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# Offshore Wind Technology Overview

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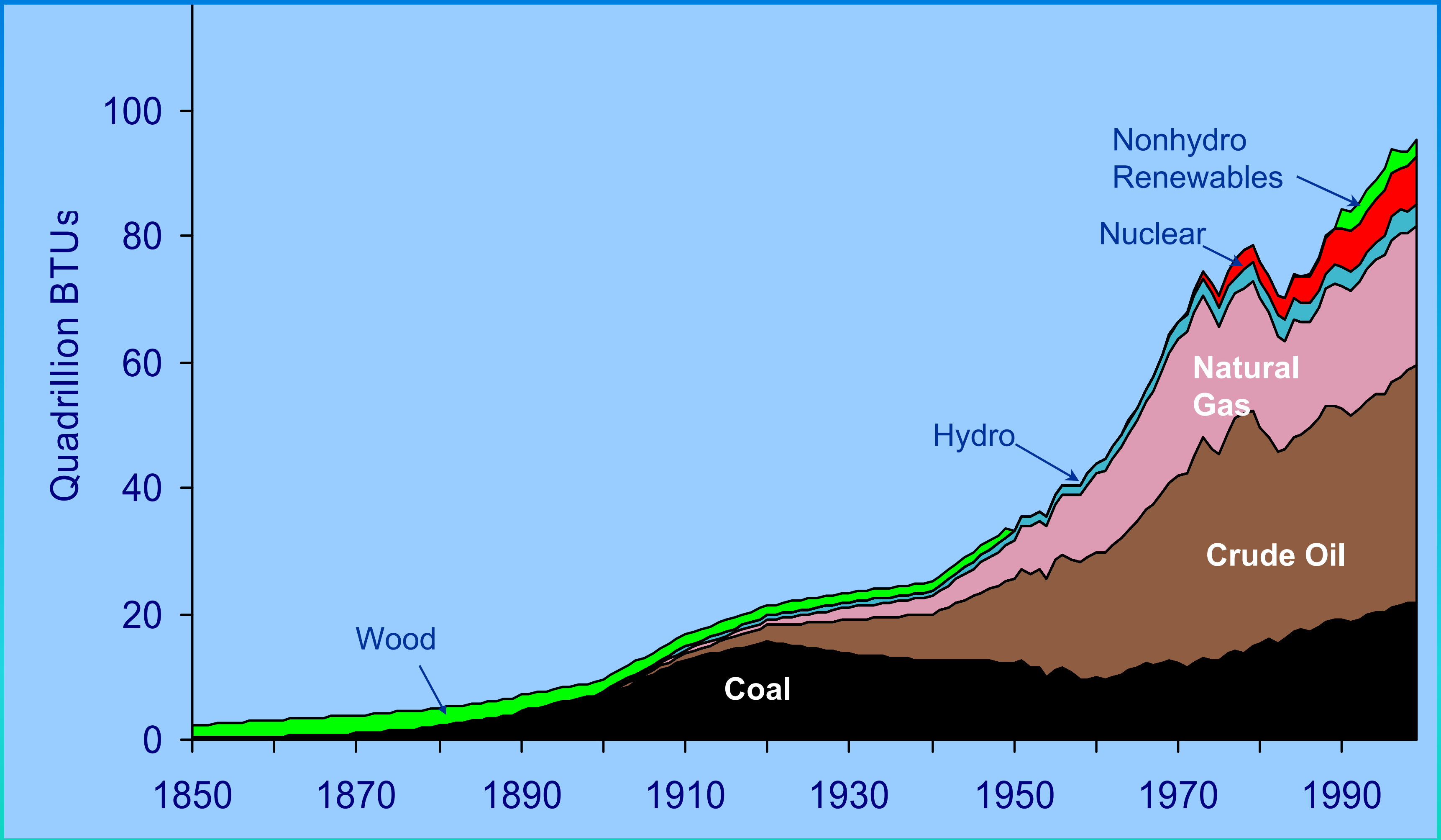
# The U.S. Energy Picture by Source - 1850-1999




Source: 1850-1949, Energy Perspectives: A Presentation of Major Energy and Energy-Related Data, U.S. Department of the Interior, 1975; 1950-1996, Annual Energy Review 1996, Table 1.3. Note: Between 1950 and 1990, there was no reporting of non-utility use of renewables. 1997-1999, Annual Energy Review 1999, Table F1b.

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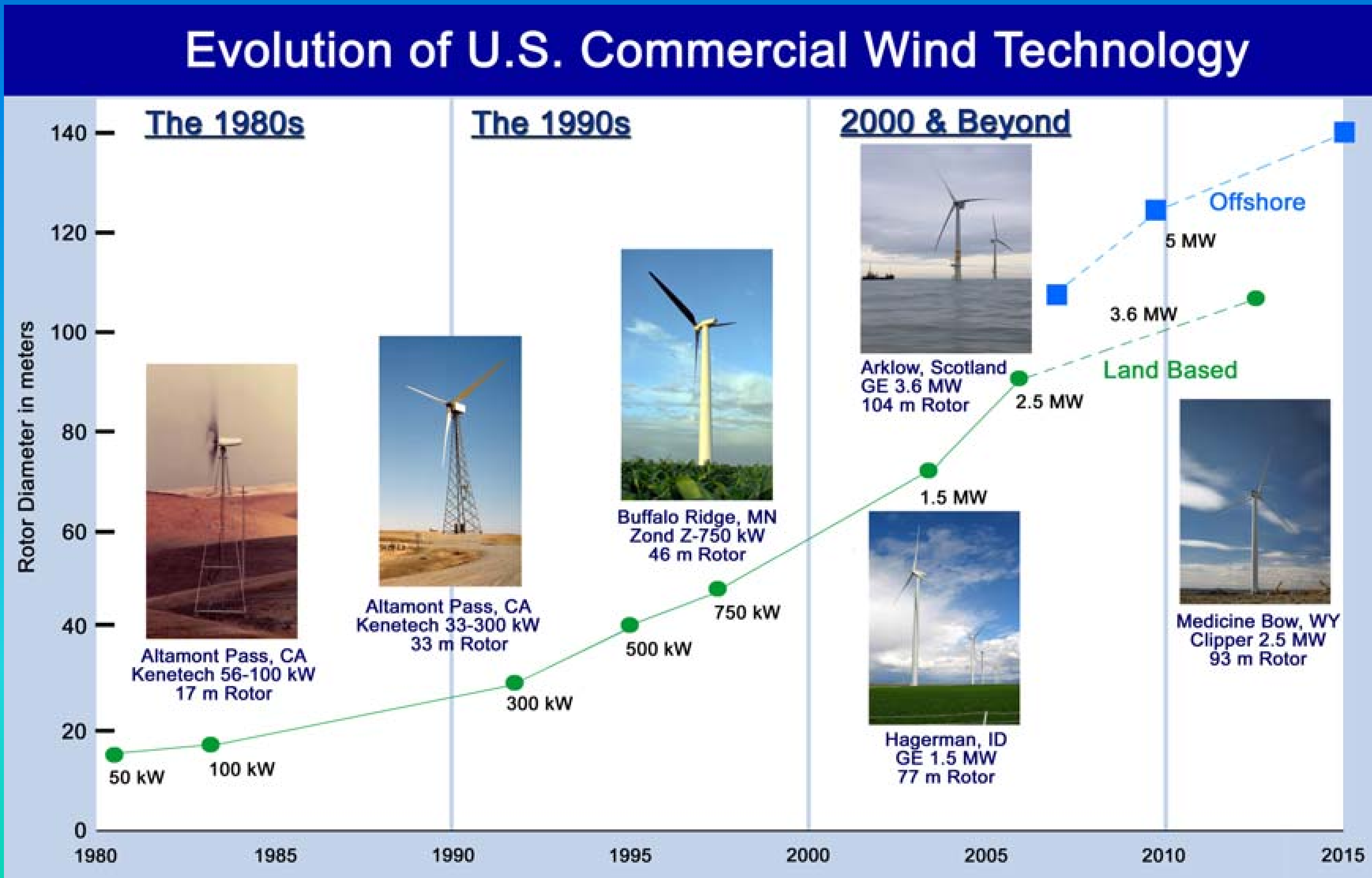
# Evolution of U.S. Commercial Wind Technology



# Offshore GE Wind Energy 3.6 MW Prototype

- Offshore GE 3.6 MW
  104 meter rotor diameter

- Offshore design requirements considered from the outset:
  - Crane system for all components
  - Simplified installation
  - Helicopter platform

# Cost of Energy Trends

**1981: 40 cents/kWh**

- **Increased Turbine Size**
- **R&D Advances**
- **Manufacturing Improvements**

**2006: 9.5 cents/kWh**

- **Multimegawatt Turbines**
- **High Reliability Systems**
- **Infrastructure Improvements**

**<u>Land-based</u>**

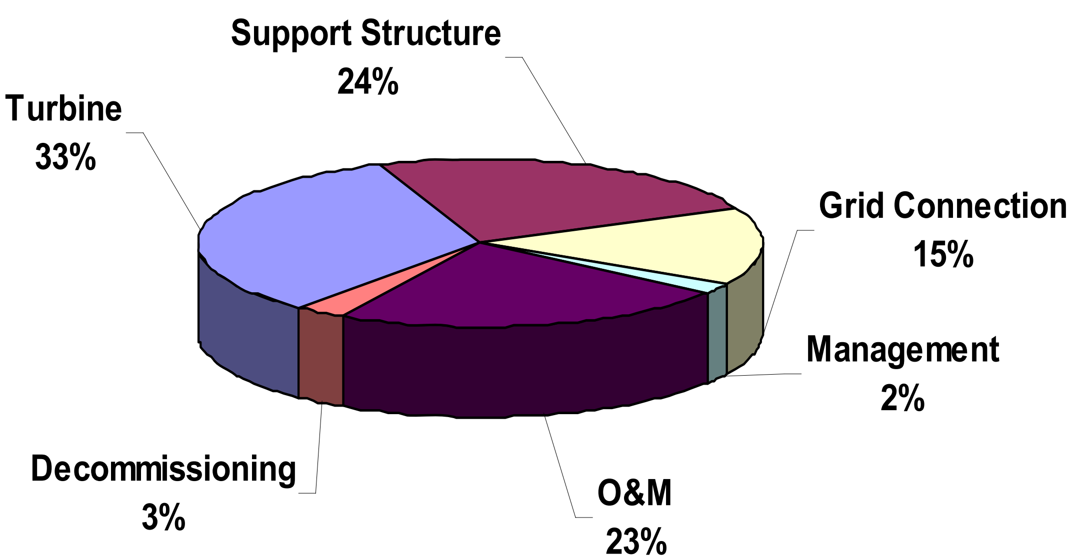
**2006: 3 - 6 cents/kWh**

**<u>Offshore</u>**

**2014: 5 cents/kWh**

# Offshore Turbine Size Drivers

- Offshore Turbines are about 1/3 of total project cost.
- Thus, as turbines grow larger:
  - Foundation costs decrease
  - Electrical infrastructure costs decrease
  - Operational expenses decrease
  - More energy is generated per area.
- Offshore infrastructure is also suited for larger machines.




***Offshore Wind - Life Cycle Cost of Energy***

GE Wind

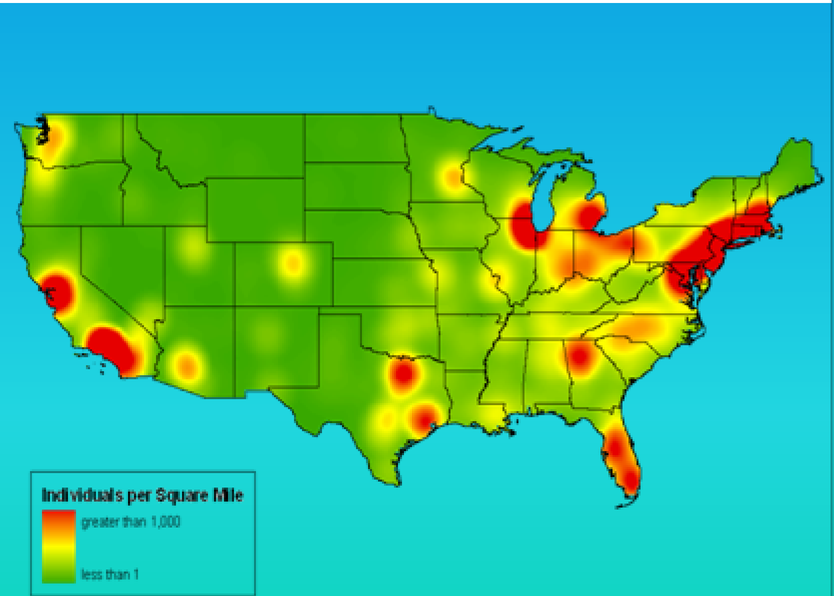
# Offshore Wind – U.S. Rationale
# Why Go Offshore?

*Windy onshore sites are not close to coastal load centers*

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

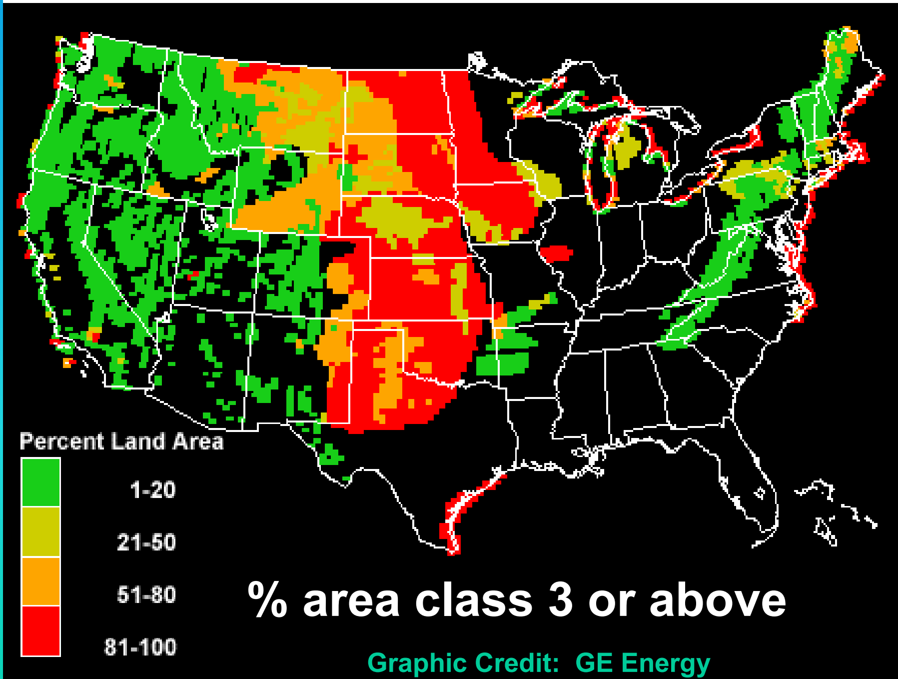
*Load centers are close to the offshore wind sites*

## US Population Concentration



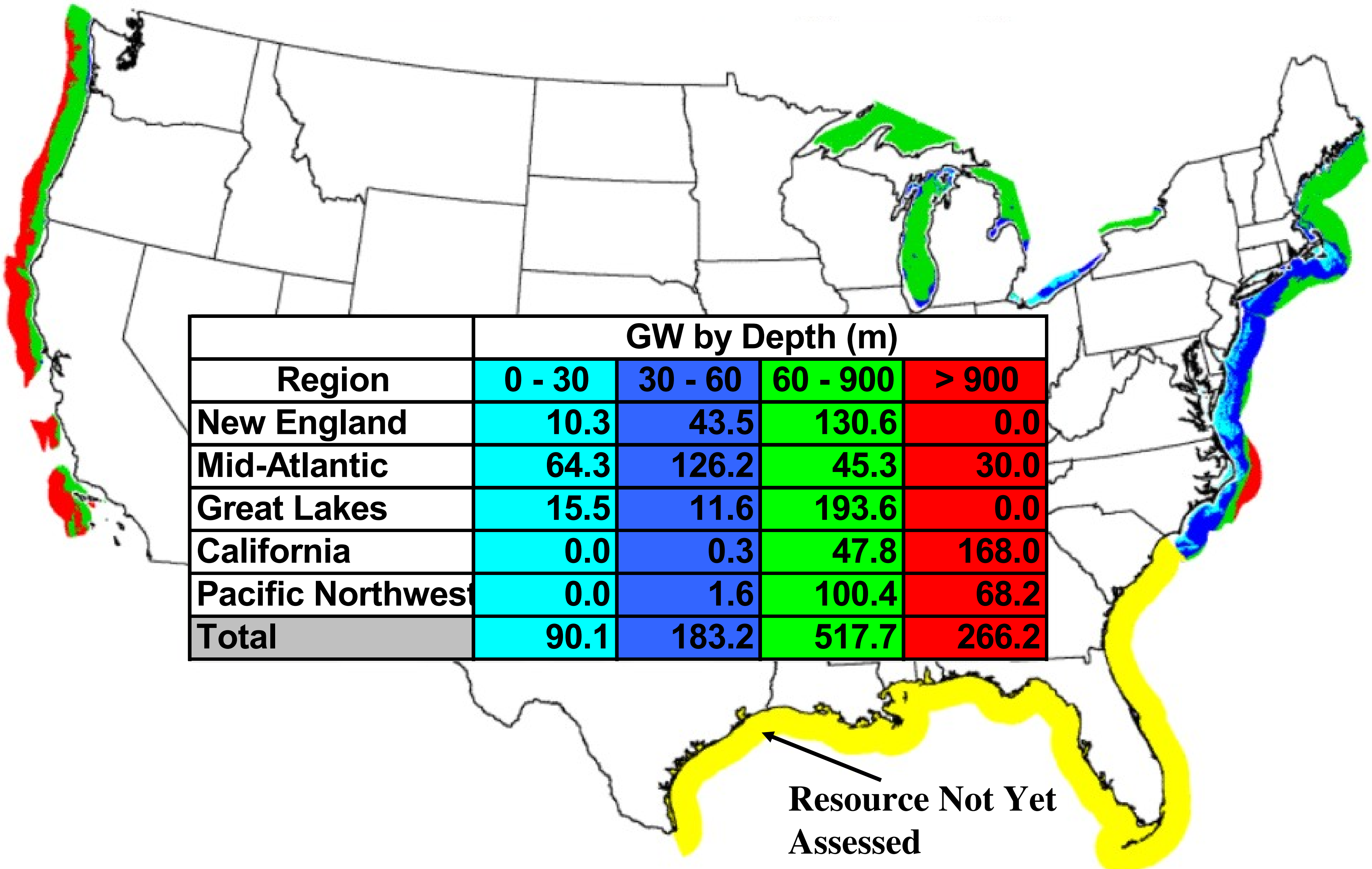

Graphic Credit: Bruce Bailey AWS Truewind

## US Wind Resource



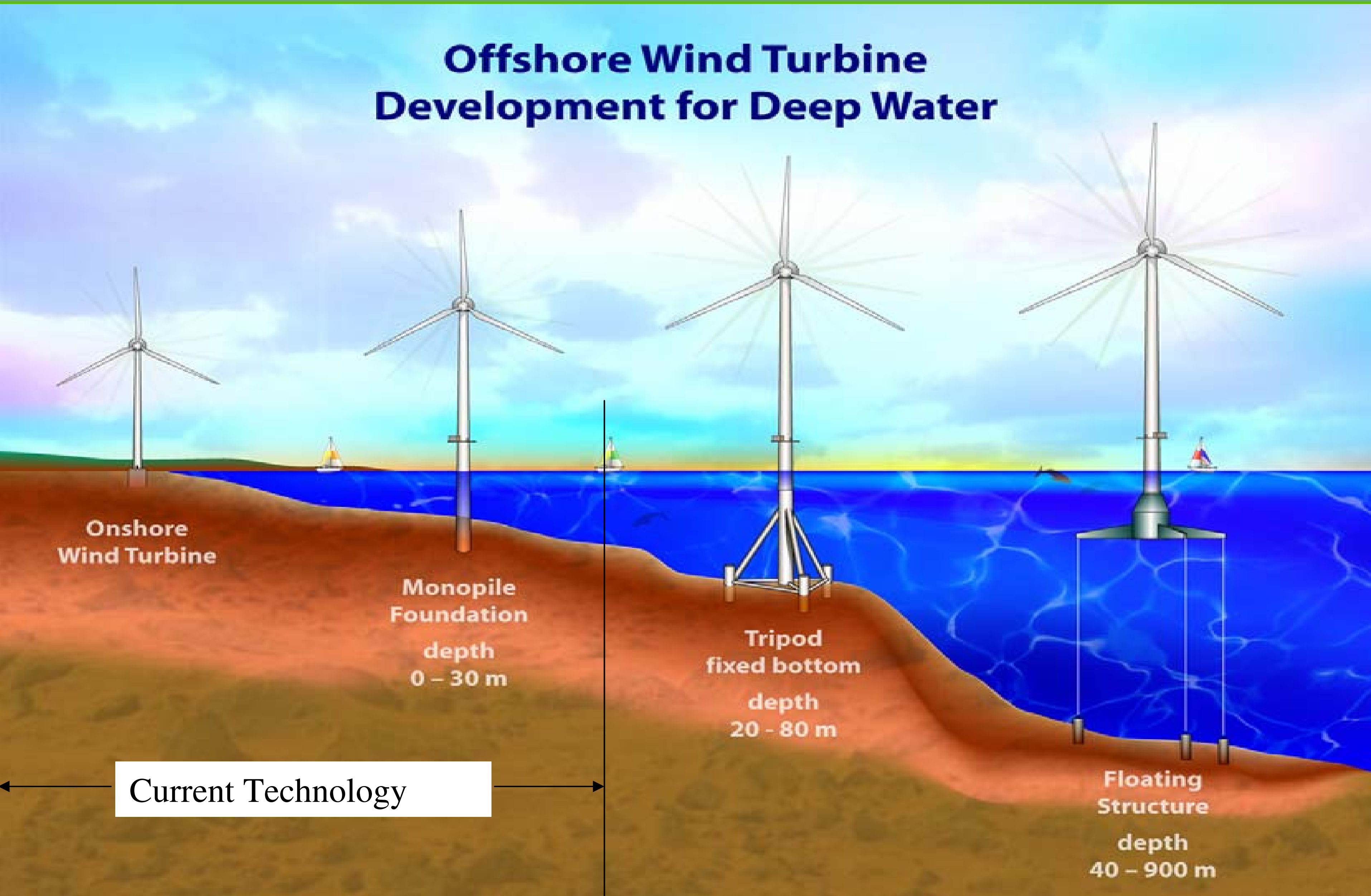

Graphic Credit: GE Energy

# U.S. Offshore Wind Energy Resource

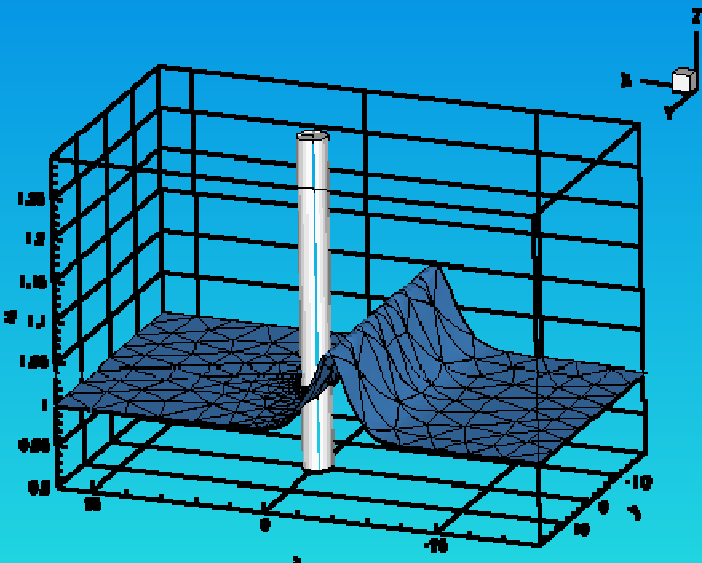



| | GW by Depth (m) | | | |
|---|---|---|---|---|
| Region | 0 - 30 | 30 - 60 | 60 - 900 | > 900 |
| New England | 10.3 | 43.5 | 130.6 | 0.0 |
| Mid-Atlantic | 64.3 | 126.2 | 45.3 | 30.0 |
| Great Lakes | 15.5 | 11.6 | 193.6 | 0.0 |
| California | 0.0 | 0.3 | 47.8 | 168.0 |
| Pacific Northwest | 0.0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

# Offshore Wind Turbine Development



# Arklow Banks Windfarm
# The Irish Sea





R. Thresher

# Fixed Bottom Substructure Technology

## Proven Designs

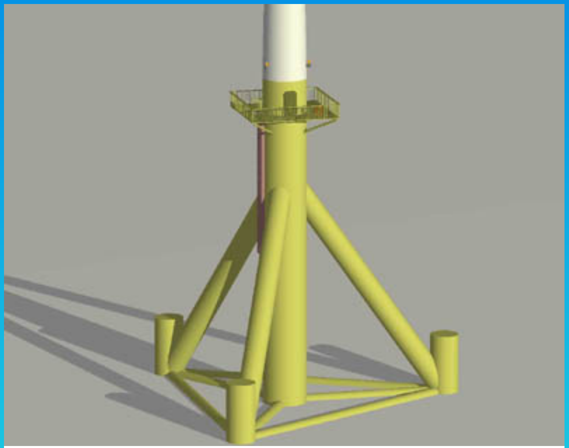
Monopile Foundation

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

Gravity Foundation

- Larger Footprint
- Depth Limit?
- Stiffer but heavy

## Future



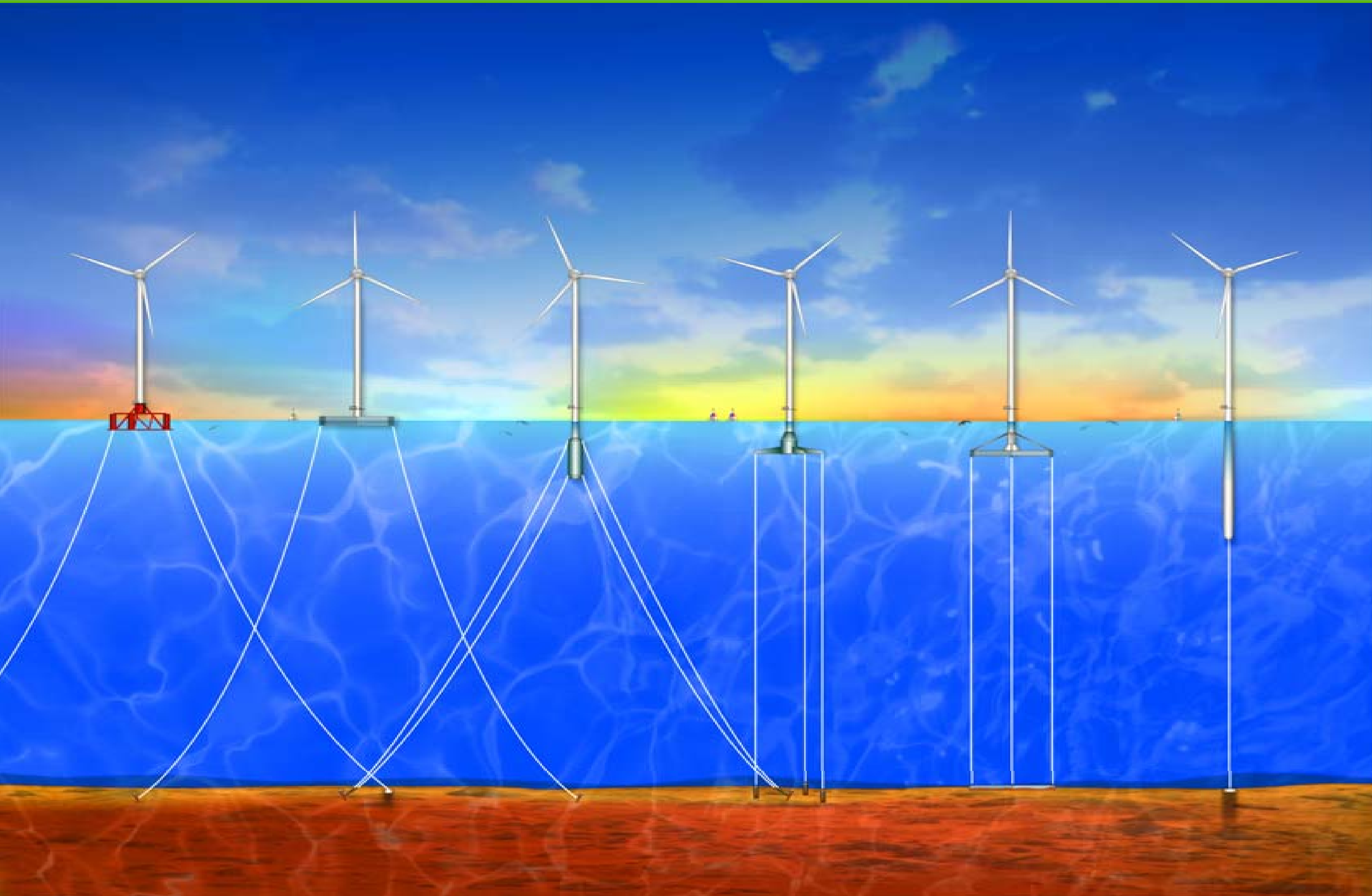
Tripod/Truss Foundation

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

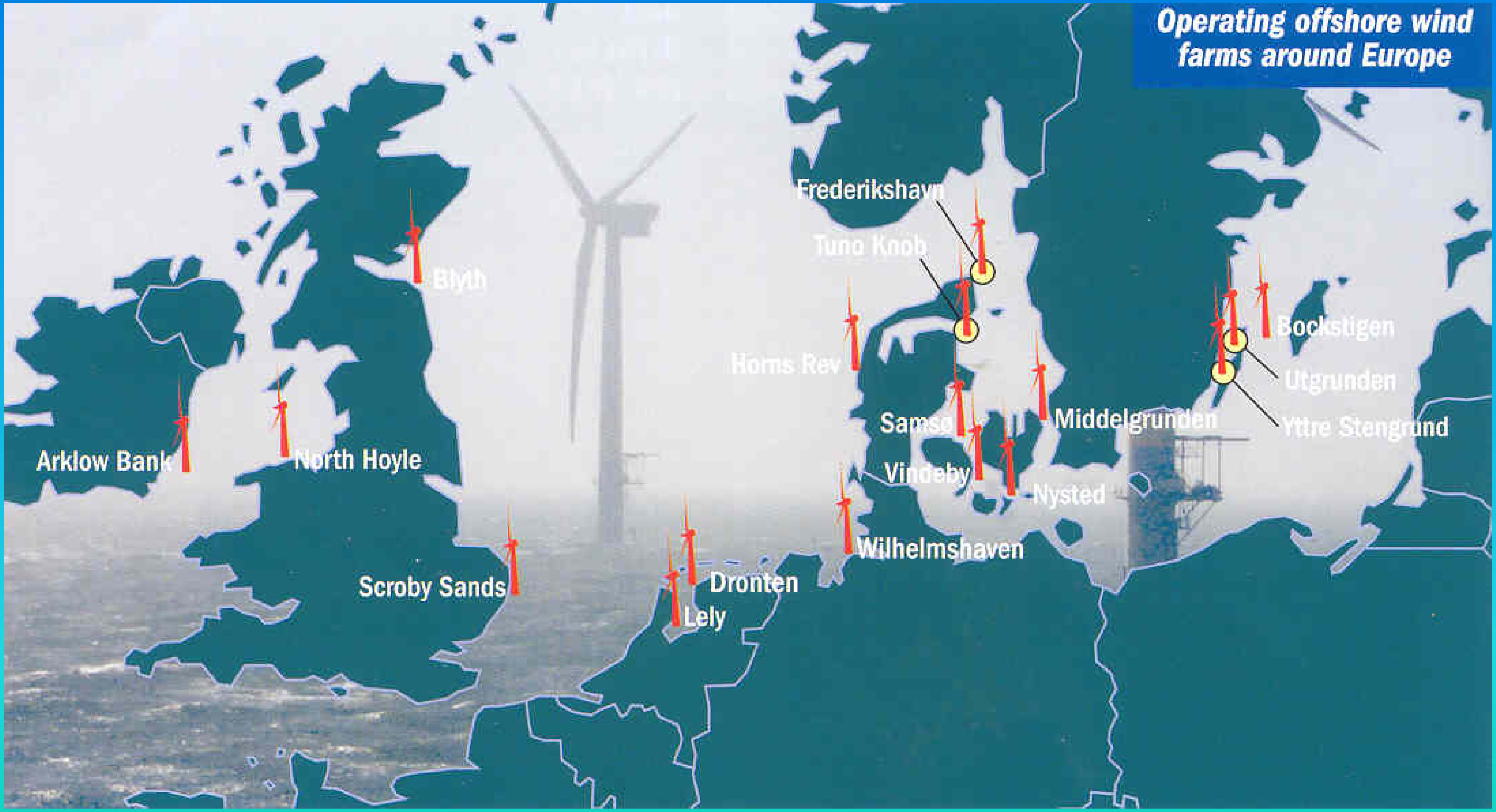
Graphics source: http://www.offshorewindenergy.org/

# Transitional Depth Foundations 30-m to 90-m Depths??

# Floating Foundations >60-m Depths



# Location of Existing Offshore Installations Worldwide




Source: Wind Directions, September 2004

# Enercon 4.5-MW Offshore Prototype

**Enercon 4.5MW 112 meter rotor**

**440 metric tonnes**

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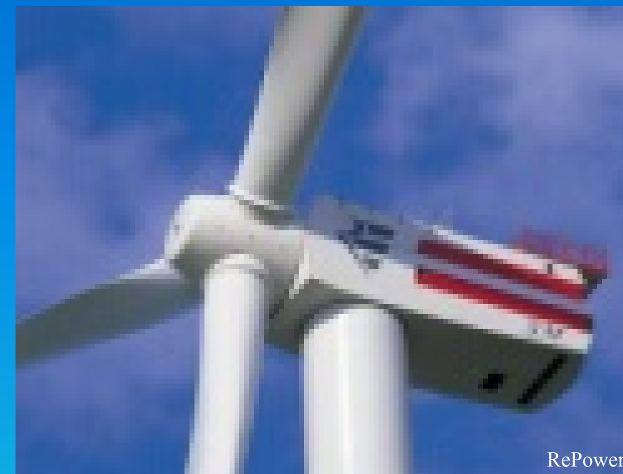
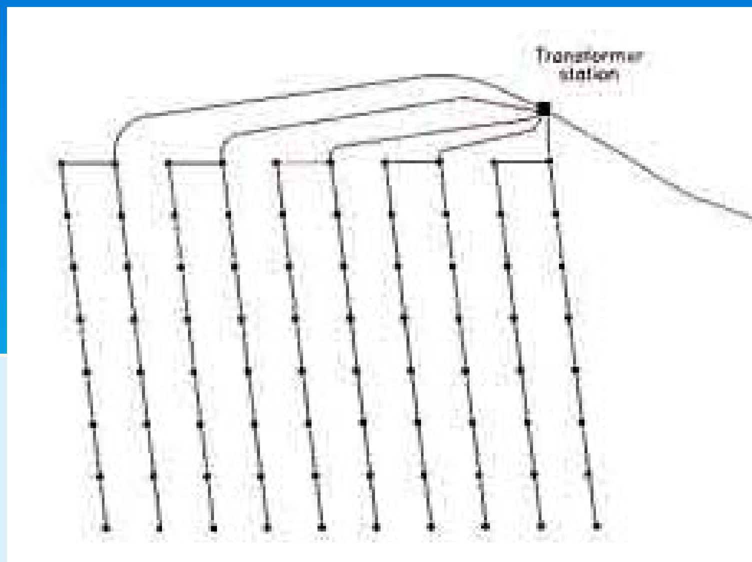
# RePower 5-MW – World's Largest Turbine

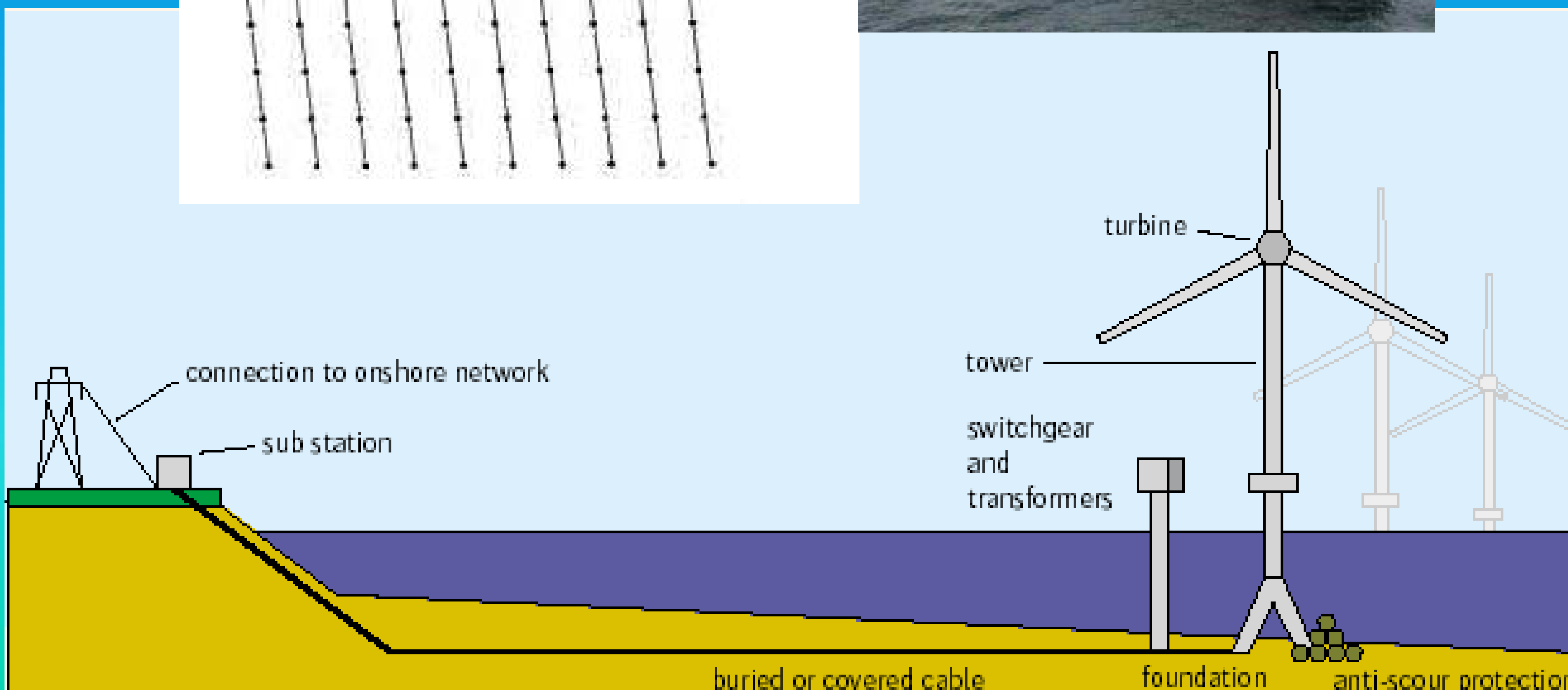




- 5-MW Rating
- 61.5-m blade length (LM Glasfibres)
- Offshore Demonstration project by Talisman Energy in Beatrice Fields
  - 45-m Water Depths
  - Two machines

# Typical Offshore Wind Farm Layout








Horns Rev

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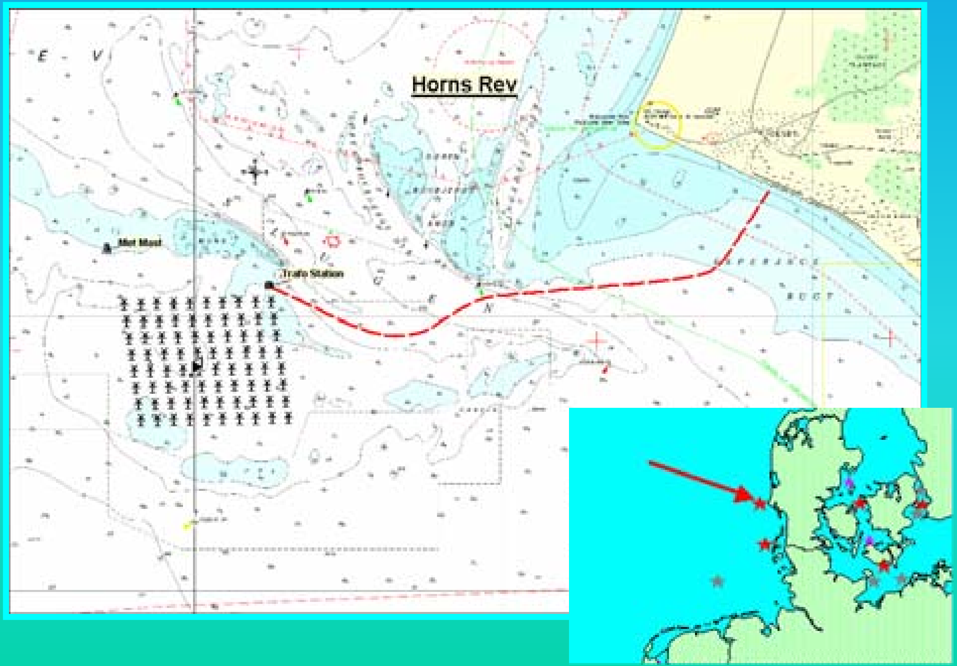
# Horns Rev Wind Farm - Denmark


**Country:** Denmark
**Location:** West Coast
**Total Capacity:** 160 MW
**Number of Turbines:** 80
**Distance to Shore:** 14-20 km
**Depth:** 6-12 m
**Capital Costs:** 270 million Euro
**Manufacturer:** Vestas
**Total Capacity:** 2 MW
**Turbine-type:** V80 – 80-m diameter
**Hub-height:** 70 m
**Mean Windspeed:** 9.7 m/s
**Annual Energy output:** 600 GWh



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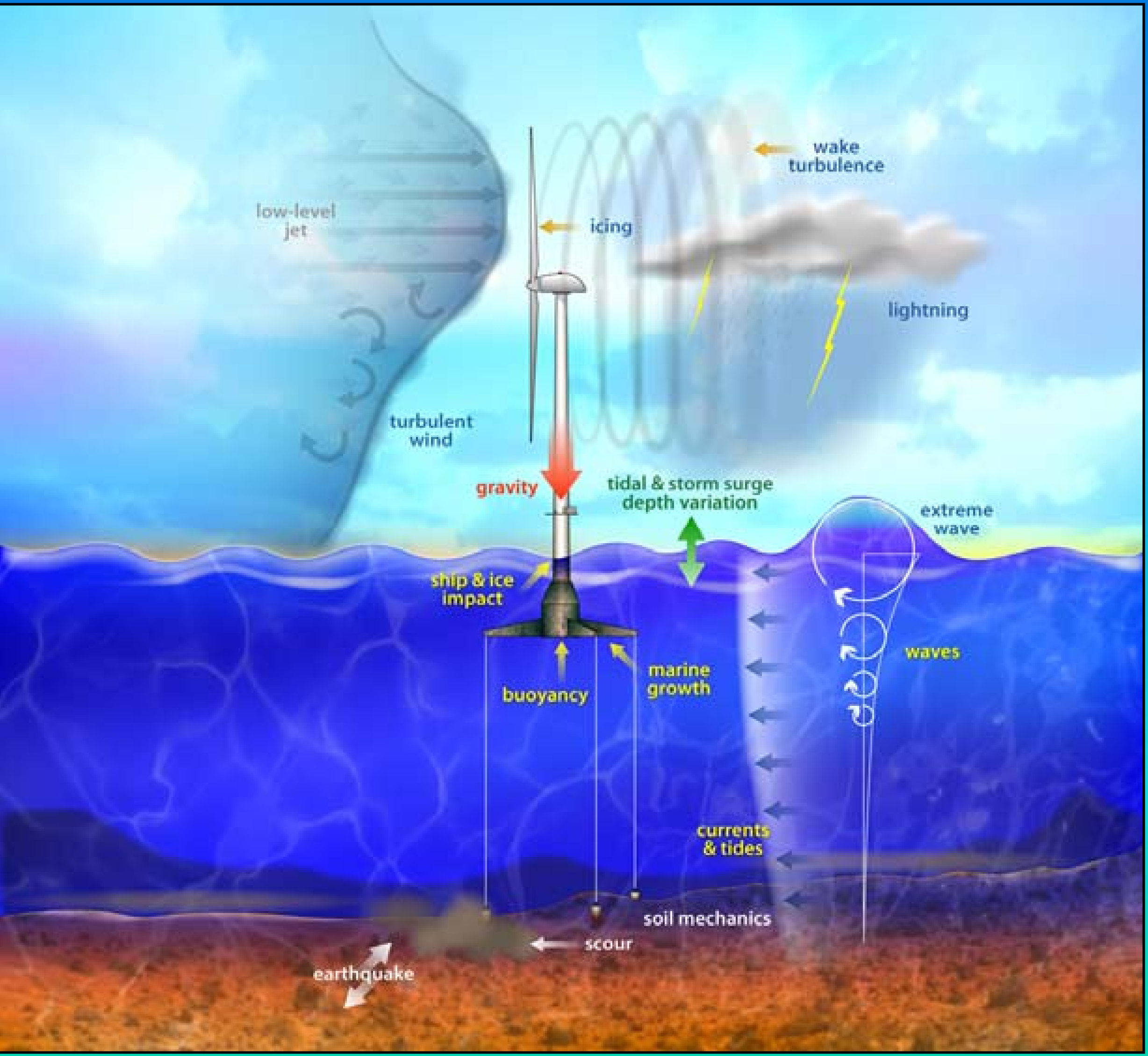
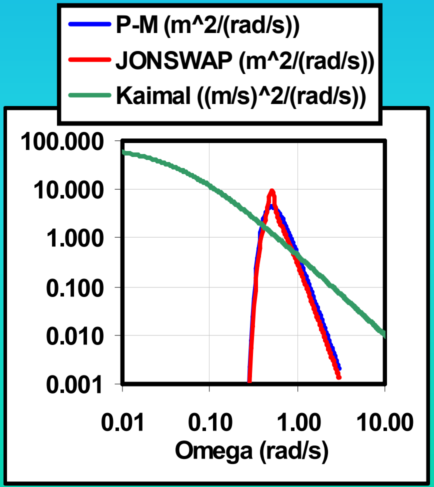
# Offshore Technical Challenges




- Turbulent winds
- Irregular waves
- Gravity / inertia
- Aerodynamics:
  - induction
  - skewed wake
  - dynamic stall
- Hydrodynamics:
  - scattering
  - radiation
  - hydrostatics
- Elasticity
- Mooring dynamics
- Control system
- Fully coupled cx




*Wind and Wave Spectra*

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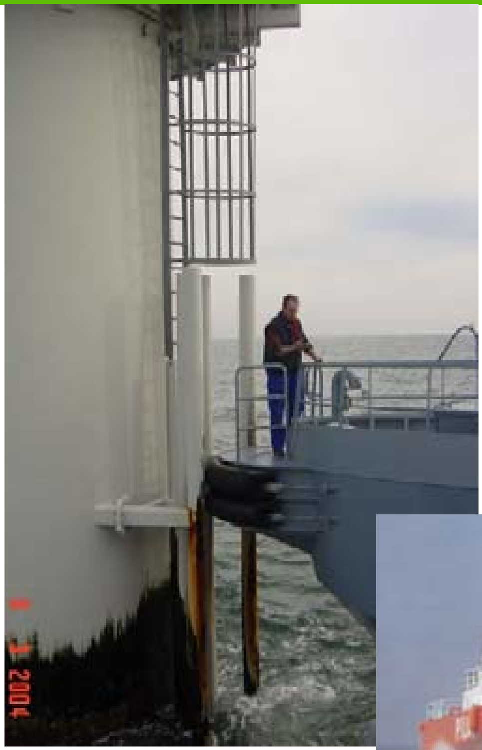
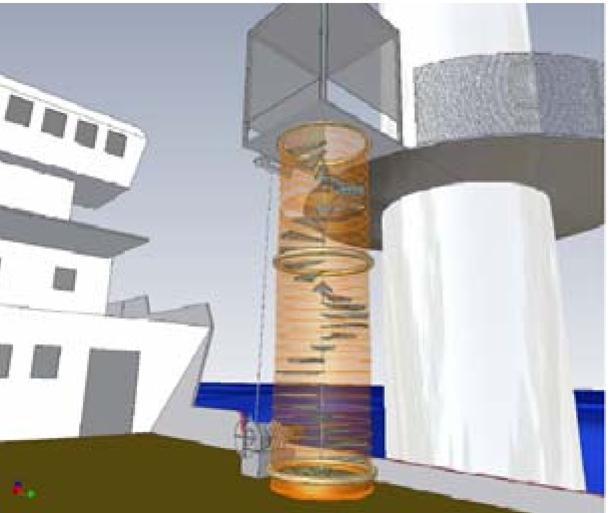
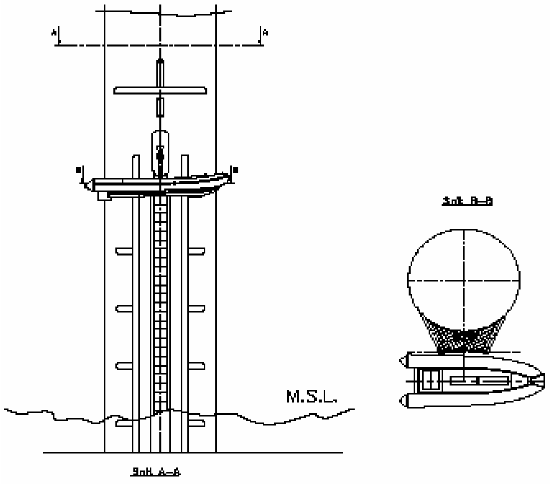
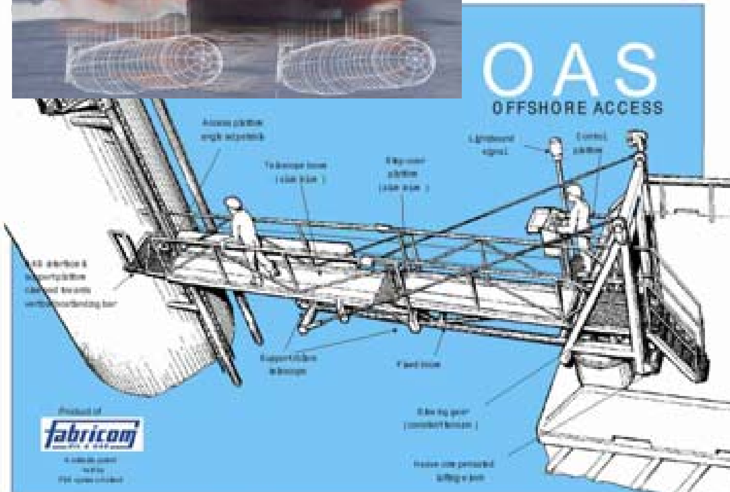
# Offshore Turbine Access

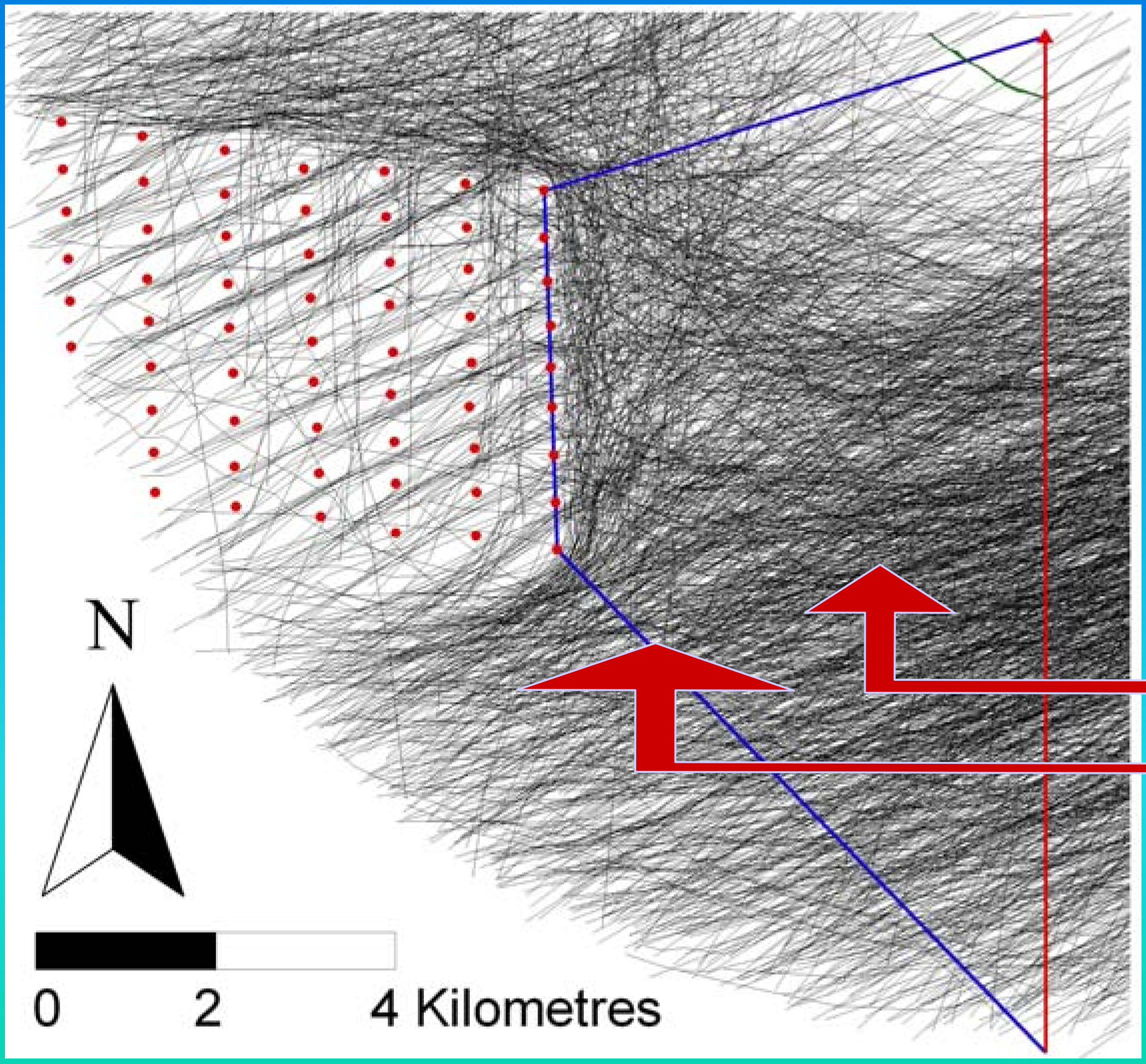




# Radar Images of Migrating Birds at Nysted Wind Power Plant - Denmark




Operation (2003):

Birds perceive the presence of wind turbines even in bad visibility

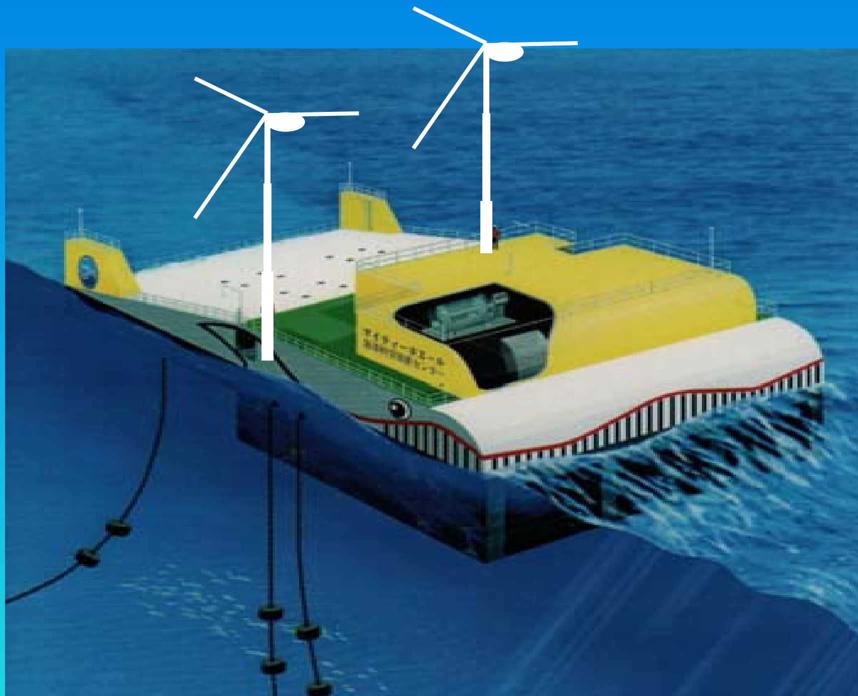
Response distance:

day = c. 3000 m

night = c. 1000 m

# Offshore Wind / Wave Synergy

## Small Wind-OWC Wave Platform



- **Common Engineering & Design Considerations**
- **Maximize Grid Interconnect Potential Through Dual Technologies**
- **Improve Intermittency & Total Energy Output**
- **Increase System Reliability & Reduce Maintenance**


**EPRI Building a Coalition of Developers, Universities and Other Stakeholders to Explore the Wind / Wave Development Potential**

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# A Future Vision for Wind Energy Markets

## Tomorrow

## Today 2005

**Bulk Power Generator**
**4-6¢ at 15 mph**

- Land Based
- Bulk Electricity
- Wind Farms

**Potential 20% of Electricity Market**

### Land Based Electricity Path

**Land Based LWST Large-Scale 2–5 MW**

**Transmission Barriers**

**LWST Turbines:**
- 3¢/kWh at 13 mph
- Electricity Market

**2012**

### Offshore Electricity Path

**Offshore Turbines 5 MW and Larger**

**Cost & Regulatory Barriers**

**Offshore LWST Turbine:**
- 5 Cents/kWh
- Shallow/***Deep*** *Water*
- Electricity Market
- Higher Wind Sites

**2012 and Beyond**

### Advanced Applications Path

**Land or Sea Based:**
- **Hydrogen**
- **Clean Water**

**Cost & Infrastructure Barriers**

**Custom Turbines:**
- Electricity
- H2 Production
- Desalinate Water
- Storage
- Multi-Market

**2030 and Beyond**