WAVE ENERGY

Umesh Chandra Sharma, PhD
Department of Chemical Engineering
University Institute of Engineering and Technology
C S J M University, Kanpur-208024

INTRODUCTION

- Ocean waves represent a form of renewable energy created by wind currents passing over open water.

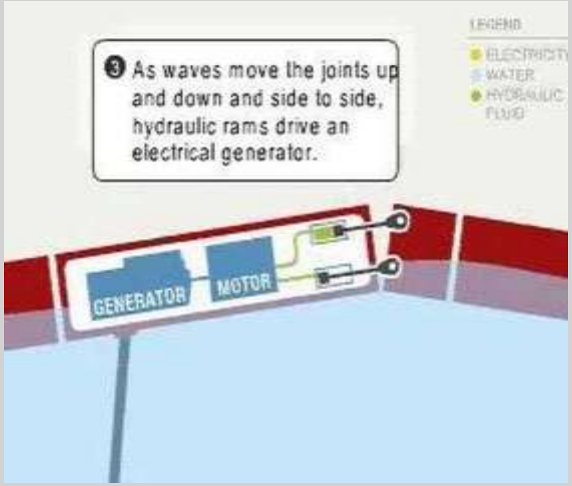
- The term **Wave Energy** refers to the harnessing of the tremendous energy of ocean waves.

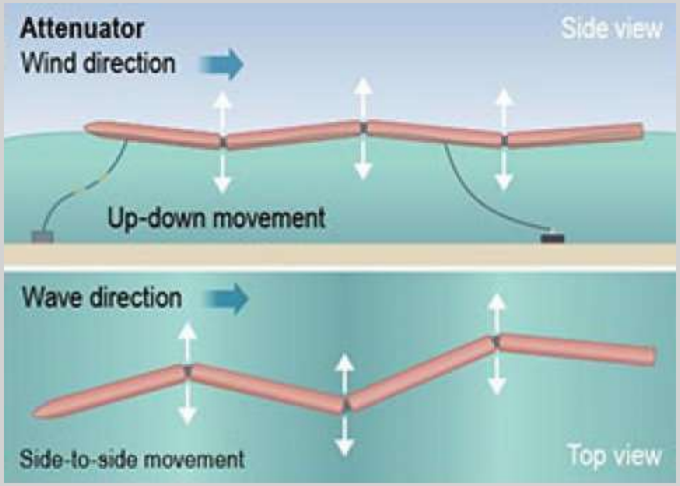
- The total power of waves breaking on the world's coastlines is estimated at 2 - 3 million MW.
- In some locations, the wave energy density can average 65 MW per mile of coastline.

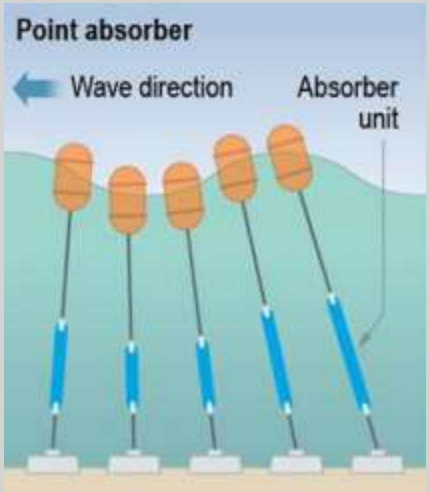
- This large amount of energy can be tapped to do useful work, like, electricity generation, water desalination, or pumping of water into reservoirs.

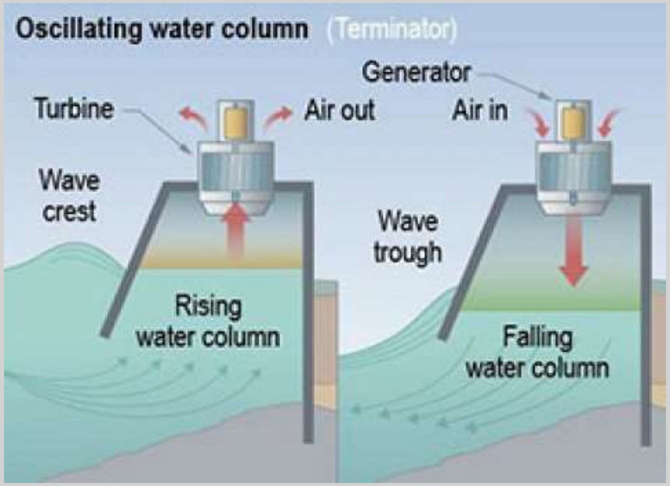
- Ocean waves are generated by the passage of wind across the surface of the sea, the gravitational pull from the sun and moon, and changes in atmospheric pressure, earthquakes, etc.
- In many areas of the world, the wind blows with enough consistency and force. When such wind blows over the surface of the ocean; the higher, longer, and powerful waves are formed that travel vast distances across the ocean at great speed.
- Wave-power rich areas of the world include the western coasts of Scotland, northern Canada, southern Africa, Australia, and the northwestern coasts of the United States.
- The traditional sources of energy such as wood, coal, natural gas and petroleum are non-renewable, and they contribute significantly to atmospheric pollution by releasing large quantities of carbon dioxide, carbon monoxide, sulphur dioxide, nitrogen oxides, and other pollutants.
- In contrast, ocean waves are a renewable source of energy that doesn't cause pollution. The only problem is to harness this energy efficiently and with minimal environmental, social, and economic impacts.

- Wave energy converters (WEC) extract wave energy directly from the surface waves or from pressure fluctuations below the surface.









HISTORY OF WAVE ENERGY

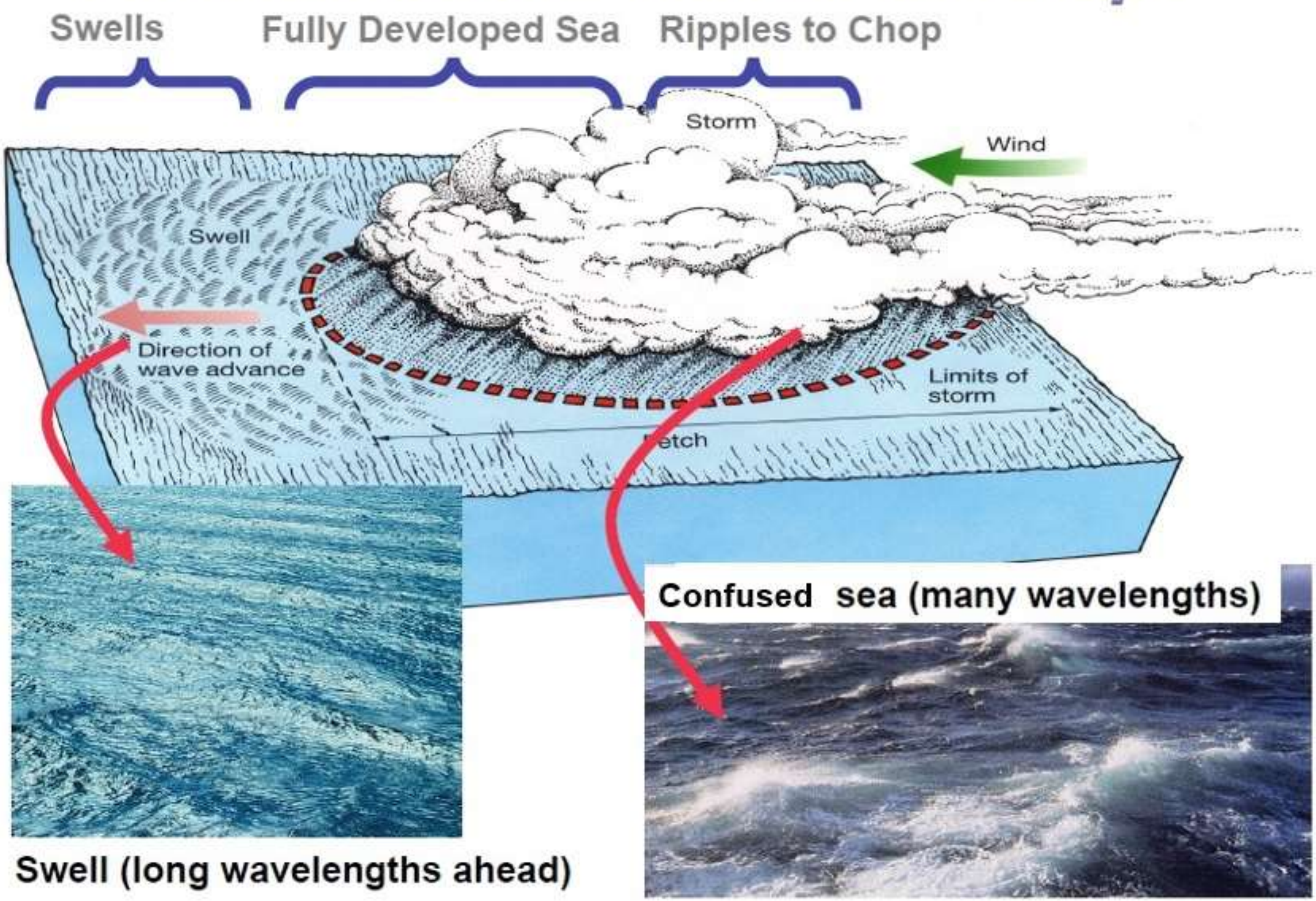
- The first known patent to utilize energy from ocean waves dates back to 1799 and was filed in Paris by Girard and his son.
- An early application of wave power was a device constructed around 1910 by Bochaux-Praceique to light and power his house at Royan, near Bordeaux in France.
- It appears that this was the first Oscillating Water Column type of wave energy device.
- From 1855 to 1973 there were already 340 patents filed in the UK alone.
- Modern scientific pursuit of wave energy was pioneered by Yoshio Masuda's experiments in the 1940s.
- Masuda tested various concepts of wave energy devices at sea, with several hundred units used to power navigation lights.
- Among these was the concept of extracting power from the angular motion at the joints of an articulated raft, which was proposed in the 1950s by Masuda.

- A renewed interest in wave energy was motivated by the oil crisis in 1973.
- A number of university researchers reexamined the potential of generating energy from ocean waves, among whom notably were Stephen Salter from the University of Edinburgh, Kjell Budal and Johannes Falnes from Norwegian Institute of Technology (now merged into Norwegian University of Science and Technology), Michael E. McCormick from U. S. Naval Academy, David Evans from Bristol University, Michael French from University of Lancaster, John Newman and Chiang C. Mei from MIT.
- Stephen Salter’s 1974 invention became known as Salter’s Duck or Nodding Duck, officially referred to as the Edinburgh Duck.
- In small scale controlled tests, Salter's Duck can stop 90% of wave motion and can convert 90% of that to electricity giving 81% efficiency.
- In the 1980s, as the oil price went down, wave-energy funding was drastically reduced. Nevertheless, a few first-generation prototypes were tested at sea.
- More recently, following the issue of climate change, there is again a growing interest worldwide for renewable energy, including wave energy.

FORMATION OF WAVES

- Wave energy can be considered a concentrated form of solar energy, because the wind that starts the waves is itself generated by uneven solar heating of the earth.
- Depending on the natural formation on the earth as well as its orientation to the sun, some spots get more heated than others.
- As some air gets heated, it becomes less dense, and thus lighter, and naturally floats upward.
- This leaves an open space for denser, colder air to rush in and take its place.
- As wind rushes up along the water, the friction causes ripples.
- Wind continues to push against these ripples in a snowball effect that eventually creates a large wave.
- Thus the energy from the sun is transferred to the wind and finally to the waves.
- As long as the waves propagate slower than the wind, there is an energy transfer from the wind to the waves.

How do Ocean Waves develop?



- The rate of energy input to waves is typically 0.01 - 0.10 W/m^2.
- This is a small fraction of the gross solar energy input, which averages 350 W/m^2, but waves can build up over oceanic distances to energy densities averaging over 100 kW/m (note that the typical measure is power per meter width of wave front).
- Because of its origin from oceanic winds, the highest average levels of wave power are found on the lee side of temperate zone oceans, primarily between 30° and 60° latitude, near the equator with persistent trade winds and in high altitudes because of polar storms.
- Wave height is determined by wind speed, the duration of time the wind has been blowing, fetch (the distance over which the wind excites the waves) and by the depth and topography of the seafloor (which can focus or disperse the energy of the waves).
- Large waves that travel far from their origin are called **swell waves**.
- In general, larger waves are more powerful but wave power is also determined by wave speed, wavelength, and water density.
- Oscillatory motion is highest at the surface and diminishes exponentially with depth.

- However, for standing waves (clapotis) near a reflecting coast, wave energy is also present as pressure oscillations at great depth, producing microseisms.
- These pressure fluctuations at greater depth are too small to be interesting from the point of view of wave power.
- Storm winds generally create irregular and complex waves.
- In deep water, after the storm winds die down, the storm waves can travel thousands of kilometers in the form of regular smooth waves, or swells that retain much of the energy of the original storm waves.
- The energy in swells or waves dissipates after it reaches waters that are less than ~200 m deep.
- At 20-m water depths, the wave’s energy typically drops to about one-third of the level it had in deep water.

POWER IN WAVES

- The waves propagate on the ocean surface, and the wave energy is also transported horizontally with the group velocity.
- The mean transport rate of the wave energy through a vertical plane of unit width, parallel to a wave crest, is called the wave energy flux or simply the wave power.
- In deep water where the water depth is larger than half the wavelength, the wave power is

$$P = \frac{\rho g^2 T H^2}{64\pi}$$

P = wave power per unit of wave-crest length (W/m)

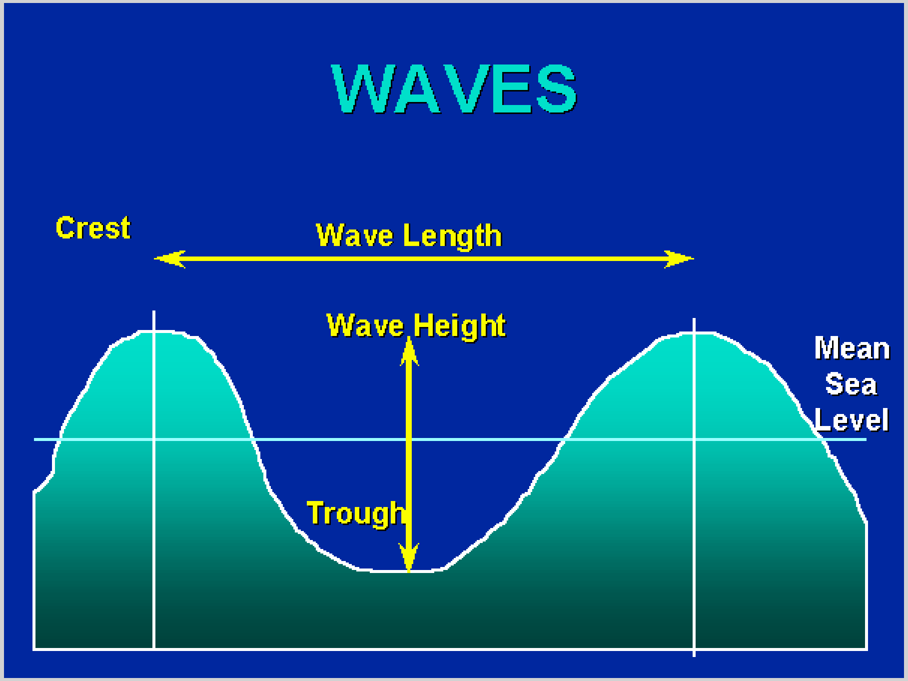
ρ = density of seawater (1025 kg/m^3)

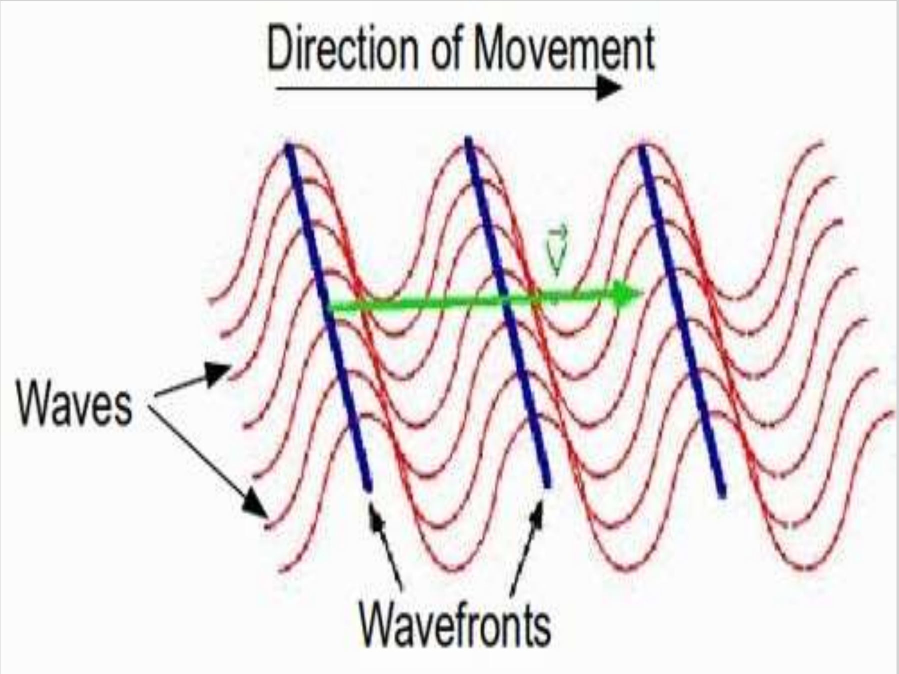
g = acceleration due to gravity (9.8 m/s^2)

T = wave period (s), and

H = significant wave height (m).

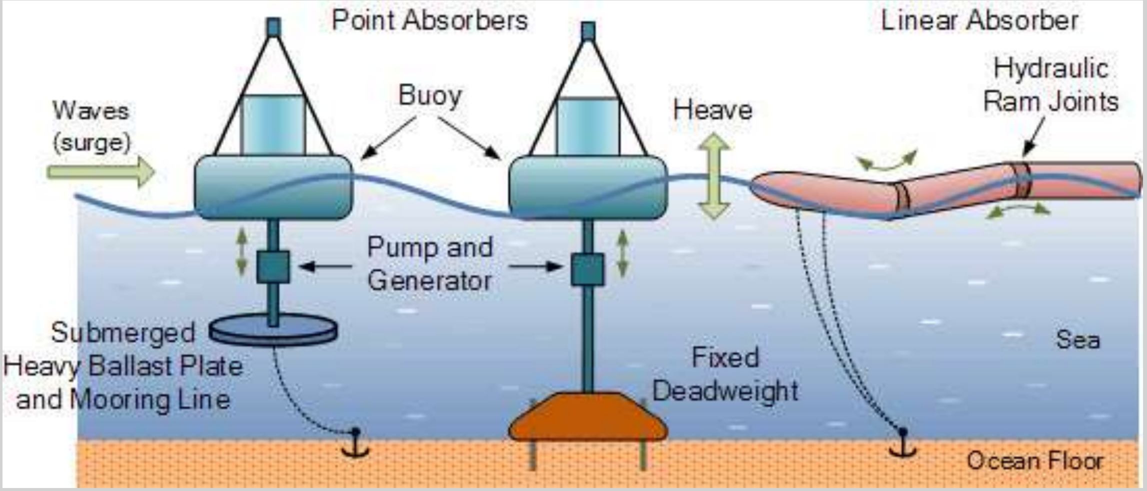
- This equation states that the energy within a wave is proportional to the square of the wave height.
- Therefore a two meter high wave has four times the power of a one-meter high wave.
- In major storms, the largest waves offshore are about 15 meters high and have a period of about 15 seconds.
- According to the above equation, such waves carry about 1.65 MW of power across each meter of wavefront.





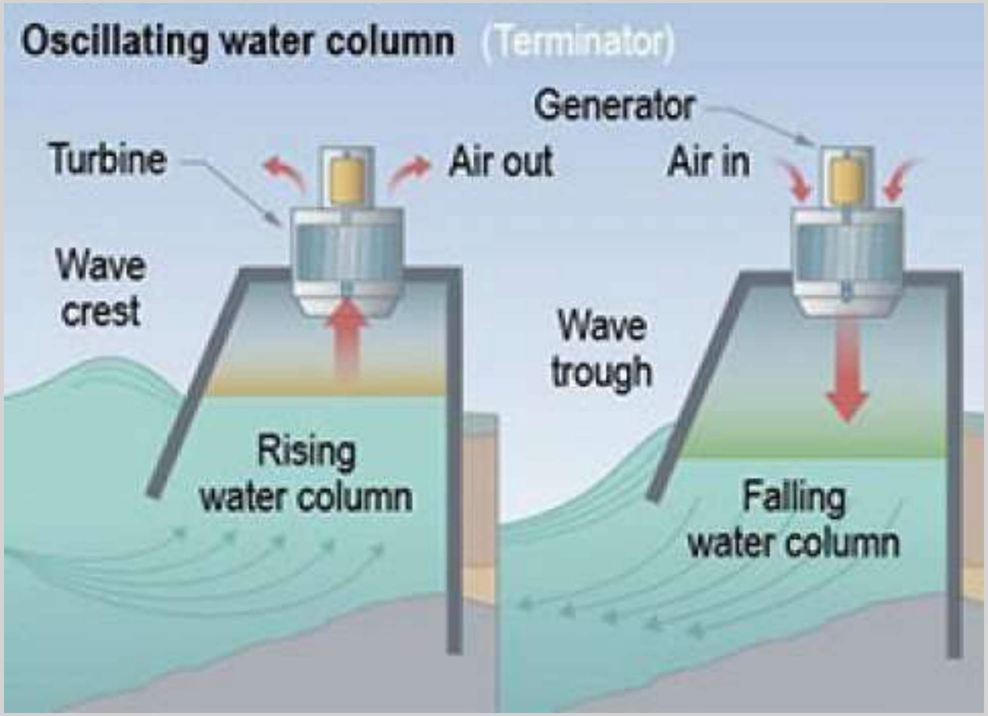
OCEAN WAVE ENERGY TECHNOLOGIES

- A variety of technologies have been designed to be installed in near shore, off shore, and far offshore locations to capture the energy from waves.
- While all wave energy technologies are intended to be installed at or near the water's surface, they differ in their orientation to the waves with which they are interacting and in the manner in which they convert the energy of the waves into electricity.
- Offshore devices are anchored to the sea floor at a depth of 40 meters or more.
- The major wave energy converters are discussed here.
- Some of the more promising designs are undergoing demonstration testing at commercial scales.



(A) Terminator

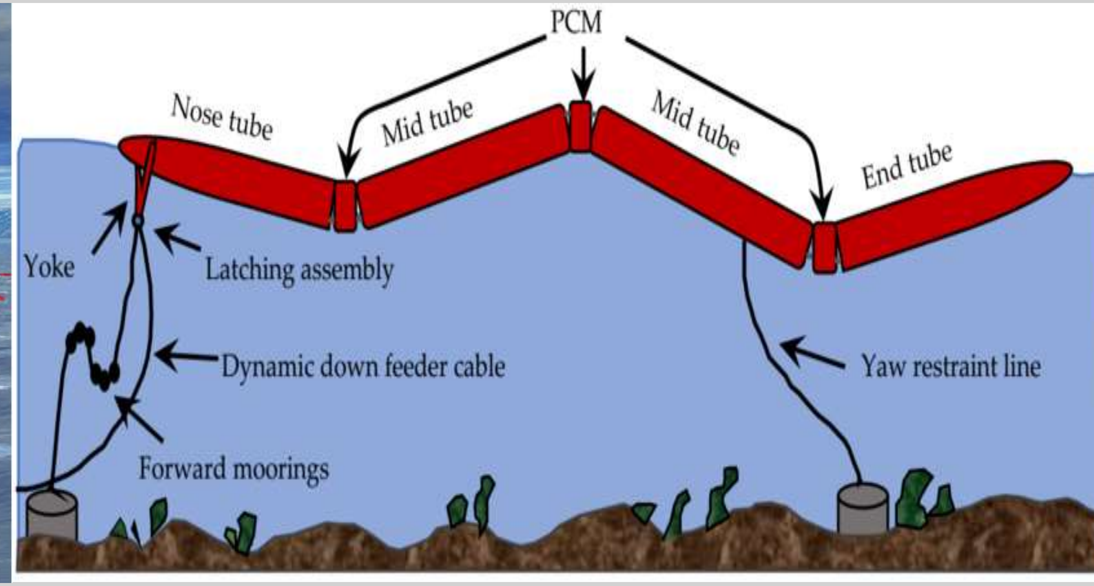
- Wave energy devices oriented perpendicular to the direction of the wave, are known as terminators.
- These devices are typically installed onshore or near-shore; however, floating versions have also been designed for offshore applications.
- These terminators include a stationary component and a component that moves in response to the wave.
- The "stationary" part could be fixed to the sea floor or shore, and must remain still in contrast to the movable part.
- The moving part works like a piston in an internal combustion engine. This motion pressurizes air or oil to drive a turbine.

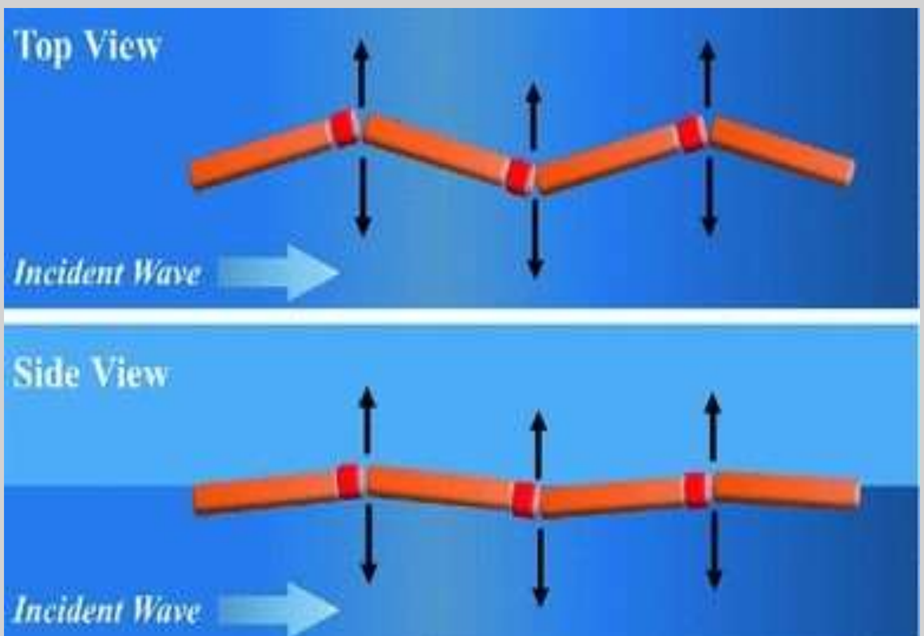


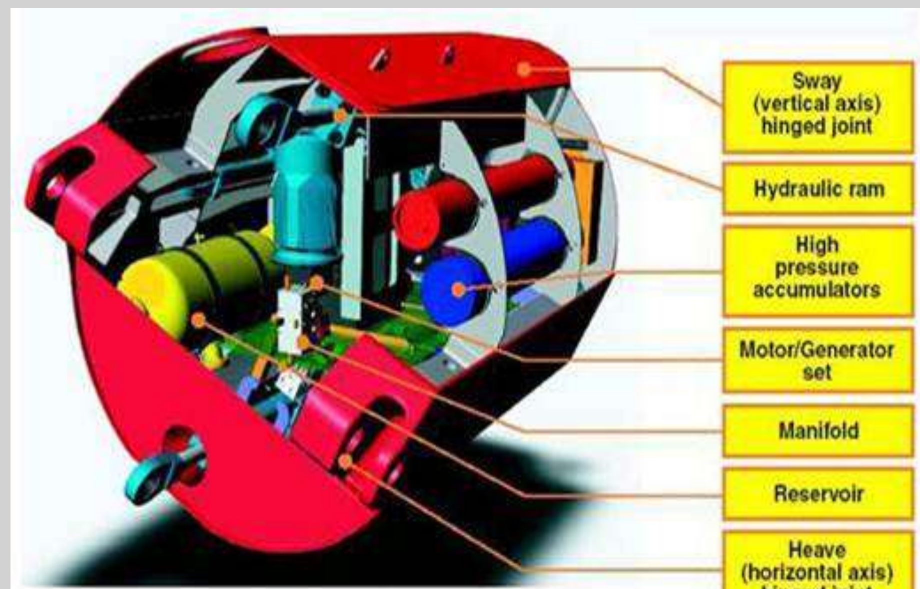
- The **oscillating water column** is a form of terminator which has two openings – one at the bottom that allows water to enter the column and one narrow passage at top to let air in and out.
- As waves come and fill the column with water, this pressurizes the air inside, which forces the air through the opening above.
- The air encounters and drives a turbine. Then, as waves pull away, water rushes out, which sucks more air back down through the top, driving the turbine again.

(B) Attenuator

- Attenuators are long multi-segment floating structures oriented parallel to the direction of the wave travel.
- The differing heights of waves along the length of the device cause flexing where the segments connect.
- This flexing, connected to hydraulic rams, drive an electric generator.
- The device sends the electricity through cables to the sea floor where it then travels through a cable to shore.
- **Pelamis,** the most advanced attenuator designed by Pelamis Wave Power Limited, UK has four 30 m long × 3.5 m dia floating cylindrical pontoons connected by three hinged joints and is anchored to the seabed.
- Flexing at the hinged joints due to wave action drives hydraulic pumps built into the joints.



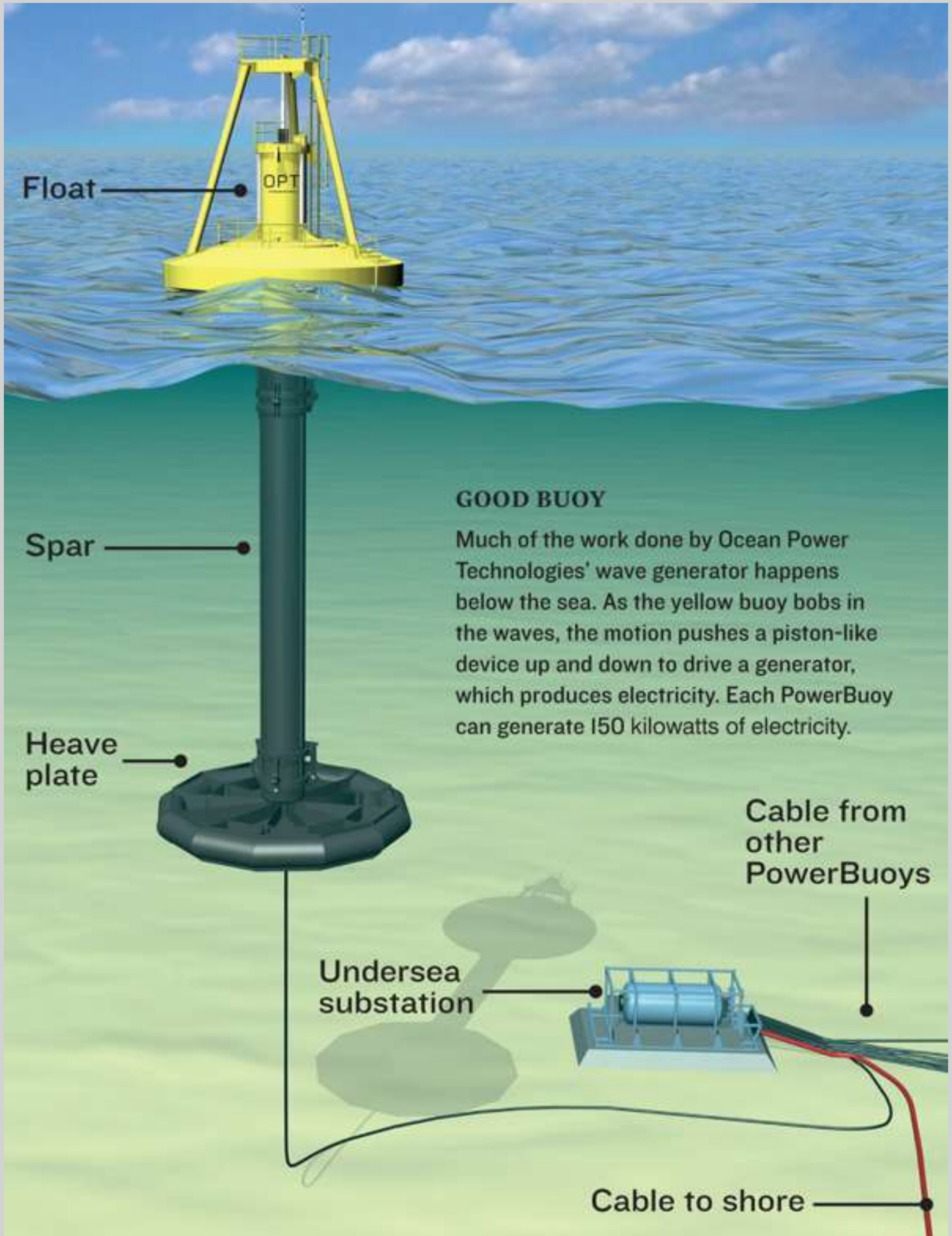


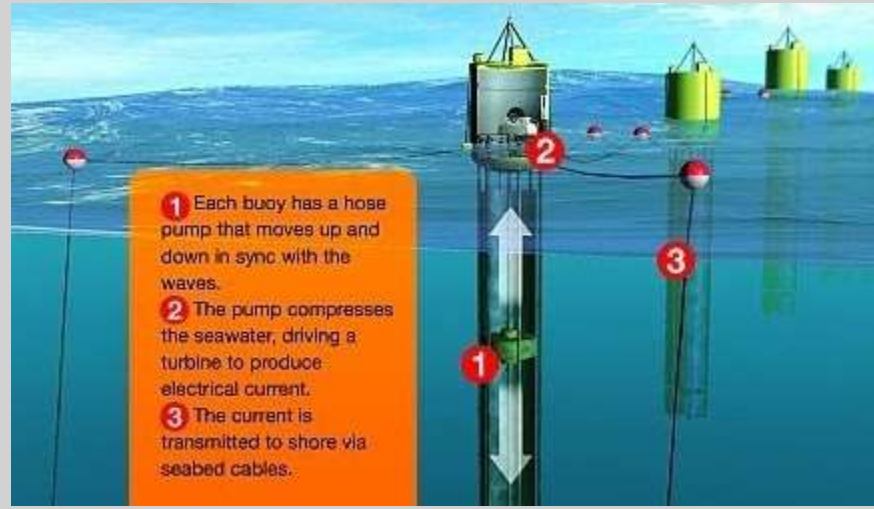


Internal view of a Pelamis Power Conversion Module.

(C) Point Absorber

- Point absorbers are devices that are not oriented a particular way toward the waves, but rather can absorb the energy of waves from any way.
- **Aquabuoy** is a point absorber type device. In a vertical tube below the water, waves rush in and drive a piston, a buoyant disk connected to hose pumps up and down to pressurize seawater inside.
- The pressurized water then drives a built-in turbine connected to an electrical generator.
- Many Aquabuoys can send electricity to a central point. From that point, electricity is sent down to the seafloor and then to shore via a cable.

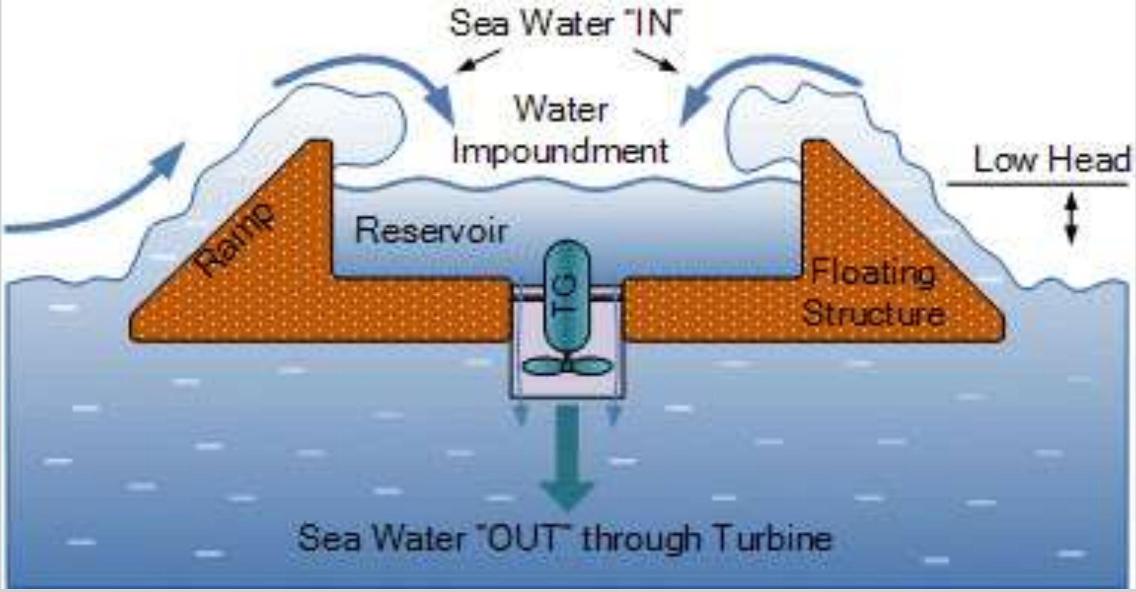

Float
OPT
Spar
Heave plate
GOOD BUOY
Much of the work done by Ocean Power Technologies' wave generator happens below the sea. As the yellow buoy bobs in the waves, the motion pushes a piston-like device up and down to drive a generator, which produces electricity. Each PowerBuoy can generate 150 kilowatts of electricity.
Cable from other PowerBuoys
Undersea substation
Cable to shore


1 Each buoy has a hose pump that moves up and down in sync with the waves.
2 The pump compresses the seawater, driving a turbine to produce electrical current.
3 The current is transmitted to shore via seabed cables.
1
2
3


OPT

(D) Overtopping Device

- An overtopping device includes a wall that collects the water from rising waves in a reservoir to levels above the average surrounding ocean.
- The water is then released back into the ocean under gravity through an opening, but while passing through, drives a hydro turbine or other conversion device.
- Salter's Duck is the most famous overtopping device that includes a bobbing, cam-shaped head that drives a turbine.
- Though not fully realized, theoretically this device is the most efficient wave energy converter.



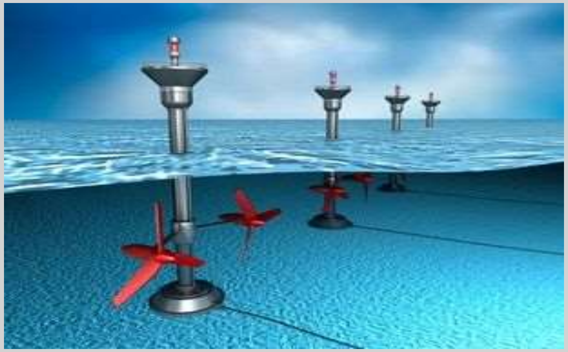
ENVIRONMENTAL CONSIDERATIONS

- Conversion of wave energy into electrical or other usable forms of energy is generally supposed to have limited environmental impacts. However, as with any emerging technology, the nature and extent of environmental considerations remain uncertain.
- The impacts that would potentially occur are also very site specific, depending on physical and ecological factors that vary considerably for potential ocean sites.
- The following environmental considerations require monitoring:

(A) Visual appearance and noise
(B) Impact on wave characteristics
(C) Impact on marine habitat
(D) Possibility of toxic releases
(E) Clash of interests with other sea space users
(F) Installation and decommissioning

(A) Visual Appearance and Noise

- Visual appearance and noise are device-specific, with considerable variability in visible freeboard height and noise generation above and below the water surface.
- Devices with OWCs and overtopping devices typically have the highest freeboard and are most visible.
- Offshore devices would require navigation hazard warning devices such as lights, sound signals, radar reflectors, and contrasting day marker painting.
- The air being drawn in and expelled in OWC devices is likely to be the largest source of above-water noise.
- Some underwater noise would occur from devices with turbines, hydraulic pumps, and other moving parts.
- The frequency of the noise may also be a consideration in evaluating noise impacts.

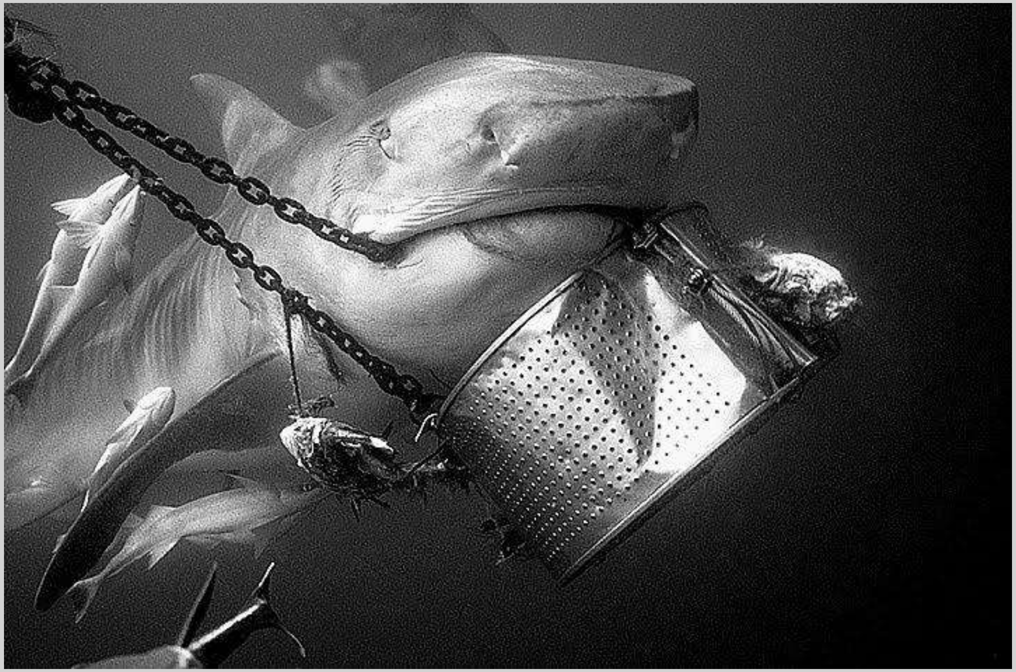


(B) Impact on Wave Characteristics

- Reduction in wave height from wave energy converters could be a consideration in some settings; however, the impact on wave characteristics would only be observed 1 to 2 km away from the WEC device in the direction of the wave travel.
- There should not be a significant onshore impact if the devices were much more than this distance from the shore.
- None of the devices currently being developed would harvest a large portion of the wave energy, which would leave a relatively calm surface behind the devices.
- It is estimated that a large wave energy facility with a maximum density of devices would cause the reduction in waves to be on the order of 10 to 15%, and this impact would rapidly dissipate within a few kilometers.

(C) Impact on Marine Habitat

- Marine habitat could be impacted positively or negatively depending on the nature of additional submerged surfaces, above-water platforms, and changes in the seafloor.
- Artificial above-water surfaces could provide habitat for seals and sea lions or nesting areas for birds.
- Underwater surfaces of WEC devices would provide substrates for various biological systems, which could be a positive or negative complement to existing natural habitats.
- With some WEC devices, it may be necessary to control the growth of marine organisms on some surfaces.



(D) Possibility of Toxic Releases

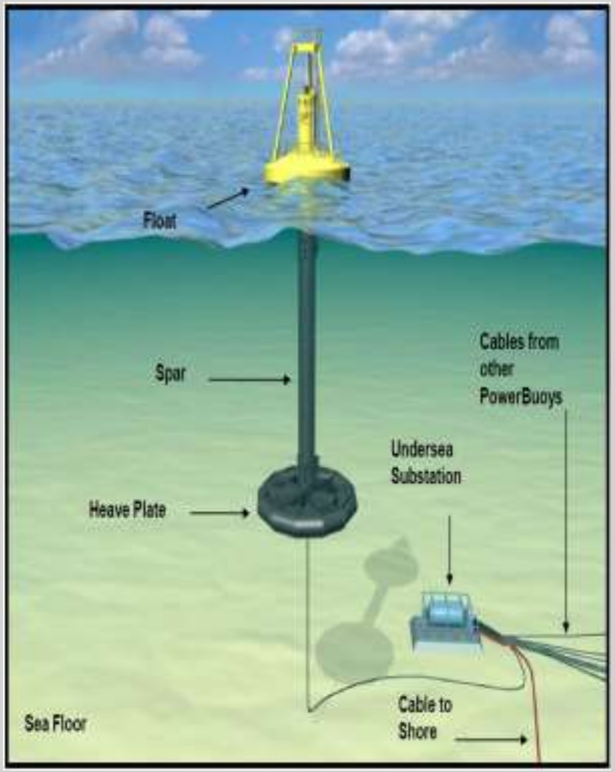
- Toxic releases may be of concern related to leaks or accidental spills of liquids used in systems with working hydraulic fluids.
- Any impacts could be minimized through the selection of nontoxic fluids and careful monitoring, with adequate spill response plans and secondary containment design features.
- Use of biocides to control growth of marine organisms may also be a source of toxic releases.

(E) Clash of Interests with Other Users

- Conflict with other sea space users, such as commercial shipping and fishing and recreational boating, can occur without the careful selection of sites for WEC devices.
- The impact can potentially be positive for recreational and commercial fisheries if the devices provide for additional biological habitats.

(F) Installation and Decommissioning

- Disturbances from securing the devices to the ocean floor and installation of cables may have negative impacts on marine habitats.
- Potential decommissioning impacts are primarily related to disturbing marine habitats that have adapted to the presence of the wave energy structures.

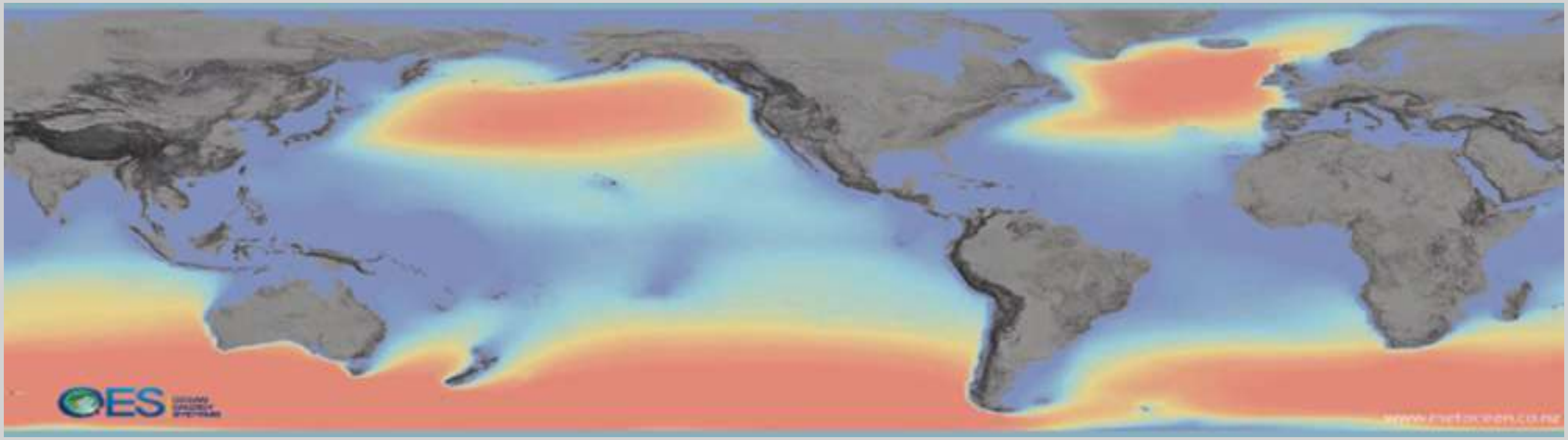


ECONOMIC CONSIDERATIONS

- Cost estimates of energy produced by WECs are dependent on many physical factors, such as system design, wave energy power, water depth, distance from shore, and ocean floor characteristics.
- Economic factors, such as assumptions on discount rate, cost reductions from a maturing technology, and tax incentives, are also critical.
- The estimated cost of electricity after tax incentives from the commercial scale facilities in offshore regions with relatively high wave energy is in the range of $0.09 to $0.11/kWh and the total capital investment range from $4,000 to $15,000/kW.
- In general, WEC facilities are highly capital intensive and significant breakthroughs in capital cost would be required to make this technology cost competitive.

WORLDWIDE POTENTIAL OF WAVE ENERGY

- The worldwide estimates of economically recoverable wave energy resource are in the range of 140 to 750 TWh/yr for existing wave energy conversion technologies.
- With projected long-term technical improvements, this could be increased by a factor of 2 to 3.
- Locations with the most potential for wave power include the western seaboard of Europe, the northern coast of the UK, and the Pacific coastlines of North and South America, Southern Africa, Australia, and New Zealand.
- The north and south temperate zones have the best sites for capturing wave power.
- The prevailing westerlies in these zones blow strongest in winter.



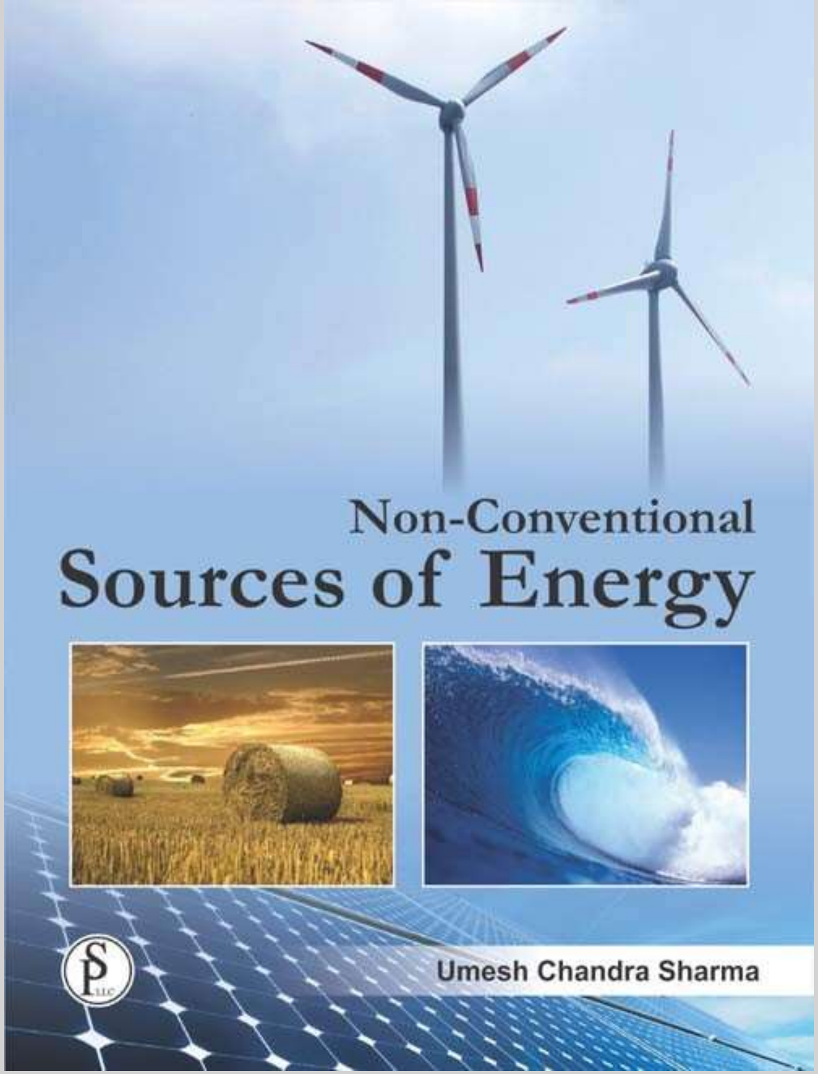
ADVANTAGES OF WAVE ENERGY

- The wave energy has the potential to be one of the most environmentally benign forms of electricity generation.
- Wave energy is more predictable than many other forms of renewable energy, such as wind or solar, and can be forecast accurately up to five days in advance.
- Wave energy is clean and renewable. It is one of the last renewable energy forms which mankind has yet to harness, and its potential is huge.
- Wave energy could play a major part in the global efforts to combat climate change, potentially displacing 1 – 2 billion tonnes of CO_2 per annum from conventional fossil fuel generating sources.
- Such installations would also provide many employment opportunities in construction, operations and maintenance.

DISADVANTAGES OF WAVE ENERGY

- It depends on the waves, means it there may be a variable energy supply.
- It needs a suitable site where waves are consistently strong.
- Some wave energy converters are too noisy.
- These devices are very costly to develop.
- The wave energy conversion devices are quite likely to disrupt distribution and types of marine life near the shore
- There is a possible threat to navigation from collisions due to the low profile of the wave energy devices above the water, making them undetectable either by direct sighting or by radar.
- The mooring and anchorage lines may interfere with commercial and sport fishing activities.
- The on-shore or near-shore wave energy devices and overhead electric transmission lines may degrade scenic ocean front views.

REFERENCE



- Sharma U.C., Non-conventional Sources of Energy, Studium Press, LLC USA (2014).


Thank You