

An aerial photograph of the ocean surface, showing deep blue water with white-capped waves and ripples. A large white circle is positioned on the left side of the image, containing the text 'MARINE RENEWABLE ENERGY' in a bold, dark blue, sans-serif font. Below the text is a short horizontal line.

MARINE RENEWABLE ENERGY

INTRODUCTION TO MARINE RENEWABLE ENERGY

DEFINITION AND SIGNIFICANCE OF MARINE RENEWABLES

Sources of Marine Energy

Marine renewables include energy from offshore wind, waves, tides, ocean temperature gradients, and salinity gradients.

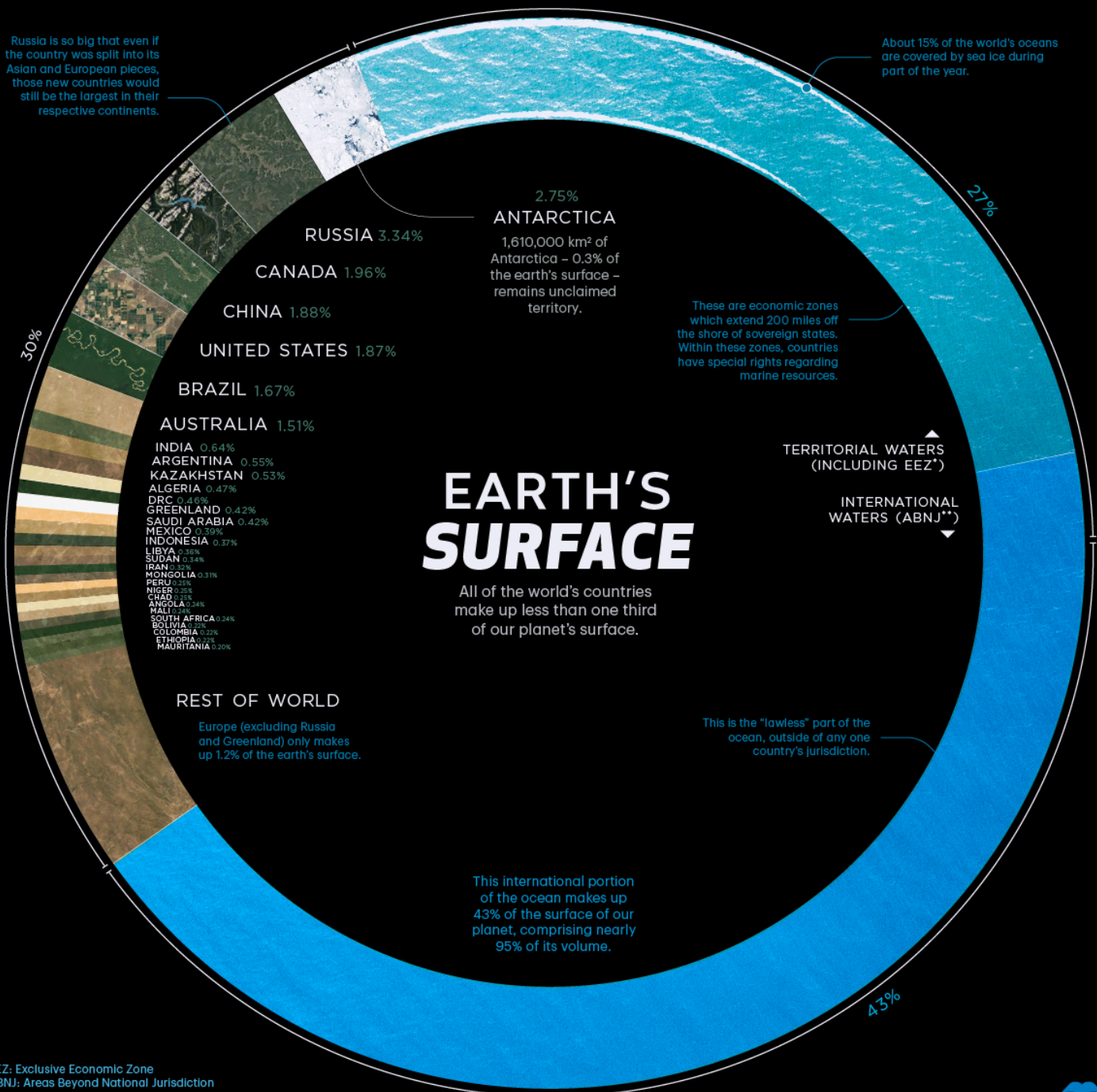


DEFINITION AND SIGNIFICANCE OF MARINE RENEWABLES

Abundance and Sustainability

These oceanic resources are abundant and sustainable, offering a reliable source of clean energy.





Oceans cover over 70% of Earth's surface, representing a vast area for renewable energy exploitation.

WIND ENERGY

Wind is a form of solar energy caused by a combination of three concurrent events:

- The sun unevenly heating the atmosphere
- Irregularities of the earth's surface
- The rotation of the earth.



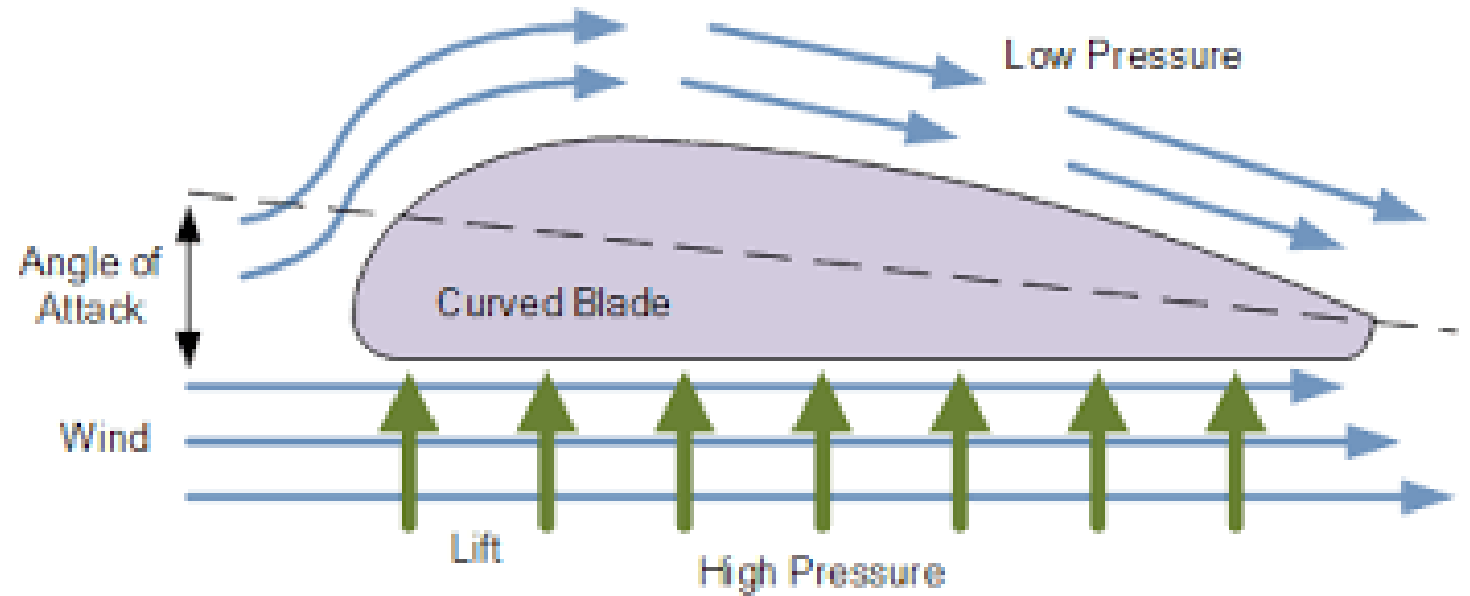
WIND ENERGY

- A wind turbine converts wind energy into electricity using the aerodynamic force from the rotor blades, which work like an airplane wing or helicopter rotor blade.



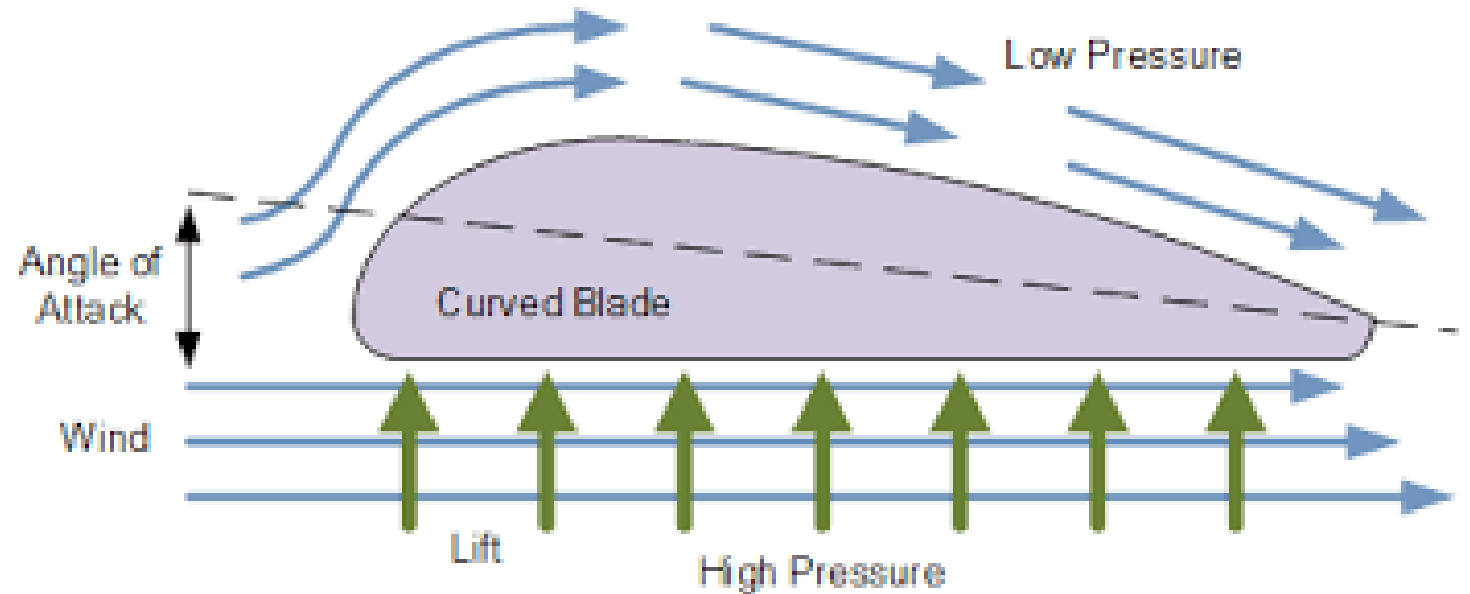
WIND ENERGY

- When wind flows across the blade, the air pressure on the curved side of the blade decreases.



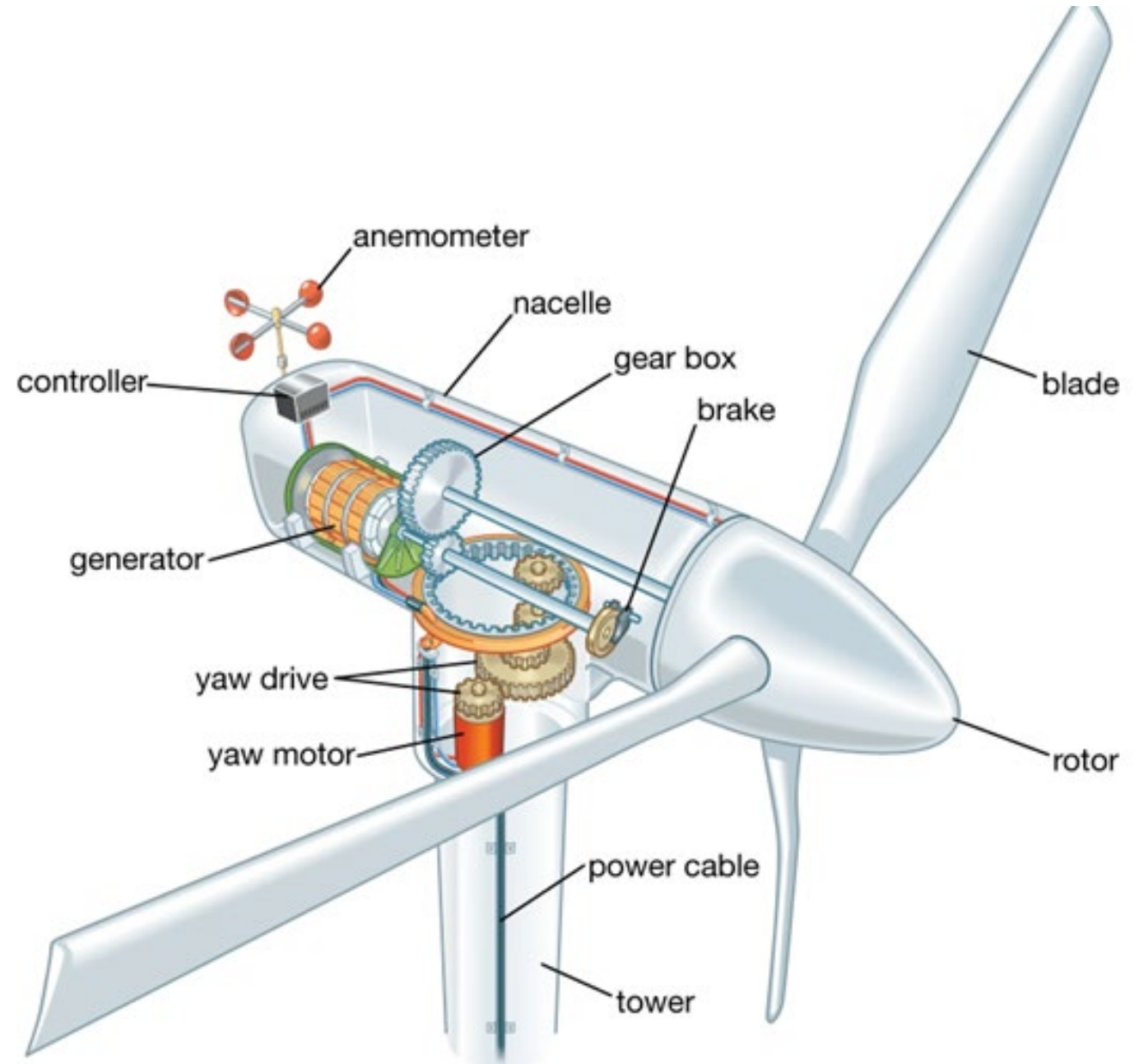
WIND ENERGY

- The difference in air pressure across the two sides of the blade creates both lift and drag. The force of the lift is stronger than the drag and this causes the rotor to spin.



WIND ENERGY

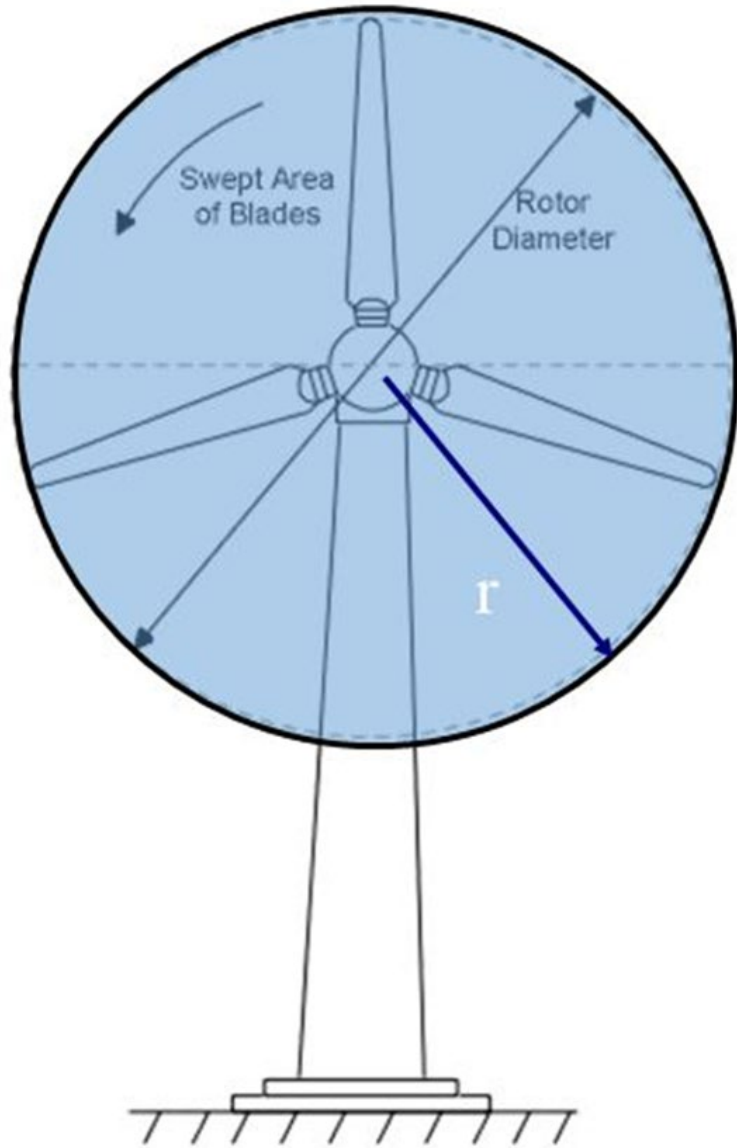
- The rotor connects to the generator, either directly (if it's a direct drive turbine) or through a shaft and a series of gears (a gearbox) that speed up the rotation and allow for a physically smaller generator.



HORIZONTAL AXIS

- Most commonly, they have three blades and operate "upwind," with the turbine pivoting at the top of the tower so the blades face into the wind.





WIND ENERGY

The potential power in the wind is given by the following equation:

$$Power (W) = \frac{1}{2} \rho A v^3$$

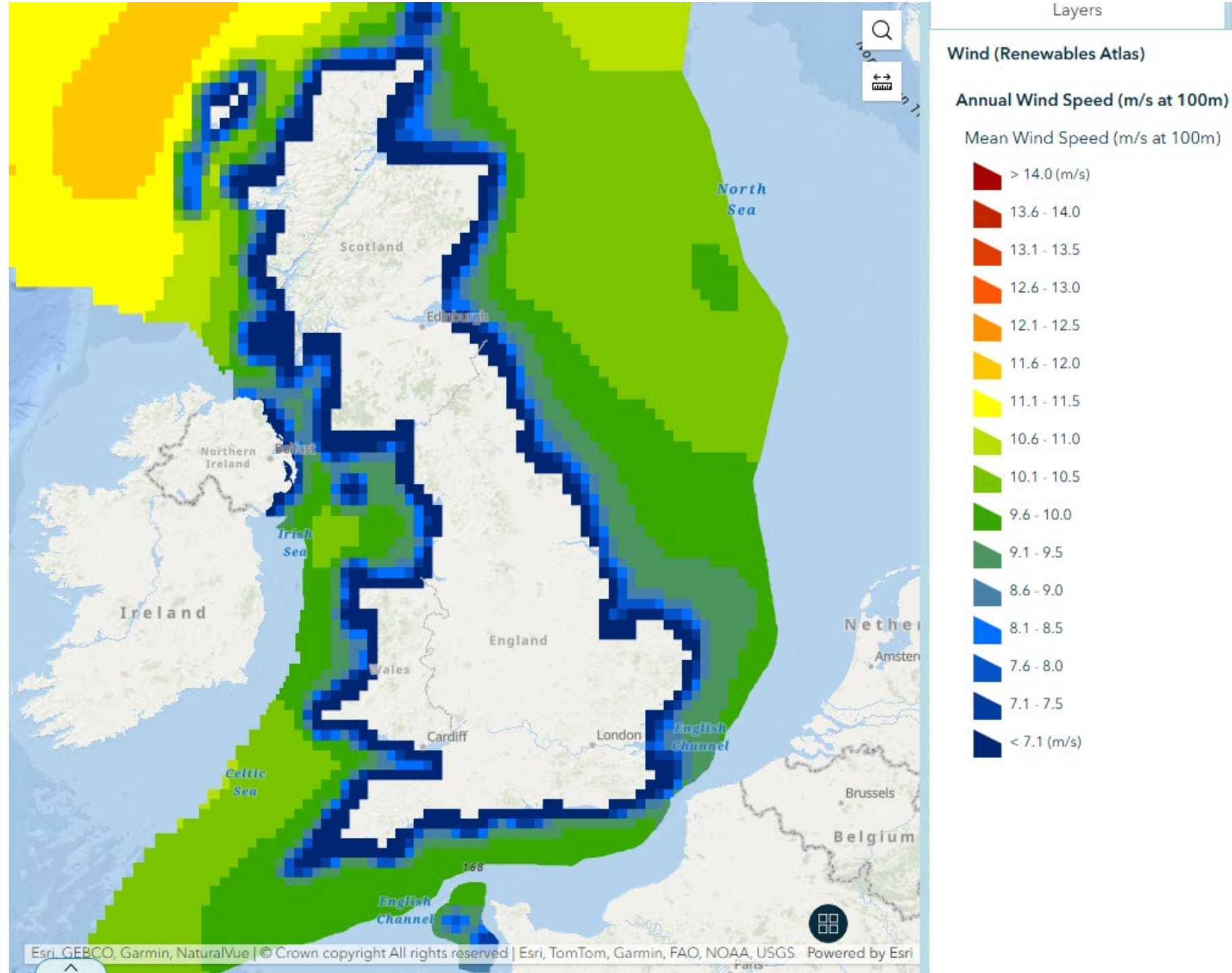
Power = Watts

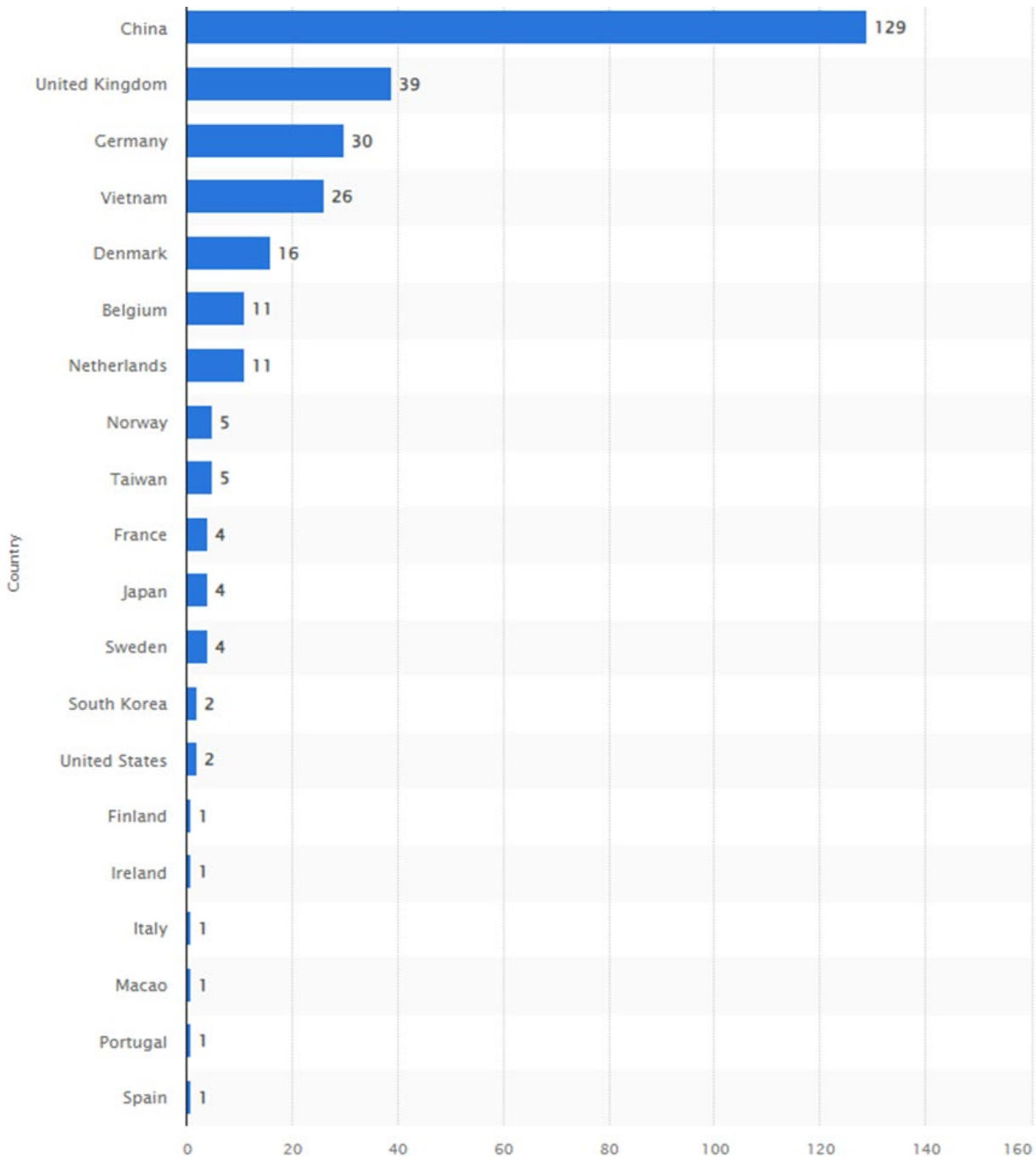
ρ = density of the air in kg/m^3

A = cross-sectional area of the wind turbine in m^2

v = velocity of the wind in m/s

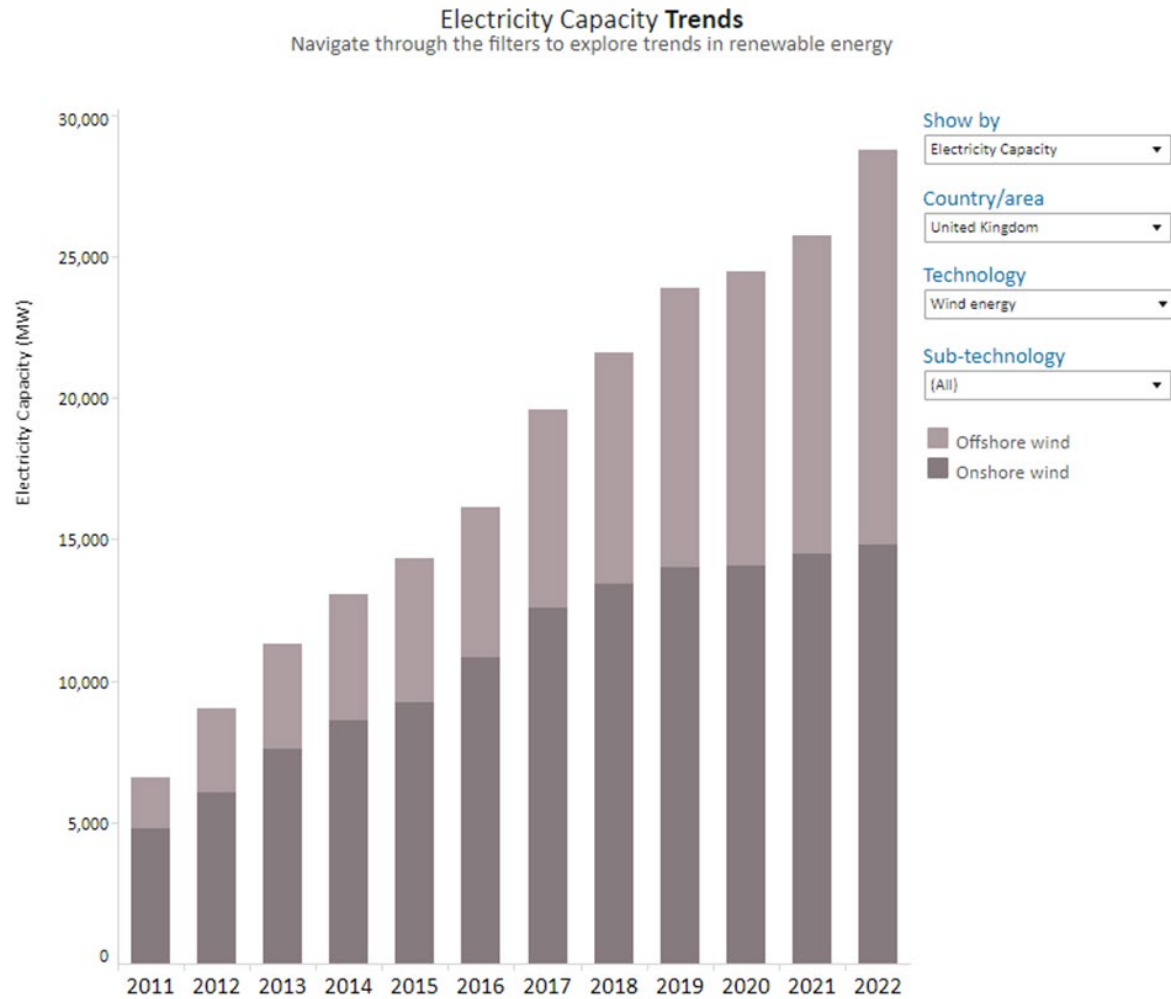
WIND ENERGY





OFFSHORE WIND

- Offshore wind power or offshore wind energy is the energy taken from the force of the winds out at sea, transformed into electricity and supplied into the electricity network onshore.

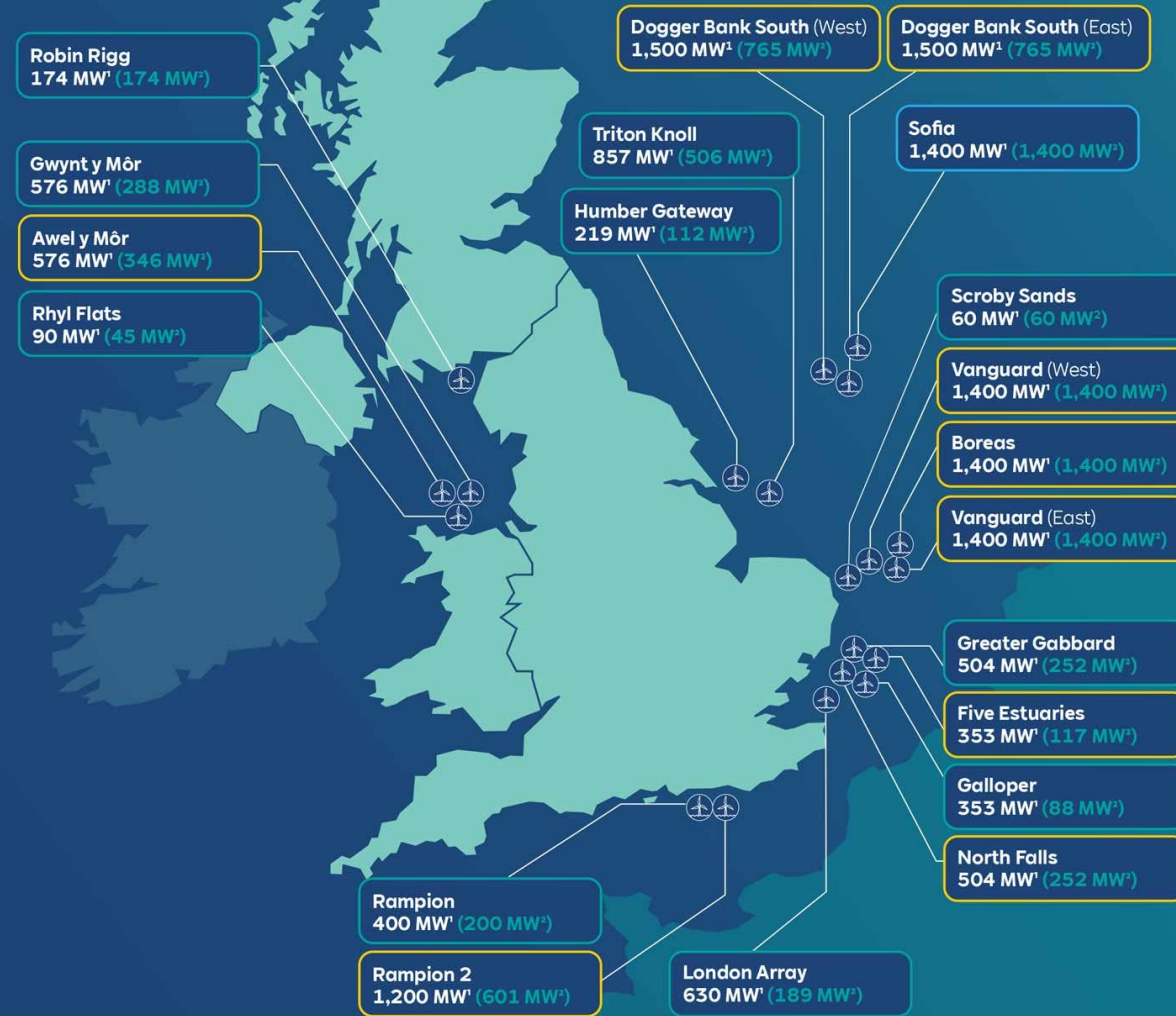


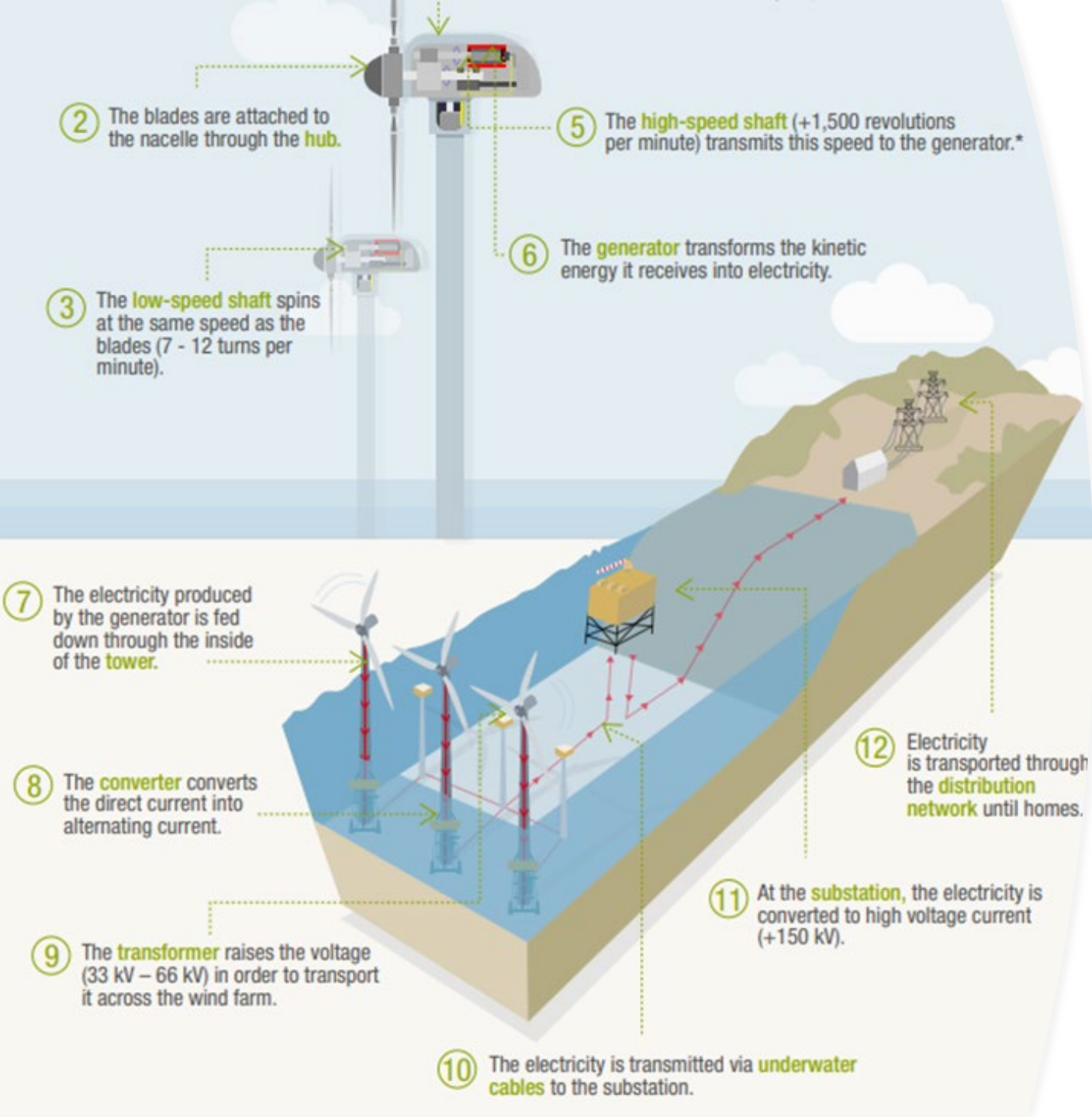
OFFSHORE WIND

- Offshore wind power or offshore wind energy is the energy taken from the force of the winds out at sea, transformed into electricity and supplied into the electricity network onshore.
- As of 2023 the UK is home to over 2,000 wind farms – with a total capacity of over 30GW – contributing to 20% of the UK's total electricity generation

Our UK offshore portfolio

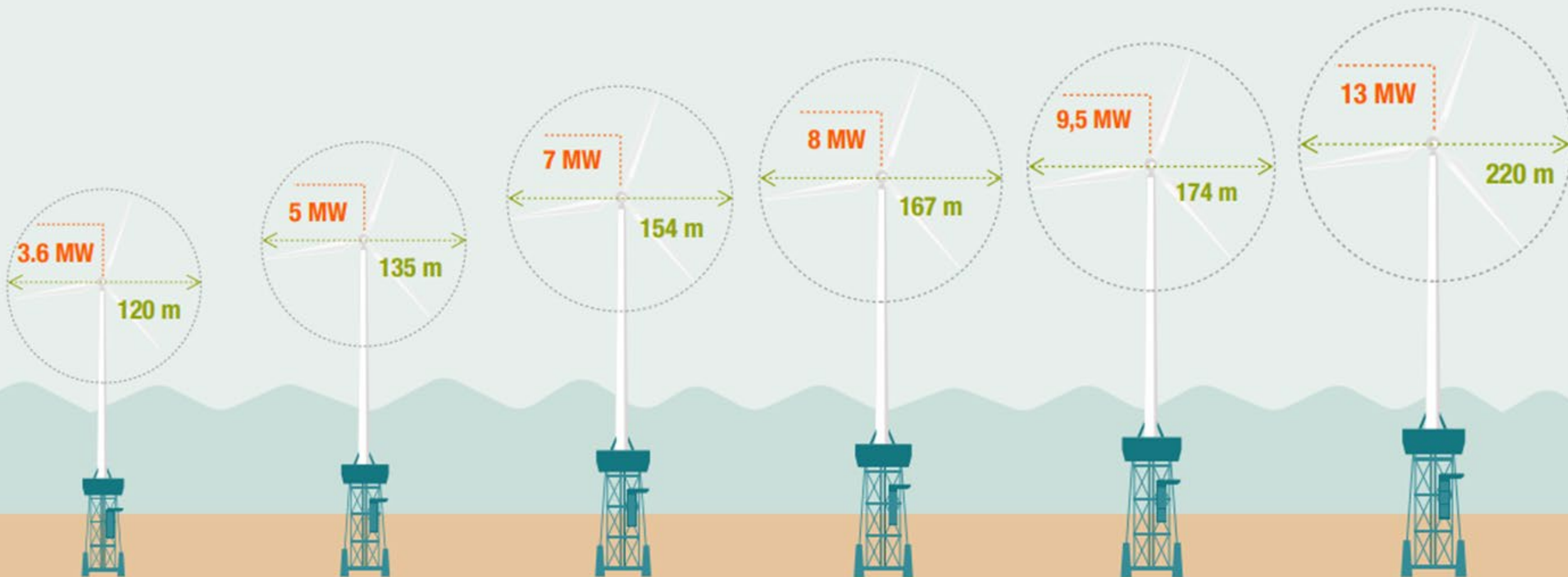
- in operation
- under construction
- in development





OFFSHORE WIND

- Currently, offshore wind farms are located in shallow waters (up to 60 metres deep) and away from the coast, marine traffic routes, strategic naval installations and spaces of ecological interest.



**WEST OF
DUDDON SANDS**

Irish Sea
(United Kingdom)

In operation since 2014

WIKINGER

Baltic Sea
(Germany)

In operation since 2017

EAST ANGLIA ONE

North Sea
(United Kingdom)

Under construction

SAINT-BRIEUC

Saint-Brieuc Bay
(France)

Under construction

BALTIC EAGLE

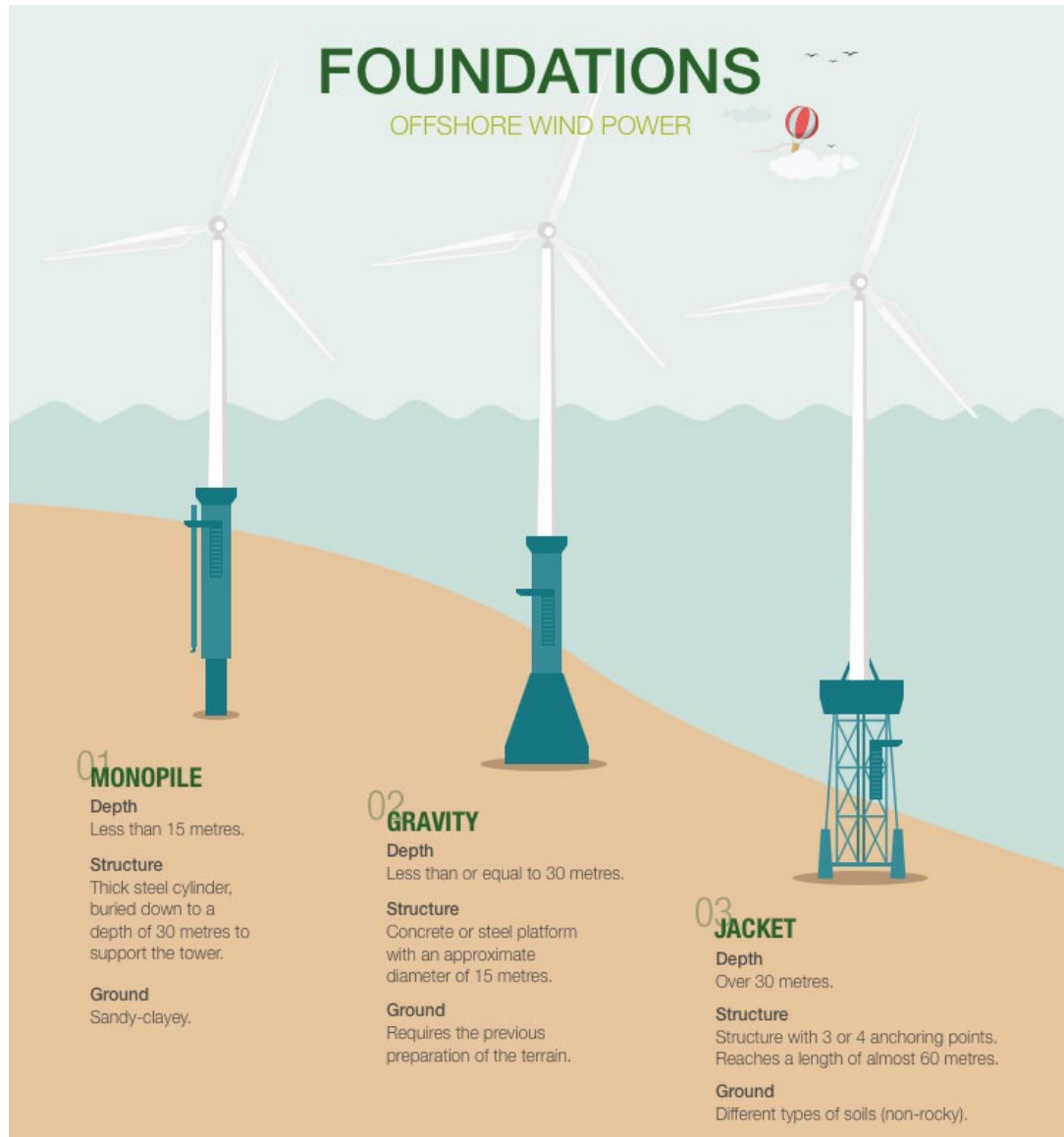
Baltic Sea
(Germany)

Under construction

VINEYARD WIND 1

Massachusetts
(USA)

Under construction



OFFSHORE WIND

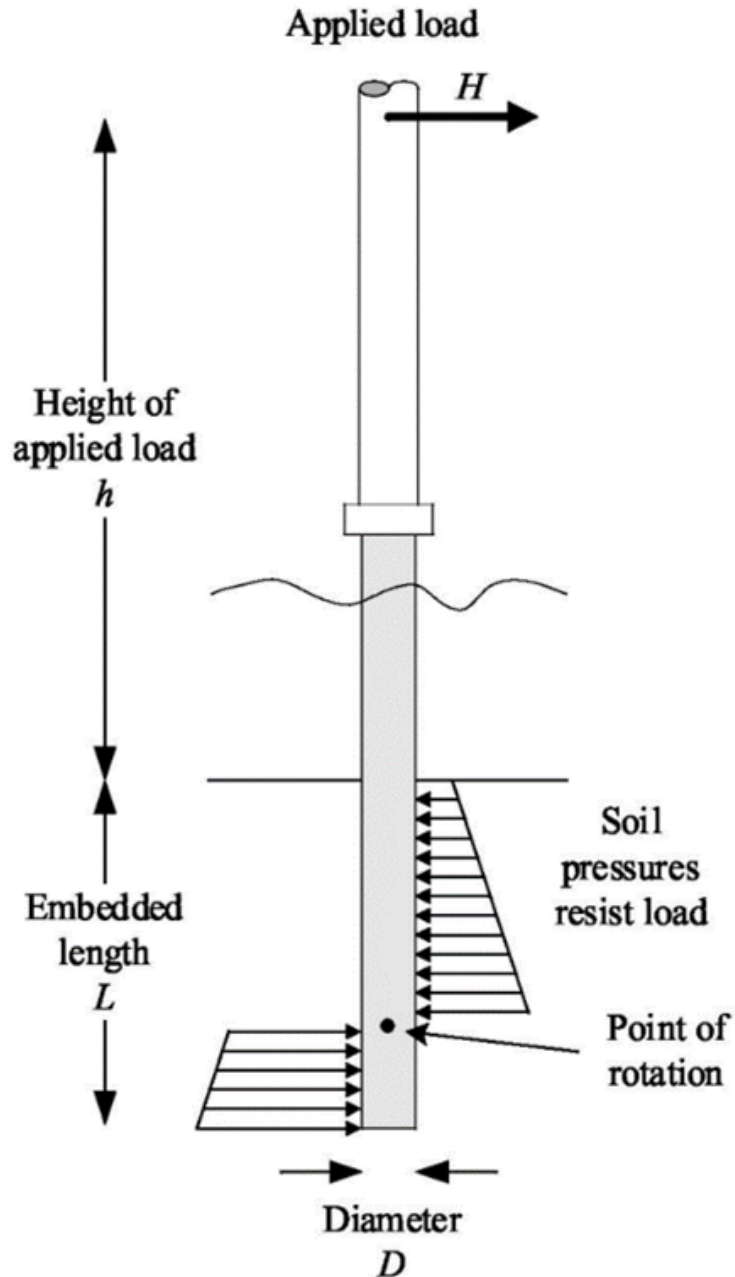
The choice of foundation for an offshore wind turbine (OWT) structure is influenced by several factors, including water depth, seabed conditions, environmental loading, and economic considerations.



OFFSHORE WIND

A monopile is a single, large-diameter steel tube driven into the seabed.

It is currently the preferred foundation choice for OWTs.

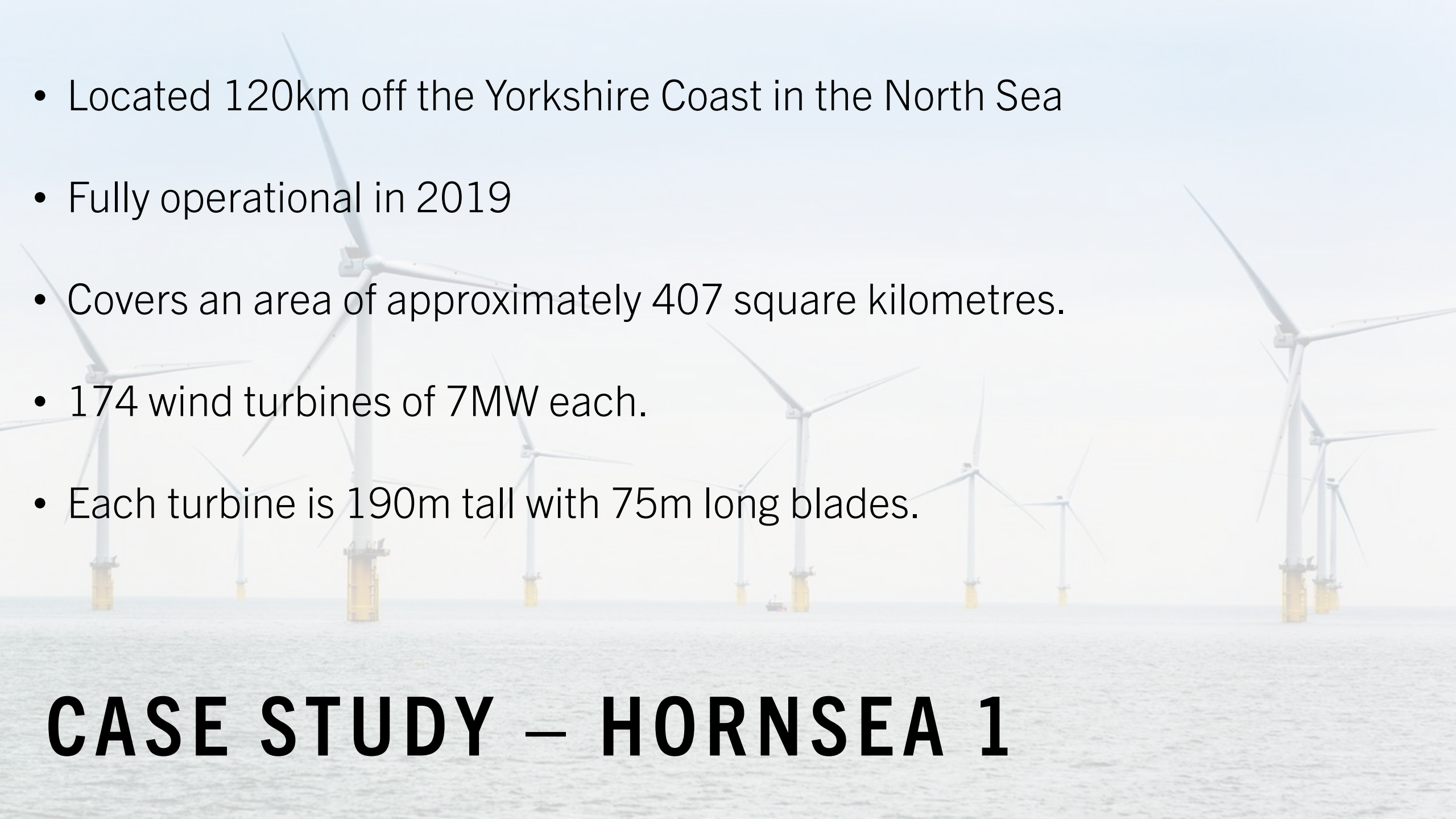


OFFSHORE WIND

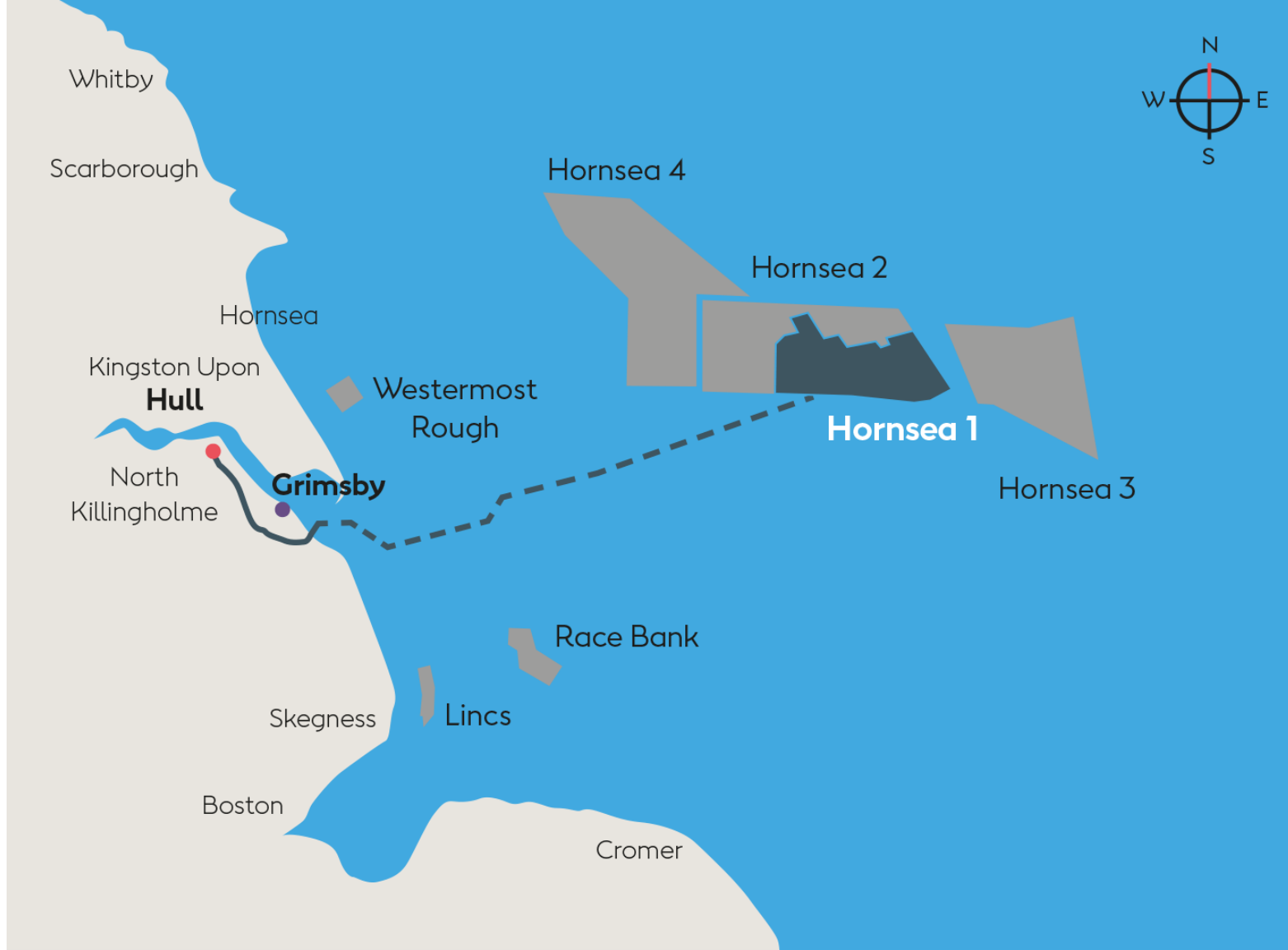
Gravity-based foundations and monopiles have load transferred to the ground through overturning moments, thus lateral loading dictates the design.



CASE STUDY – HORNSEA 1

- 
- Located 120km off the Yorkshire Coast in the North Sea
 - Fully operational in 2019
 - Covers an area of approximately 407 square kilometres.
 - 174 wind turbines of 7MW each.
 - Each turbine is 190m tall with 75m long blades.

CASE STUDY – HORNSEA 1



Hornsea One Offshore Wind Farm

--- Cable Corridor / Route

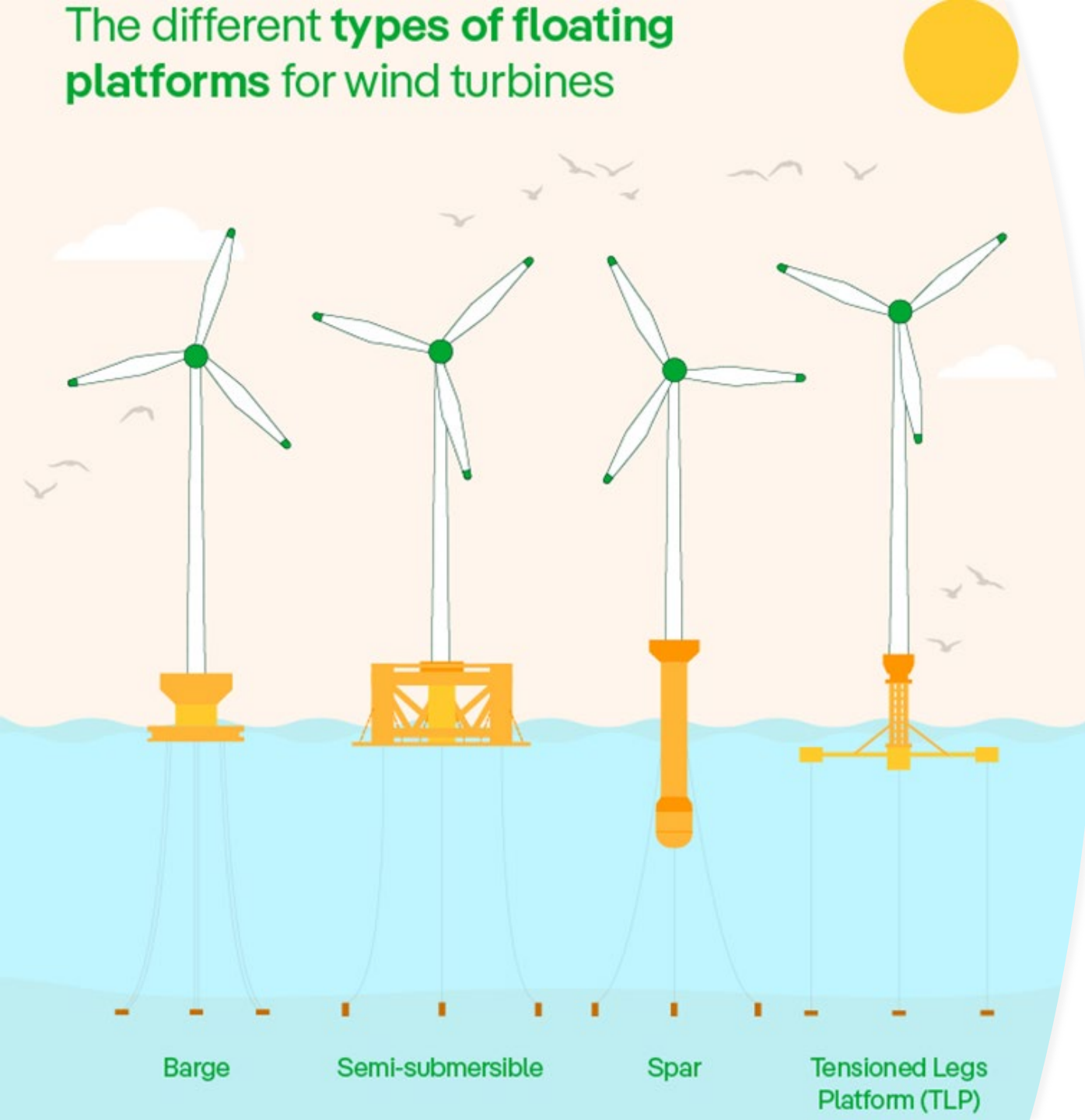


Onshore Substation



Operations and Maintenance Base

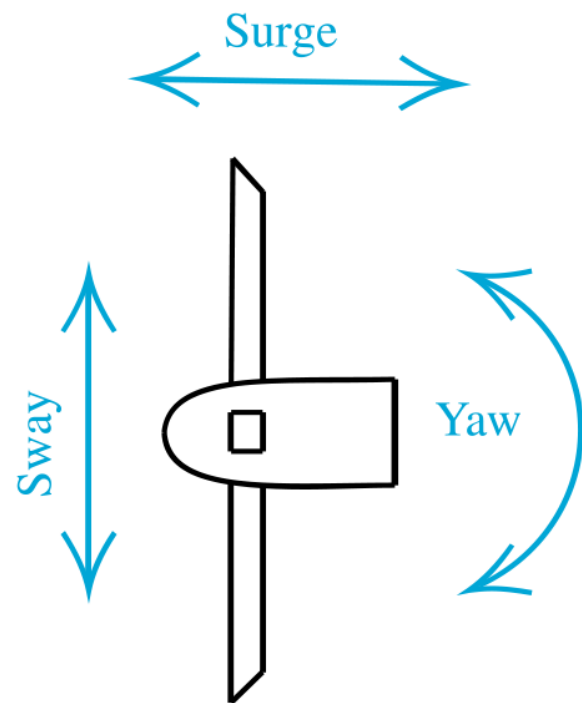
The different types of floating platforms for wind turbines



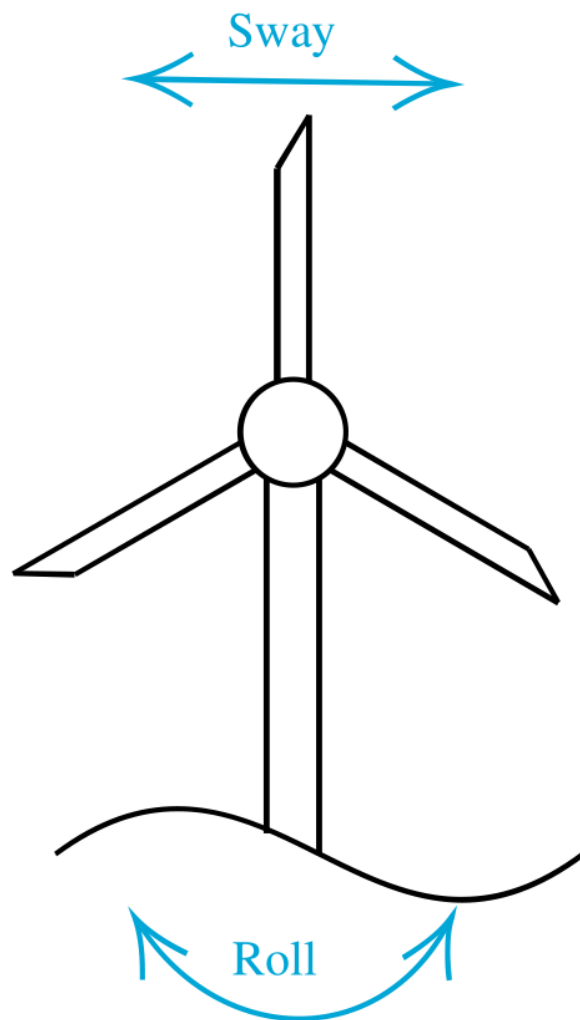
FLOATING OFFSHORE WIND

- Floating wind farms are made up of wind turbines that are placed on floating structures and stabilised by moorings and anchors, and the design of the structure distributes the masses and weights.

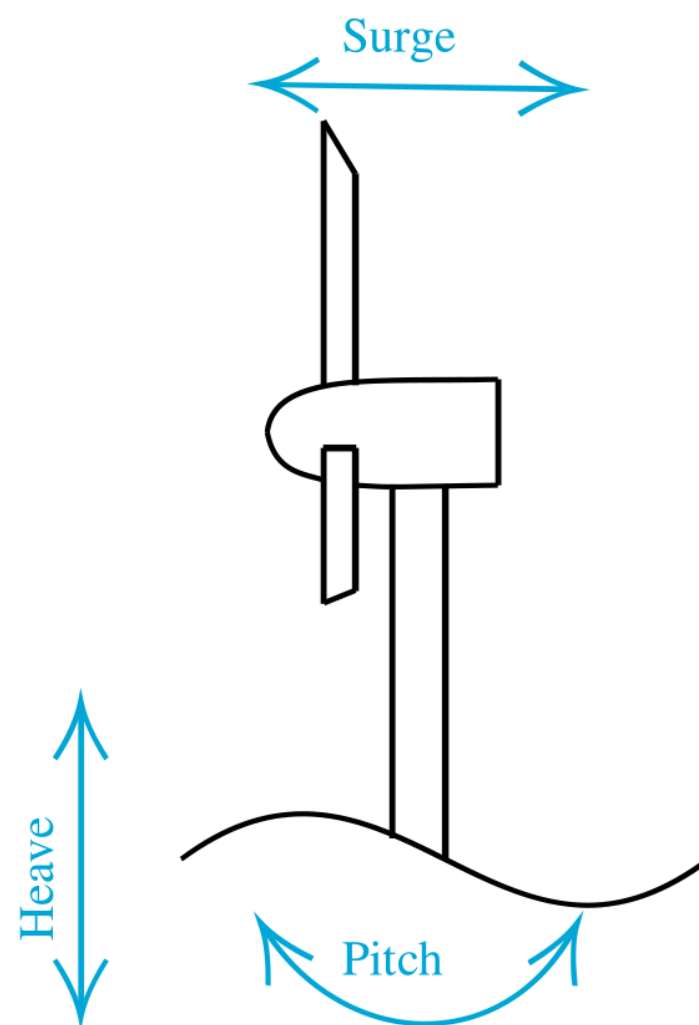
Top View

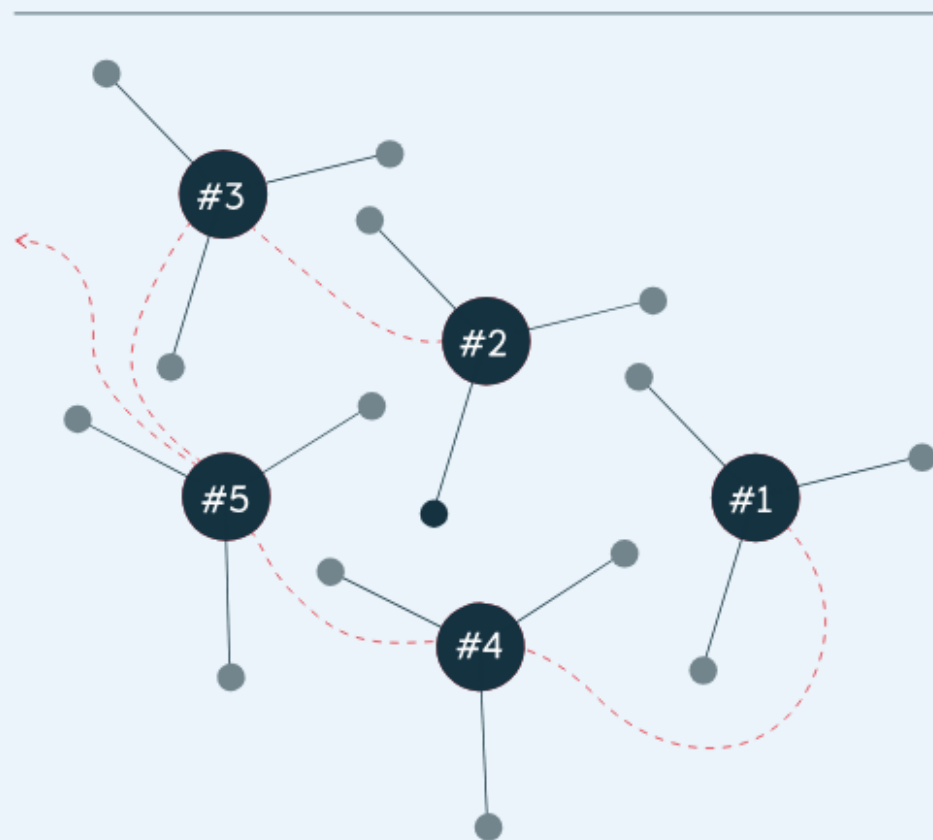


Front View

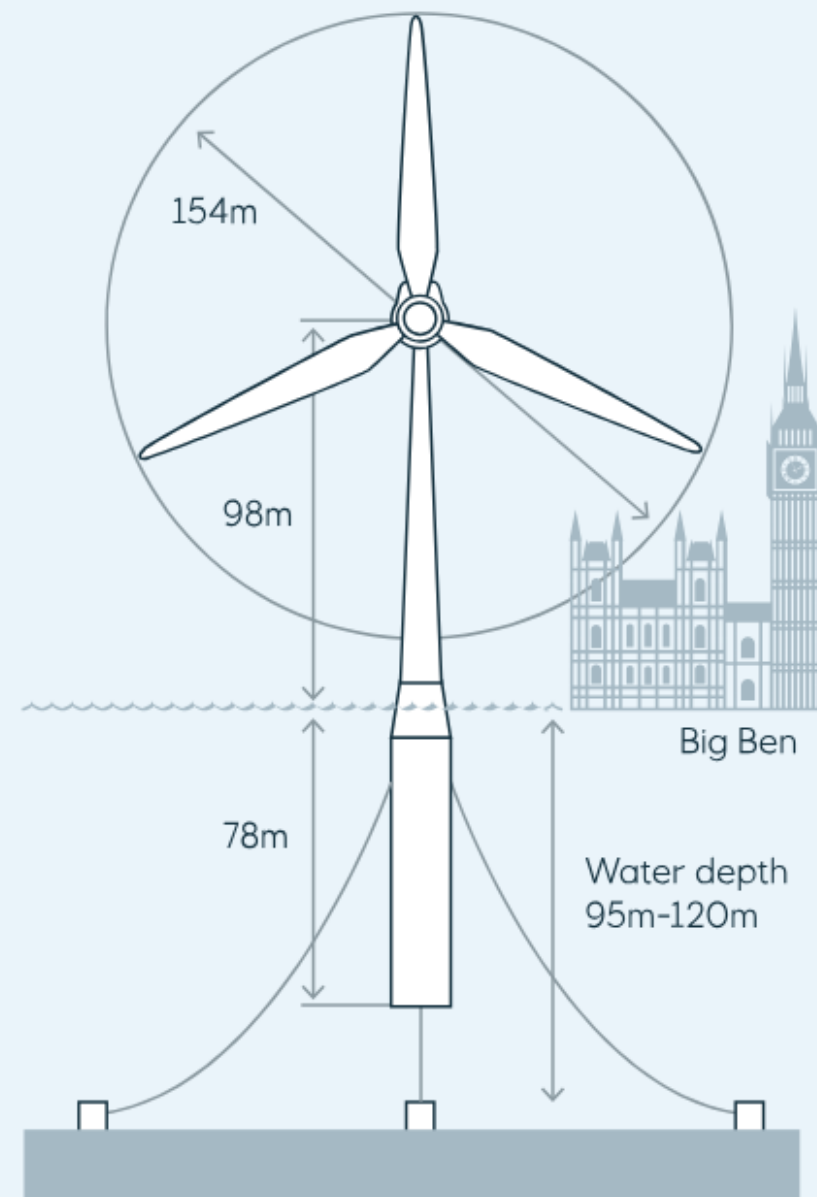


Side View

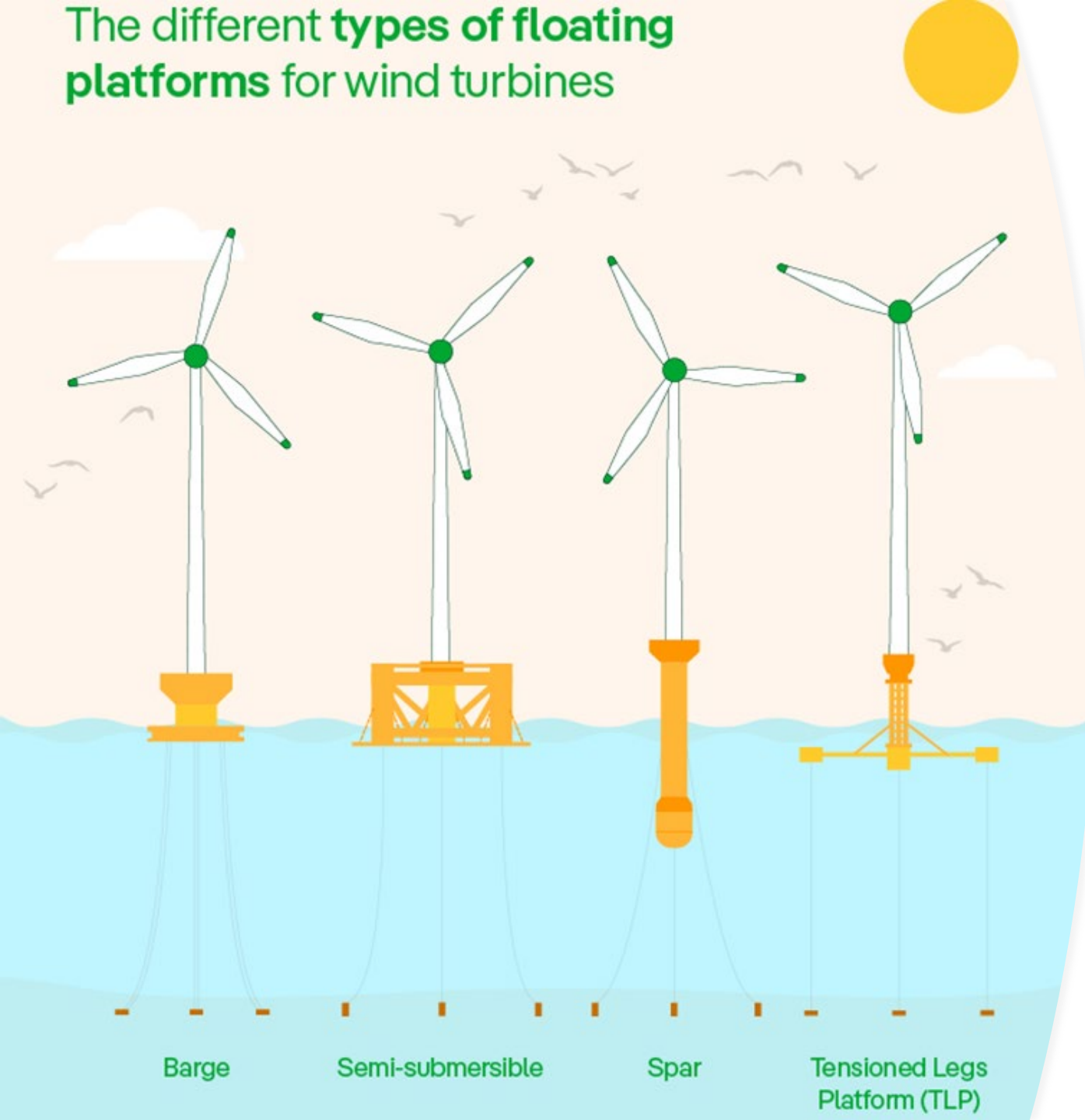




- Turbine
- Anchor
- Mooring line
- - - Electrical line



The different types of floating platforms for wind turbines



FLOATING OFFSHORE WIND

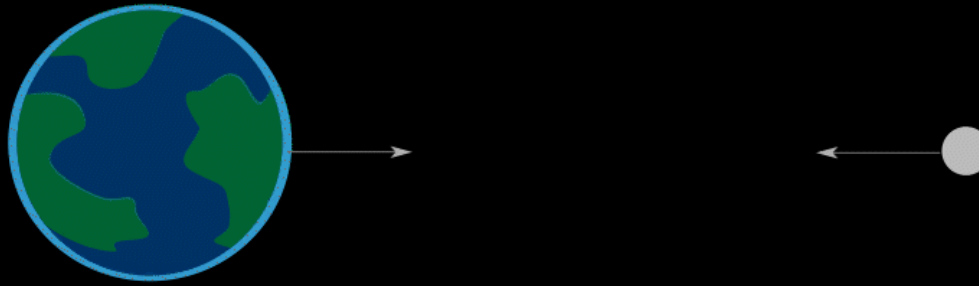
- Among the advantages of floating offshore wind are the potentially low environmental impact and the ease of manufacture and installation, as the floating turbines and platforms can be built and assembled on land and then towed to the offshore installation site

TIDAL ENERGY SYSTEMS



TIDAL ENERGY

Tidal energy is a form of power produced by the natural rise and fall of tides caused by the gravitational interaction between Earth, the sun, and the moon.



NOT TO SCALE

TIDE GENERATION

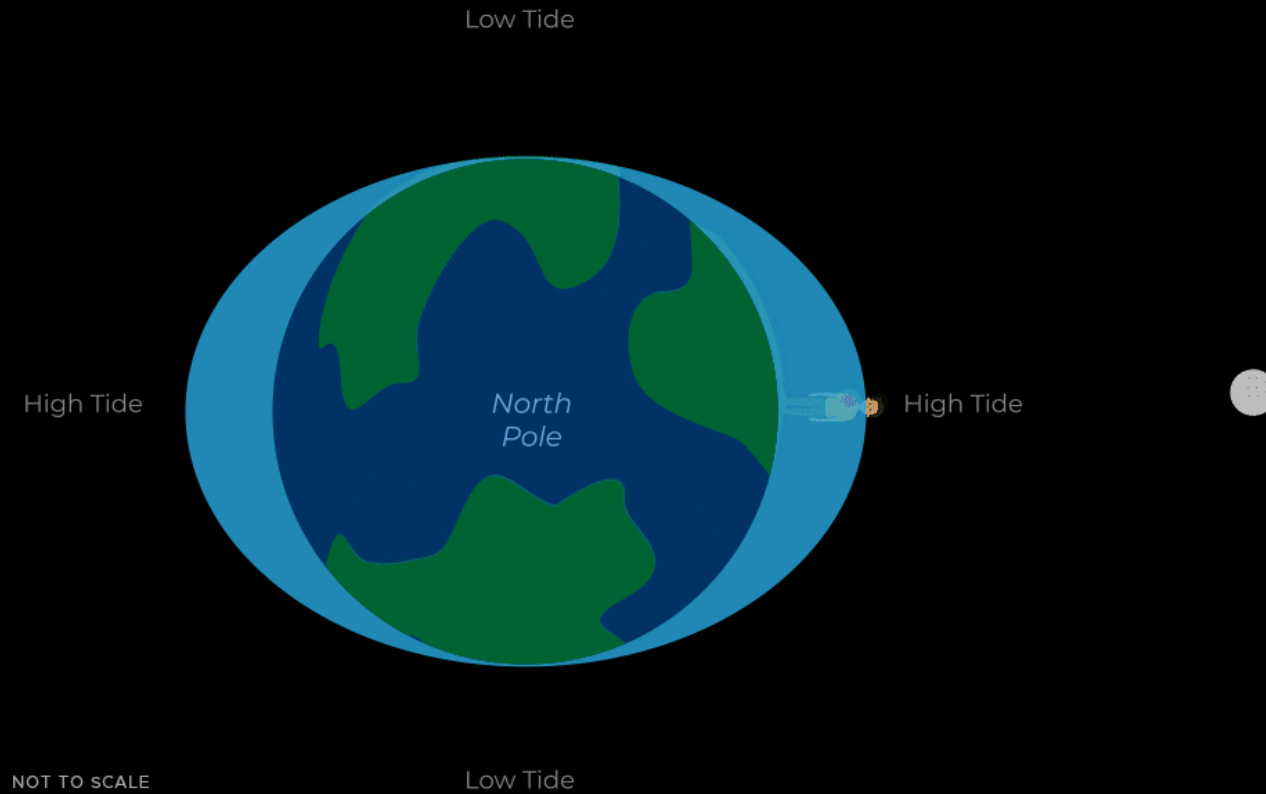


Moon

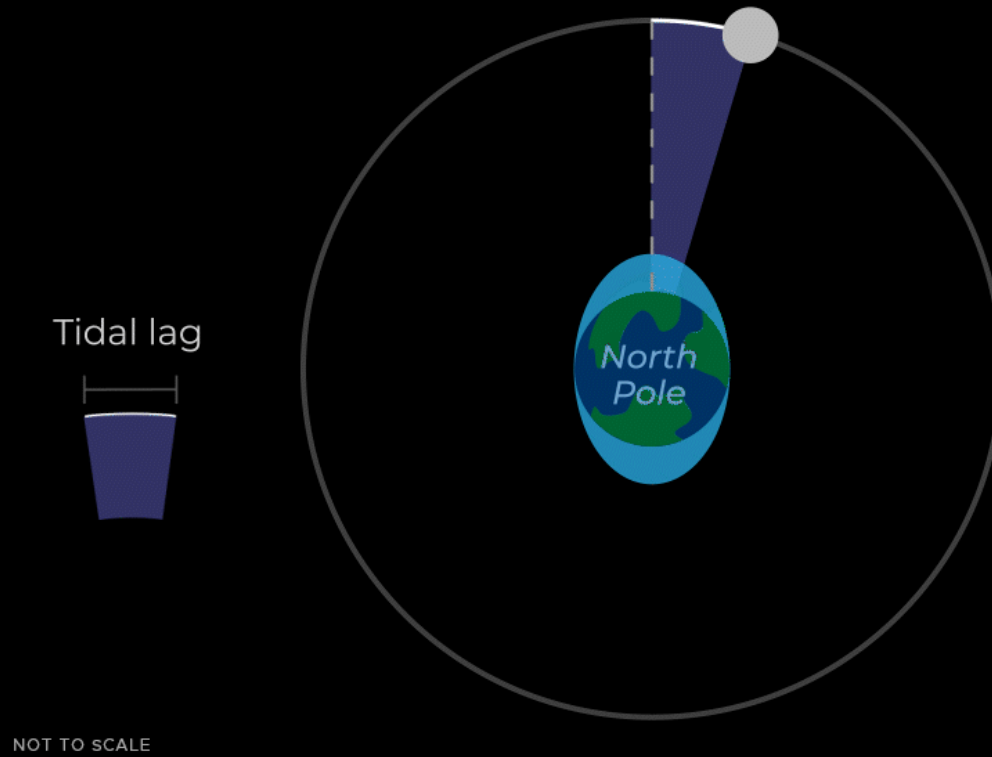
Net Tide Generating Force

NOT TO SCALE

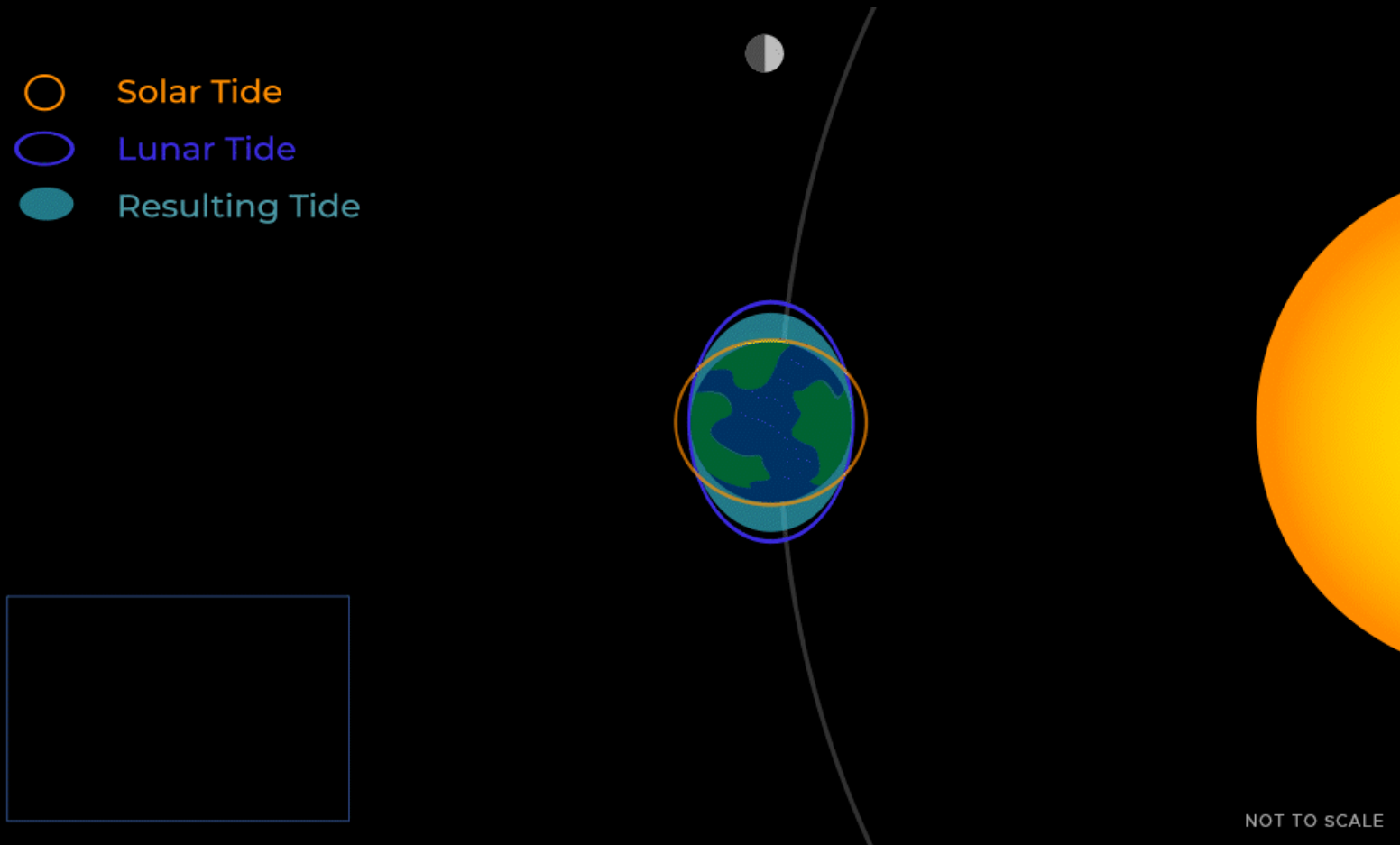
TIDE GENERATION



TIDE GENERATION

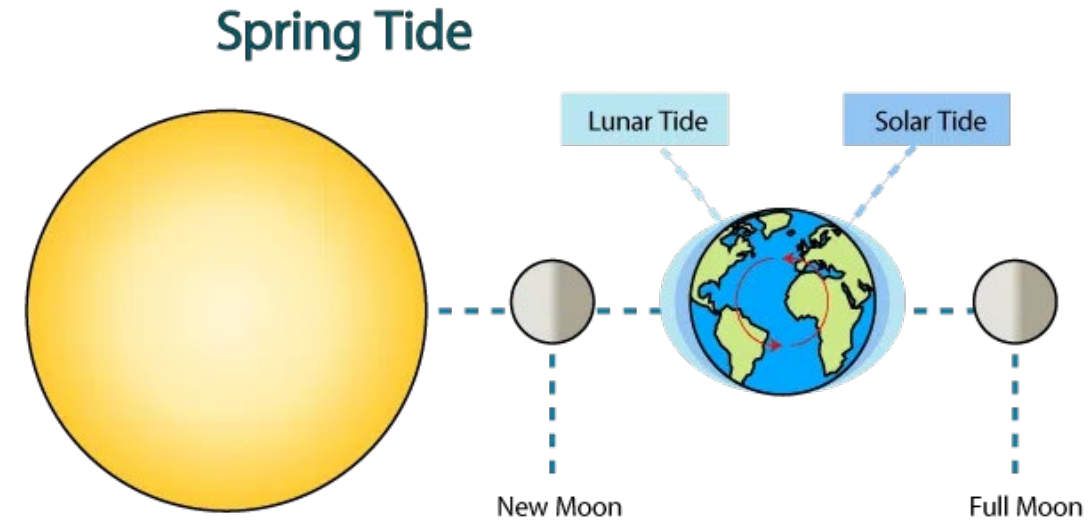
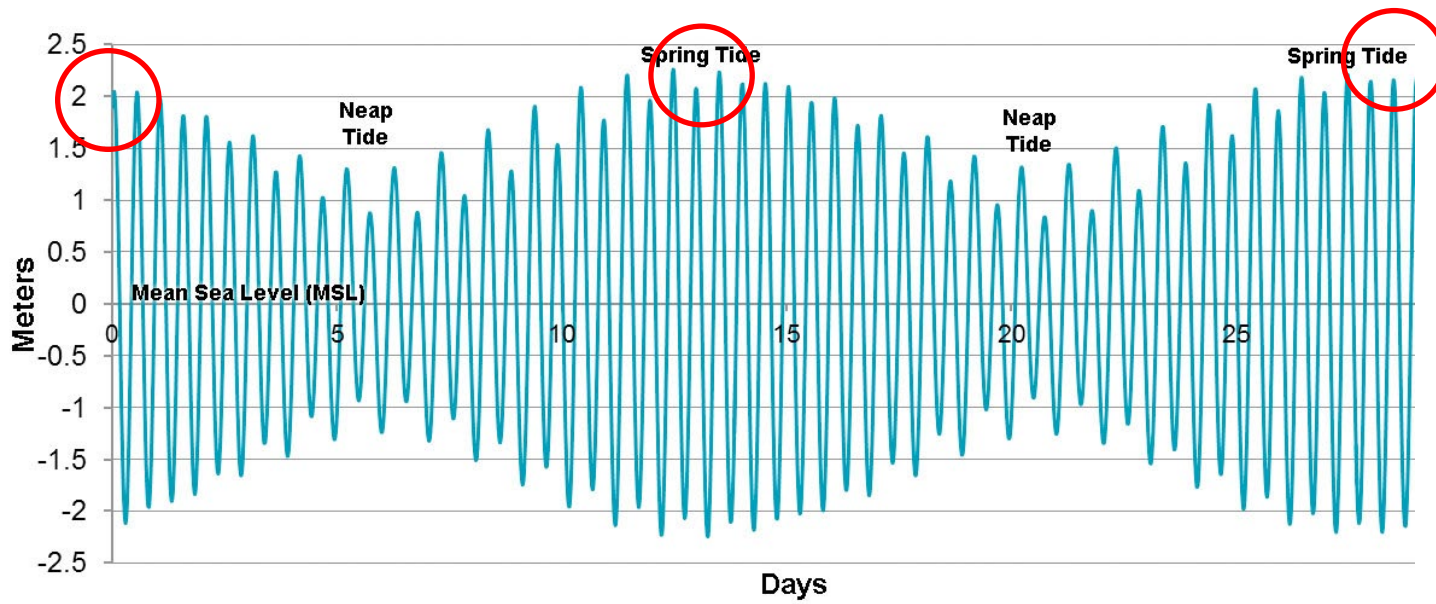


TIDE GENERATION

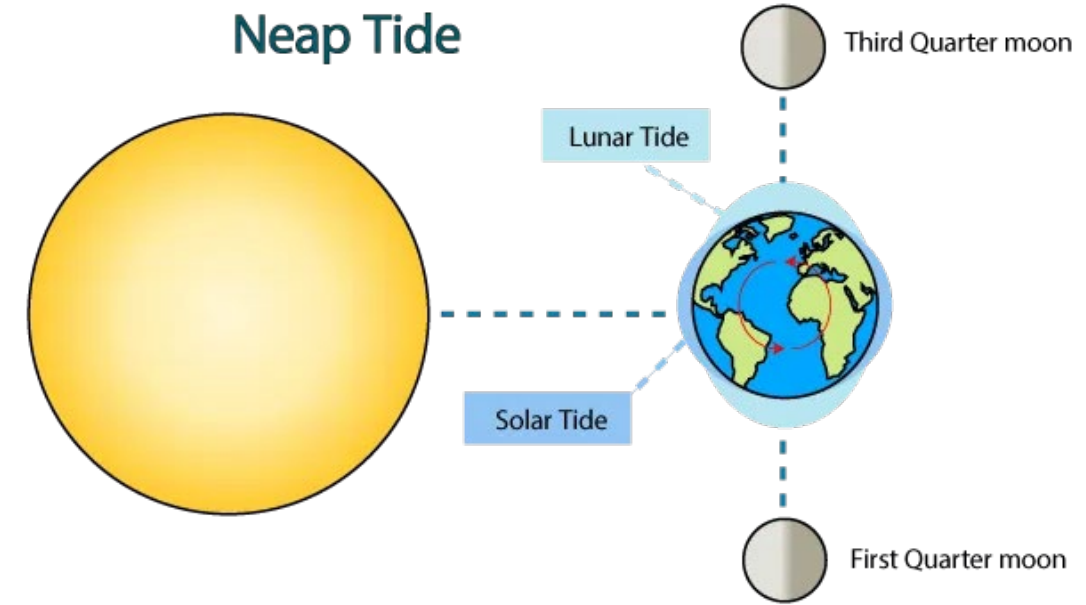
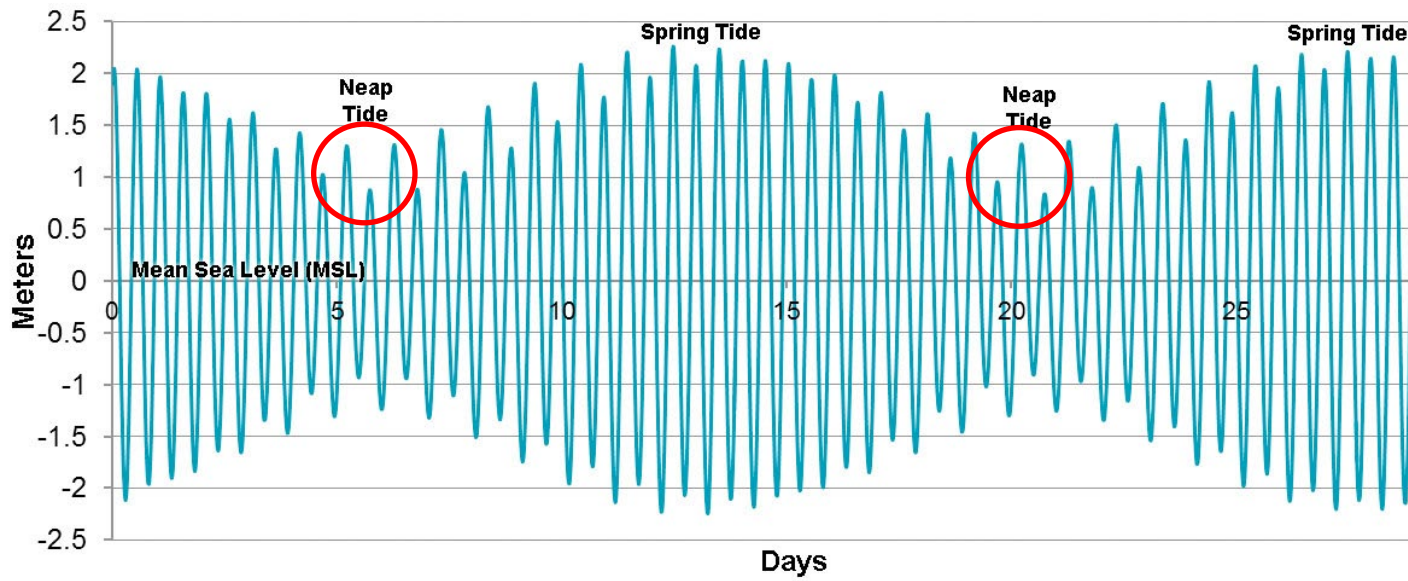


TIDE GENERATION

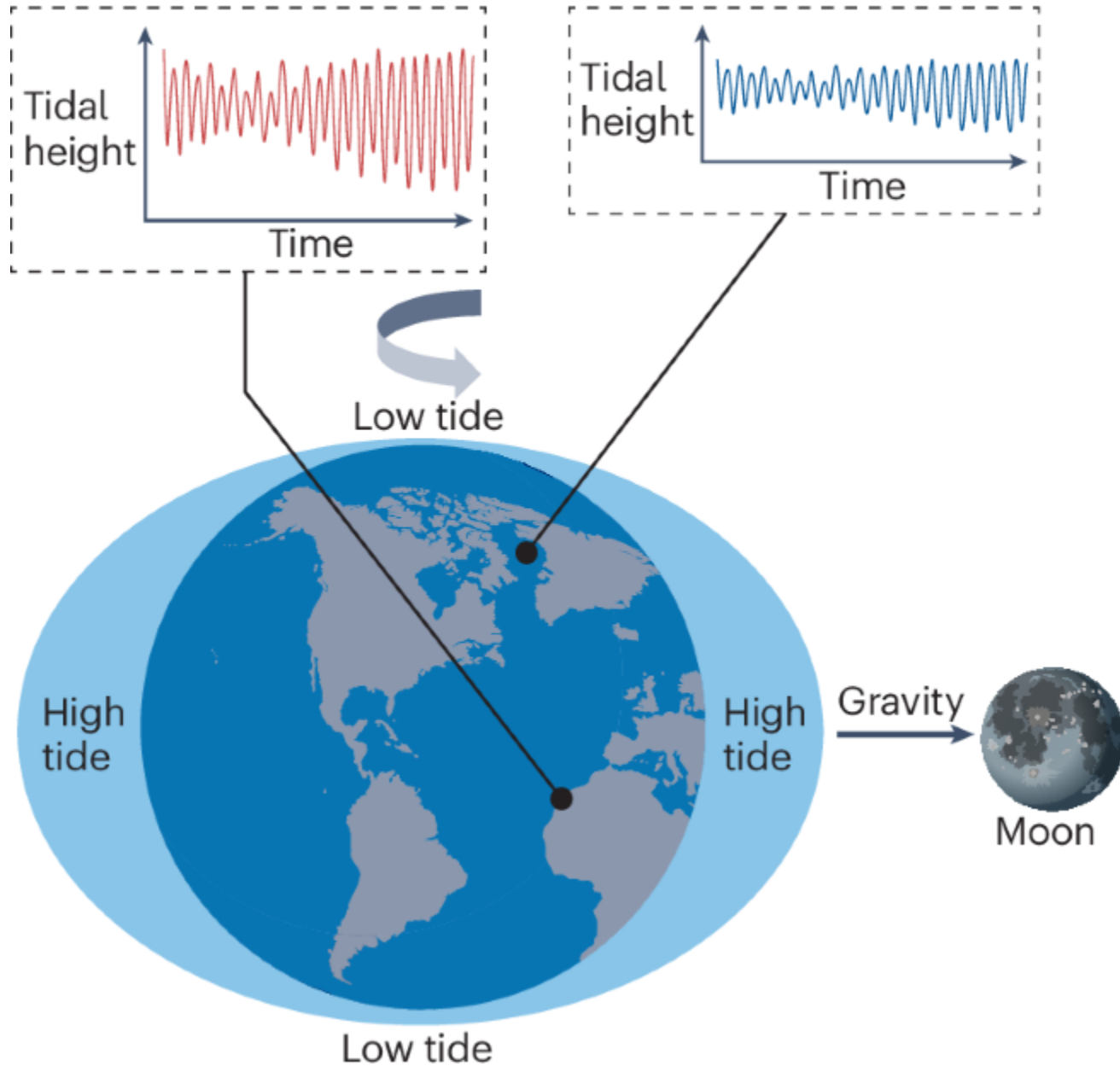
TIDAL RESOURCE



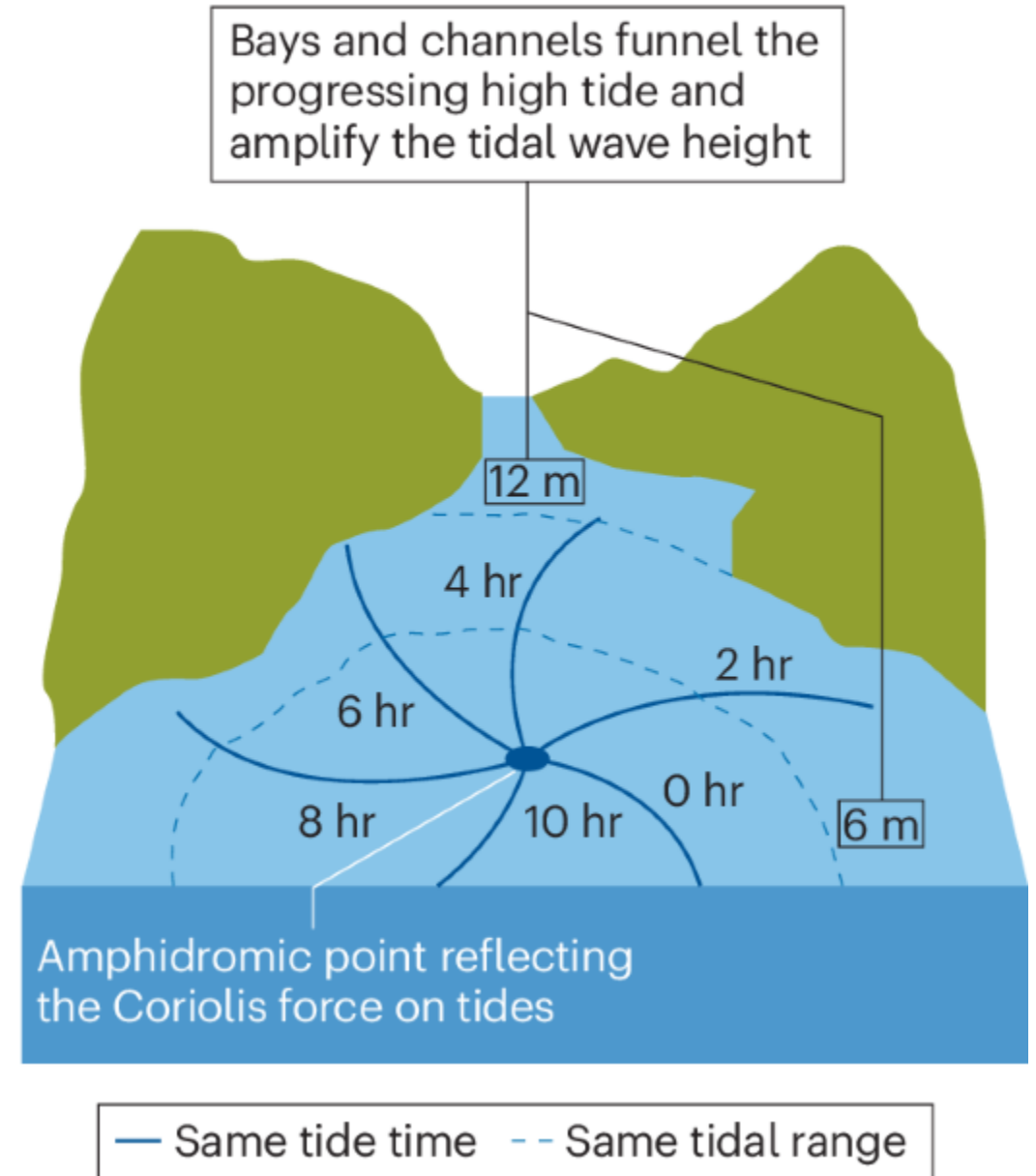
TIDAL RESOURCE



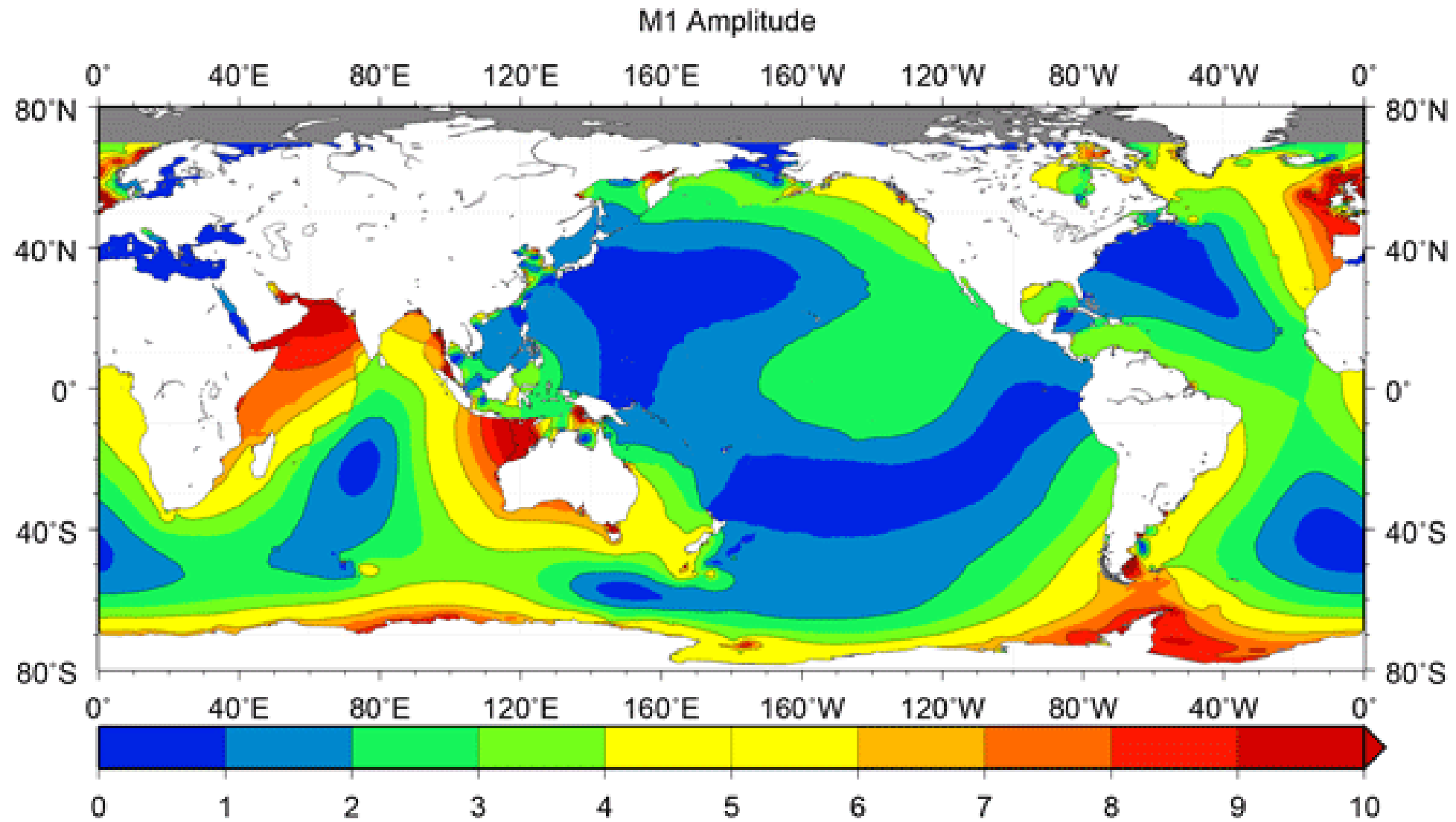
a Factors driving tides



b Tidal funnelling and amphidromic points



TIDAL RESOURCE





TIDAL ENERGY

Tidal energy can be harnessed in two main ways, depending on how the movement of seawater is converted into usable power.

TIDAL ENERGY

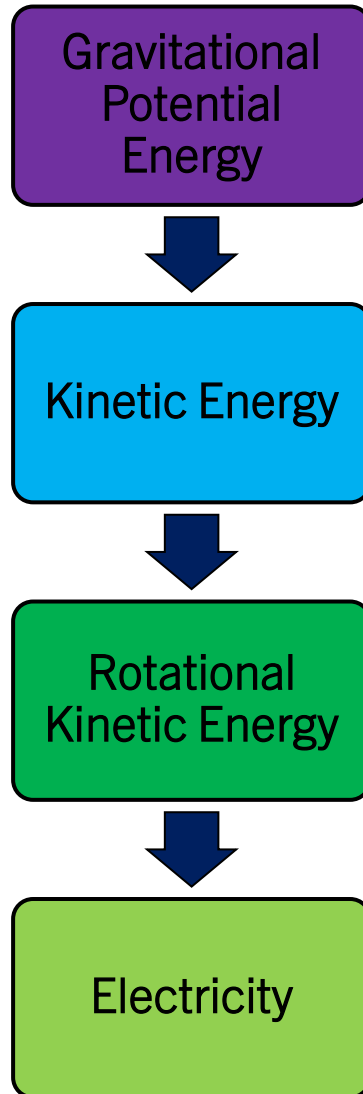
Tidal Range Energy



Tidal Stream Energy



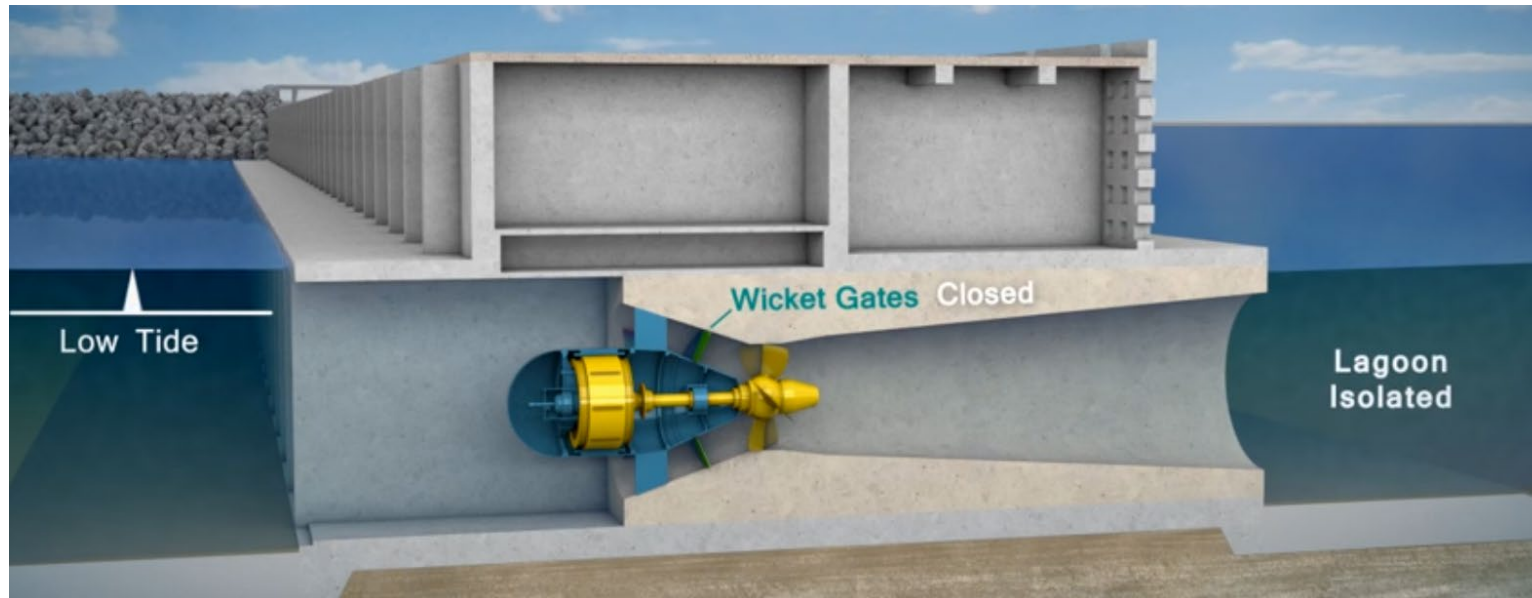
TIDAL RANGE



- Tidal barrages are built across estuaries and are designed to extract gravitational potential energy from the rise and fall of tides.
- Energy is extracted by directing water through turbines located in passages within the barrage.

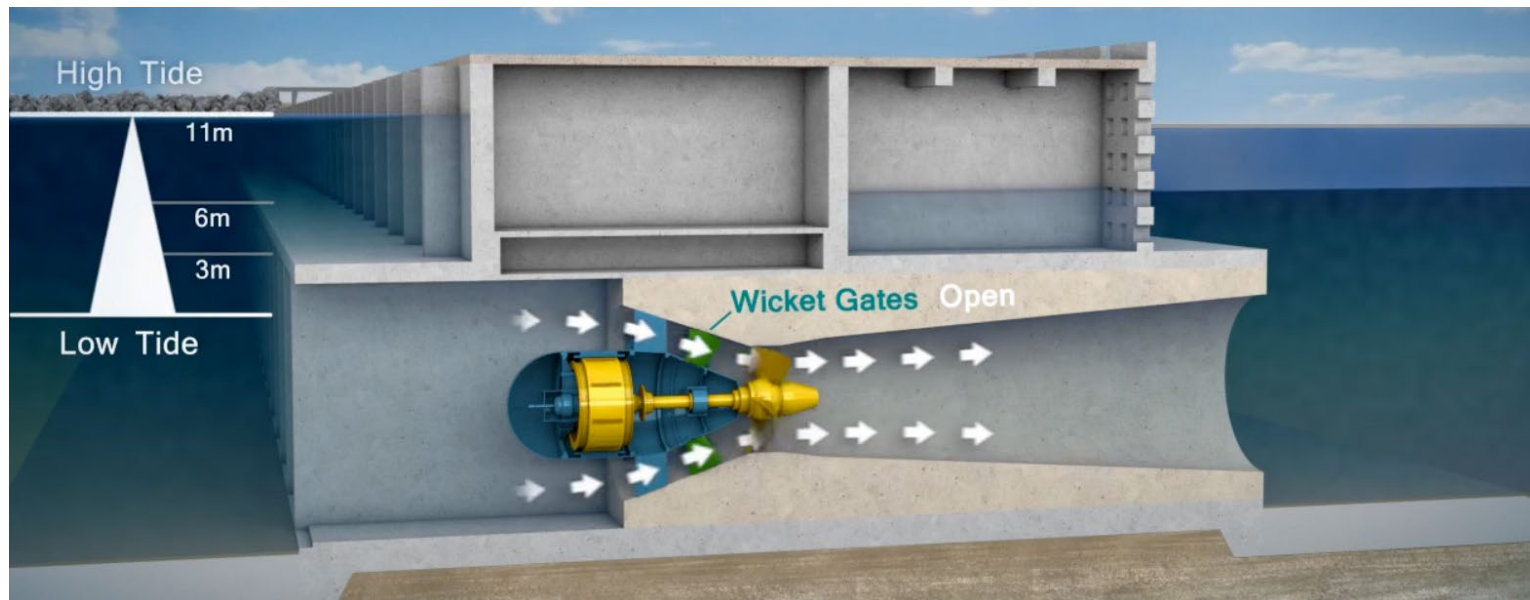
TIDAL RANGE

- Tide flows into estuary.
- Wicket gates in barrage closed.
- Head difference allowed to develop.



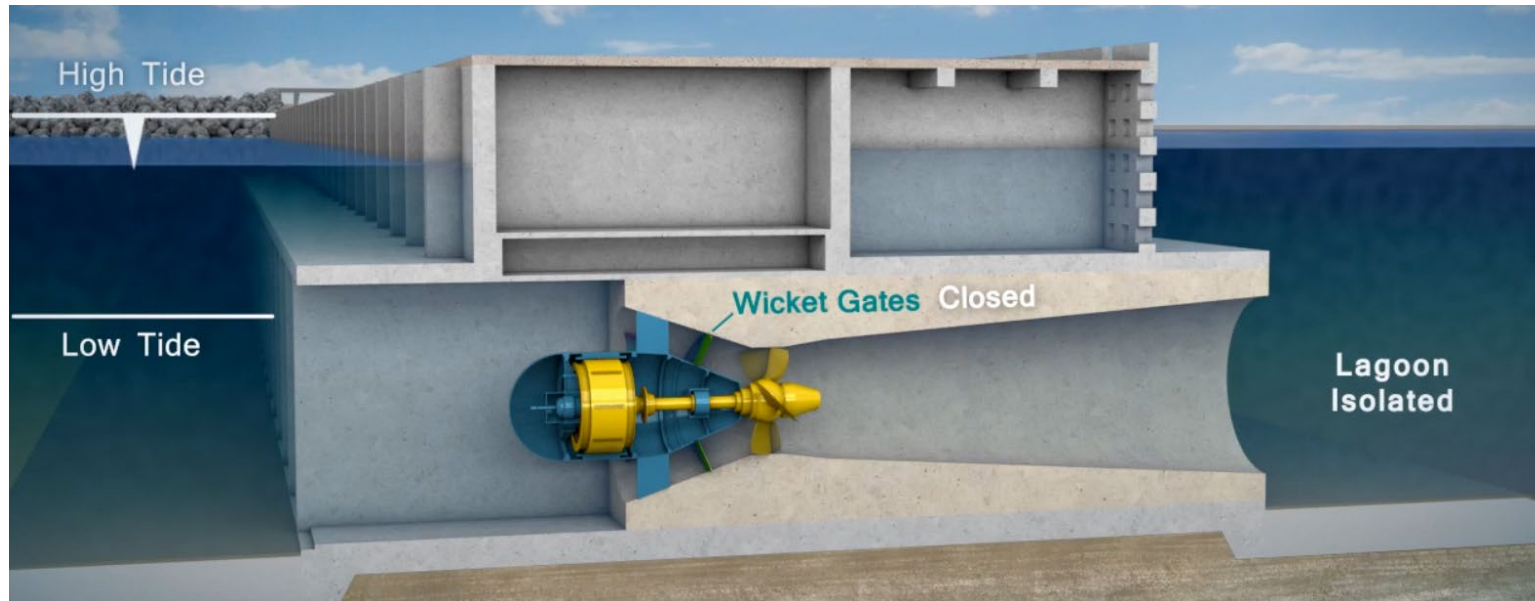
TIDAL RANGE

- Tide continues to flow into estuary.
- Wicket gates in barrage opened
- Water allowed to flow through turbines
- Tidal barrage flood generation



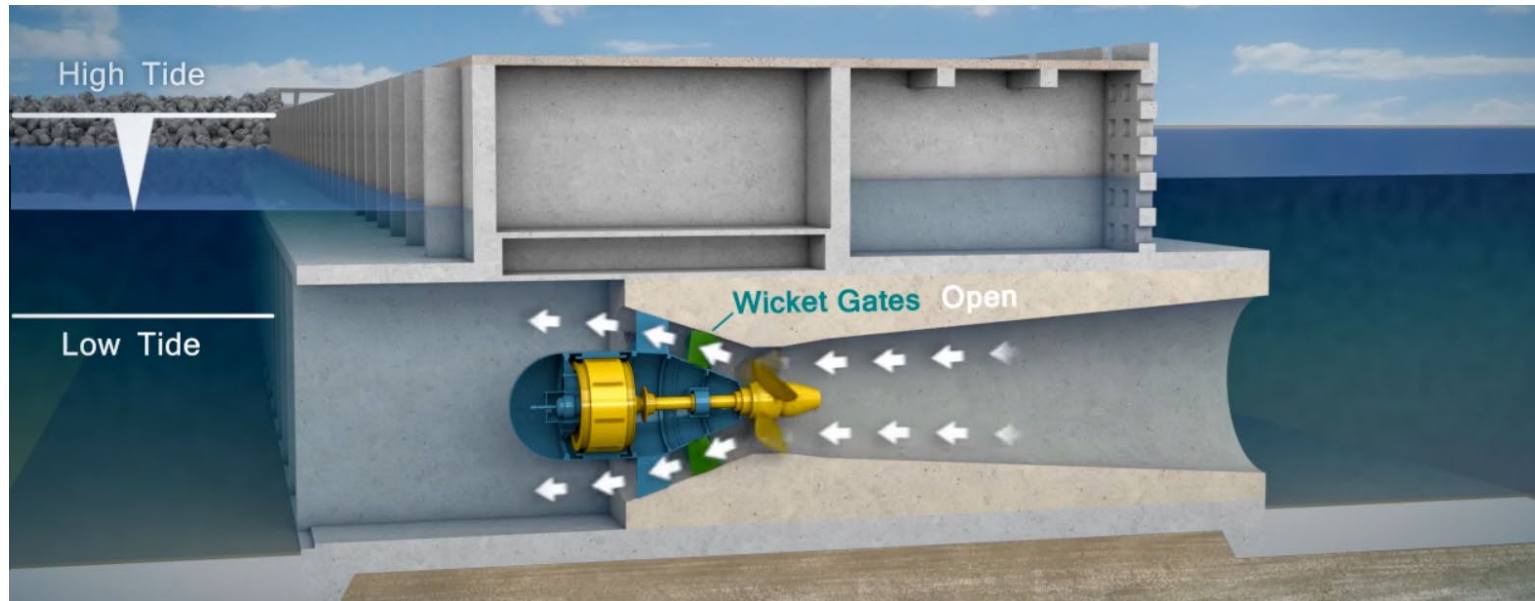
TIDAL RANGE

- Tide turns, flowing out of estuary.
- Wicket gates in barrage closed
- Head difference allowed to develop



TIDAL RANGE

- Tide continues to flow out of estuary.
- Wicket gates in barrage opened
- Water allowed to flow through turbines
- Tidal barrage ebb generation



GRAVITATIONAL POTENTIAL ENERGY

- The energy available from a barrage comes in the form of gravitational potential energy.
- When the height of water rises, the work done in raising the water level is transferred into gravitational potential energy of the water.

GRAVITATIONAL POTENTIAL ENERGY

- The basic formula for gravitational potential energy is:

$$E_P = mgh$$

- Where m is the mass of the object in kg, g is the gravitational acceleration in ms^{-2} and h is the height in m.

GRAVITATIONAL POTENTIAL ENERGY

In the case of a tidal barrage:

- h is the head difference between the water on either side of the barrage, this is the equivalent of the tidal range.
- The mass, m of the water can be calculated by assuming a basin with a surface area, A , in m^2 , multiplied by h , the tidal range in m , and ρ , the density of the water, in kgm^{-3} .

GRAVITATIONAL POTENTIAL ENERGY

- The formula can now be re-written as:

$$E_P = \frac{1}{2}Ah\rho gh = \frac{1}{2}A\rho gh^2$$

- The half is included because as the basin empties through the turbines, the hydraulic head over the dam reduces.

TIDAL RANGE – CASE STUDY

- La Rance, France



[La Rance Tidal Barrage | Tethys \(pnnl.gov\)](https://tethys.pnnl.gov/)

TIDAL RANGE – CASE STUDY

Phase	Stressor & Receptor	Design and Methods	Results
Post-Installation Monitoring	Habitat Change Invertebrates	Distribution of benthic species and communities. N/A	Completed By 1980, the basin was providing habitat for 110 worm species and 47 crustacean species.

TIDAL RANGE – CASE STUDY

Phase	Stressor & Receptor	Design and Methods	Results
Post-Installation Monitoring	Habitat Change Birds, Fish, Invertebrates, Marine Mammals	General Flora and Fauna distribution. N/A	Completed An increasingly diverse flora and fauna became established. The patterns of distribution of this flora and fauna, their grouping into ecological units and the nature of their interrelationships, indicate a variable degree of biological adjustment to the new environmental conditions.

TIDAL RANGE – CASE STUDY

Phase	Stressor & Receptor	Design and Methods	Results
Post-Installation Monitoring	Habitat Change Human Dimensions, Fisheries	New fishery activities. N/A	Completed Scallops and Belon oysters are now the new fishery activities.

TIDAL RANGE – CASE STUDY

Phase	Stressor & Receptor	Design and Methods	Results
Post-Installation Monitoring	Changes in Flow Physical Environment	Sediment dynamics. N/A	Completed Modification of tidal stream in the estuary, in particular during ebb has provoked more silt deposit in the low intertidal zone. When comparing the Rance estuary with other regional estuaries, sediments dynamic processes are similar to those of natural estuaries.

TIDAL RANGE – CASE STUDY

Phase	Stressor & Receptor	Design and Methods	Results
Post-Installation Monitoring	Changes in Flow Physical Environment	Mean water level and hydrodynamic regime. N/A	Completed The 2.5 m rise of the mean water level has resulted in a decrease of the tidal range which includes less volume of water entering the estuary the slack period to be longer.

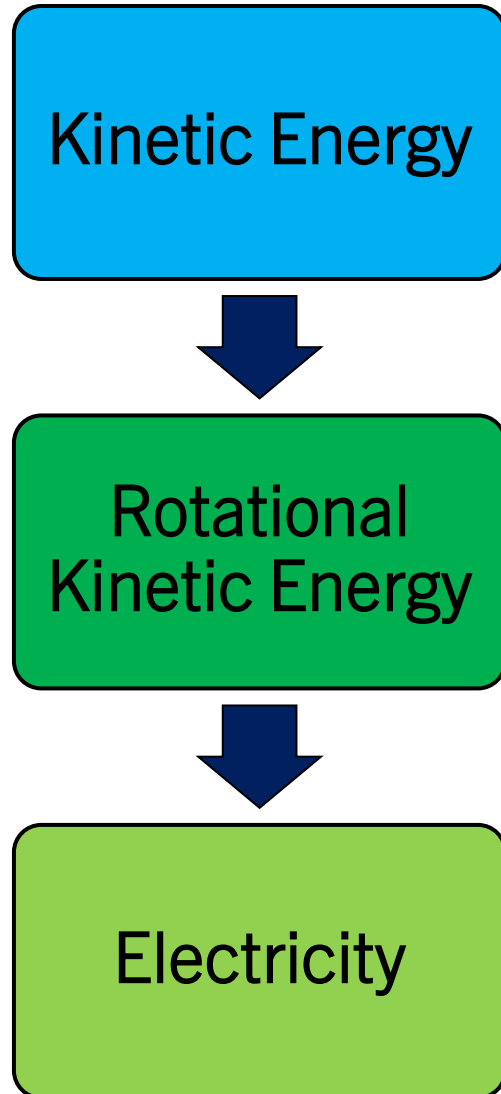
TIDAL RANGE – CASE STUDY

Phase	Stressor & Receptor	Design and Methods	Results
Post-Installation Monitoring	Displacement Birds	Utilization of the basin by overwintering birds. N/A	Completed Bird species variety is the same as before (120 species). A well-developed community of fish-eating birds has been developed (gulls, guillemots, shags). Birds have decreased their use of sand area (intertidal area). Birds can also find food in the other Bays (mudflats).

TIDAL RANGE – CASE STUDY

Phase	Stressor & Receptor	Design and Methods	Results
Post-Installation Monitoring	Displacement Marine Mammals	Seals distribution. N/A	Completed Since 2000, a seal female has been living in the basin, passing through the sluice gates or even the lock. Despite vain attempts to send her back to join seal communities, she always goes back to the Rance estuary!

TIDAL STREAM

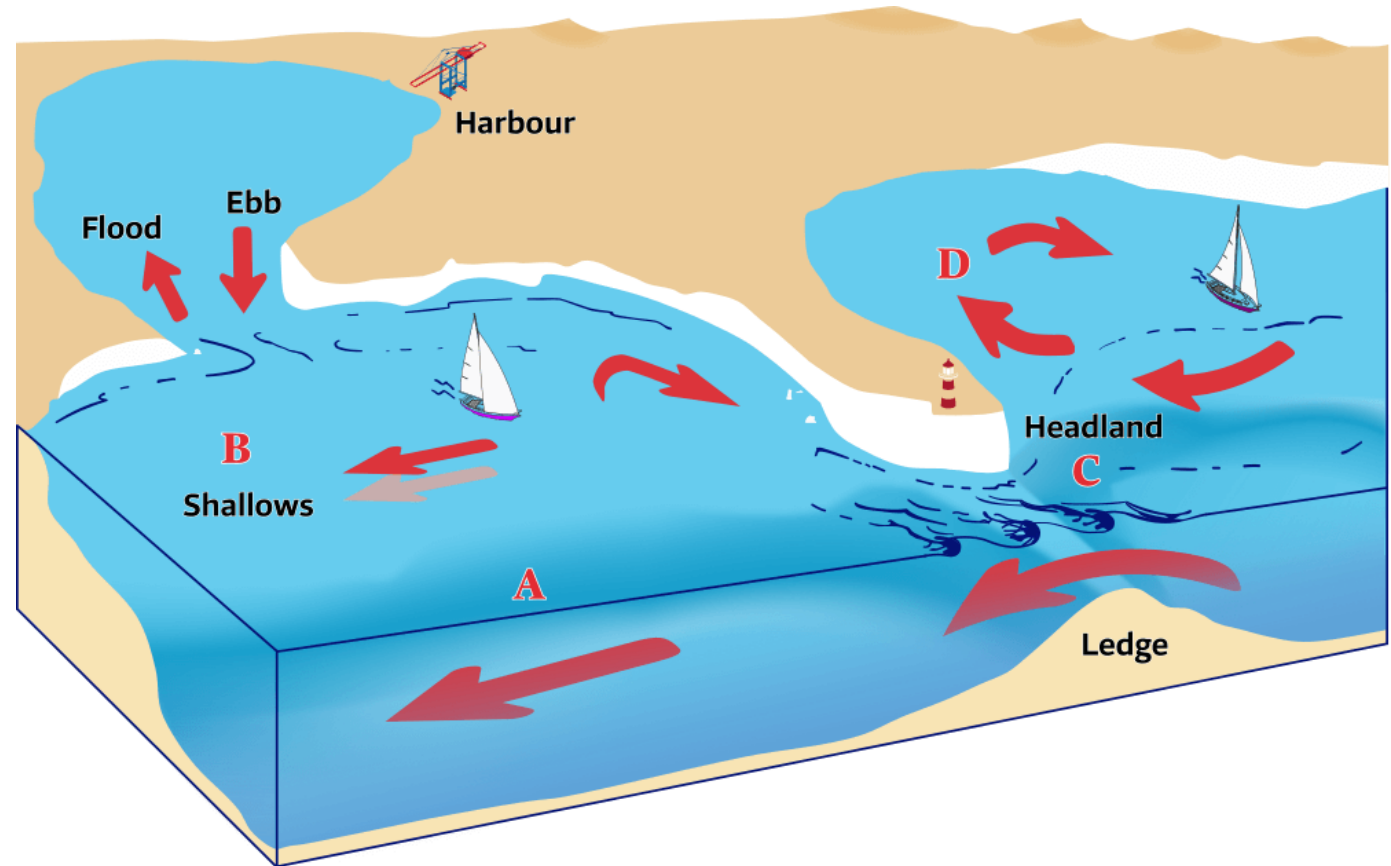


- Tidal stream systems generate electricity from the kinetic energy of moving water — the natural currents created as tides flow in and out of coastal areas, straits, or around headlands.
- It's like how wind turbines generate energy from moving air, except underwater.

TIDAL STREAM

Tidal currents flow:

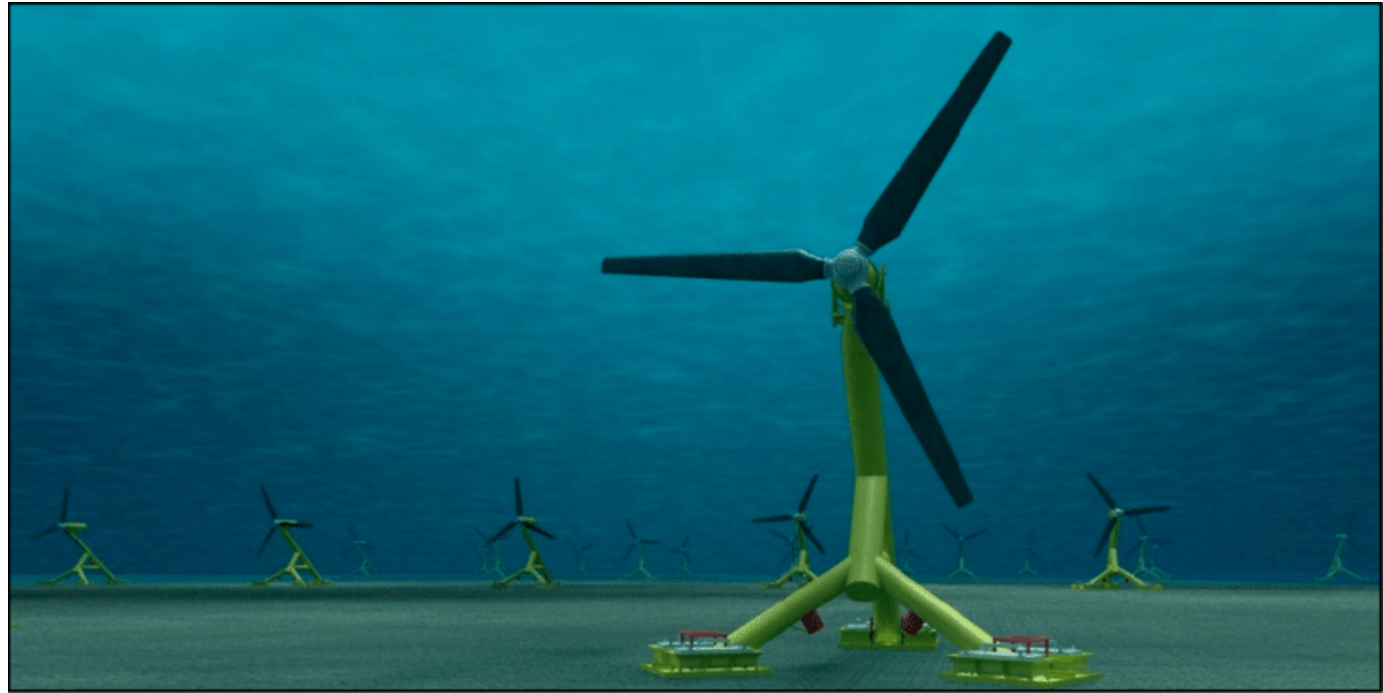
- When tides rise and fall, large volumes of water move horizontally between the ocean and coastal regions, creating strong, predictable currents.



TIDAL STREAM

Underwater Turbines:

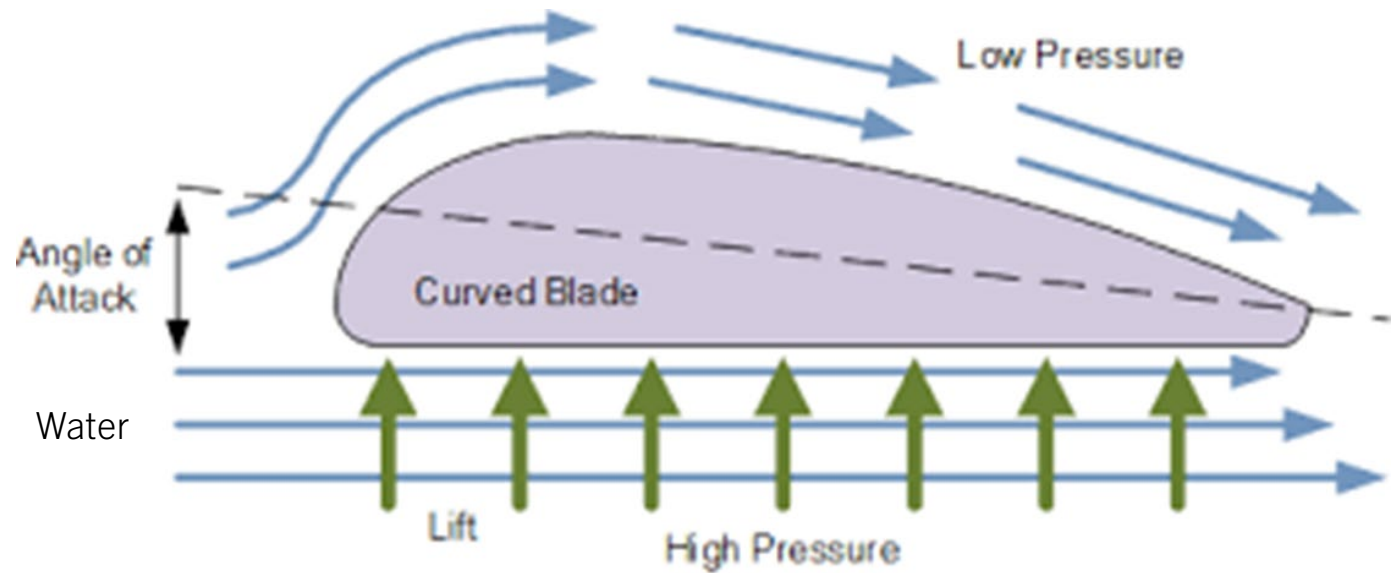
Turbines are anchored to the seabed or float in areas where currents are strongest (often between islands or narrow straits).



TIDAL STREAM

Blades rotate with the current:

The moving water turns the blades of the turbine.

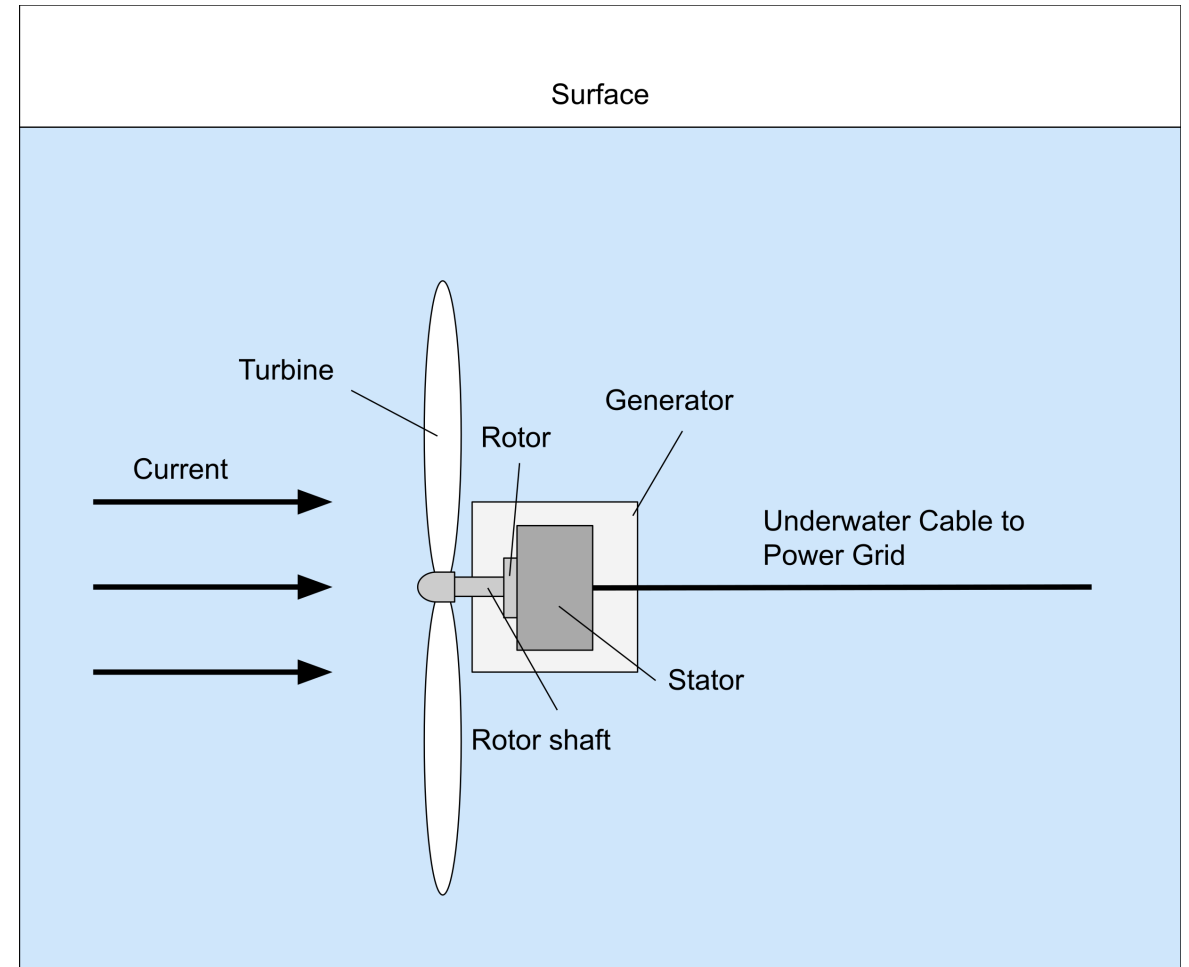


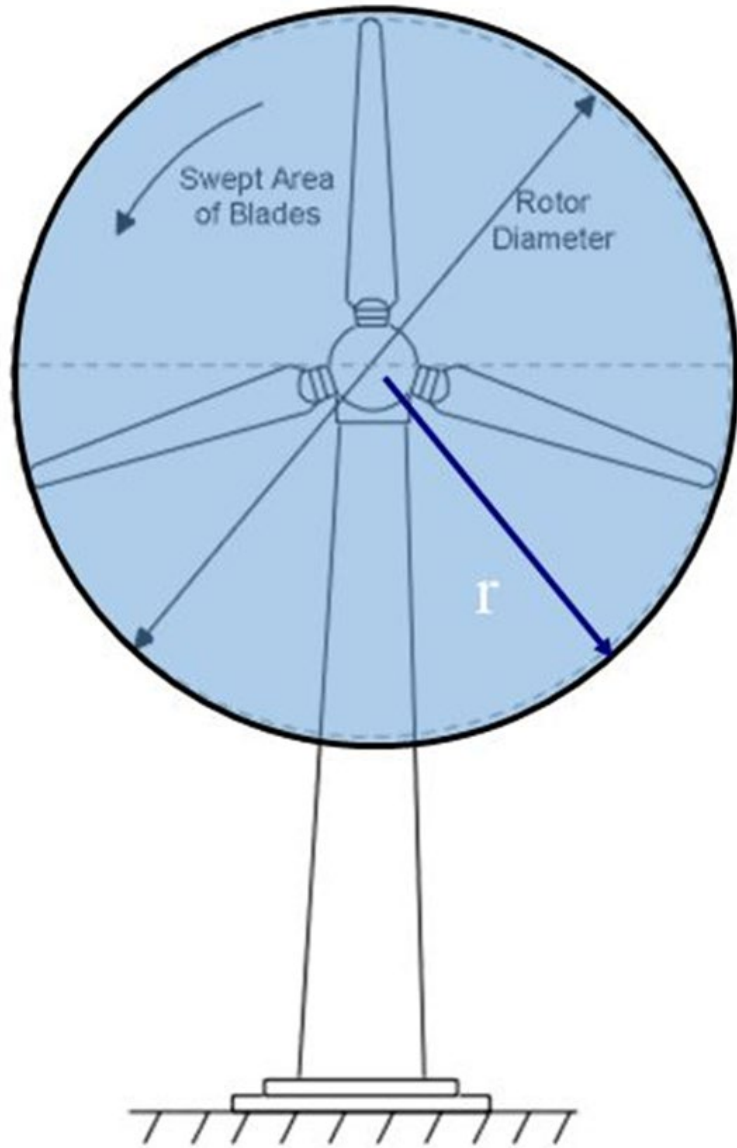
TIDAL STREAM

Turbine converts motion to electricity:

The rotor drives a generator (through a gearbox or direct drive).

The generator converts mechanical energy into electrical energy.





TIDAL STREAM

The potential power in the current is given by the following equation:

$$Power (W) = \frac{1}{2} \rho A v^3$$

Power = Watts

ρ = density of the seawater in kg/m³

A = cross-sectional area of the tidal stream turbine in m²

v = velocity of the tidal current in m/s

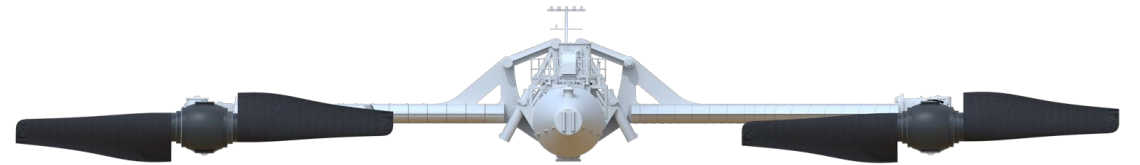
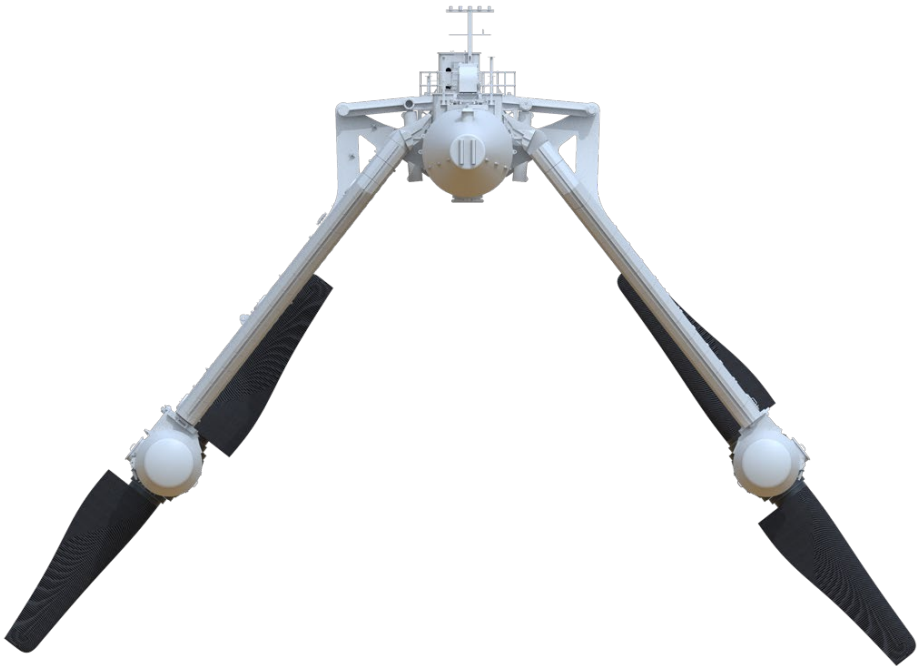
TIDAL STREAM – CASE STUDY

- Orbital, Scotland



TIDAL STREAM – CASE STUDY

- Orbital, Scotland



SITE SELECTION AND ENVIRONMENTAL CONSIDERATIONS



Tidal Site Analysis

Selecting tidal sites involves analysing tidal ranges and stream velocities for optimal energy generation.

Ecological Sensitivity

Assessment of ecological sensitivity is critical to minimise adverse impacts on marine life and habitats.

Environmental Impact

Consideration of sediment transport and water quality ensures sustainable tidal energy development.

Socio-Economic Impacts

Evaluating socio-economic impacts helps balance tidal energy projects with community well-being.

WAVE ENERGY TECHNOLOGIES

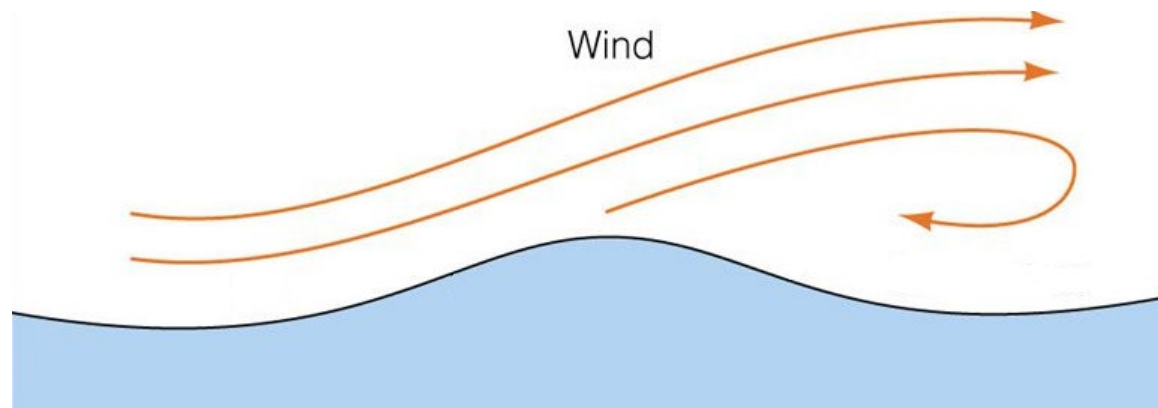


WAVE ENERGY

Wave energy is the power generated from the up-and-down (oscillating) movement of ocean surface waves.

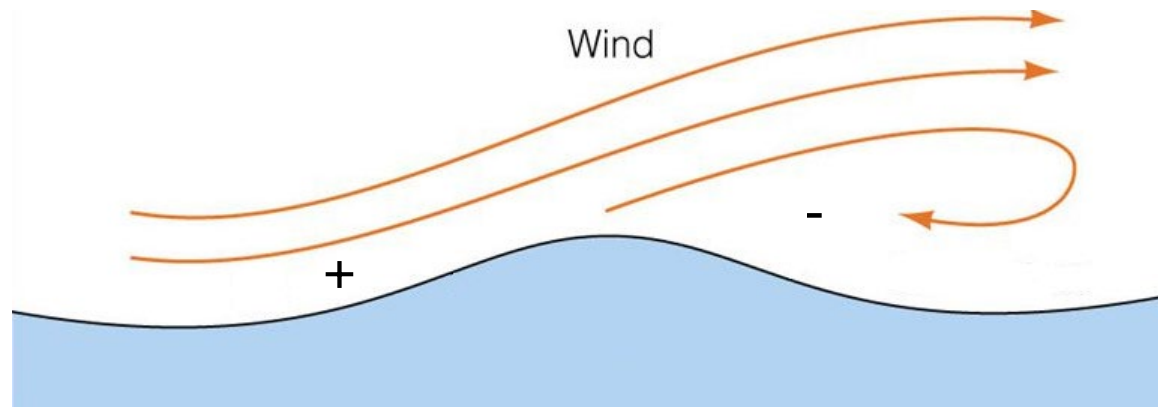
WAVE ENERGY

- Air flows over the sea, exerts a tangential stress, leading to formation and growth of waves.



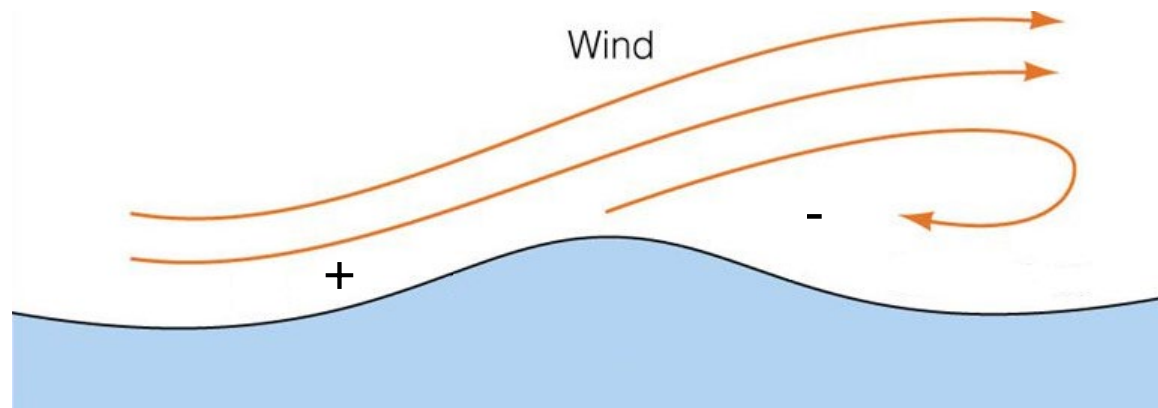
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WAVE ENERGY

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- Turbulent air flow close to water surface creates rapidly varying shear stresses and pressure fluctuation. When in phase with existing wave, they grow further.
- One waves are big enough, the force exerted by the wind increases causing further growth.



WAVE ENERGY

- Locally generated waves are called storm waves.

WAVE ENERGY

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- Waves can travel vast distances from their point of origin without losing energy, these are known as swell waves.

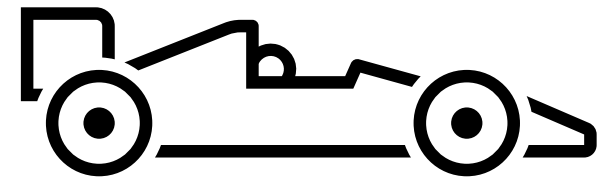
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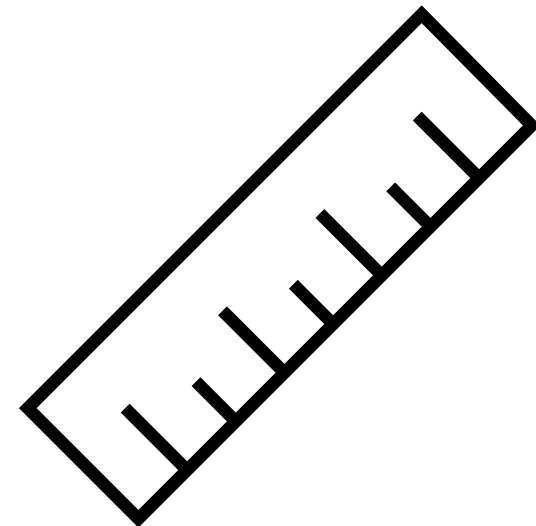
1. Wind Speed



WAVE ENERGY

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1. Wind Speed
2. Fetch



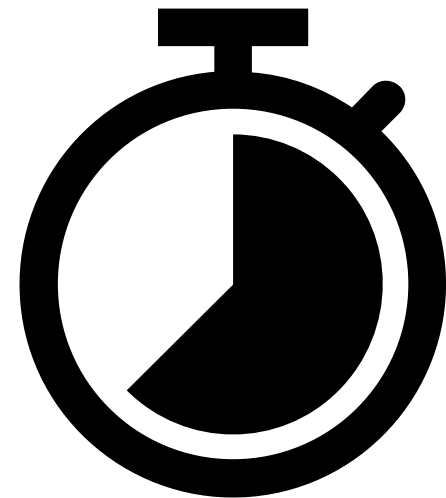
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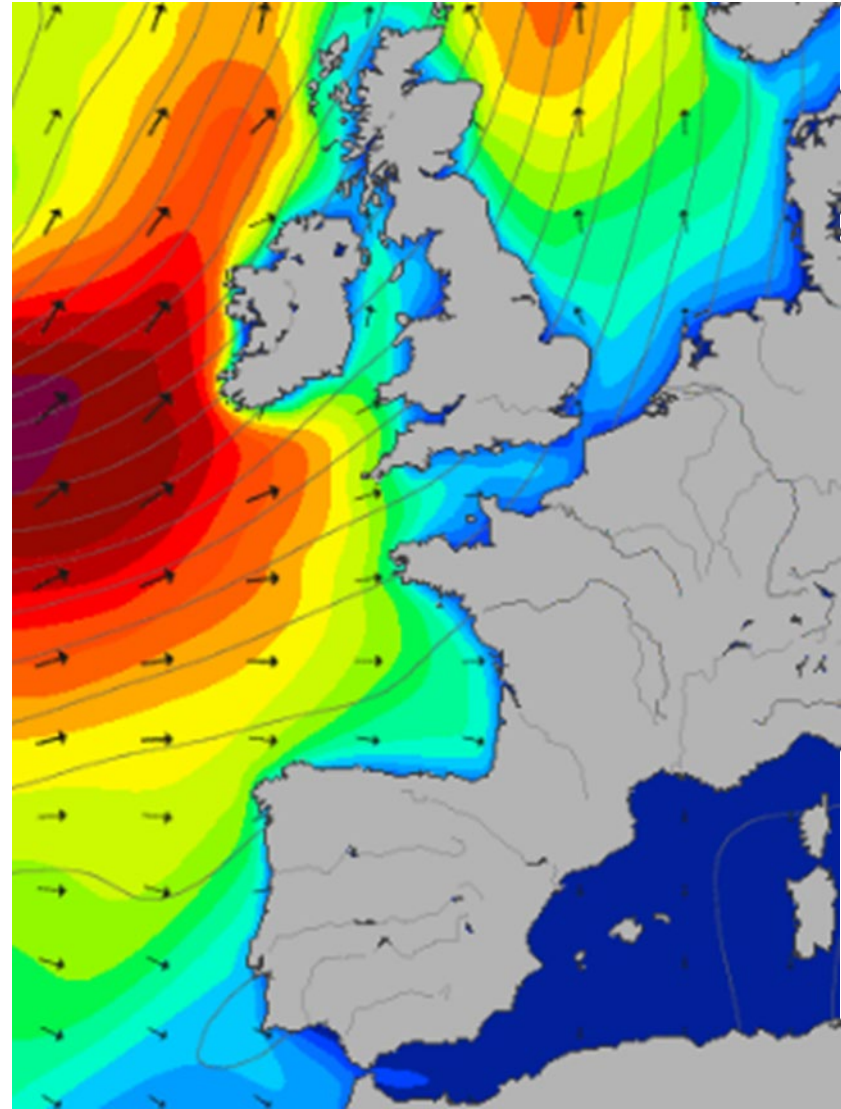
3. Duration



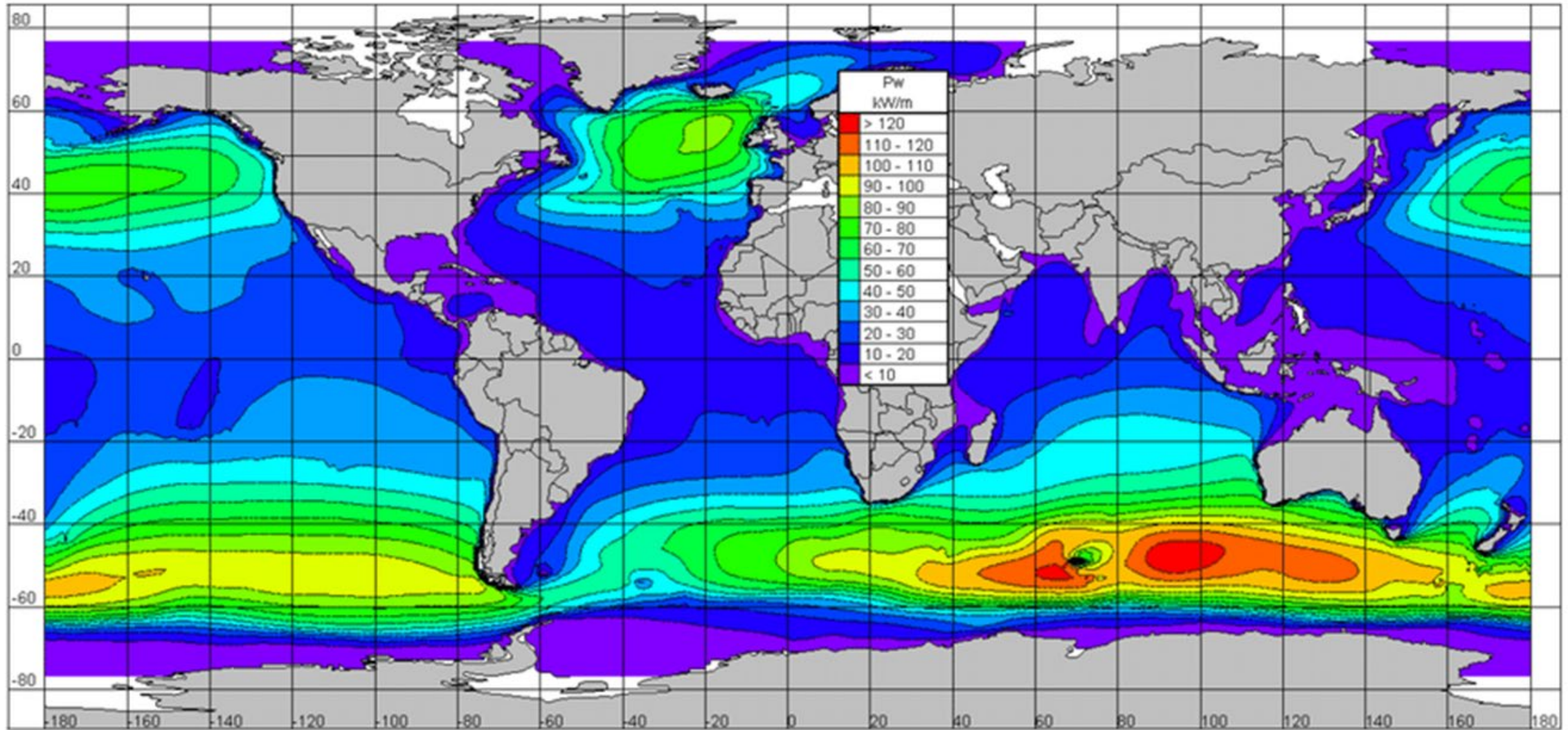
WAVE ENERGY



WAVE ENERGY



WAVE ENERGY



WAVE ENERGY

For a typical irregular sea, the average total power in one metre of wave crest is given by:

$$P = \frac{\rho g^2 H^2 T}{32\pi}$$

P = average power per metre of wave front (W/m)

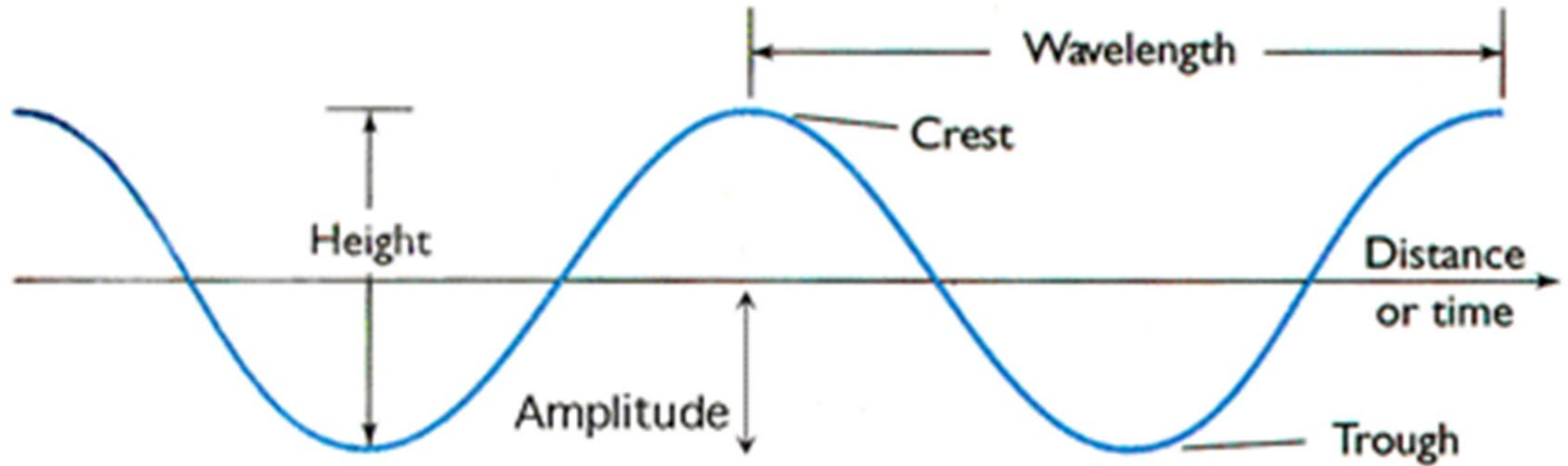
ρ = density of seawater

g = acceleration due to gravity

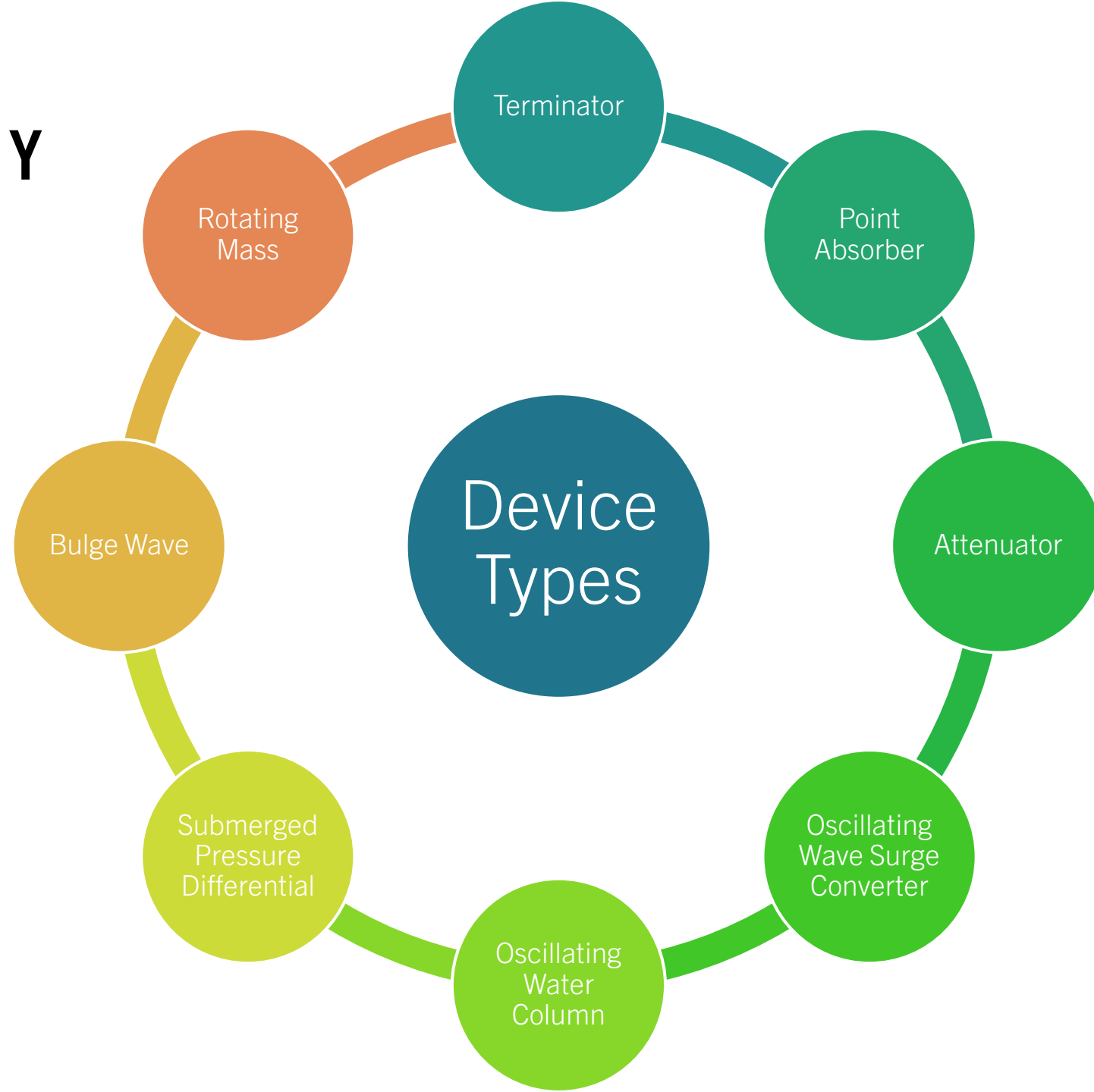
H = wave height (metres)

T = wave period (seconds)

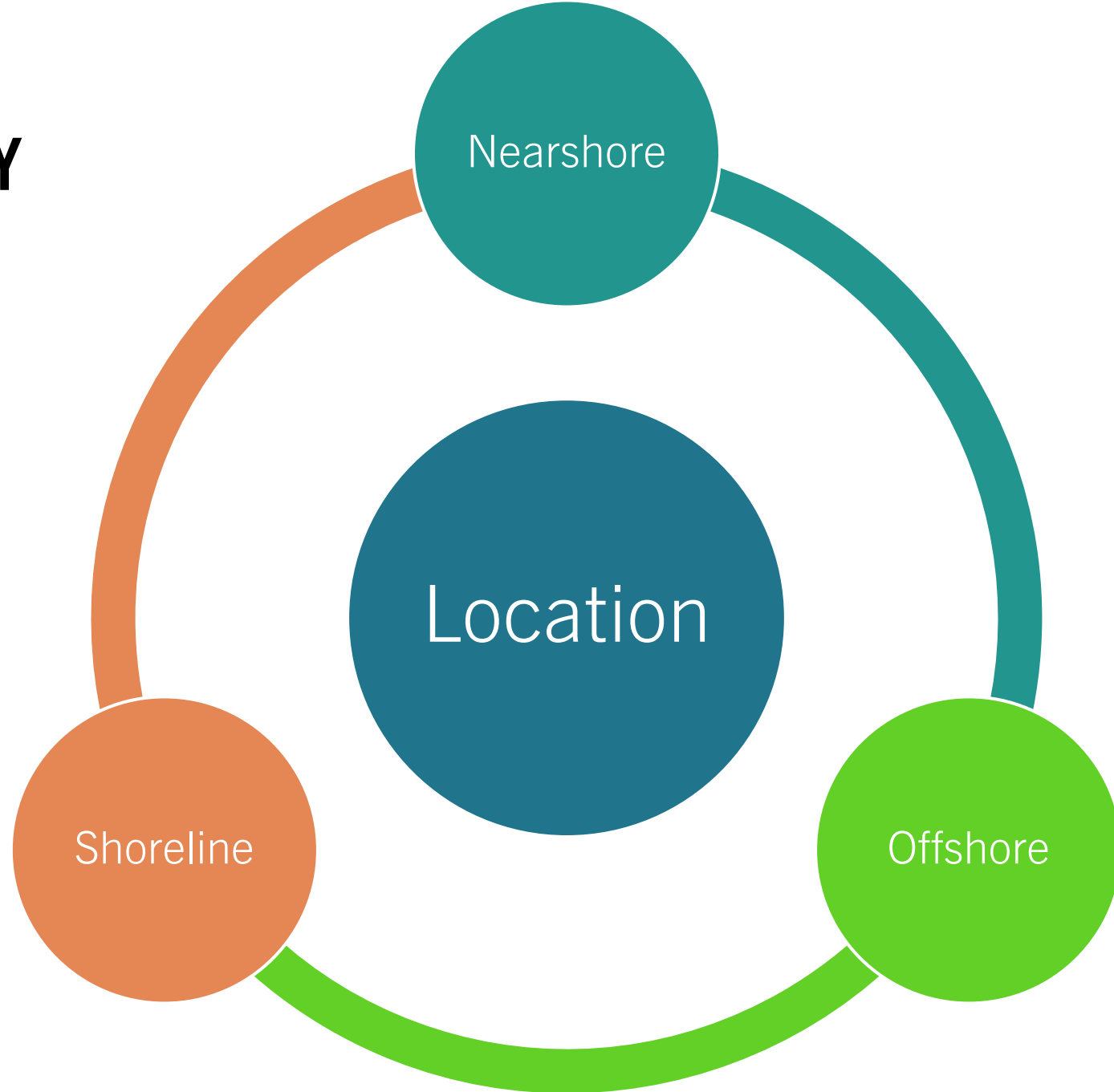
WAVE ENERGY



WAVE ENERGY



WAVE ENERGY

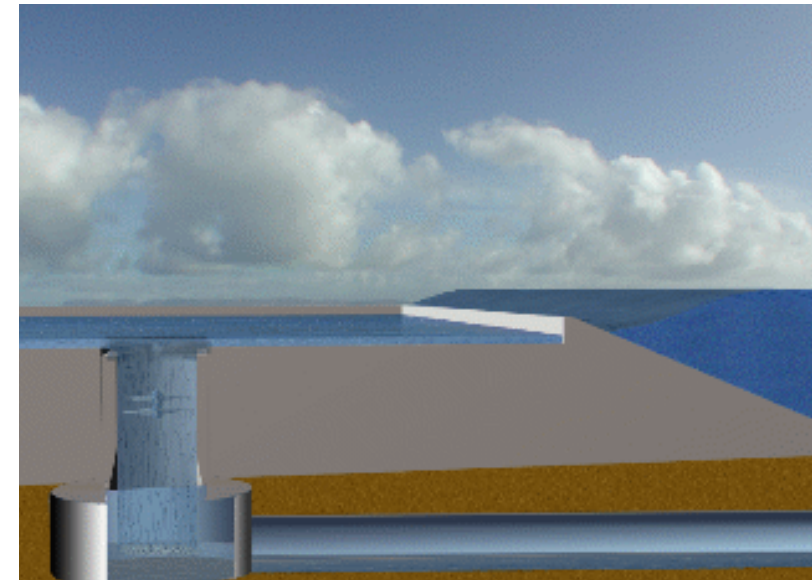


WAVE ENERGY

Offshore

Terminator

- Overtopping devices allow waves to overtop a structure.
- Water is captured as waves break into a storage reservoir.
- Water is returned to the sea passing through a conventional low-head turbine which generates power.
- An overtopping device may use 'collectors' to concentrate the wave energy.



WAVE ENERGY

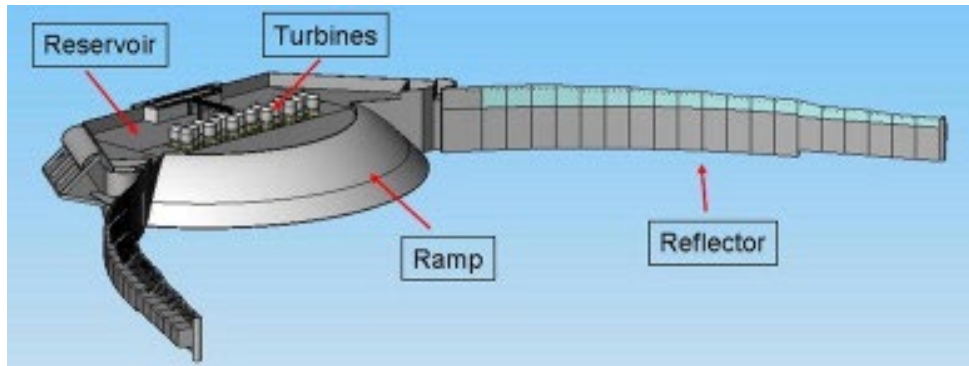
Offshore

Terminator

Wave Dragon

Location: Milford Haven, Wales

Capacity: 1.5 – 12 MW

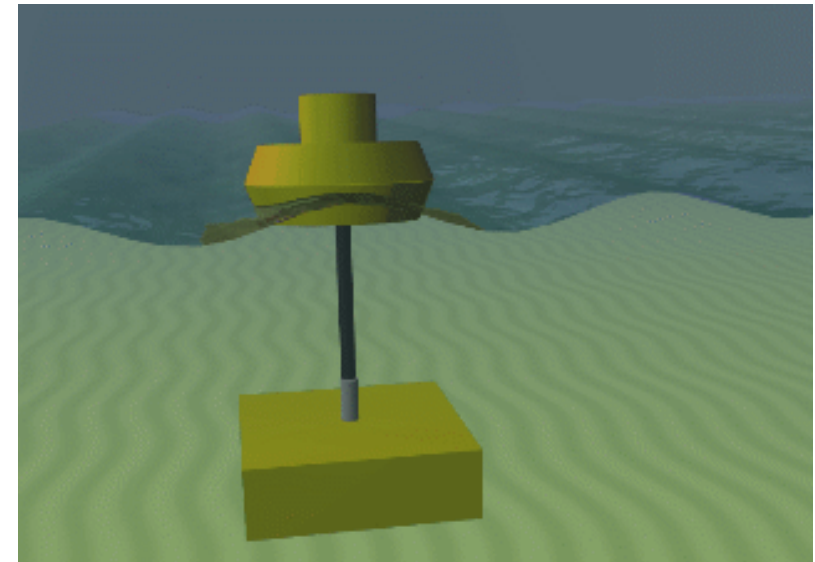


WAVE ENERGY

Offshore

- Surface point absorbers are floating structures that can absorb energy from all directions.
- Convert the motion of the buoyant top relative to the base into electrical power

Point
Absorber



WAVE ENERGY

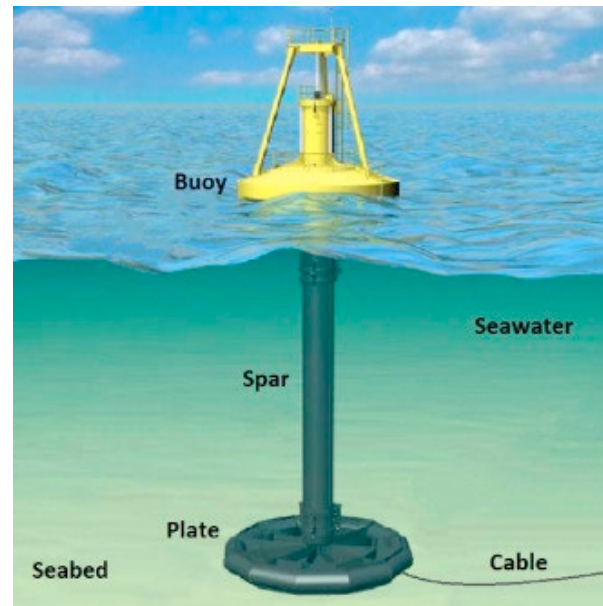
Offshore

Point
Absorber

Wave Buoy

Location: New Jersey, USA

Capacity: 3 – 15 KW

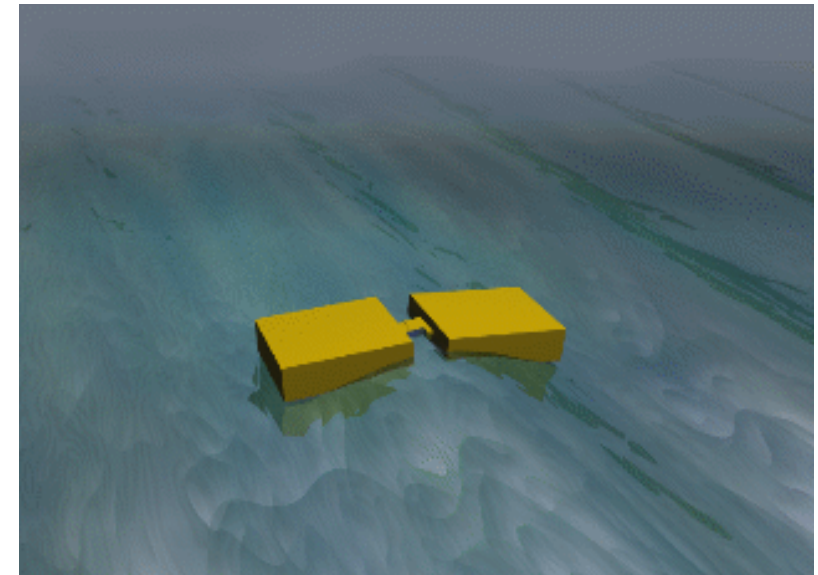


WAVE ENERGY

Offshore

- An attenuator is a floating device which operates parallel to the wave direction and effectively rides the waves.
- These devices capture energy from the relative motion of the two or more arms as the wave passes them

Attenuator



WAVE ENERGY

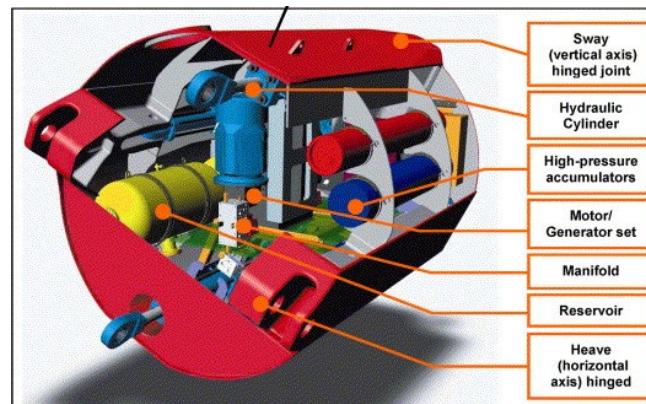
Offshore

Attenuator

Pelamis

Location: Orkney, Scotland

Capacity: 750 KW

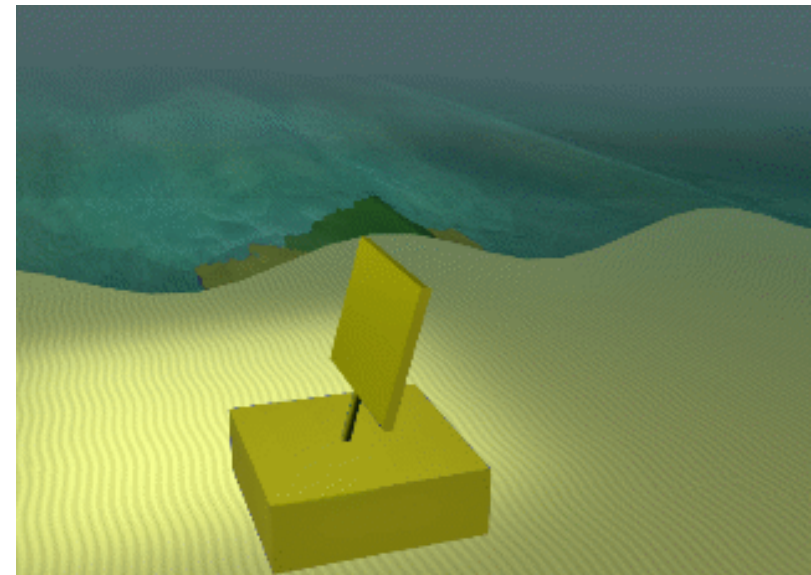


WAVE ENERGY

Nearshore

Oscillating
Wave
Surge
Converter

- Oscillating wave surge converters extract energy from wave surges and the movement of water particles within them.
- The flap moves back and forth on a hinge in response to the movement of water in the waves.



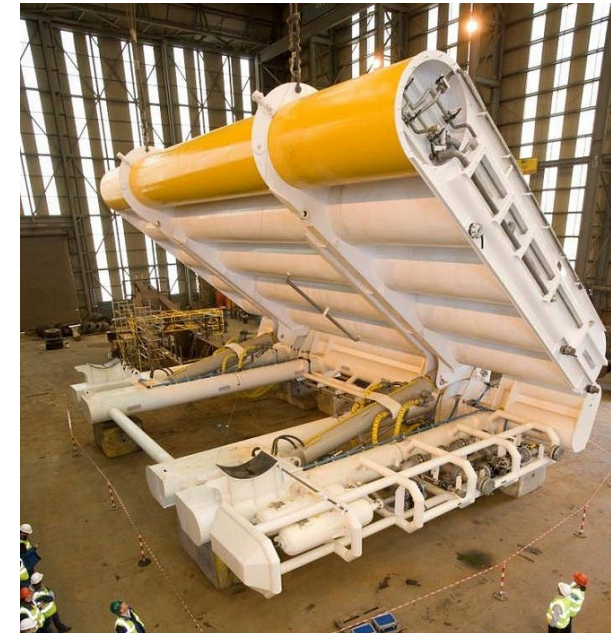
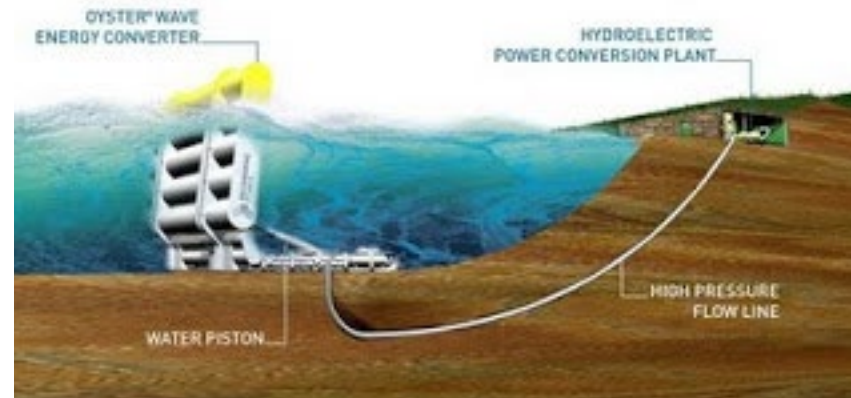
WAVE ENERGY

Nearshore

Oscillating
Wave
Surge
Converter

Oyster

Location: Orkney, Scotland
Capacity: 800 KW

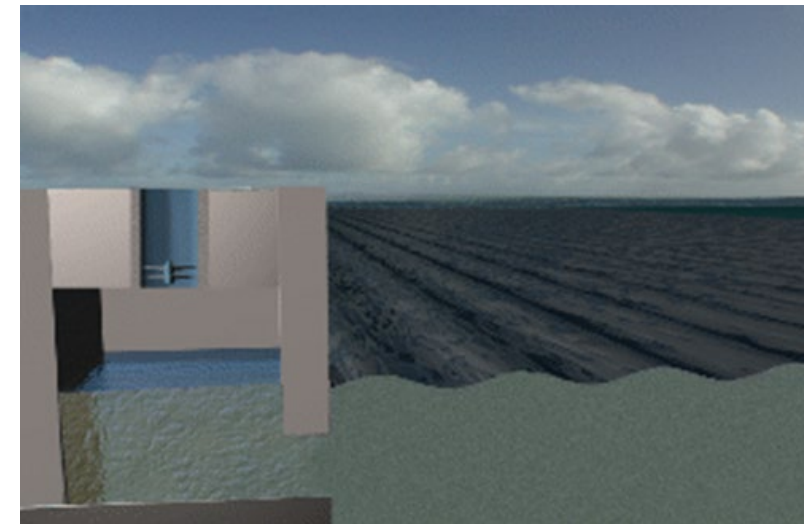


WAVE ENERGY

Shoreline

Oscillating
Water
Column

- Partially submerged, hollow structure.
- Open to the sea below the water line, enclosing a column of air on top of a column of water.
- Waves cause the water column to rise and fall, which in turn compresses and decompresses the air column.
- This trapped air is allowed to flow to and from the atmosphere via a turbine.
- The rotation of the turbine is used to generate electricity.



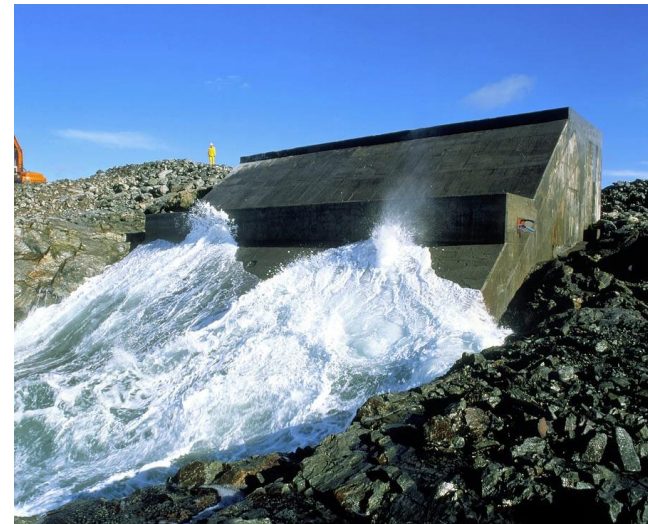
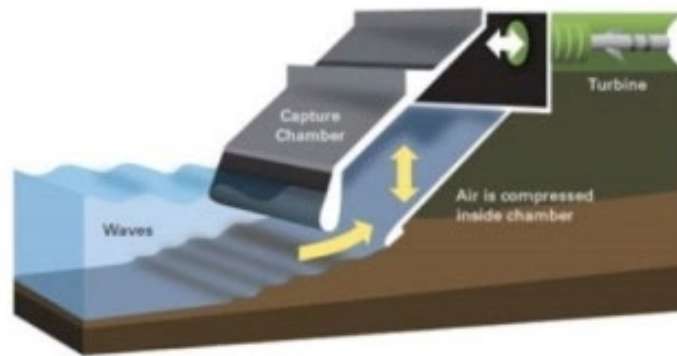
WAVE ENERGY

Shoreline

Oscillating
Water
Column

LIMPET

Location: Islay, Scotland
Capacity: 250 kW

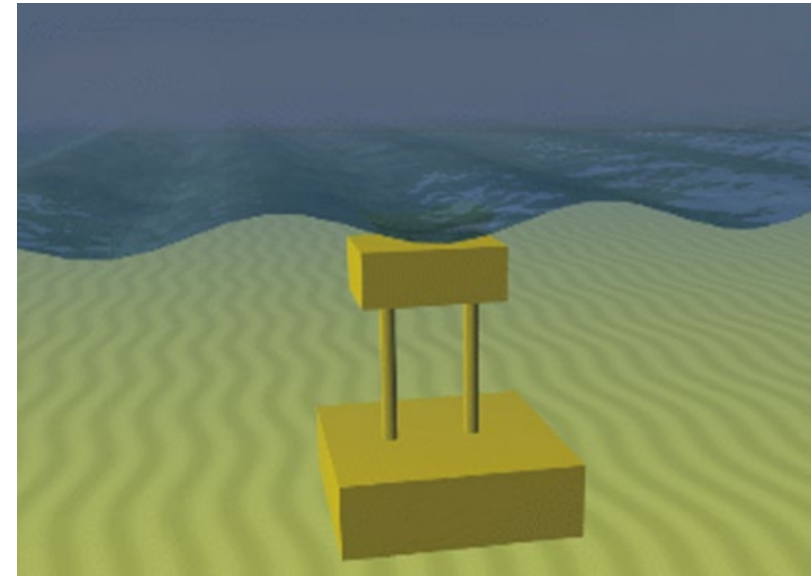


WAVE ENERGY

Nearshore

Submerged
Pressure
Differential

- Submerged pressure differential devices are typically located near shore and attached to the seabed.
- Motion of the waves causes the sea level to rise and fall above the device, inducing a pressure differential in the device.
- Alternating pressure pumps fluid through a system to generate electricity.



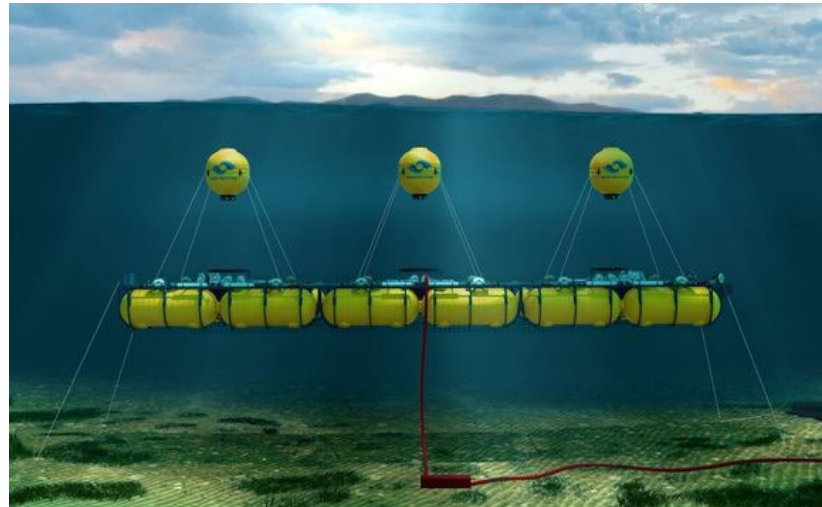
WAVE ENERGY

Nearshore

Submerged
Pressure
Differential

WaveSub

Location: Falmouth, England
Capacity: 5 MW

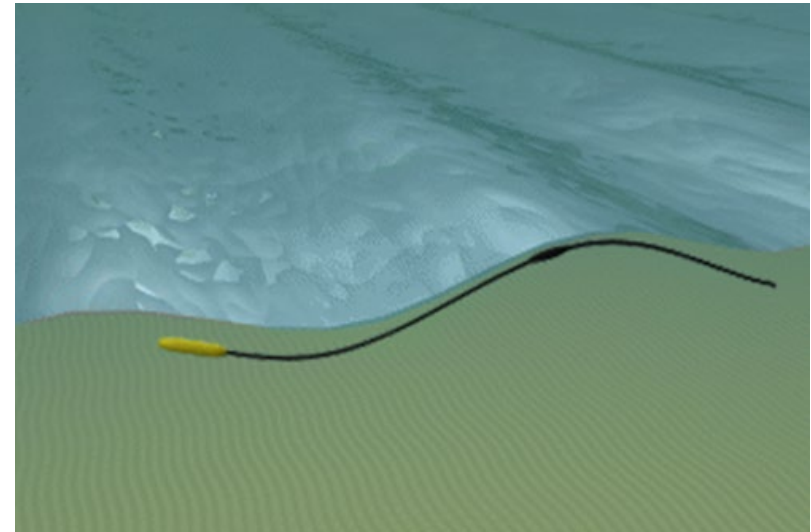


WAVE ENERGY

Offshore

Bulge
Wave

- Bulge wave technology consists of a rubber tube filled with water, moored to the seabed heading into the waves.
- Water enters at one end and the passing wave causes pressure variations along the length of the tube, creating a 'bulge'.
- As the bulge travels through the tube it grows, gathering energy which can be used to drive a standard low-head turbine located at the other end, where the water returns to the sea



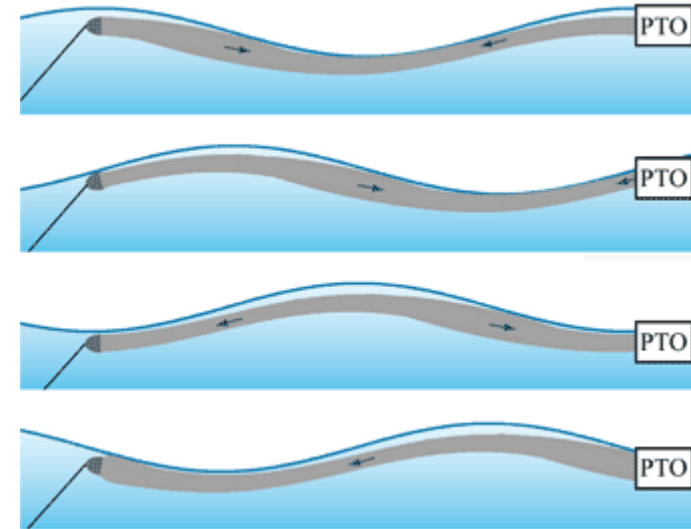
WAVE ENERGY

Offshore

Bulge
Wave

Anaconda

Location: N/A
Capacity: N/A

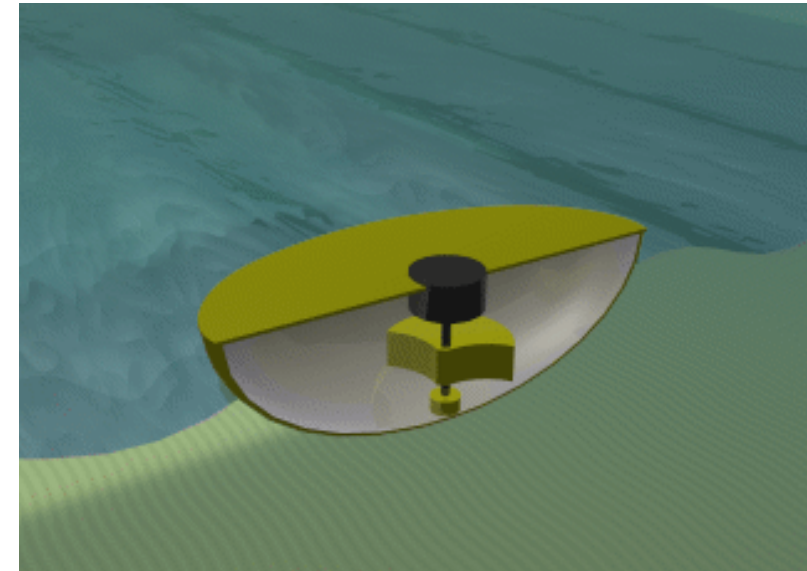


WAVE ENERGY

Offshore

Rotating
Mass

- Two forms of rotation are used to capture energy by the movement of the device heaving and swaying in the waves.
- This motion drives either an eccentric weight or a gyroscope causes precession.
- The movement is attached to an electric generator inside the device.



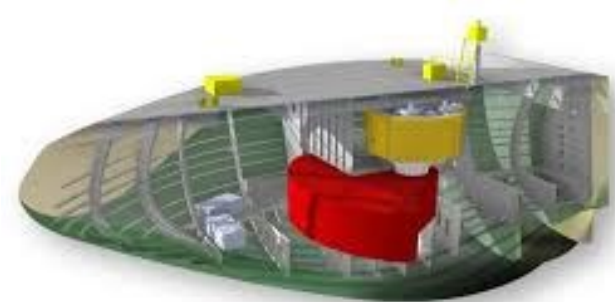
WAVE ENERGY

Offshore

Rotating
Mass

Penguin

Location: Orkney, Scotland
Capacity: 600 KW



WAVE ENERGY

WEC	Current commercial status	Notes
Wave Dragon	Inactive / company dissolved	Proof-of-concept only
Pelamis	Defunct company, tech retired	Early pioneering project, no roll-out
Anaconda	Active R&D, pre-commercial	Preparing sea trials, no commercial deployment yet
LIMPET	Demonstrator only	Historic site, no scaling
Oyster	Company ceased trading	Demonstrator only
WaveSub	Active development	Prototype completed, commercial stage yet to be reached
Penguin	Company bankruptcy	Demonstrator success, no commercial product

CHALLENGES AND ADVANCEMENTS IN WAVE ENERGY



Marine Environment Challenges

Wave energy devices must withstand harsh marine conditions including strong waves and corrosion.

Device Durability Issues

Improving the durability of wave energy devices is critical to reducing maintenance and operational costs.

Technological Advancements

Recent innovations include better materials and novel designs to enhance efficiency and durability.

Scalability and Integration

Pilot projects demonstrate wave energy scalability and potential for grid integration.

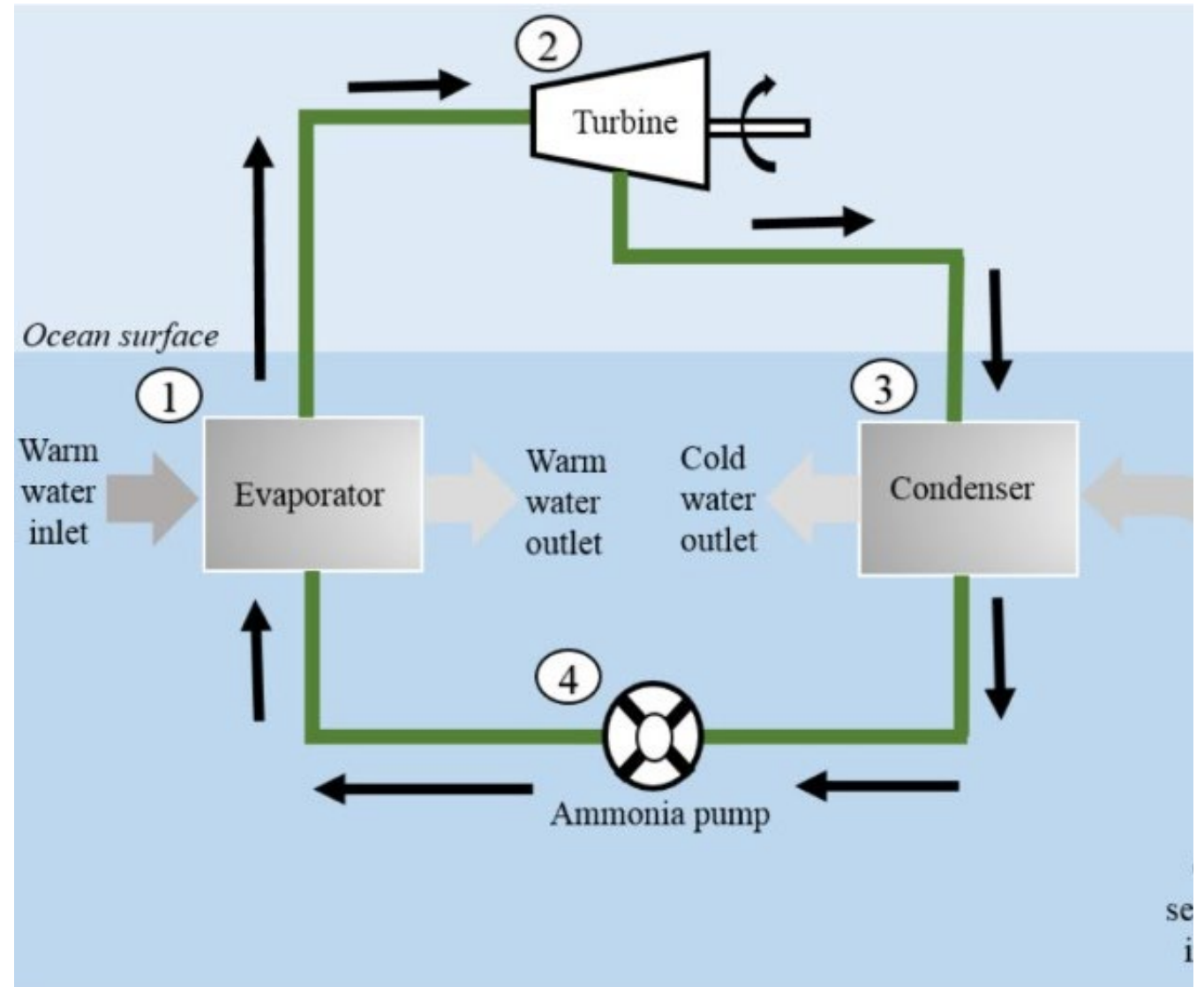
OCEAN THERMAL AND SALINITY GRADIENT POWER



OCEAN THERMAL ENERGY

OTEC uses the temperature difference between warm surface seawater (around 25–30 °C in the tropics) and cold deep seawater (about 4–5 °C) to run a heat engine and generate electricity.

OTEC

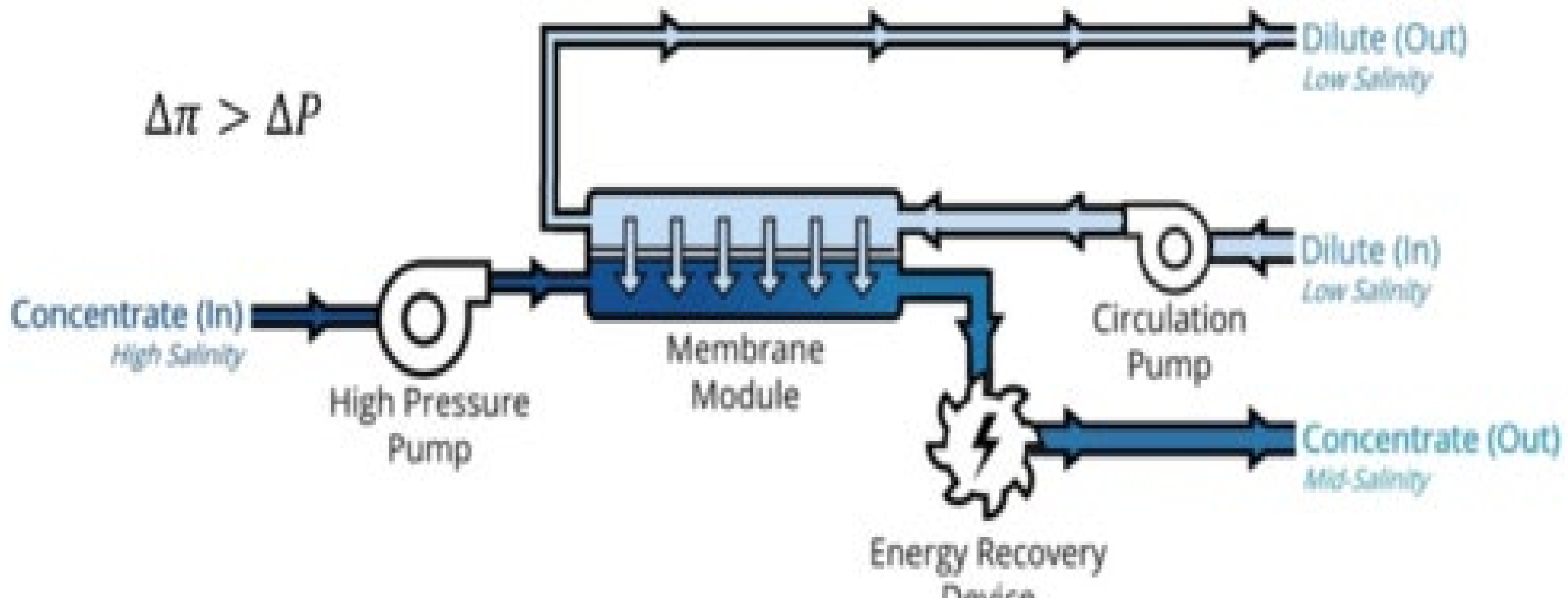




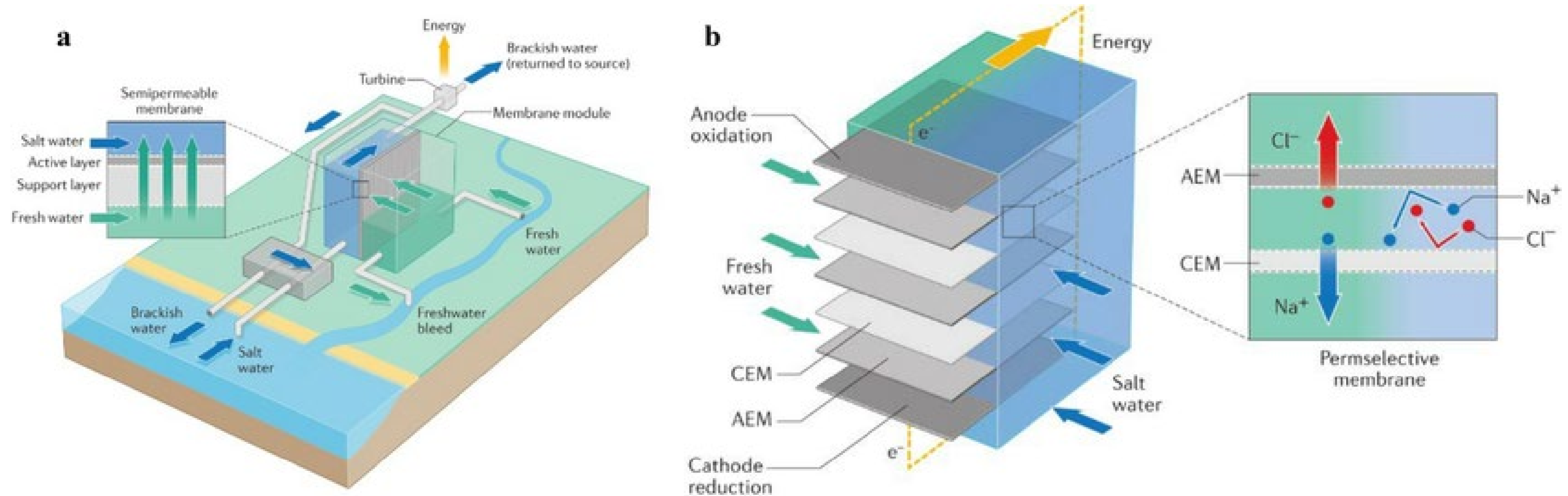
SALINITY GRADIENT

Salinity gradient power harnesses the chemical potential difference between freshwater and seawater to generate energy sustainably.

PRESSURE RETARDED OSMOSIS



REVERSE ELECTRODIALYSIS



INTEGRATION, CHALLENGES, AND FUTURE OUTLOOK



GRID INTEGRATION

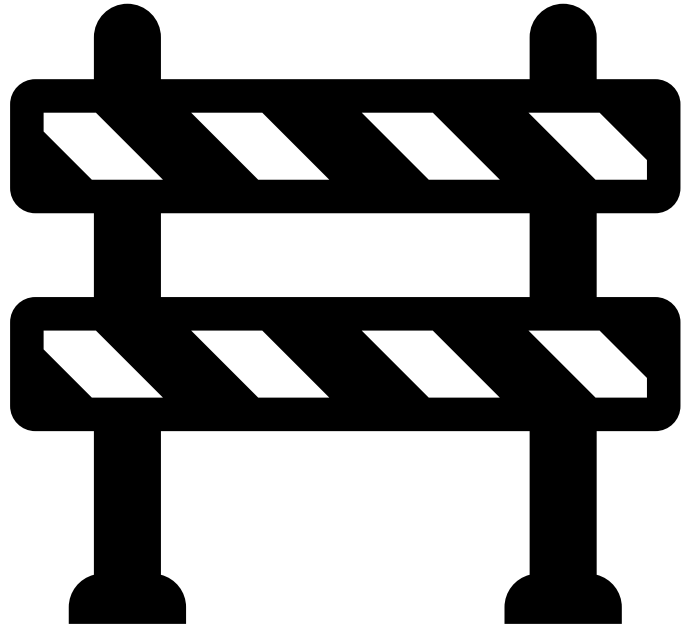
Integrating marine energy into power grids involves overcoming variability and transmission issues for reliable energy supply.



HYBRID SYSTEMS

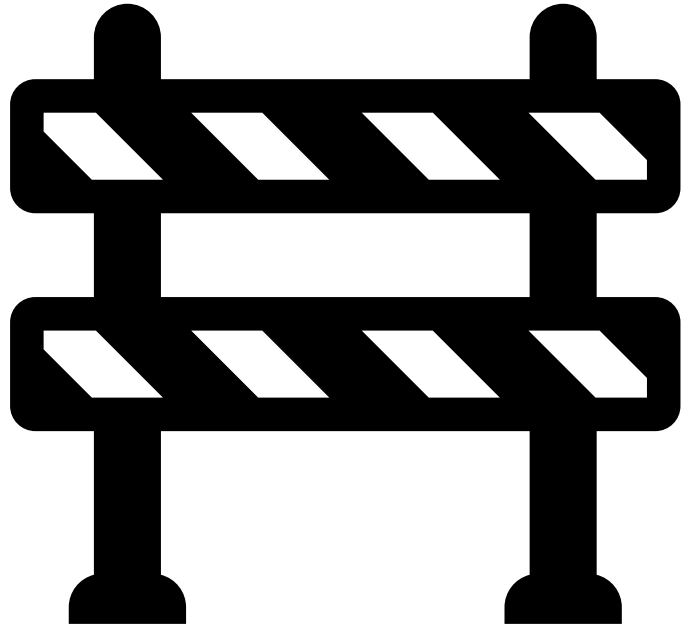
Hybrid systems combine multiple renewable sources to enhance grid stability and improve energy efficiency.

CHALLENGES



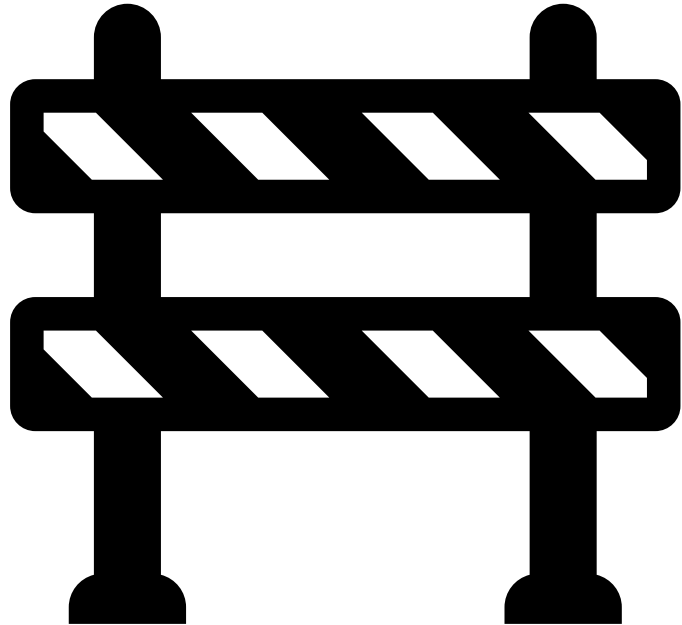
High capital costs are a major barrier that limit investment and project feasibility.

CHALLENGES



Permitting and environmental regulations add complexity and delay project approvals.

CHALLENGES



Issues like corrosion and maintenance challenge operational efficiency and longevity.