Floating Wind Turbines

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Power in the Wind

$$E_k = \frac{1}{2} m v^2$$

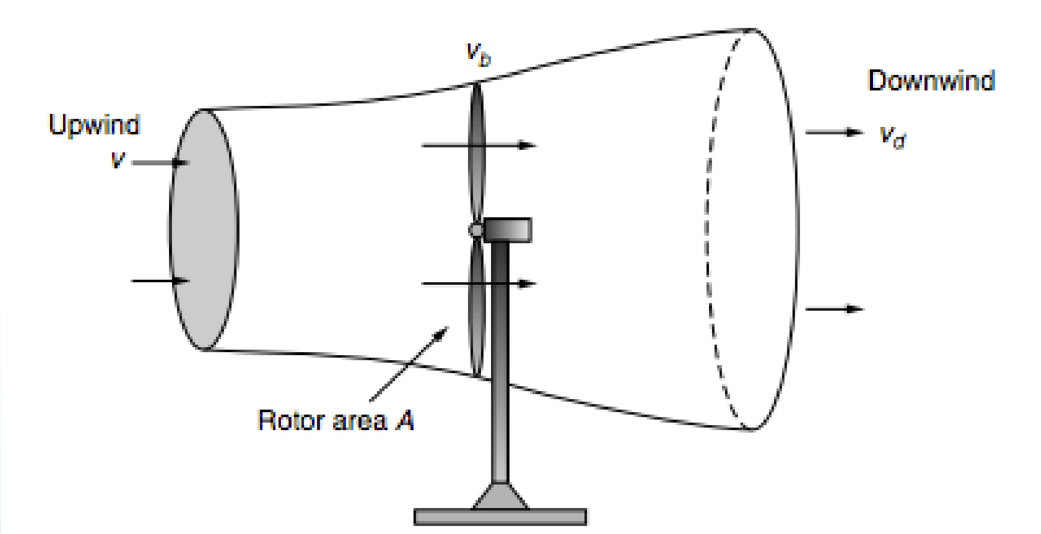
$$P = \frac{Energy}{time} = \frac{(\frac{1}{2} m v^2)}{time} = \frac{1}{2} \frac{m}{time} v^2$$

mass going through area, A:

$$\frac{m_A}{time} = \rho A v$$

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

Extractable Power



Power extracted by the blades:

$$P_b = \frac{1}{2} m (v^2 - v_d^2)$$

Wind speed at rotor:

$$v_b = \frac{v + v_d}{2}$$

$$P = \frac{1}{2}\rho A v_b (v^2 - v_d^2) = \frac{1}{2}\rho A \frac{v + v_d}{2}(v^2 - v_d^2)$$

Assume $\lambda = \dfrac{v_d}{v}$

$$P = \quad \frac{1}{2}\rho A v^3 \quad (\frac{1}{2}(1+\lambda)(1-\lambda)^2)$$

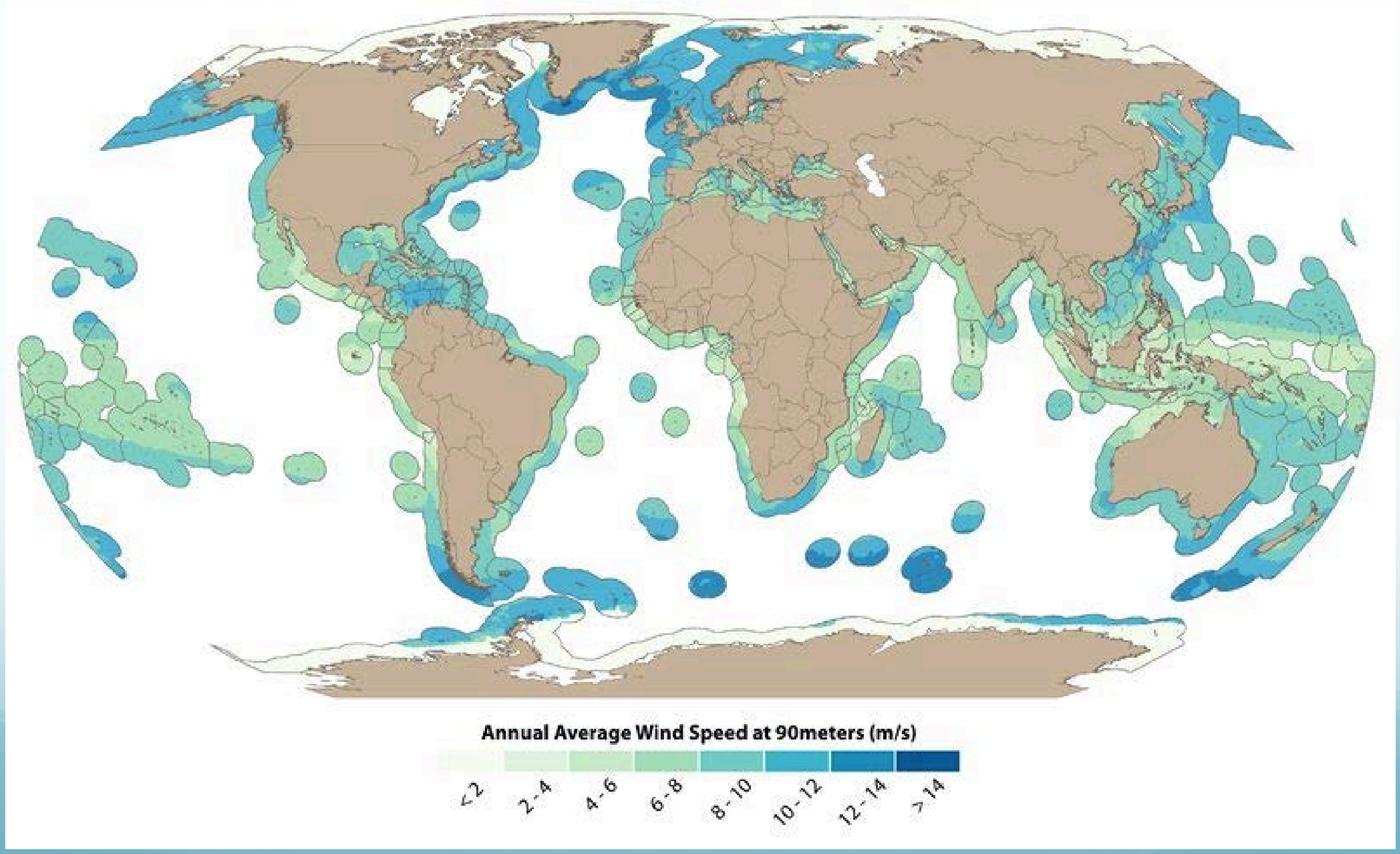
$P =$ Power in the wind $\times$ Blade Efficiency

Power- Betz Limit

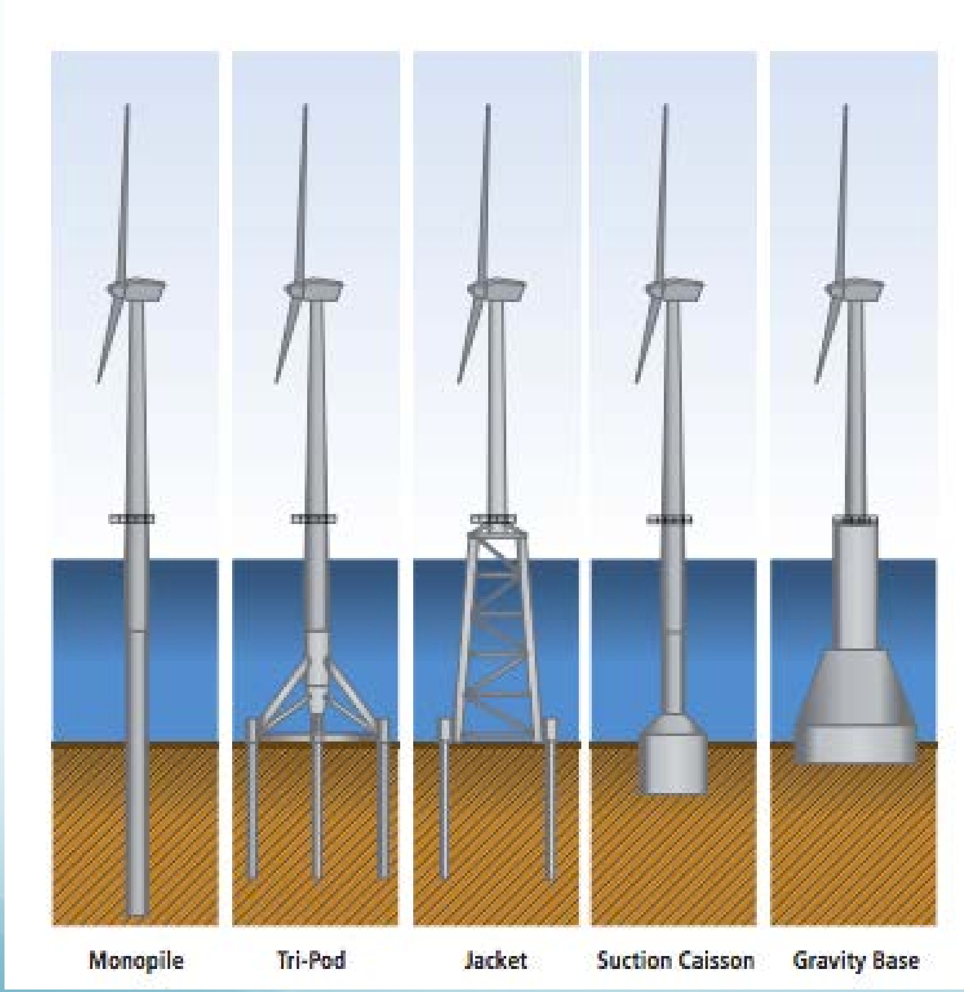
- To find maximum possible efficiency, take the derivative of blade efficiency with respect to lambda and set equal to zero
- Comes out to 59.3%

Taking it Offshore

- Construction of wind farms in bodies of water to generate electricity from wind



Traditional Fixed Bottom



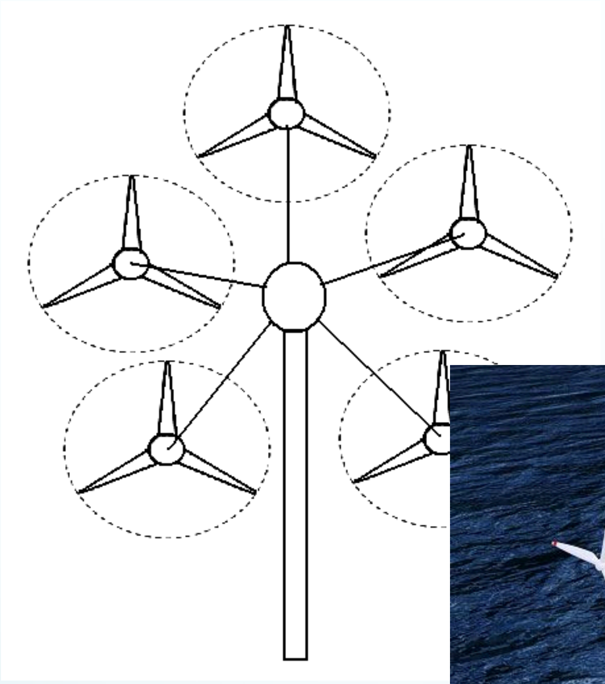
- 20-80m deep
- Expensive

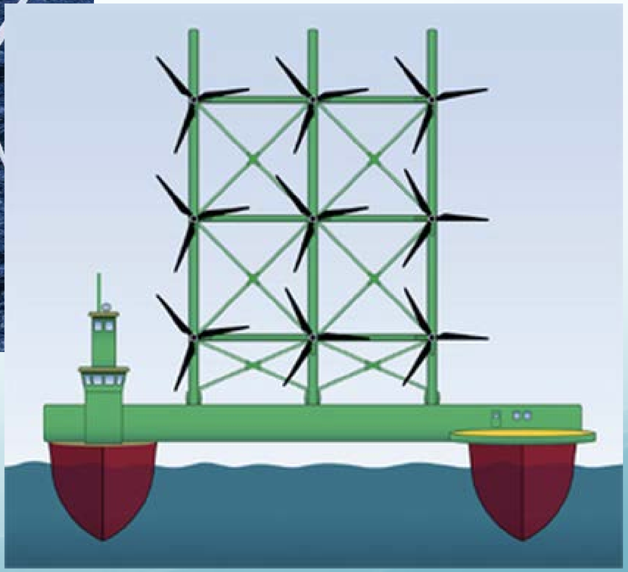
Floating Wind Turbines

Topologies

- Single-turbine floater
  - Simplicity
  - Lower structural requirements
  - Standard yaw control options
  - Individual anchor costs
- Multiple-turbine floater
  - Wave stability
  - Shared anchors
  - Mass optimization
  - High cost support structure
  - Complex yaw control

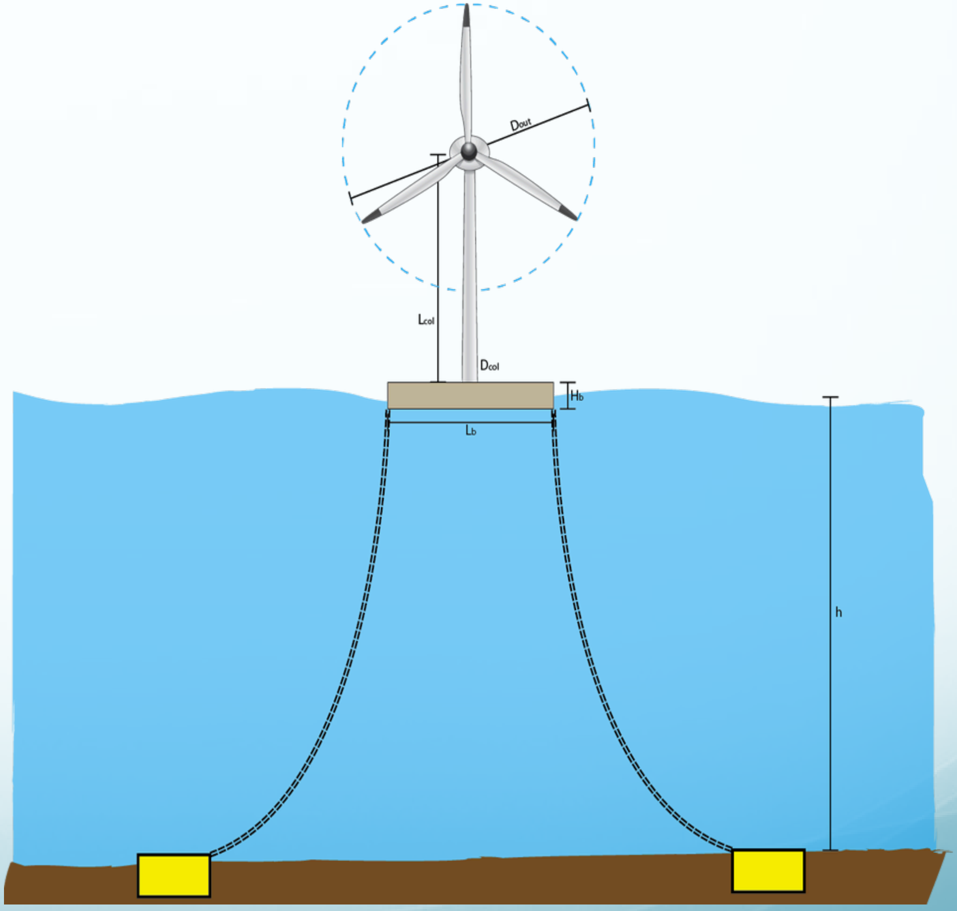
Multiple-turbine Floater





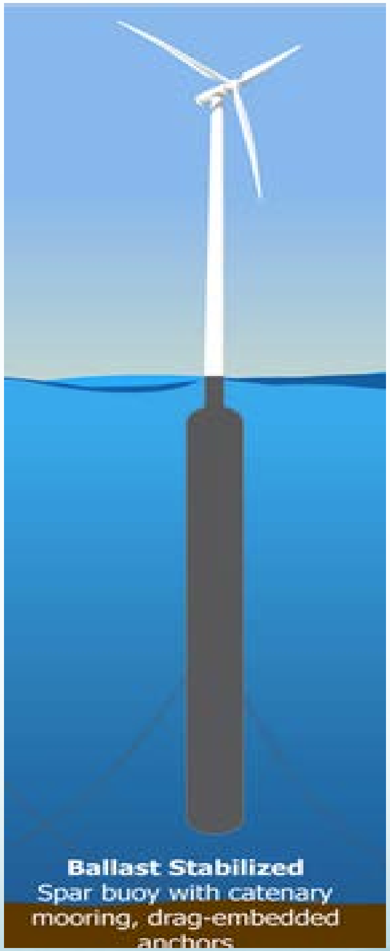
Buoyancy Stabilized Platform

- Stabilization in the platform (barge)
- Catenary mooring
- Drag-embedded anchors



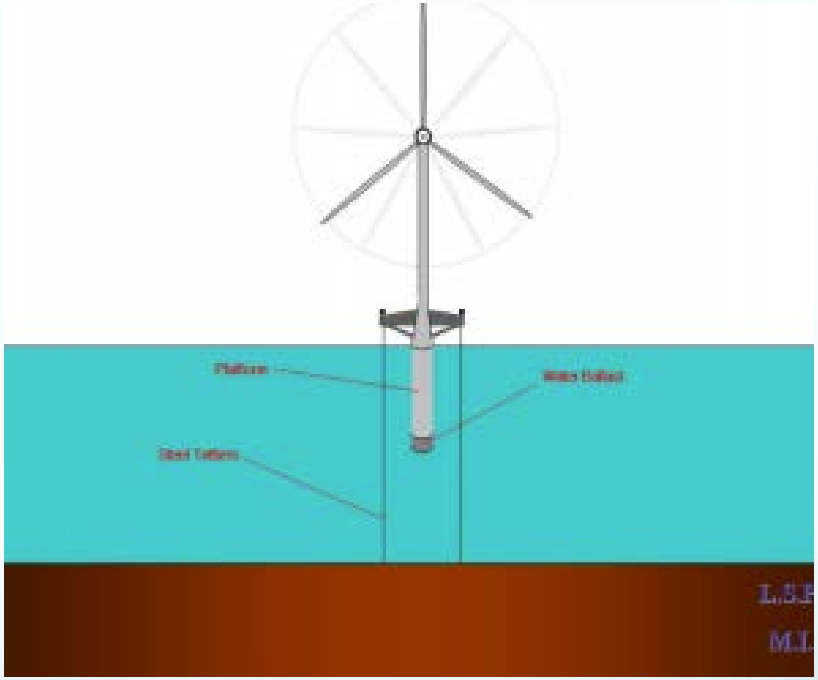
Ballast Stabilized

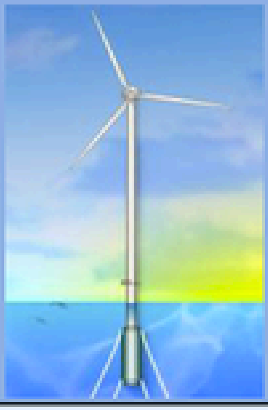
- Spar buoy
- Catenary mooring
- Drag-embedded anchors



Tension Leg Platform/Mooring Line Stabilized Platform

- Inspired by the same concept developed in the oil industry
- Suction pile anchors
- Buoy chosen such that the tethers do not go slack in a 3 hour seastate with a 98% probability
- Minimum footprint and wave sensitivity



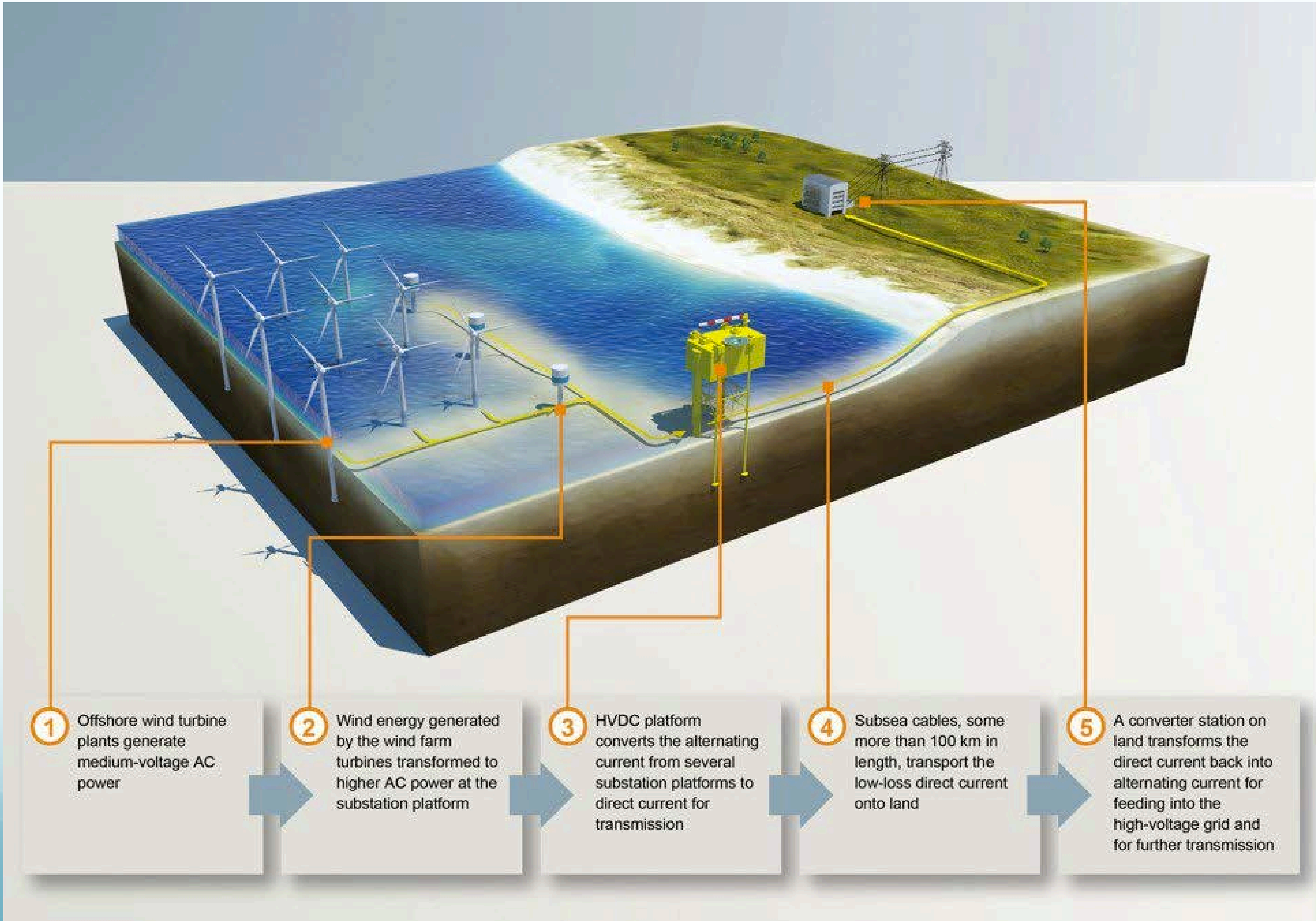
+ relative advantage **0 neutral** **– relativedisadvantage**	**TLP** 	**Spar** 	**Barge** 
Pitch Stability	Mooring	Ballast	Buoyancy
Natural Periods	+	0	–
CoupledMotion	+	0	–
Wave Sensitivity	0	+	–
TurbineWeight	0	–	+
Moorings	+	–	–
Anchors	–	+	+
Construction & Installation	–	–	+
Maintenance	+	0	–

Stability

- Designed to not bob
- Only shift 3-6 feet
- Blades will still be above peak of highest wave
- Dampers to reduce sideways motion

HVDC

- AC technology reached its limits
- AC to DC to AC
- 80 to 600 kilometers
- Converter stations closer to shore and have small station footprint and low weight
- Losses < 4%


1
Offshore wind turbine plants generate medium-voltage AC power
2
Wind energy generated by the wind farm turbines transformed to higher AC power at the substation platform
3
HVDC platform converts the alternating current from several substation platforms to direct current for transmission
4
Subsea cables, some more than 100 km in length, transport the low-loss direct current onto land
5
A converter station on land transforms the direct current back into alternating current for feeding into the high-voltage grid and for further transmission

Benefits

- Reduced pollution
- Deep waters/further from shore
- Lower costs
- Assembled onshore
- 20% higher wind speeds leading to 70% greater energy yield

Economics

- For a 1 GW Farm:
  - 200 units
  - 10cents/kWh
  - $400 million annual revenue
  - Breakeven cost versus CCGT
    - $3 million to $9-15 million (Natural gas price projections)
  - Capable to transfer electricity up to 120km
  - Emits 300Kg/CO2/MWh compared to 1ton Co2/MWh for coal plants

July 2014 (Siemens)

Typical annual yields			
	Inland	**Coastal** (onshore)	**Offshore**
2.3 MW turbine	7 GWh	9 GWh	–
3.6 MW turbine	–	12 GWh	18 GWh
6.0 MW turbine	–	23 GWh	31 GWh

Concepts

- Ideol
  - New floating platform concept using mechanical and software solutions
- Nautica Windpower
  - Reduce weight, complexity and costs for deepwater
- OC3-Hywind
  - Depths of 320 meters

Recent News

- November 5th, 2015: Scotland approves world's largest floating wind farm
  - 6MW turbines, 25km offshore
  - 20,000 households
- November 7th, 2015: California's first offshore wind farm proposed near Hearst Castle (halfway between LA and SanFran

References

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