Offshore Wind Energy Potential for the United States

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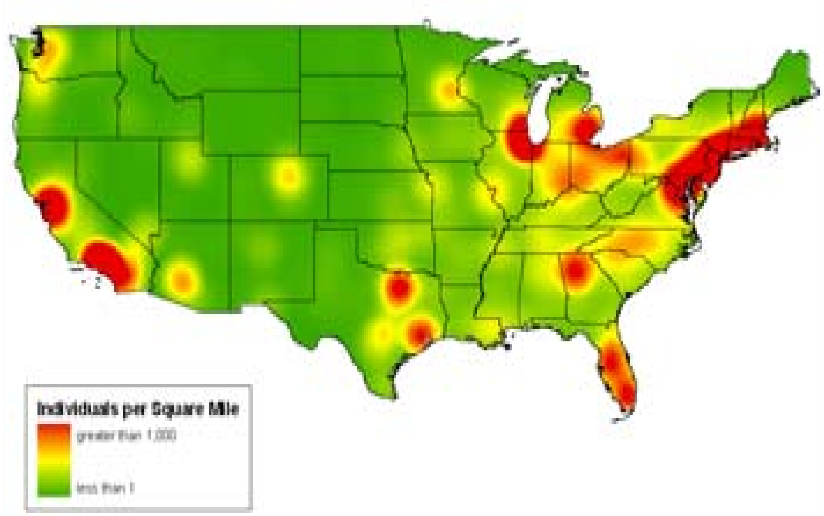
Offshore Wind – U.S. Rationale
Why Go Offshore?

Windy onshore sites are not close to coastal load centers

The electric utility grid cannot be easily set up for interstate electric transmission

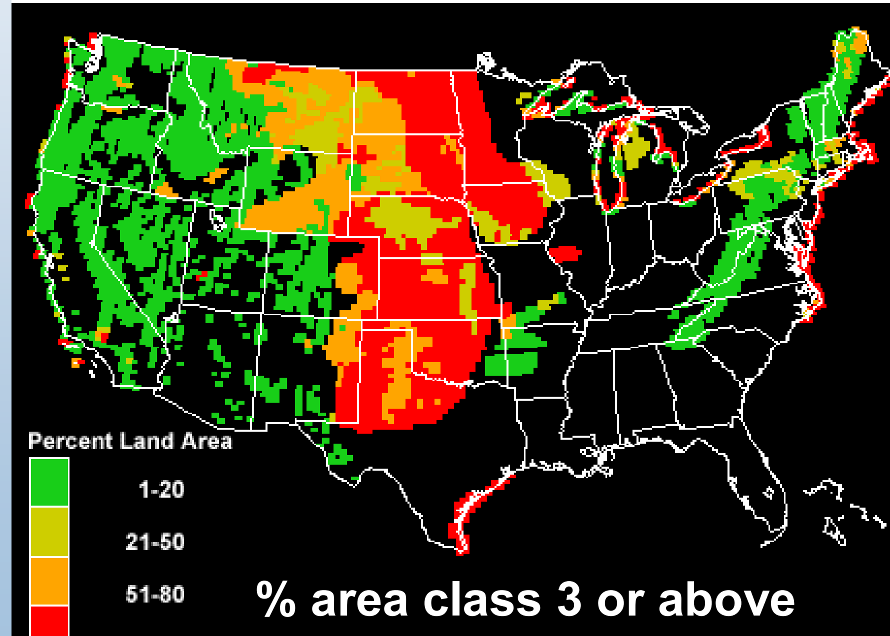
Load centers are close to the offshore wind sites

US Population Concentration



Graphic Credit: Bruce Bailey AWS Truewind

US Wind Resource



Graphic Credit: GE Energy

Offshore Wind Benefits

- Better wind resources
  - Reduced turbulence – steadier wind
  - Higher mean wind speed
- Aesthetics – Visual concerns will be less objectionable at greater distances.
- Increased transmission options
  - Proximity to high value load centers
  - Access to less heavily loaded lines
- Avoid constraints on turbine size
  - Larger machines may be more economical.
  - **Shipping** – onshore roadway limits
  - **Erection** – onshore crane limits

Current Situation - Offshore Wind

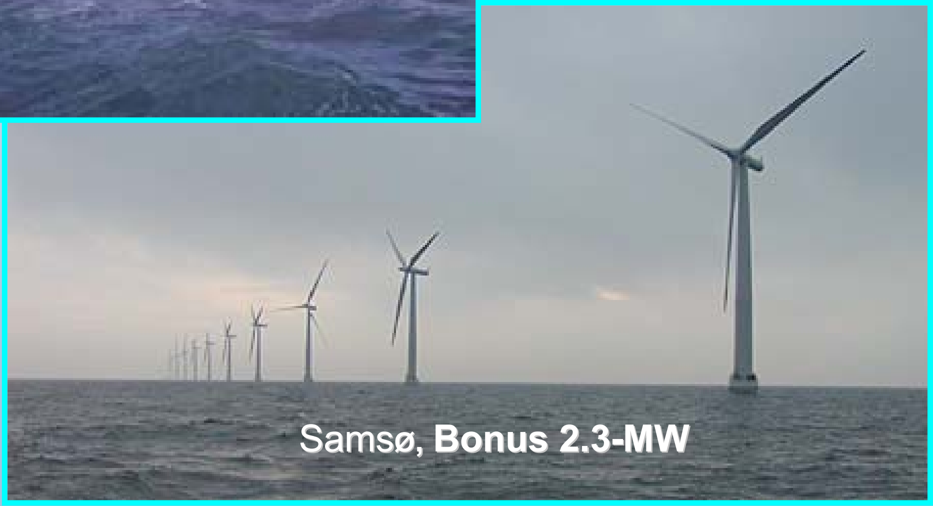
- 600+ MW total installed capacity offshore in Europe
- 11+ GW of offshore wind is planned by 2010 worldwide.
- Most development in Denmark, Germany, and UK.
- Shallow offshore costs range from 2200 €/kW to 1500€/kW

  Horns Rev ~ 1650€/kW
- Shallow water deployment depths

  4 to 18 meters
- Foundation types - monopile and gravity base.
- US planned projects
  - Cape Cod, MA
  - Long Island, NY


GE 3.6 MW Arklow Banks

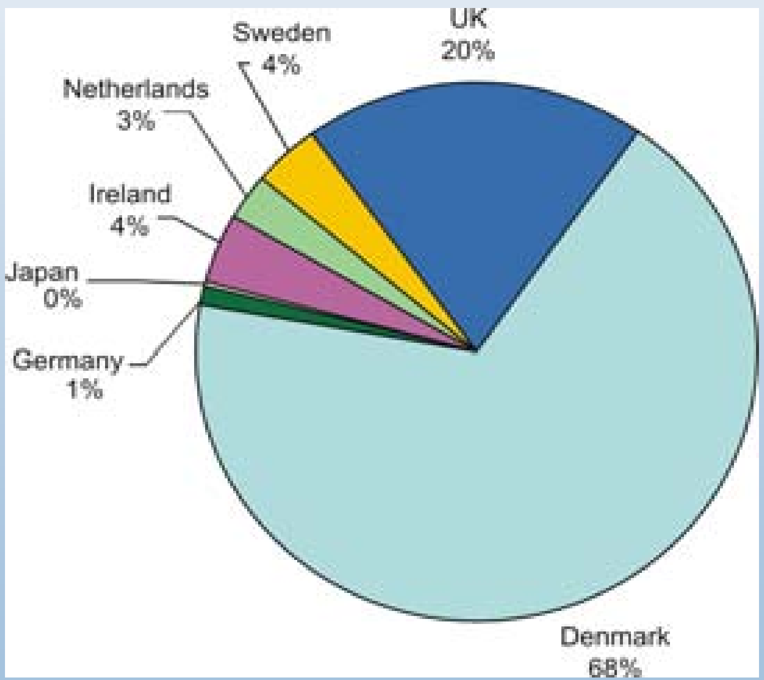

Capewind MET Tower


Samsø, Bonus 2.3-MW

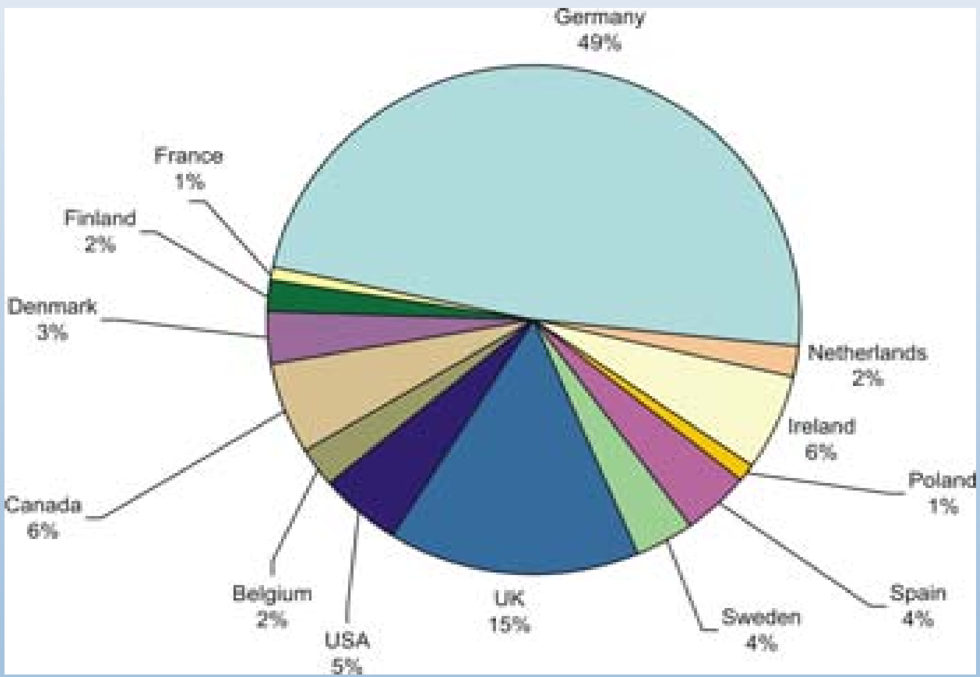
Offshore Wind Present and Future Prospects

- Shallow offshore costs range from or 8-15 cents per kWh
- Shallow water deployment depths --- up to ~20 meters
- Foundation types - monopile and gravity base
- US projects in permit phases
  - Cape Cod, MA
  - Long Island, NY

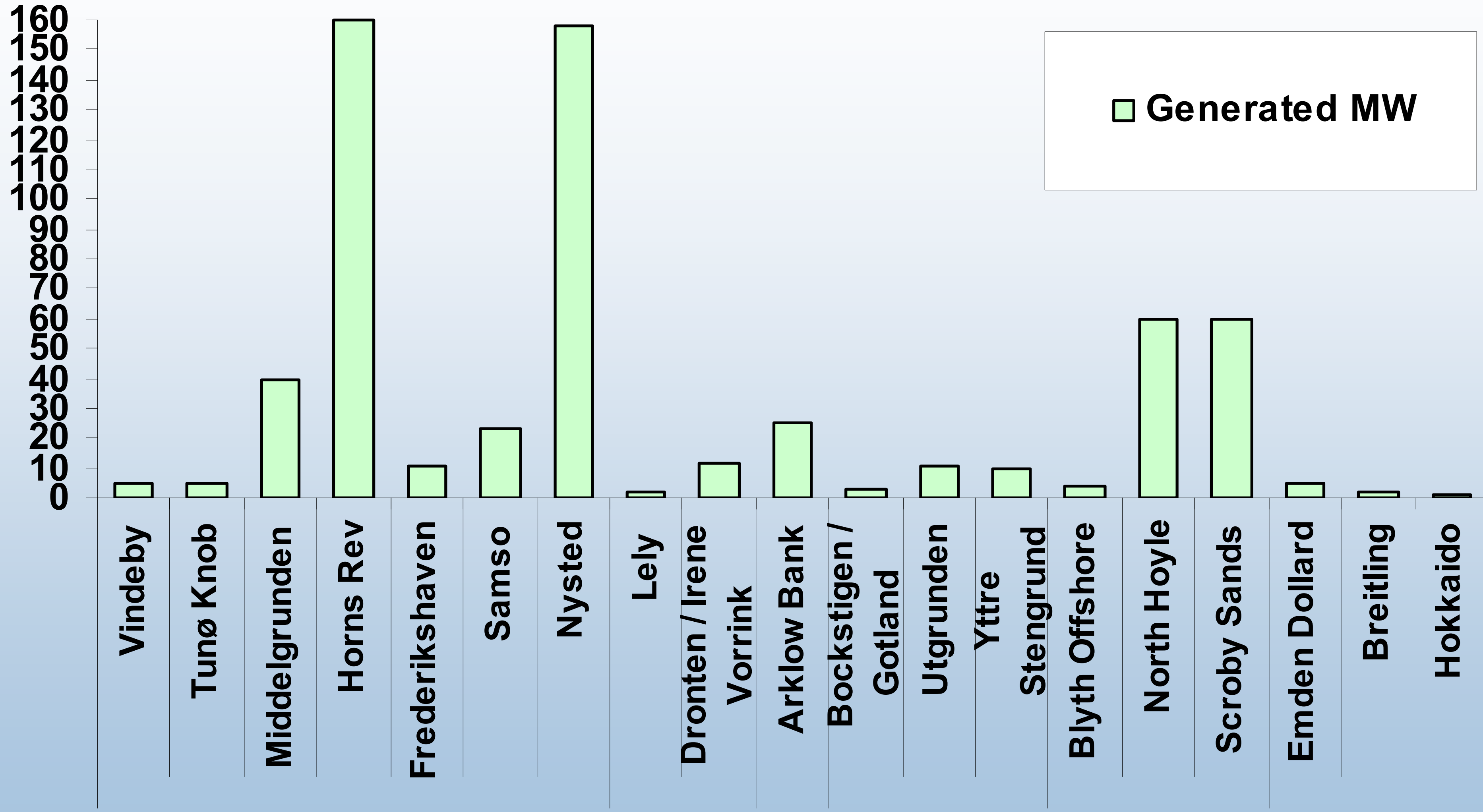
Offshore Wind Projects Worldwide: 617 MW (2004)

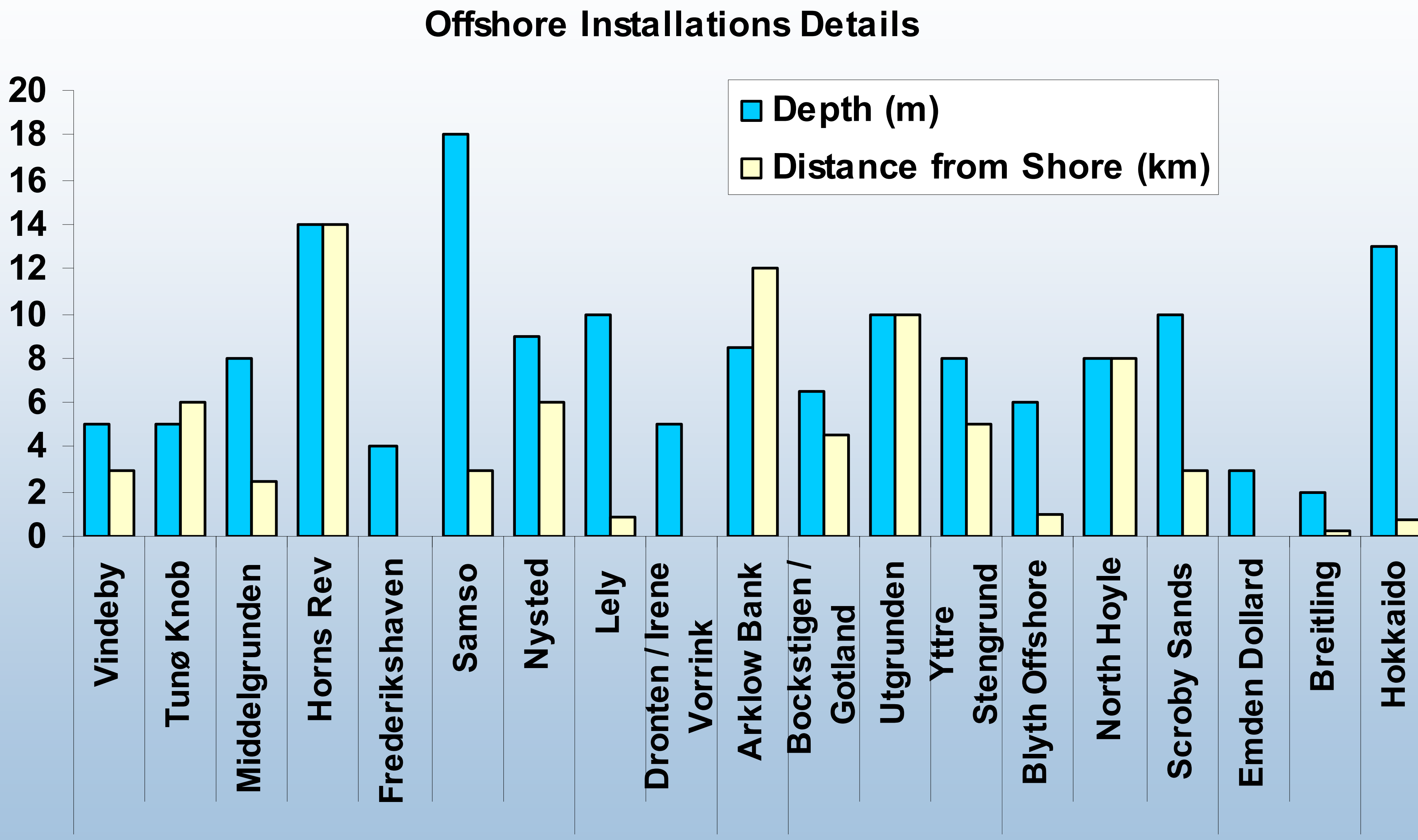


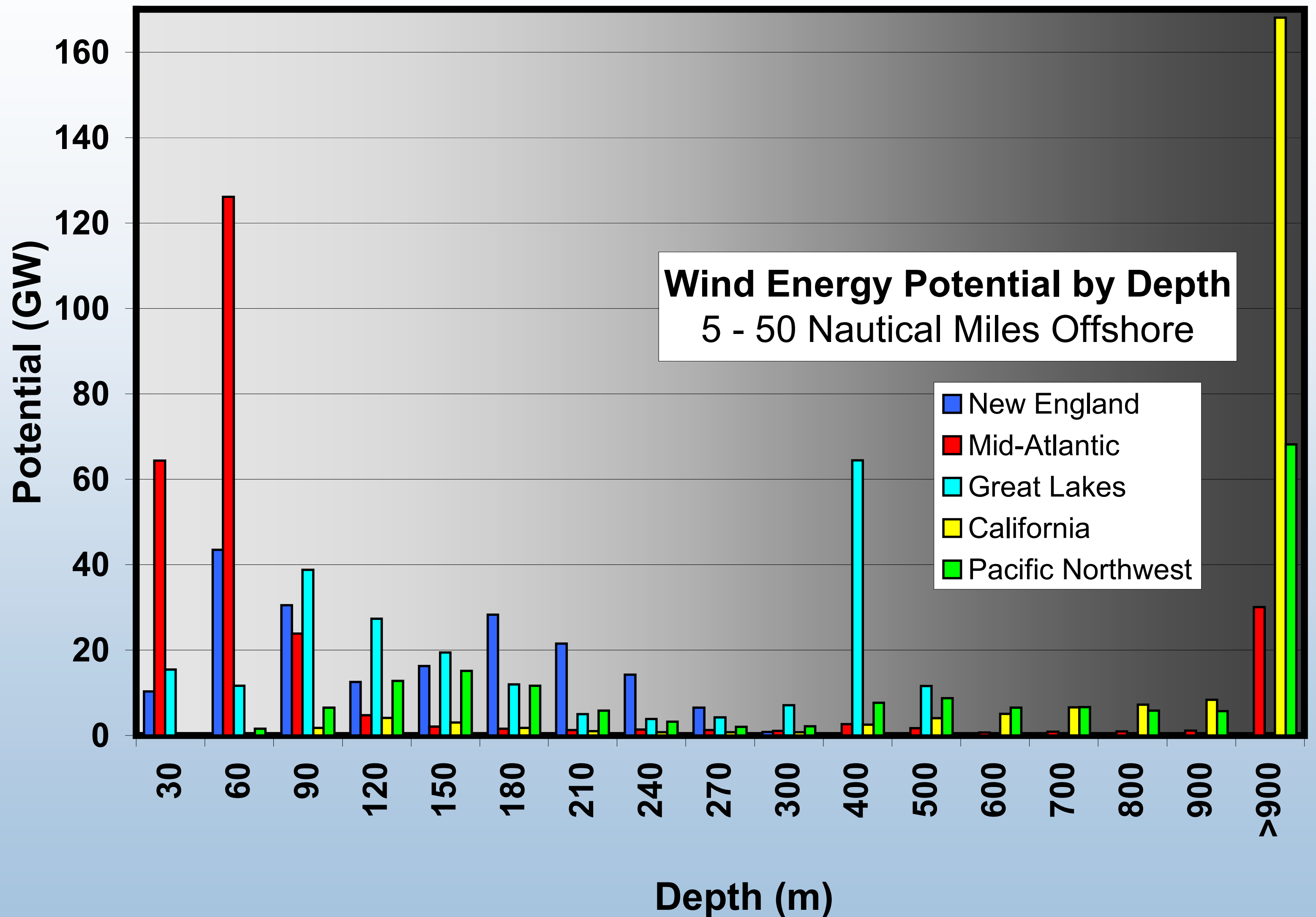
Proposed Offshore Wind Projects: 11,455 MW (through 2010)



Operating Wind farms through 2004

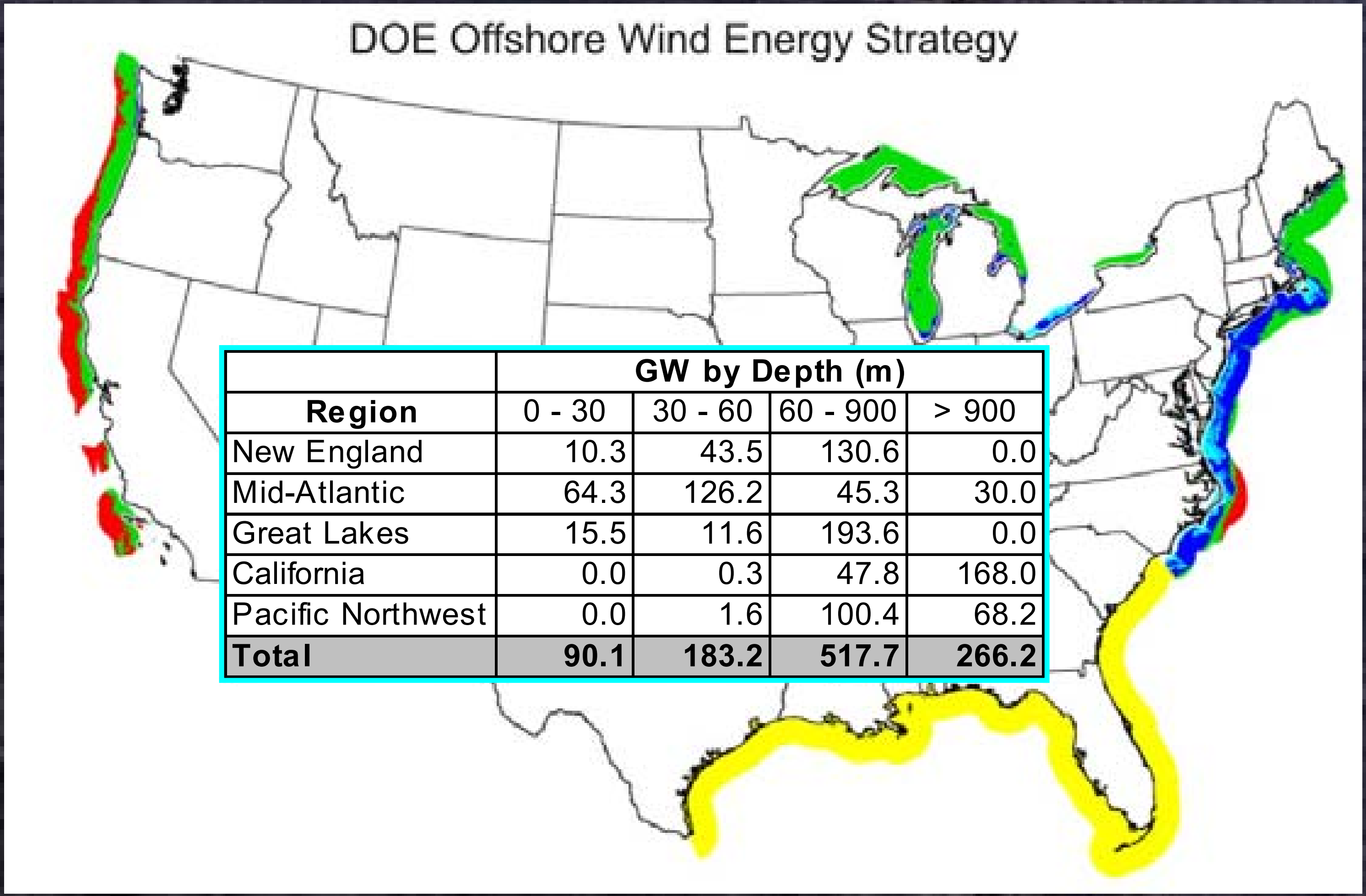



Offshore Installations Details
Depth (m)
Distance from Shore (km)
0
2
4
6
8
10
12
14
16
18
20
Vindeby
Tunø Knob
Middelgrunden
Horns Rev
Frederikshaven
Samso
Nysted
Lely
Dronten / Irene Vorrink
Arklow Bank
Bockstigen / Gotland
Utgrunden
Yttre Stengrund
Blyth Offshore
North Hoyle
Scroby Sands
Emden Dollard
Breitling
Hokkaido



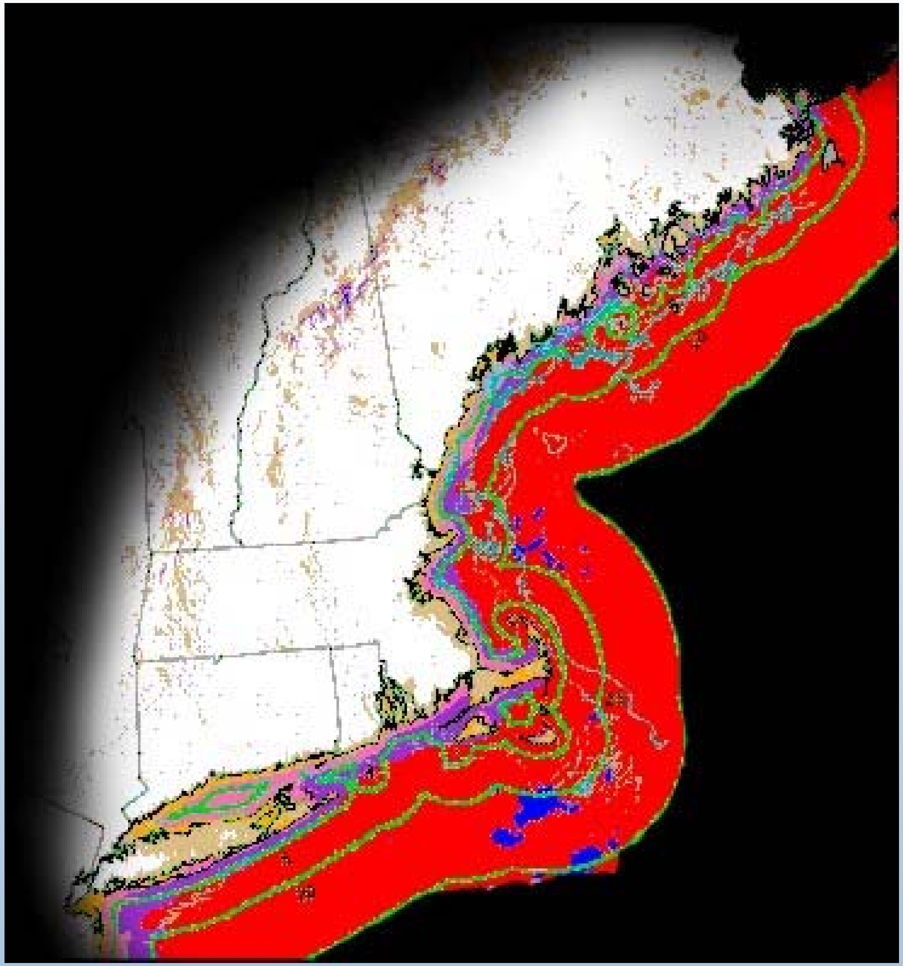
National Renewable Energy Laboratory

U.S. Offshore Wind Energy Opportunity



Region	GW by Depth (m)			
	0 - 30	30 - 60	60 - 900	> 900
New England	10.3	43.5	130.6	0.0
Mid-Atlantic	64.3	126.2	45.3	30.0
Great Lakes	15.5	11.6	193.6	0.0
California	0.0	0.3	47.8	168.0
Pacific Northwest	0.0	1.6	100.4	68.2
Total	**90.1**	**183.2**	**517.7**	**266.2**

US Offshore Wind Resource Exclusions



	GW by Depth (m)			
Region	0 - 30	30 - 60	60 - 900	> 900
New England	10.3	43.5	130.6	0.0
Mid-Atlantic	64.3	126.2	45.3	30.0
Great Lakes	15.5	11.6	193.6	0.0
California	0.0	0.3	47.8	168.0
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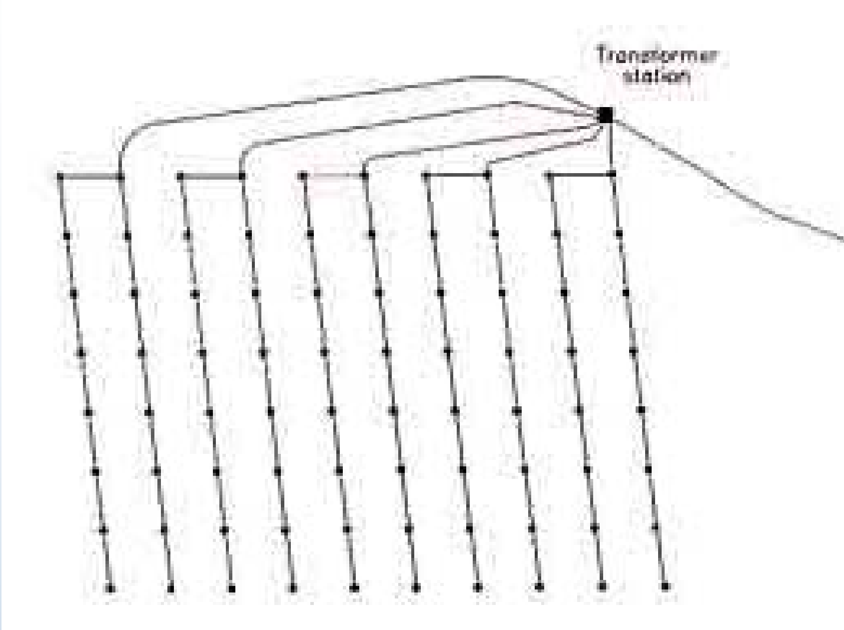
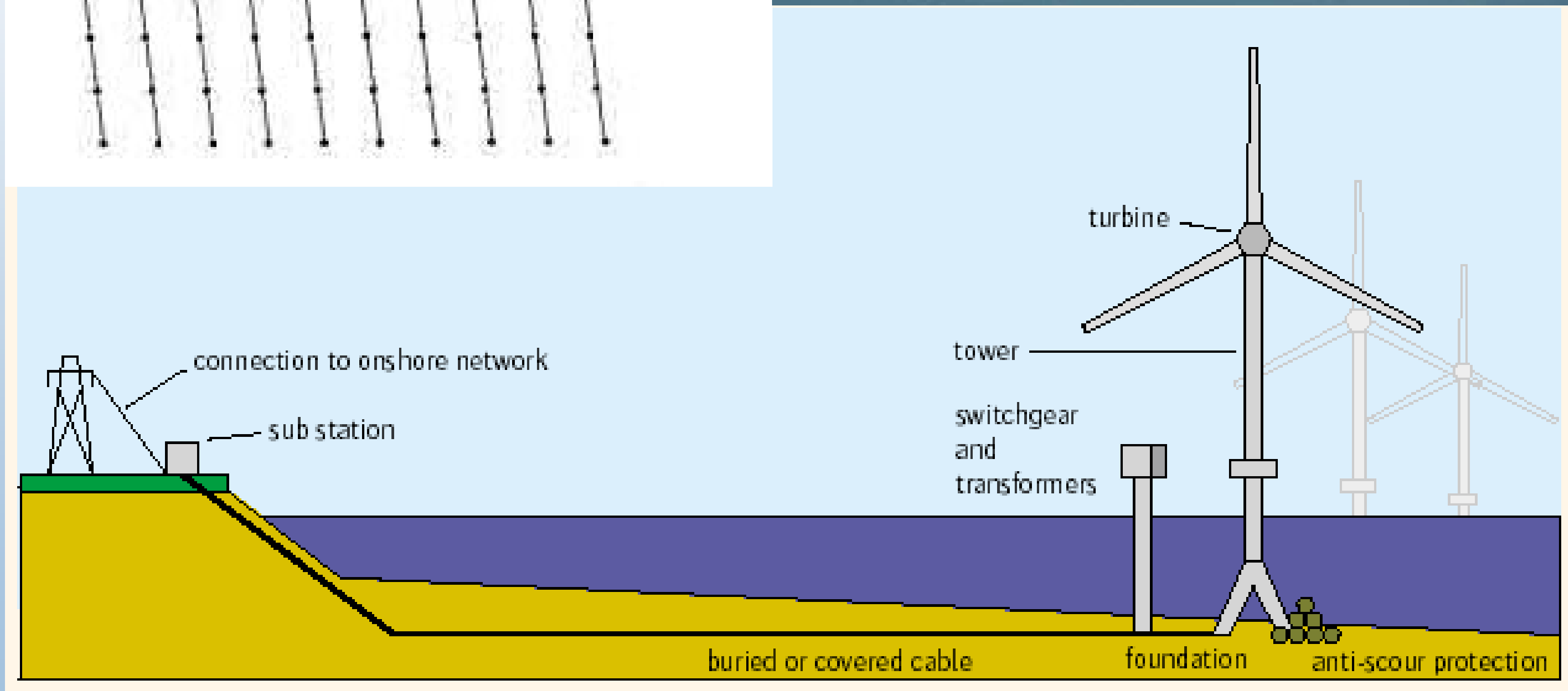
Total	**90.1**	**183.2**	**517.7**	**266.2**

- **Findings are preliminary**
- **Inside 5nm – 100% exclusion**
- **67% - 5 to 20nm resource exclusion to account for avian, marine mammal, view shed, restricted habitats, shipping routes & other habitats.**
- **33% exclusion– 20 to 50 nm**
- **Total estimated capacity – 908-GW**

(Reference: total U.S. electrical generation capacity for all fossil, nuclear and renewable generation is 914 GW)

Typical Offshore Wind Farm Layout

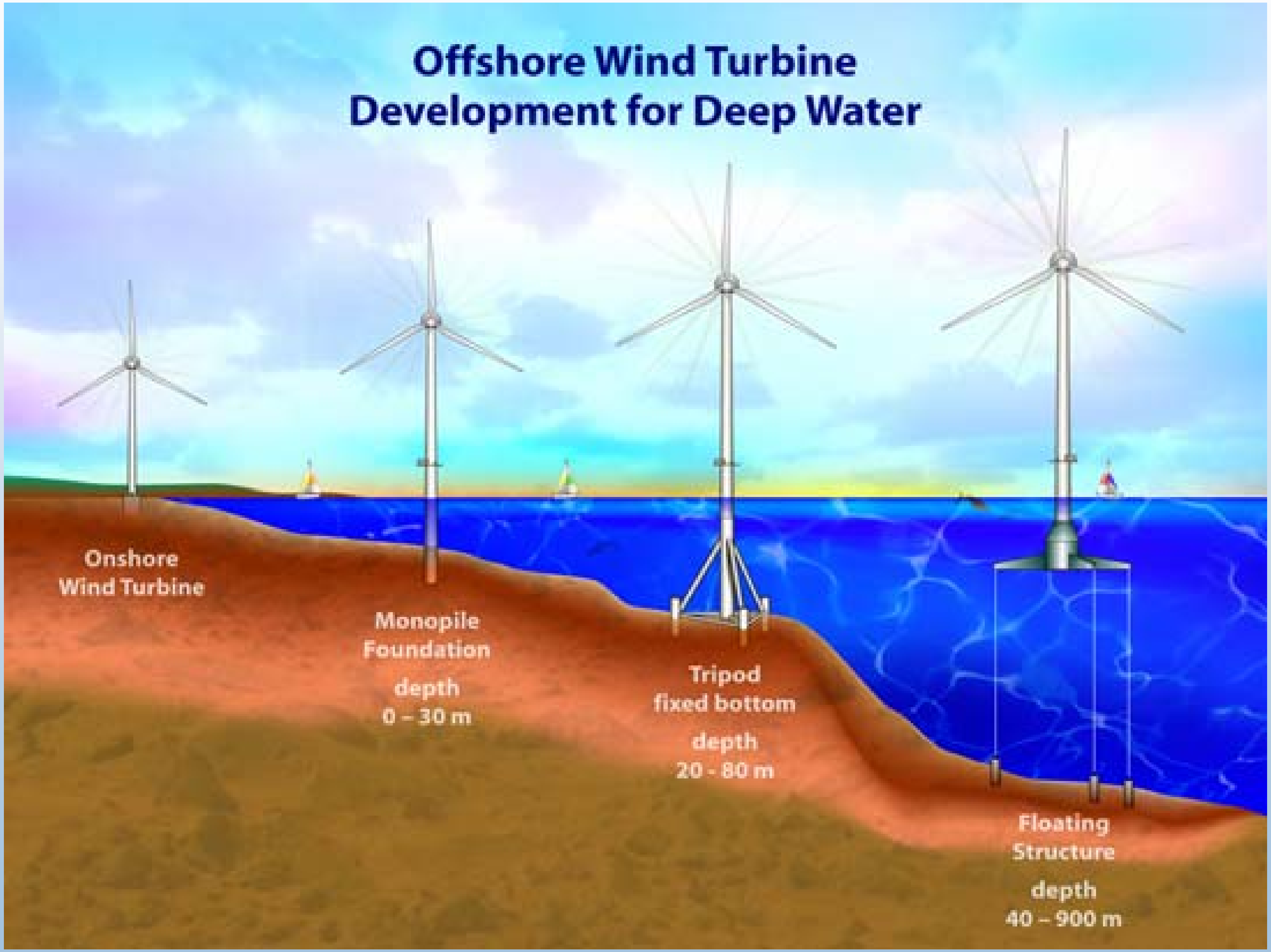




Potential Effects/Concerns

- Viewshed
- Sea mammals
- Fisheries
- Avian
- Hydrography & Coastal effects
- Seabed
- Socioeconomics
- Community acceptance
- Noise/Vibrations
- Radar/Radio Disturbances (military/commercial uses)
- Boating/Marine Traffic
- Transmission Lines
- Subsea Cables/ Electromagnetic Fields
- Navigation & Risk collision
- Air Traffic Safety
- Marine Archaeology

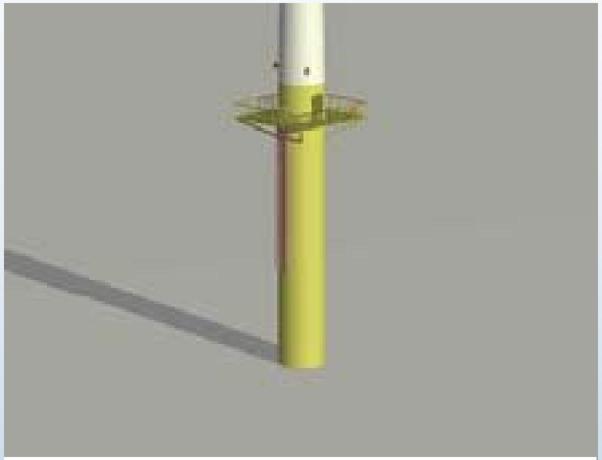
Deep Water Wind Turbine Development



NREL National Renewable Energy Laboratory

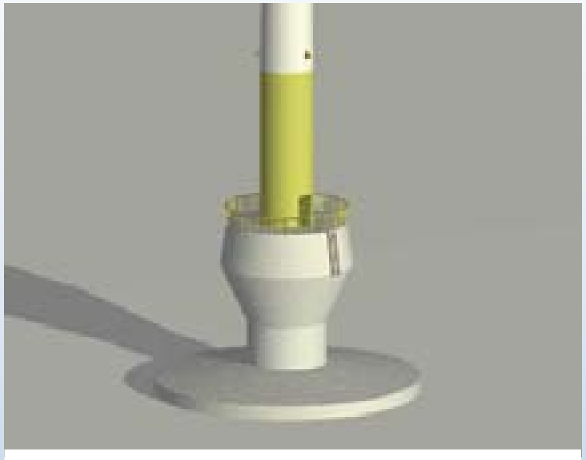
Fixed Bottom Substructure Technology

Proven Designs



Monopile Foundation

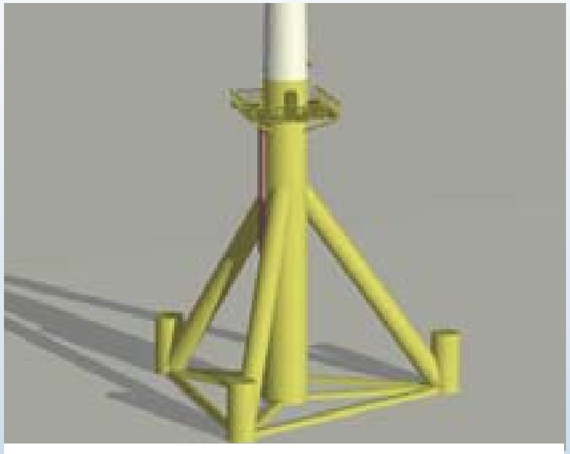
- Most Common Type
- Minimal Footprint
- Depth Limit 25-m
- Low stiffness



Gravity Foundation

- Larger Footprint
- Depth Limit?
- Stiffer but heavy

Future

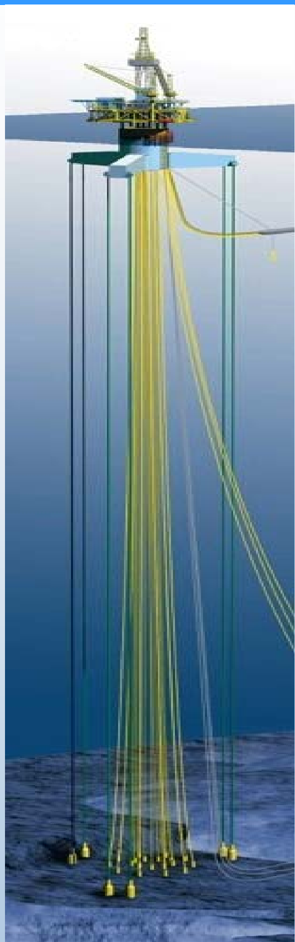


Tripod/Truss Foundation

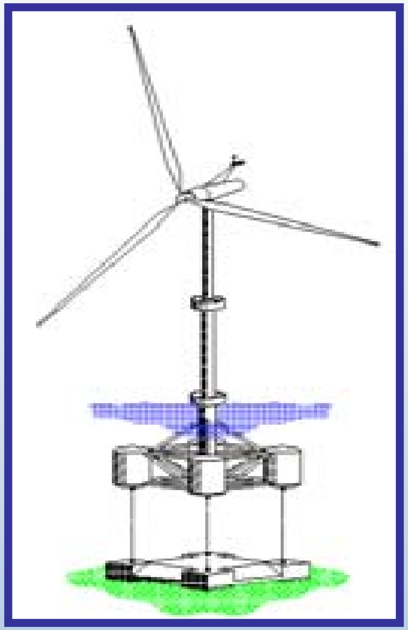
- No wind experience
- Oil and gas to 450-m
- Larger footprint
- Talisman project

Graphics source: http://www.offshorewindenergy.org/

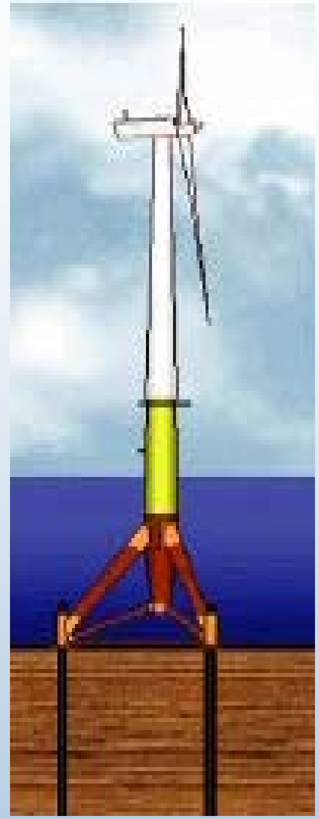
Deepwater Platform Concepts



Oil Rig on a tension leg platform -TLP



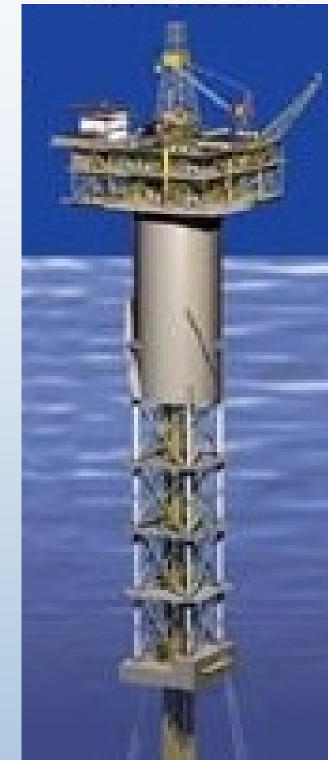
Wind Turbine on a TLP
Hannevig-Bone – Sea Breeze Partnership



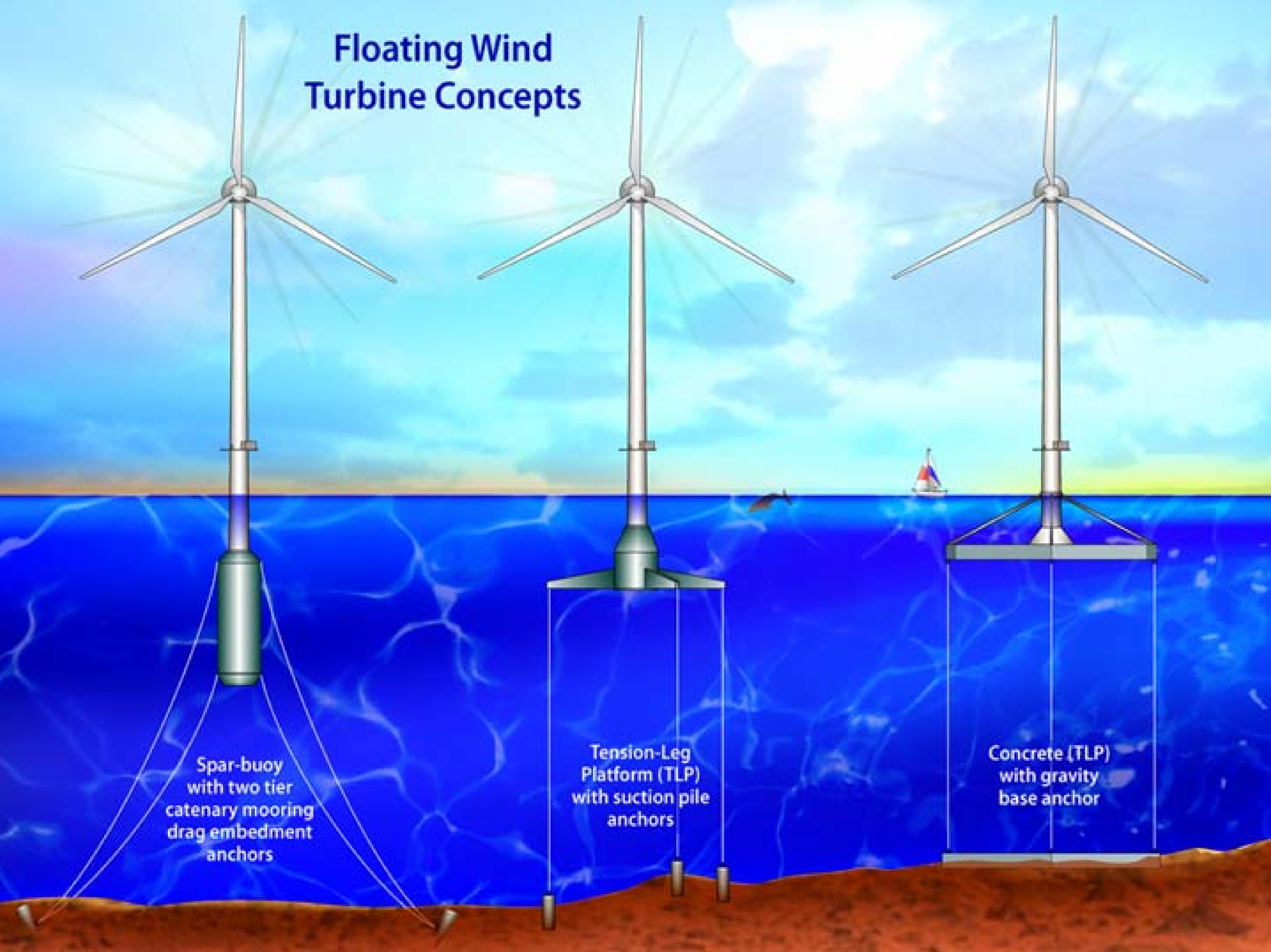
Wind Turbine on Tripod Tower
DOWNVInD Talisman Energy

Wind Turbine on a Spar Buoy

Wind Turbine on Dutch Tri-floater



Oil Rig on a Spar Buoy



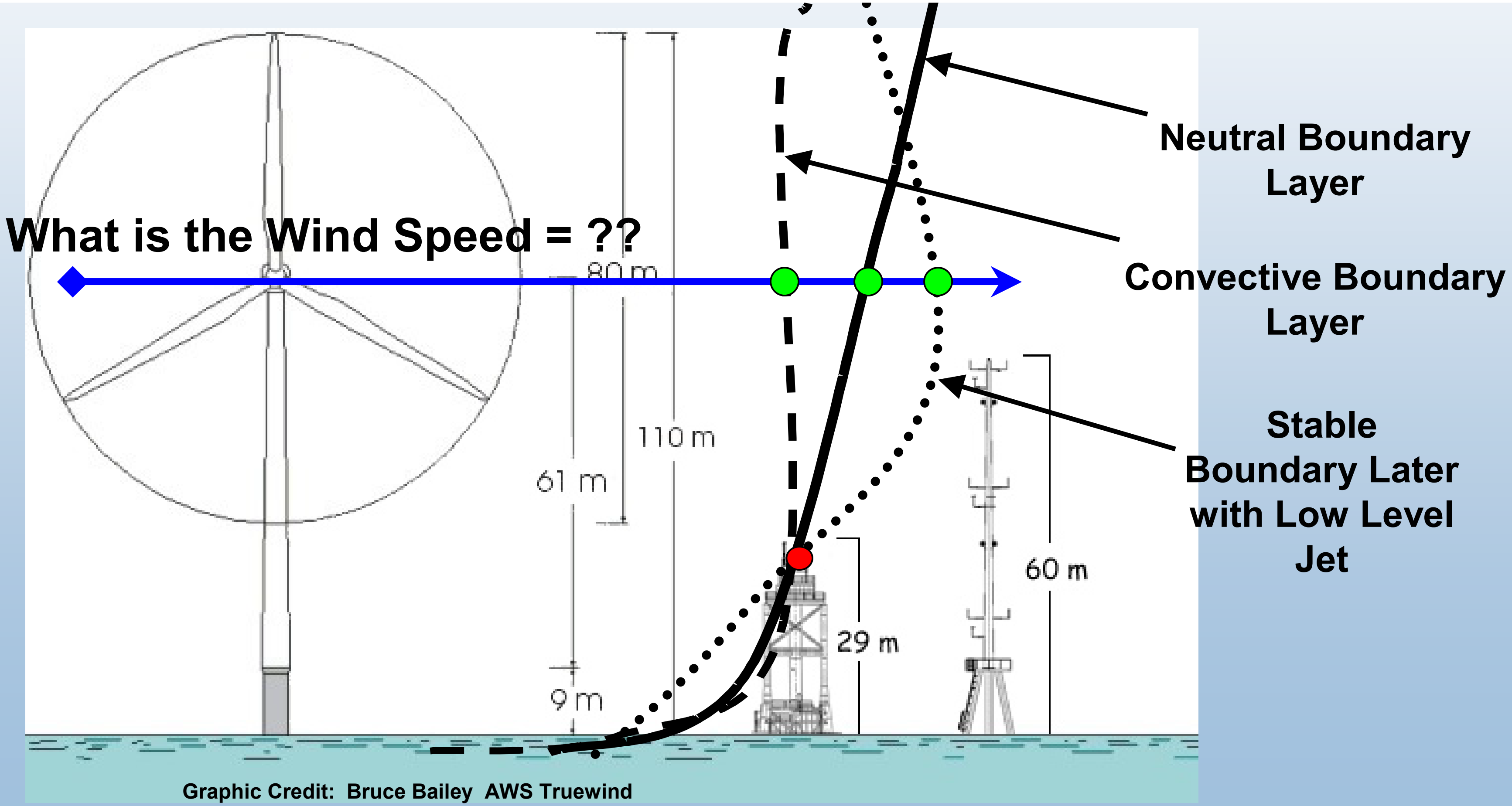
Floating Wind Turbine Concepts
Spar-buoy with two tier catenary mooring drag embedment anchors
Tension-Leg Platform (TLP) with suction pile anchors
Concrete (TLP) with gravity base anchor

Deepwater Wind Energy Workshops Research Priorities

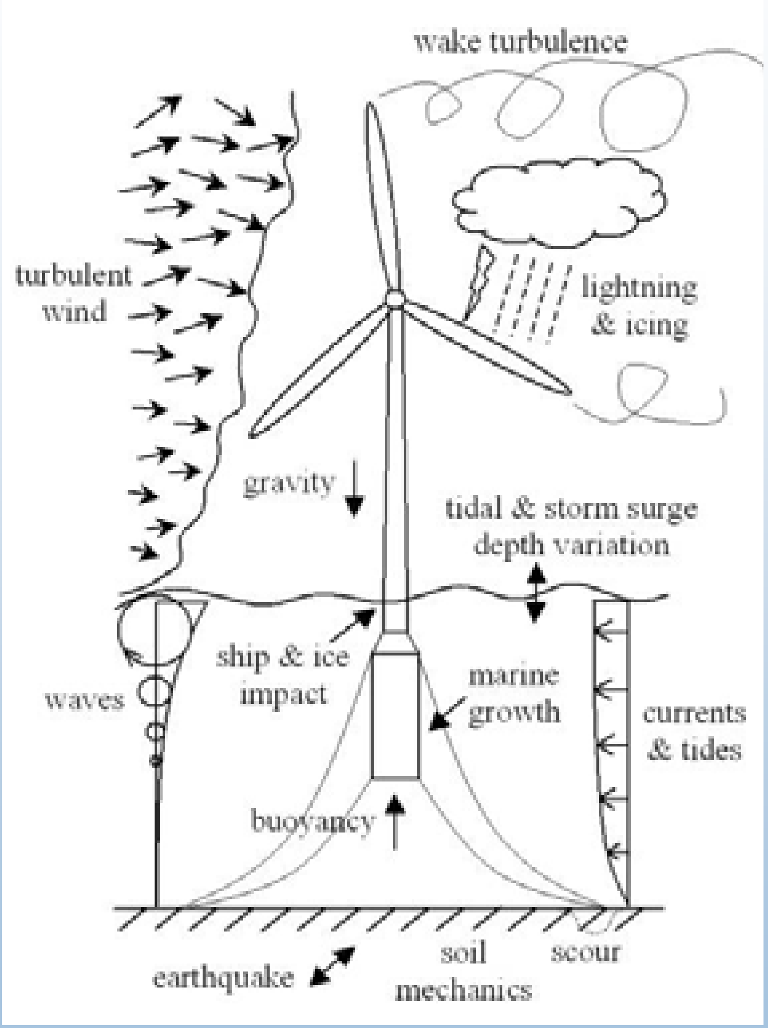
- Establish a design basis for a deepwater offshore turbine.
- Perform turbine/substructure system optimizations.
- Develop strategies to minimize work done at sea.
- Develop low-cost anchor system concepts.
- Deepwater site characterization methods.
- Conduct research on novel wind turbine technologies.

Understanding Offshore Wind

- Develop new measurement techniques and sensors for accurate wind speeds at heights where wind turbines operate – without MET towers!
- Understand and utilize available offshore data sets – Offshore MET measurements may come from many sources.
- Validate wind speed/potential – From meso-scale to micro-scale.
- Validate profile variations (wind shear) – Profiles may change with windspeed, season, and time of day.



Offshore Turbine Design Basis



Define External Conditions –

Measurements - Extreme wind, extreme wave, wind/wave combinations, sea state, wind shear, ice, currents, tide, soil mechanics, ship collisions, turbulence, wind farm turbulence.

Design Studies – Narrow the options

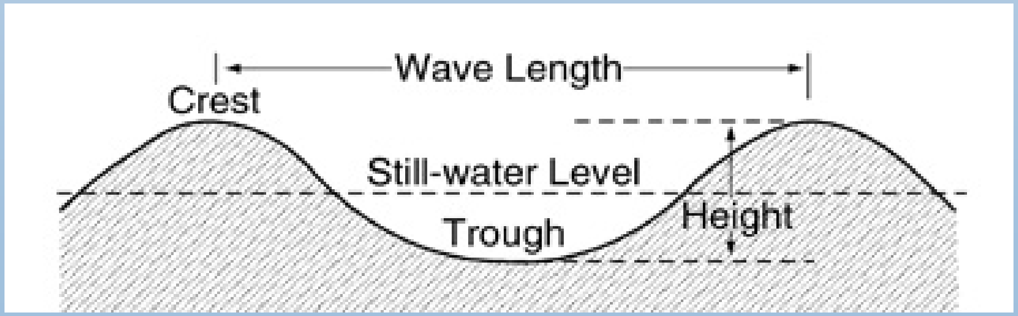
- **What is the design load envelope?**
- **What foundations achieve the lowest cost?**
- **What are the design drivers?**

Code development

- **Coupled platform/turbine responses**
- **Ocean Test Bed Validation**

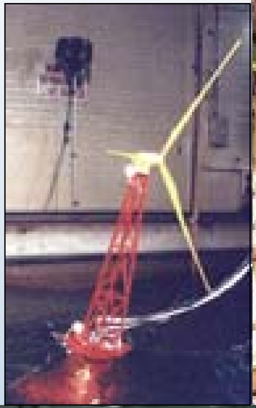
Design standards

- **IEC, ABS, DNV, GL, API**



Testing and Validation

- **<u>Scale model testing</u> – configuration tradeoff studies in wind/wave tank.**
- **<u>Hybrid testing</u> – wave simulations can be conducted in a subscale test-bed on land under real wind conditions.**
- **<u>Full-scale blade and drivetrain test facilities</u> – Multi-megawatt wind turbine components must be tested and verified before field deployment. New facilities are needed now. States may play a key role.**
- **<u>Field testing</u> – full-scale test loads in real ocean environments are essential.**
  - Certification
  - Code validation
  - Safety verification

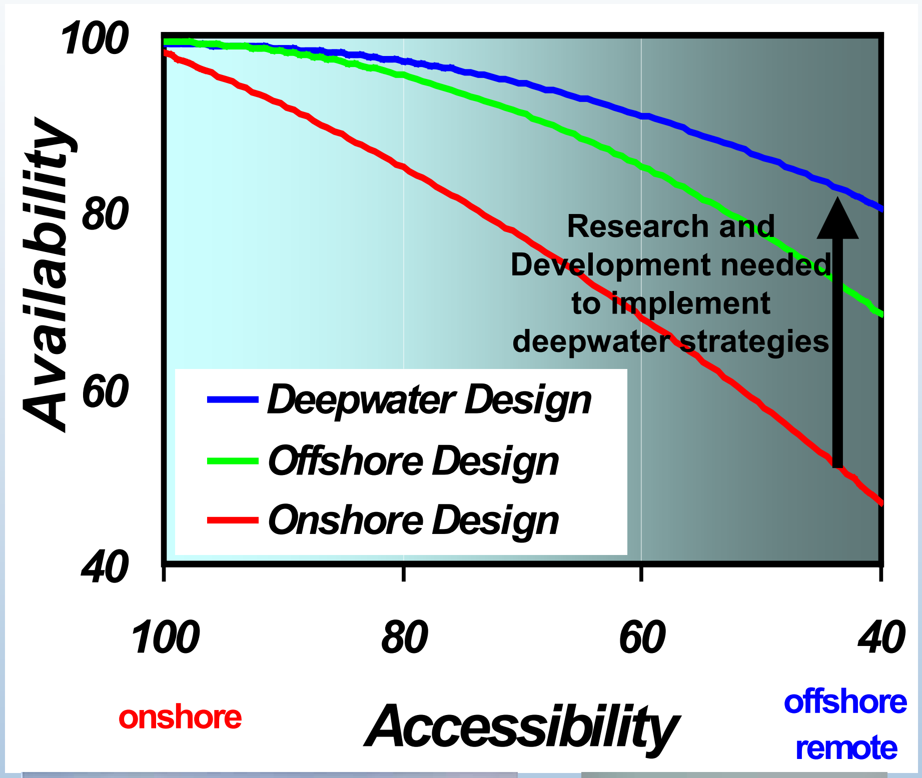


Minimize Work at Sea

Offshore labor and equipment costs are key drivers

Current turbine designs use onshore practices

High offshore availability will require turbine designs that are tolerant of inaccessible periods



Installation Strategies

- *Standardize and mass-produce platforms and substructures.*
- *Float-out whole systems*
- *Reduce large vessel dependency*
- *Develop low cost mooring systems*

Operation and Maintenance Strategies

As machines get larger and more remote smarter systems will become economical

- *Offshore turbines must close the loop between O&M and turbine design.*
- *High reliability designs*
- *Designs for in-situ repair*
- *Remote condition monitoring*
- *Turbine self diagnostics*
- *Safer and faster personnel transport*

Photo Credits: GE Energy

Environmental and Regulatory Issues

- **Jurisdictional Uncertainties**
- **Programmatic EIS with Regional Focus**
- **R&D study focus**
  - Before and after construction
  - Avian: collision, habitat disturbance, barrier effect
  - Mammals
  - Marine ecology
- **European methodologies/ Lessons learned**
- **Environmental Exclusions**

Summary

- European experience is driving industry but costs are higher than onshore.
- US Offshore wind energy potential is over 1000-GW.
- US offshore wind resource is complementary to on-shore wind resource.
- US deepwater wind resource is necessary for full offshore wind energy deployment.
- Near term offshore experience in shallow water will accelerate deepwater technology.
- Environmental and regulatory issues are important drivers.
- Further R&D (technology and environmental) is necessary for cost effective offshore wind energy.
- Commercial deepwater technology is 10-15 years away.