Energy 101: Offshore wind

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Laboratory for Ship and Platform flows, MIT

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Why offshore wind?

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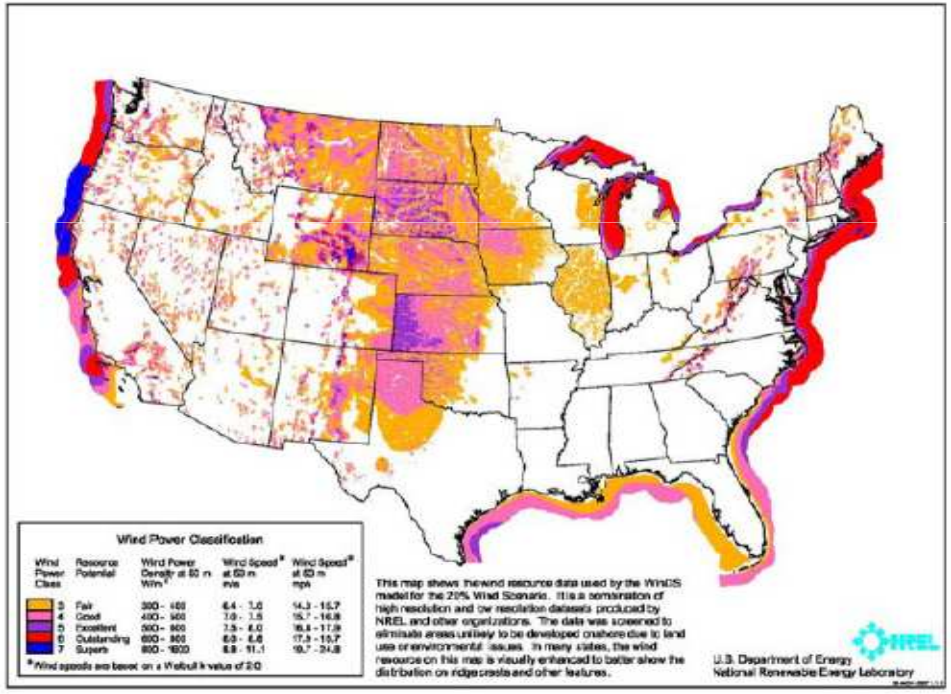
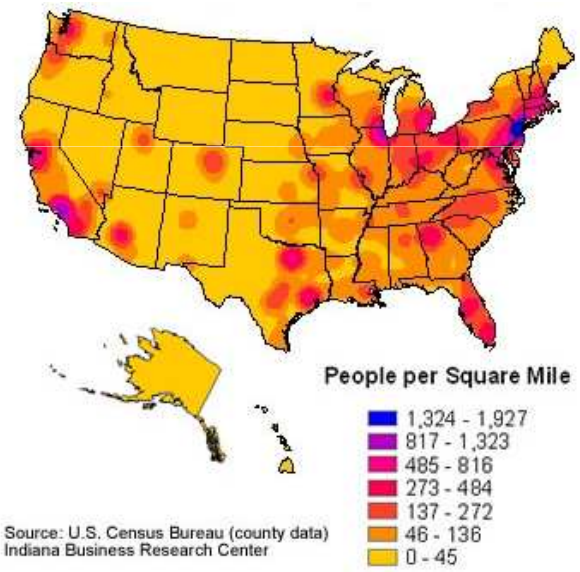
Why offshore wind?

Reason #1: Stronger wind close to the people

US Wind Resource



US population density



Source: U.S. Census Bureau (county data)
Indiana Business Research Center

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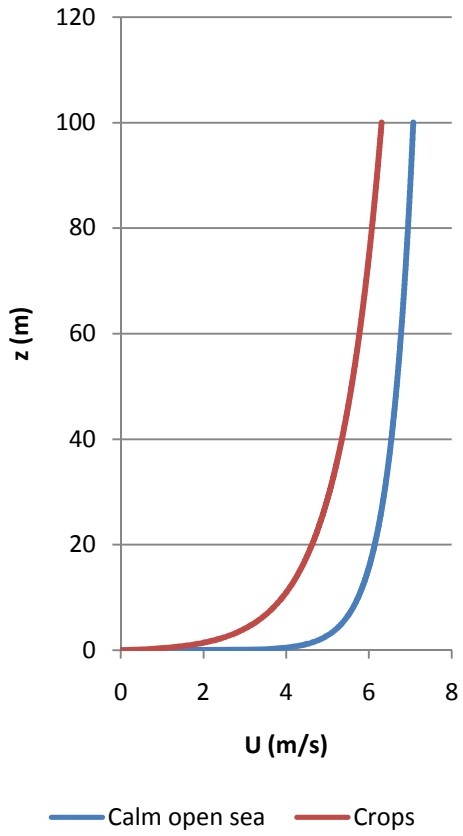
Why offshore wind?

Reason #2: Better wind



- Stronger wind
- Steadier wind direction
- Better wind shear profile
- Less turbulence

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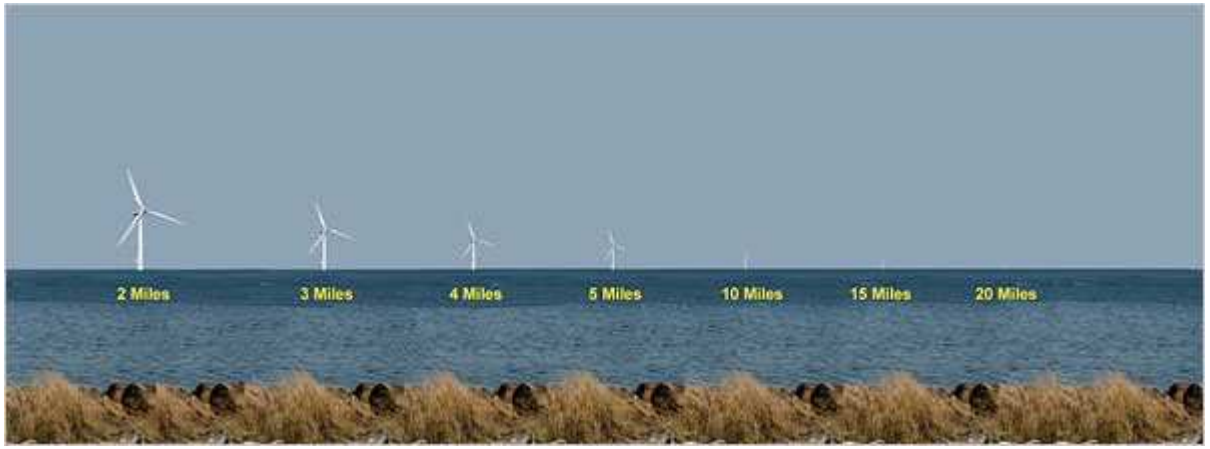
Why offshore wind?

Reason #3: Not In My Back Yard!



$$L = \sqrt{2HR}$$

H = 90 m (hub height) => L = 34 km

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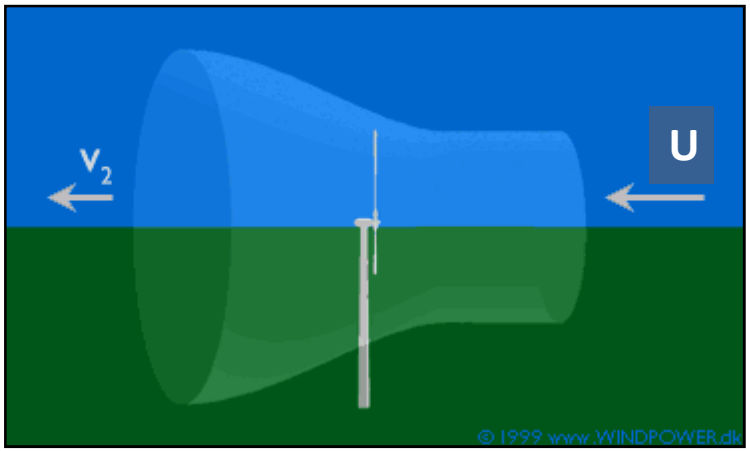
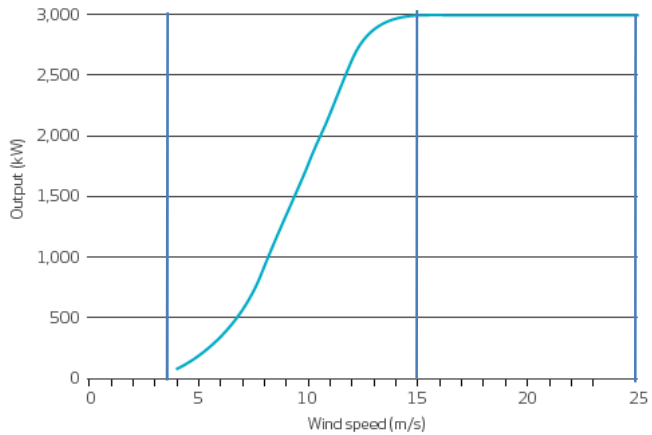
Wind Energy in 1 slide



Power curve V90-3.0 MW
Noise reduced sound power modes are available.

Rated power 3MW →



Cut-in speed | Rated speed | Cut-out speed

Power in wind at speed U:

$$P_W = \frac{1}{2}\rho A U^3$$

Extracted power by turbine:

$$P = \frac{1}{2}\rho A U^3 C_P$$

↑ Power coefficient

Betz limit: max C_P = 59%
Actual turbines: C_P close to 50%

Rated power ~ 3 to 5 MW

Capacity factor on site:

$$\frac{\text{Power produced during year}}{\text{Potential production}}$$

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Current state of offshore wind

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Offshore wind works!

- Offshore wind parks: 30 in 10 countries
  - Operational since 1991
  - Current installed capacity: 1,500 MW
  - Global wind total: 120,000 MW+, equals over 35 million homes; US total today over 7 million homes powered by wind
  - 2,500 MW of offshore under construction
  - Over 20,000 MW in permitting offshore Europe

Source : Bluewater Wind, 2009

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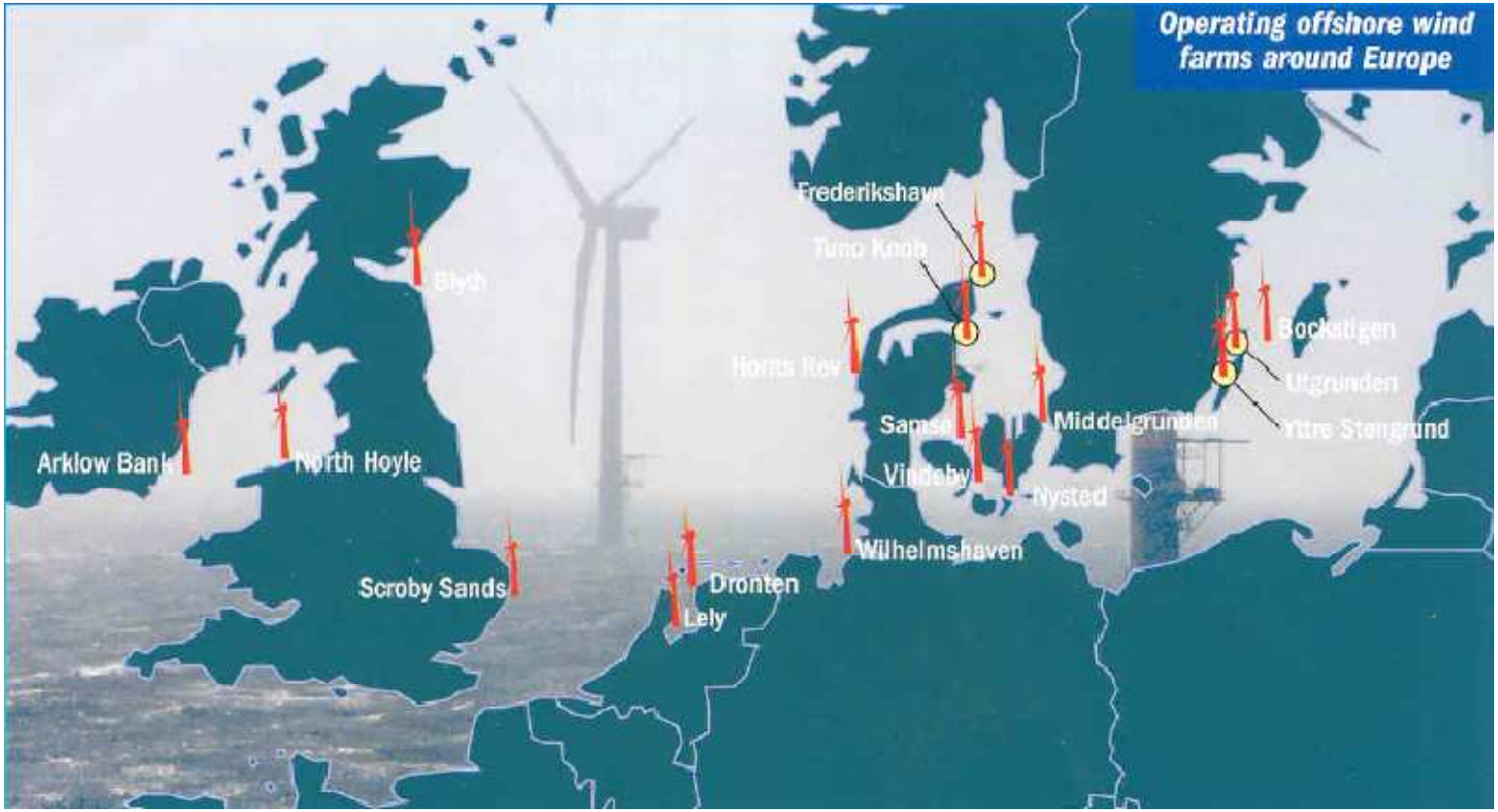
Offshore wind map



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Horns Rev (Denmark)

Operational since 2002

Distance from the coast : 14-20 km

Water depth : 6-12 m

Capacity : 160 MW (80 x 2MW)

Annual production : 600 GWh

High capacity factor (42%) !

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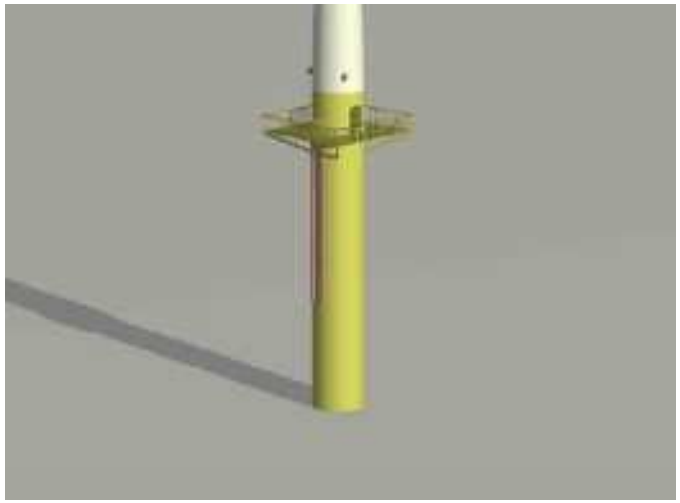
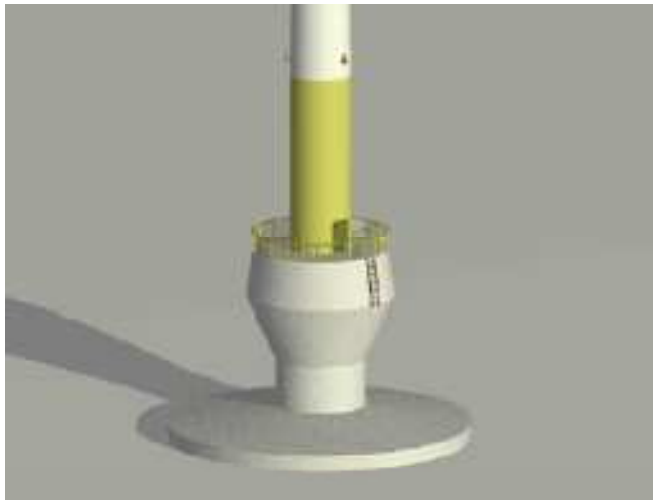
Foundation types



Monopile foundation

- Most common type
- Minimal footprint
- Low stiffness
(due to the soil composition)



Gravity foundation

- Larger footprint
- Stiffer but heavy

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Installation (1/2)

Monopile driving

Tower lifting

Nacelle lifting

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Installation (2/2)

Oh, let’s not forget the blades!

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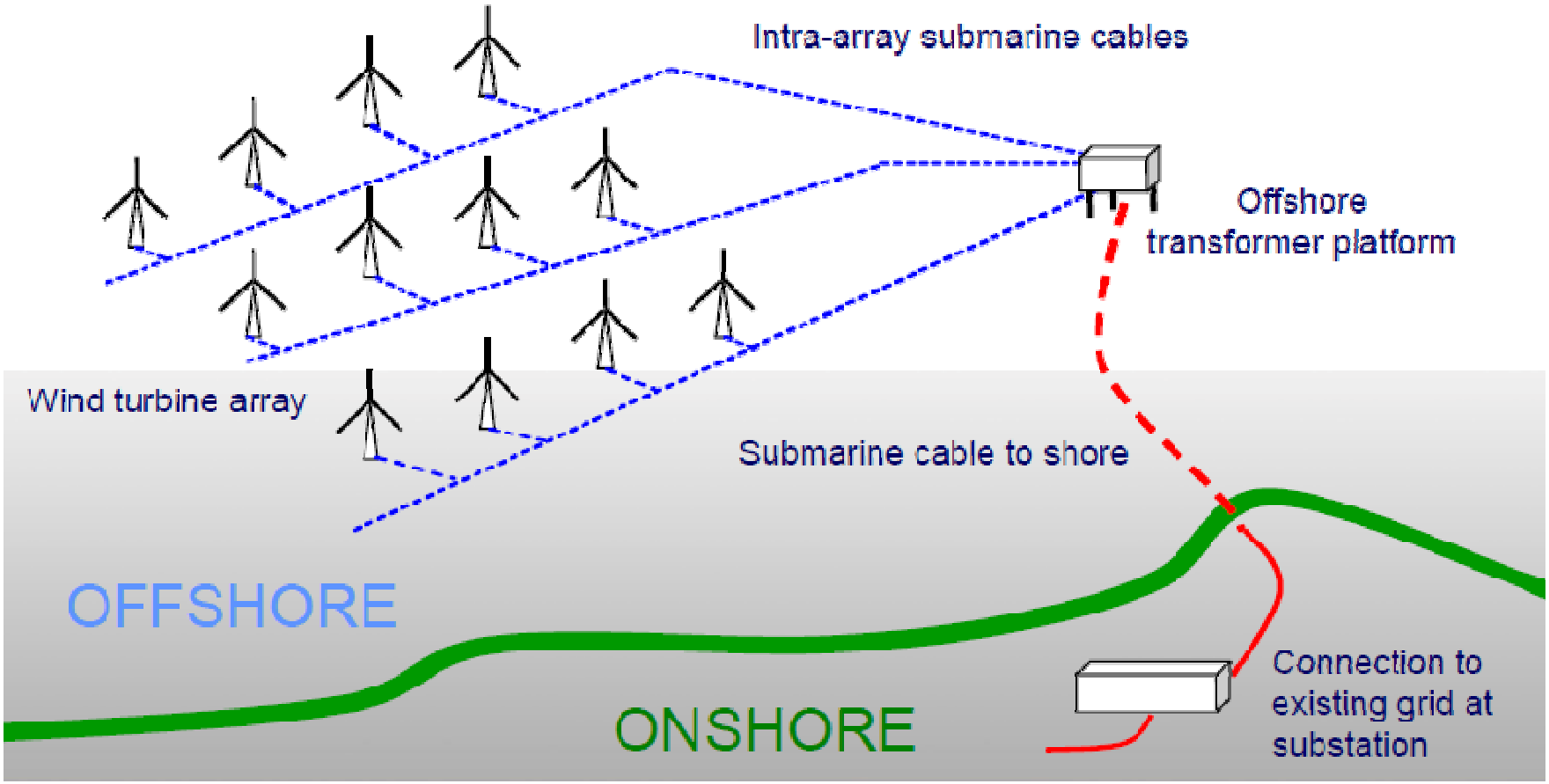
Transmission



Source : Bluewater Wind, 2009

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Proposed US sites

Total capacity ~ 3-4 GW

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Economics

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Economics – Costs

	Onshore	Offshore (bottom-mounted)
Turbine	1000 €/kW	1300 €/kW
Foundation	100 €/kW	600 €/kW
Electrical	200 €/kW	500 €/kW
Other	200 €/kW	40 €/kW
Total	**1500 €/kW**	**2540 €/kW**
O & M	15 €/MWh	30 €/MWh
Electricity cost	**6.6 - 7.3 €c/kWh**	**10 – 14 €c/kWh**

Sources:
EWEA, Wind Energy – The Facts, 2009
Windpower Monthly, Annual Power Costs comparison: What a difference a year can make, 2010

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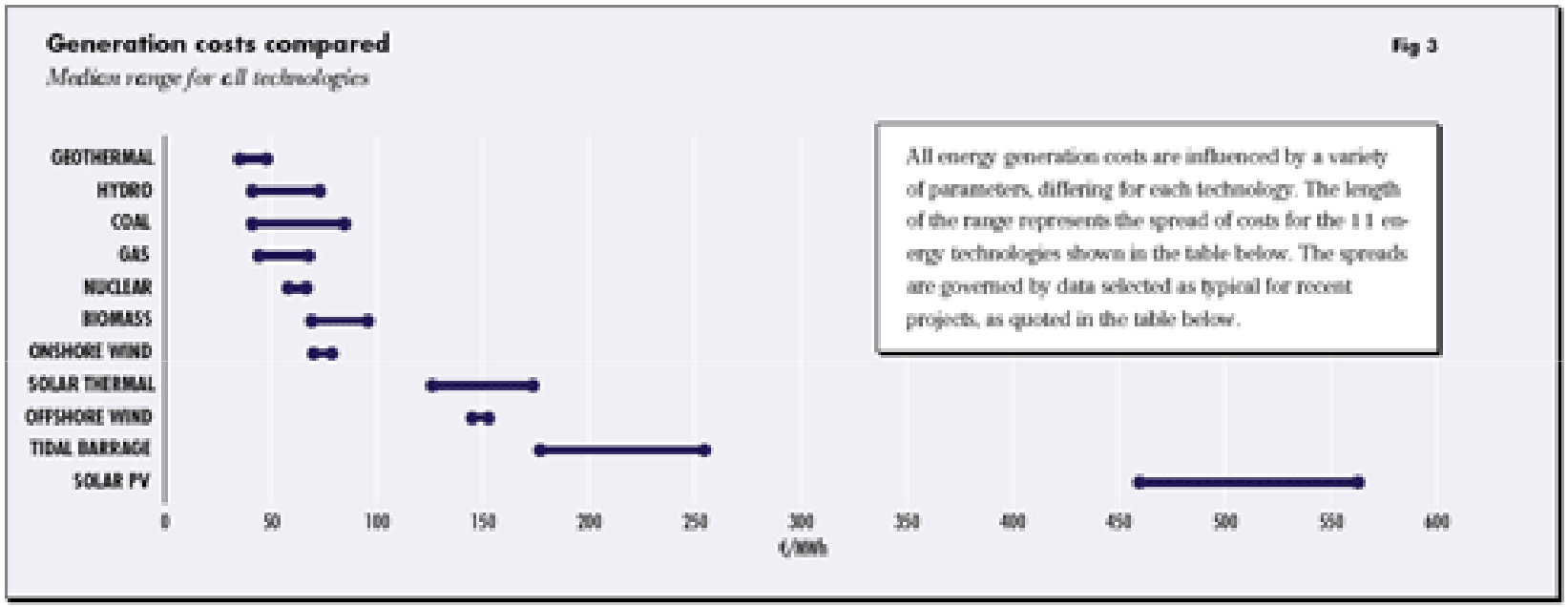
Economics – Costs



Sources:
EWEA, Wind Energy – The Facts, 2009
Windpower Monthly, Annual Power Costs comparison: What a difference a year can make, 2010

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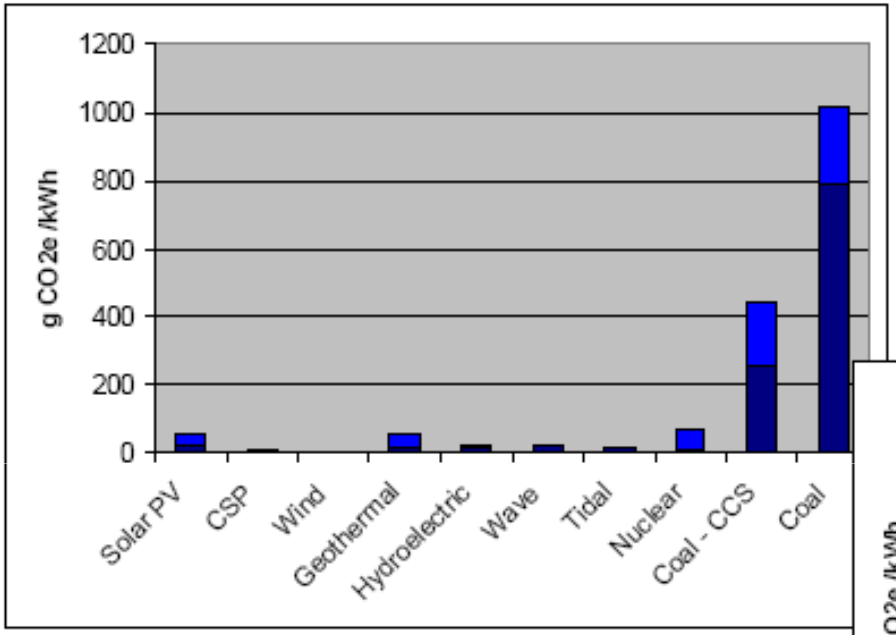
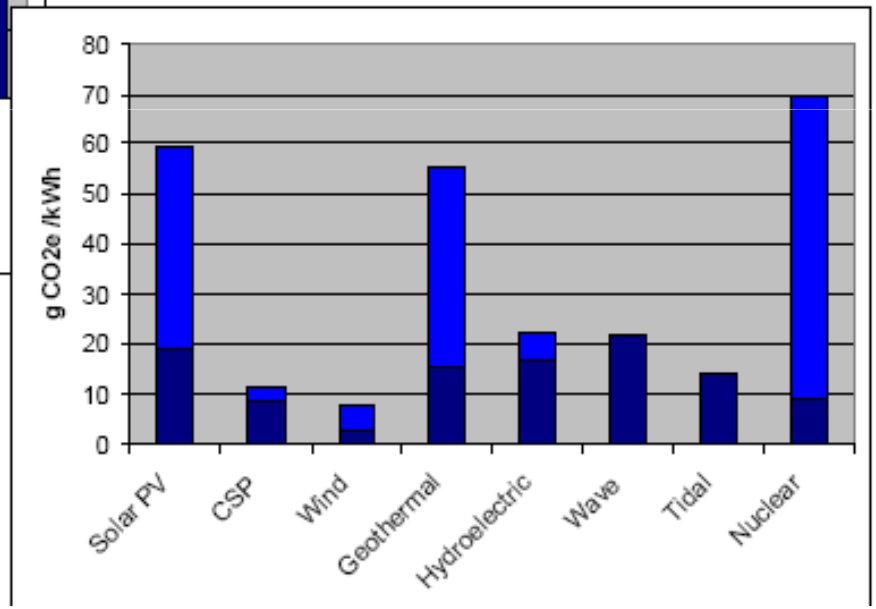
Lifecycle emissions





Source: M. Jacobson, Energy & Env. science (2009)

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From bottom-mounted to floating

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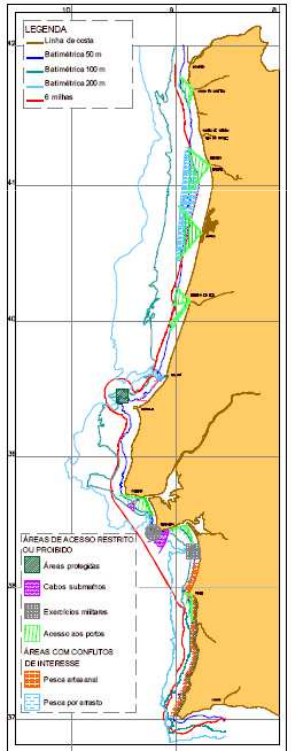
Issues with bottom-mounted

- Expensive installation

- Max water depth 30 m

Portugal water depth



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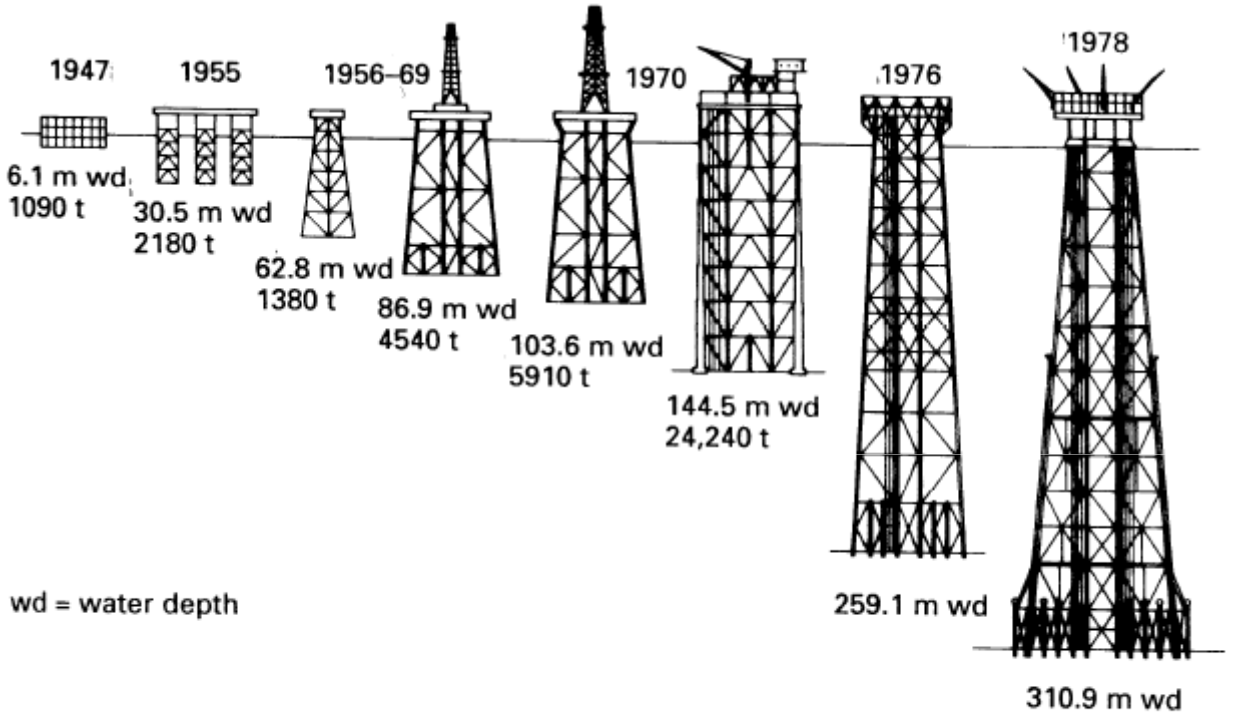
Offshore Oil since 1947



Source: Lee (1980)

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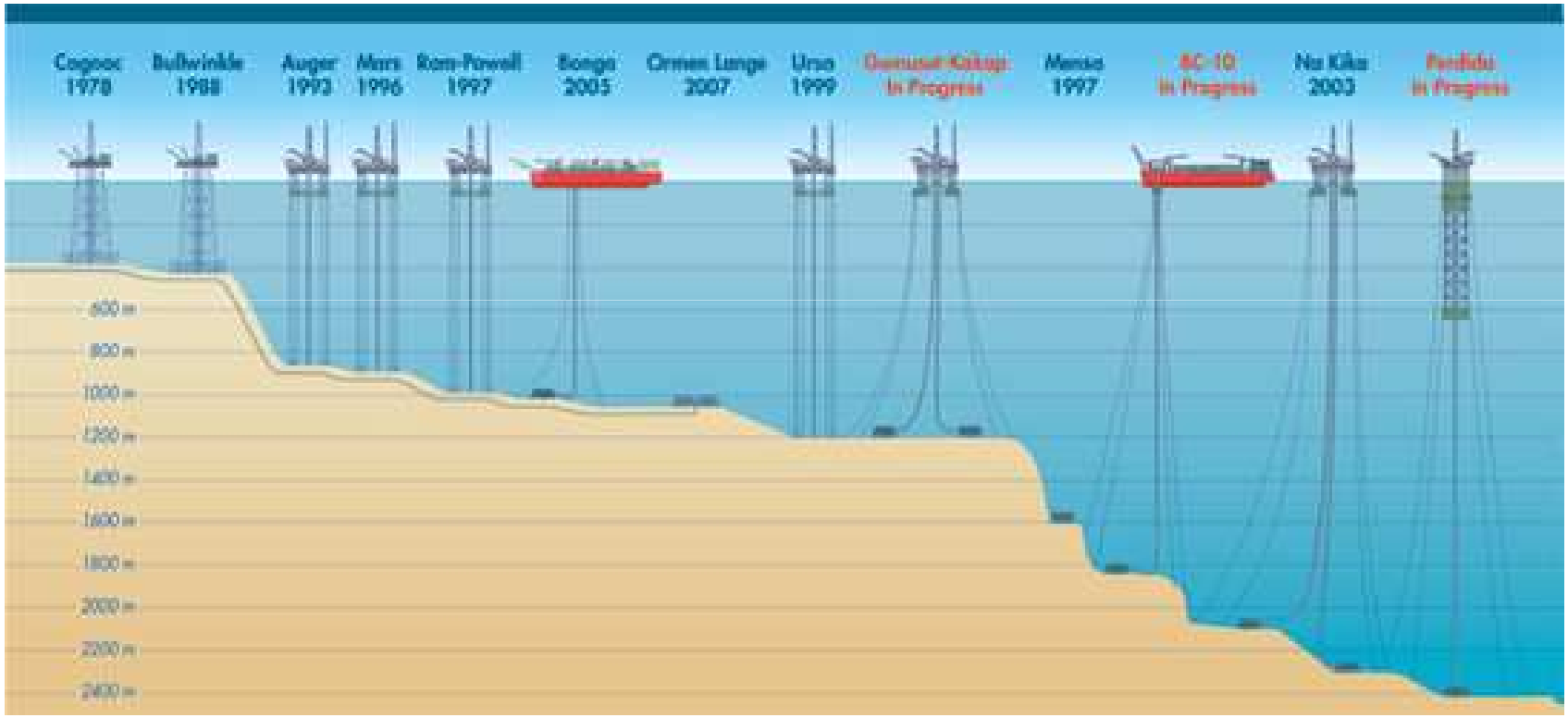
Offshore Oil since 1947

Jacket TLP FPSO Semi-Sub Spar



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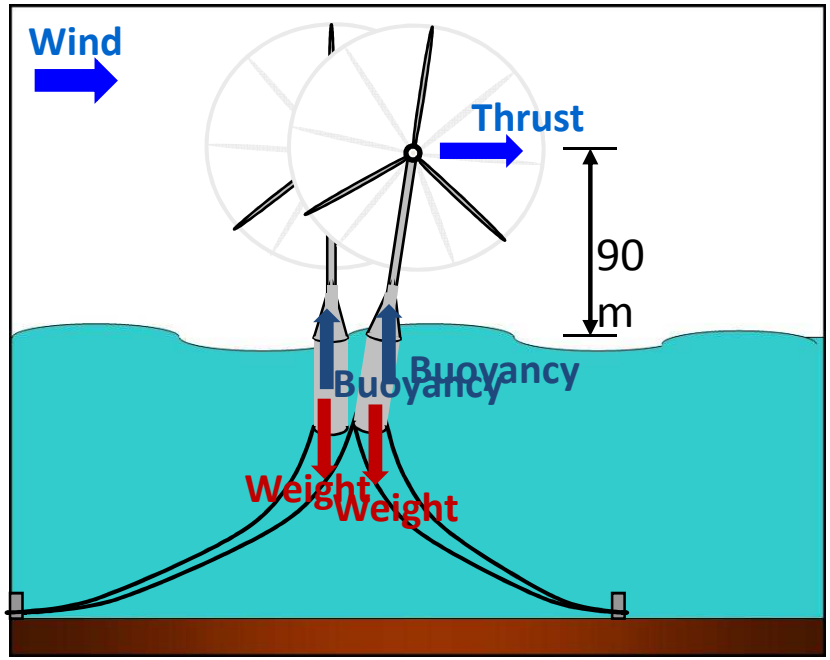
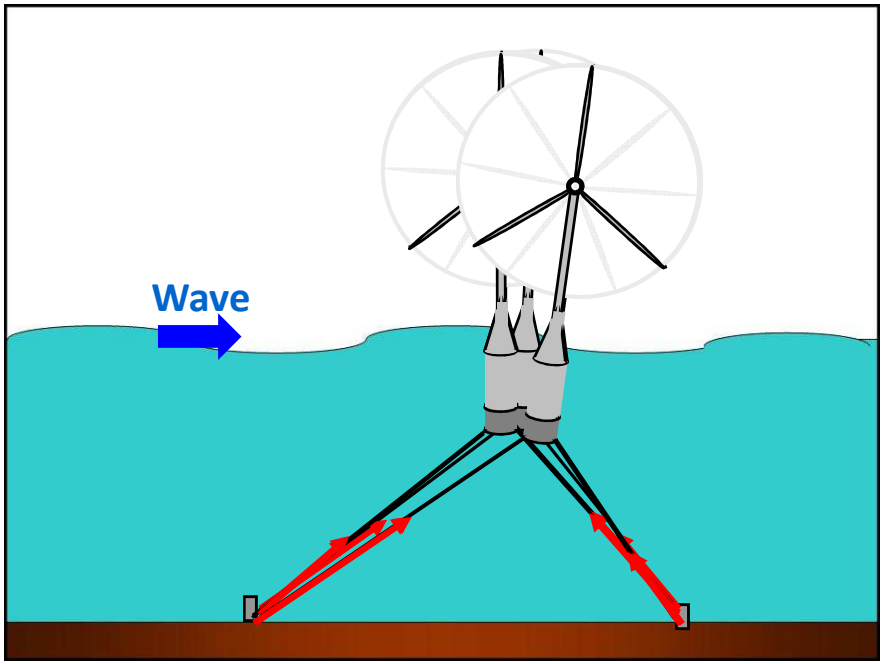
Basic principle



Wind force



Wave force

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Design criteria

- Storm survival
- Installation
- Cost

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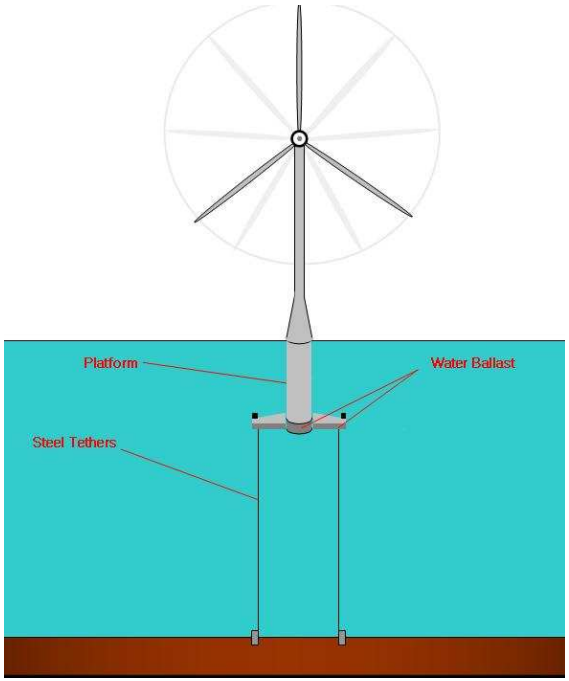
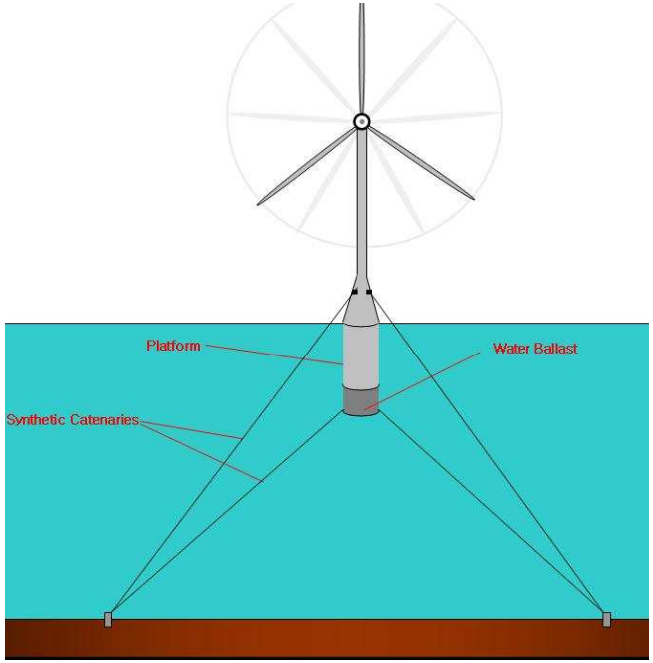
Concepts - MIT



Tension-Leg Platform



Tension-Leg Buoy

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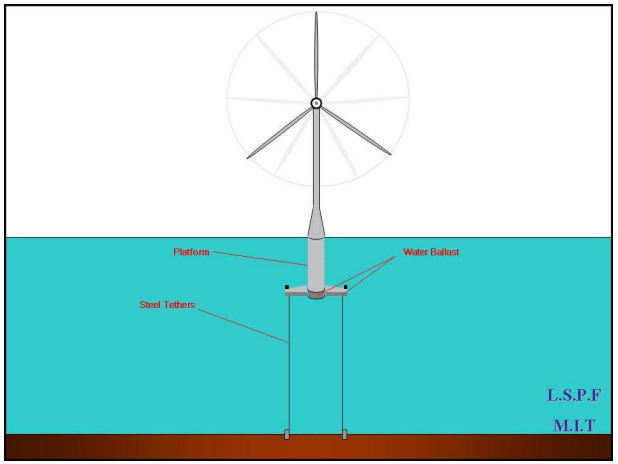
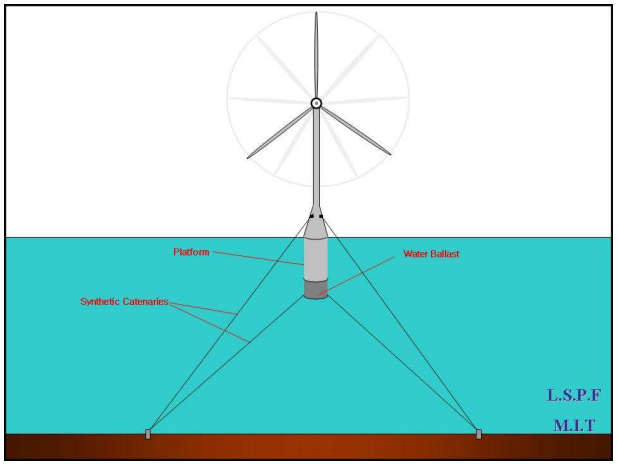
Concepts - MIT





- System stability provided by mooring lines
- Design optimization for various sea conditions
- Hydrodynamic modeling of the survival sea condition, 100 year storm
- Control system design of the turbine blades

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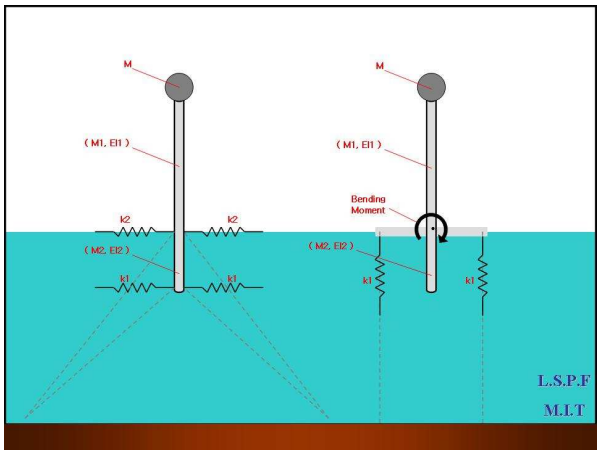
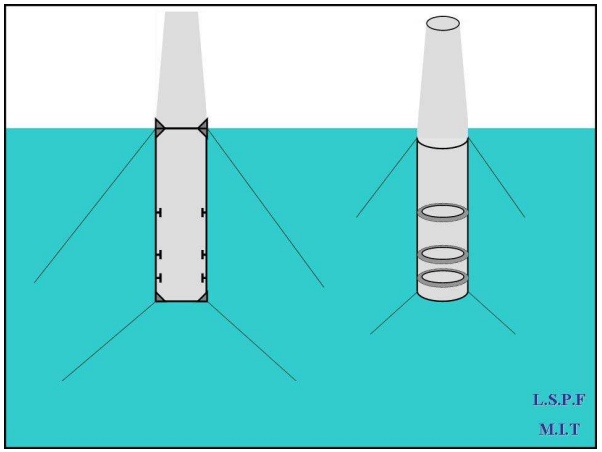
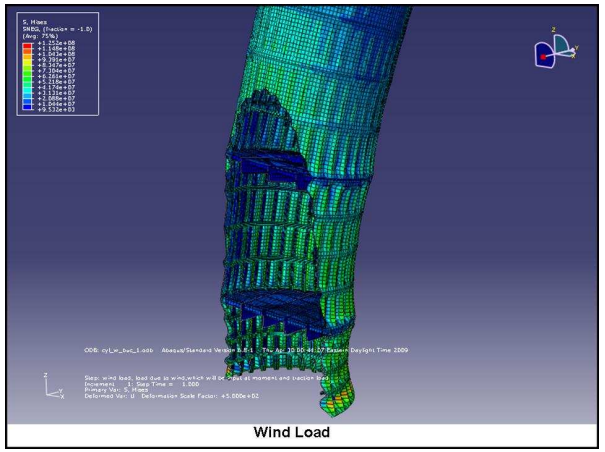
Concepts - MIT





- Flexural vibration analysis of the turbine tower
- Structural analysis of the floating platform


Wind Load

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Concepts – Hywind

- Developed by Statoil
- Prototype installed offshore Norway in 2009
- Spar buoy design
- Commercial plans: North Sea – oil platform electricity and utility-scale wind farms

Statoil

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Concepts – Hywind

65 m

100 m

Siemens 2.3MW
offshore turbine

↓

5MW for commercial application

Spar buoy

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Concepts – Hywind

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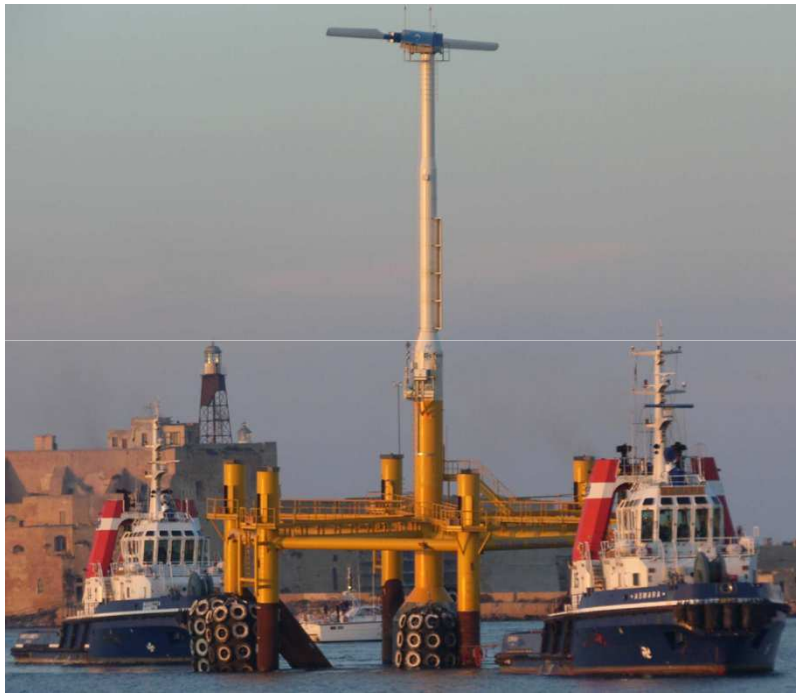
Concepts – Blue H

- Tension-Leg Platform design
- Two-blade 2MW turbine
- Small-scale prototype offshore Italy in 2008
- Plans for full-scale prototype near Martha's Vineyard
- Commercial deployment planned offshore Italy



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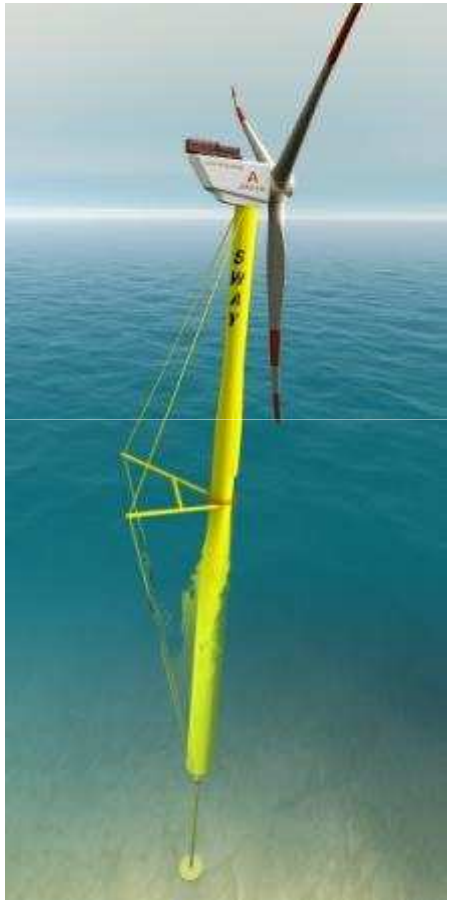
Concepts – Sway

- Downwind tower with single tensioned mooring line
- New 10MW turbine from Areva-Multibrid
- Concession for full-scale prototype offshore Norway granted in Nov 2009



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Concepts – Windfloat

- Developed by Principle Power
- Semi-submersible with dynamic ballast system
- Design phase, plans for commercial deployment offshore Portugal

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Challenges & Future trends

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Challenges & Future trends

- Installation

Turbine Installation Vehicle

Deep-water yards

Hywind tow-out

Windflip concept

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Challenges & Future trends

- Installation
- Marine operations

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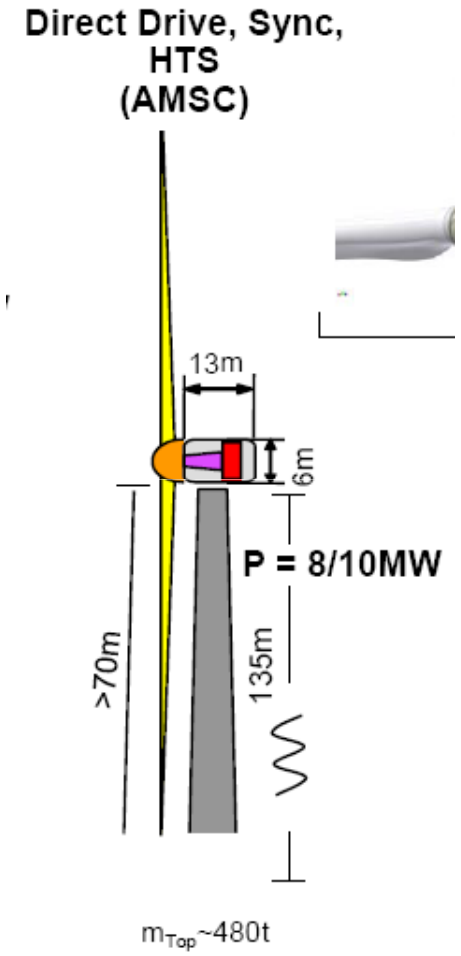
Challenges & Future trends

- Installation
- Marine operations
- Next generation turbines for offshore

Multibrid downwind



AMSC direct drive

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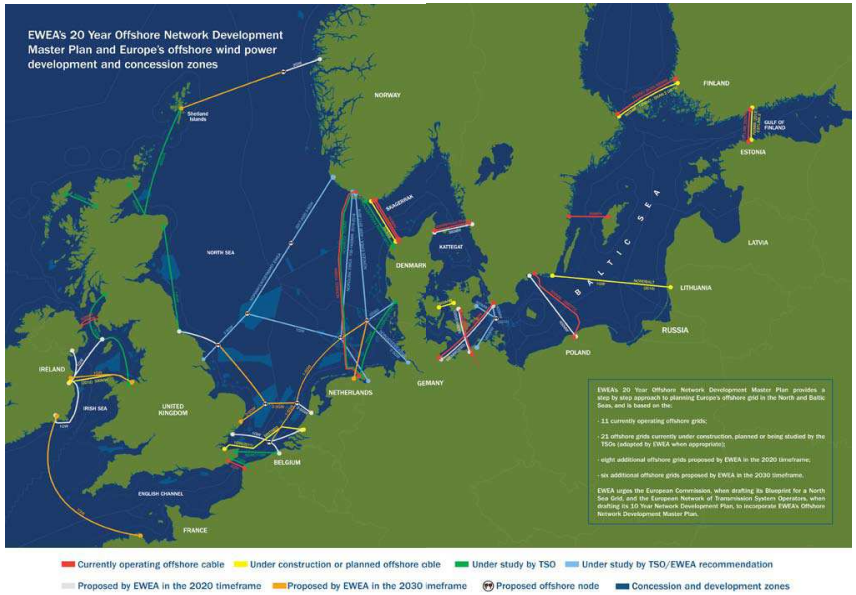
Challenges & Future trends

- Installation
- Marine operations
- Next generation turbines for offshore
- Grid development



Source: EWEA

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Thank you!

Now (7pm): Join us at the Energy club social in the R&D pub
(4th floor of Stata center)

Tomorrow:
Energy discussions: Offshore wind policy & Cape Wind
12-1pm
4-145

Friday March 5th :
Meet us at the MIT Energy conference showcase

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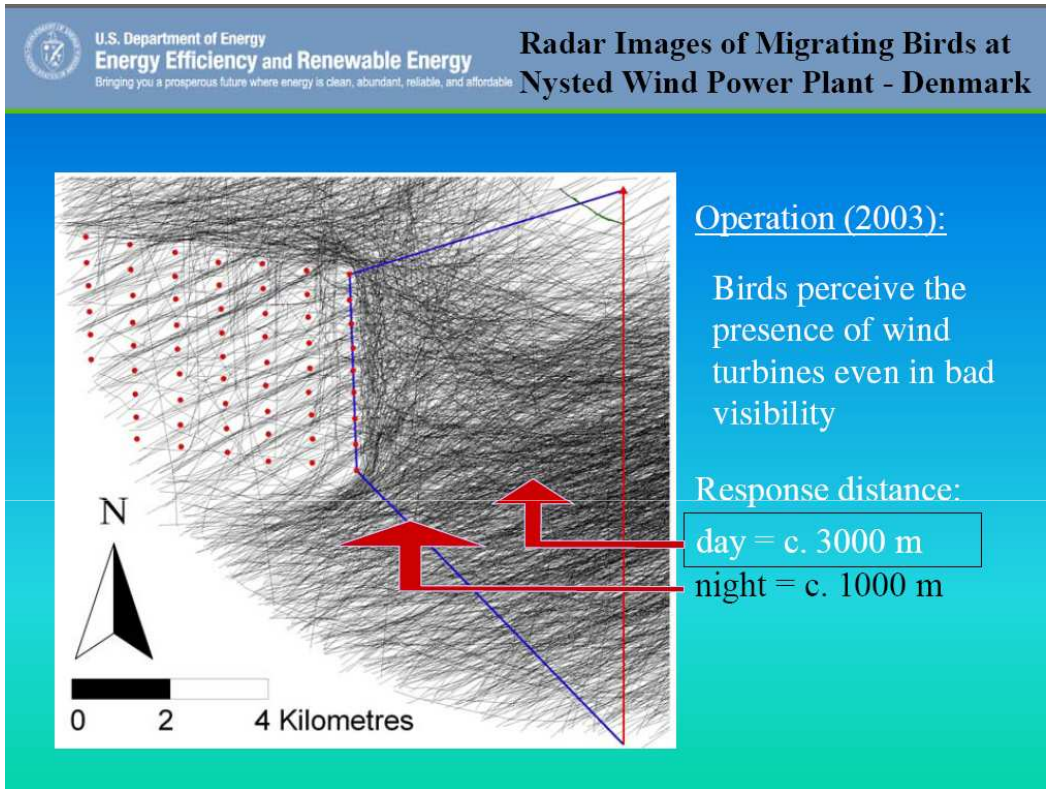
Birds



Source: NREL

- "Avian Collisions with Wind Turbines: A Summary of Existing Studies and Comparisons to Other Sources of Avian Collision Mortality in the United States," (2001): 2.19 bird deaths/turbine/year
- in US: 100 million to 1 billion birds collide with windows/year
- 100 million with cars and trucks

Fish and marine life

See *Effects of marine windfarms on the distribution of fish, shellfish and marine mammals in the Horns Rev area (2000)*

- Short-term: disturbed
- Long-term: positive effects: - safe haven – artificial reef effect
- Noise: very low-frequency
- Magnetic field: confined to 1m

Turbines

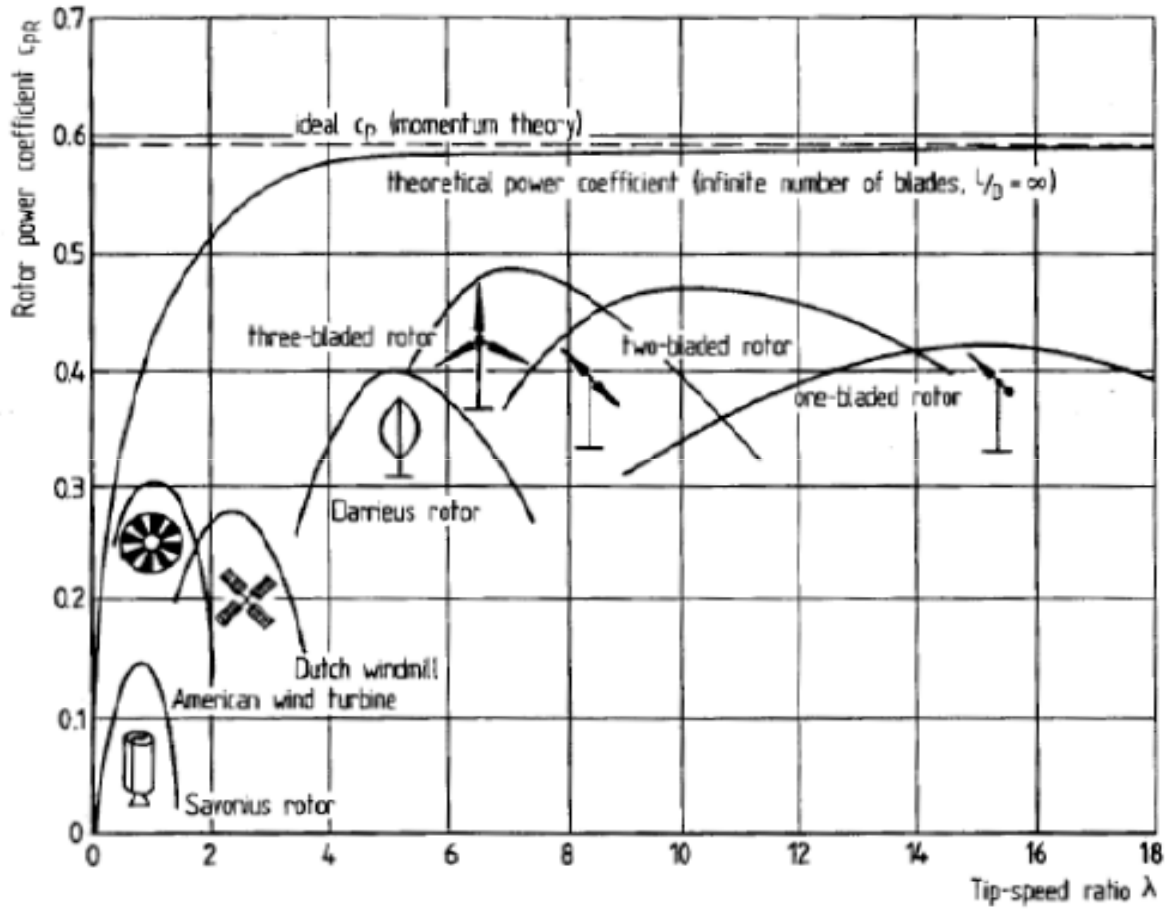
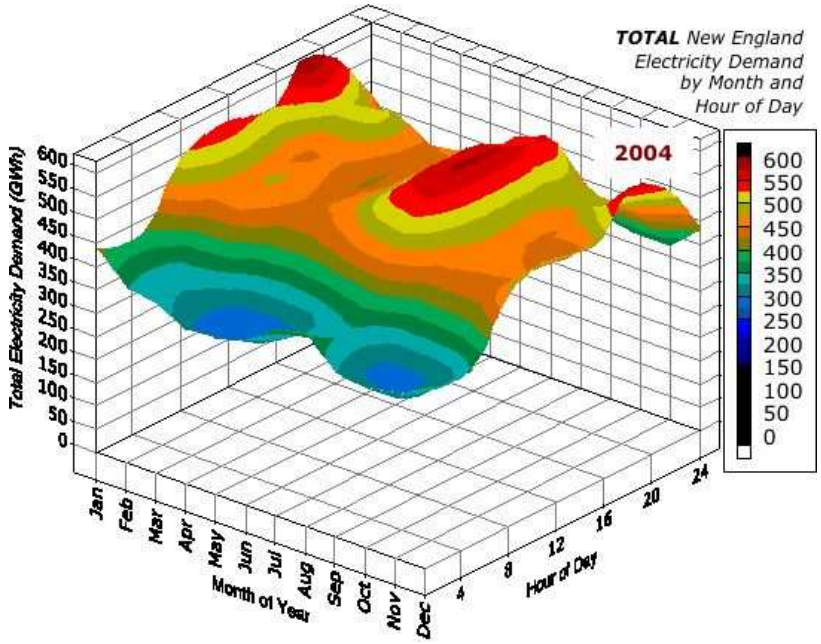


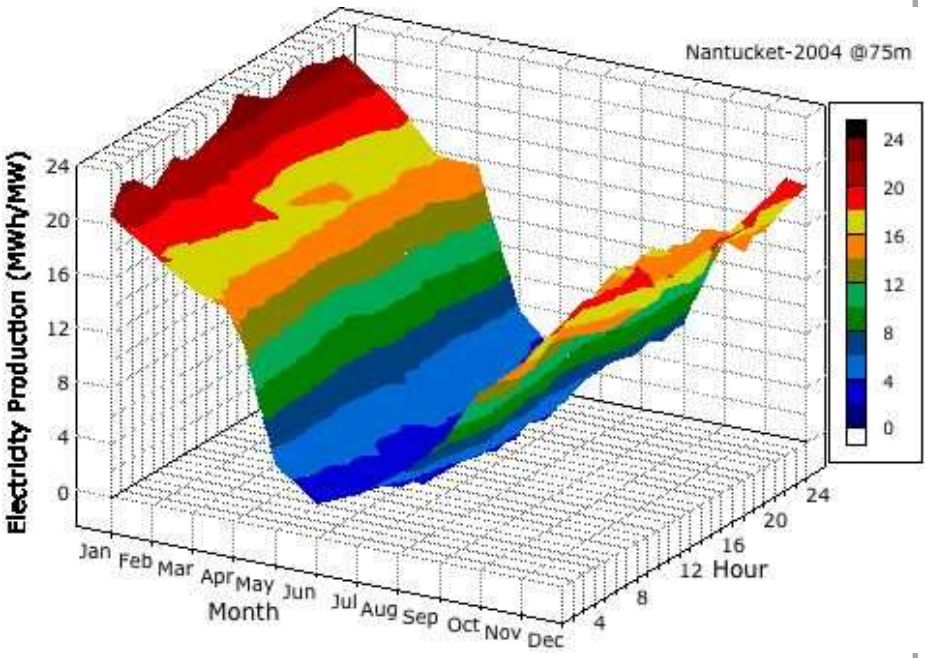
Fig. 5.10. Power coefficients of various of wind rotors [2]

- two-bladed?
- downwind?
- direct-drive?
- vertical axis?

Grid integration



New England electricity demand



Potential wind generation, Nantucket

1: Graphics Courtesy of Steve Connors, MIT Energy Initiative

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Grid integration