NREL National Renewable Energy Laboratory
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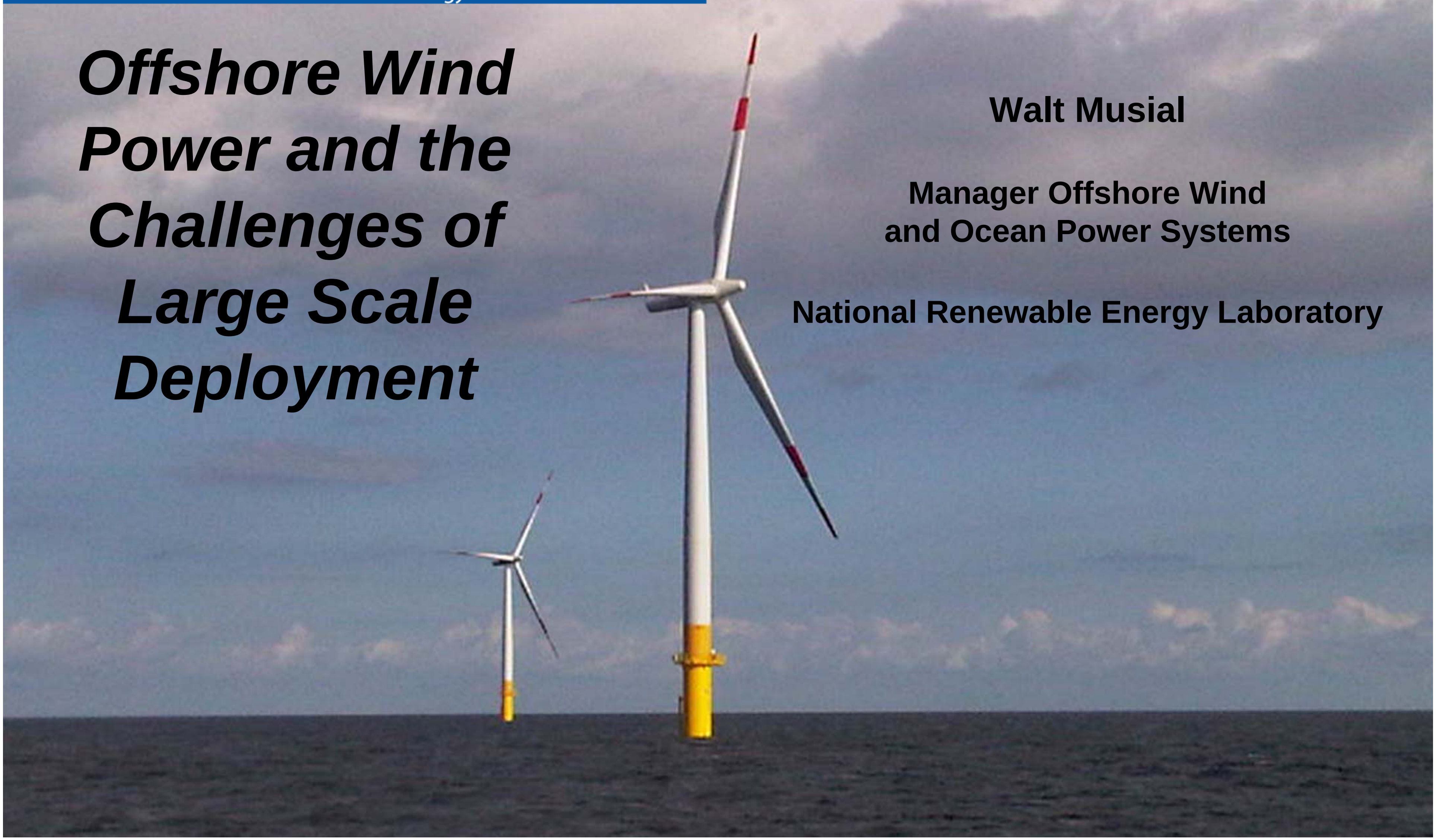


Offshore Wind Power and the Challenges of Large Scale Deployment

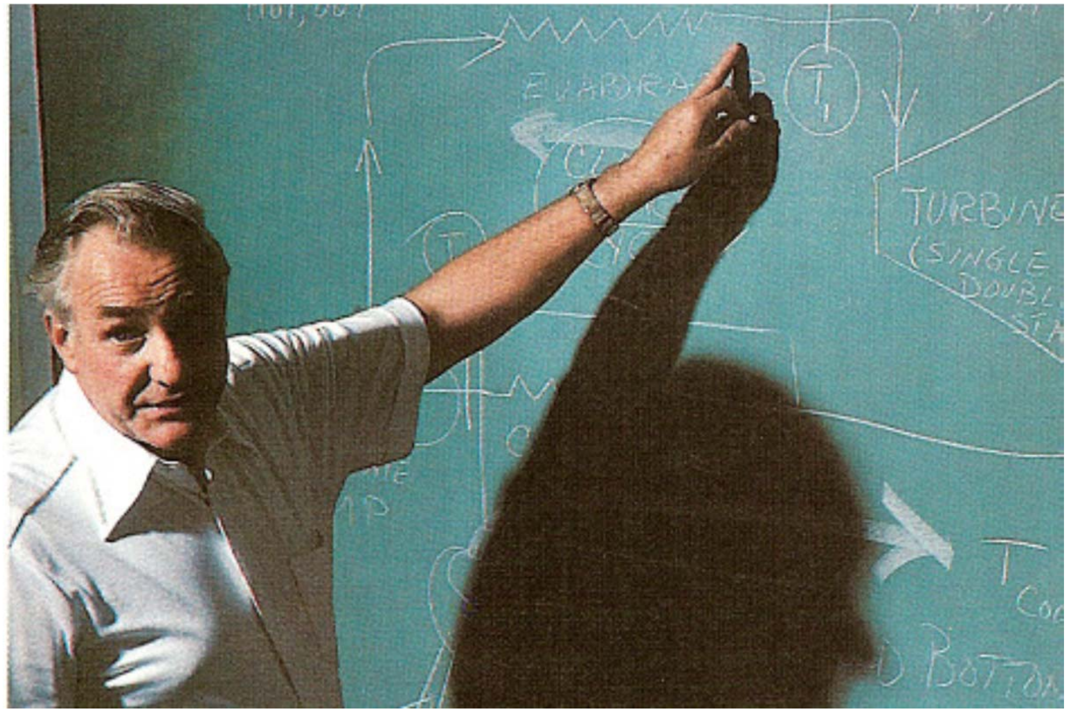
Walt Musial

Manager Offshore Wind and Ocean Power Systems

National Renewable Energy Laboratory

Inaugural Meeting of the North American Wind Energy Academy
August 7th - 9th, 2012
University of Massachusetts Amherst

Photo: Baltic I – Wind Plant Germany 2010 Credit: Fort Felker



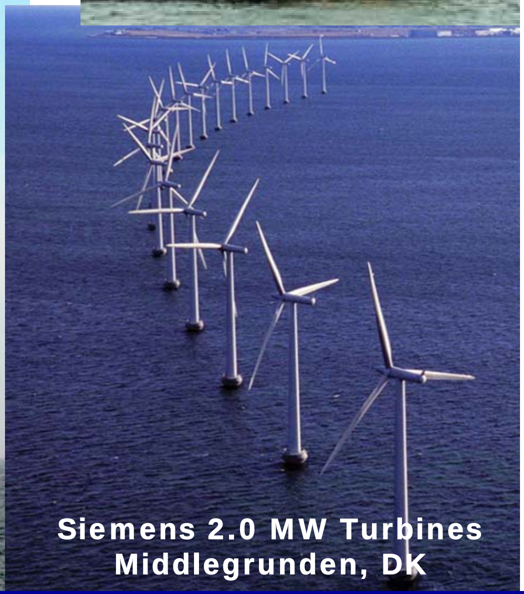
William E. Heronemus
University of Massachusetts
Circa 1973

UMass has Pioneered Offshore Wind Energy

Offshore Wind Technology Status

Vestas 2.0 MW Tu ne
Horns Rev, DK

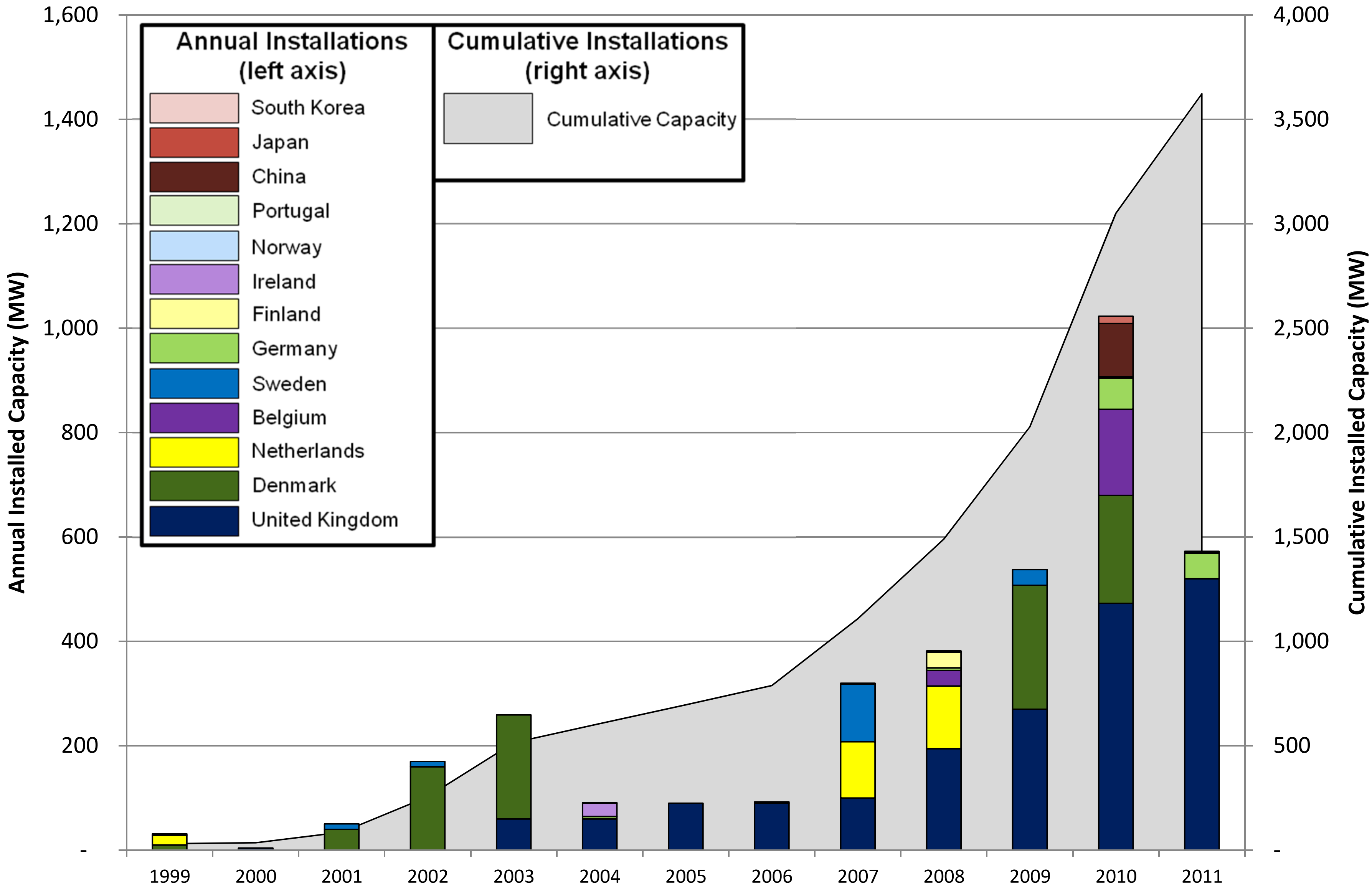
Alpha Ventus – RePower
5-MW Turbine



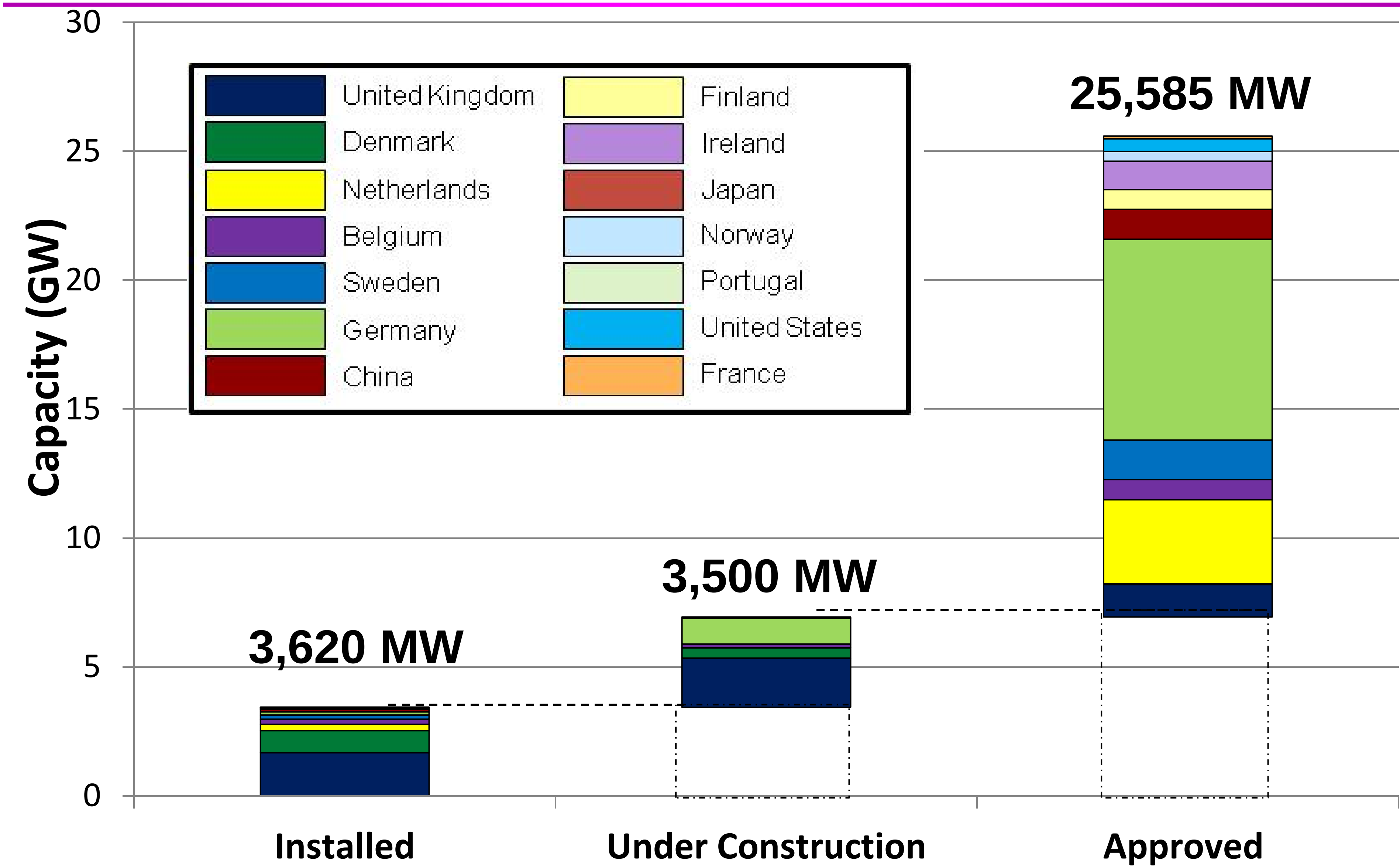
Siemens 2.0 MW Turbines
Middlegrunden, DK

- 51 projects, 3,620 MW installed (end of 2011)
- 49 in shallow water <30m
- 2-5 MW upwind rotor configuration (3.8 MW ave)
- 80+ meter towers on monopoles
- Modular geared drivetrains
- Marine technologies for at sea operation.
- Submarine cable technology
- Oil and gas experience essential
- Capacity Factors 40% or more
- Higher Cost and O&M have contributed to project risk.

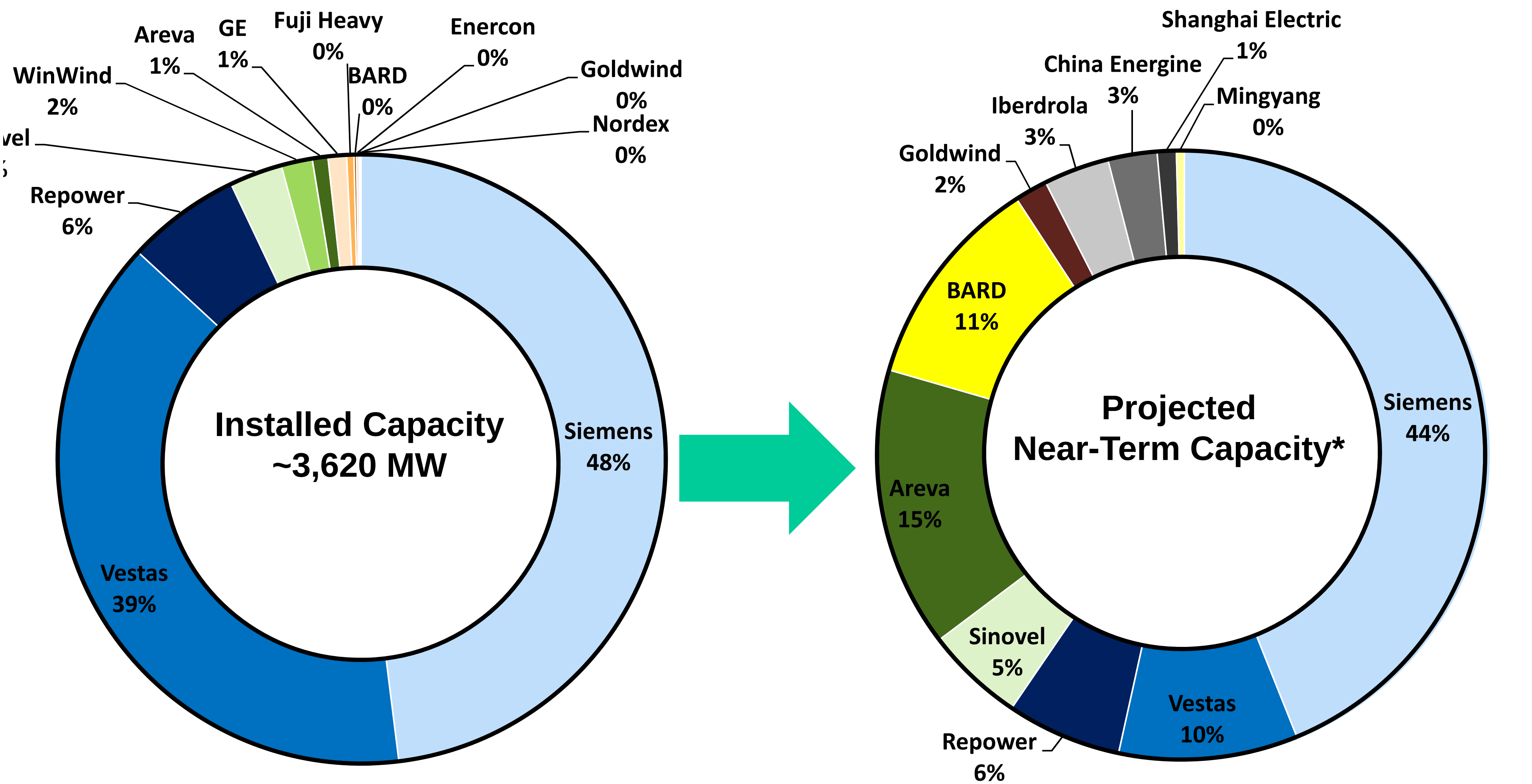
Offshore Wind Projects Cumulative And Annual Installation; The U.K. And Denmark Account For Nearly 75% Of Capacity



Offshore Wind Projects
Installed, Under Construction, and Approved

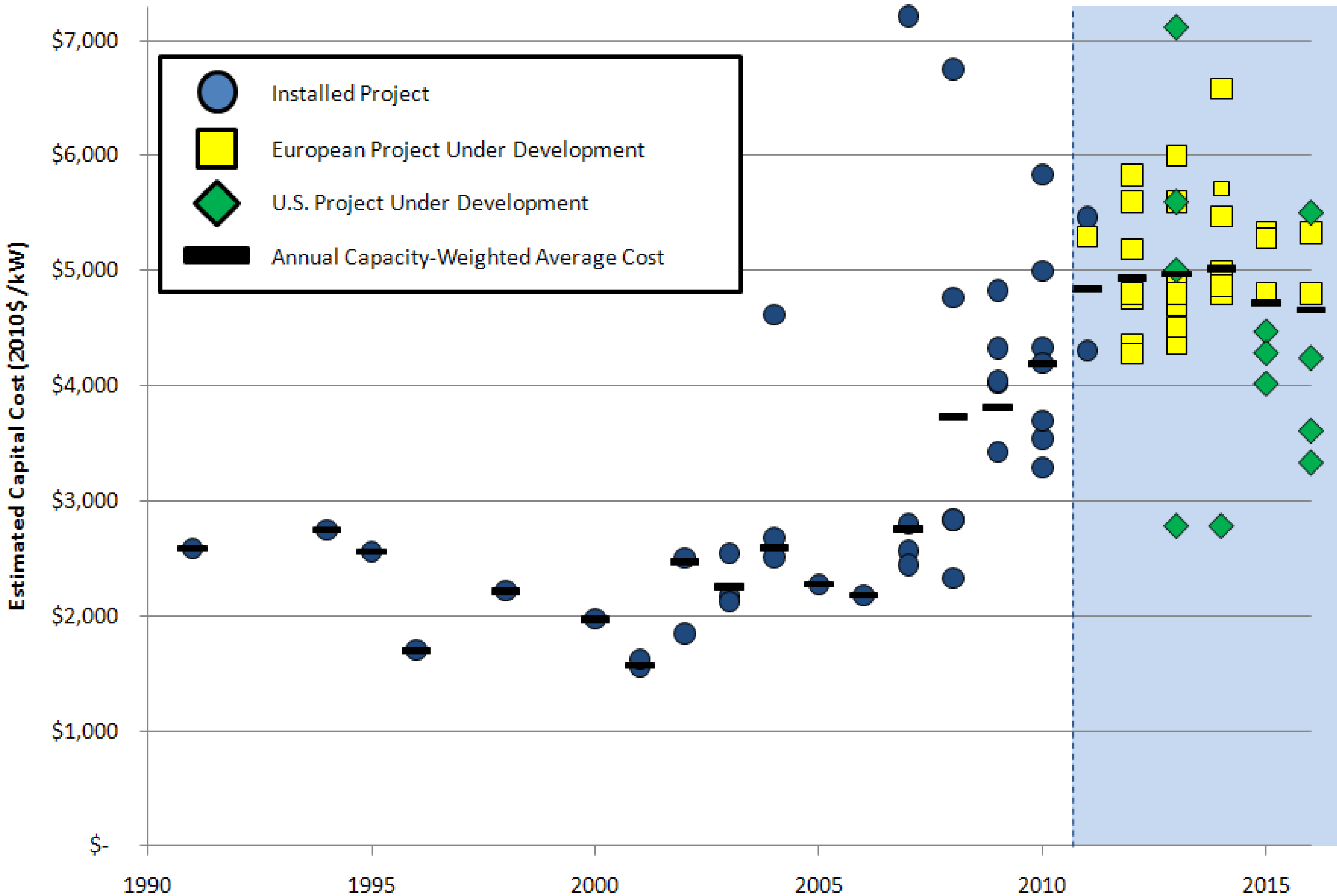


Offshore Wind Turbine Market Is Becoming Increasingly Diversified



* Includes projects under construction and approved projects that have announced a turbine manufacturer

Installed capital costs have increased substantially from 2005 levels



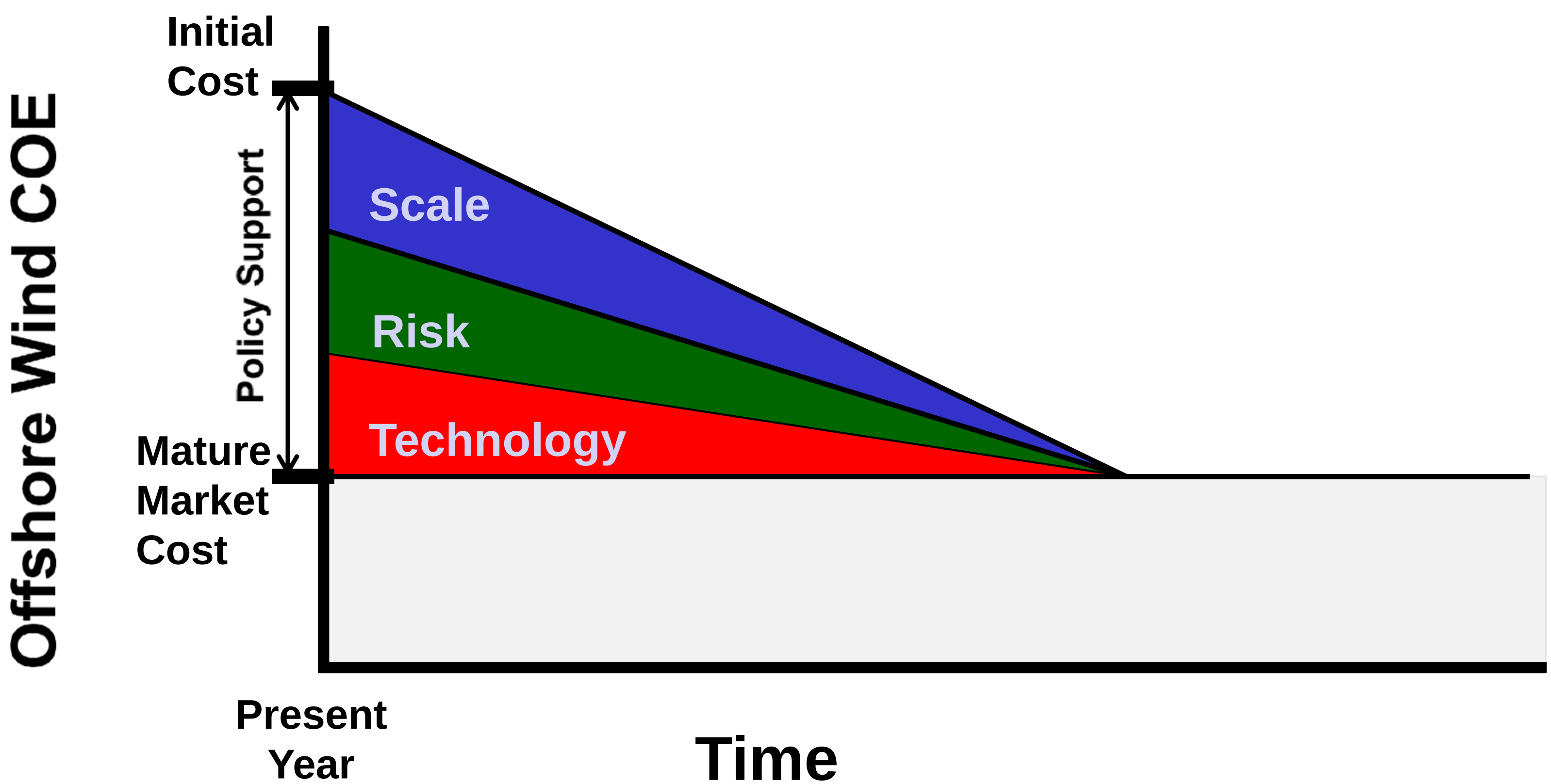
Weighted-average cost of planned offshore wind projects = $4,862/kW

Offshore Wind Cost of Energy Reduction

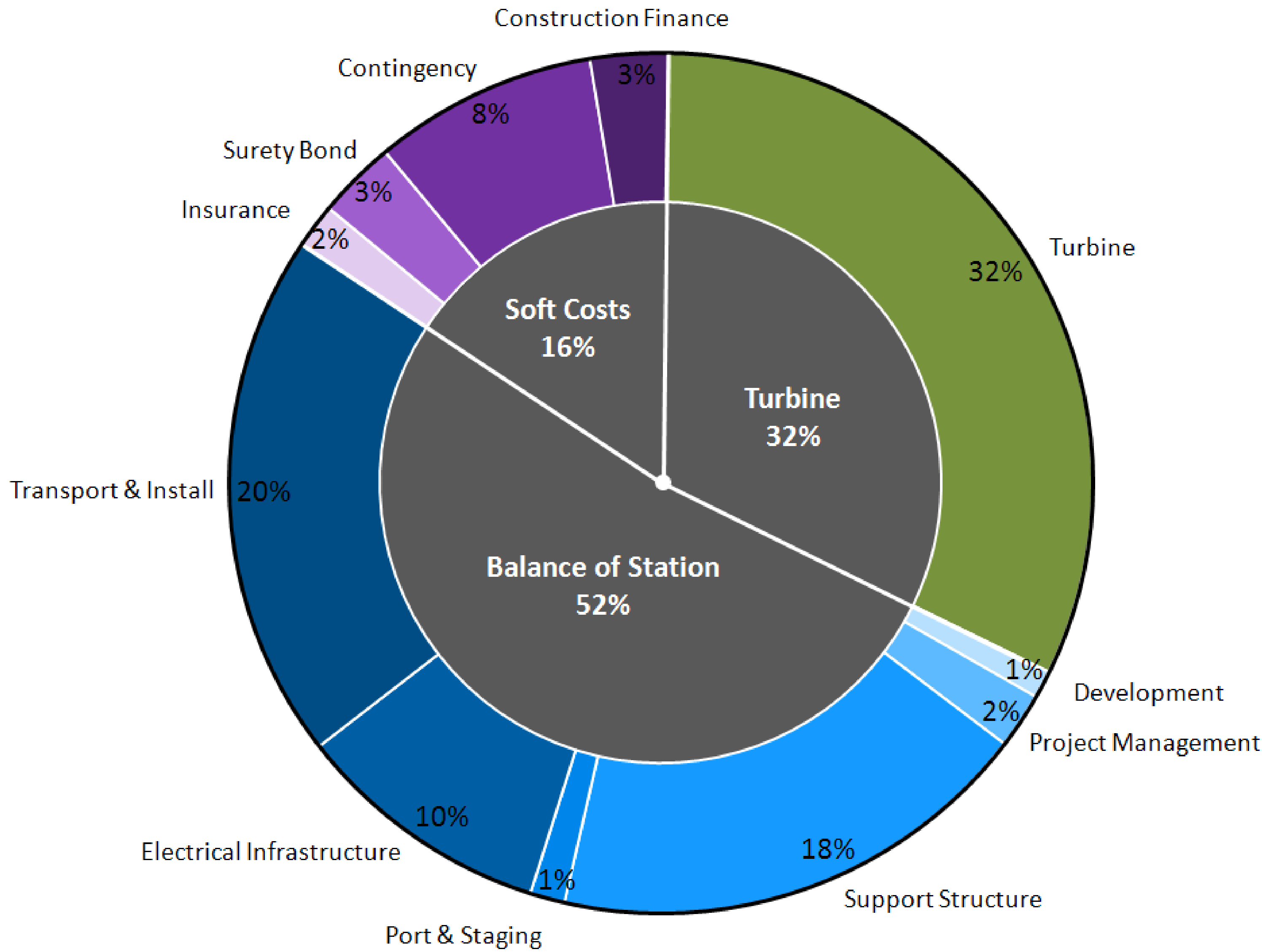
Scale of Global Deployment
- Learning Curve
- Volume Production
- Supply Chain Maturity
- Deployment and Field Experience

Risk Reduction
- Permitting
- Construction Delays
- Ops – Reliability & Production
- Financial and Market Uncertainty

Technology Innovation
- Turbine Optimization
- Balance of Station
- Offshore Grid
- Array optimization
- Integration



Installed capital costs for offshore wind turbines
Turbines account for only 32% of ICC

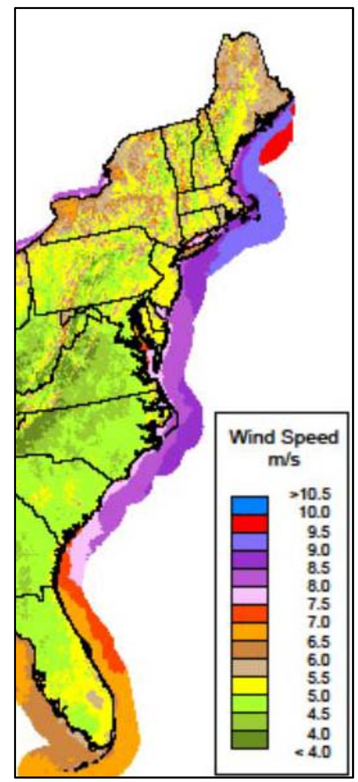


Larger scale is needed to achieve lower offshore wind cost

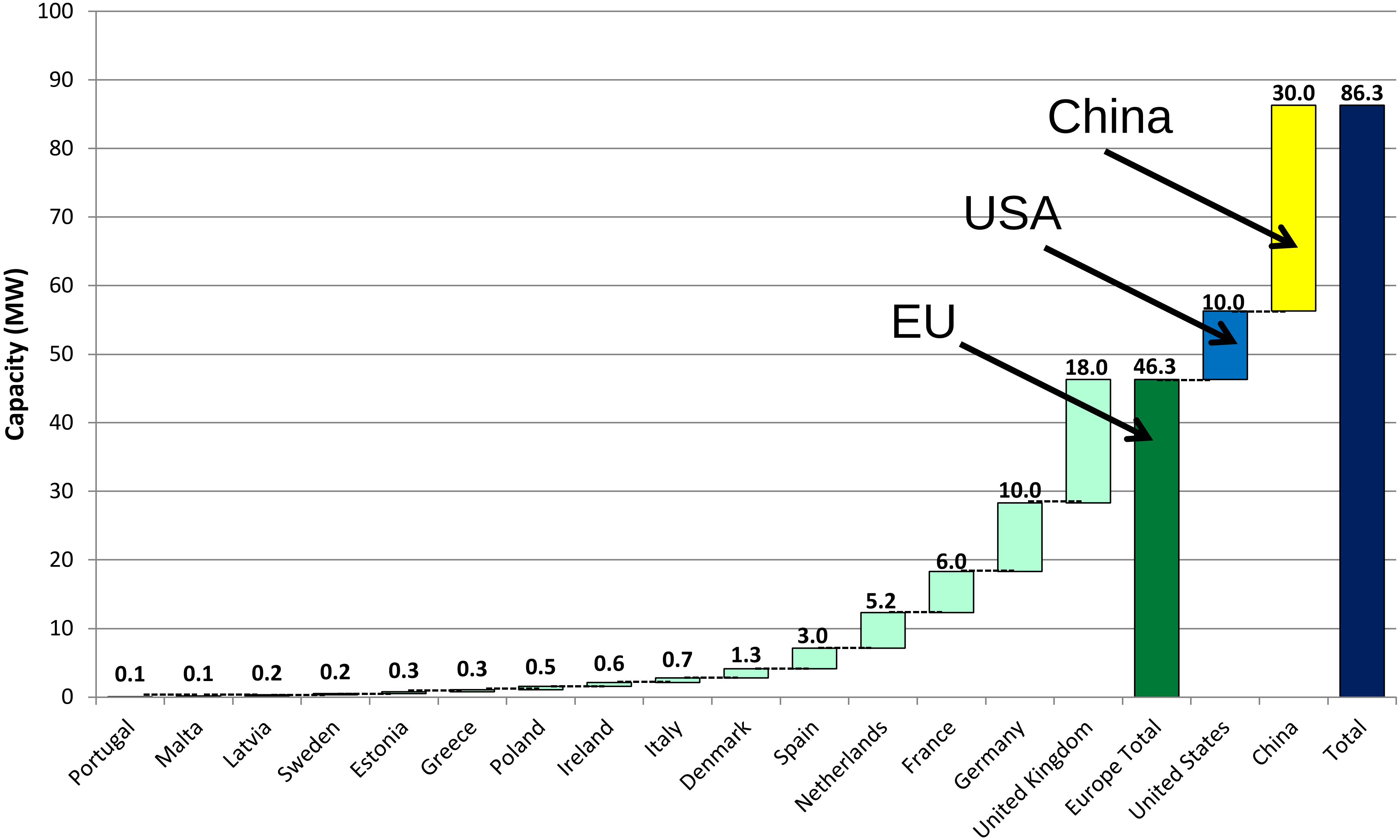
Larger Turbine Sizes

Increased Wind Plant Sizes

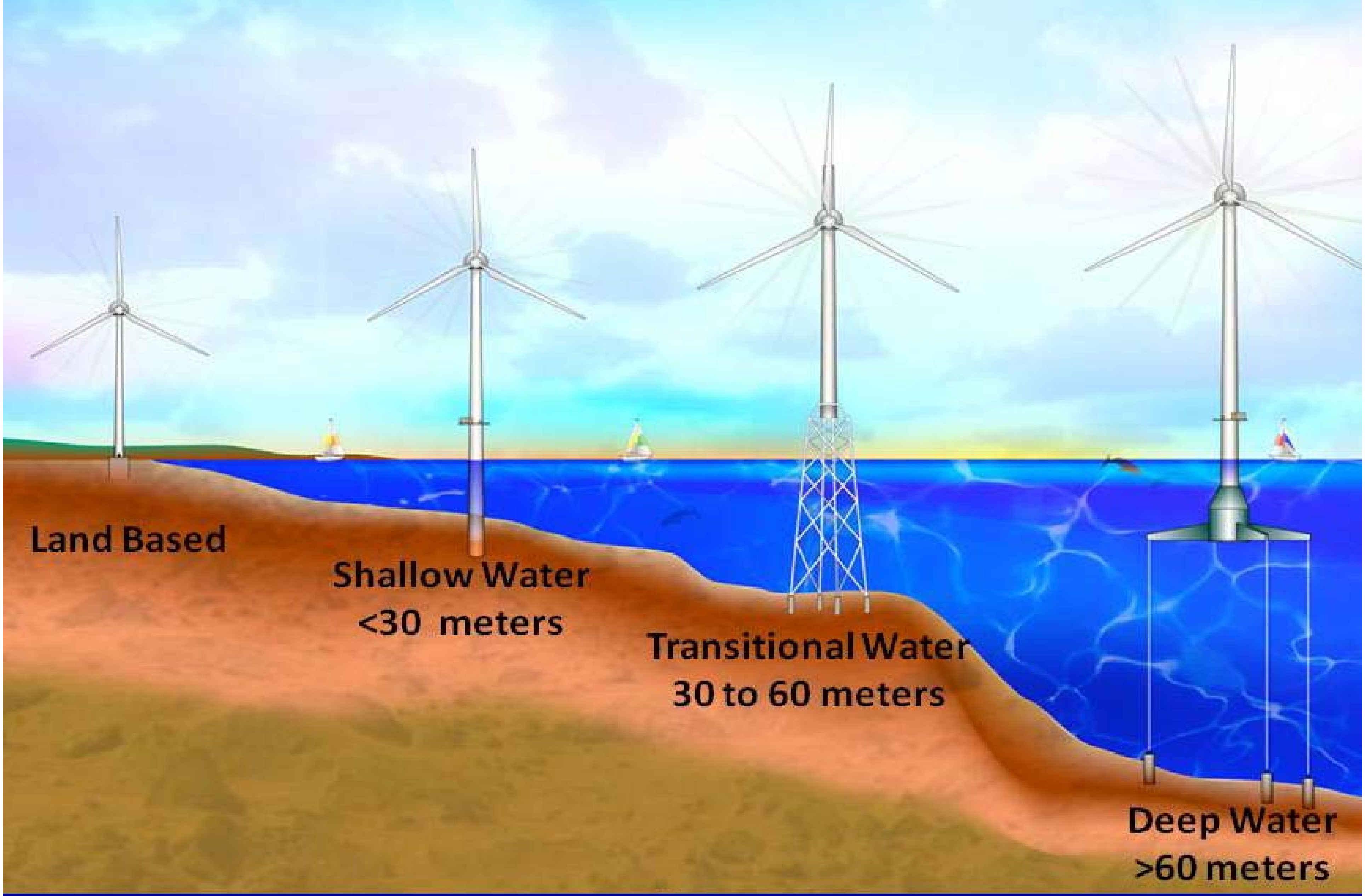
Large Scale Deployment



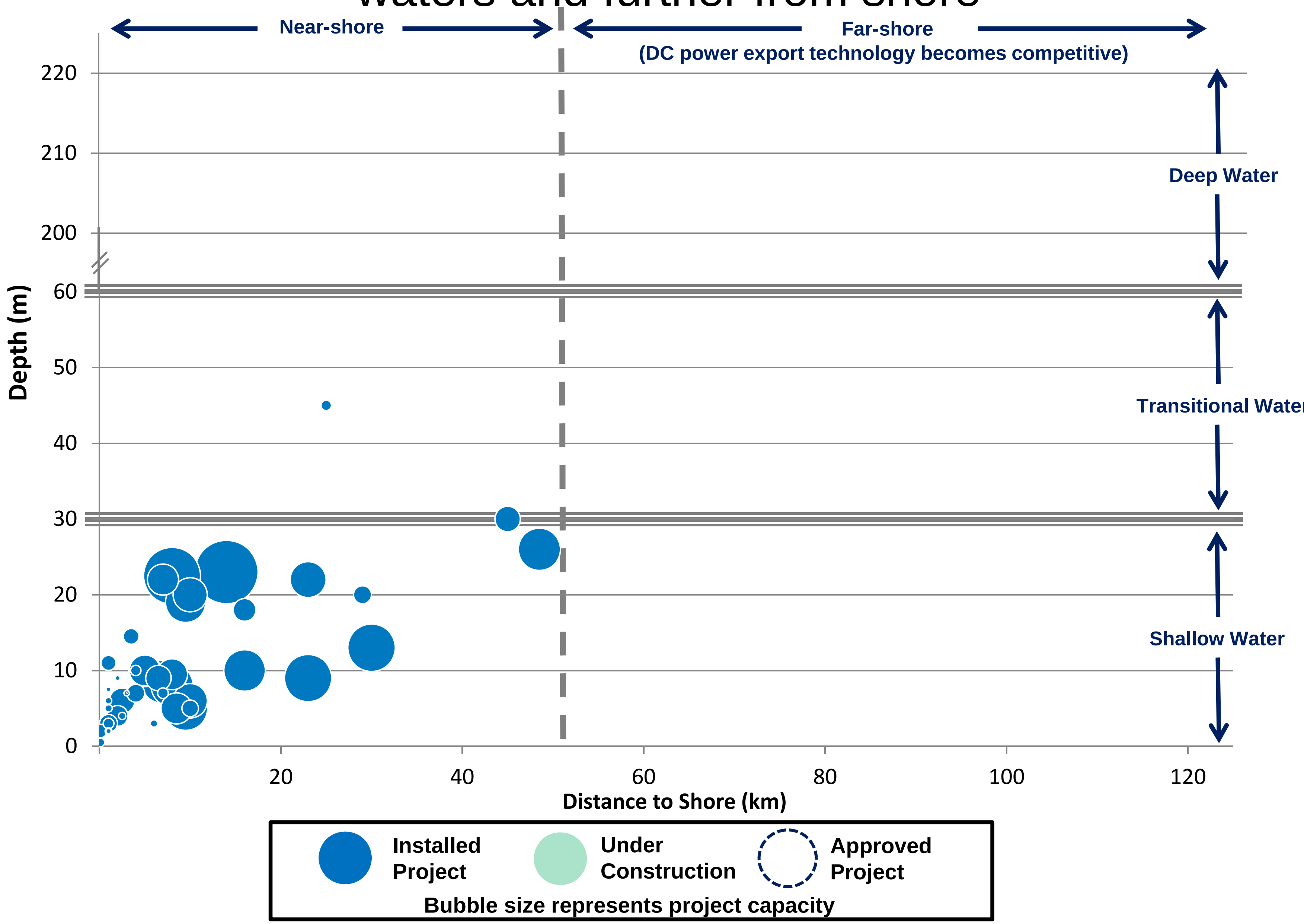
National deployment targets in the E.U., U.S., and China call for ~86 GW of offshore wind to be installed by 2020



Offshore Wind Technology is Depth Dependent



Near-term offshore wind projects will be installed in deeper waters and further from shore



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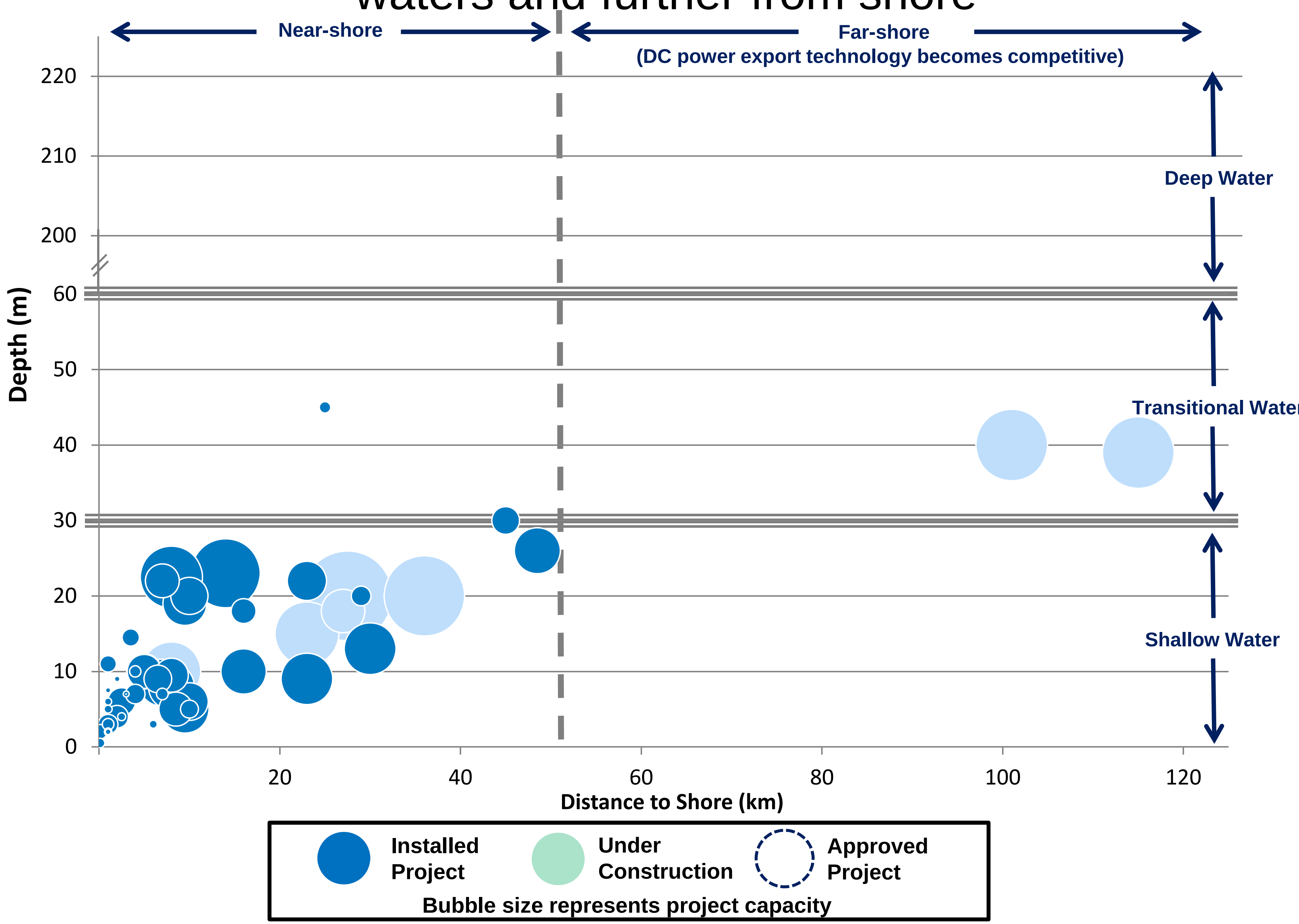

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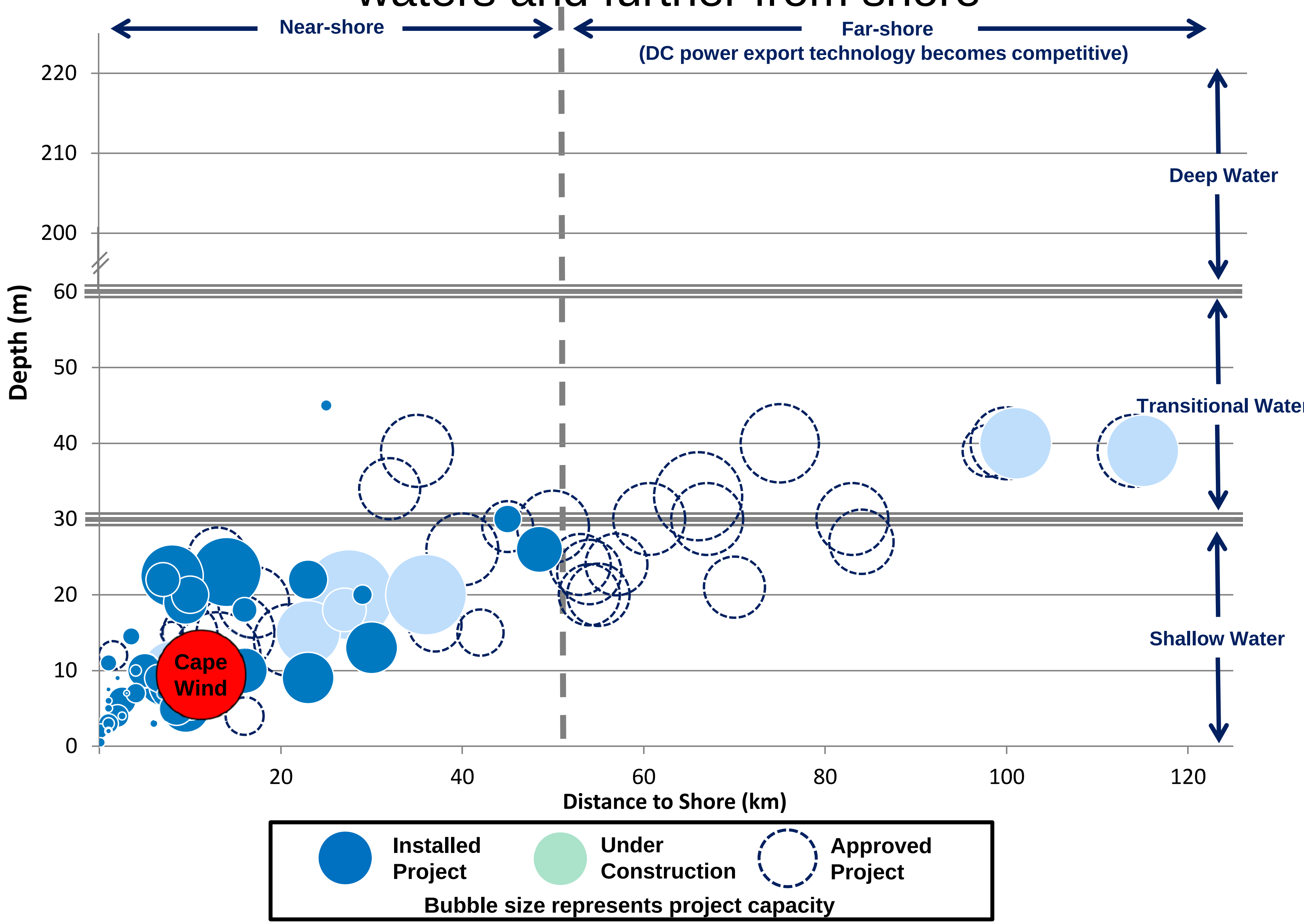
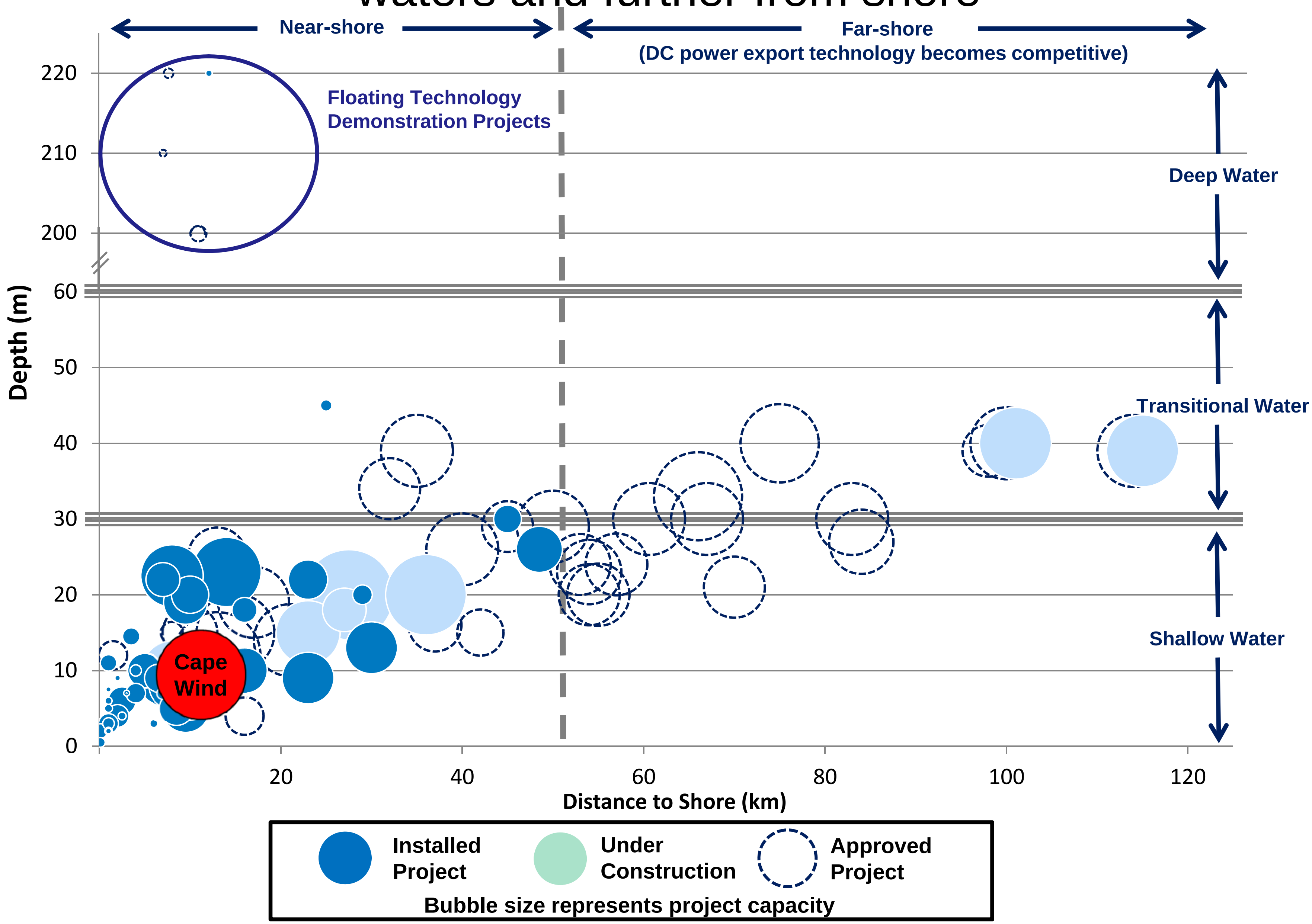
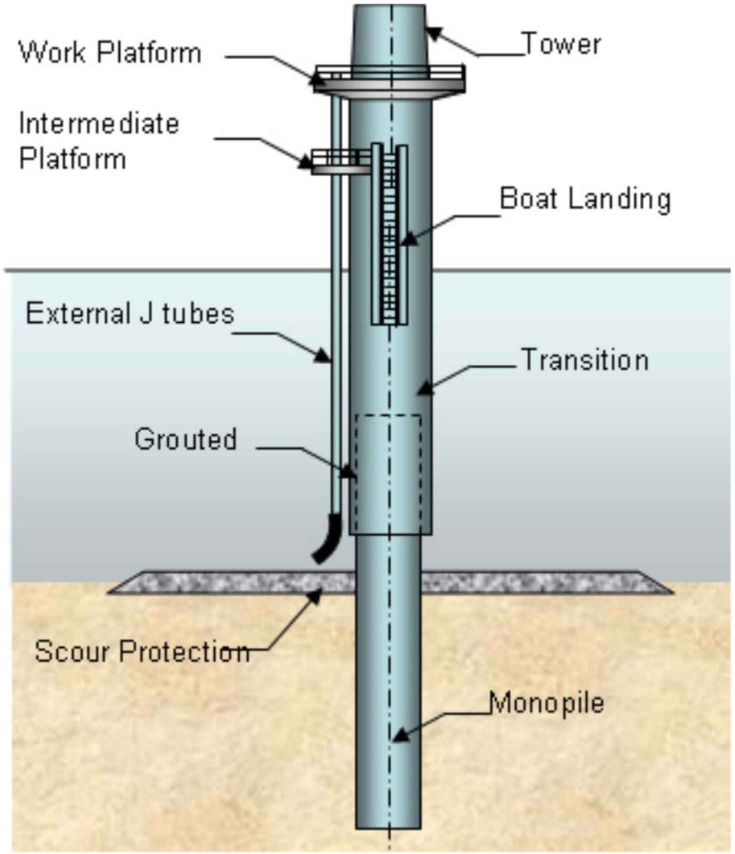


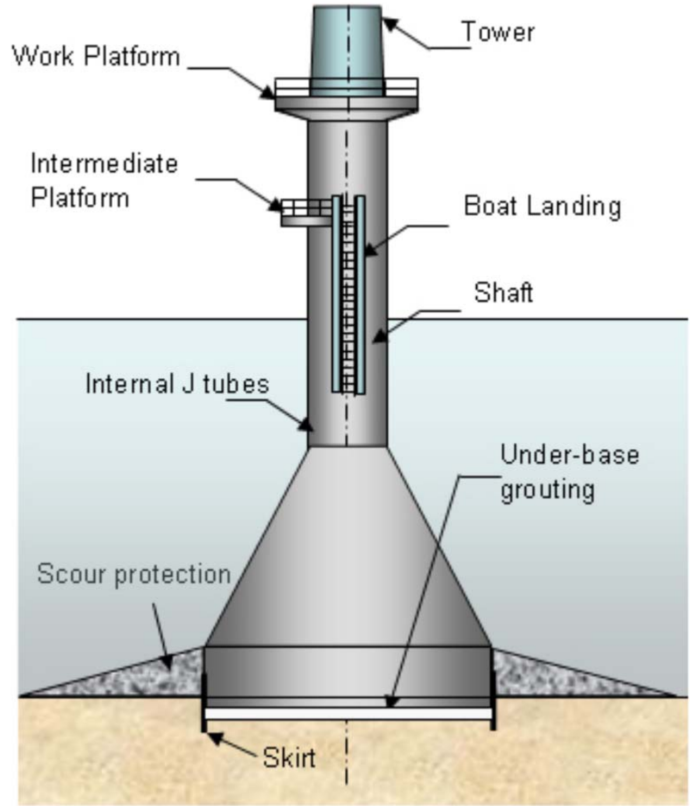
Near-term offshore wind projects will be installed in deeper waters and further from shore



Common Foundation Types Used in Shallow Water (0-30m depths)



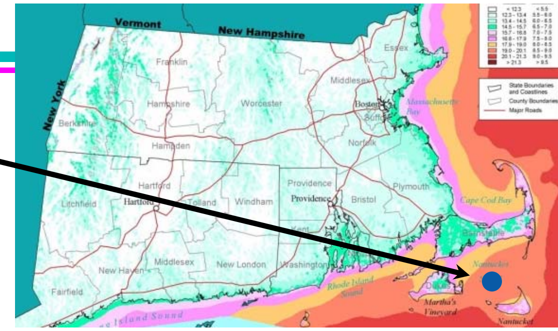
Monopiles
73% of Current Installations

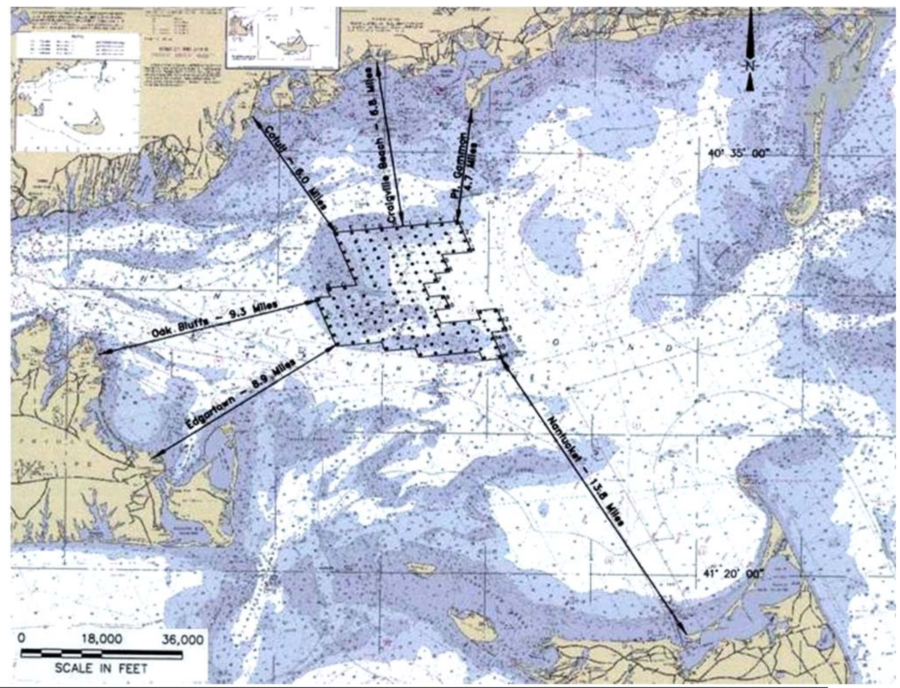


Gravity Base
21% of Current Installations

Cape Wind 468-MW Wind Plant - Massachusetts

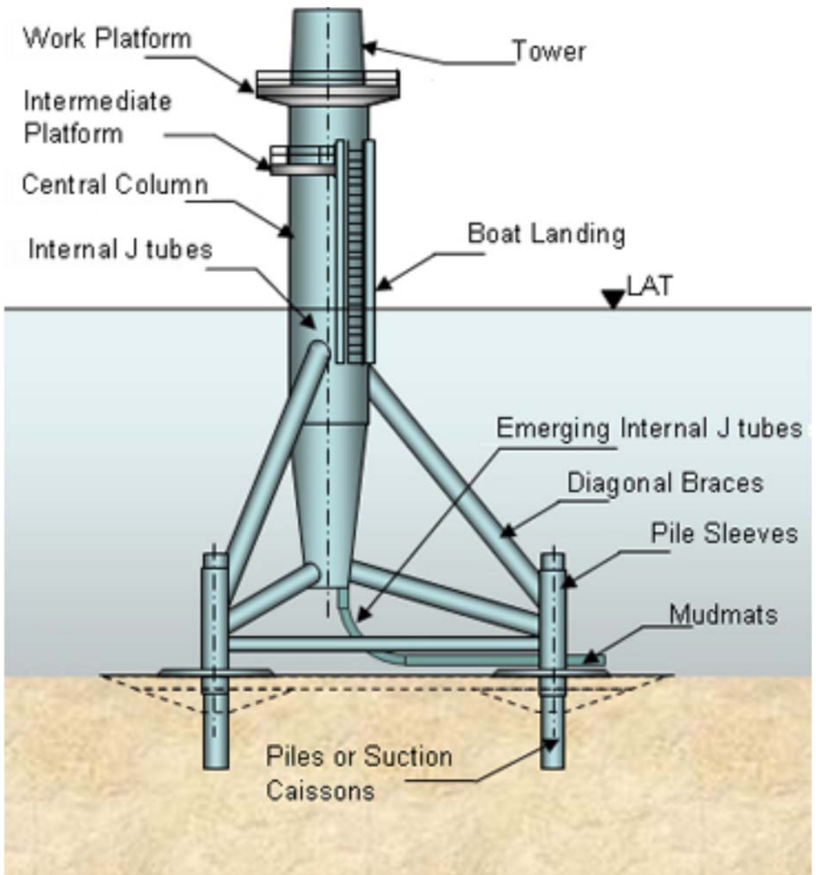
Location:	**Nantucket Sound, MA**
Turbine Size/Description:	130 Siemens 3.6 MW wind turbines
Expected Deployment Date :	2013
Foundation Type:	Monopiles
Average distance from shore	9.5 miles
Average Water Depth	11-m
Expected Energy production	1.5 Billion KWh/yr
Approximate Budget:	$ 2.6 B USD



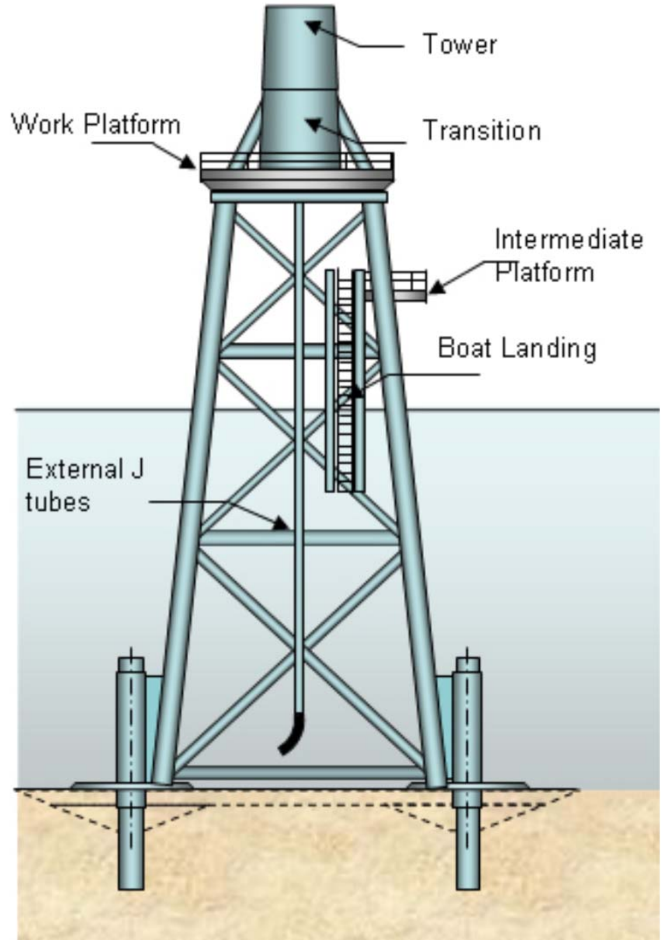


The Cape Wind project is the first and only offshore wind project to receive a license to begin construction in U.S. federal waters The project will produce 75% of the electricity for Cape Cod and the Islands.

Transitional Water Depths Need Multi-pile Support Structures (30-60m)

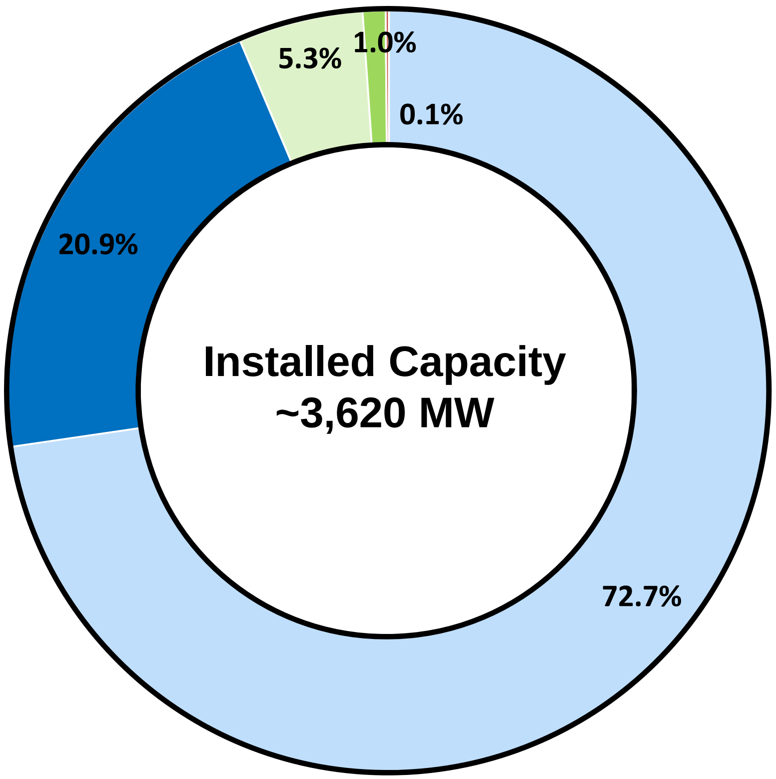


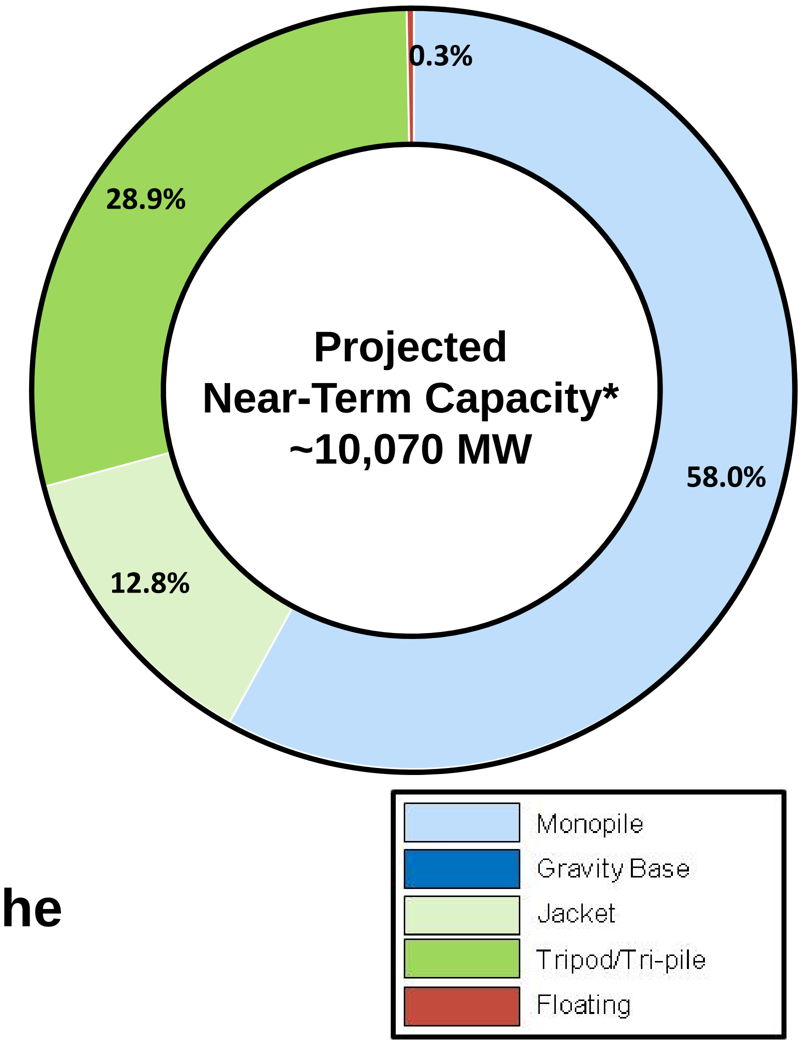
Tripod Type



Jacket or Truss Type

Multi-pile foundation designs are gaining market share as larger turbines are installed in deeper water

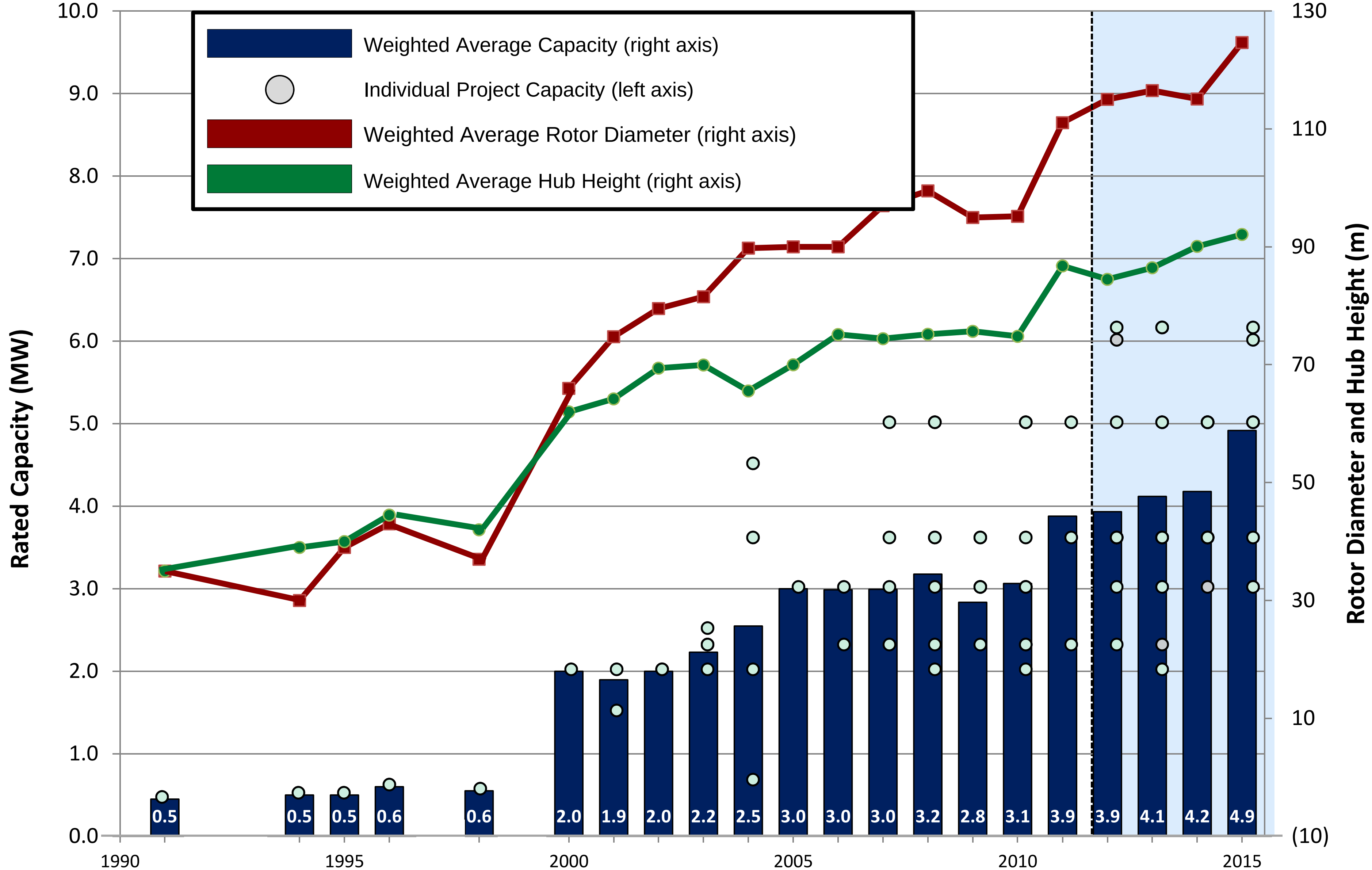




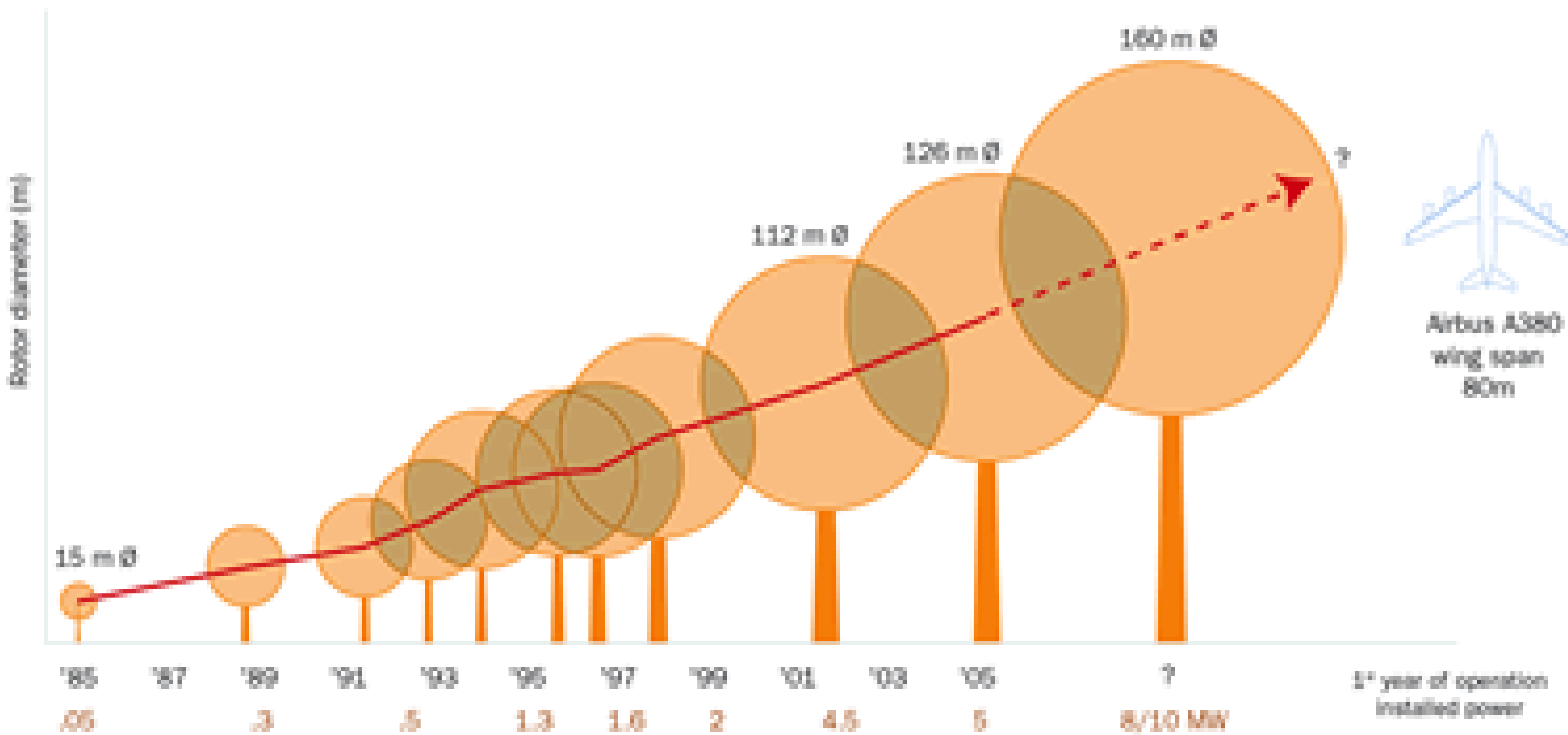
Gravity bases are not represented in the near-term plans of developers

* Includes projects under construction and approved projects that have announced a foundation design

Turbine Scaling Trend Based on Current Installations: Generator size, rotor diameter, and hub height are increasing



Offshore Turbines Sizes are Expected To Continue To Grow



Source : Jos Beurskens - ECN Netherlands

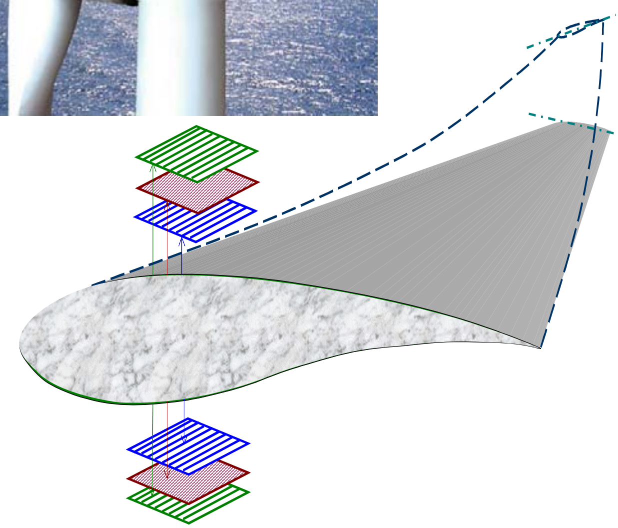
Large Offshore Turbine Technology (5-10 MW)

Challenges

- Mass scaling laws limit conventional designs
- Installation vessel capacity limits design options
- Composite technology for large machines is unproven

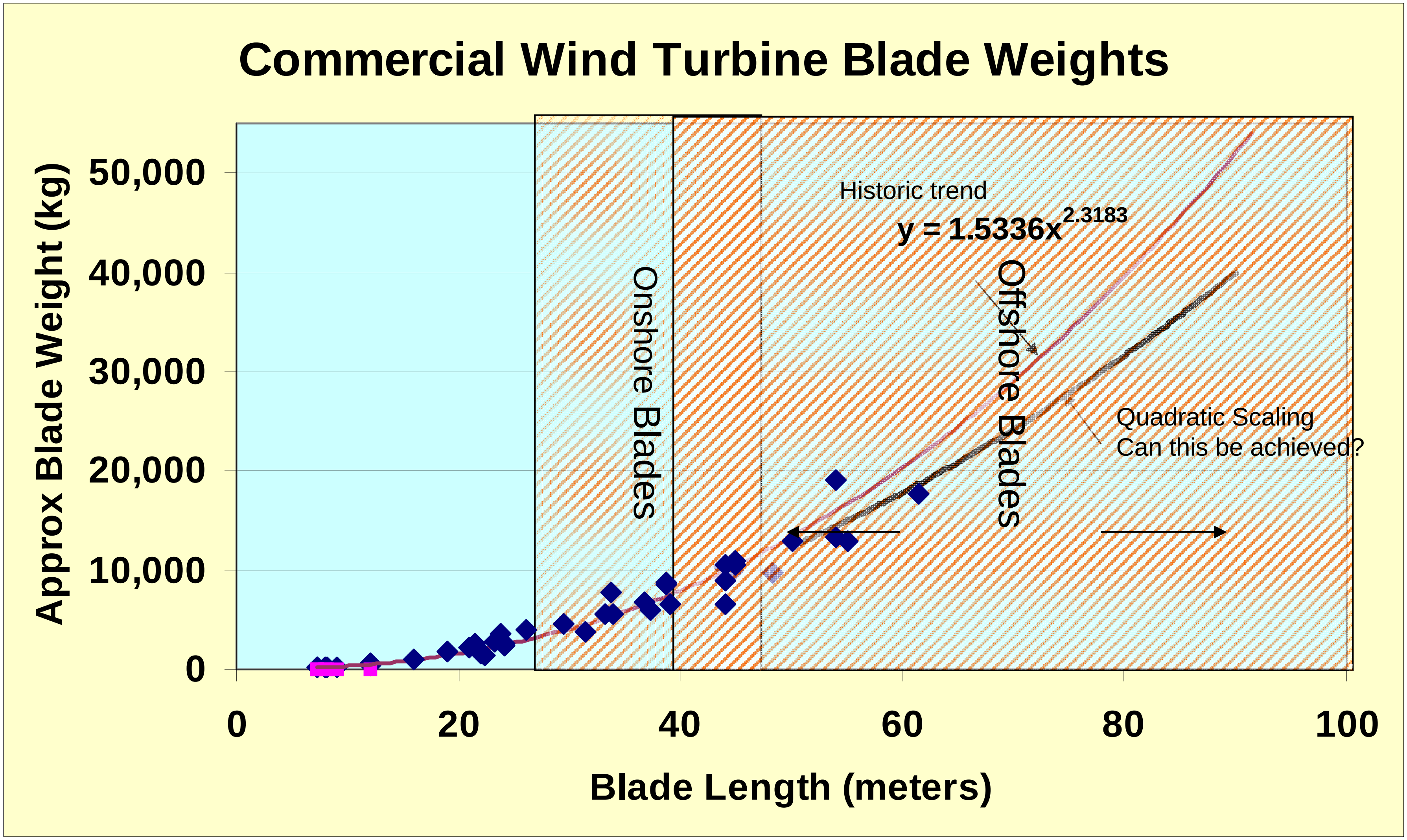
Enabling technologies for large machines

- Ultra-long blades/rotors
- Downwind rotors
- Direct drive-generators (possible HTSC)
- High reliability integrated systems
- Innovative deployment systems
- Special purpose vessels

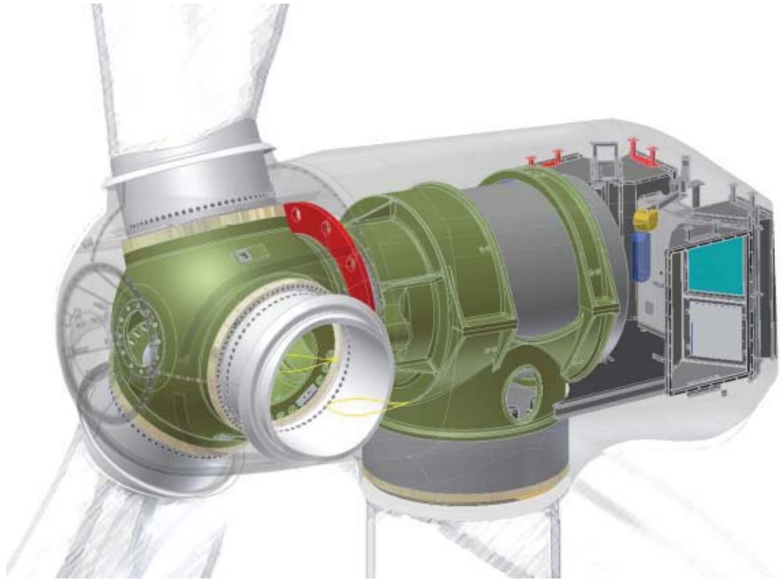


Blade Scaling Critical for Large Turbines

The need for larger blades is driving advanced material, manufacturing, and design innovations



Offshore Trend Toward Direct Drive Generators



Graphic: Courtesy of American Superconductor

Siemens Wind Power

- Conventional gear driven turbines offered lightest and lowest cost but have had suffered high maintenance costs
- Direct drive generators (DDG) promise higher reliability due to fewer moving parts
- New designs promise lighter weight
- Most OEMs are developing 5-7MW class DDGs wind turbine (or medium speed)

Electric Grid and System Integration

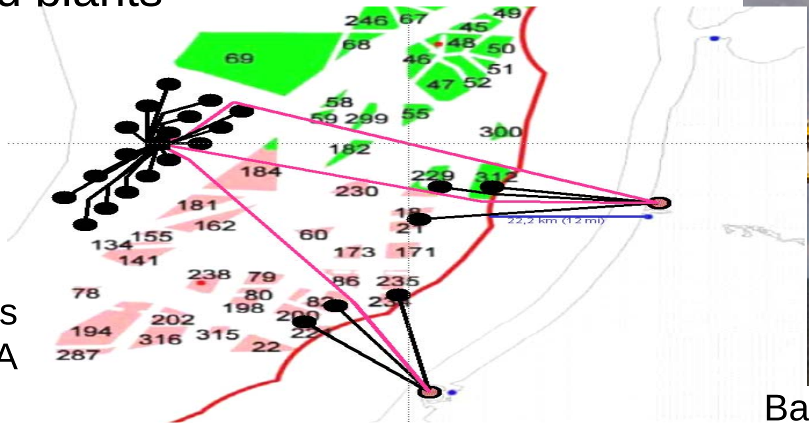
Challenges

- 54-GW by 2030 of Offshore Wind
- Constrained land-based grid in high population density coastal regions
- Variable power delivery and establishing capacity value
- Up to 80% of Offshore Insurance claims

New Offshore Grid Technologies

- Offshore backbones for power delivery
- HVDC for long distance power
- Aggregate offshore wind plants
- Cable protocols

Proposed Super-grid for European Offshore Wind



HVDC Power Networks
Credit: KEMA

Baltic 1 Substation

Offshore Metocean Characterization Tools

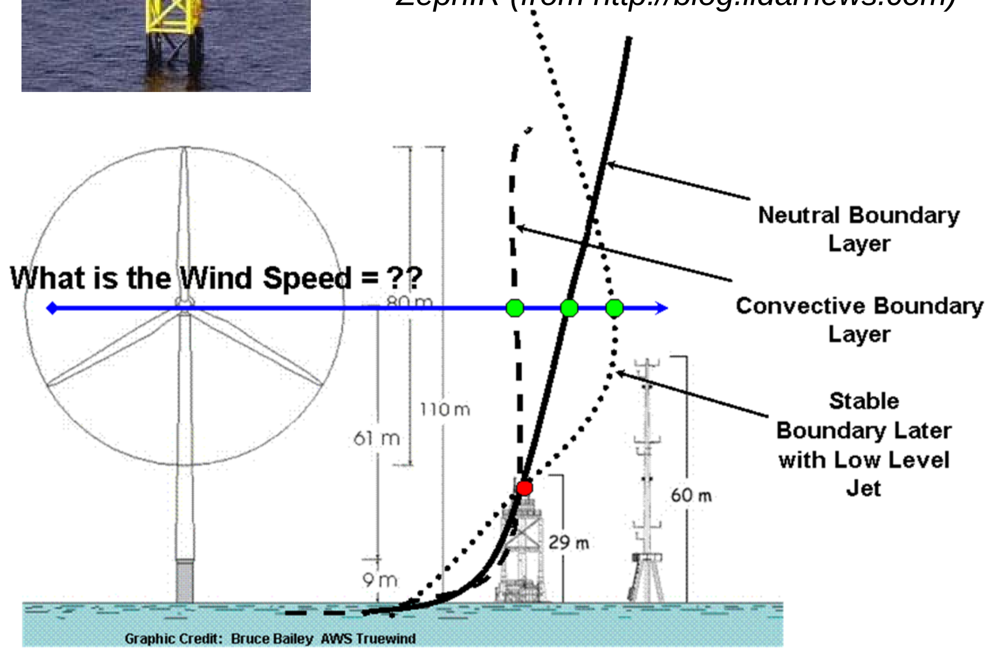
Challenges

- High cost of MET masts has inhibited widespread 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 not well understood

New Technology for Metocean Characterization:

- Remote sensing (LIDAR, SODAR)
- Measurement campaigns for metocean conditions at hub height
- Improved weather models
- Integration of multiple data sources for validation (e.g. satellites, met towers)
- Improved forecasting

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



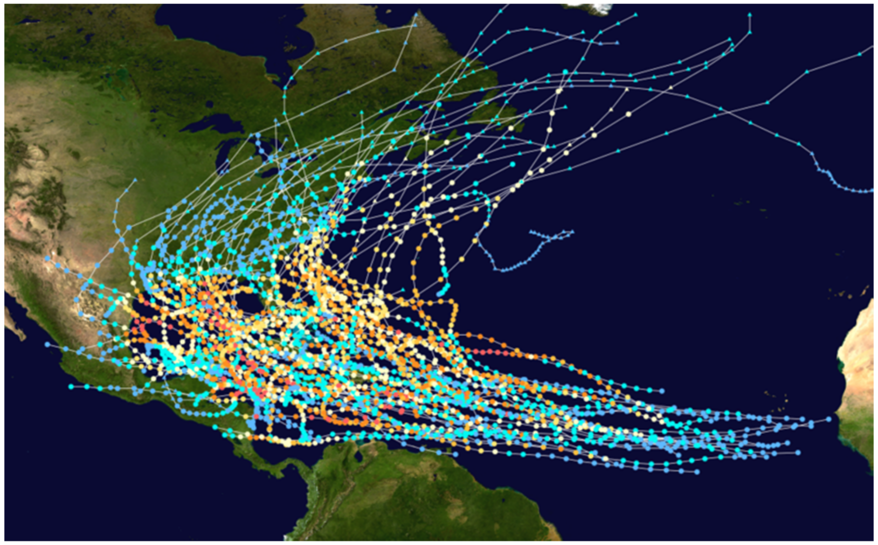
OFFSHORE WIND ARRAY EFFECTS

Offshore Wind Turbines in Atlantic and GOM Must be Designed for Hurricanes

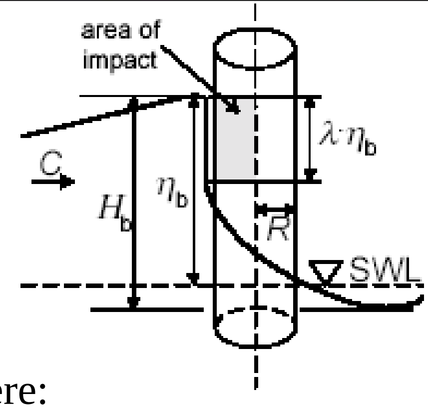
- Wind Turbines are often ***Type Certified*** before site conditions are known
- High uncertainty in predicting hurricane ***probability*** and ***intensity***
- U.S. Hurricane conditions can exceed IEC Class 1A wind specifications
- New Standards and Protocols will address Hurricane Design

Table 1. Saffir/Simpson Hurricane Scale, modifed from Simpson (1974).

Scale Number (Category)	Winds (Mph)	Typical characteristics of hurricanes by category (Millibars)	(Inches)	Surge (Feet)	Damage
1	74-95	> 979	> 28.91	4 to 5	Minimal
2	96-110	965-979	28.50-28.91	6 to 8	Moderate
3	111-130	945-964	27.91-28.47	9 to 12	Extensive
4	131-155	920-944	27.17-27.88	13 to 18	Extreme
5	> 155	< 920	< 27.17	> 18	Catastrophic



Breaking Waves:
A potential design driver



IEC 61400-3 Breaking Wave Model is not validated

- Breaking waves can occur when wave height approaches water depth (critical at some locations)
- Design must consider occurrence during extreme 50/100 year return storms
- Breaking waves can double the load magnitude
- Validation data is needed to improve and validate the model.

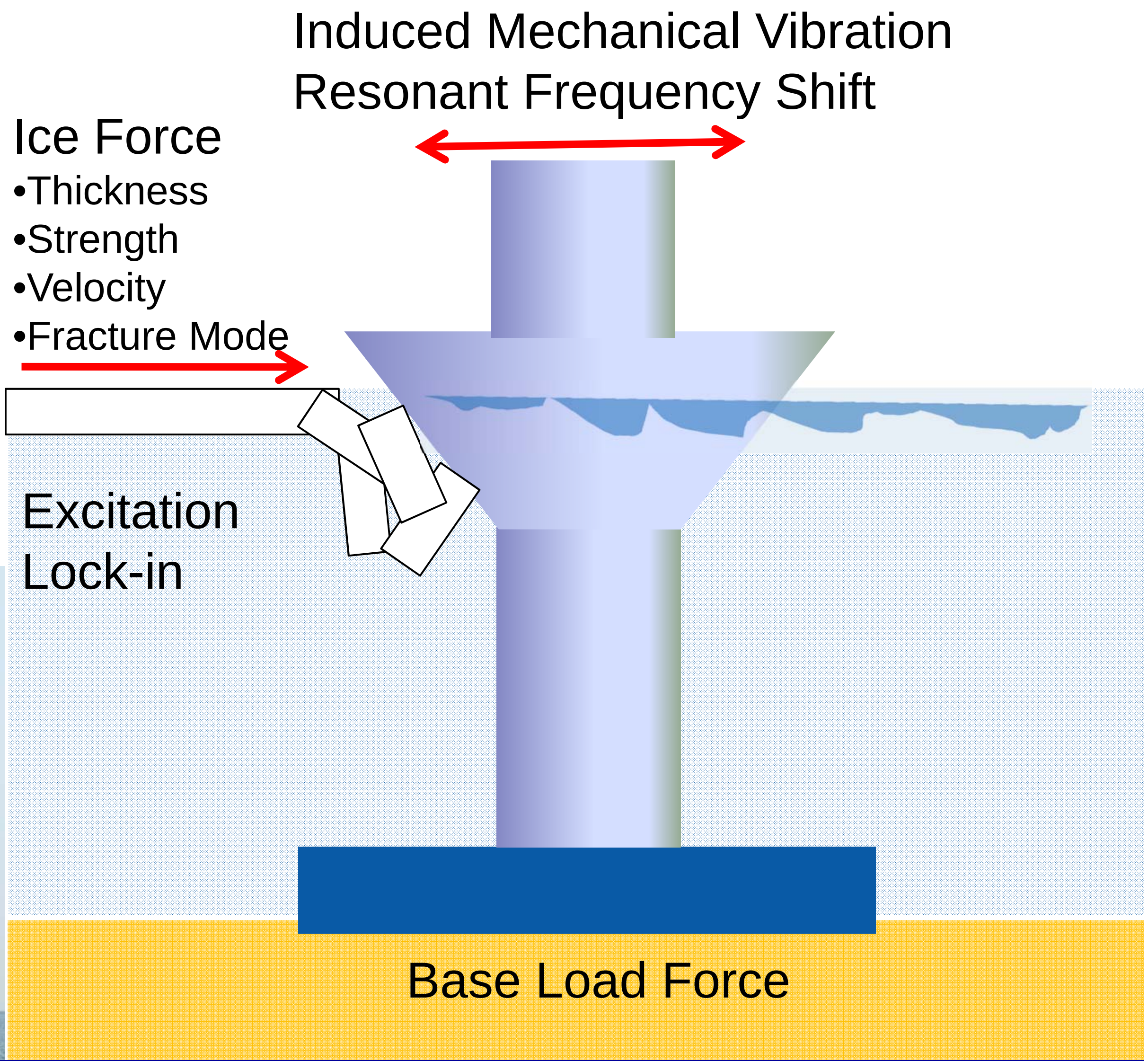
where:

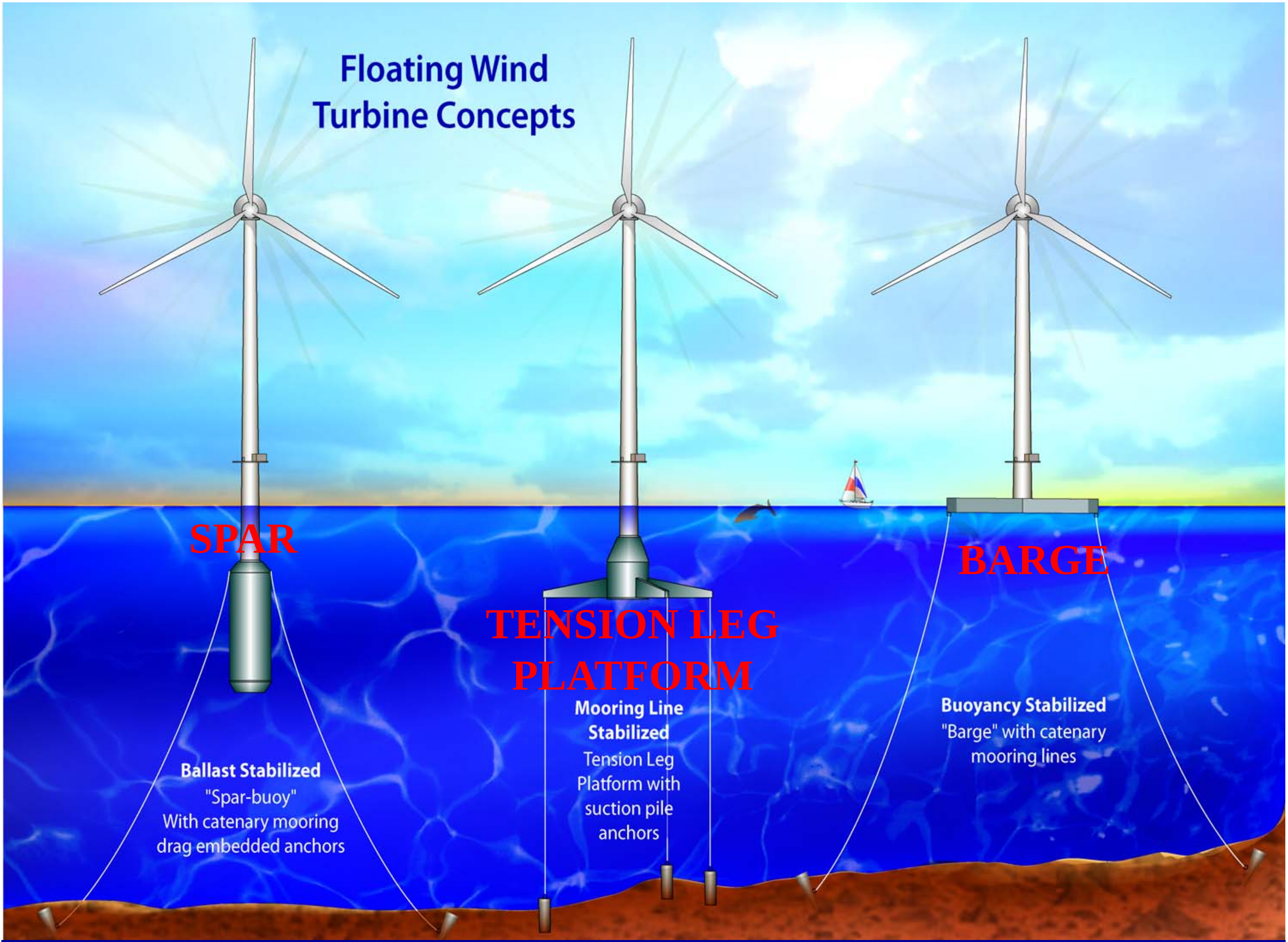
C	=	wave celerity
H_b	=	wave height at the breaking location
η_b	=	maximum elevation of the free water surface
R	=	radius of the cylinder
λ	=	curling factor ≈ 0,5

Ice Loading Design and Mitigation

Baltic Sea – Windpower Monthly Cover Photo Feb 2003

Wind Turbines at Nysted with Ice Cones




Floating Wind
Turbine Concepts
SPAR
TENSION LEG
PLATFORM
BARGE
Ballast Stabilized
"Spar-buoy"
With catenary mooring
drag embedded anchors
Mooring Line
Stabilized
Tension Leg
Platform with
suction pile
anchors
Buoyancy Stabilized
"Barge" with catenary
mooring lines

Floating Offshore Wind Turbines

Photo: Hywind/Statoil
SPAR

Graphic: Glosten
Associates, PELESTAR
TLP

Photo: Principle
Power Inc.
SEMI-
SUBMERSIBLE

Summary of Challenges and Opportunities

- Initial costs are high due to smaller scales, higher risk, and immature technology
- Global scale deployment is needed for cost reduction
- Stable policy incentives are needed to offset first adopter cost challenges
- Technology innovations are needed to lower cost and expand siting options
- Unique environmental conditions require optimized turbine designs
- Mature costs realized through scale and innovation.

Thank you for your attention!

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