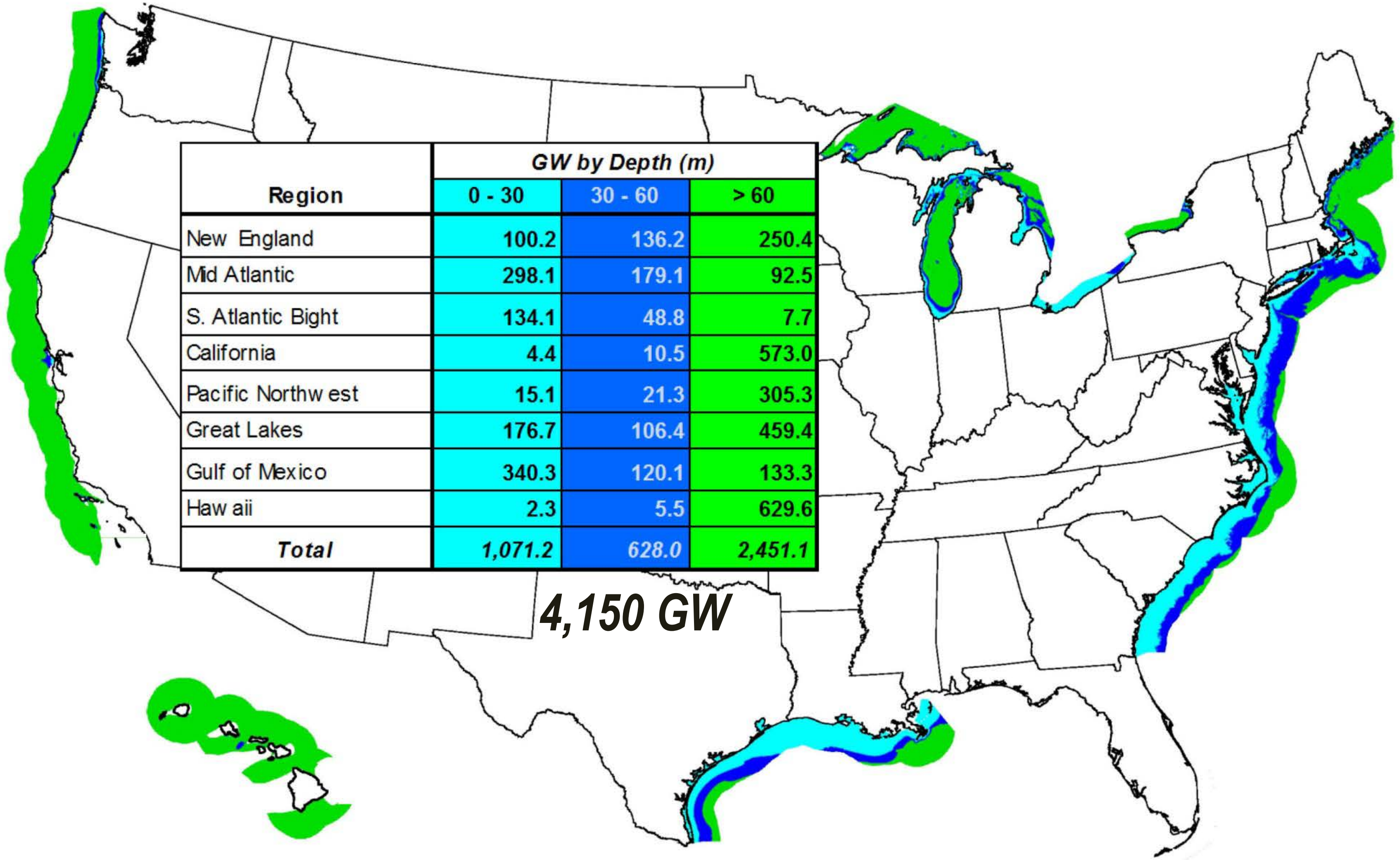


Figure Credit: NREL

U.S. Gross Offshore Wind Resource

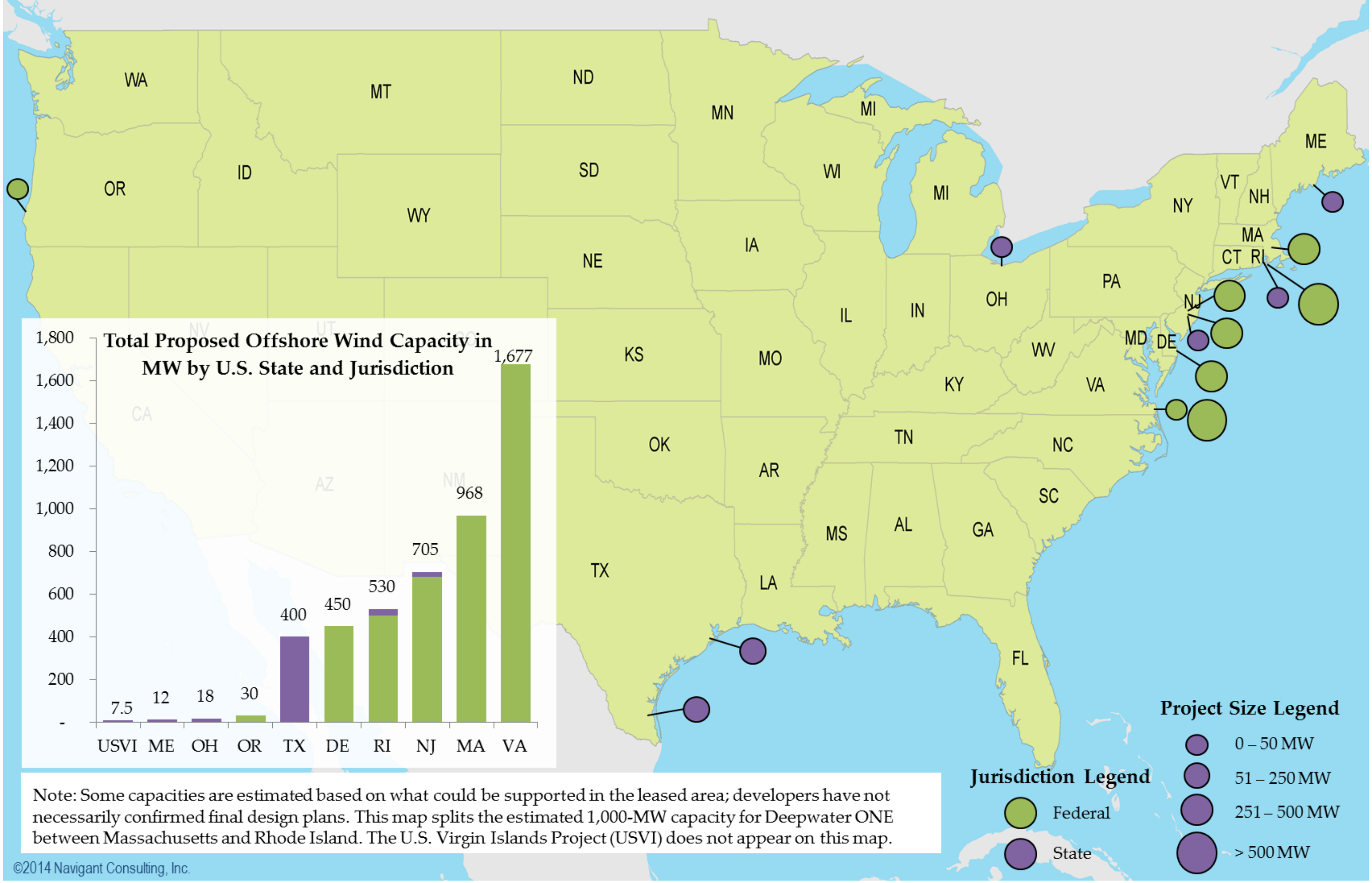


Region	GW by Depth (m)		
	0 - 30	30 - 60	> 60
New England	100.2	136.2	250.4
Mid Atlantic	298.1	179.1	92.5
S. Atlantic Bight	134.1	48.8	7.7
California	4.4	10.5	573.0
Pacific Northwest	15.1	21.3	305.3
Great Lakes	176.7	106.4	459.4
Gulf of Mexico	340.3	120.1	133.3
Hawaii	2.3	5.5	629.6
Total	***1,071.2***	***628.0***	***2,451.1***

4,150 GW

Graphic Source: NREL

Summary of US Proposed Offshore Wind Projects



Note: Some capacities are estimated based on what could be supported in the leased area; developers have not necessarily confirmed final design plans. This map splits the estimated 1,000-MW capacity for Deepwater ONE between Massachusetts and Rhode Island. The U.S. Virgin Islands Project (USVI) does not appear on this map.

Physical Siting Considerations

- Water Depth
- Distance to shore
- Geotechnical/Geophysical soil conditions
- Wave climate – sheltered vs open ocean
- Extreme climate conditions – e.g. tropical storms
- Availability of grid connections/load proximity
- Supply chain
- Competing use issues
- Environmental Impacts

Primary stakeholder concerns about offshore wind power are generally site specific

Marine animal populations:

European studies suggest minimal impacts. U.S. studies needed to understand potential risks and mitigation strategies. **Pile driving during construction has highest impact**. Mitigation strategies may be effective.

Commercial / Recreational Fishing

Offshore wind turbines and electric cables may limit some types of fishing activities and access to some areas.

Visual effects:

Coastal residents near offshore wind farms may be concerned about visual impacts. More research is needed to understand sensitivities.

Property values:

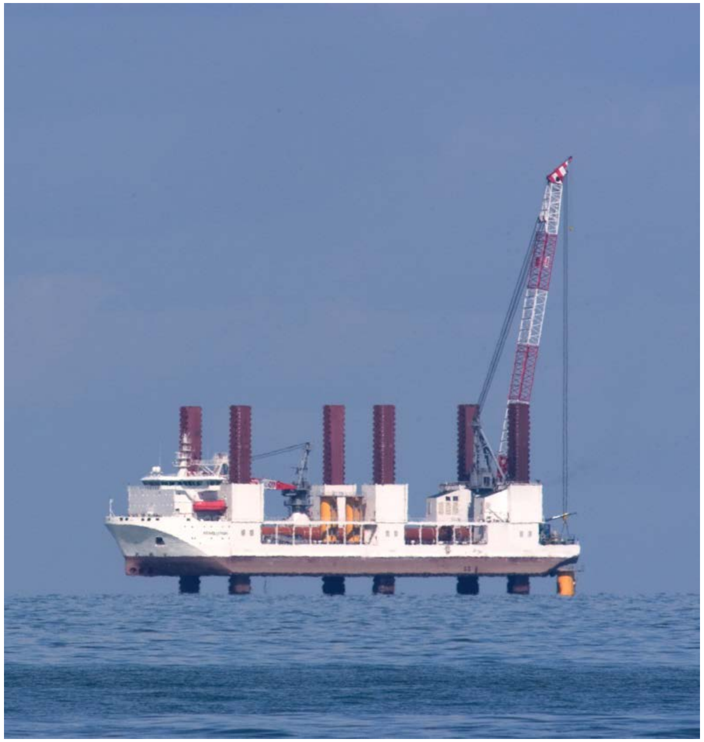
Studies conducted on land-based wind projects show minimal to no impact. Extensive studies have not been conducted for offshore wind.

Tourism:

Impacts on tourism concern some coastal communities. Some evidence is ambiguous but actual effects appear to be minimal or positive.

Marine safety:

The possibility of a ship colliding with a turbine poses concerns from fuel leaks to human safety due to turbine collapse. No reported incidents have occurred to date.



Visual Impact of Offshore Turbines – Horns Rev

- Seashore is important recreation resource in US
- Siting far offshore can minimize or eliminate visual impact
- Far shore siting leads to deeper water

Pre-visualization of the Horns Rev wind farm from Blåvands Huk (above) and actual post-construction photograph from Blåvands Huk (below) at 7 nautical miles (Credit: DONG Energy)

Siting Practices and Policies Account for Potential Environmental Risks

- Protected sites and species
- Benthic ecology
- Fish and shellfish/ Fisheries
- Marine birds
- Marine mammals
- Seabed sediments
- Marine and coastal processes
- Seabed disturbance
- Water quality

One of largest environmental impacts found is sea mammal disturbance due pile driving noise

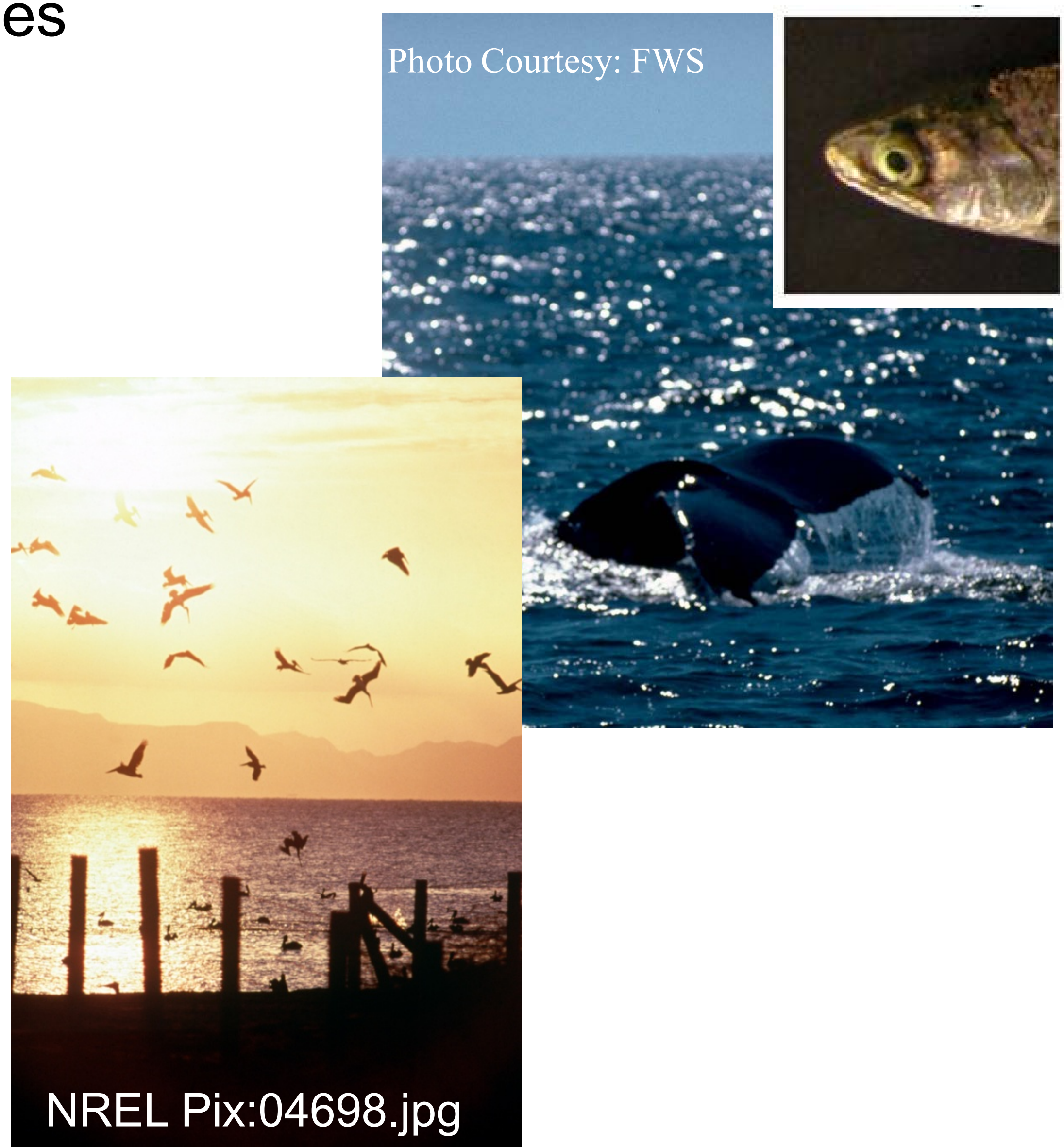
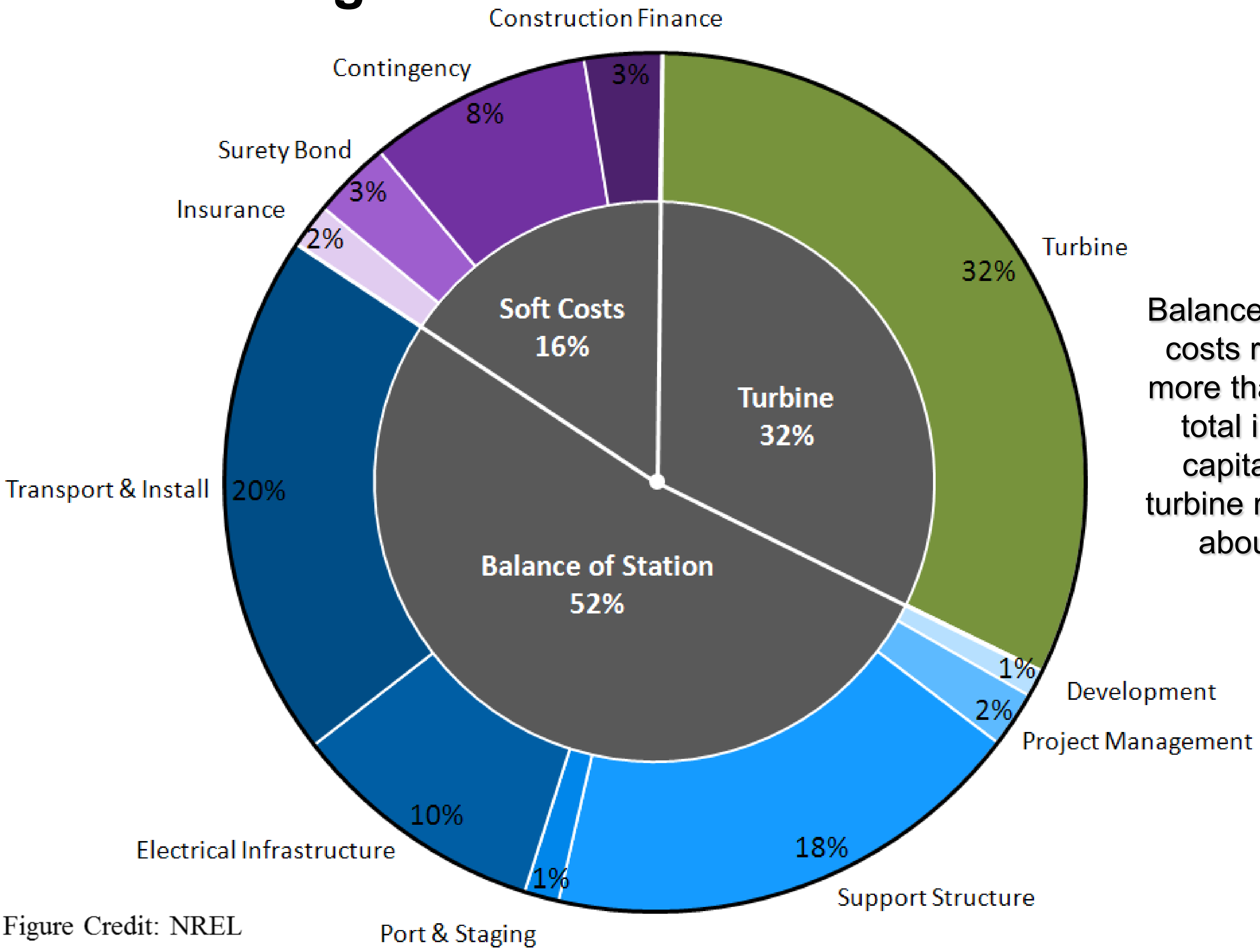


Photo Courtesy: FWS

NREL Pix:04698.jpg

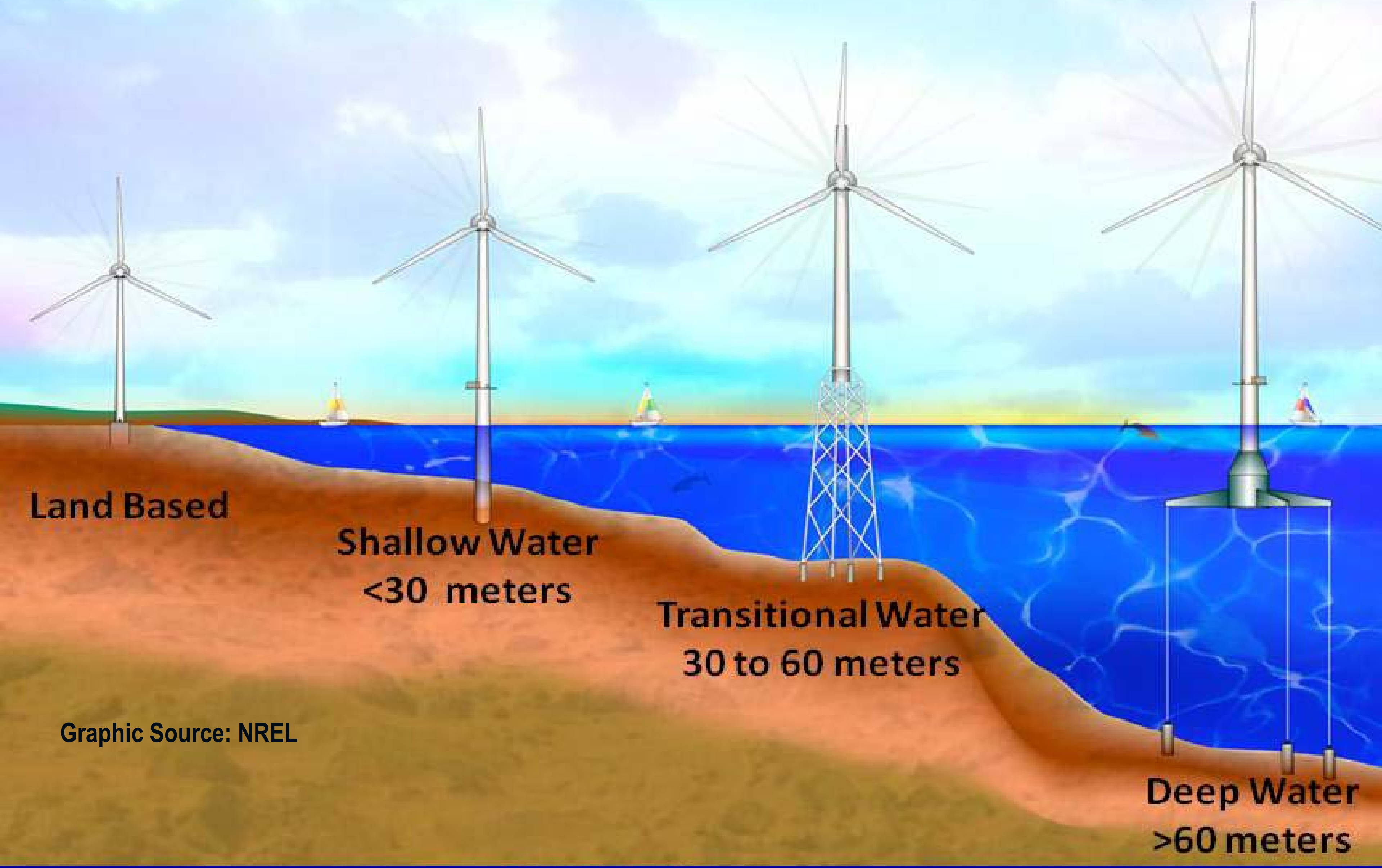
Offshore Wind Project Capital Expense Breakdown
Lowering Cost of Offshore Wind is Essential



Balance of station costs represent more than 50% of total installed capital costs, turbine represents about 32%

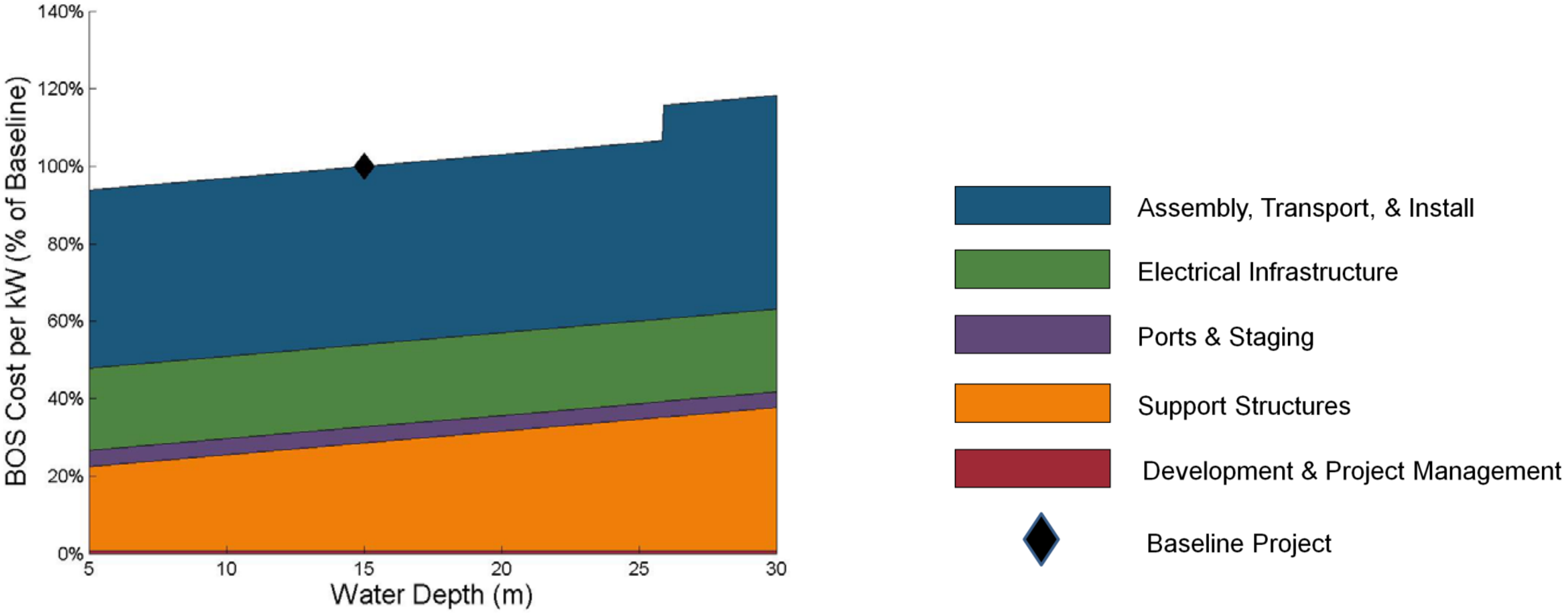
Figure Credit: NREL

Offshore Wind Technology is Depth Dependent



Graphic Source: NREL

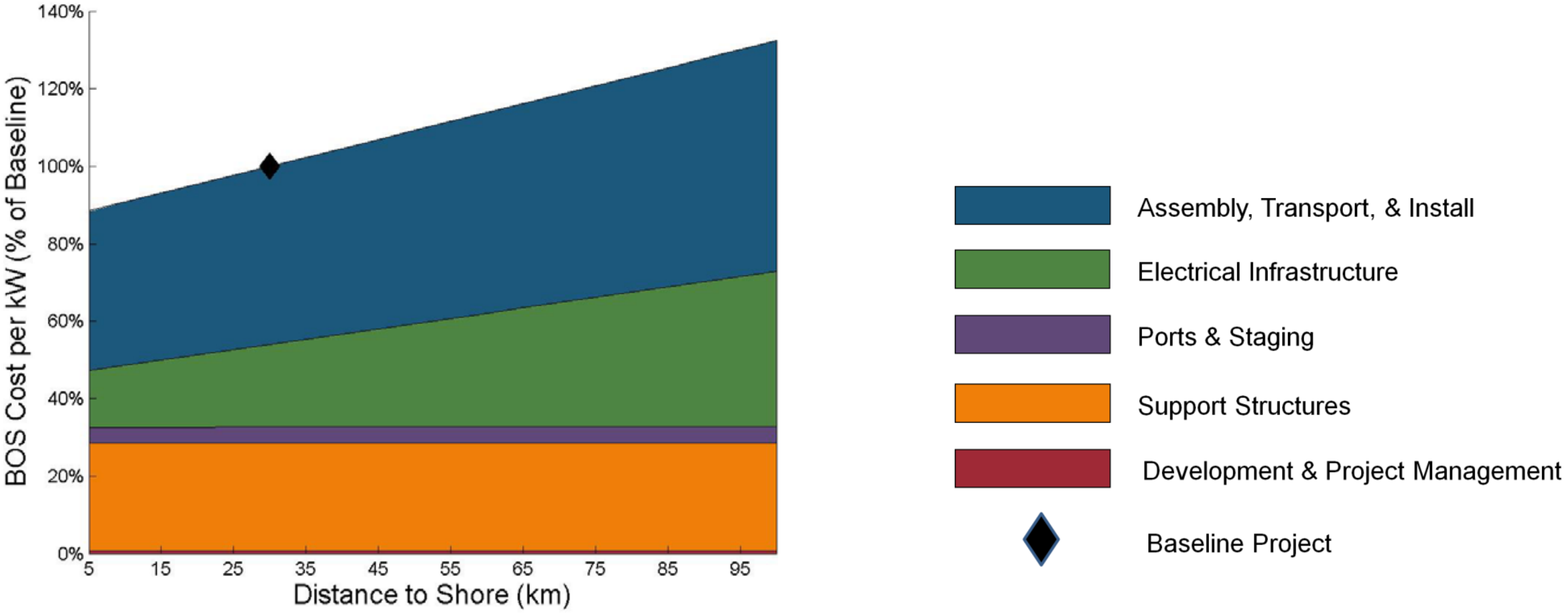
Cost Sensitivity to Water Depth



- Water depth shows no impact to electrical costs. However, it does impact support structure costs, which leads to increased total BOS cost.
- At shallow water depths, the assembly, transport, and install costs are unaffected by water depth. As the water depth increases, the monopile gets substantially heavier, which triggers a step change in costs due to the need to use a larger and more expensive class of installation vessels.

Graphic Source: NREL

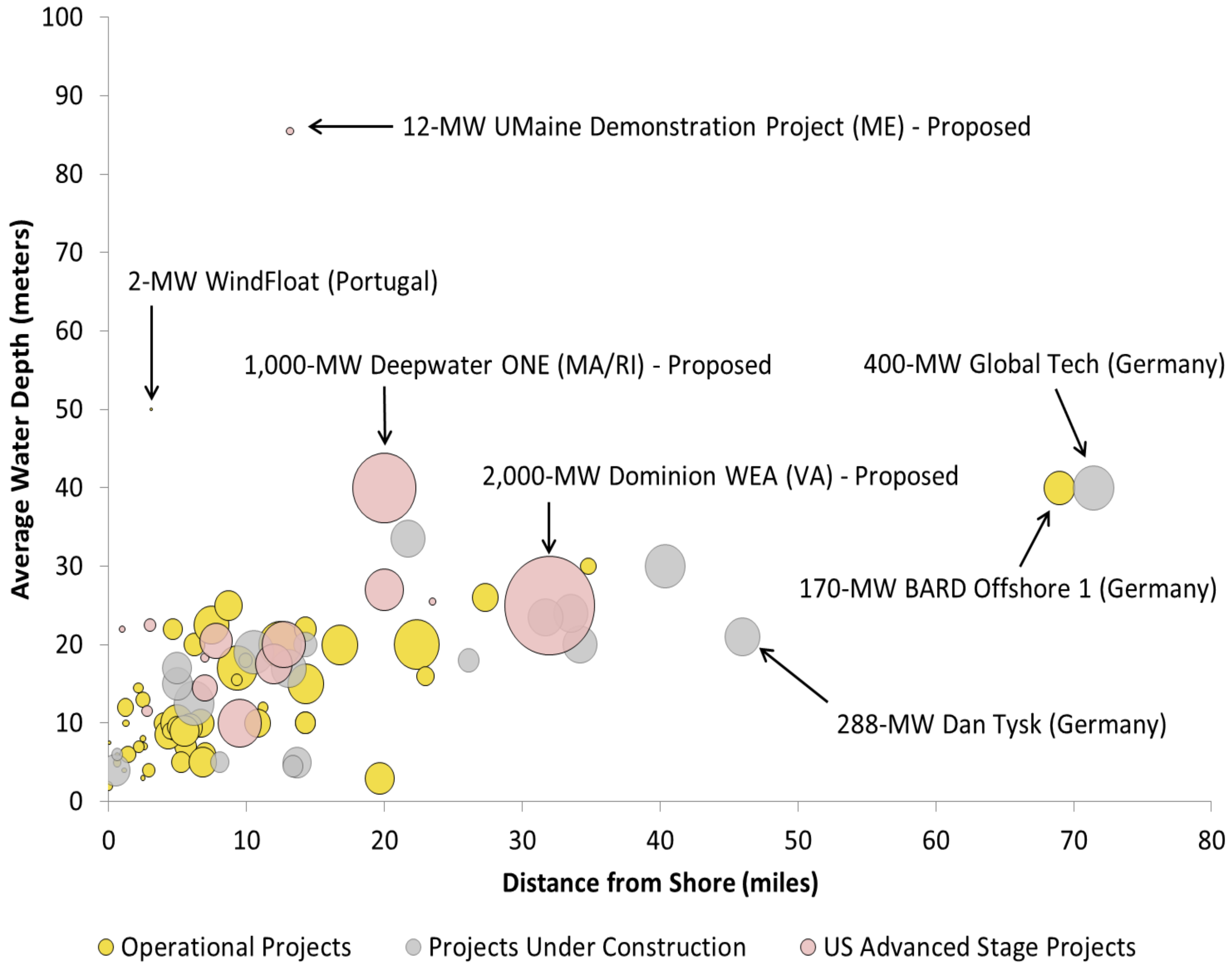
Cost Sensitivity to Distance to Shore



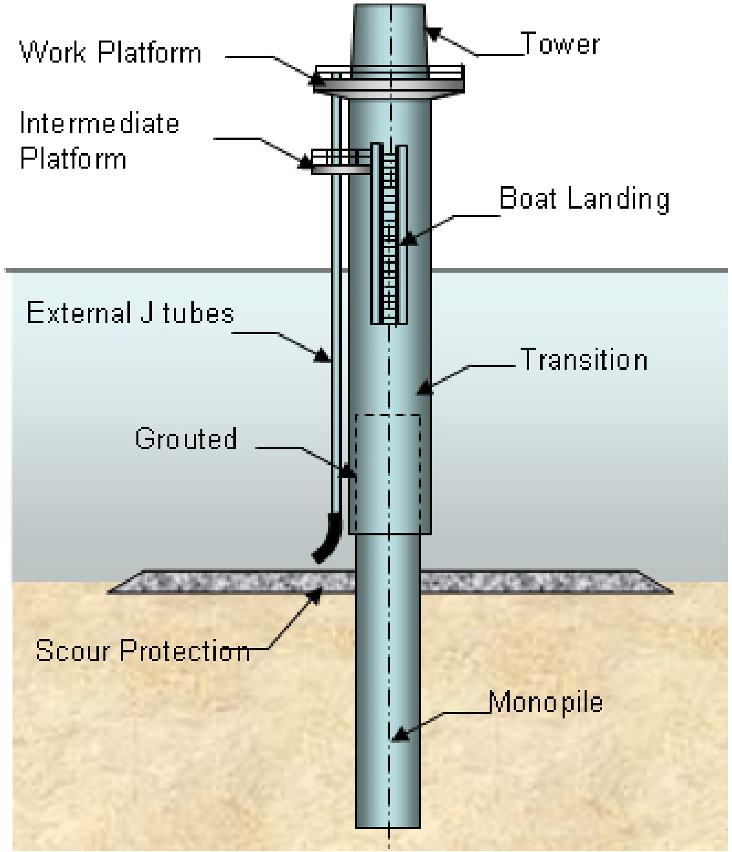
- Balance of Station costs rise due to long electrical cabling
- Assembly, transport, and installation costs increase due to longer transport distances.

Graphic Source: NREL

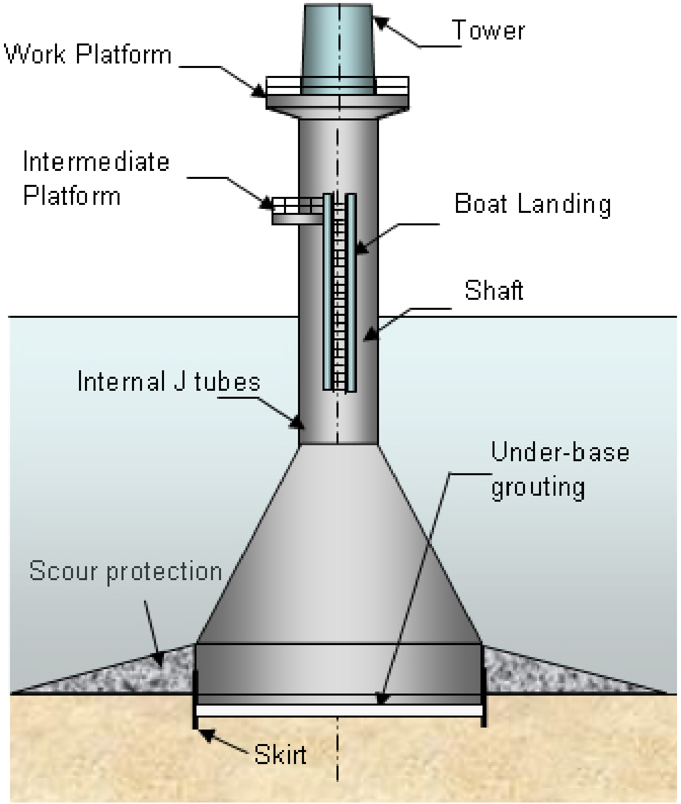
Projects are Deeper and Farther from Shore



Shallow Water (0-30m depths) Foundation Types



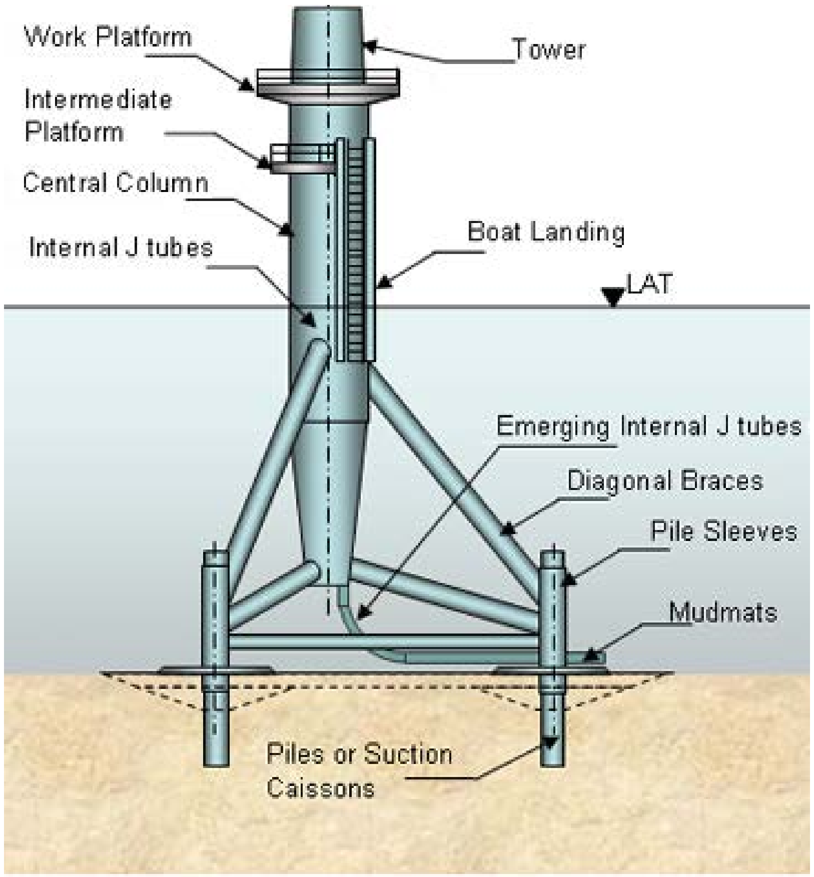
Monopile



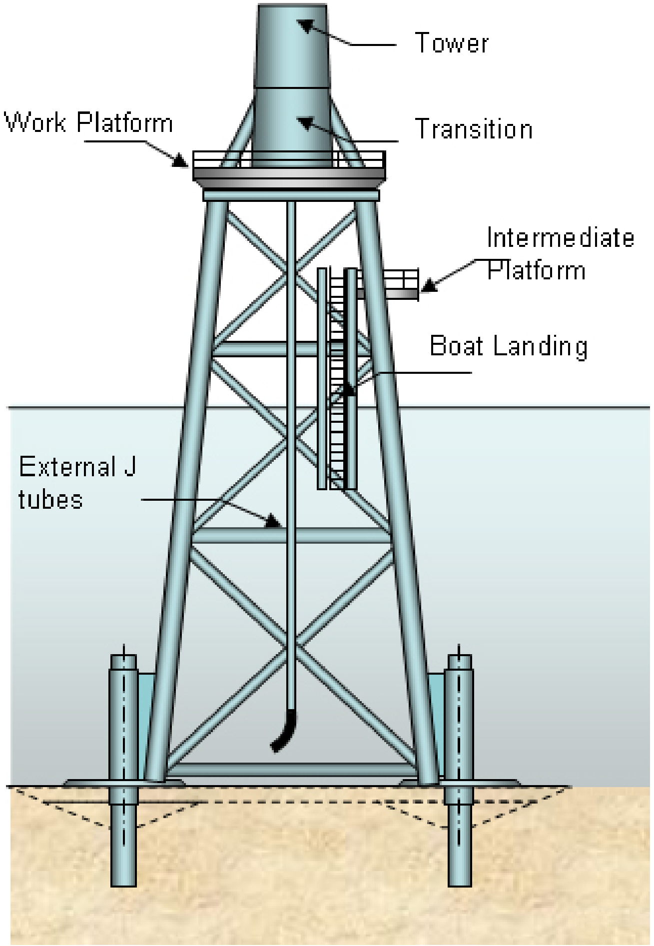
Gravity Base

Photo Source: Vattenfall

Transitional Water (30-60m depth) Foundation Types



Tripod Type



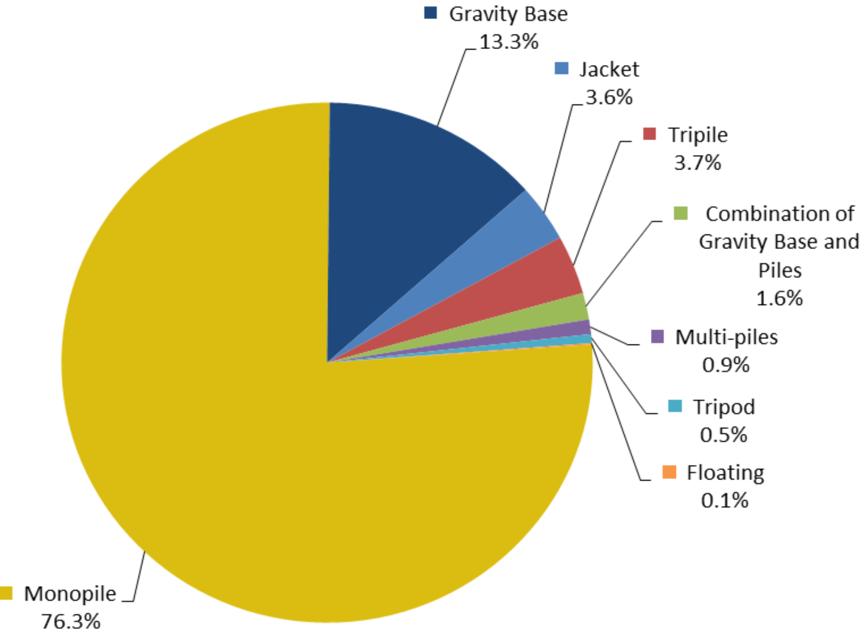
Jacket or Truss Type

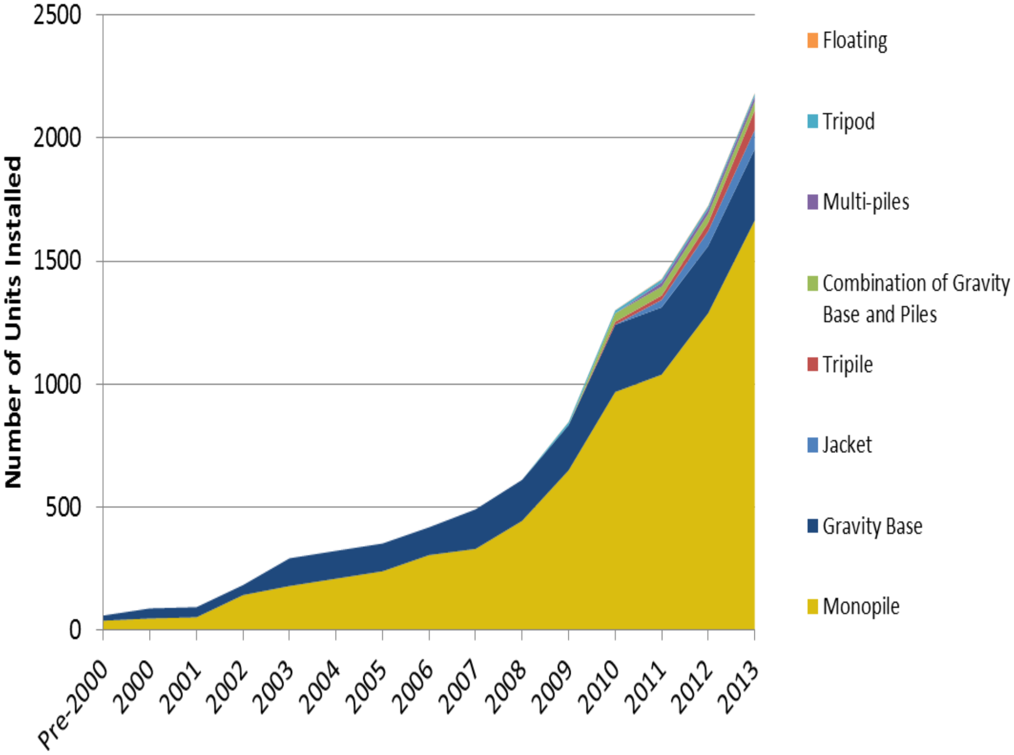
Jackets and Tripods at Alpha Ventus - Germany

Photo Credit: Gary Norton

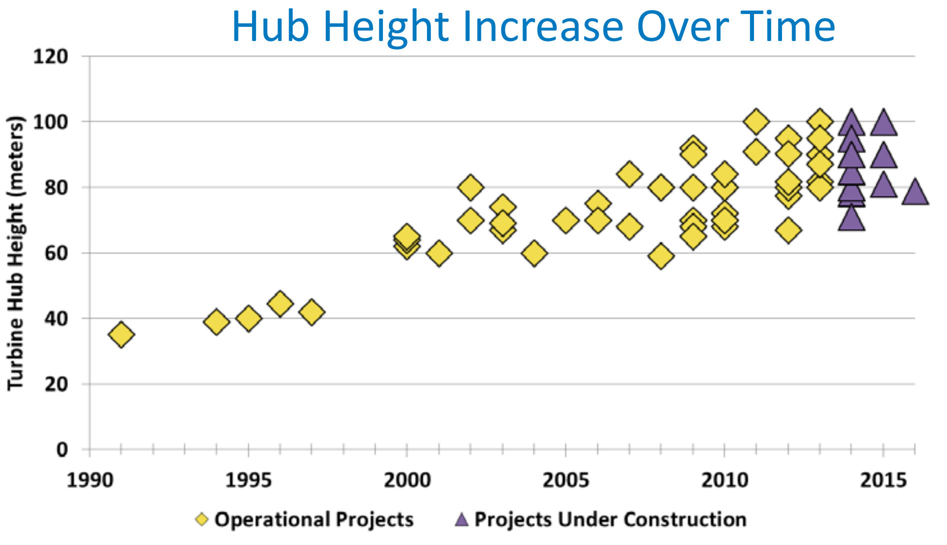
Substructures for Offshore Wind are Diversifying

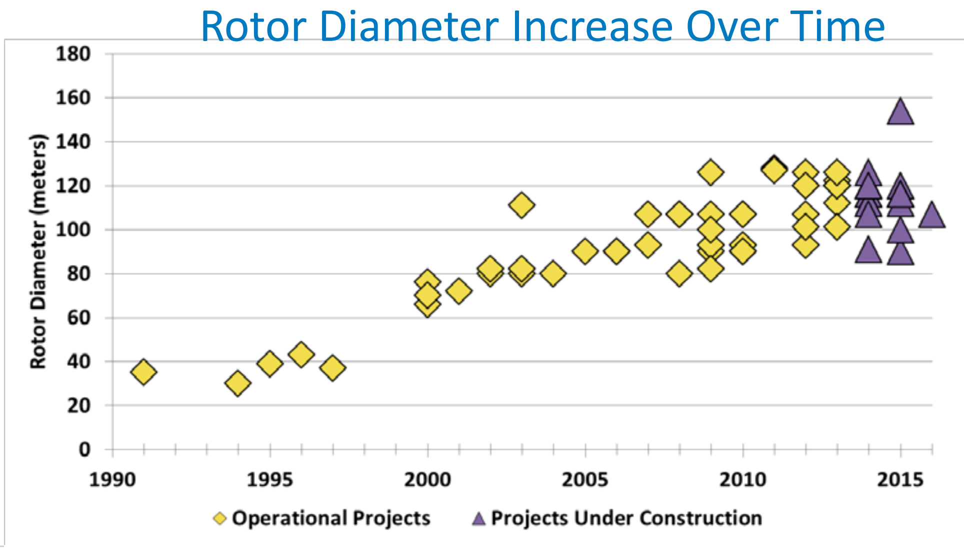
Monopiles Still Dominate the Market but Future Trend Suggest greater deployment of multi-pile foundations as projects go deeper.

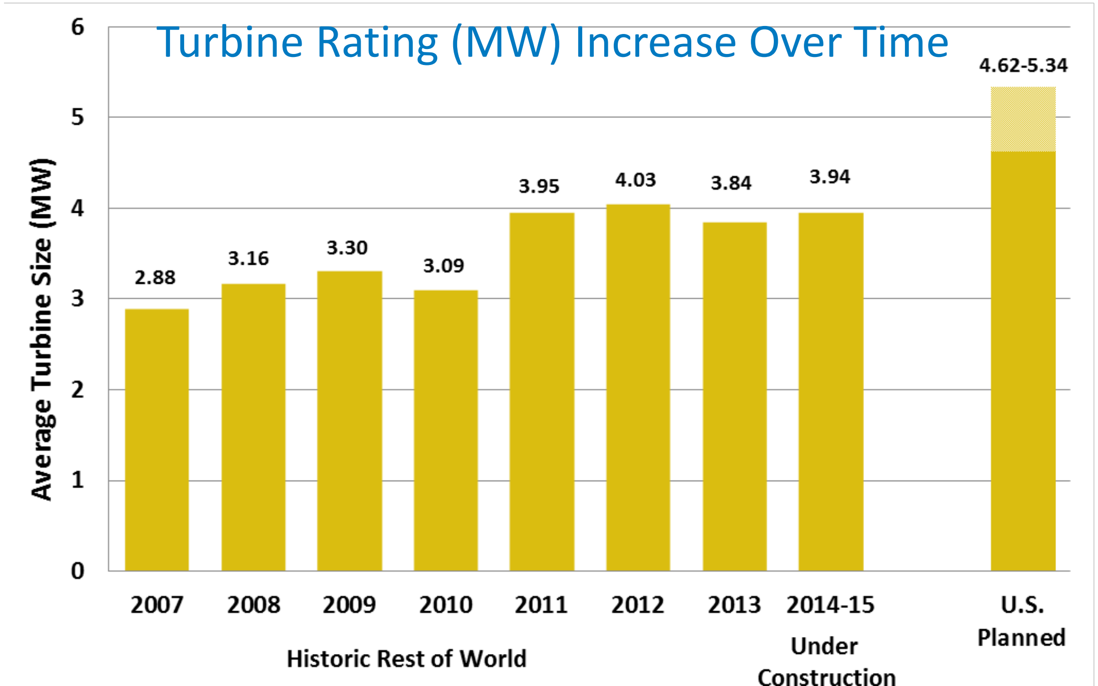




Average Rating, Hub Height, and Rotor Diameter

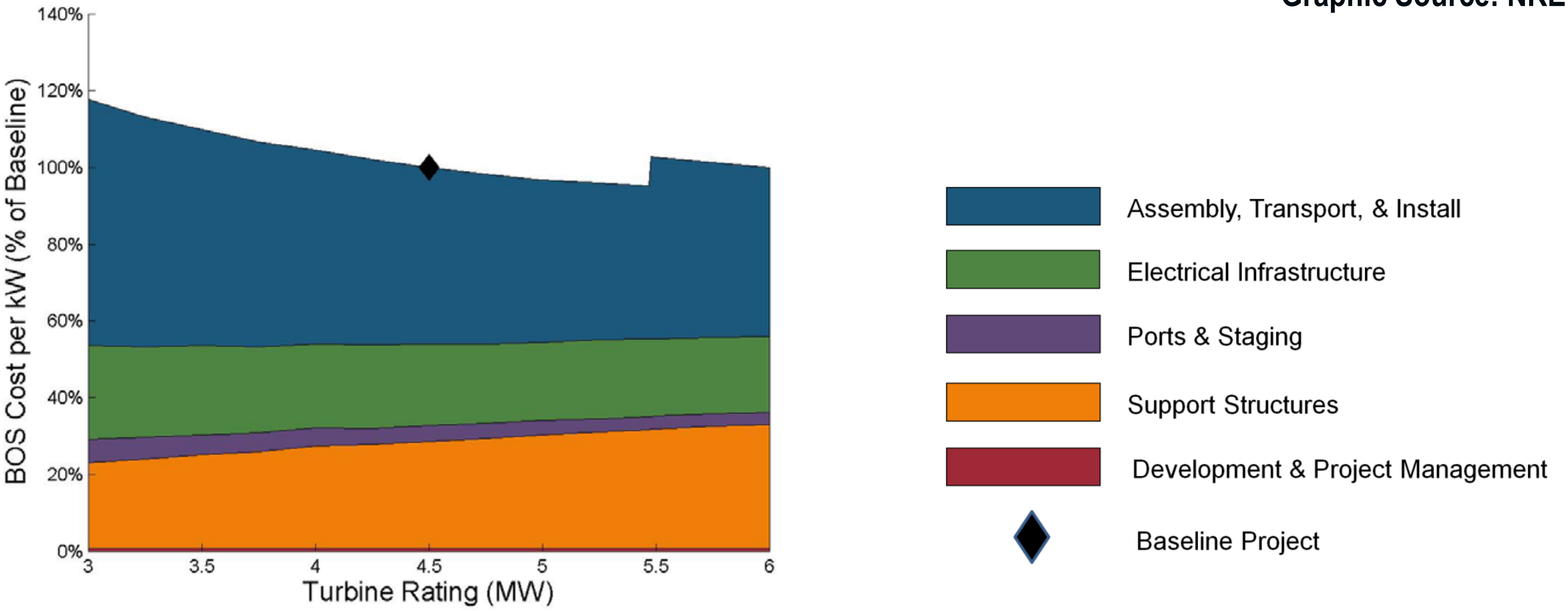

Hub Height Increase Over Time


Rotor Diameter Increase Over Time


Turbine Rating (MW) Increase Over Time

Sensitivity to Turbine Size

Graphic Source: NREL



- The total BOS cost is generally reduced as turbine size increases. Monopile support structure costs increase as the turbine rating increases, but the cost increase is outweighed by the reduction in electrical infrastructure and assembly, transport, and install costs.
- The step change increase in assembly, transport, and install cost is associated with a change to a larger class of vessels. This change is needed to handle the increased monopile size required for the higher loads that are associated with larger turbines.

Large Offshore Turbine Technology (5-10 MW)

Motivation

- Offshore economics favor larger machines
- O&M costs, electric distribution costs, specific energy production, installation cost, foundations costs all improve with turbine size

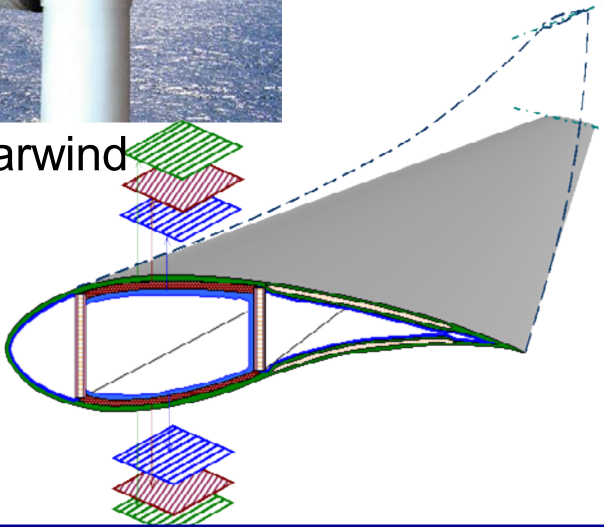
Challenges

- Large turbine enabling technology is needed
- Vessels and infrastructure are limited

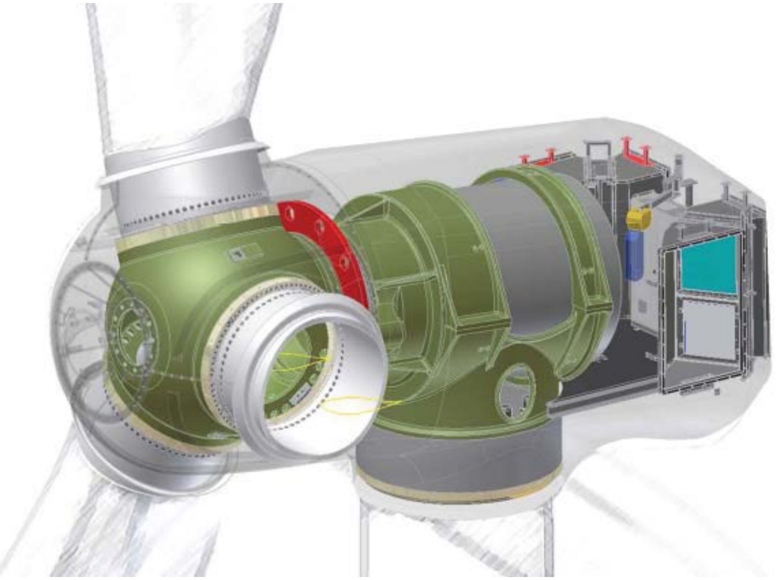
Solutions

- Innovative deployment systems
- Ultra-long blades/rotors
- Down wind rotors
- Direct drive-generators (possible HTSC)
- Weight optimized wind turbines
- Special purpose vessels

XEMC Darwind



Offshore Trend Toward Direct Drive Generators



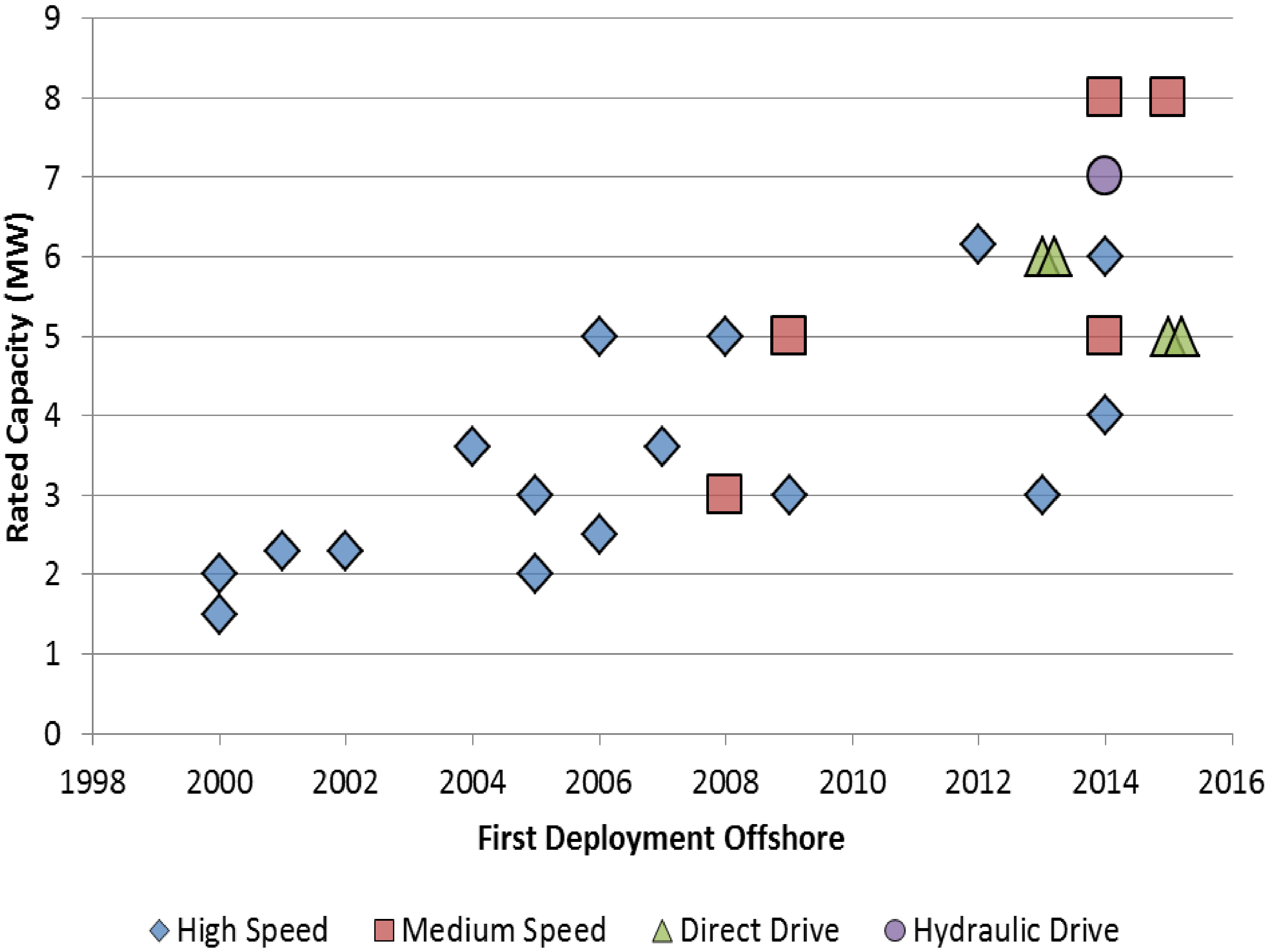
Graphic: Courtesy of American Superconductor

Siemens Wind Power

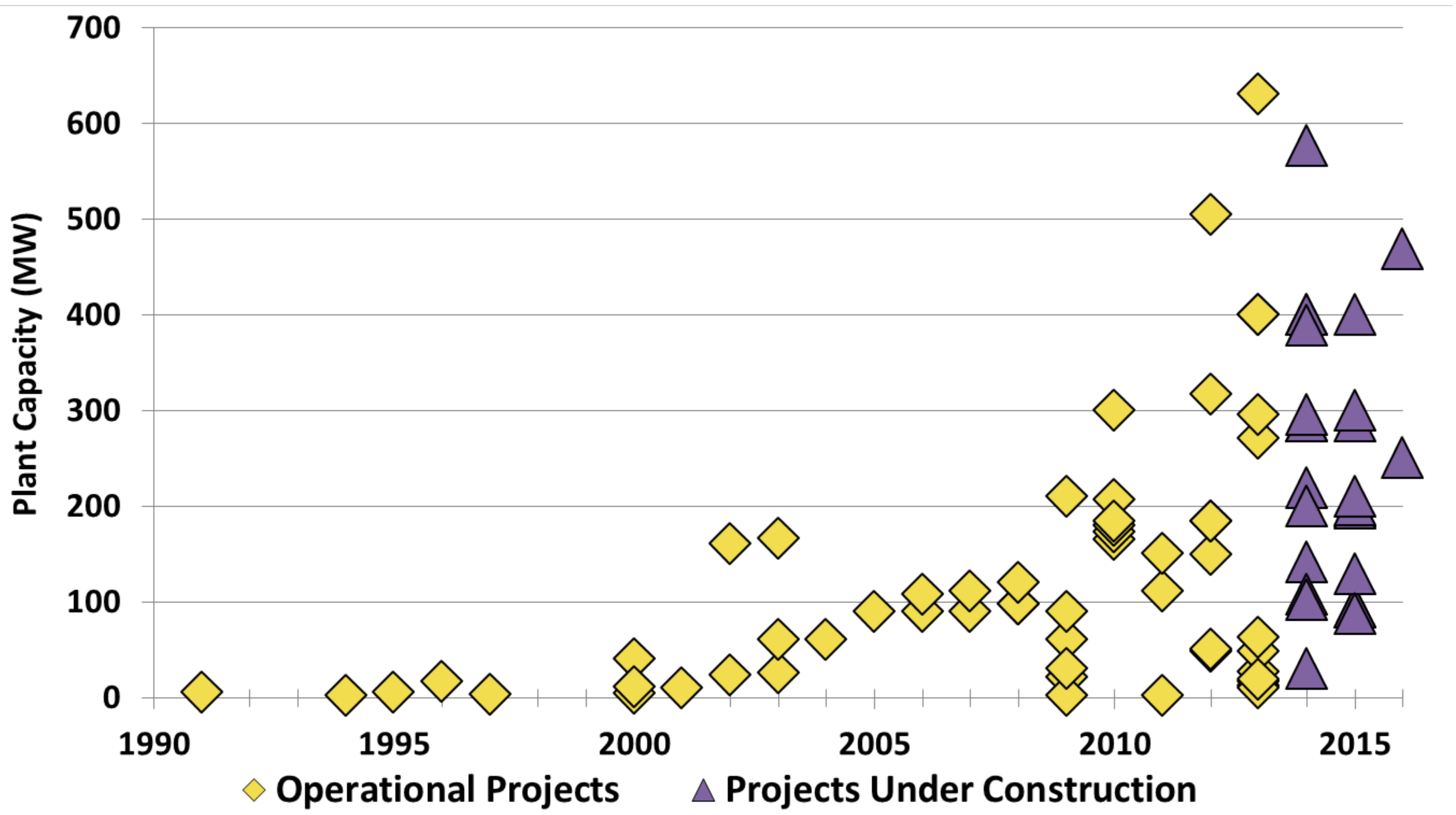
- Geared drivetrain failures contribute to O&M costs
- Direct drive generators (DDG) promise higher reliability due to fewer moving parts
- Gear driven turbines have the lowest weight and initial cost but have had poor reliability
- Current DDG designs are heavy
- Lower weight (hence cost) DDG are being developed by most major turbine manufacturers

Offshore Wind Turbine Technology Trends

Bigger Turbines – More Diverse Drivetrains



Offshore Plant Capacity by Year of Installation



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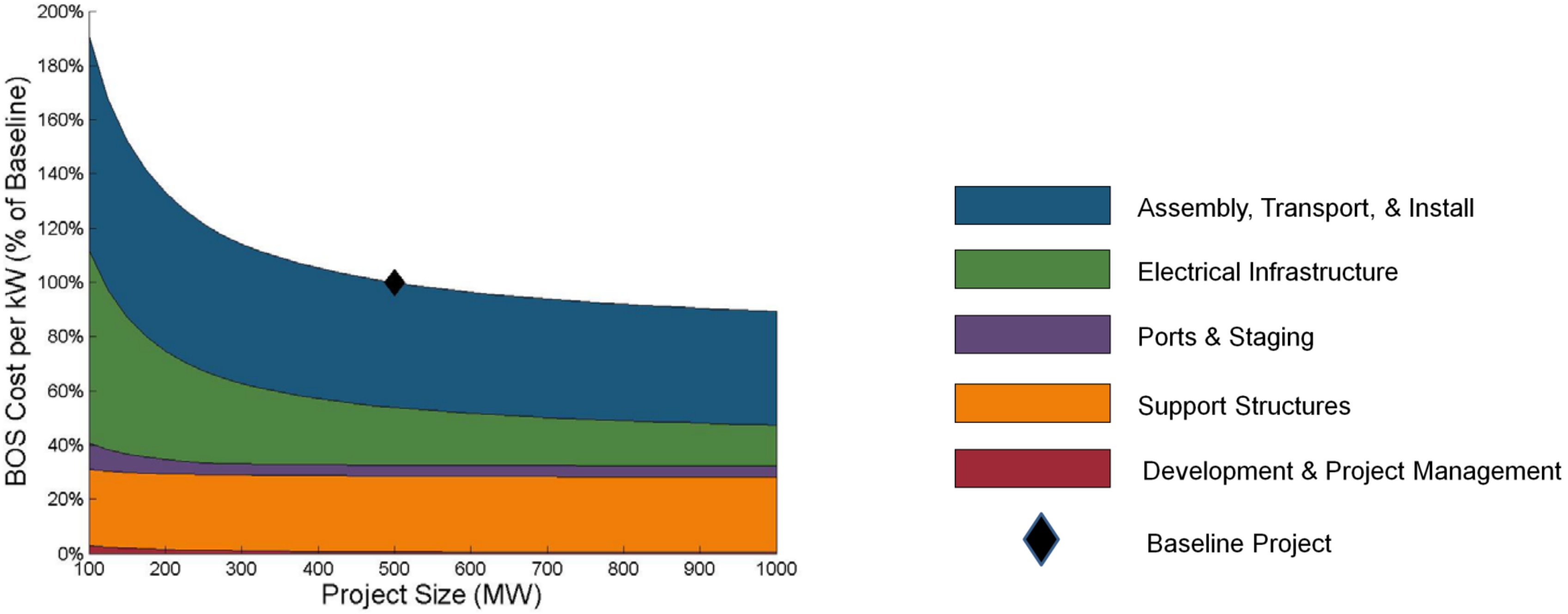
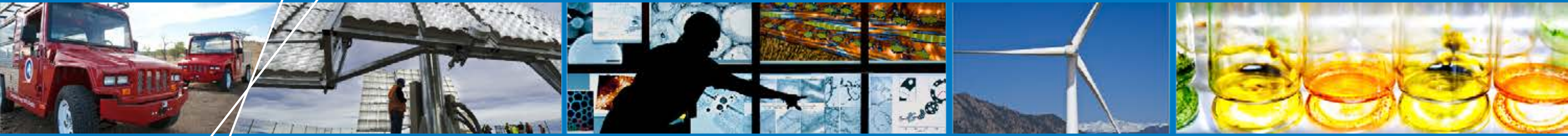
Sensitivity to Project Size



- Fixed costs such as vessel mobilization, export cable landfall operations, and others can dominate smaller project costs.
- Further reductions come from increased order sizes that reduce per item costs.
- The electrical costs represent a significant percentage of project costs at low project sizes. At larger project sizes, the support structure and assembly, transport, and install costs dominate.

Graphic Source: NREL

Floating Offshore Wind Technology



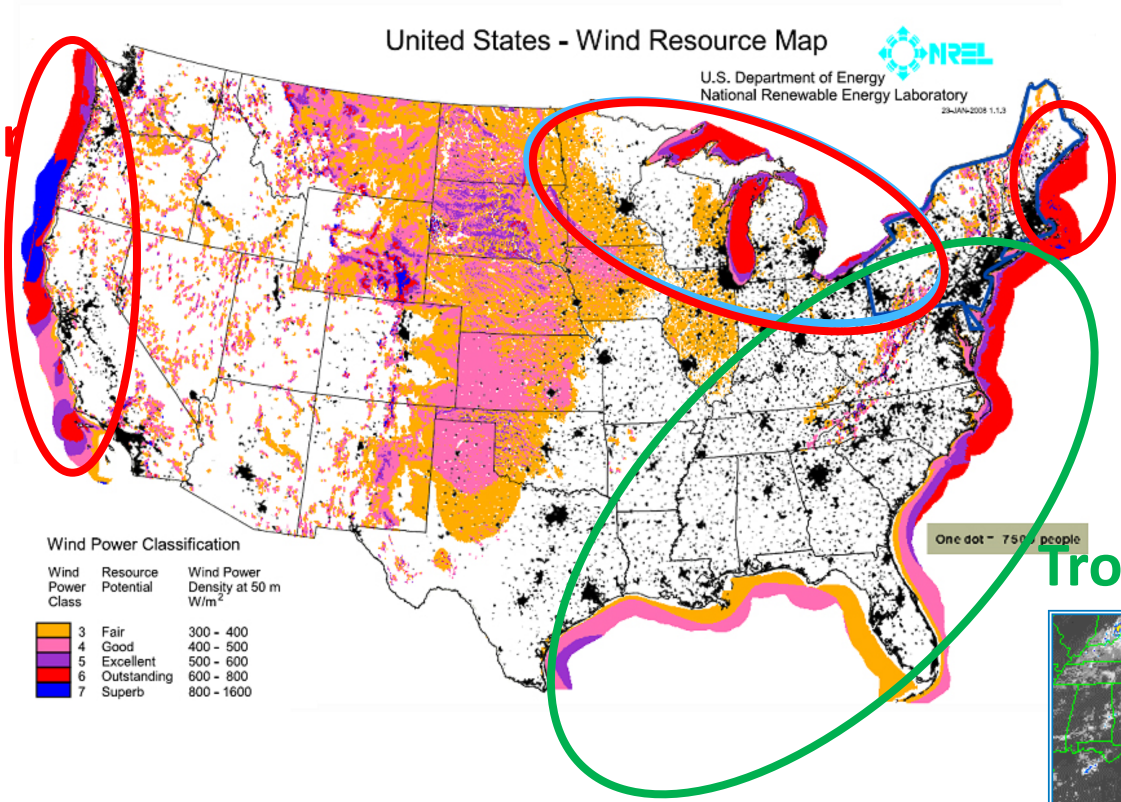
United States Technology Challenges

Addressing Challenges Will Expand Offshore Wind Resource Area

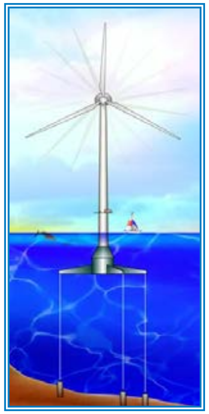
Freshwater Ice

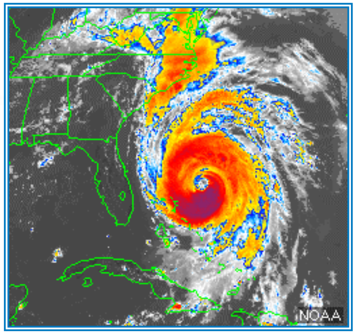
Deep Water

Deep Water



Tropical Storms

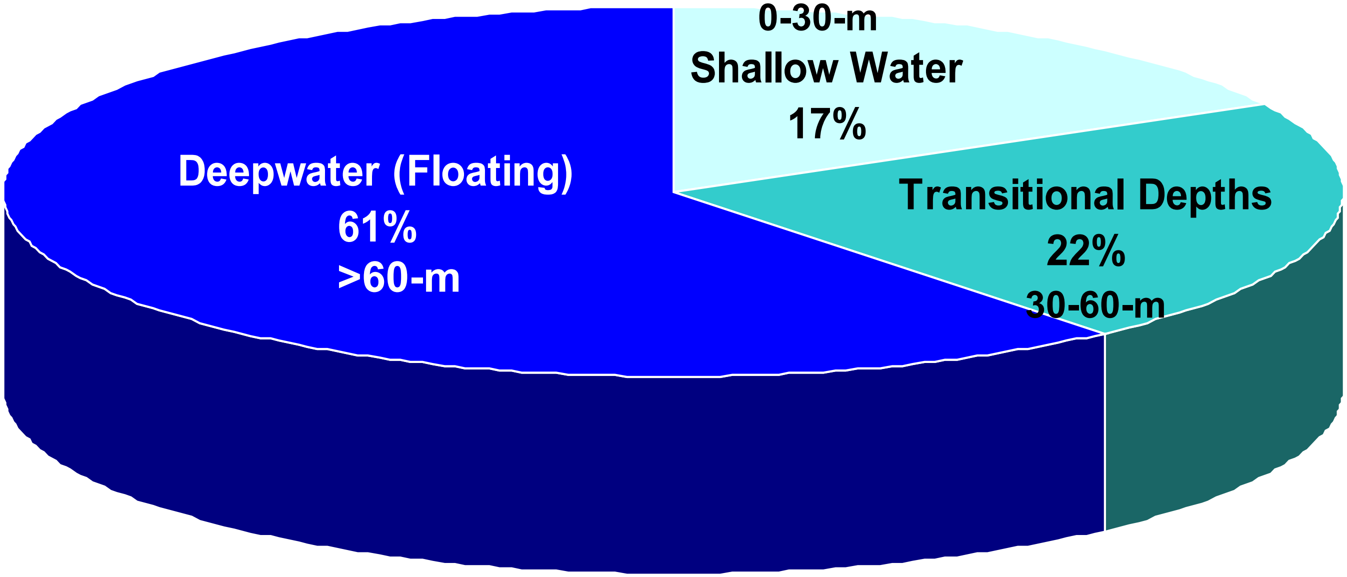




Graphic Source: NREL

US Offshore Resource: 61% of resource

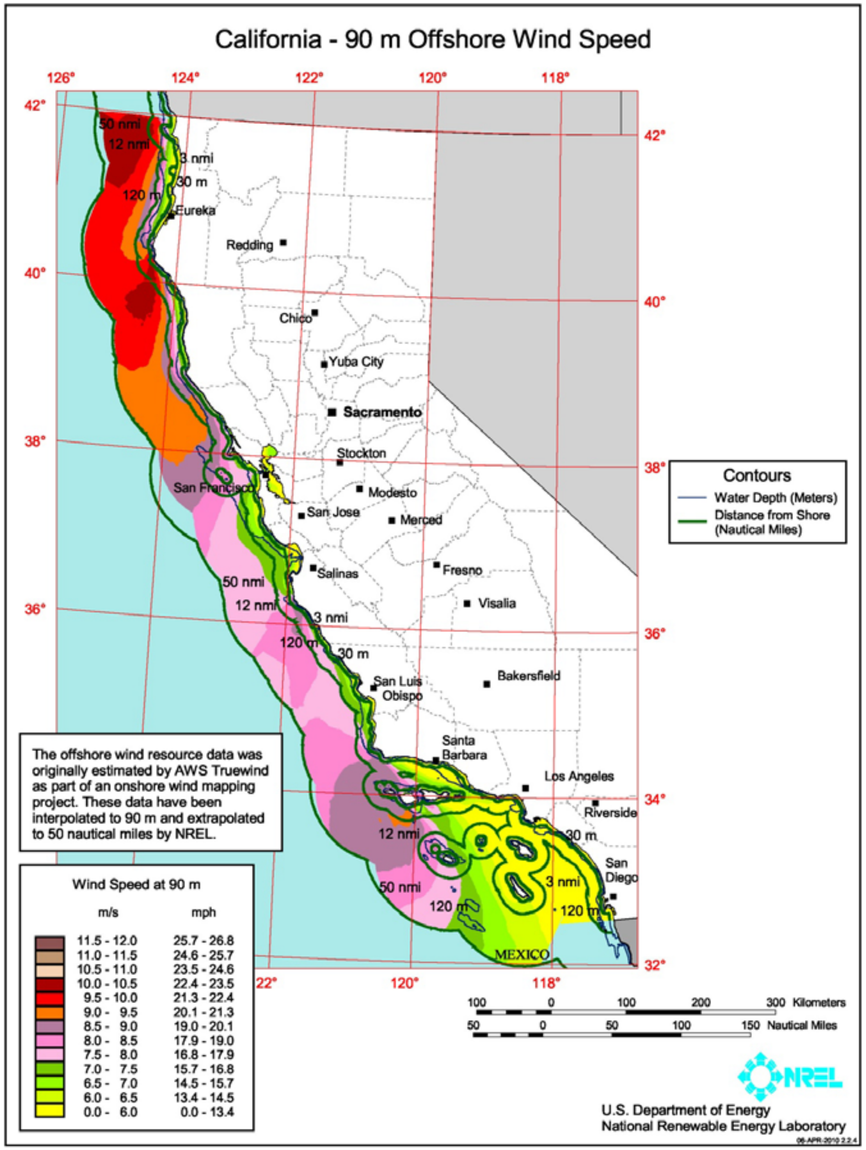
~4000-GW Total Technical Potential



Approximate percentage of Gross Offshore Wind Resource Area for Three Technology Stages (based on NREL estimates – 0-50nm from shore, 60% of resource excluded, AK and HI not included, Class 5 winds and above only)

Graphic Source: NREL

California Offshore Wind Resource

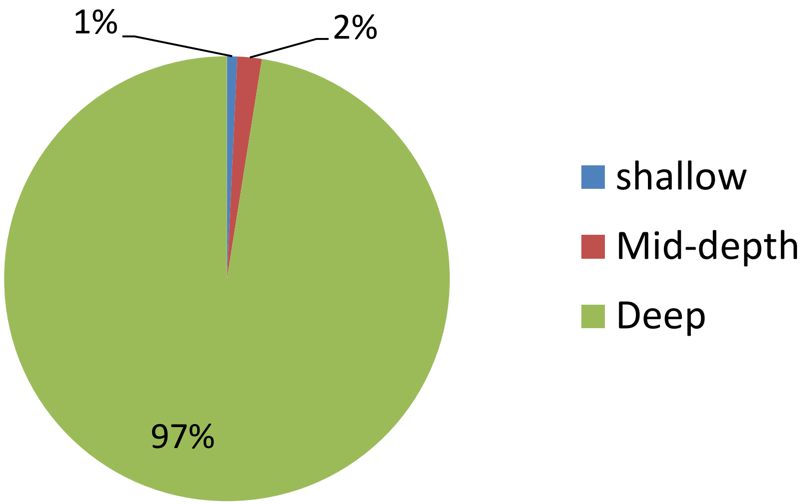


The offshore wind resource data was originally estimated by AWS Truewind as part of an onshore wind mapping project. These data have been interpolated to 90 m and extrapolated to 50 nautical miles by NREL.

U.S. Department of Energy
National Renewable Energy Laboratory

Graphic Source: NREL

- **97% of offshore wind resource is in deep water**
- **114,593 km² of windy water**
- **573-GW of gross resource potential over 7 m/s**

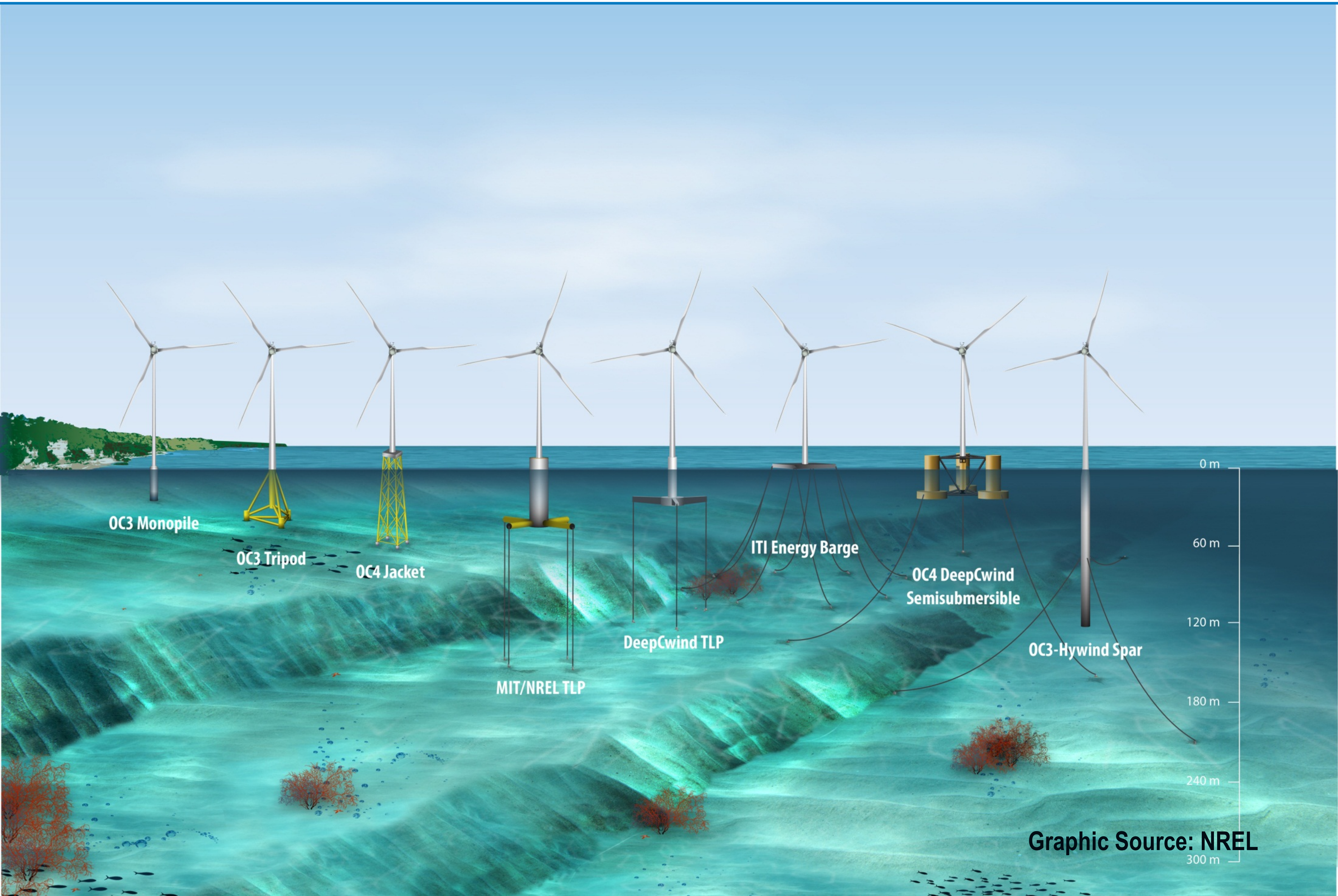


Schwartz, M.; Heimiller, D.; Haymes, S.; Musial, W. (April 2010). Assessment of Offshore Wind Energy Resources for the United States. NREL/TP-500-45889. Golden, CO: National Renewable Energy Laboratory, June 2010. Accessed [include date]. http://www.nrel.gov/docs/fy10osti/45889.pdf.

California offshore wind resource by region, speed interval and distance from shore within 50 nm of shore.

	Distance from Shore (nm)								
	0 - 3			3 - 12			12 - 50		
Depth Category	Shallow (0 - 30 m)	Transitional (30 - 60m)	Deep (> 60m)	Shallow (0 - 30 m)	Transitional (30 - 60m)	Deep (> 60m)	Shallow (0 - 30 m)	Transitional (30 - 60m)	Deep (> 60m)
90 m Wind Speed Interval (m/s)	Area km^2 (MW)	Area km^2 (MW)	Area km^2 (MW)	Area km^2 (MW)	Area km^2 (MW)	Area km^2 (MW)	Area km^2 (MW)	Area km^2 (MW)	Area km^2 (MW)
7.0 - 7.5	266 *(1,331)*	236 *(1,181)*	257 *(1,287)*	101 *(504)*	457 *(2,284)*	4,554 *(22,770)*	8 *(38)*	23 *(115)*	5,537 *(27,684)*
7.5 - 8.0	239 *(1,196)*	257 *(1,285)*	190 *(948)*	79 *(394)*	596 *(2,978)*	3,855 *(19,273)*	0 *(0)*	33 *(165)*	19,616 *(98,080)*
8.0 - 8.5	125 *(626)*	178 *(891)*	282 *(1,409)*	7 *(36)*	106 *(529)*	4,539 *(22,695)*	0 *(0)*	0 *(0)*	17,822 *(89,111)*
8.5 - 9.0	43 *(216)*	142 *(708)*	176 *(882)*	1 *(3)*	38 *(190)*	4,560 *(22,799)*	0 *(0)*	0 *(0)*	17,892 *(89,460)*
9.0 - 9.5	2 *(10)*	19 *(94)*	15 *(74)*	0 *(0)*	1 *(4)*	988 *(4,940)*	0 *(0)*	0 *(0)*	12,160 *(60,801)*
9.5 - 10.0	0 *(0)*	6 *(30)*	14 *(69)*	0 *(0)*	0 *(0)*	656 *(3,280)*	0 *(0)*	0 *(0)*	14,555 *(72,774)*
>10.0	0 *(0)*	0 *(0)*	0 *(1)*	0 *(0)*	0 *(0)*	288 *(1,441)*	0 *(0)*	0 *(0)*	6,638 *(33,188)*
Total >7.0	676 *(3,379)*	838 *(4,189)*	934 *(4,670)*	187 *(937)*	1,197 *(5,985)*	19,440 *(97,198)*	8 *(38)*	56 *(279)*	94,220 *(471,098)*

Technology Evolution to Deeper Water



Graphic Source: NREL

There are three main classes of floating substructures

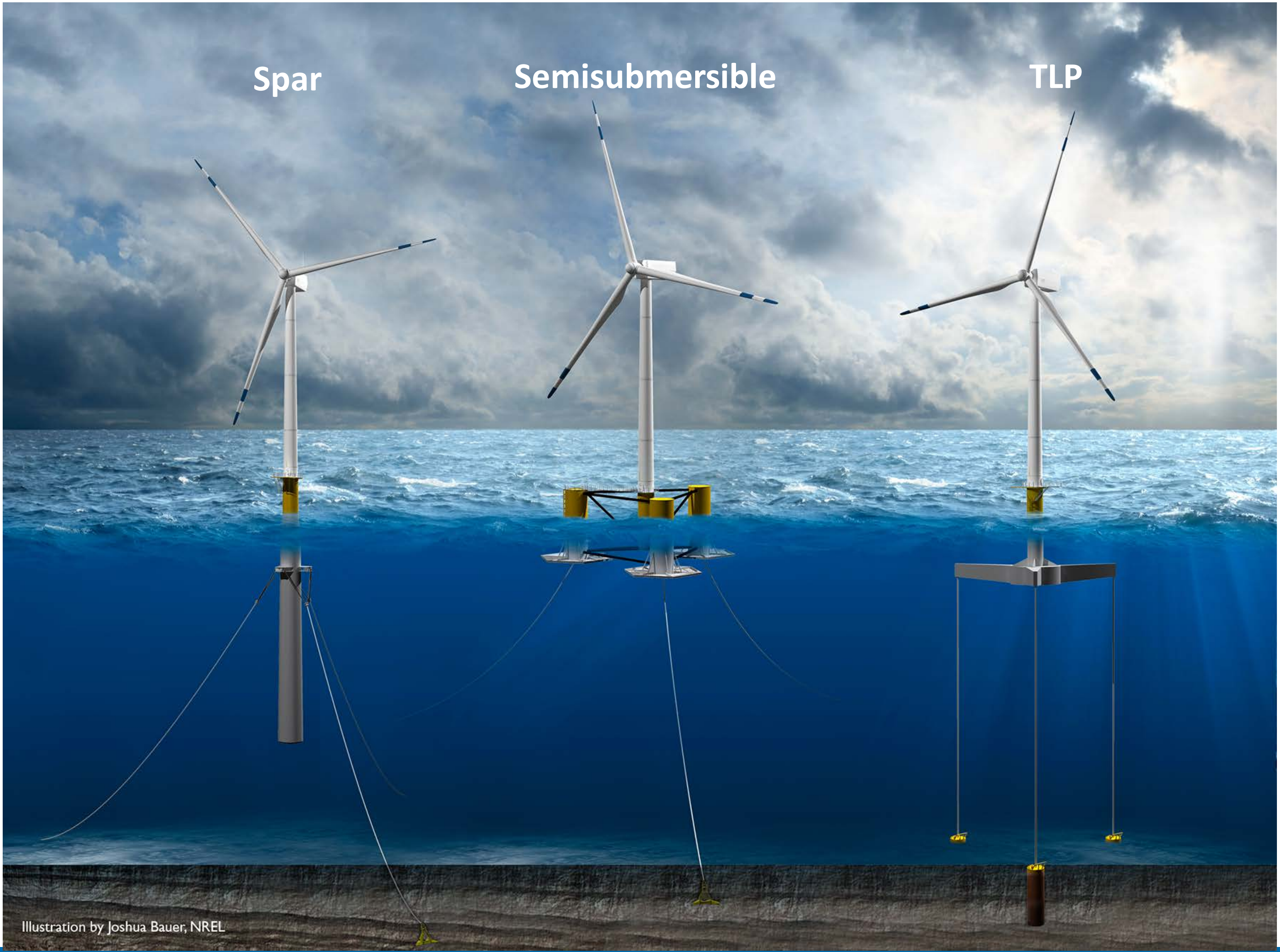


Illustration by Joshua Bauer, NREL

A brief history of floating offshore wind technology

Concept proposed by Professor William E. Heronemus

spar

Hywind Demo Norway

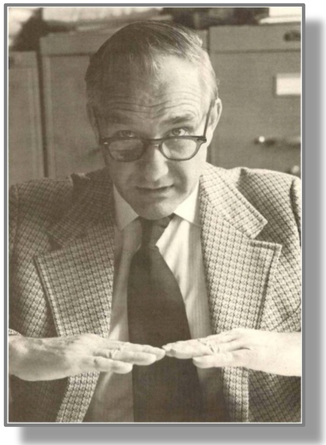
spar

Kabashisma Japan

Semi-submersible

Fukushima I Japan

1970s **2009** **2010** **2011** **2012** **2013** **2014**



Professor Bill Heronemus 1974

WindFloat Demo Portugal

VolturnUS 1:8 United States

Semi-submersibles

Can Floating Wind Turbines Lower Cost of Offshore Wind?

- **Decoupling from seabed:**
  - **Enable uniform design**
  - **Mass Production**
  - **Reduces Labor at sea**
- **Minimizing labor at sea**
  - **Lowest cost:1-3-8 rule of ship building**
  - **Integrated quayside assembly and float-out strategies**
- **Lower anchoring and mooring costs**
- **Reduced system weight for lower system cost.**

2009 Statoil HyWind Turbine Load-out

2011 Principle Power Portugal Deployment

Floating Wind is at the beginning of learning curve

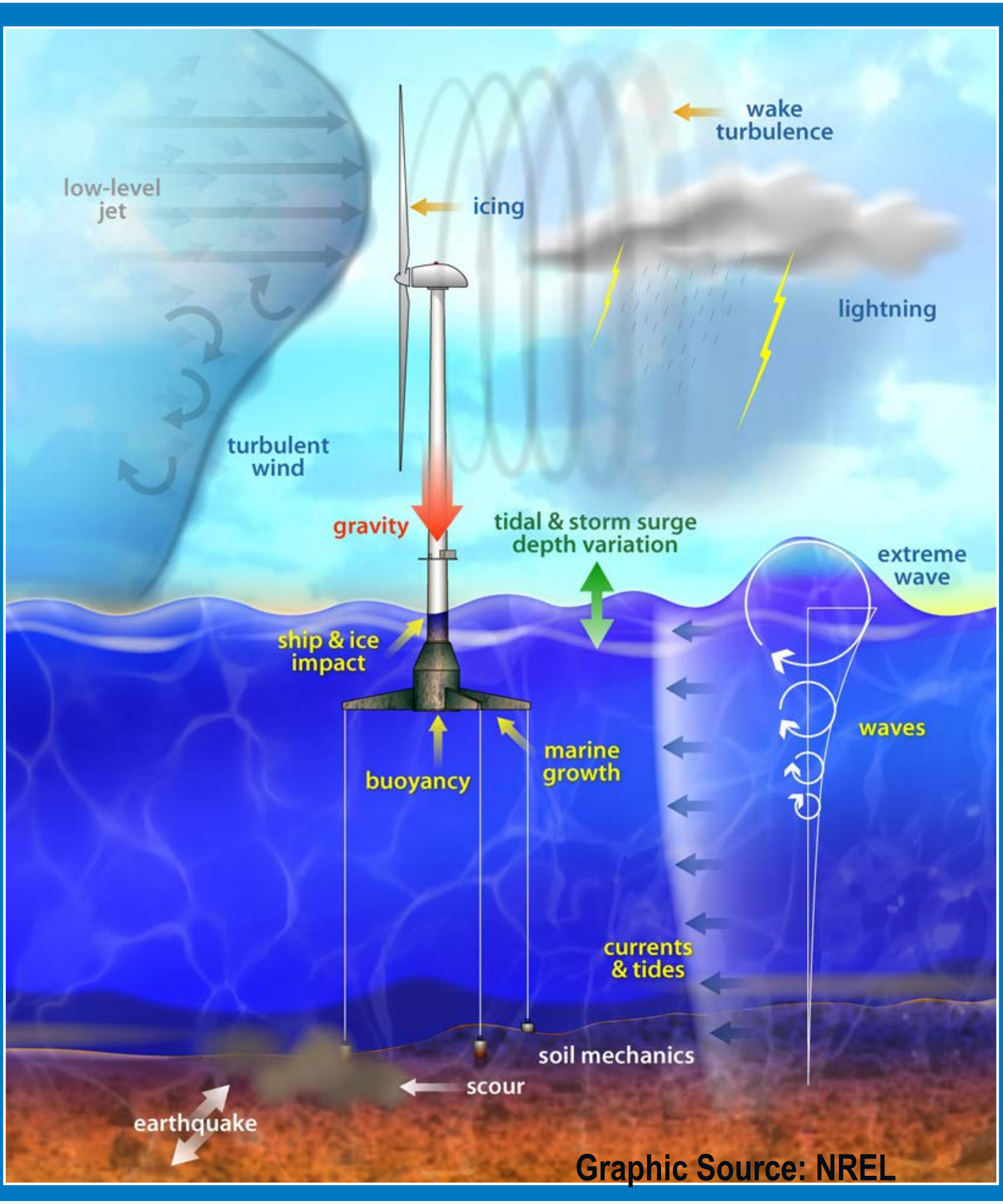
	Potential technical innovations for Floating Wind
Turbine	• Turbine up-scaling . 10MW + • More efficient, reliable and lighter weight drivetrains • Reduced Topside Mass (rotor, nacelle tower) per MW • Integrated turbine /substructure designs
Substructure	• Mass production and automation of substructure fabrication • Use of alternative materials (steel-concrete composites) • Optimization of hull designs (mass, complexity)
Moorings and Anchors	• Synthetic mooring lines • Innovative anchoring solutions
Ports and Staging	• Optimization of port facilities and infrastructure • Increased assembly/installation/commissioning work at quayside
Turbine and Substructure Installation	• Innovative installation vessels and philosophies (for spar, TLP) • Optimization of logistics • Purpose-built anchor installation vessels
Electrical Infrastructure and Installation	• Reduction in material cost of dynamic cables • Higher voltage array and export cables (e.g., 66 kV, HVDC) • Higher voltage export cables • Wet mate connectors to reduce installation requirements • Improved cable installation vessels and equipment (e.g., ROVs) • Standardized substations
O&M	• Increased system reliability • Innovative vessels systems and O&M logistics strategies • Tow-to-shore maintenance strategies could offer lower costs if technical challenges overcome

Source: Vattenfall/Jorrit Lousberg

Source: GICON

Challenges for Floating Offshore Wind Design

- **Added flexibility in primary structure**
- **System mass reduction**
- **Complex aerodynamic and hydrodynamic interactions**
- **Platform stability and controls**
- **Mooring system dynamics**
- **Dynamic cabling**



Graphic Source: NREL

International Energy Agency Offshore Code Comparison Collaborative Verifies Floating Design Codes

125 participants from 47 organizations in 18 countries have participated in the task.

Country Commitments – 12

Country
Chinese Wind Energy Association
Denmark
Finland
Germany
Greece
Japan
Korea
The Netherlands
Norway
Portugal
Spain
United States

Participating Codes – 22+

- 3Dfloat
- ADAMS-AeroDyn-HydroDyn
- ADAMS-AeroDyn-WaveLoads
- ADCoS-Offshore
- ADCoS-Offshore-ASAS
- ANSYS
- Bladed
- Bladed Multibody
- FAST-AeroDyn-HydroDyn
- FAST-AeroDyn-TimeFloat
- FAST-CHARM3D
- FEDEM-AeroDyn
- FLEX5
- FLEX5-Poseidon
- HAWC2
- Modelica
- OneWind
- PHATAS
- SESAM
- Simo-Riflex
- SIMPACK-AeroDyn-HydroDyn
- USFOS-VpOne
- VIDYN

iea wind

Statoil's Hywind 2.3 MW Demo Project

Characteristics	
Country/Sponsor:	Norway/Statoil
Major Partners:	Siemens
Turbine Size/Description:	2.3 MW Siemens – Pitch control
Deployment date :	June 2009
Platform Type:	Spar
Site:	Stavanger, Norway
Water Depth	200-m
Budget:	$70M USD

2.3 MW Statoil Floating Turbine in 2009

The Statoil 2.3 MW Demo was the first floating wind turbine in the world. Four years of data for a spar buoy in deep water. Statoil was awarded an Advanced Technology Demonstration Project ($4M) under the current DOE program.

Principle Power 2-MW Demonstration

Characteristics	
Country/Sponsor:	Portugal
Major Partners:	Vestas, EDP
Turbine Size/Description:	Vestas V-80, 2 MW wind turbine
Deployment date :	September 2011
Platform Type:	Three – tank semisubmersible – 6 line mooring
Site:	Aguçadoura, Portugal
Water Depth	40 to 50-m
Approximate Budget:	$ 25M USD

The PPI WindFloat semi-submersible wind system was installed and commissioning off the Portuguese coast in Sept 2011. The installation includes a grid-connected Vestas V80 2-MW wind turbine. Testing has been underway. An EU Framework 7 award increased their testing capability. DOE has been participating for data analysis and model validation.

Fukushima Forward Demonstration

Characteristics	
Country/Sponsor:	Japan
Major Partners:	Mitsubishi, IHI, MITI, Hitachi
Turbine Size/Description:	MHI 7.0 MW wind turbine
Deployment date :	2013 - 2015
Platform Type:	Semisubmersible or spar or hybrid
Site:	Fukishima, Japan
Water Depth	100 – 200 meters
Approximate Budget:	$ 189M USD

Phase 1 – Photo credit NY Times

Japan has initiated a major shift in energy policy following the Fukushima disaster in 2011. Floating wind technology development has accelerated significantly.

On November 11 the first 2-MW floating turbine went into operation off the shore of Fukushima Prefecture. Two 7 MW turbines are slated to be added to this by the year 2015.

http://www.nytimes.com/2013/10/25/business/international/to-expand-offshore-power-japan-builds-floating-windmills.html?pagewanted=all&_r=0

Kabashima 2.0MW Demonstration

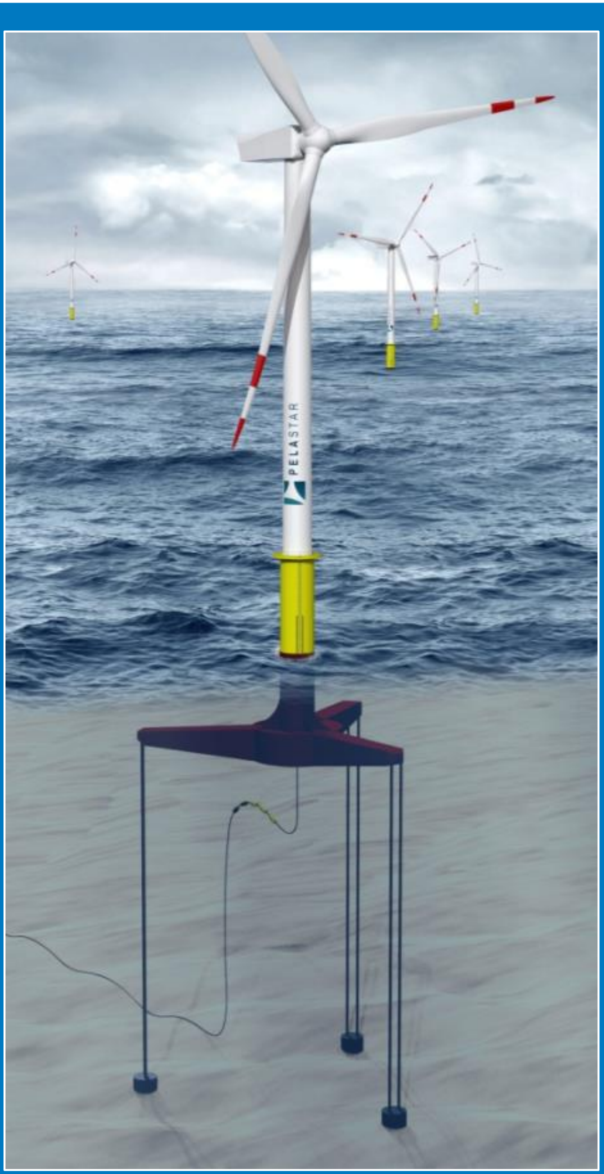
Characteristics	
Country/Sponsor:	Japan
Major Partners:	Toda, Kyoto University, Hitachi, Ministry of Environment
Turbine Size/Description:	Hitachi 2.0 MW wind turbine
Deployment date :	2015
Platform Type:	spar
Site:	Kabashima, Japan
Water Depth	80-100m
Approximate Budget:	---

On October 28, 2013 a 2 MW floating wind turbine (Ministry of the Environment) went into operation off the coast of Kabashima Island, Goto City, Nagasaki Prefecture.

http://fukushima-is-still-news.over-blog.com/article-the-choshi-coast-windmill-111596082.html

Tension Leg Platform Substructures

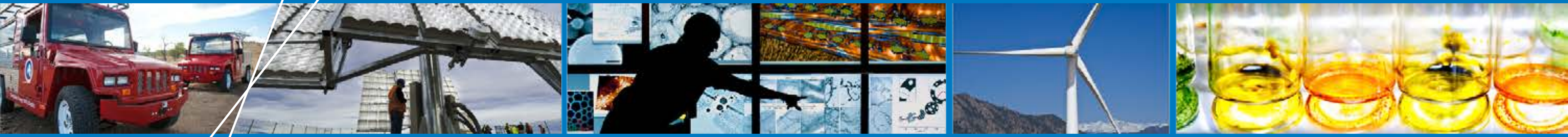
- Tension Leg Platform provides stability by differential tension on tendons
- Not stable without connection to tendons – challenging deployment
- Suitable for wide range of transitional and deep water depths



Pelestar TLP – Courtesy of Glosten Associates

BOEM Offshore Renewable Energy Workshops:

Wakes and Array Effects



Walt Musial, NREL

July 29, 2014

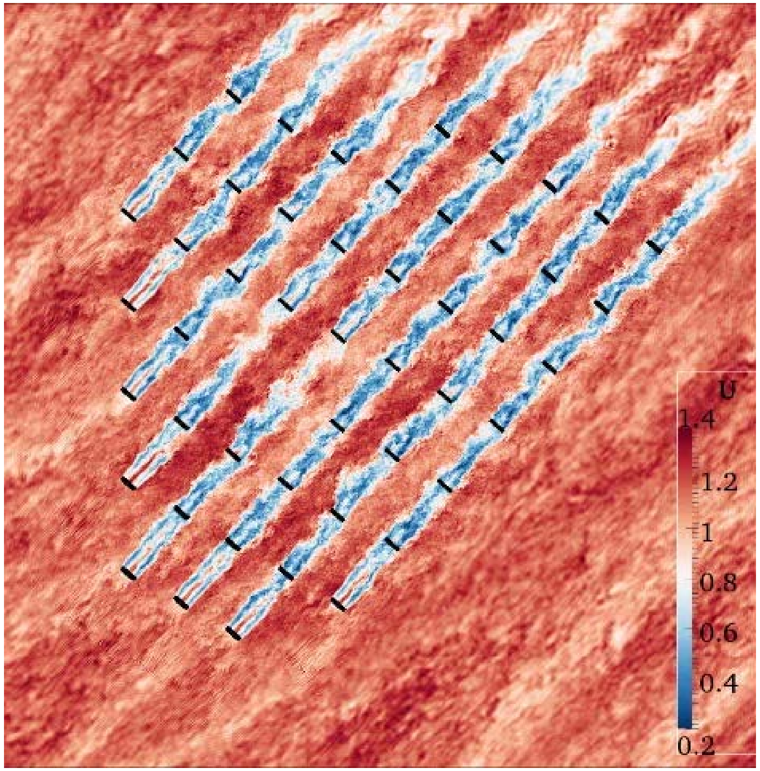
Wakes and Arrays

Horns Rev Offshore Wind Plant

Typical Array Spacing 7D - 10D

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

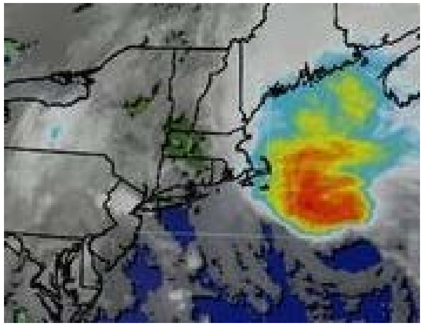


Simulator for Wind Farm Applications showing turbine wake effects (Source: NREL)

High Definition Wind Plant Modeling

Simulator for Offshore Wind Farm Applications (SOWFA)

Scale: **Mesoscale** **Farm Array** **Turbine**



Tools: **WRF** ↔ **OpenFOAM** ↔ **FAST**

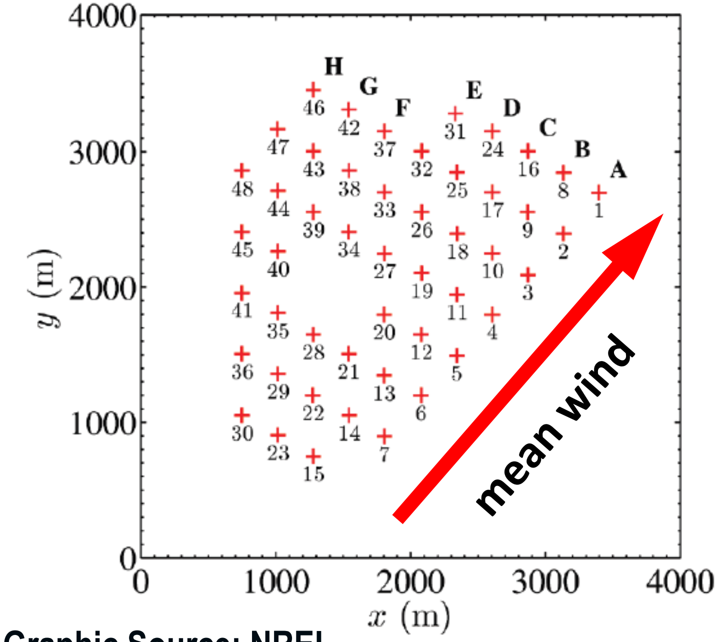
SOWFA

- Enables Optimum Wind Plant System Design Layout
- Understanding of Fatigue Loading Due to Wake Effects
- Understanding Deep Array Effects
- Enables Optimized Wind Plant Control

Graphic Source: NREL

Wind Plant Simulation Example

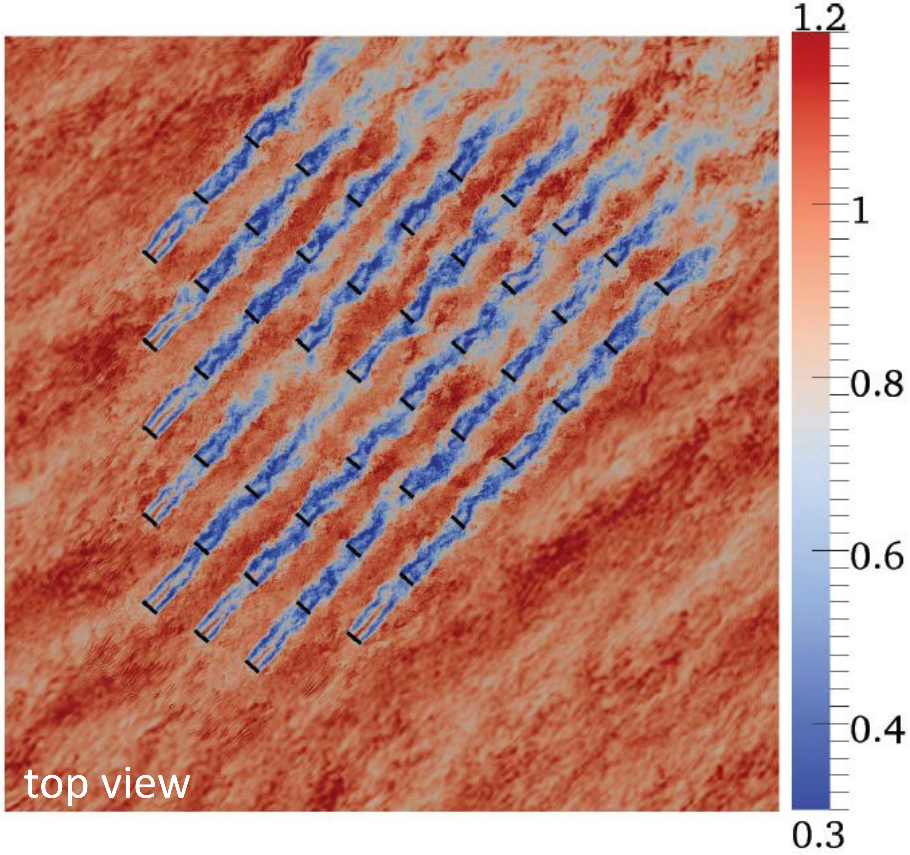
- **Lillgrund**
  - 7 km off coast of Malmö, Sweden
  - 48 Siemens SWT-2.3-93, 2.3MW
  - 4.3D and 3.3D spacing (not recommended)
  - Mean wind: 8 m/s hub height first row



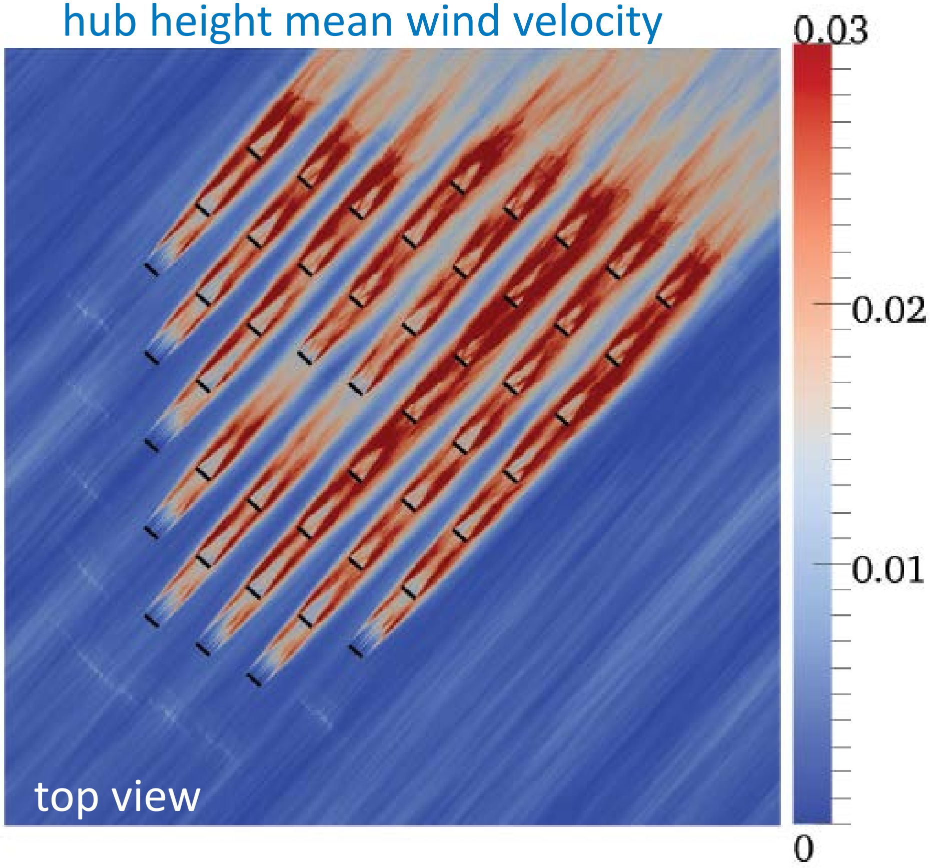
Graphic Source: NREL

Results – Wind Plant Simulation

Instantaneous velocity normalized by hub height mean wind velocity



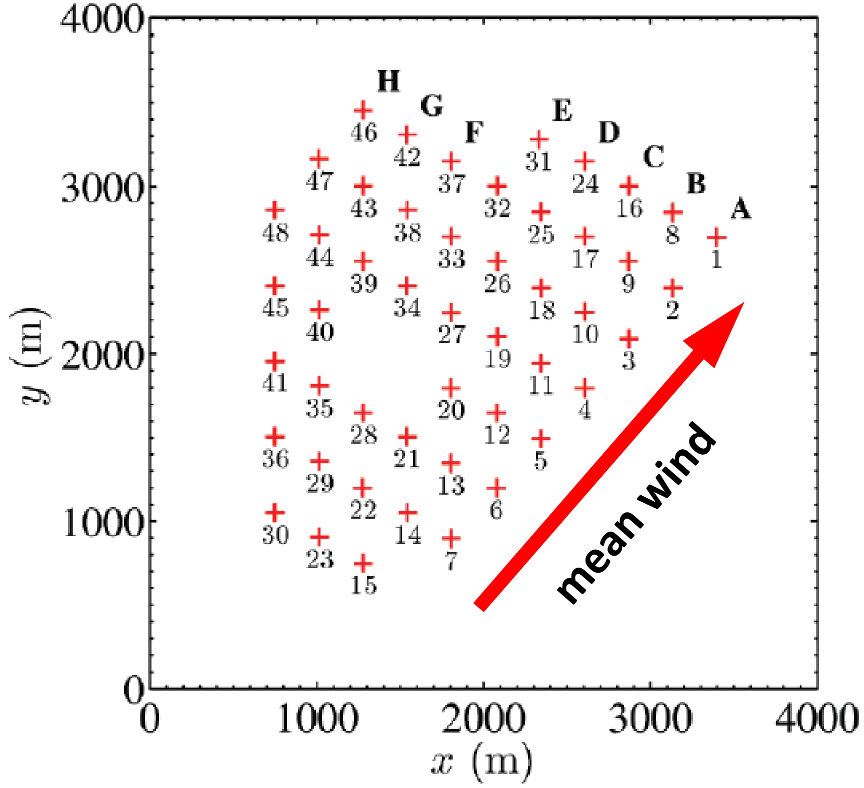
Resolved-scale turbulent kinetic energy normalized by square of hub height mean wind velocity

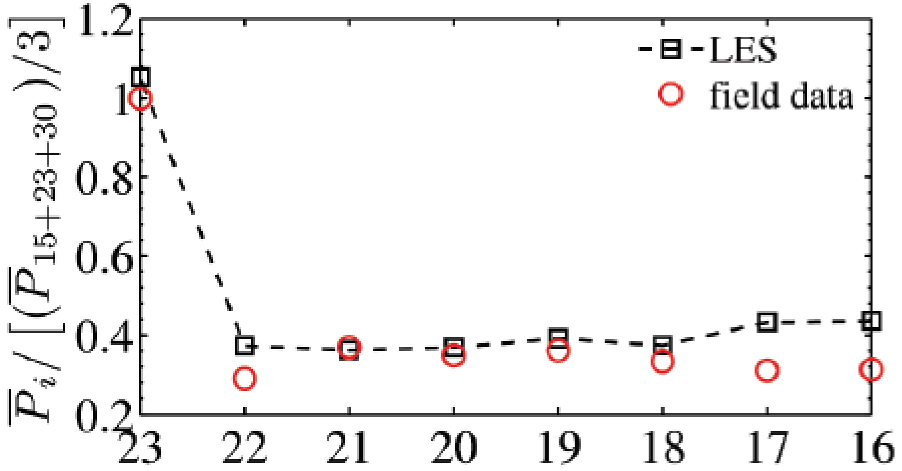


Meandering shows up in resolved turbulent kinetic energy

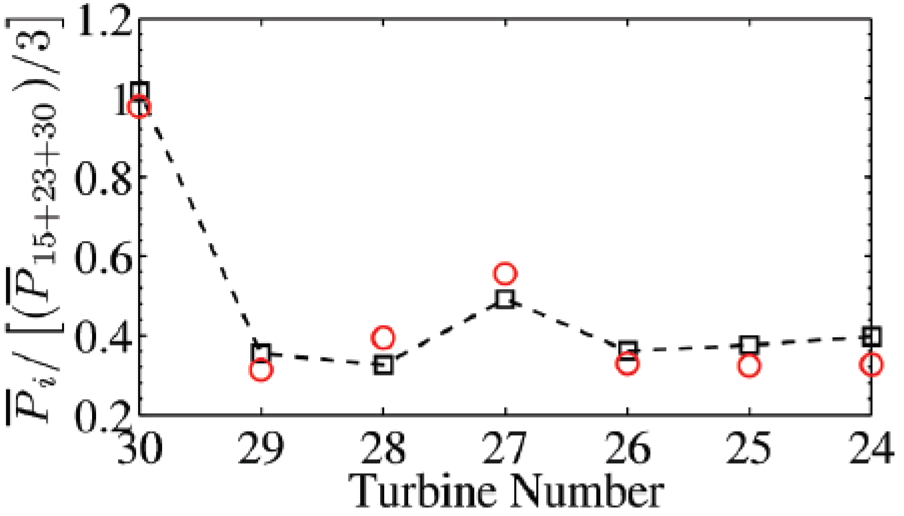
Graphic Source: NREL

Results – Wind Plant Simulation





Row C

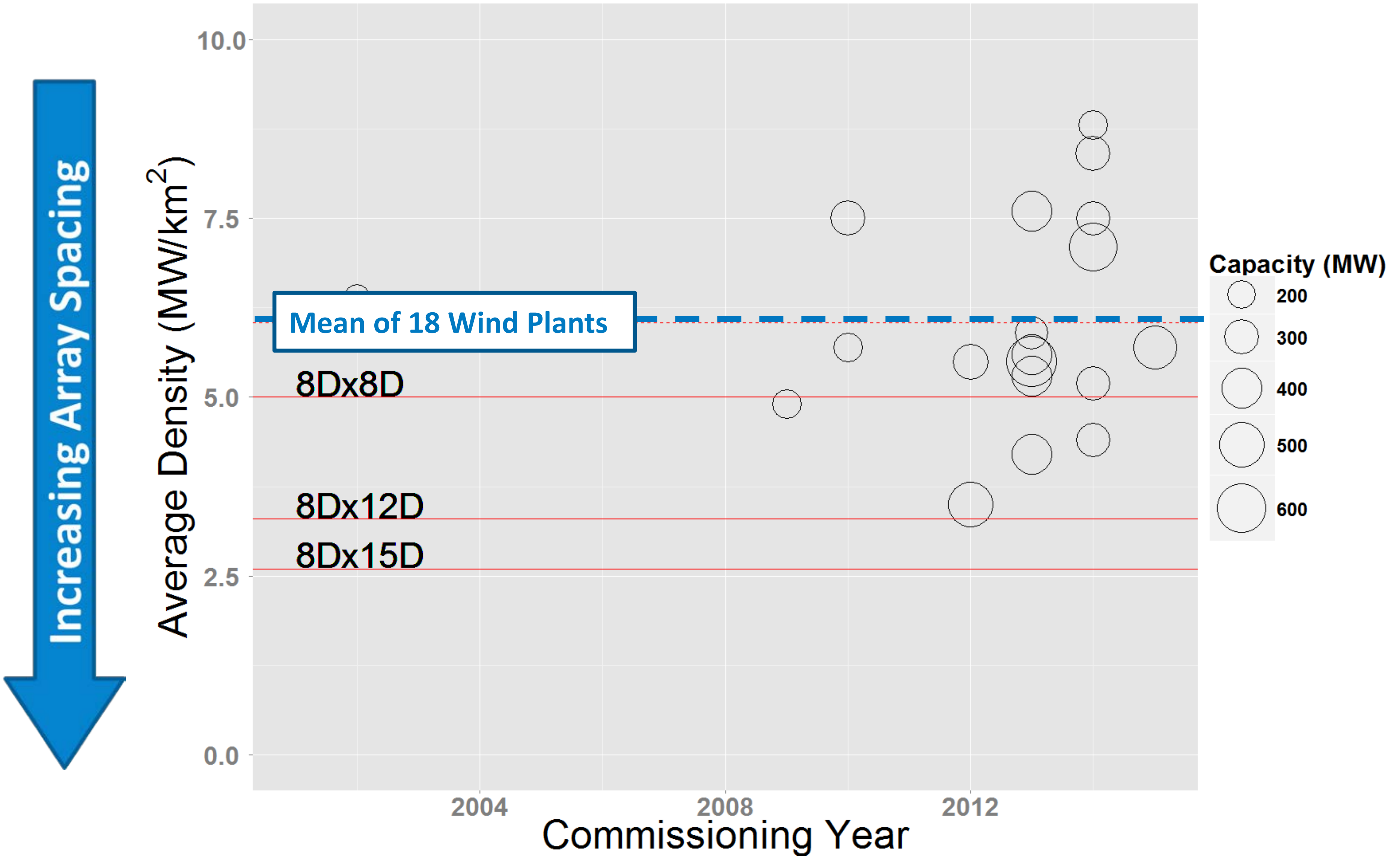


Row D

Reasonable agreement with field data

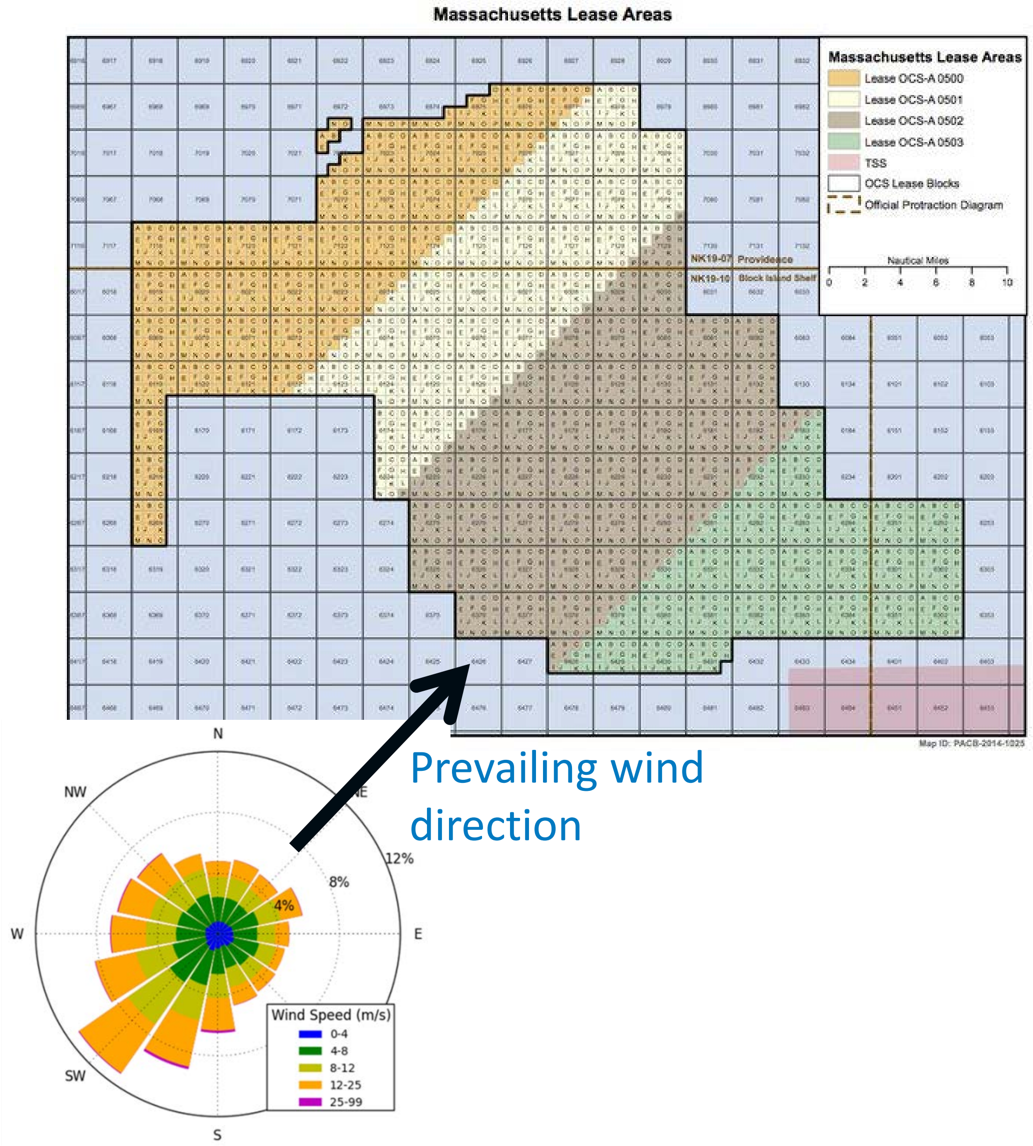
Graphic Source: NREL

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



63

Massachusetts WEA Lease Areas



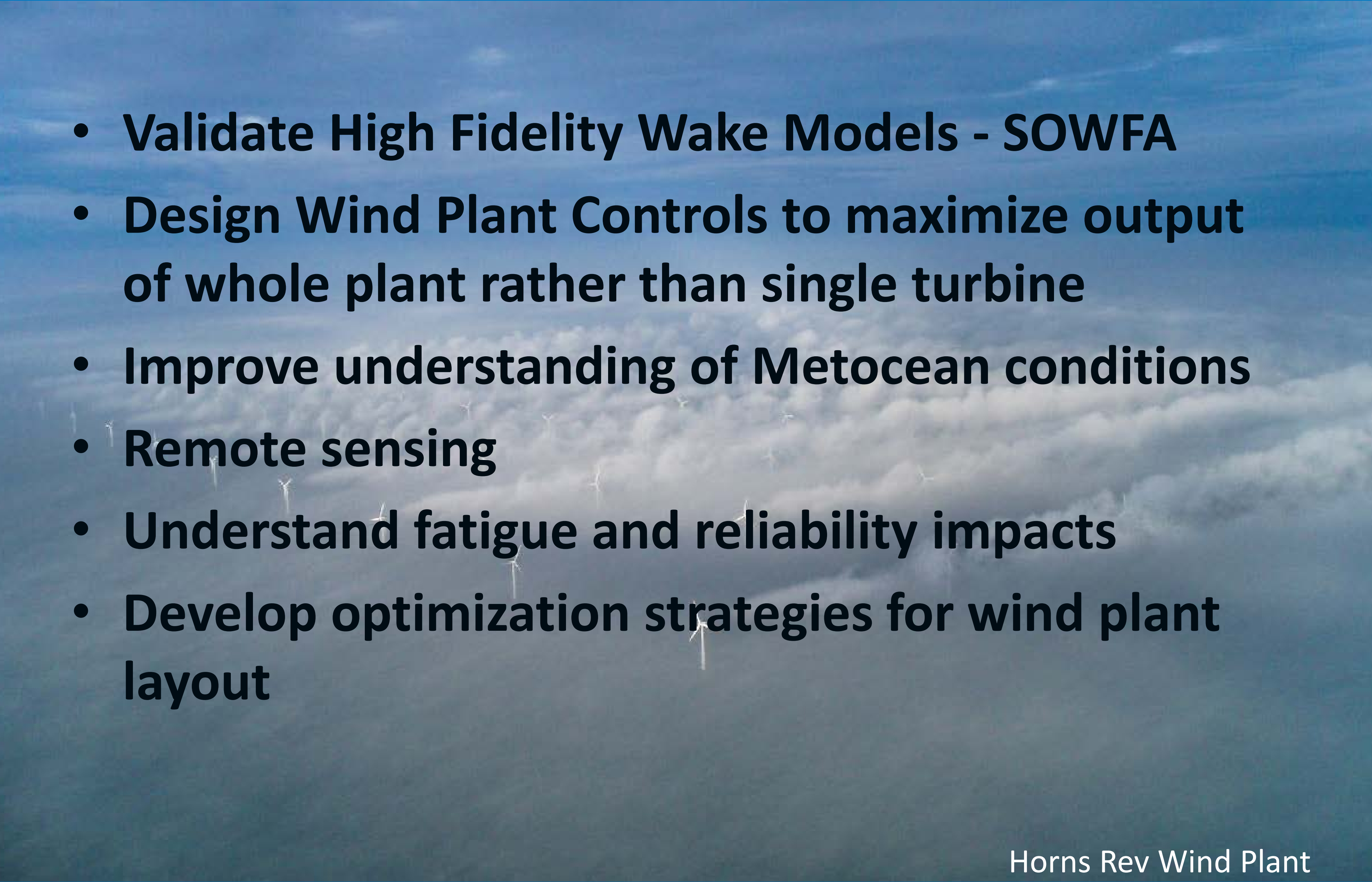
Prevailing wind direction

Delineation Objectives:

1. **Approximate balance in energy production potential each lease area (>50m water depth area)**
2. **Minimize wake loss potential between lease areas**
3. **Consider at least one 500-MW wind plant in water depths < 50m**

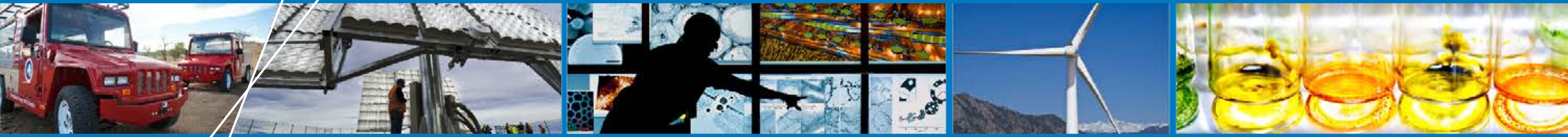
Future Wakes and Array Effects

- Validate High Fidelity Wake Models - SOWFA
- Design Wind Plant Controls to maximize output of whole plant rather than single turbine
- Improve understanding of Metocean conditions
- Remote sensing
- Understand fatigue and reliability impacts
- Develop optimization strategies for wind plant layout



Horns Rev Wind Plant

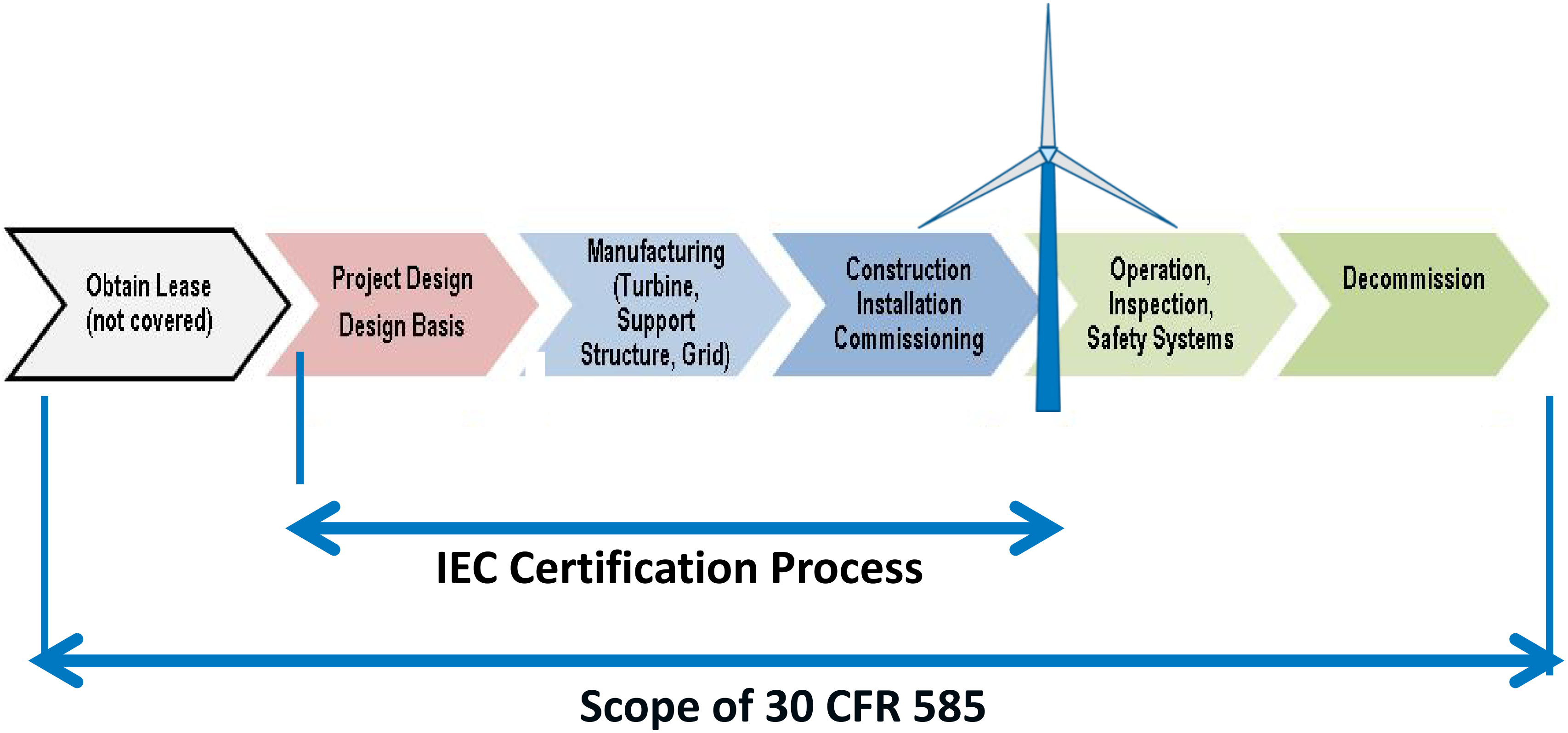
BOEM Offshore Renewable Energy Workshops: Phases of Offshore Wind Plant Development



Walt Musial, NREL

July 29, 2014

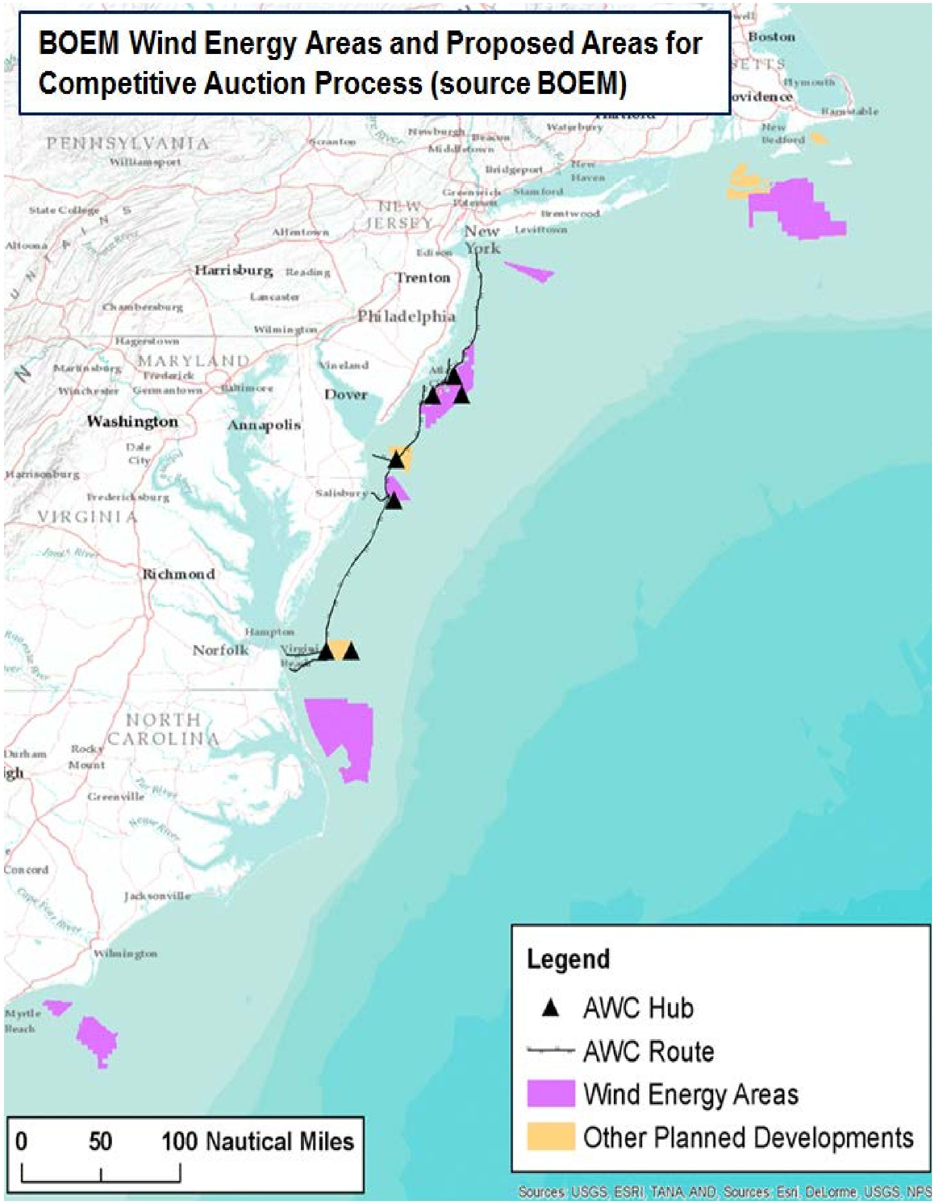
Typical Offshore Wind Facility Development Process



- Six development phases from site development to decommissioning
- IEC Standards cover period from design to commissioning
- BOEM regulations cover entire development pathway
- All regulatory domains – state or federal
- All utility scale turbine and project sizes

Obtaining Site Control / Lease

- **BOEM 30 CFR 585**
- **"Smart form the Start"**
- **NEPA / EA - EIS**
- **Wind Energy Areas Lease Zone Auctions**
- **Lease Types**
  - Research Leases (e.g. VA)
  - Commercial – competitive and non-competitive
  - State waters
  - Cape Wind (grandfathered)



BOEM Wind Energy Areas and Proposed Areas for Competitive Auction Process (source BOEM)

Sources: USGS, ESRI, TANA, AND, Sources: Esri, DeLorme, USGS, NPS

Summary of BOEM WEA Statistics

WEA	Status	Area (acres)	Area (sq. km)	Estimated OSW potential (GW)*
MA	Announced	742,974	3,007	9.0
RI-MA	Awarded	164,750	667	2.0
NY	Scoping	81,280	329	1.1
NJ	Announced	354,275	1,434	4.3
DE	Scoping	103,323	418	1.3
MD	Announced	79,706	323	1.0
VA	Awarded	112,799	457	1.4
Total (GW)				**20**

[1] Assumes an average capacity density of 3 MW per square kilometer based on standard spacing metrics developed in Musial et al. 2013a and Musial et al. 2013b

Project Design - Design Basis Outline

- **Project Description – Physical Characteristics**
- **Definition of structure and site limitations**
  - Definition of Standards
  - Turbine selection – type certificate?
  - Tower and sub-structure design (Allowable frequency range, Transition piece, Tower, Other secondary structures)
  - Corrosion, salinity
- **Definition of physical environmental conditions**
  - Water depths
  - Water levels (tide, surge)
  - Currents
  - Wave parameters (Scatter diagram, Extreme values, Wave directions, Breaking waves, Wind parameters)
  - Wind distributions (Turbulence intensity, Extreme values, Wind directions
  - Wind-wave-directionality
- **Other metocean parameters (temperature, ice, marine growth, seismic)**
- **Soil conditions (soil profiles, scour)**
- **Structural load assumptions**
  - Modeling of the coupled turbine/substructure system
  - Load assumptions
  - Design load cases (fatigue, extreme, transportation, assembly)

Recent Offshore Wind Standards Activities

- BOEM 30 CFR 585 – 2009
- National Academies Report: *Structural Integrity of Offshore Wind Turbines: Oversight of Design, Fabrication, and Installation* –2011
- IEC TC-88 61400-03 Maintenance Team (MT3)
- IEC TC-88 RP – Floating Wind Turbines (MT3-2)
- DNV, GL, ABS updating guidelines for offshore wind
- API standards activities – new revisions of RP-2A and RP-2MET in 2014
- AWEA Offshore Compliance Recommended Practices AWEA OCRP 2012 – Oct 2012

ABS

GUIDE FOR BUILDING AND CLASSING

FLOATING OFFSHORE WIND TURBINE INSTALLATIONS

JANUARY 2013

American Bureau of Shipping
Incorporated by Act of Legislature of
the State of New York 1862

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American Bureau of Shipping
ABS Plaza
16855 Northchase Drive
Houston, TX 77060 USA

AWEA OCRP 2012 September 16, 2012

AWEA Large Turbine Compliance Guidelines:

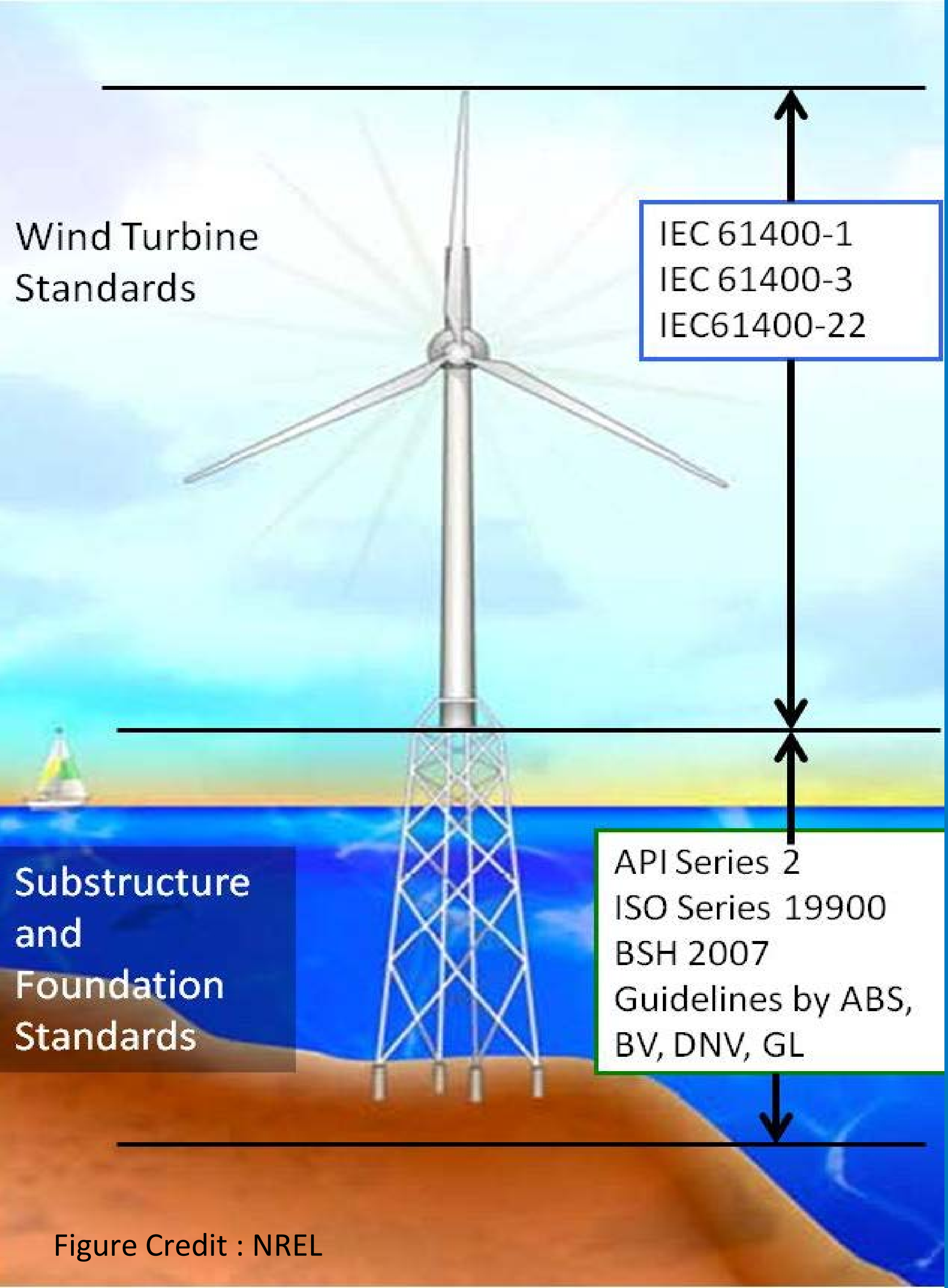
AWEA Offshore Compliance Recommended Practices (2012)

Recommended Practices for Design, Deployment, and
Operation of Offshore Wind Turbines in the United States

AWEA AMERICAN WIND ENERGY ASSOCIATION

Page | 1

Applicability of Offshore Wind Design Standards



Wind Turbine Standards

IEC 61400-1
IEC 61400-3
IEC61400-22

Substructure and Foundation Standards

API Series 2
ISO Series 19900
BSH 2007
Guidelines by ABS, BV, DNV, GL

Figure Credit : NREL

- Safety should be the same for turbine and support structure using different codes
- Recommendation L-2 Exposure Category for unmanned structures
- Higher safety is recommended to account for possible serial failure consequences due to design replication

Certified Verification Agents for Offshore Wind

- Certified Verification Agents (CVA) are third party experts hired by the developer to check and confirm integrity of offshore wind project design and implementation.
- 30 CFR 585 rule proposes a CVA process similar to that applied for offshore oil and gas facility oversight.
- The specified role of the CVA is to review, assess, and comment to BOEM. Focuses on structural aspects and foundations.

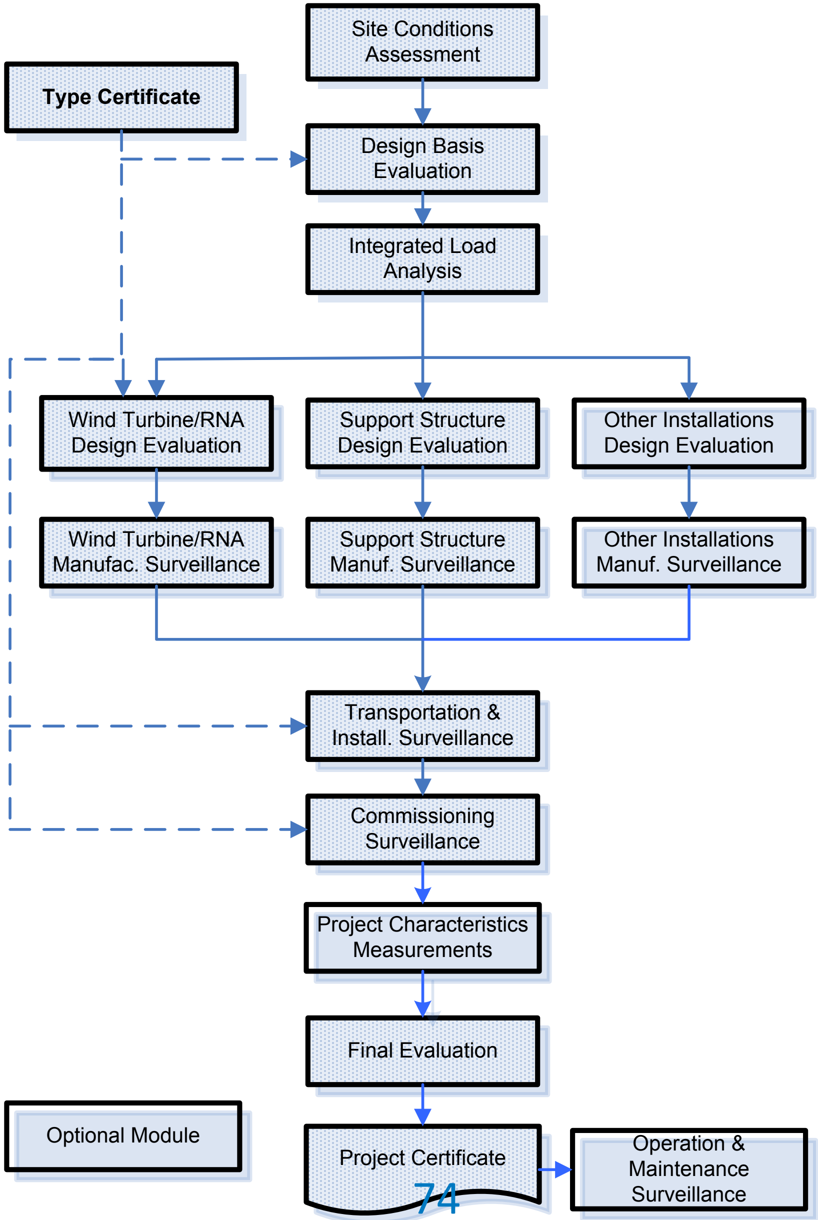
Reference: NAS report "Structural Integrity of Offshore Wind Turbines: Oversight of Design, Fabrication, and Installation", published April 2011

Photo credits: Gary Norton

Project Certification from IEC 61400-22

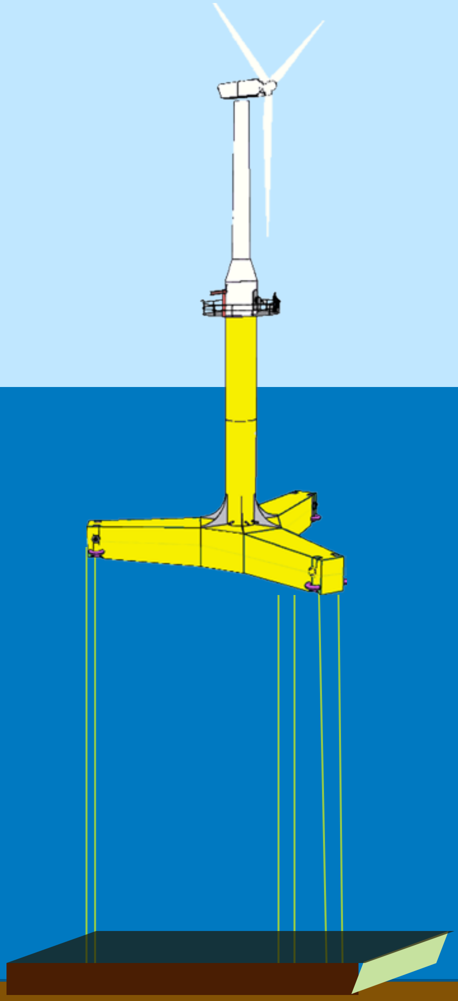
Project certificates ensure conformity of type-certified wind turbines to specific foundation design, site conditions, and local codes.

Project Certificates provide site-specific conformity to hurricane conditions.



Source: IEC TS 61400-22 CDV

Floating Offshore Wind Design Standards

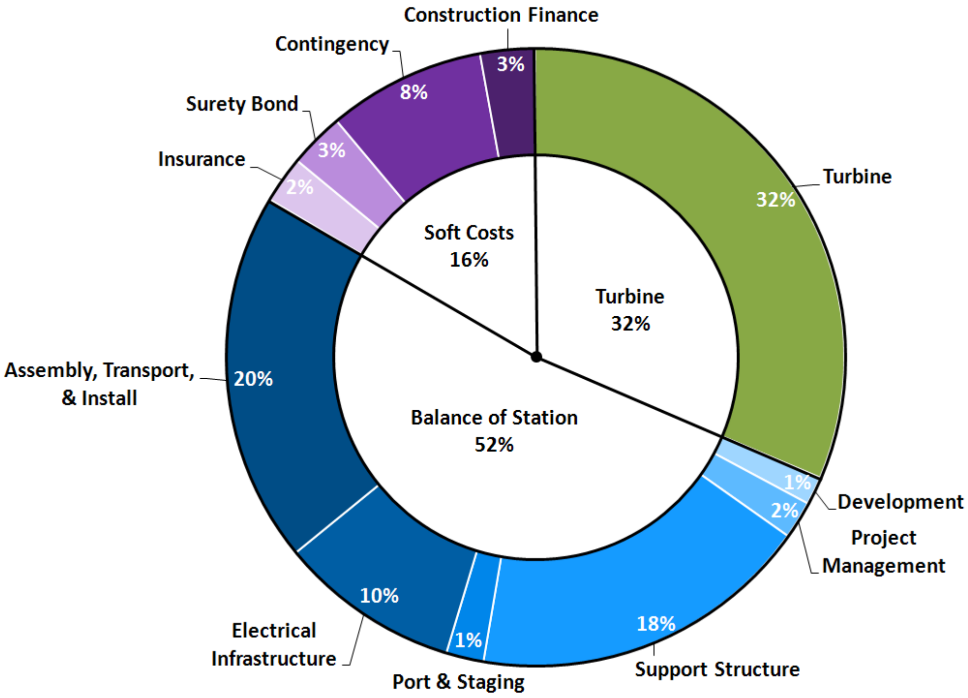


Glosten Pelestar TLP

- No standards address floating wind turbine
- Most floating standards applicable for oil and gas
- IEC has begun developing a recommended practice for floating wind turbines 61400-03-2.

Manufacturing and Testing

- Markets and supply chain are currently based in Europe
- Turbines may be imported in the near-term but long term opportunities exist for domestic content
- Substantial portions of balance of station development can be domestic content
- Manufacturing and testing of turbine and subcomponents are covered under IEC 61400-22, AWEA OCRP and companion standards



Graphic Source: NREL

Installation, Construction and Commissioning

- High dependency on heavy lift vessels
- Jones act requires US flagged ships
- Assembly, transportation, and installation cost are 20% of capital expenditures
- Developers optimize construction phases to fit in one season
- Floating systems could lower percentage of time at sea

Photos: Walt Musial

National Renewable Energy Laboratory
Innovation for Our Energy Future

Offshore Wind Operational Issues

Photo Credit: Vestas Wind Turbines

- Corrosion Protection
- Nacelle pressurization
- Personnel Access, shelter, and safety
- Navigational safety
- Ship Collisions
- Submarine cable electrical infrastructure upkeep
- Condition monitoring and predictive maintenance
- Inspection
- Decommissioning

Offshore Maintenance Issues

Credit: ABB

Credit: GE Energy

- Vessel deployment cost
- Logistics
- Reliability and in situ repair
- Condition Monitoring
- Accessibility and Availability
- Weather Windows

Wave Height can affect weather windows

U.S. Marine Hydrokenetic (MHK) Wave Atlas

http://maps.nrel.gov/mhk_atlas; http://www1.eere.energy.gov/water//pdfs/mappingandassessment.pdf

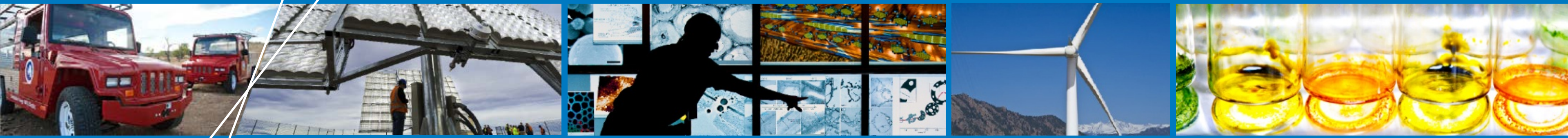
Operations and Safety

- Recommendations for equipment safety best practices are covered in AWEA OCRP 2012
- AWEA safety committee is addressing human safety issues and report is pending
- Condition monitoring equipment will help detect failures and faults remotely
- Some oil and gas and land based wind procedures will be applicable.

Photo Credit: Siemens

Decommissioning and Design Life

- Most offshore wind turbines are designed for 20-year operational life. Trends are toward longer design lives.
- Balance of plant equipment and infrastructure may survive up to 50-years.
- Offshore wind projects may be repowered – reuse of major components
- Decommissioning plan is required prior to construction. Bond may be required to hold revenues to cover decommissioning costs (maybe 3%)
- Some support structures may be more cost effective to remove than others



Back-up slides

Parametric Sensitivity Analysis on Balance of Station Costs

Baseline project parameters	
Project Size (MW)	500
Turbine Rating (MW)	4.5
Rotor Diameter (m)	126
Hub Height (m)	90
Distance to Shore (km)	30
Water Depth (m)	15
Foundation	Monopile
Array Spacing (Rotor Diameters)	8x8
Array Voltage (kV)	33
Transmission Voltage (kV)	220
IEC Wind Turbine Class	II

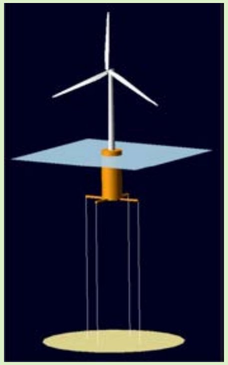
- Baseline parameters were chosen to reflect a representative offshore wind project in the mid-Atlantic
- To represent the impact of altering a single variable, all analyses use common baseline project parameters while the variable under investigation is changed.

Parameters investigated

1. Project Size
2. Turbine Size
3. Water Depth
4. Distance to Shore
5. Vessel Day Rates

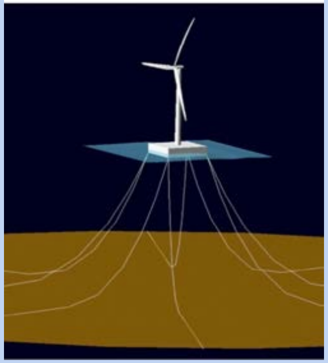
Floating Wind Turbine Design Codes Development

Ultimate and fatigue loads from six floating wind systems were compared to a land-based turbine, enabling better understanding of the behavior of different platform types.

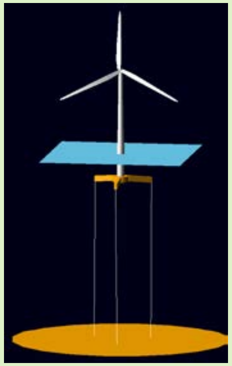


MIT/NREL TLP

OC3 Hywind Spar



ITI Energy Barge



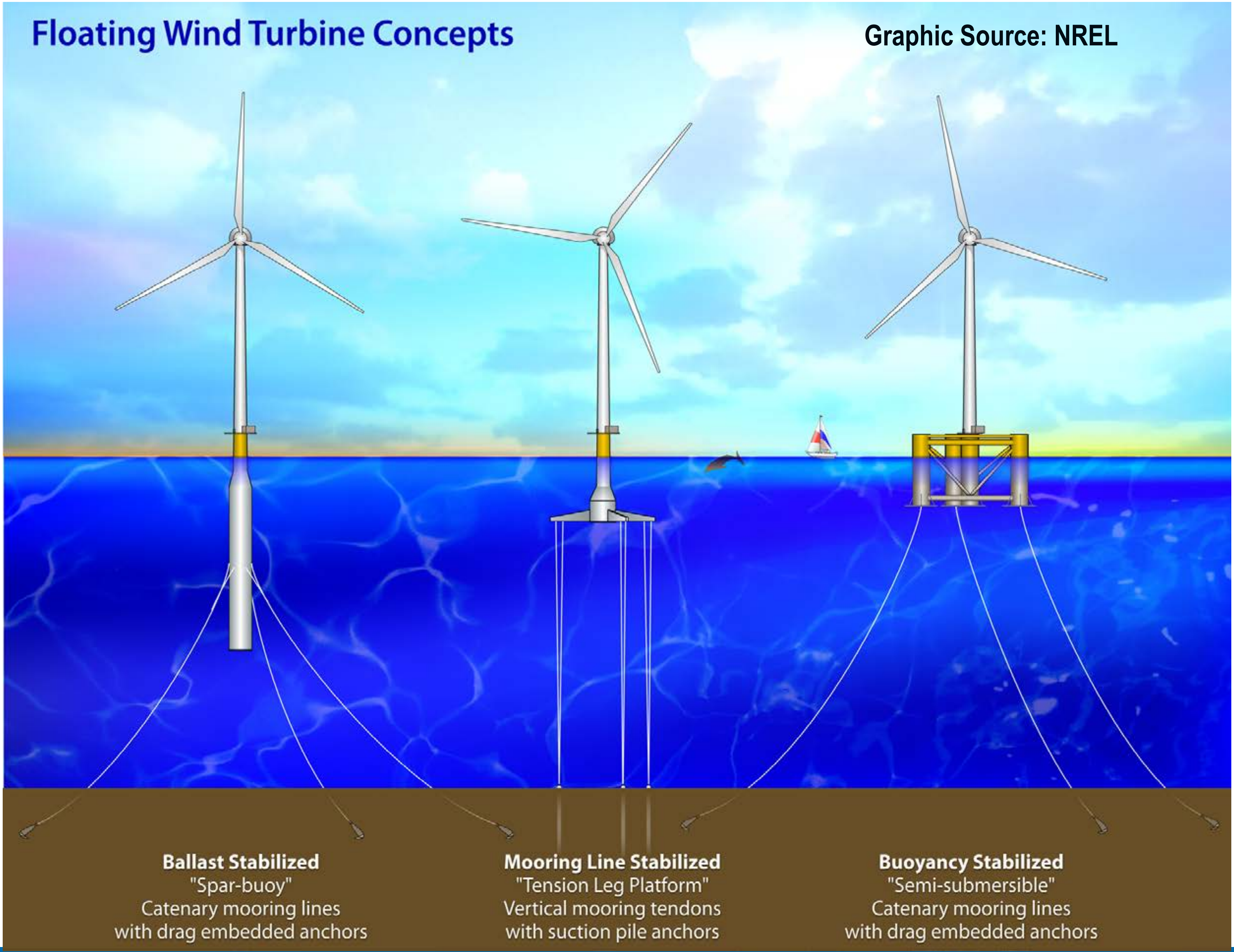
UMaine TLP

UMaine Hywind Spar

UMaine Semi-submersible

Graphic Source: NREL

Each type of floating support structures uses a different way of achieving static stablity



Offshore MET/Ocean Validation Tools

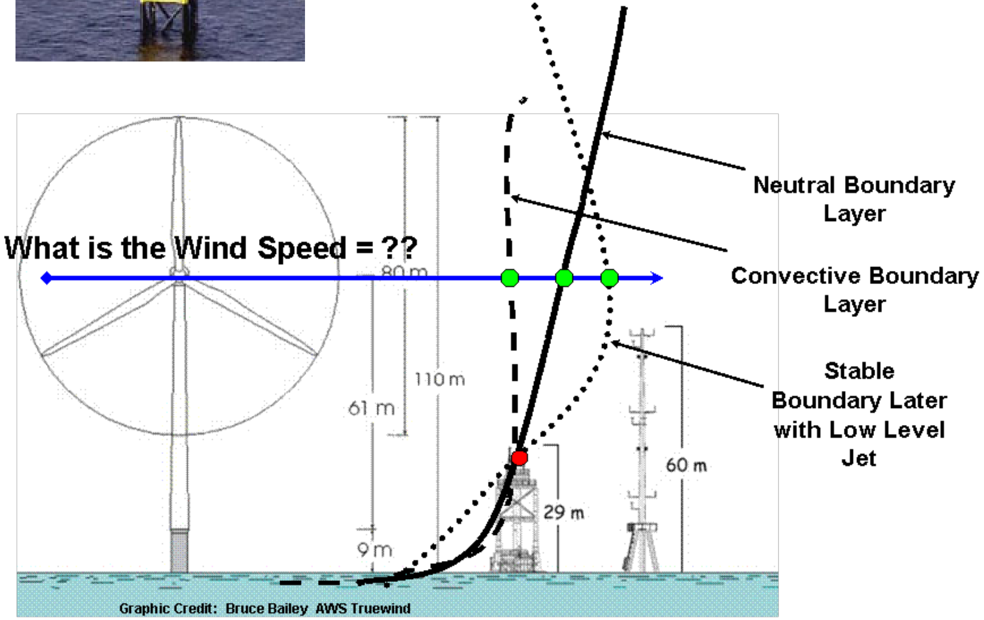
Challenges

- High cost of MET masts has inhibited accurate metocean characterization
- Marine boundary layer (wind shear, stability, and turbulence) is not well characterized
- Resource assessments rely on sparse measurements for validation
- External design conditions for turbines are poorly understood

Solutions:

- Remote sensing systems (LIDAR, SODAR)
- R&D to measure metocean conditions at sea
- Improved weather models
- Integration of multiple source data to validate resource models (e.g. satellites, met towers, etc)
- Improved forecasting

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



Graphic Credit: Bruce Bailey AWS Truewind