Ocean Energy

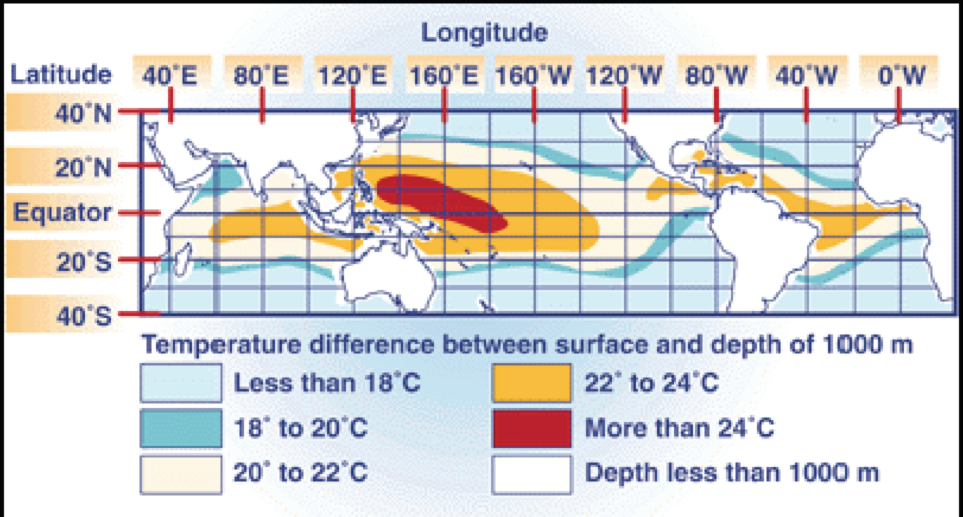
Text Book: sections 2.D, 4.4 and 4.5

Reference: *Renewable Energy by Godfrey Boyle, Oxford University Press, 2004.*

Ocean Energy

Oceans cover most of the (70%) of the earth's surface and they generate thermal energy from the sun and produce mechanical energy from the tides and waves.

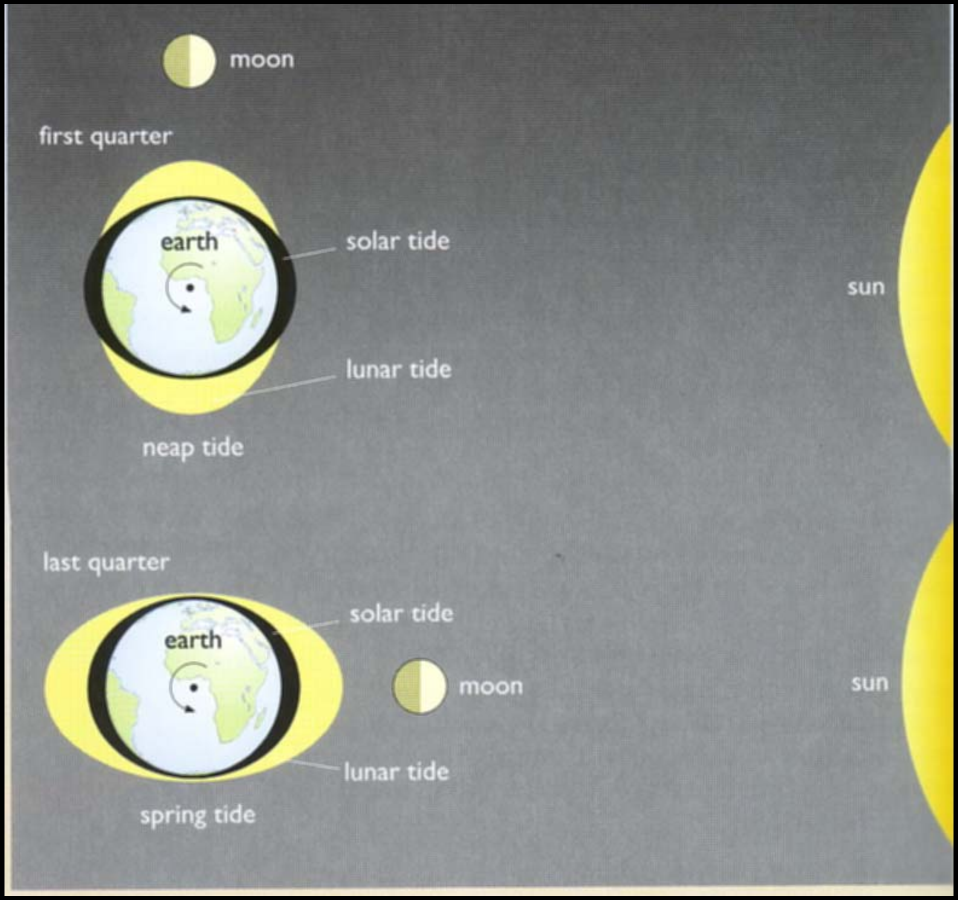
The solar energy that is stored in the upper layers of the tropical ocean, if harnessed can provide electricity in large enough quantities to make it a viable energy source.



World ocean temperature difference at a depth of 1000 m

This energy source is available throughout the equatorial zone around the world or about 20 degrees north and south of the equator - where most of the world's population lives.

Tides



The ocean tides are caused by the gravitational forces from the moon and the sun and the centrifugal forces on the rotating earth. These forces tend to raise the sea level both on the side of the earth facing the moon and on the opposite side. The result is a cyclic variation between flood (high) and ebb (low) tides with a period of 12 hours and 25 minutes or half a lunar day. Additionally, there are other cyclic variations caused by by the combined effect of the moon and the sun. The most important ones are the 14 days spring tide period between high flood tides and the half year period between extreme annual spring tides. Low flood tides follow similar cycles. The ocean bottom topography has pronounced effect on the local tides. The tides are accurately predictable.

Tidal Power Potential

Country	Mean tidal range/m	Basin area/ km^2	Installed capacity/ MW	Approx. annual output/ TWh per year	Annual plant load factor/%
Argentina					
San José	5.8	778	5040	9.4	21
Golfo Nuevo	3.7	2376	6570	16.8	29
Rio Deseado	3.6	73	180	0.45	28
Santa Cruz	7.5	222	2420	6.1	29
Rio Gallegos	7.5	177	1900	4.8	29
Australia					
Secure Bay	7.0	140	1480	2.9	22
Walcott Inlet	7.0	260	2800	5.4	22
Canada					
Cobequid	12.4	240	5338	14.0	30
Cumberland	10.9	90	1400	3.4	28
Shepody	10.0	115	1800	4.8	30
India					
Gulf of Kachchh (Kutch)	5.0	170	900	1.6	22
Gulf of Cambay (Khambat)	7.0	1970	7000	15.0	24
Korea (Rep)					
Garolim	4.7	100	400	0.836	24
Cheonsu	4.5	–	–	1.2	–
Mexico					
Rio Colorado	6–7	–	–	54	–
USA					
Passamaquoddy	5.5	–	–	–	–
Knik Arm	7.5	–	2900	7.4	29
Turnagain Arm	7.5	–	6500	16.6	29
Russian Federation					
Mezeh	6.7	2640	15000	45	34
Tugur[1]	6.8	1080	7800	16.2	24
Penzhinsk	11.4	20530	87400	190	25

1 7000 MW variant also studied

Adapted from a table on the World Energy Council website, http://worldenergy.org [accessed 23 December 2003]

The world potential for tidal power exceeds 450 TWh

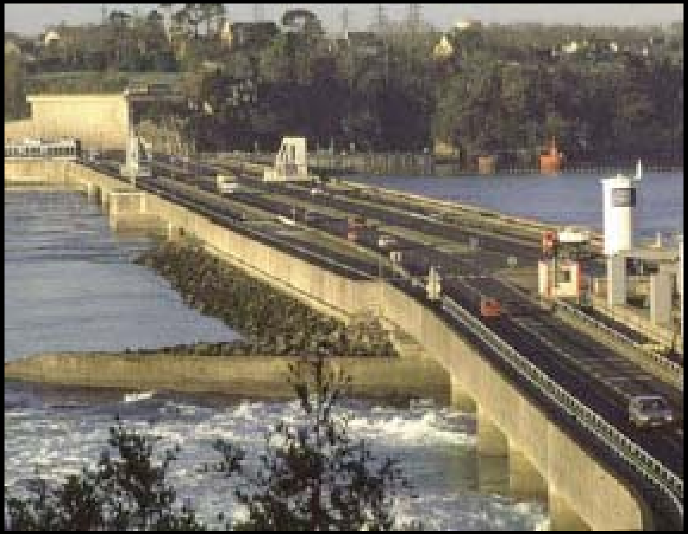
In the open ocean, the maximum amplitude of the tides is about one meter. Tidal amplitudes are increased substantially towards the coast, particularly in estuaries. This is mainly caused by shelving of the sea bed and funneling of the water by estuaries. In some cases the tidal range can be further amplified by reflection of the tidal wave by the coastline or resonance. This is a special effect that occurs in long, trumpet-shaped estuaries, when the length of the estuary is close to one quarter of the tidal wave length. These effects combine to give a mean spring tidal range of over 11 m in the Severn Estuary (UK). Tidal energy is highly predictable in both amount and timing.

The available energy is approximately proportional to the square of the tidal range. Extraction of energy from the tides is considered to be practical only at those sites where the energy is concentrated in the form of large tides and the geography provides suitable sites for tidal plant construction. Such sites are not commonplace but a considerable number have been identified in the UK, France, eastern Canada, the Pacific coast of Russia, Korea, China, Mexico and Chile. Other sites have been identified along the Patagonian coast of Argentina, Western Australia and western India.

Tidal Energy

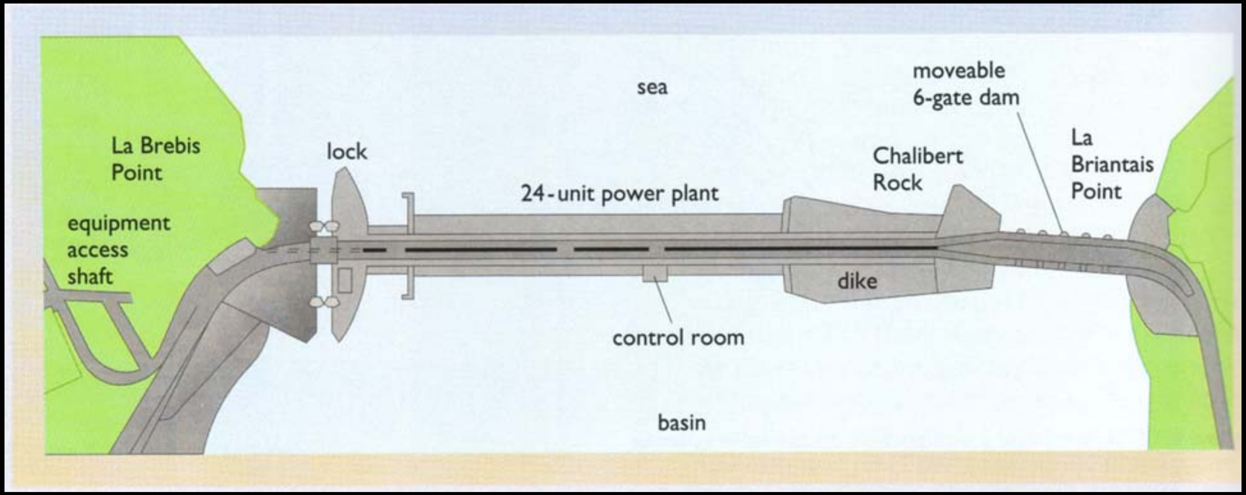
Tide mills were in use as far back as 1100 AD on the coasts of Spain, France and the UK. They consisted of a pond filled through a sluice during the flood or high tide and emptied on the ebb or low tide through an undershot water wheel.

Today, a tide mill consists of a semi-permeable barrage built across an estuary, allowing flood waters to fill a basin via a series of sluices. At high water the sluice gates are closed, creating a head of water on the low tide. Electricity is generated by releasing water through a series of conventional water turbines.



The La Rance tidal power station generates 240 MW power. The tides are caused by the Moon and the Sun moving around the Earth and so in many places the tides happen twice a day without fail. This means that it is a more reliable way of generating electricity than using wind or sunshine. Generating electricity this way doesn't produce any greenhouse gases that cause climate change.

La Rance Barrage



24 Reversible pump turbines

Maximum tidal range : 12 m

Typical water head = 5 m

Net output = 480 GWh per year

Typical electricity cost: 10 - 15 ¢ per kWh

Tidal Energy Types

Types of tidal energy:

The potential energy of sea level differences associated with the tides

Dams close off sea basins at flood or high tide and low head turbines through which the trapped water are released at low tide.

The kinetic energy of the tidal currents

Water mills submerged in the tidal stream - tidal stream turbines

The fluid power of the flow is given by:

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

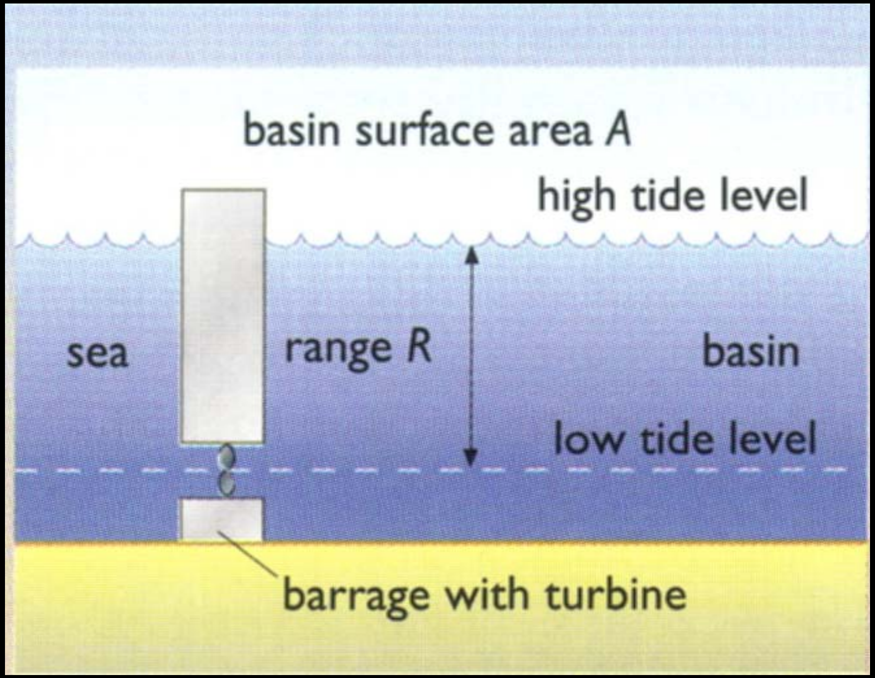
W/m²

1025 kg/m³ (ρ)

Area swept by turbine (A)

Tidal turbine

Tidal Power



The center of gravity for the mass of water will be at R/2 above the lower tide level.

Consider a rectangular basin with a constant surface area of *A.*

Tidal range: R

Total volume of basin water = AR

Mass = ρAR

Potential energy available = $\rho A R g\,(R/2)$

Tidal Period = T

Average potential energy extracted = $\rho A R^2 g/2T$

Wave Energy

Waves, particularly those of large amplitude, contain large amounts of energy. Wave energy is in effect a stored and concentrated form of solar energy, since the winds that produce waves are caused by pressure differences in the atmosphere arising from solar heating. The strong winds blowing across the oceans create large waves, making many coastal regions around the globe ideally suited to wave energy schemes. The global wave power resource is estimated to be about 2 TW with electricity generation potential of about 2000 TWh annually.

Air flowing over the sea exerts a tangential stress on the water surface resulting in the formation and growth of waves

Turbulent air flow close to the water surface creates rapidly varying shear stresses causing ripples, known as capillary waves. Capillary waves create more water surface increasing the friction between water and wind. This adds more energy, which increases the size of the waves, making them larger and larger.

When the winds slow down or stop, the waves continue their journey, gradually but very slowly losing their energy. Waves may travel thousands of km before rolling ashore. This predictability of waves is one of the advantages of wave energy as an energy source.

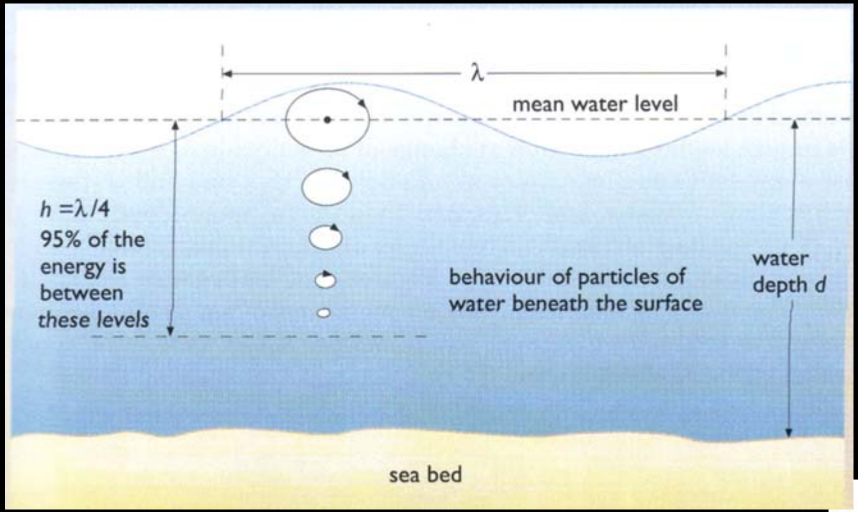
An ocean wave in deep water appears to be a massive moving object - a crest of water traveling across the sea surface. An ocean wave is the movement of energy. Out in the ocean where waves move the water's surface up and down, the water is not moving towards the shore. So, an ocean wave does not represent a flow of water. Instead it represents a flow of motion or energy from its origin to its eventual break up. This break up may occur in the middle of the ocean or against the coast.

Wave Energy

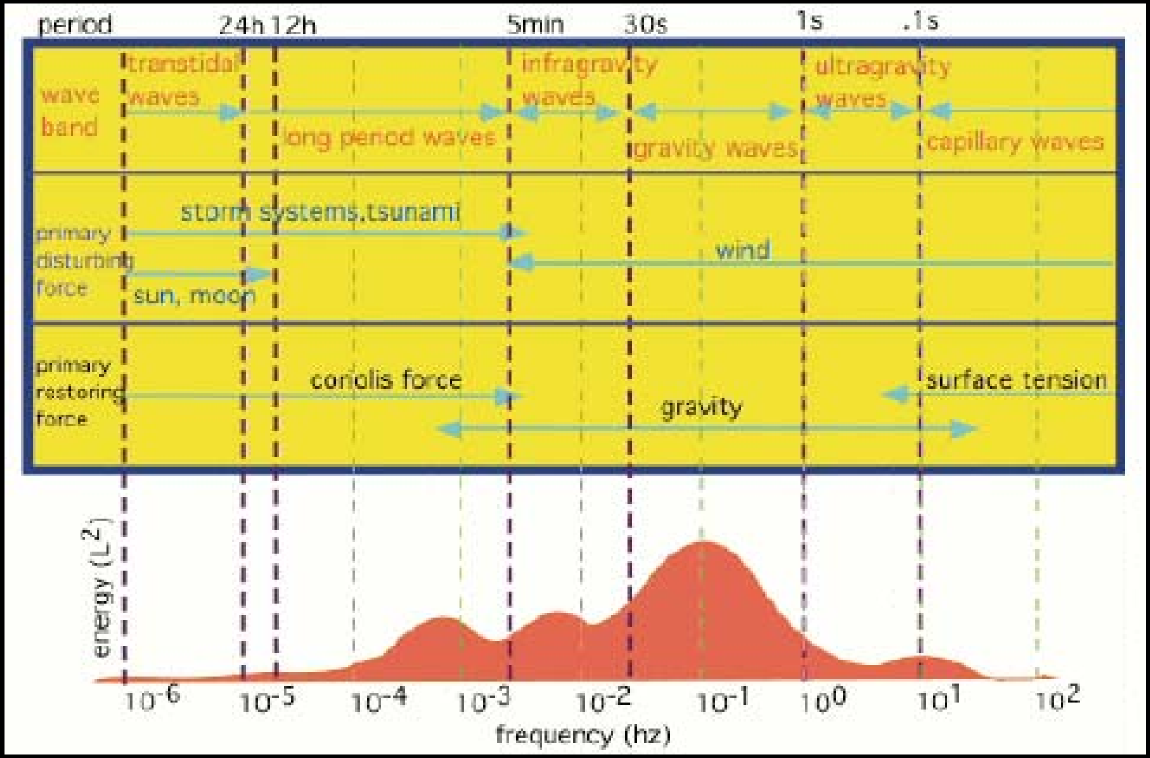
The water molecules in an ocean wave move in circles. The behavior of waves depends largely on the relationship between a wave's size and the depth of water through which it is moving. The movement of water molecule changes from circular to ellipsoidal as a wave approaches the coast and water depths decrease. Eventually when the wave rolls up on a beach - and when most of us observe waves - the movement is mostly horizontal. When talking of ocean wave, and a potential deployment of Wave Dragon, the influence of water depth is negligible. Ocean waves are as mentioned above essential movement of energy. Waves consist of two kinds of energy.

The individual water molecules are moving steadily and rather slowly in a circular way, and this energy - kinetic energy - can be utilized in different kinds of wave energy converters, either directly via some kind of propeller or indirectly by Oscillating Water Columns wave energy converters

In its circular movement the individual water molecules are elevated above the still-water line and thus represent a potential energy.

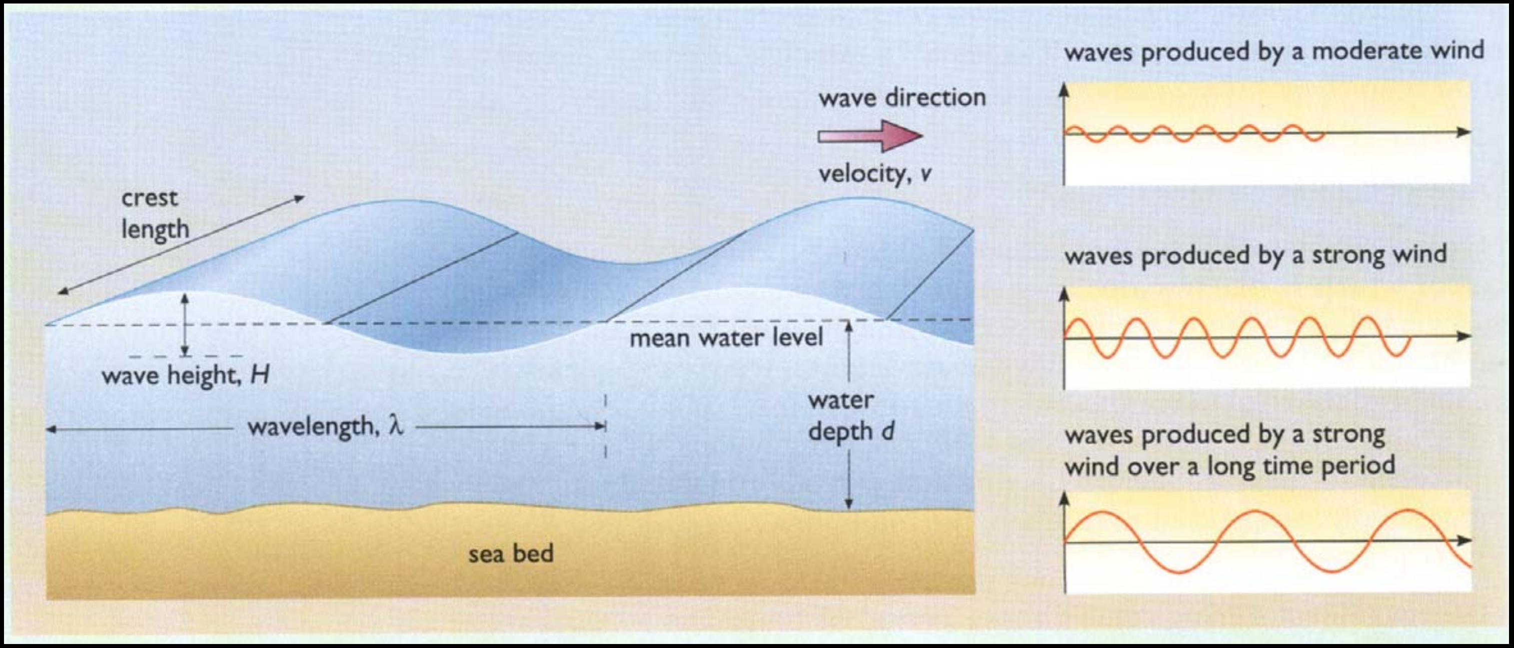


Distribution of Ocean Surface Wave Energy



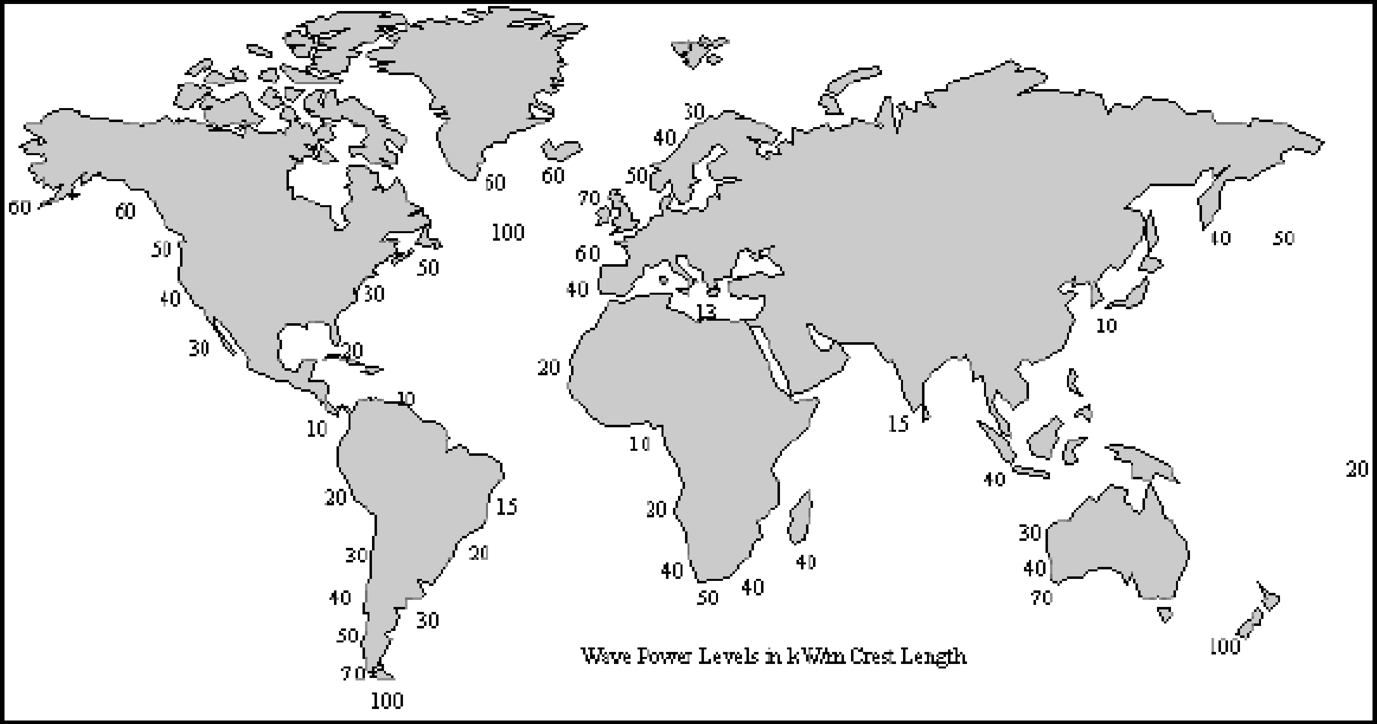
Source: Kinsman, 1965

Wave Power



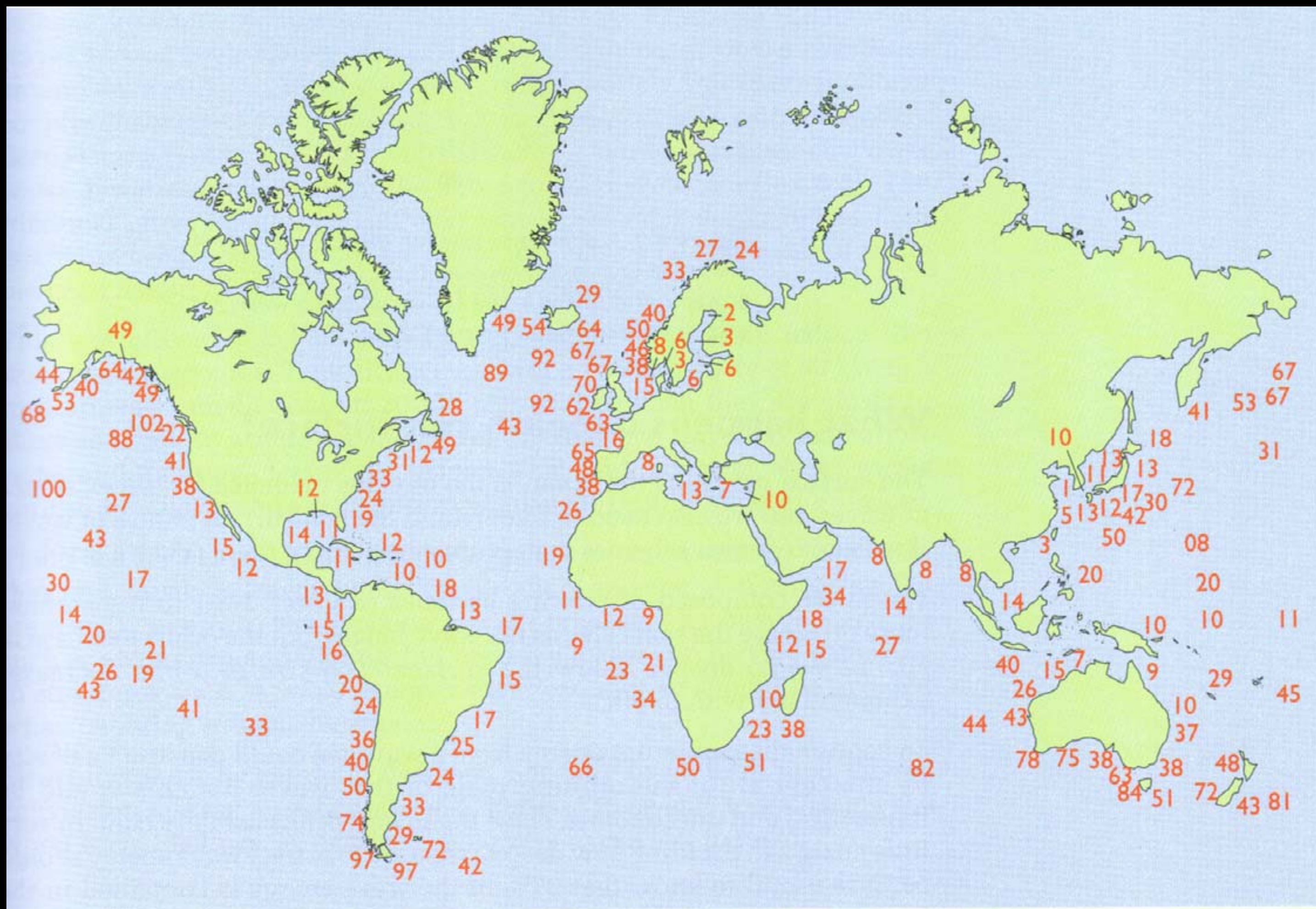
Power, $P = (\rho g^2 H^2 T)/32\pi$ W/m ; T= wave period

Deep Water Wave Power Sources

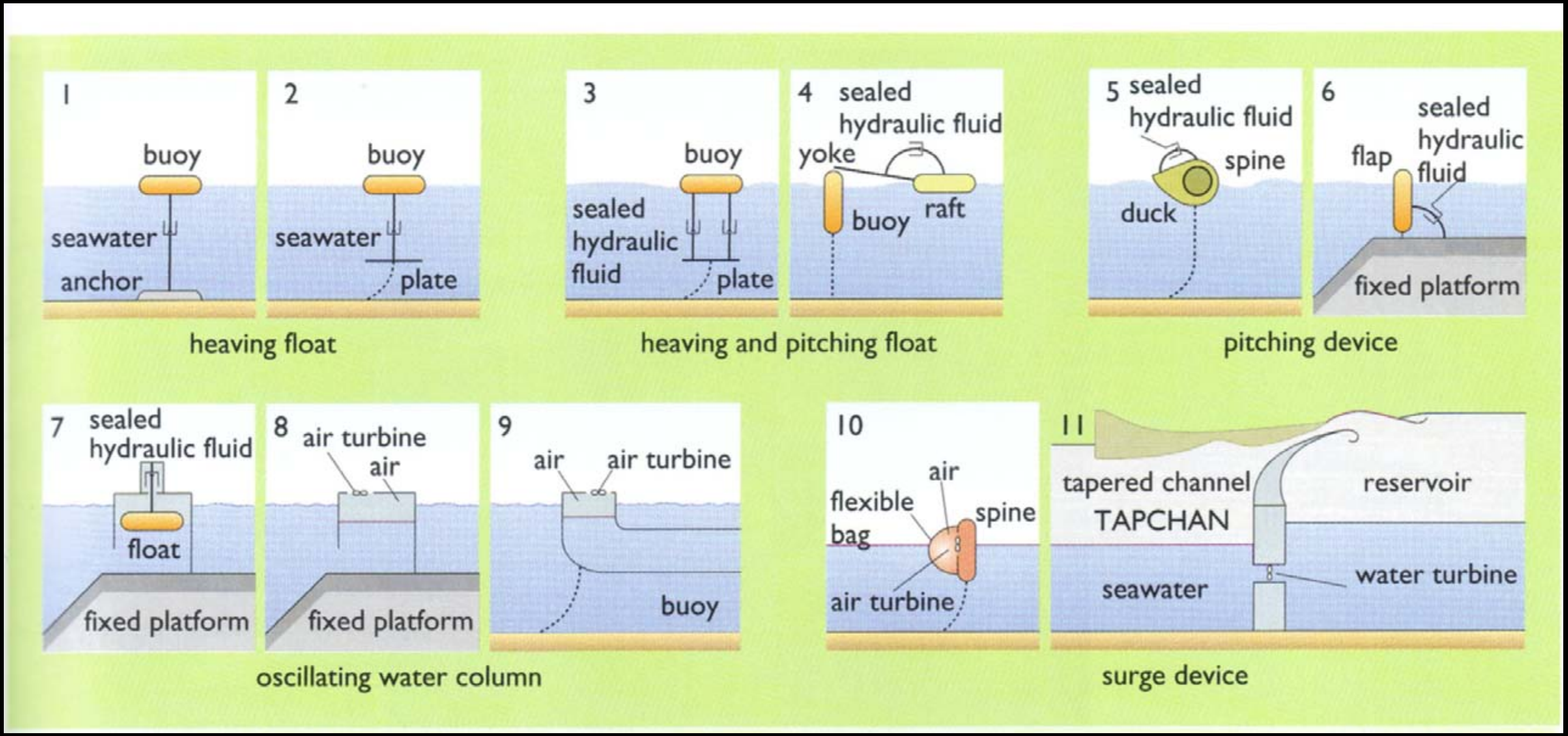


The highest energy waves are concentrated off the western coasts in the 40º–60º latitude range north and south. The power in the wave fronts varies in these areas between 30 and 70 kW/m with peaks to 100kW/m in the Atlantic SW of Ireland, the Southern Ocean and off Cape Horn. The capability to supply electricity from this resource is such that, if harnessed appropriately, 10% of the current level of world supply could be provided.

Global Wave Power Sources



Wave Energy Conversion Types



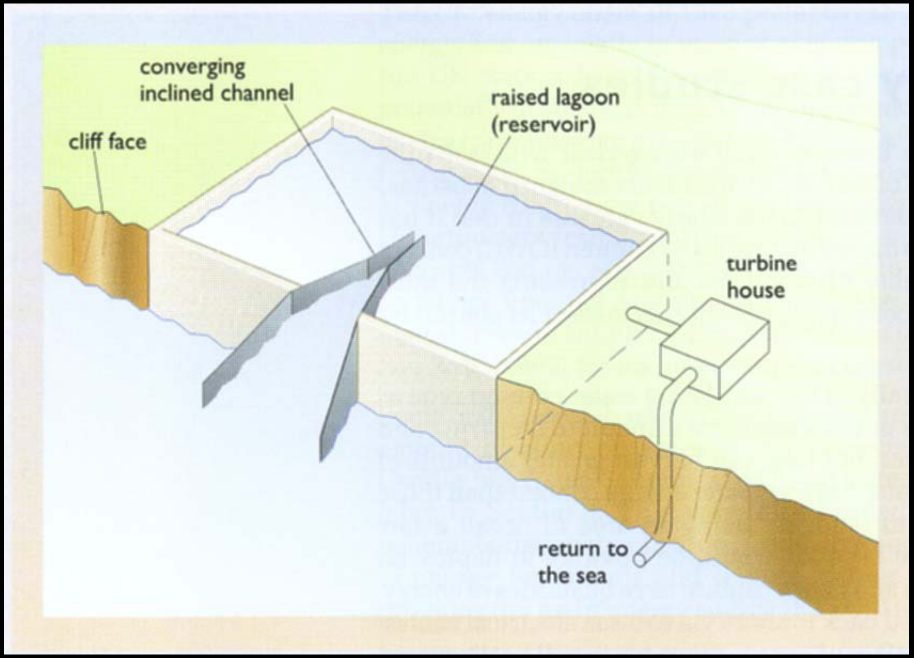
Wave Energy Devices

Shoreline devices - Oscillating water column (OWC); the convergent channel (TAPCHAN); Pendulum

Near shore devices - situated in shallow waters, typically 10 - 25 m

Off shore devices - situated in deeper water, typically > 40 m

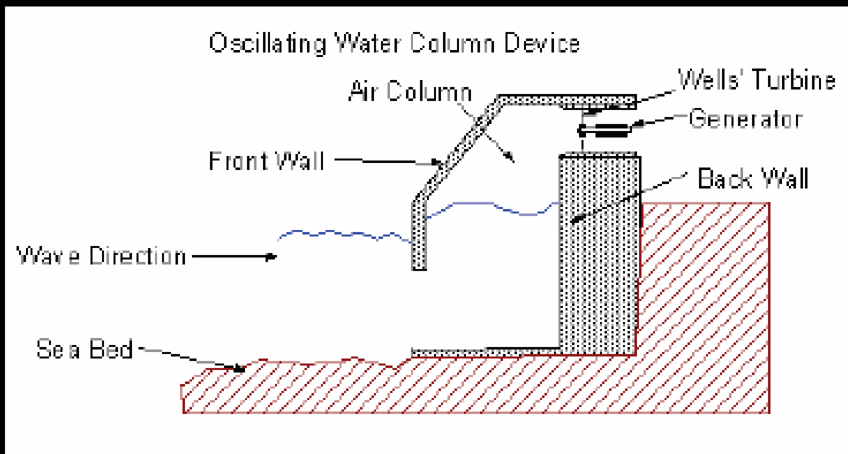
TAPCHAN

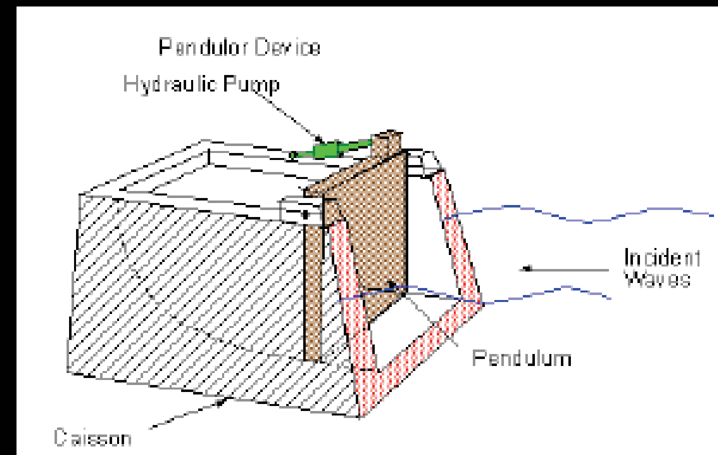


The tapered channel wave energy conversion device:

The Tapchan comprises a gradually narrowing channel with wall heights typically 3 to 5 m above mean water level. The waves enter the wide end of the channel and, as they propagate down the narrowing channel, the wave height is amplified until the wave crests spill over the walls to a reservoir which provides a stable water supply to a conventional low head turbine. The requirements of low tidal range and suitable shoreline limit the use of this device.

Shoreline Devices

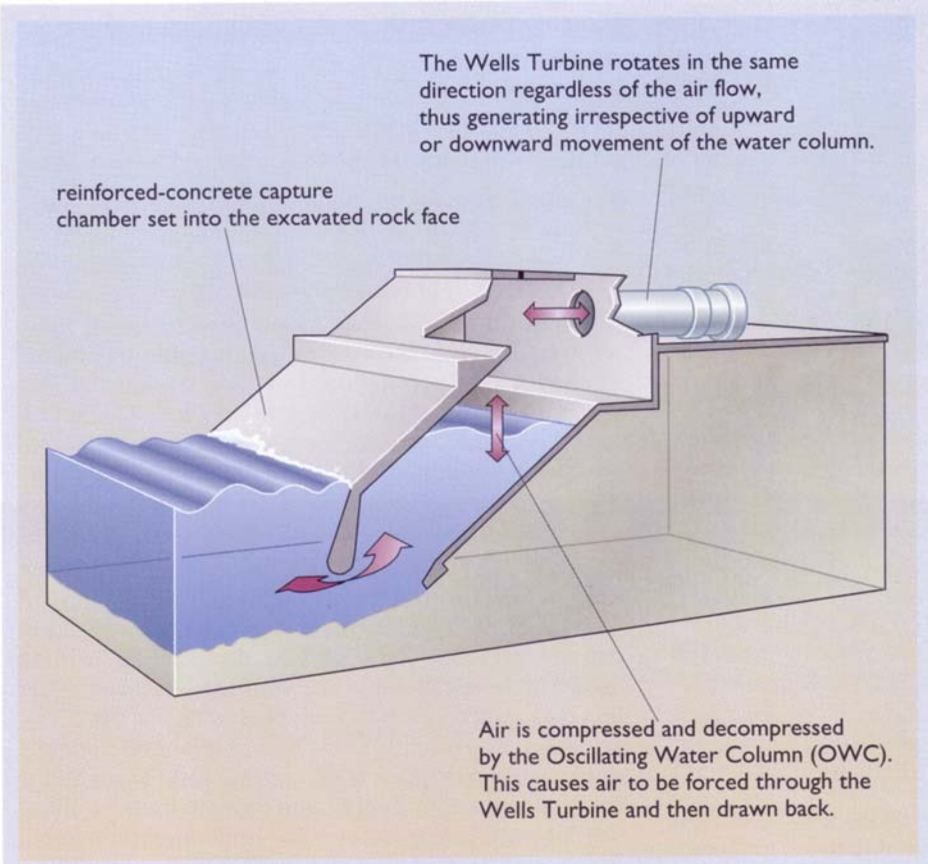


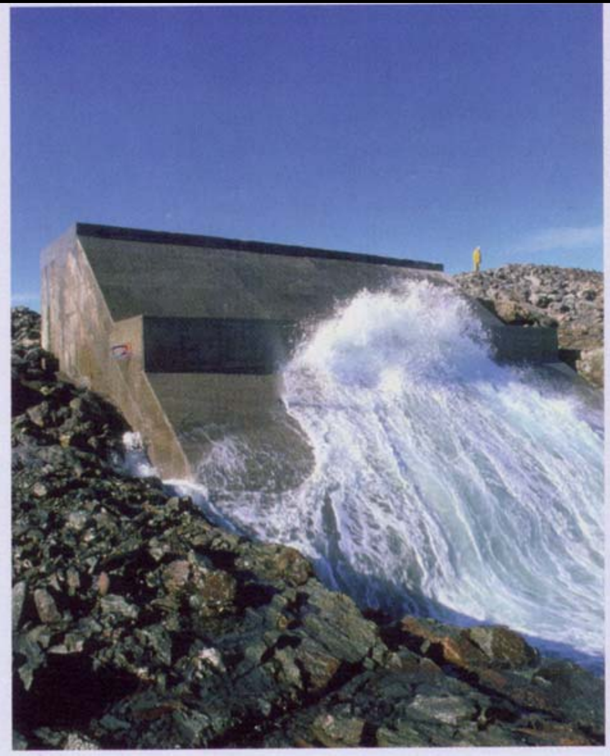


The OWC comprises a partly submerged concrete or steel structure, which has an opening to the sea below the water line, thereby enclosing a column of air above a column of water. As waves impinge on the device, they cause the water column to rise and fall, which alternately compresses and depressurizes the air column. This air is allowed to flow to and from the atmosphere through a turbine which drives an electric generator. Both conventional (i.e. unidirectional) and self- rectifying air turbines have been proposed. The axial-flow Wells turbine, invented in the 1970s, is the best known turbine for this kind of application and has the advantage of not requiring rectifying air valves.

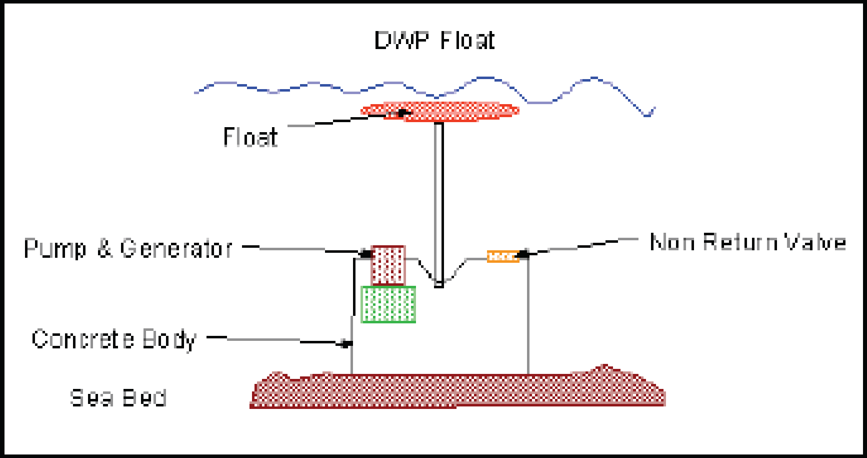
The Pendulum device consists of a rectangular box, which is open to the sea at one end. A pendulum flap is hinged over this opening, so that the action of the waves causes it to swing back and forth. This motion is then used to power a hydraulic pump and generator.

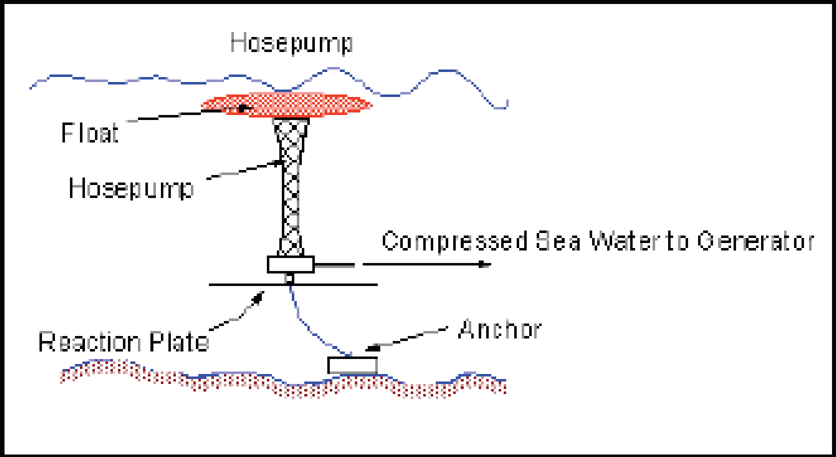
OWC Plant


The Wells Turbine rotates in the same direction regardless of the air flow, thus generating irrespective of upward or downward movement of the water column.
reinforced-concrete capture chamber set into the excavated rock face
Air is compressed and decompressed by the Oscillating Water Column (OWC). This causes air to be forced through the Wells Turbine and then drawn back.



Offshore Devices

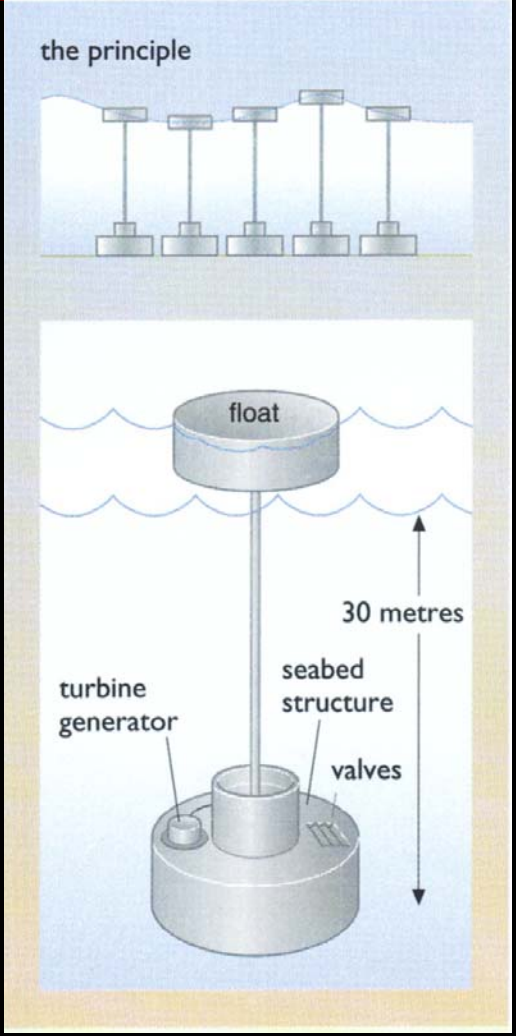


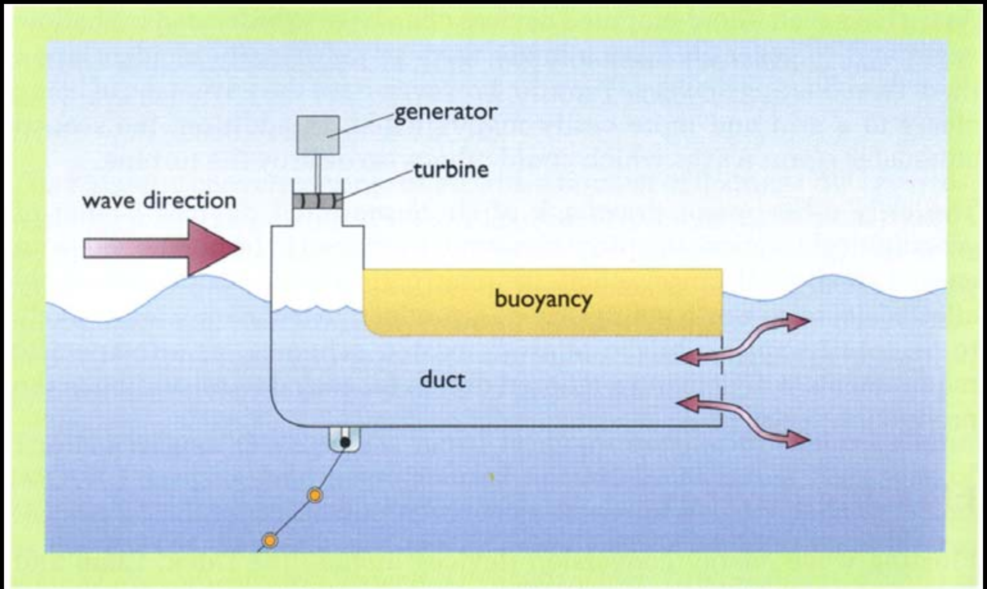


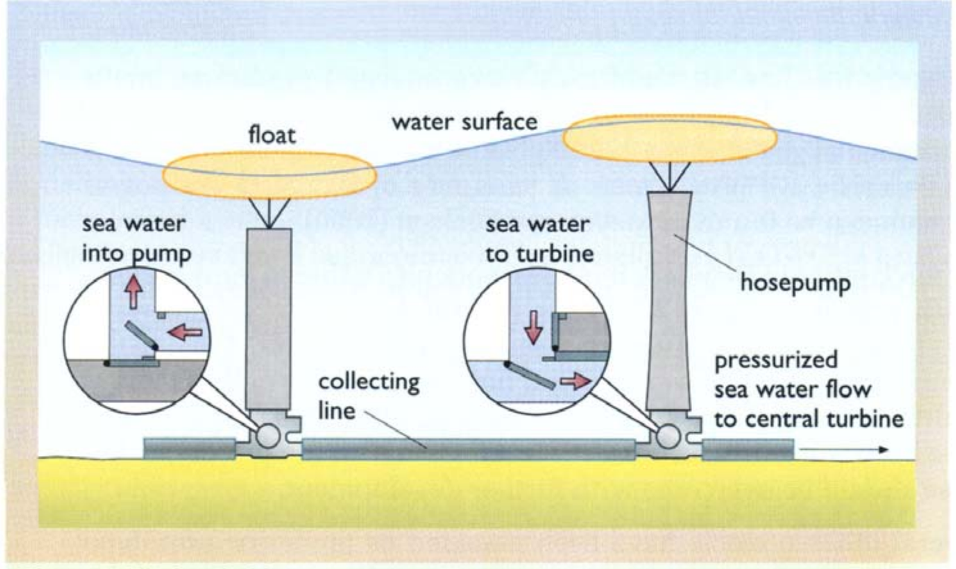
The Danish Wave Power float-pump device uses a float which is attached to a seabed mounted piston pump; the rise and fall motion of the float causes the pump to operate driving a turbine and generator mounted on the pump. The flow of water through the turbine is maintained as uni-directional through the incorporation of a non-return valve.

The Swedish Hosepump has been under development since 1980 It consists of a specially reinforced electrometric hose (whose internal volume decreases as it stretches), connected to a float which rides the waves. The rise and fall of the float stretches and relaxes the hose thereby pressurizing sea water, which is fed (along with the output from other Hosepumps) through a non-return valve to a central turbine and generator unit.

OWC Devices

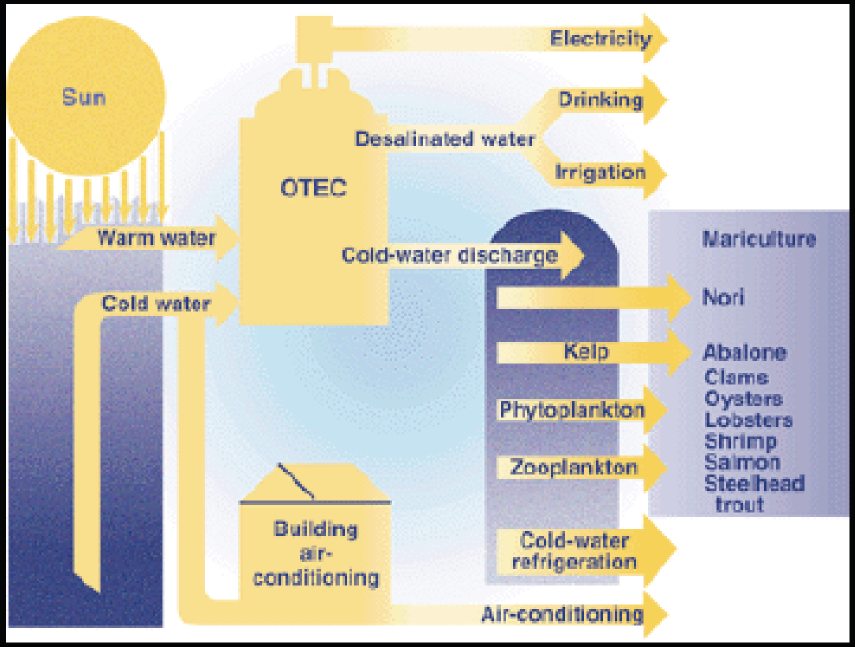

the principle
float
30 metres
turbine
generator
seabed
structure
valves


generator
turbine
wave direction
buoyancy
duct

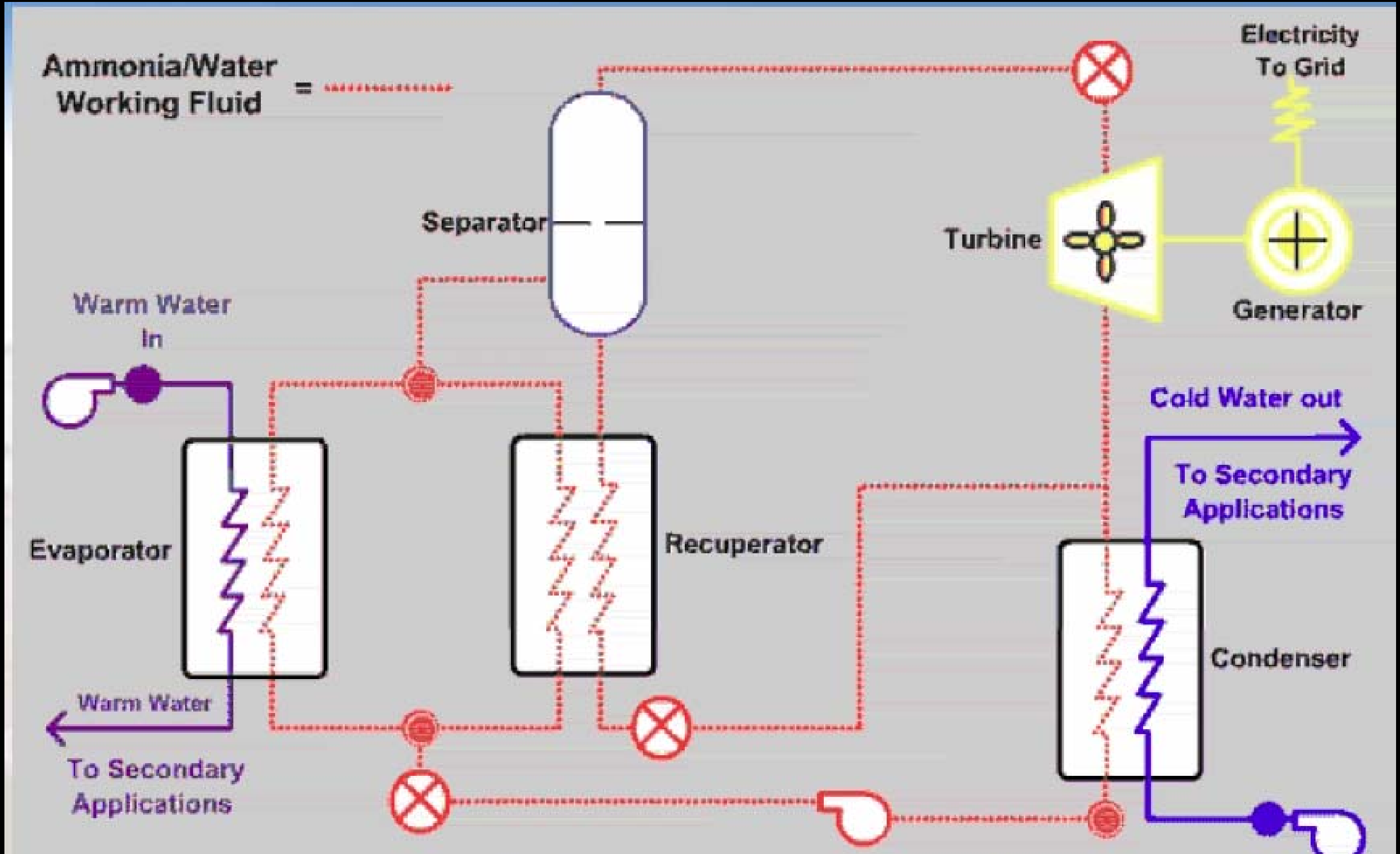

float
water surface
sea water
into pump
sea water
to turbine
hosepump
collecting
line
pressurized
sea water flow
to central turbine

Ocean Thermal Energy Conversion

Ocean Thermal Energy Conversion (OTEC) is a means of converting into useful energy the temperature difference between surface water of the oceans in tropical and sub-tropical areas, and water at a depth of approximately 1000 m which comes from the polar regions. For OTEC a temperature difference of 20^{o}C is adequate, which embraces very large ocean areas, and favors islands and many developing countries.

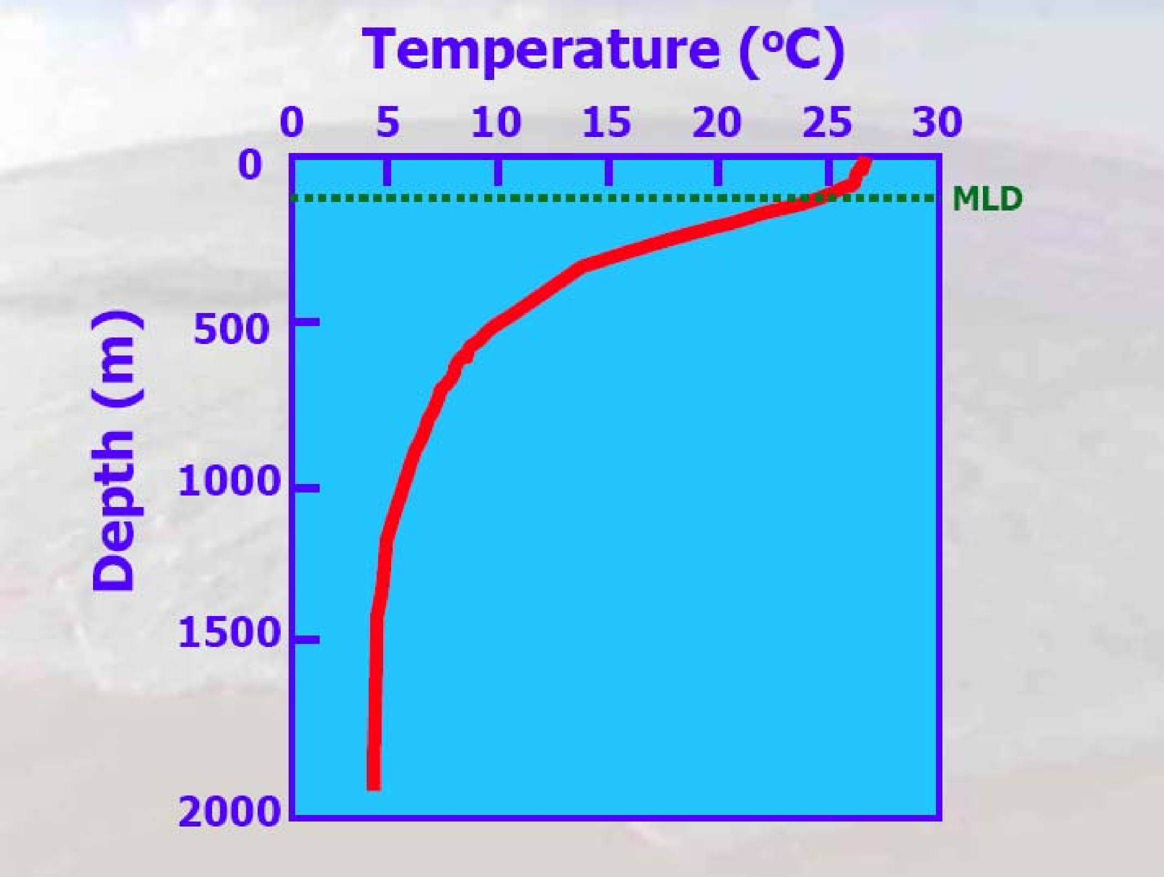


OTEC Thermodynamic Cycle



Simplified Kalina Cycle™(Exergy,Inc.)

Typical Ocean Temperature Profile



Integrated OTEC System