ANKARA UNIVERSITY
DEPARTMENT OF ENERGY ENGINEERING

TIDAL/MARINE ENERGY

INSTRUCTOR
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CONTENTS

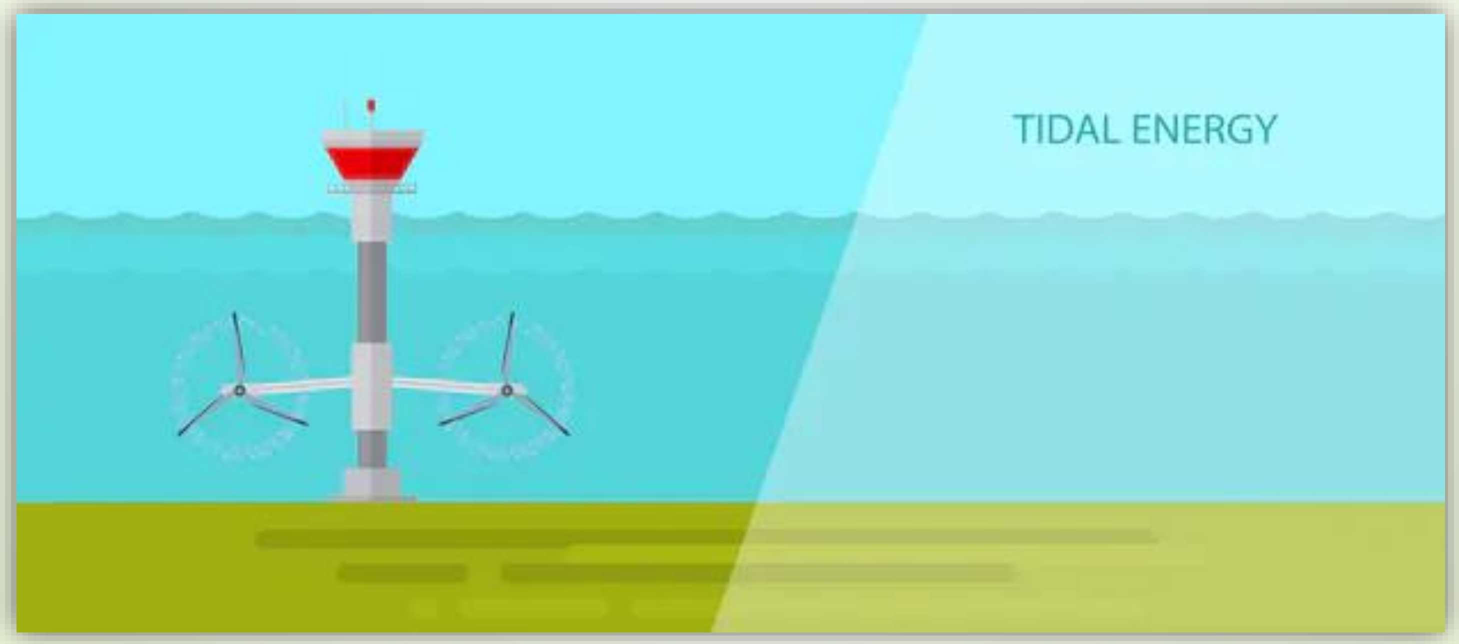
Tidal/Marine Energy

a. Basic concepts: Fundamentals of tidal/wave energy

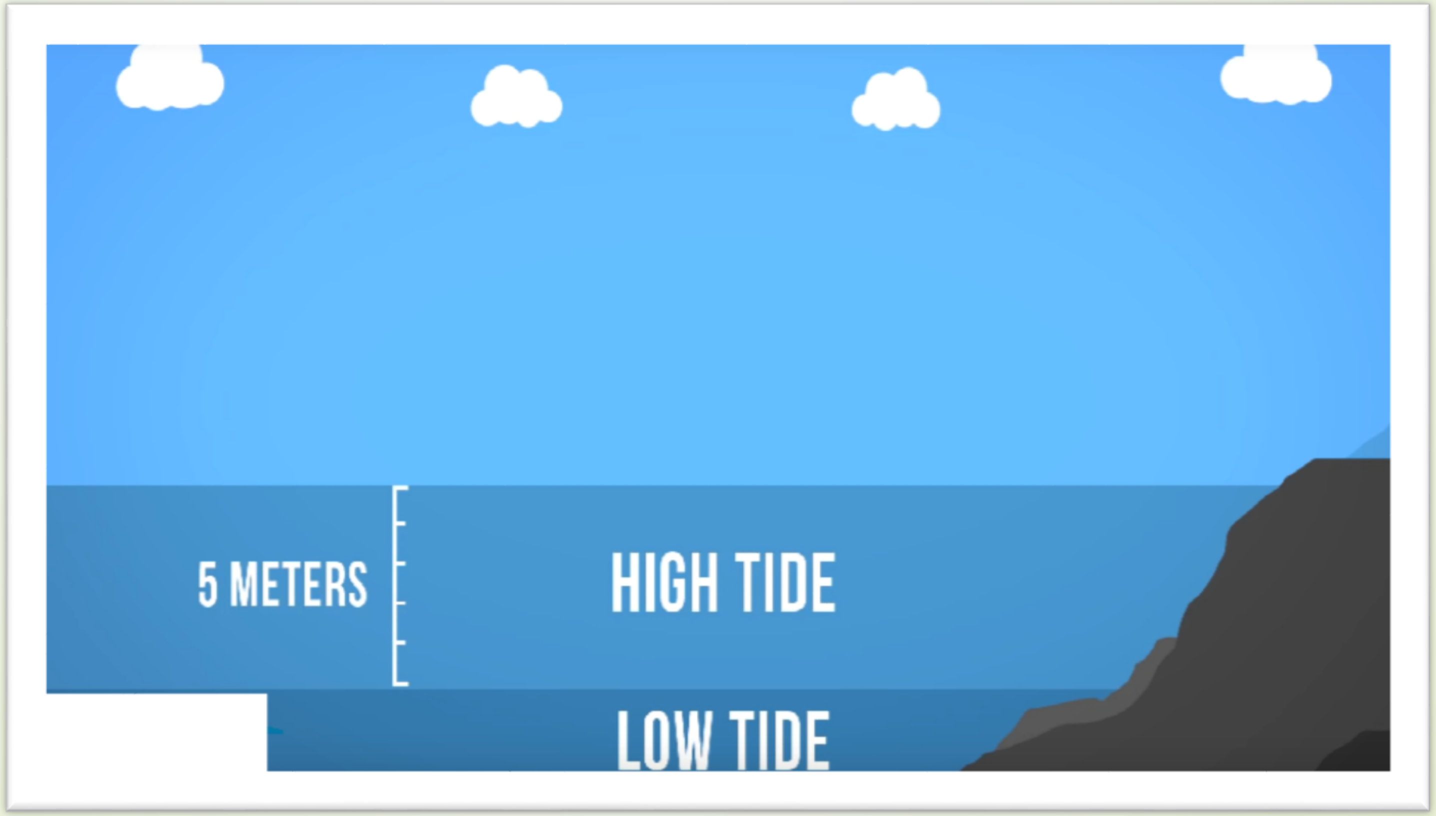
b. Tidal/wave energy conversion: characterizations

TIDAL ENERGY

- ***Tidal energy is one of the oldest forms of energy generation. It is a renewable form of energy that converts the natural rise and fall of the tides into electricity. Tides are caused by the combined effects of gravitational forces exerted by the Moon, the Sun, and the rotation of the Earth.***

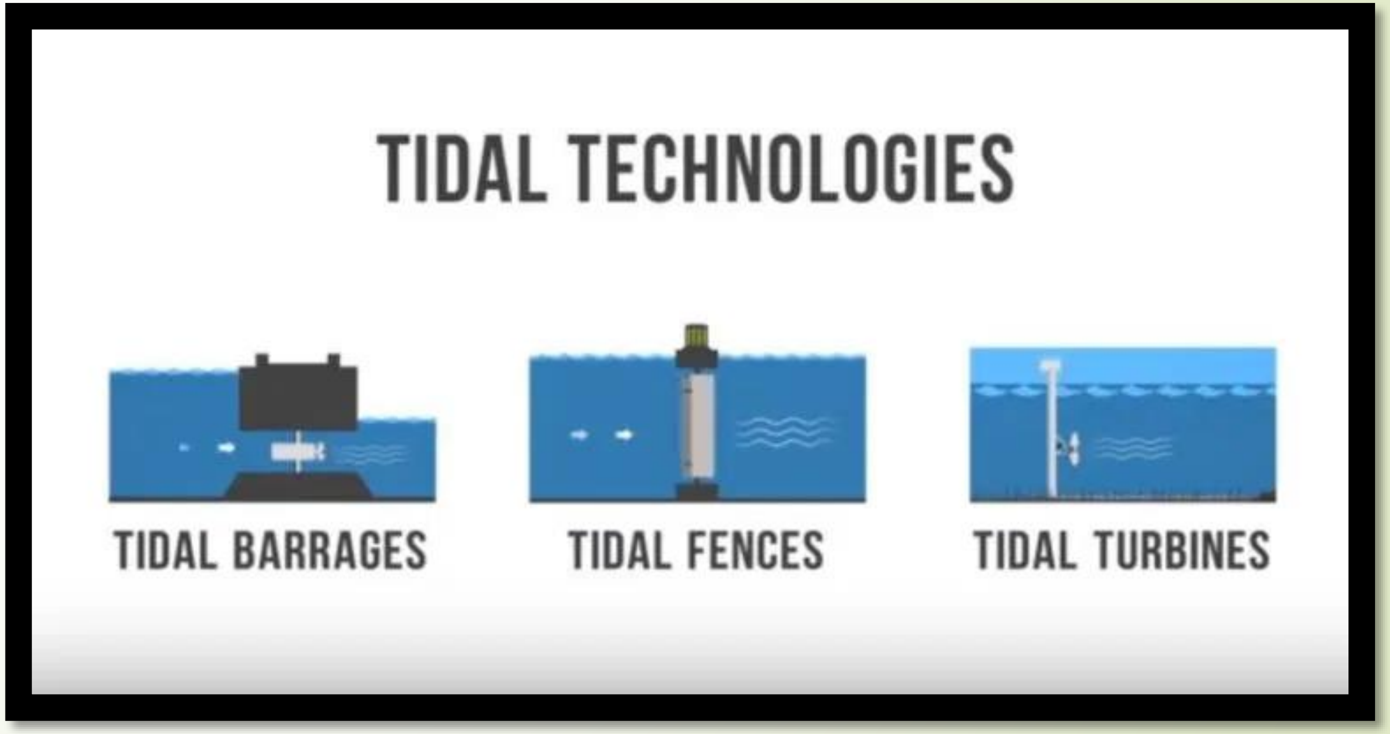


Tidal energy presents an evolving technology with tremendous potential. However, it can only be installed along coastlines. Coastlines often experience two high tides and two low tides on a daily basis. The difference in water levels must be at least 5 meters high to produce electricity.



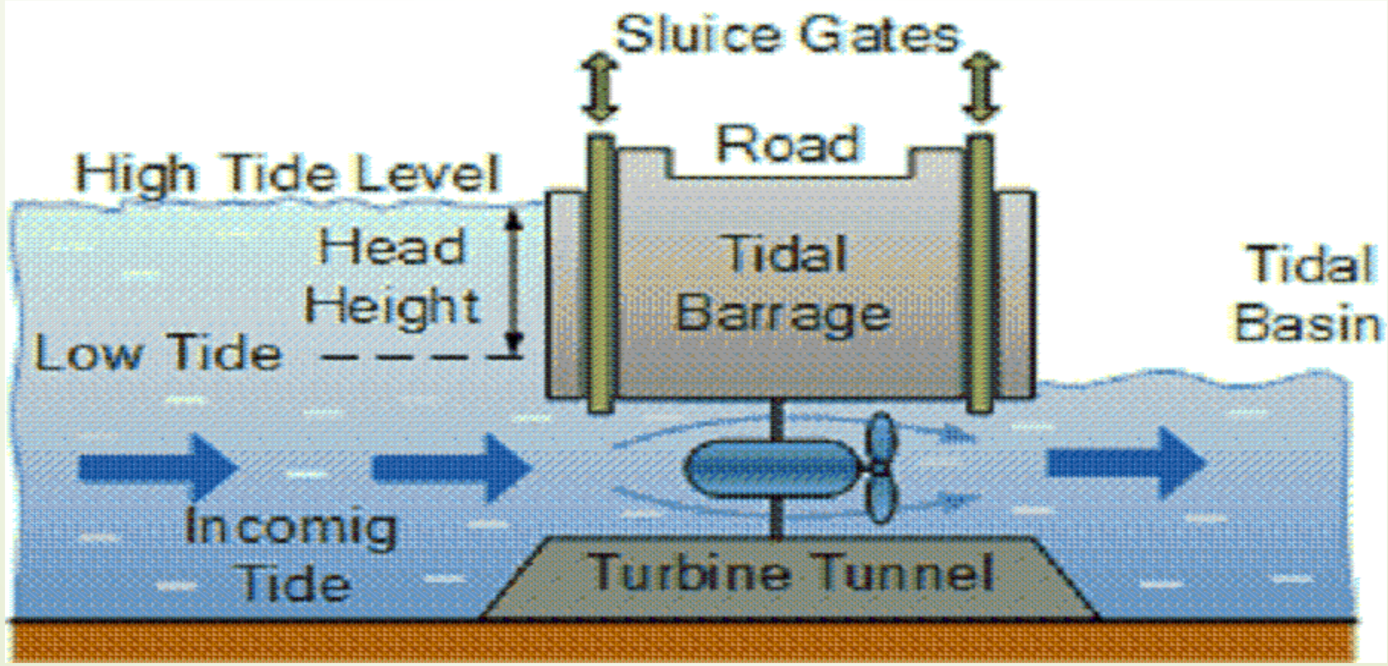
Tidal electricity can be created from several technologies, the main ones being,

- ***Tidal Barrages***
- ***Tidal Fences***
- ***Tidal Turbines***



Tidal Barrages

Tidal barrages are the most efficient tidal energy sources. A tidal barrage is a dam that utilizes the potential energy generated by the change in height between high and low tides. This energy turns a turbine or compresses air, which generates electricity.

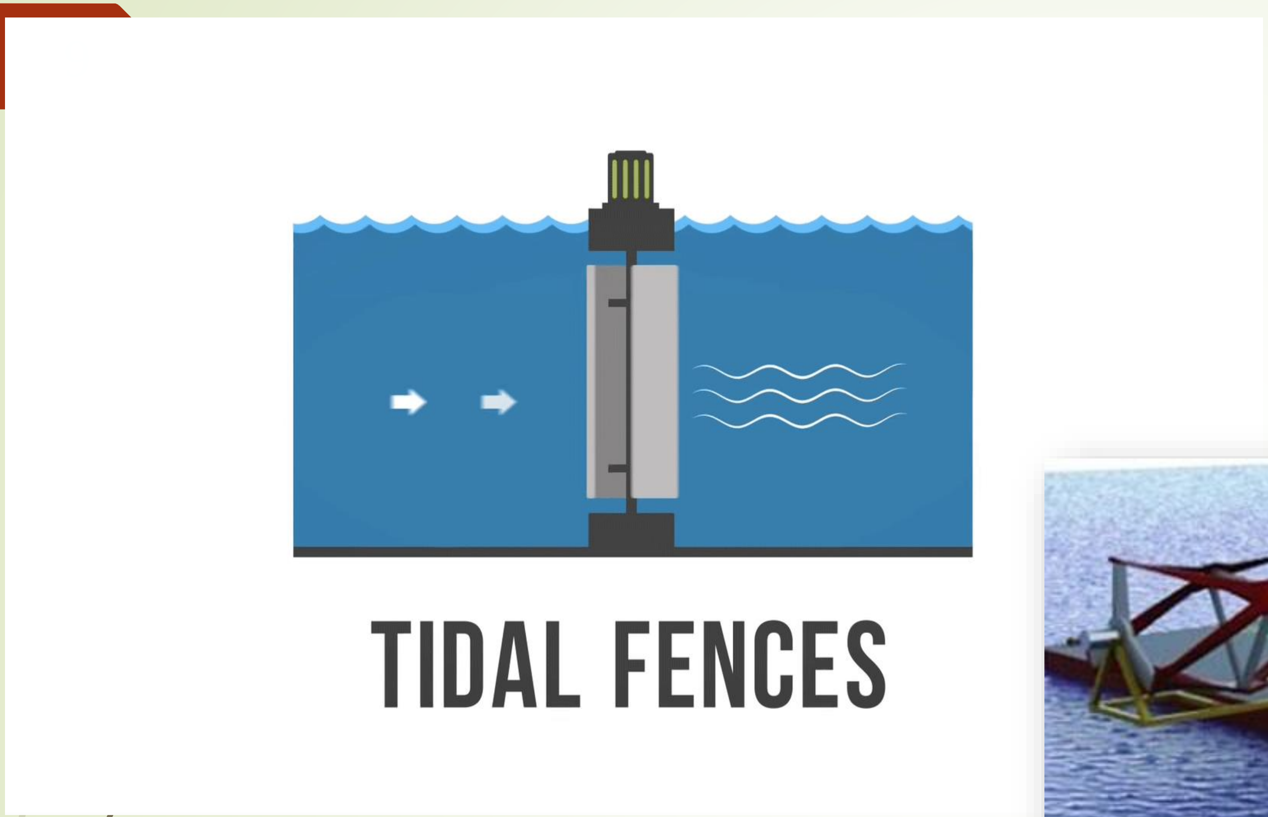


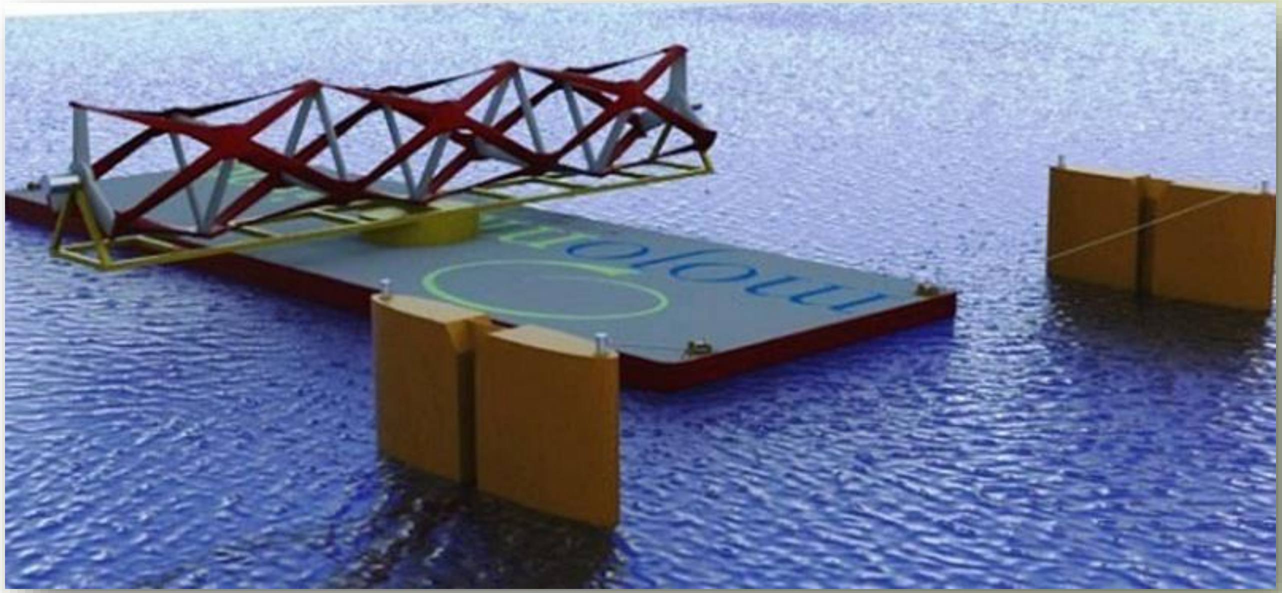
World’s largest tidal power plant in the Rance estuary near St Malo, France

Rance Tidal Power Station

Tidal Fences

Tidal fences are turbines that operate like giant turnstiles, while tidal turbines are similar to wind turbines only under water. In both cases, electricity is generated when the mechanical energy of tidal currents turns turbines connected to a generator. Ocean currents generate relatively more energy than air currents because ocean water is 832 times more dense than air and therefore applies greater force on the turbines.


TIDAL FENCES



Tidal Turbines

Tidal turbines are very much like underwater windmills except the rotors are driven by consistent, fast-moving currents. The submerged rotors harness the power of the marine currents to drive generators, which in turn produce electricity. Water is 832 times denser than air and consequently tidal turbine rotors are much smaller than wind turbine rotors and therefore can be deployed much closer together and still generate equivalent amounts of electricity.

Tidal turbines utilize tidal currents that are moving with velocities of between 2 and 3 m/s to generate between 4 and 13 kW/m^2.

ADVANTAGES AND DISADVANTAGES OF TIDAL POWER

Advantages:

- Tidal power is a renewable and sustainable energy resource. It reduces dependence upon fossil fuels.
- It produces no liquid or solid pollution. It has little visual impact.
- Tidal power exists on a worldwide scale from deep ocean waters.
- Tidally driven coastal currents provide an energy density four times greater than air, which means that a 15 m diameter turbine will generate as much energy generated by a 60m diameter windmill.

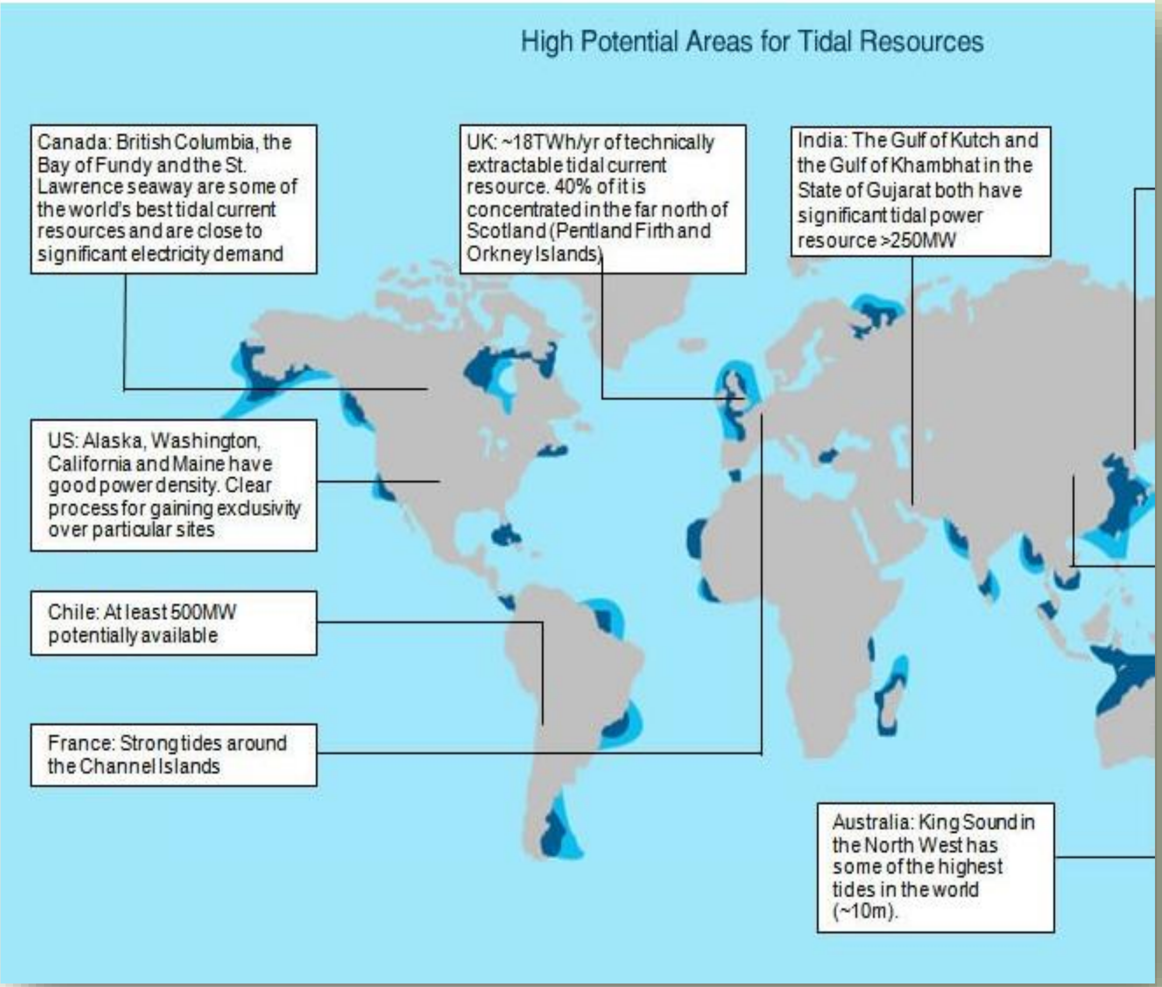
- Tidal currents are both predictable and reliable, a feature which gives them an advantage over both wind and solar systems. Power outputs can be accurately calculated far in advance, allowing for easy integration with existing electricity grids.

Disadvantages:

- High cost of construction, installation and generation.
- Barrages can disrupt natural migratory routes for marine animals and normal boating pathways.
- Turbines can kill up to 15% of fish in area, although technology has advanced, the turbines have to move slow enough not to kill many.
- Flooding and ecological changes.
- Research is still in initial stages.

Tidal Energy Usage Worldwide

The first major tidal-power project in the United States was installed in April 2007 in the East River between Queens and Roosevelt Island in New York City. Other than the United States, tidal generators are also found in Europe, Australia, Canada, and South Korea.



Tidal Giants – The World's Five Biggest Tidal Power Plants

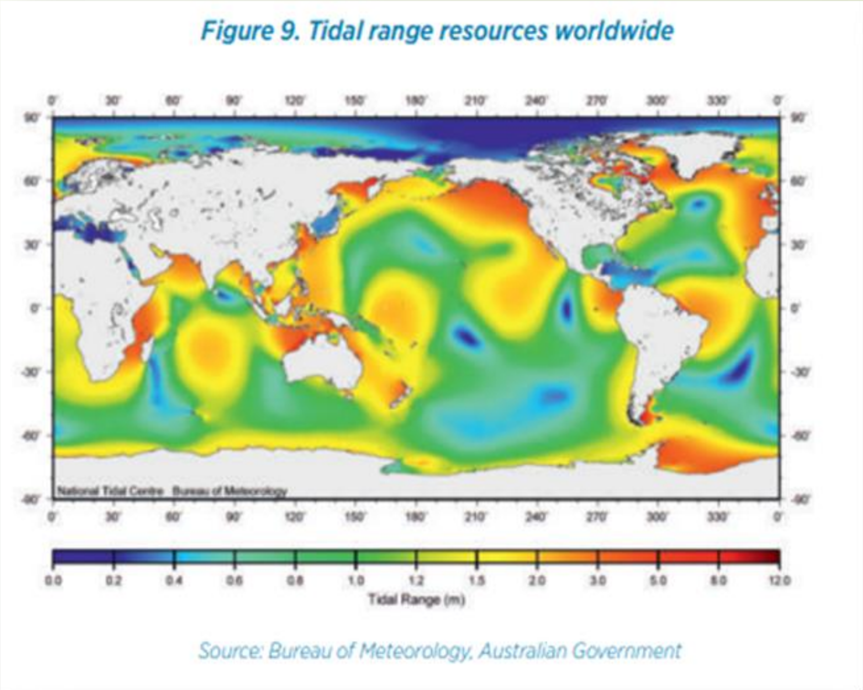
1. Sihwa Lake Tidal Power Station, South Korea – 254 MW

2. La Rance Tidal Power Plant, France – 240 MW

3. Swansea Bay Tidal Lagoon, United Kingdom – 240 MW

4. MeyGen Tidal Energy Project, Scotland – 86 MW

5. Annapolis Royal Generating Station, Canada – 20MW



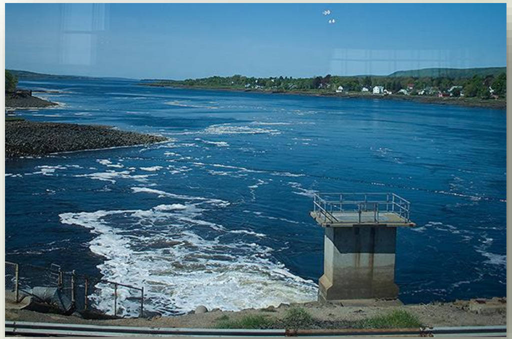


Table 2.6 *Annual global ocean energy resources*

Energy resource	*TWh*	*EJ*
Tidal energy	22,000	79
Wave energy	18,000	65
Ocean thermal energy	2,000,000	7200
TOTAL	**2,040,000**	**7344**

Note: The potential of ocean thermal energy is difficult to assess but is known to be much larger than for the other types of ocean energy. The estimate used here assumes that the potential for ocean thermal energy is two orders of magnitude higher than for tidal or wave energy.

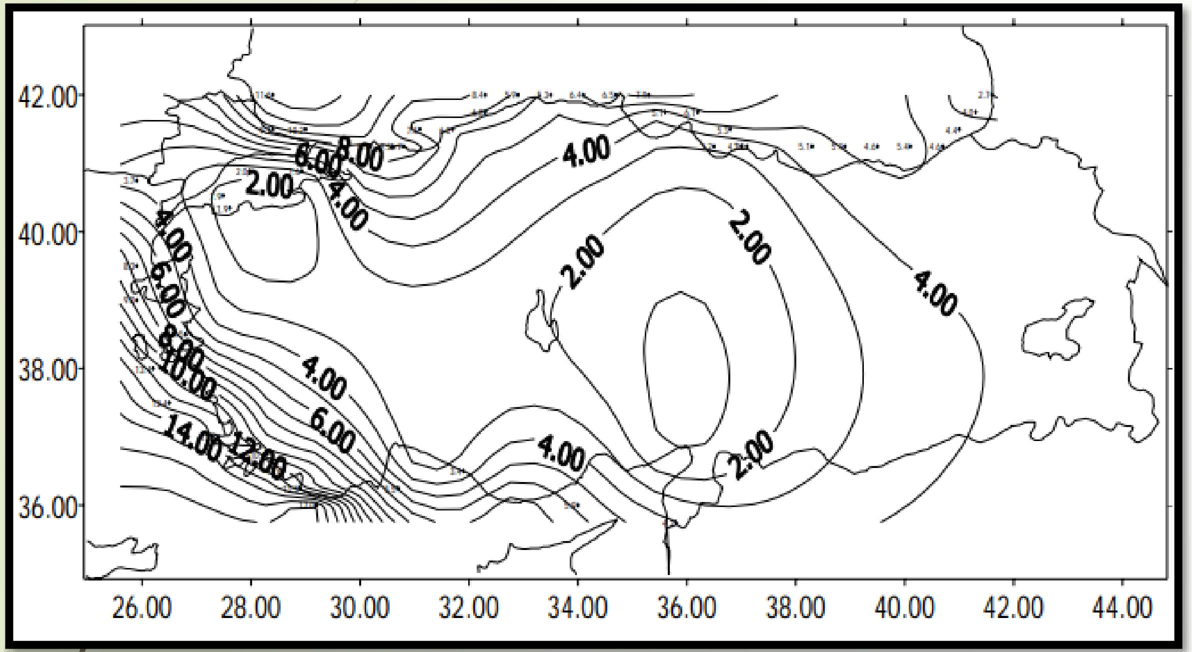
Source: WEA (2000)

Table 8.2 Relative Sizes of Some Various Hydro Resources

Energy Source	Potential (GW)	Practical (GW)	To Date
Freshwater hydro	4,000	1,000	654
Waves	1,000–10,000	500–2,000	2.5
Tides	2,500	1,000	59
OTEC	200,000	10,000	0

Source: Tester, J. W. et al., *Sustainable Energy: Choosing among Options*, MIT Press, Cambridge, Massachusetts, 2005.

Marine Energy in Turkey



Maximum Wave Energy Levels

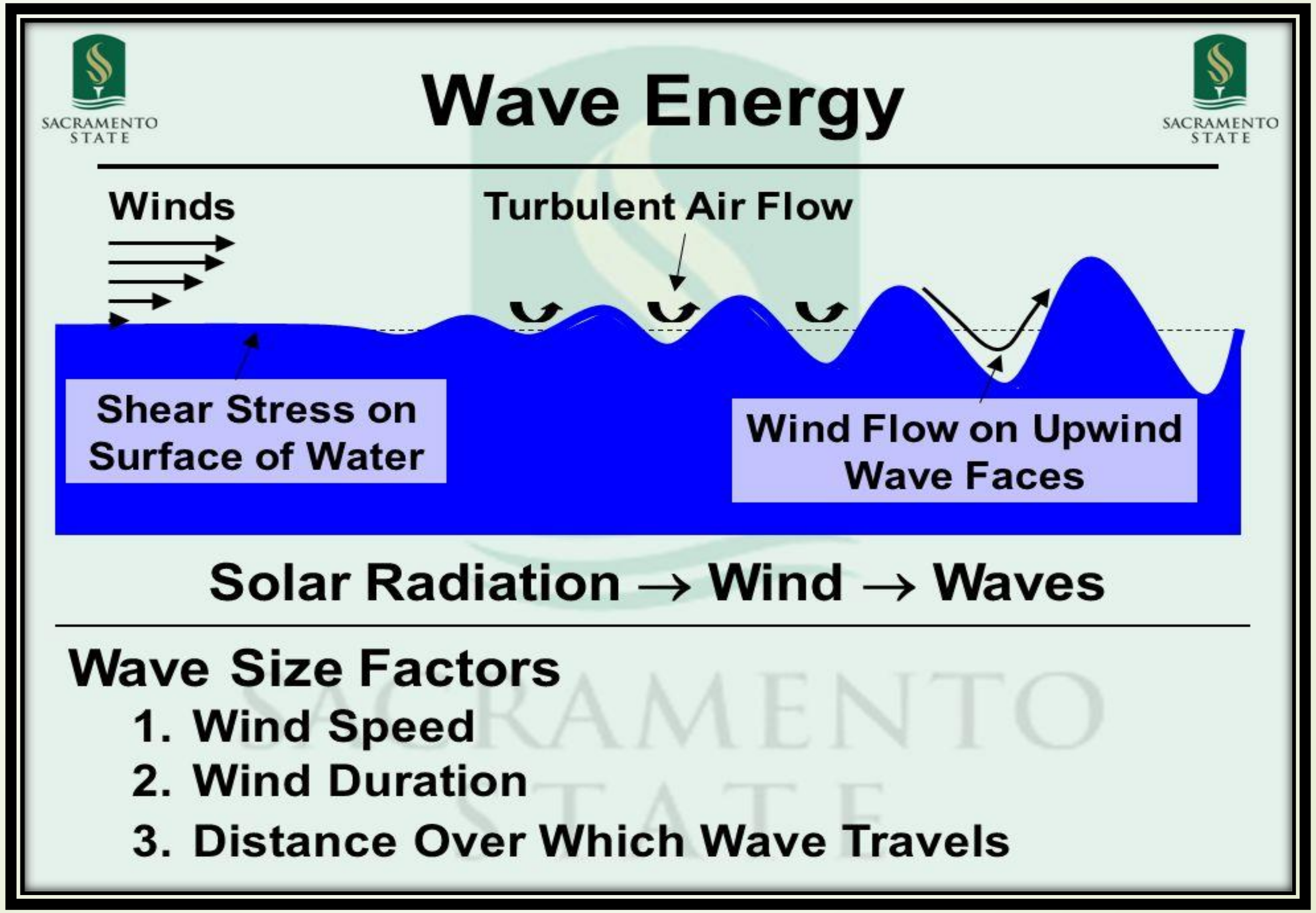
Region	Power
Black Sea	1.96-4.22 kWh/m
Marmara Sea	0.31-0.69 kWh/m
Aegean Sea	2.86-8.75 kWh/m
Mediterranean	2.59-8.26 kWh/m
İzmir-Antalya	3.91-12.05 kWh/m

WAVE ENERGY

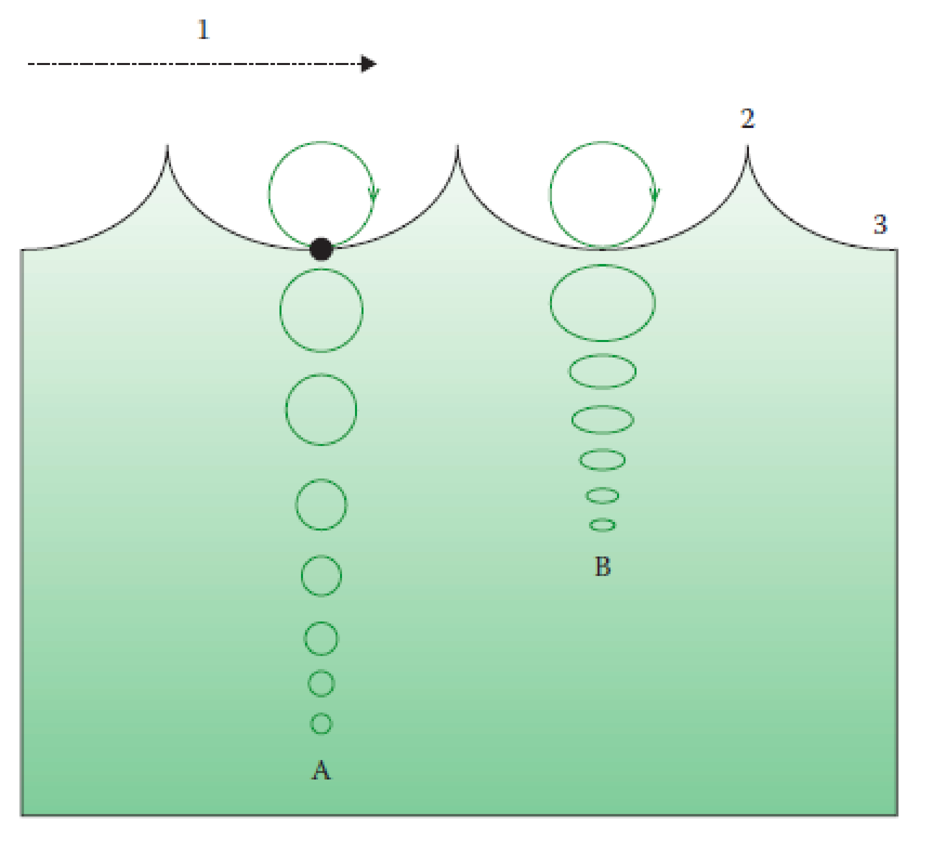
Wave energy can be described as a concentration and moving reservoir of solar energy. As the world heats differentially from incoming solar irradiance, air masses heat and cool, moving air from high pressure to low pressure areas, thereby creating wind. When this wind blows over vast stretches of unobstructed ocean fetch, waves are generated.

Oceans cover more than 70% of Earth's surface and ocean waves carry enormous power. By utilizing the largest source of untapped clean energy, it could supply a substantial part of the world's electricity.

Sizable ocean waves can be generated when the wind acts for a sustained period and interacts with the surface of the water. The height of the waves depends on the wind speed, how long a time it has been blowing, and various other factors.



A molecule of the water has both up and down (transverse) motions as well as back and forth (longitudinal) motions as the wave passes. The combination of these two motions out of phase by 90° results in either a circle or an ellipse, depending on whether the water is deep or shallow with deep meaning that the depth is large compared to the wavelength.



Simplified motion of a water molecule at various depths as a wave passes. Case **A** is for deep water and case **B** is for shallow water.

The mass of the column shown is dm = ρy.dx, so its gravitational potential energy is

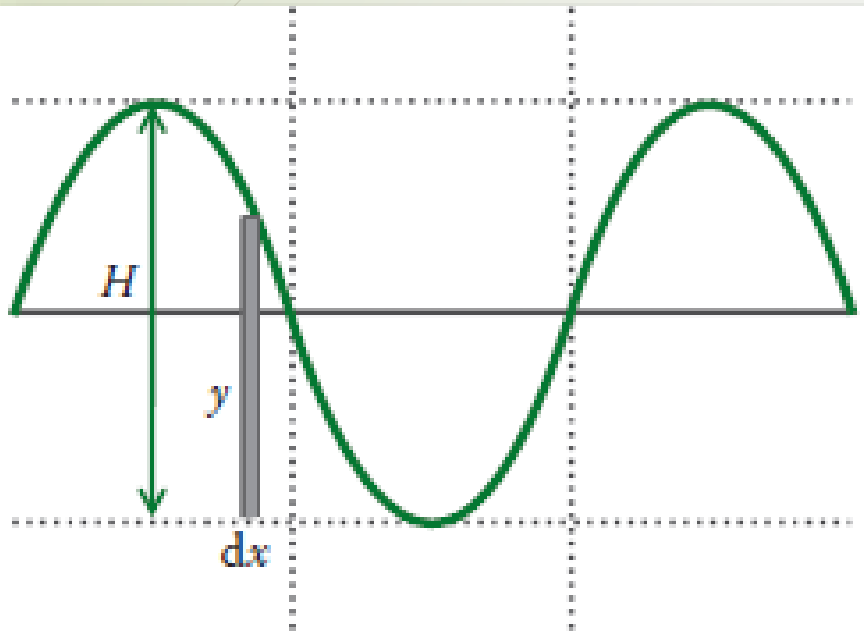


Figure 8.11 Wave of height H. y shows the height of a column of water of thickness dx.

Potential Energy

$$PE = \frac{1}{2}mgy = \frac{1}{2}\rho g y^2\,\mathrm{d}x$$

y → Height of a column of water

The power passing point *x* associated with the **potential energy** is given by **P= *PE/t***. To find the average power over time, we use $\boldsymbol{y_{av_g}^2 = H^2/2}$ so as to obtain:

Average Power → $$P_{avg} = \frac{1}{4}\rho g v H^2$$

H → Height of wave

y_{avg} → Average height of a column of water

25

This is only the power associated with the potential energy. For a mass moving in simple harmonic motion, the kinetic energy adds an equal contribution, which doubles the previous result. Power (and energy) is transported by a wave by its **group velocity**, which, for **deep water ocean waves**, is given by

$$v = \frac{gT}{4\pi}$$

→ **Group Velocity** $(\boldsymbol{T}: \boldsymbol{Dalga\ periyotu})$

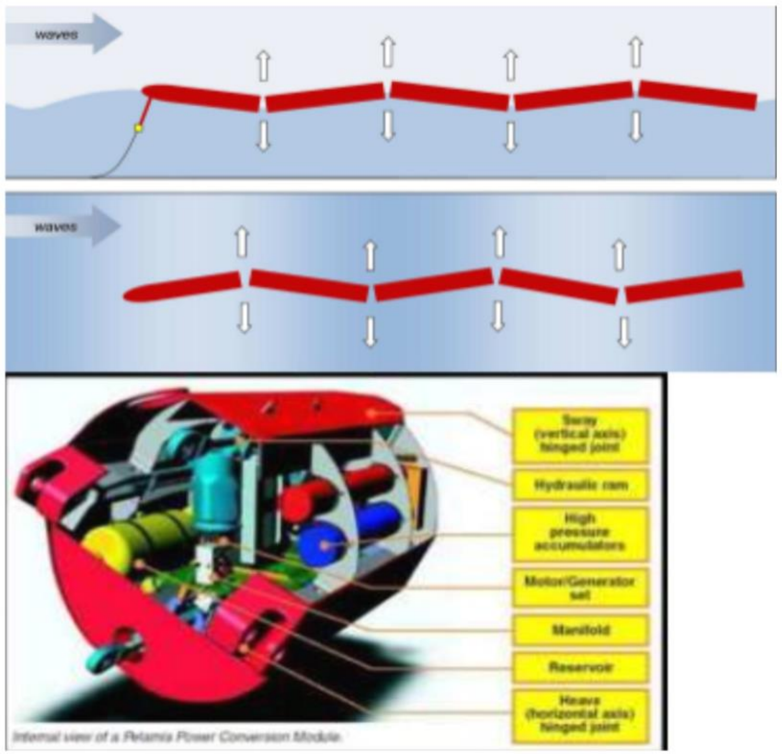
we obtain for the average **total power** (kinetic plus potential):

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

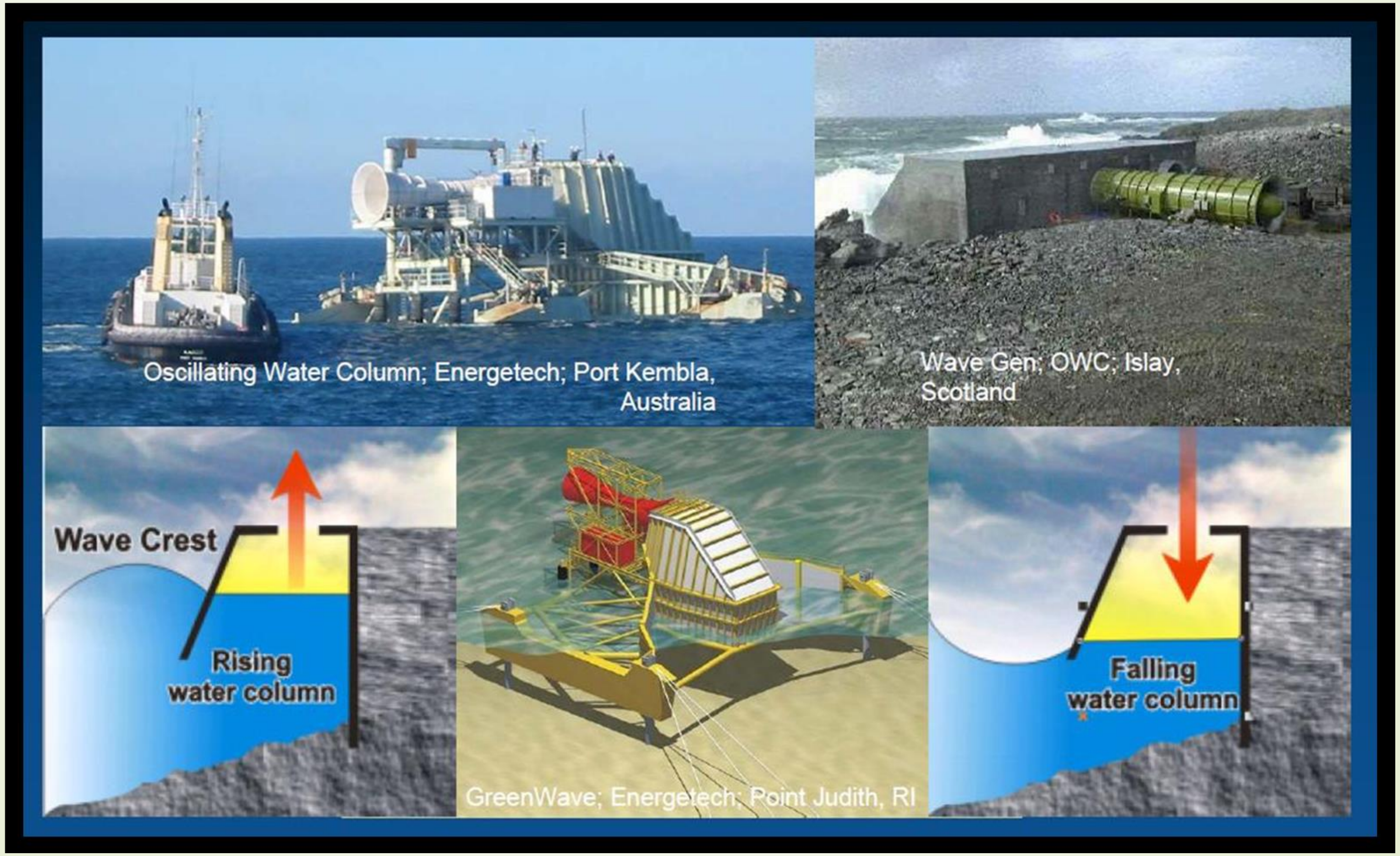
The design of ocean wave energy converters is based on the utilization of either the speed of the seawater, the changes in the wave surface angle, or the changes in the hydrostatic or total hydrodynamic pressure of the waves. There are mainly three types of wave energy conversion technologies;

- One type uses floats, buoys, or pitching devices to generate electricity using the rise and fall of ocean swells to drive hydraulic pumps.

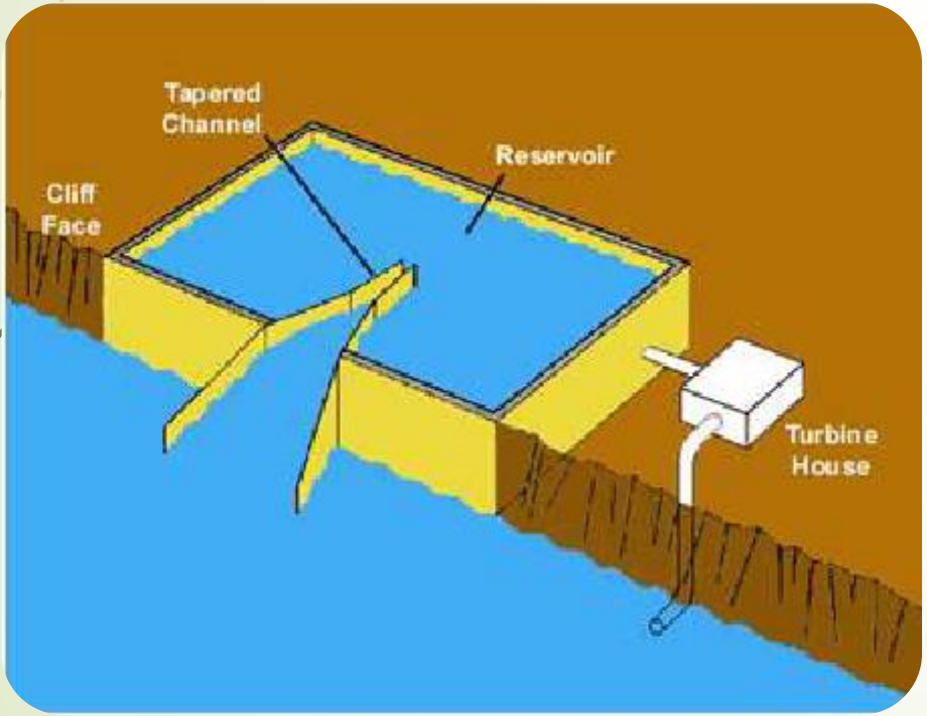
Fig. 9 E.ON P2 Pelamis operating in Orkney July 2011 [27]

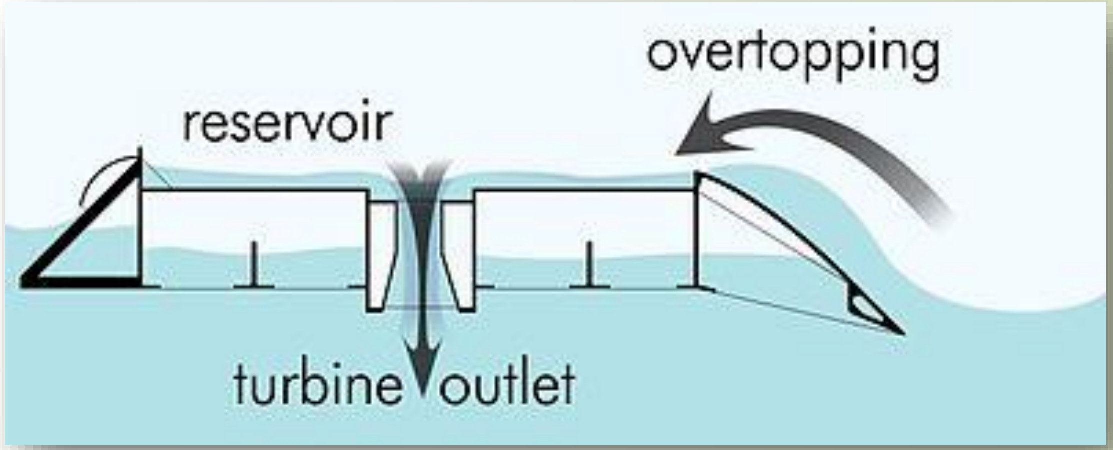


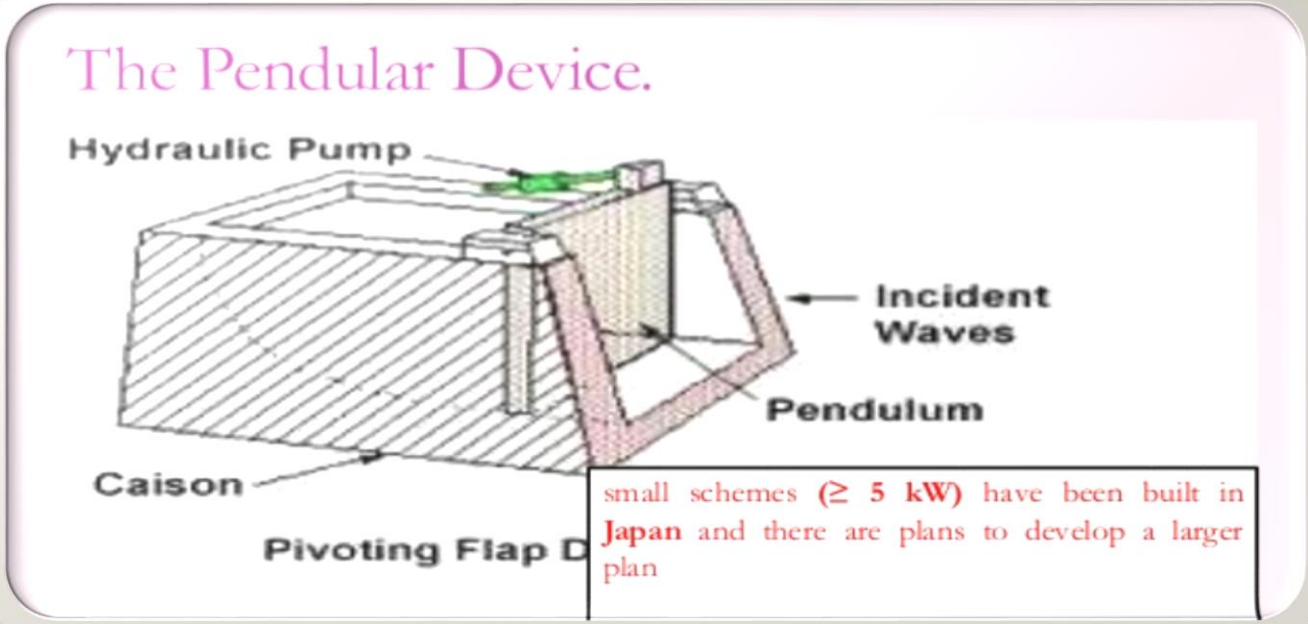
- A second type uses oscillating water column (OWC) devices to generate electricity at the shore using the rise and fall of water within a cylindrical shaft. The rising water drives air out of the top of the shaft, powering an air driven turbine.



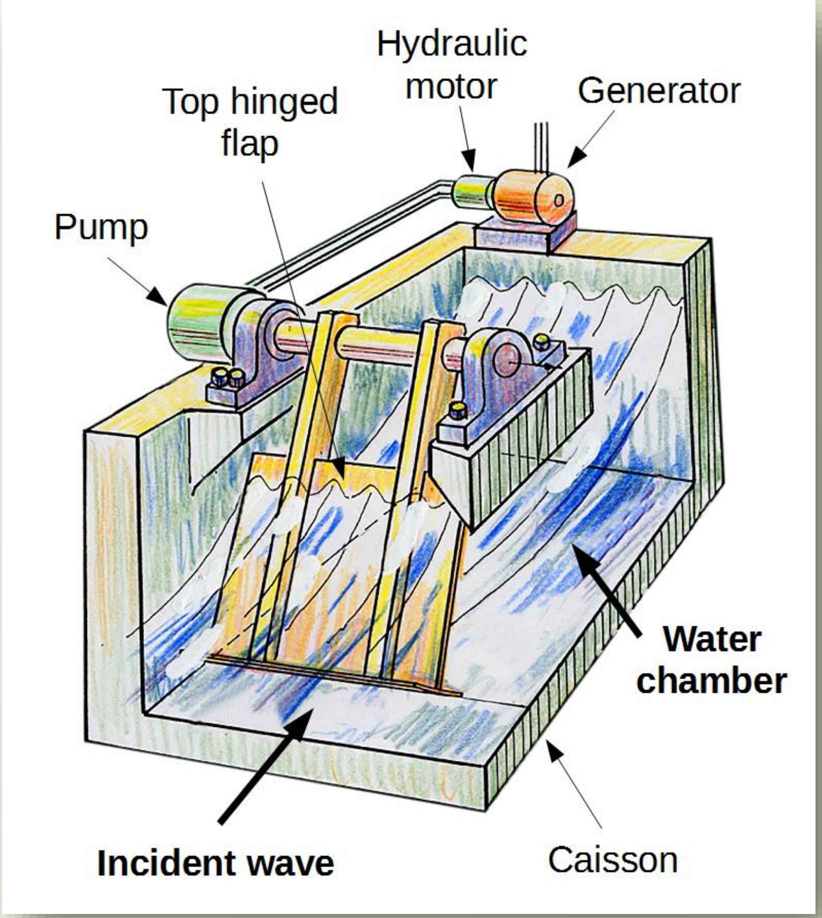
- Third type is a tapered channel, or overtopping device can be located either on or offshore. They concentrate waves and drive them into an elevated reservoir, where power is then generated using hydropower turbines as the water is released. The vast majority of recently proposed wave energy projects would use offshore floats, buoys or pitching devices.







The pendulor wave-power device consists of a rectangular box, which is open to the sea at one end. A flap is hinged over the opening and the action of the waves causes the flap to swing back and forth. The motion powers a hydraulic pump and a generator.



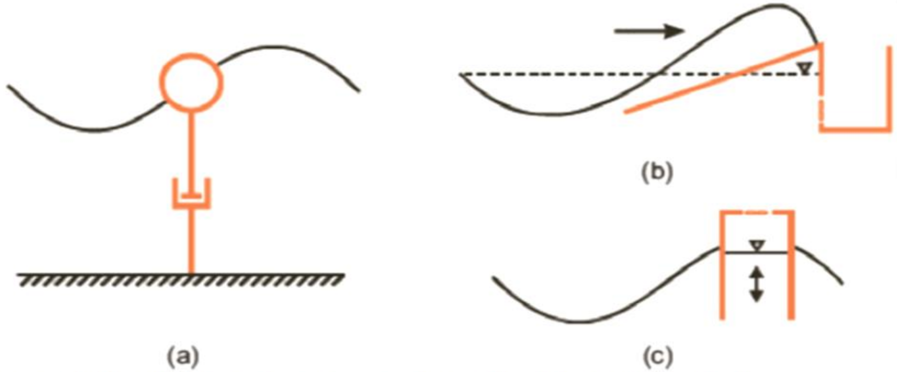


Figure 1: Classification of wave energy devices [a) Wave activated bodies, b)Overtopping devices , c) Oscillating water columns]

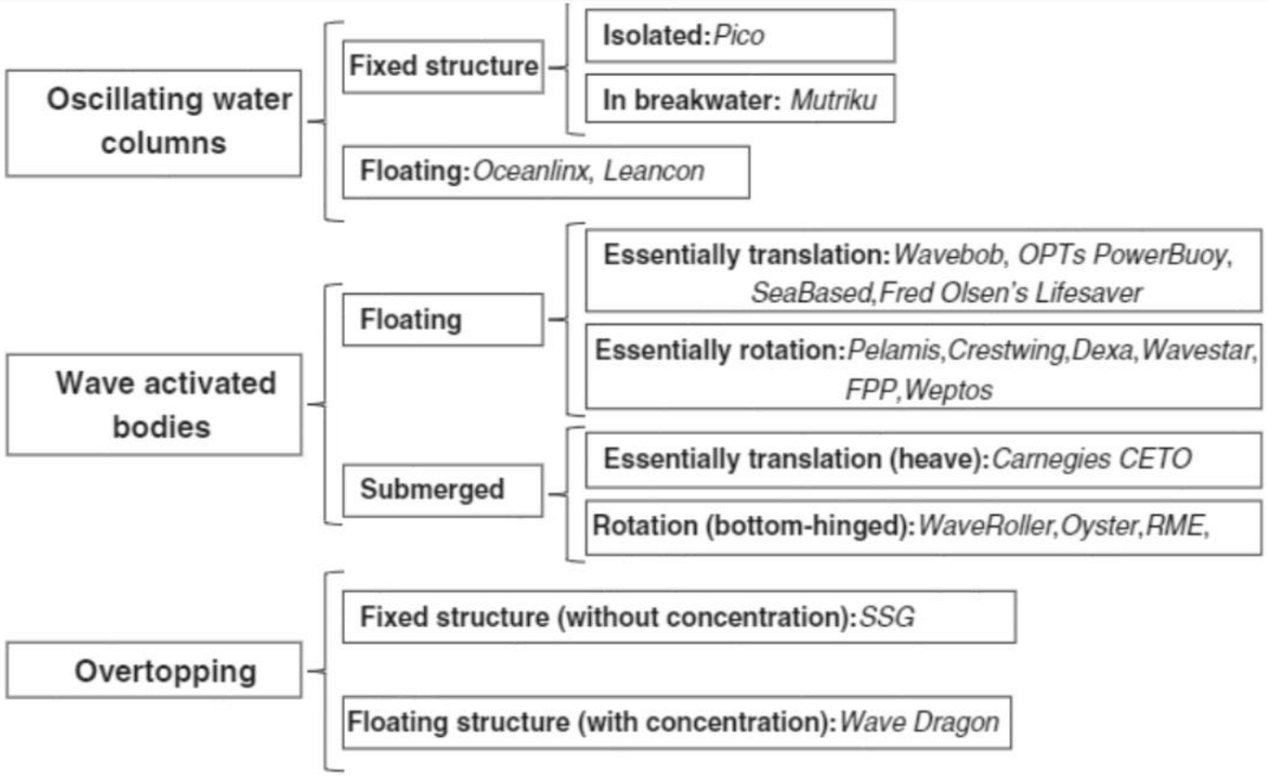
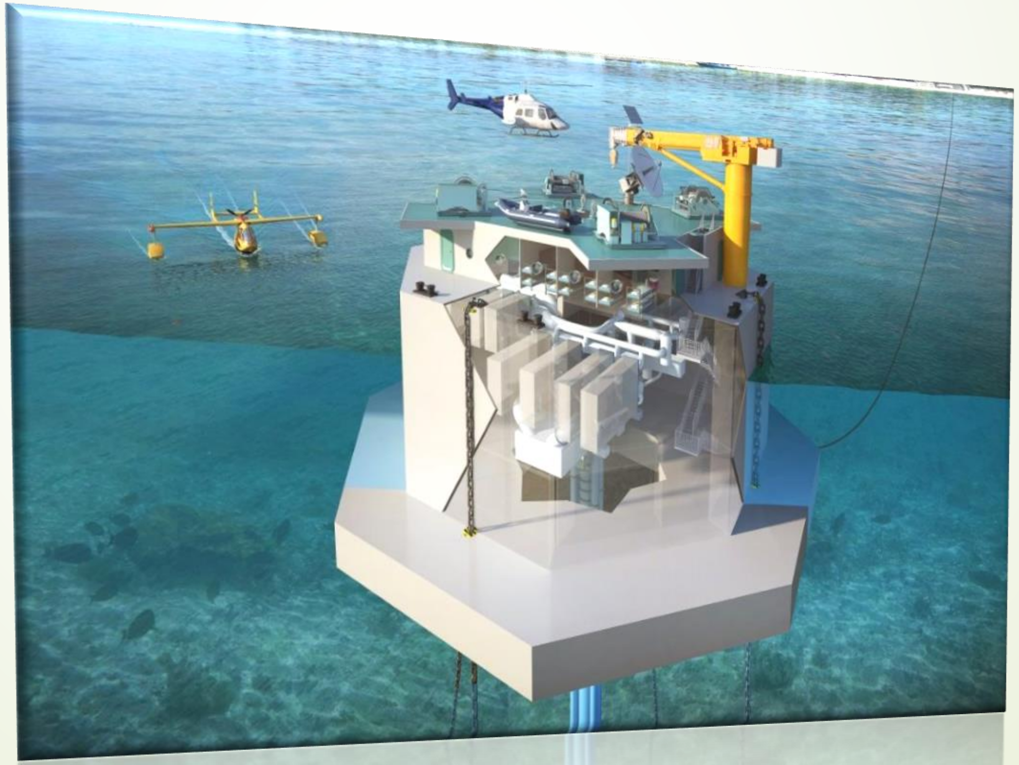


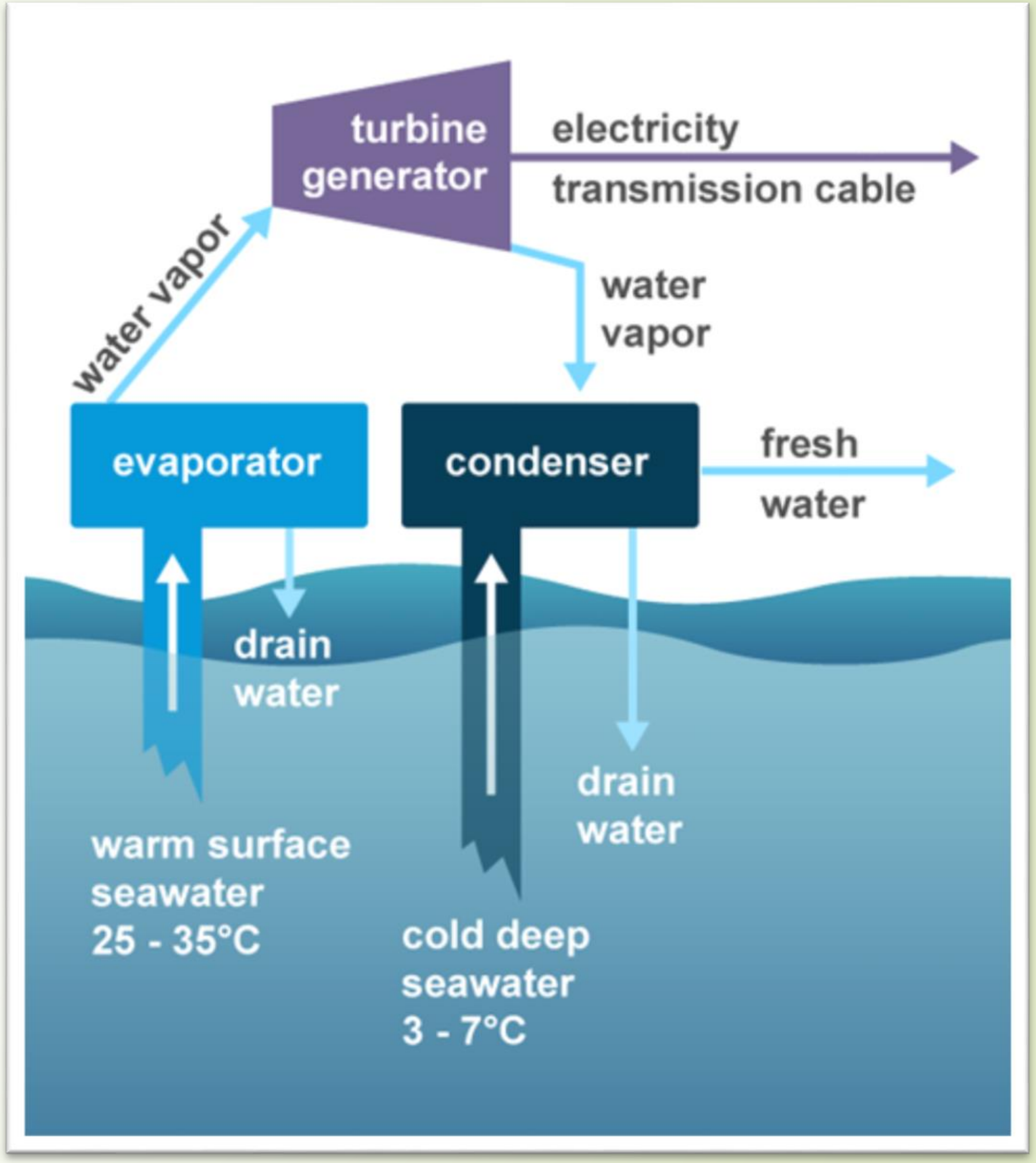
Fig. 5 Categorization of wave energy technologies following IEA – Ocean Energy Systems [16]. Technologies mentioned in the various categories are the ones illustrated in the following figures

Ocean Thermal Energy Conversion

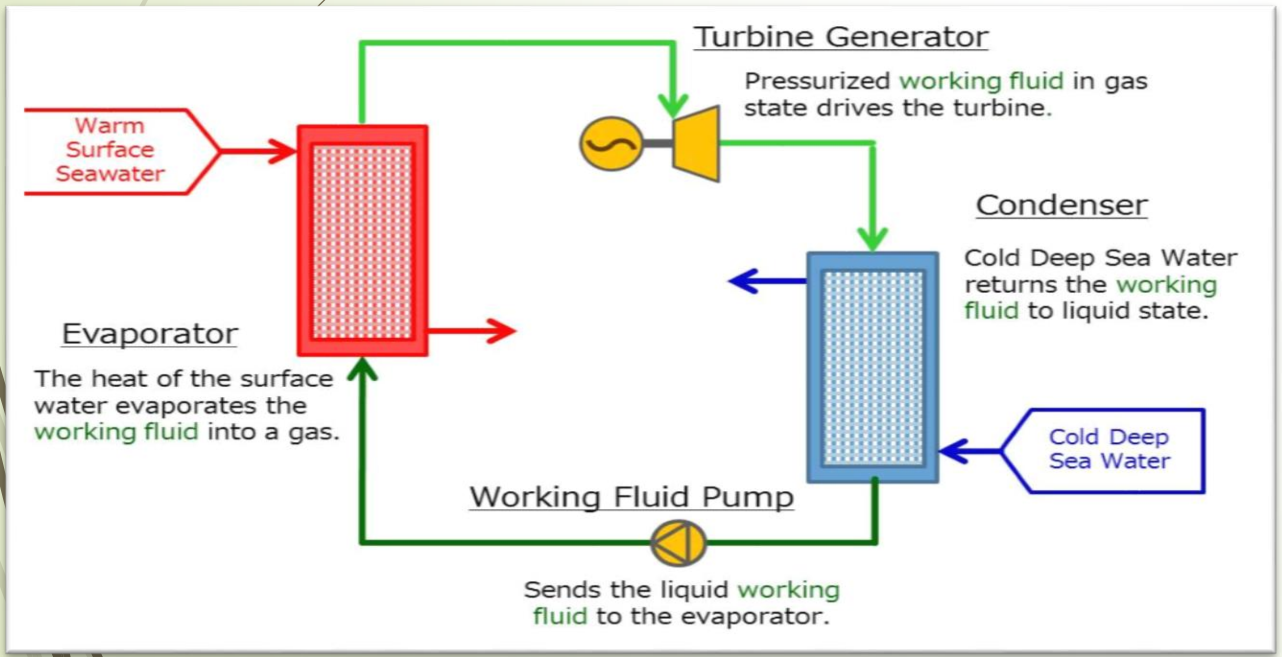
Energy conversion, commonly designated as OTEC. The OTEC uses the difference of temperature prevailing between different ocean waters layers to produce electrical power.

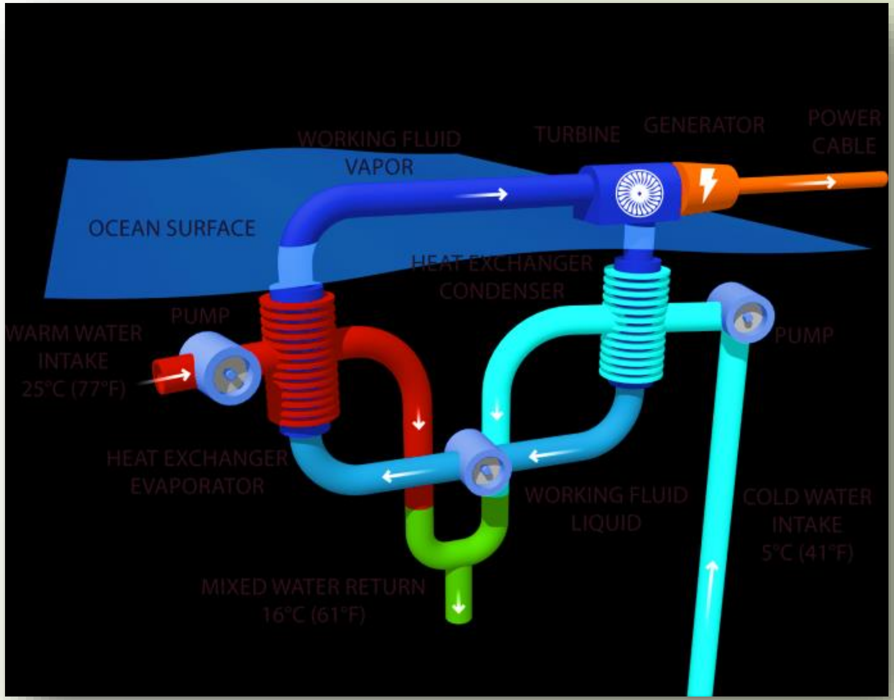


Energy from the sun heats the surface water of the ocean. In tropical regions, surface water can be much warmer than deep water. This temperature difference can be used to produce electricity and to desalinate ocean water. Ocean Thermal Energy Conversion (OTEC) systems use a temperature difference (of at least 77° Fahrenheit) to power a turbine to produce electricity.



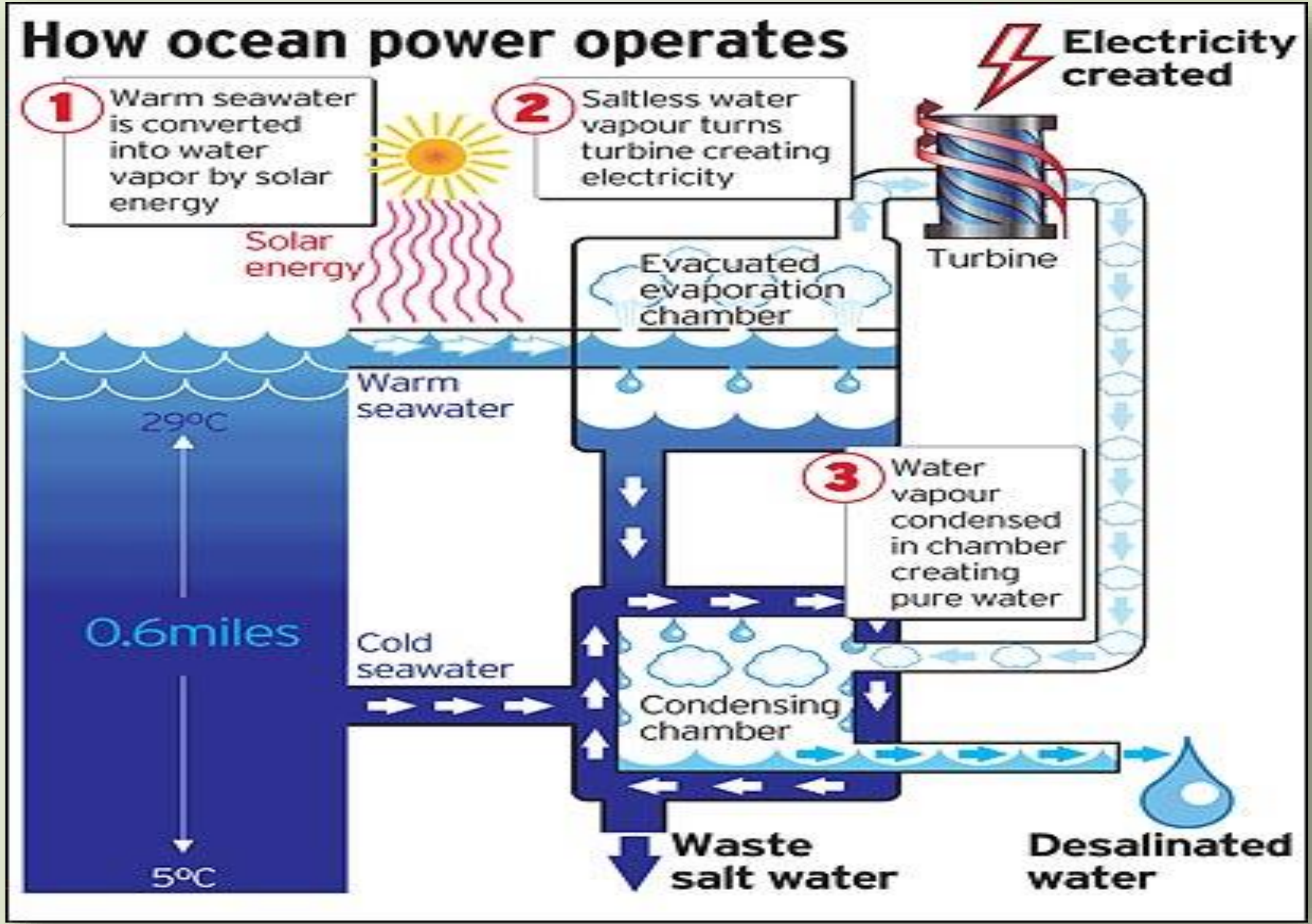
Warm surface water is pumped through an evaporator containing a working fluid. The vaporized fluid drives a turbine/generator. The vaporized fluid is turned back to a liquid in a condenser cooled with cold ocean water pumped from deeper in the ocean. OTEC systems using seawater as the working fluid can use the condensed water to produce desalinated water.





OPEN (CLAUDE) CYCLE

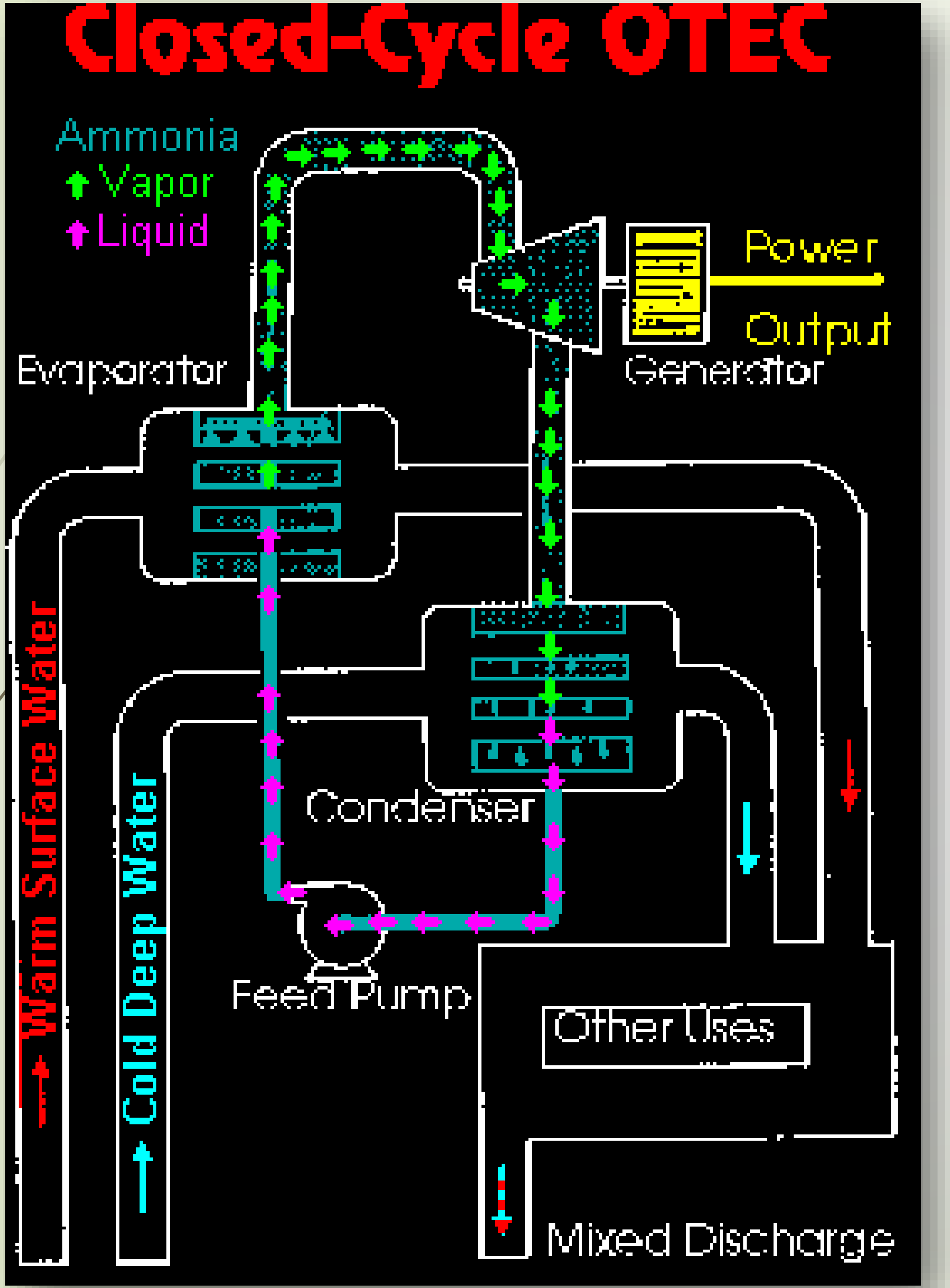
- When warm seawater is placed in a low-pressure container, it boils.
- The expanding steam drives a low-pressure turbine attached to an electrical generator.
- The steam, which has left its salt behind in the low pressure container, is almost pure fresh water. It is condensed back into a liquid by exposure to cold temperatures from deep-ocean water.

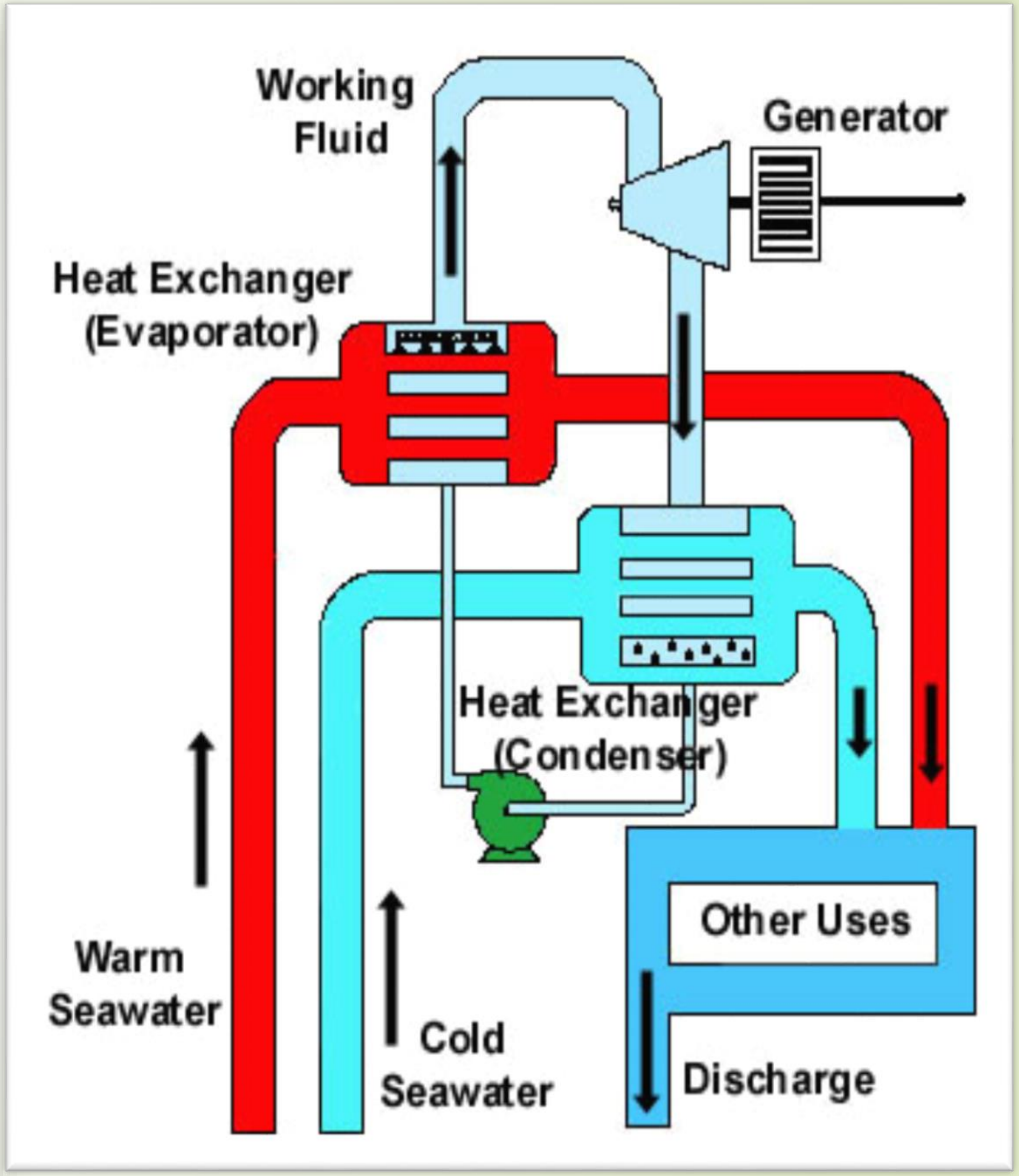

How ocean power operates
Electricity created
1 Warm seawater is converted into water vapor by solar energy
2 Saltless water vapour turns turbine creating electricity
Solar energy
Turbine
Evacuated evaporation chamber
Warm seawater
29°C
0.6miles
5°C
3 Water vapour condensed in chamber creating pure water
Cold seawater
Condensing chamber
Waste salt water
Desalinated water

Closed-cycle systems

- Closed-cycle systems (Rankine) use fluid with a low boiling point, such as ammonia, to rotate a turbine to generate electricity.

- Warm surface seawater is pumped through a heat exchanger where the low-boiling-point fluid is vaporized. The expanding vapor turns the turbo generator. Then, cold deep seawater is pumped through a second heat exchanger which condenses the vapor back into liquid, which is then recycled through the system.


Closed-Cycle OTEC
Ammonia
Vapor
Liquid
Power
Output
Evaporator
Generator
Warm Surface Water
Cold Deep Water
Condenser
Feed Pump
Other Uses
Mixed Discharge


Working
Fluid
Generator
Heat Exchanger
(Evaporator)
Heat Exchanger
(Condenser)
Other Uses
Warm
Seawater
Cold
Seawater
Discharge

Demonstration of 1 MW OTEC Device
Thermo-dynamic Rankine cycle
(Saga University, Japan)

Experimental 30 kW OTEC system
(Saga University, Japan)

OTEC

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