

Course: Renewable Energy Sources – 21EE652

Module-5: Sea Wave Energy

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- Waves get their energy from the solar energy through the wind.
- Wave energy will never be depleted as long as the sun shines. Energy intensity may, however, have variation but it is available 24 h a day in the entire year.
- They are caused by the wind blowing over the surface of the ocean with enough consistency and force in many areas of the world to provide continuous waves along the shore line.
- It contains tremendous energy potential and wave power devices extract energy from either the surface motion of ocean waves or from pressure fluctuations below the surface.
- The movement of the ocean water and the changing water wave heights and speed of the swells are the main sources of wave energy.
- Kinetic energy in the wave motion is tremendous that can be extracted by the wave power devices from either the surface motion of ocean waves or from pressure fluctuations below the ocean surface.

Motion in the Sea Waves

- When the wind blows across smooth water surface, air particles from the wind grab the water molecules they touch.
- Stretching of the water surface by the force or friction between the air and the water creates capillary waves (small wave ripples).
- Surface tension acts on these ripples to restore the smooth surface, and thereby, waves are formed.
- The combination of forces due to the gravity, sea surface tension, and wind intensity are the main factors of origin of sea waves as shown in Figure 5.1, which illustrates the formation of sea waves by a storm.
- Wave size is determined by wind speed and fetches (defined as the distance over which the wind excites the waves) and by the depth and topography of these abed (which can focus or disperse the energy of the waves).

- Sea waves have a regular shape at far distance from the fetch and this phenomenon is called swell.
- Wave formation makes the water surface further rough and the wind continuously grips the roughened water surface, and thus, waves are intensified.

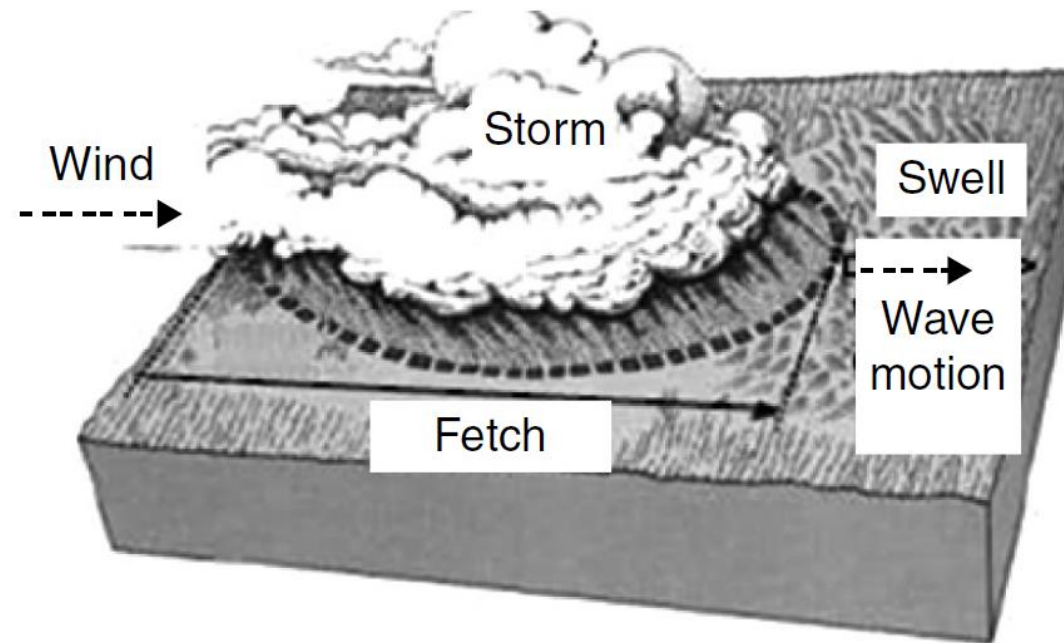


Figure 5.1 Sea wave formation by storm

- A wave is a forward motion of energy and not the water in deep sea. In true sense, the seawater does not move forward with a wave.
- Waves are characterized by the following parameters, as shown in **Figure 5.2**.
- **Crest:** The peak point (the maximum height) on the wave is called the crest.
- **Trough:** The valley point (the lowest point) on the wave is called the trough.
- **Wave height (H):** Wave height is a vertical distance between the wave crest and the next trough (m).
- **Amplitude (a):** It is defined as $H/2$ (m).
- **Wave length (Lambda):** It is the horizontal distance either between the two successive crests or troughs of the ocean waves (m).

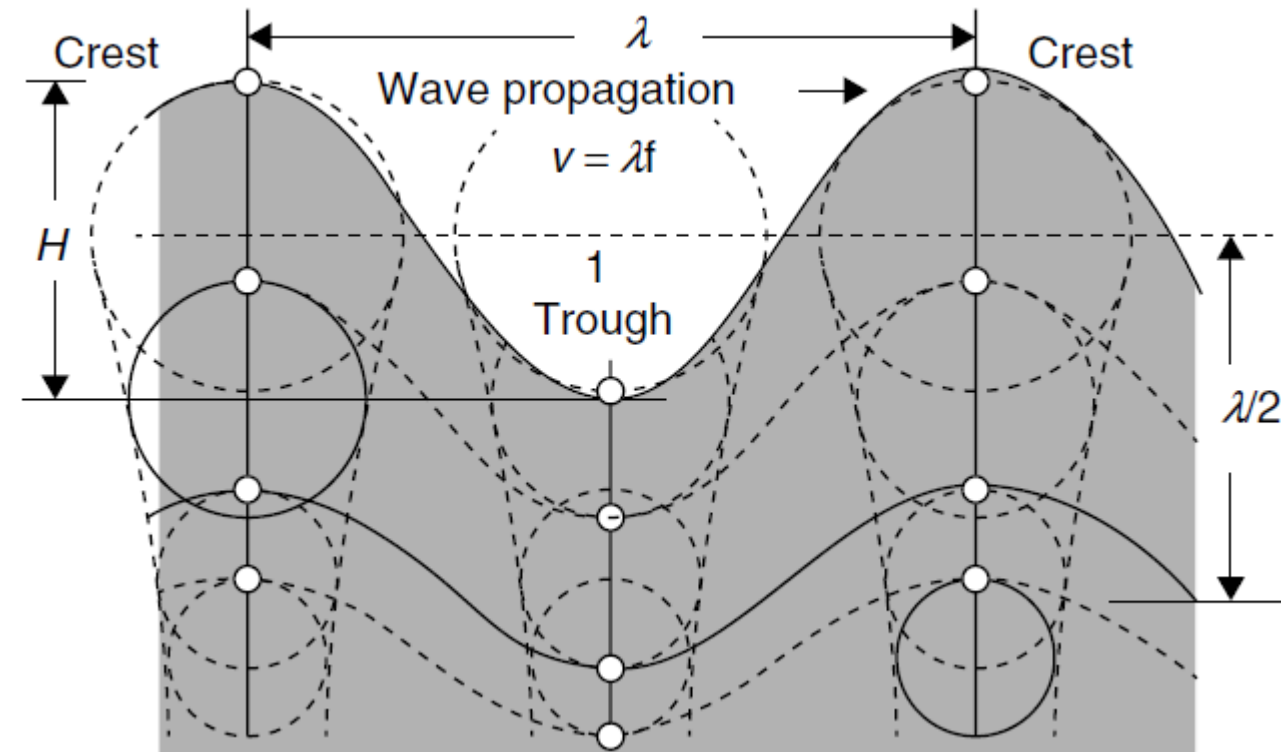


Figure 5.2 Sea wave propagation

- **Wave propagation velocity (v):** The motion of seawater in a direction (m/s).
- **Wave period (T):** It measures the size of the wave in time(s). It is the time required for two successive crests or two successive troughs to pass a point in space.
- **Frequency (f):** The number of peaks (or troughs) that pass a fixed point per second is defined as the frequency of wave and is given by $f = 1/T$ (cycle/s).

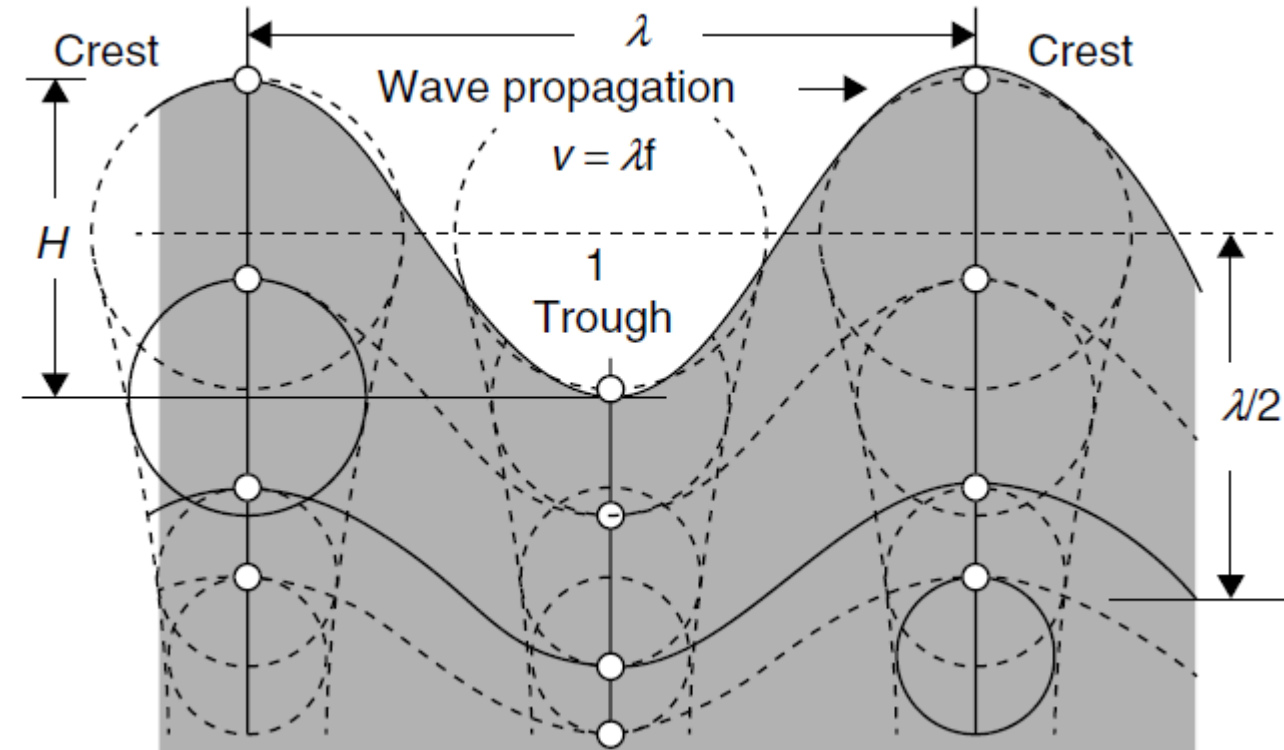


Figure 5.2 Sea wave propagation

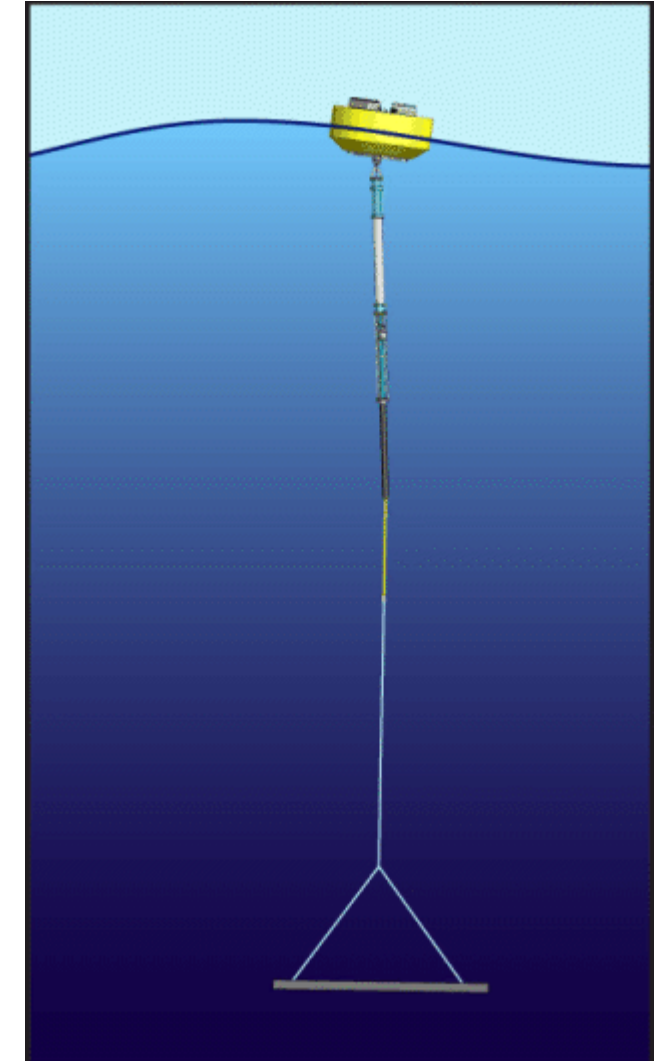
Devices for Harnessing Wave Energy

Terminator devices:

- It is a wave energy device oriented perpendicular to the direction of the wave and has one stationary and one moving part.
- The moving part moves up and down like a car piston in response to ocean waves and pressurizes air or oil to drive a turbine.
- An oscillating water column (OWC) converter is an example of terminator device. These devices generally have power ratings of 500 kW to 2 MW, depending on the wave parameters and the device dimensions.



Aquabuoy WEC



Attenuator devices:

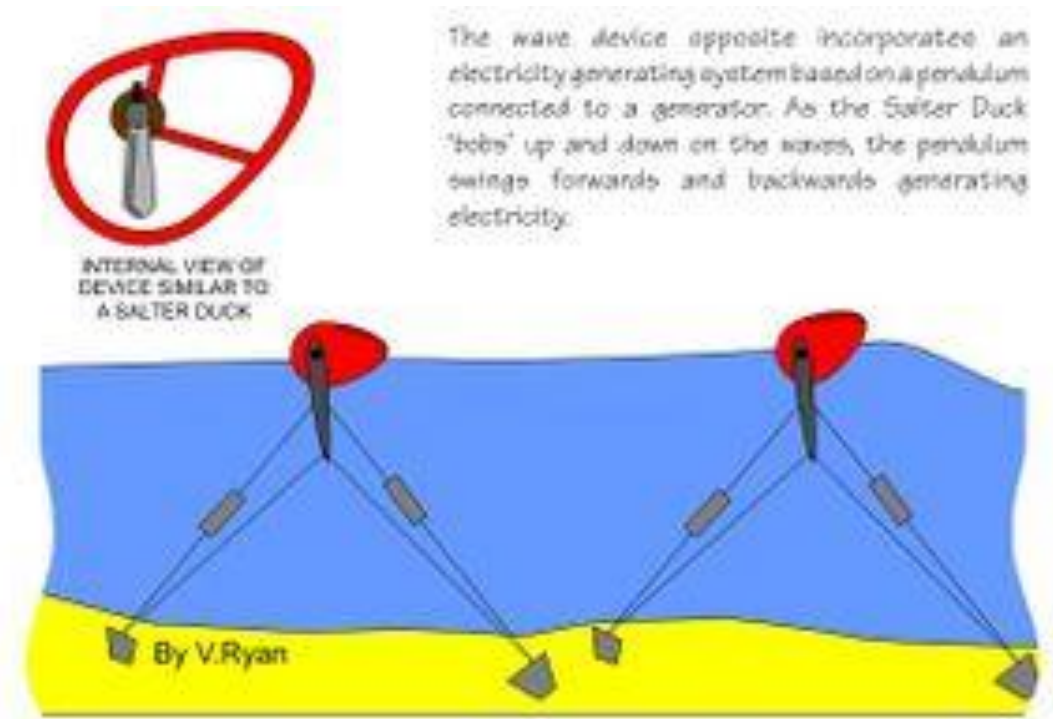
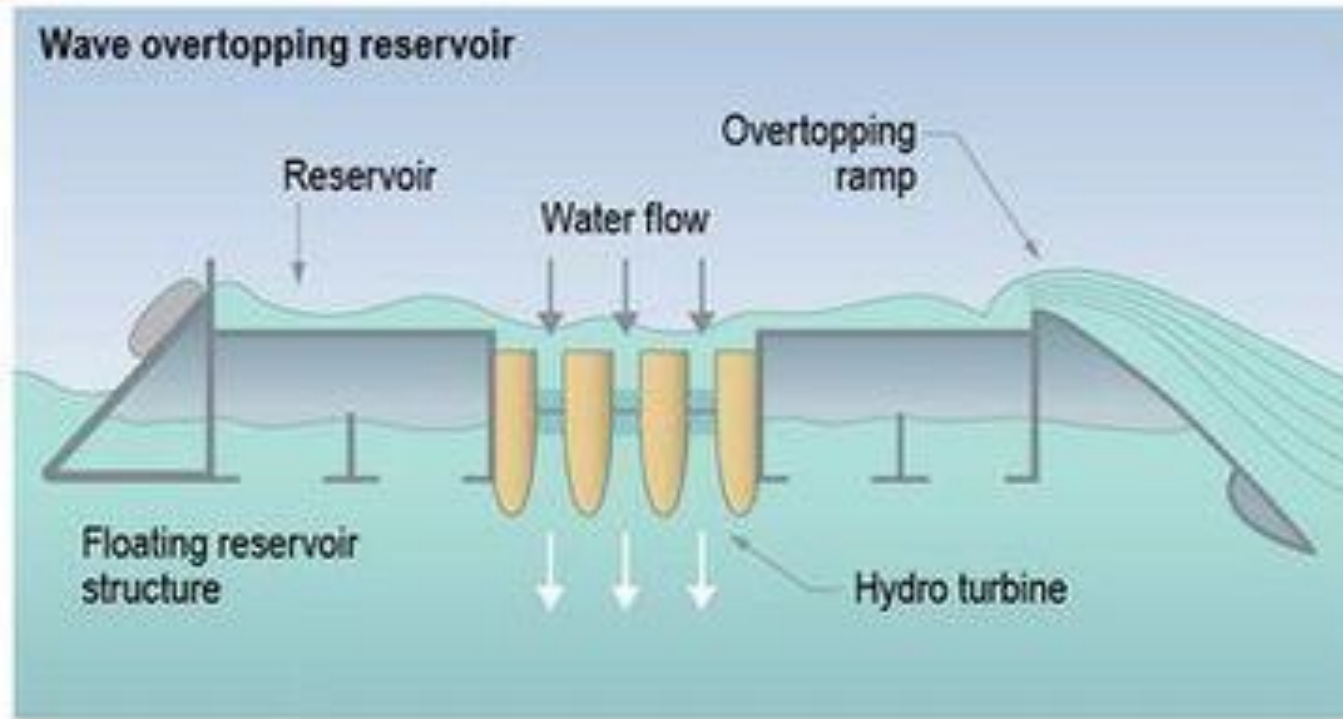
- These devices are oriented parallel to the direction of the waves and are long multi-segment floating structures.
- It has a series of long cylindrical floating devices connected to each other with hinges and anchored to the seabed.
- They ride the waves like a ship, extracting energy by using restraints at the bow of the device and along its length.
- The segments are connected to hydraulic pumps or other converters to generate power as the waves move across.
- Pelamis wave energy converter is one of the known examples of attenuator devices.

Point absorber:

- It is a floating structure with parts moving relative to each other owing to wave action but it has no orientation in any defined way towards the waves instead absorbs the wave energy coming from any direction.
- It utilizes the rise and fall of the wave height at a single point for energy conversion.
- The pressurized water creates up and down bobbin type motion and drives a built-in turbine generator system to generate electricity.
- AquaBuOY WEC is an example of point absorber devices.

Overtopping devices:

- These devices have reservoirs like a dam that are filled by incoming waves, causing a slight build-up of water pressure.
- Gravity causes released water from reservoir to flow back into the ocean through turbine coupled to an electrical generator.
- Salter Duck WEC is the example of overtopping devices.



Salter Duck WEC

ADVANTAGES AND DISADVANTAGES OF WAVE POWER

Advantages

1. Sea waves have high energy densities and provide a consistent stream of electricity generation capacity.
2. Wave energy is clean source of renewable energy with limited negative environmental impacts.
3. It has no greenhouse gas emissions or water pollutants.
4. Operating cost is low and operating efficiency is optimal.
5. Damage to ocean shoreline is reduced.

Disadvantages

1. High construction costs.
2. Marine life is disrupted and displaced.
3. Damage to the devices from strong storms and corrosion create problems.
4. Wave energy devices could have an effect on marine and recreation environment.

Ocean thermal energy conversion (OTEC)

- Low-temperature heat obtained from renewable energy resources, such as solar thermal, geothermal, ocean thermal, etc. is presently converted into electricity and utilized for direct heating applications.
- About 70% of earth's surface is covered by ocean which is continuously heated by solar heat.
- Solar heat is stored as uneven distribution of heat between warm surface water and cold deep ocean water (called gradient) from where it is harnessed as ocean thermal energy.
- OTEC sites that are located between the Tropic of Cancer and Tropic of Capricorn (23.5°N and 23.5°S of equator) found to be best locations.
- Ocean water with temperature gradient of 5°C and more is known as ocean thermal energy.

- However, significant amount of electric power can be generated in the location where a temperature difference of 20°C and above exists between warm surface water and cold deep water.
- In many regions, ocean surface water is generally maintained at 25°C or above and more than 1,000 metres below the surface is generally at about 5°C .
- Therefore, OTEC is an energy technology that converts solar radiation to electric power through heat of ocean water.
- These systems use ocean's natural thermal gradient.
- As long as the temperature difference between the warm surface water and the cold deep water below 600 metres by about 20°C , an OTEC system can produce a significant amount of power.
- Thus, oceans are vast renewable resources with the potential to produce thousands of kW of electric power.

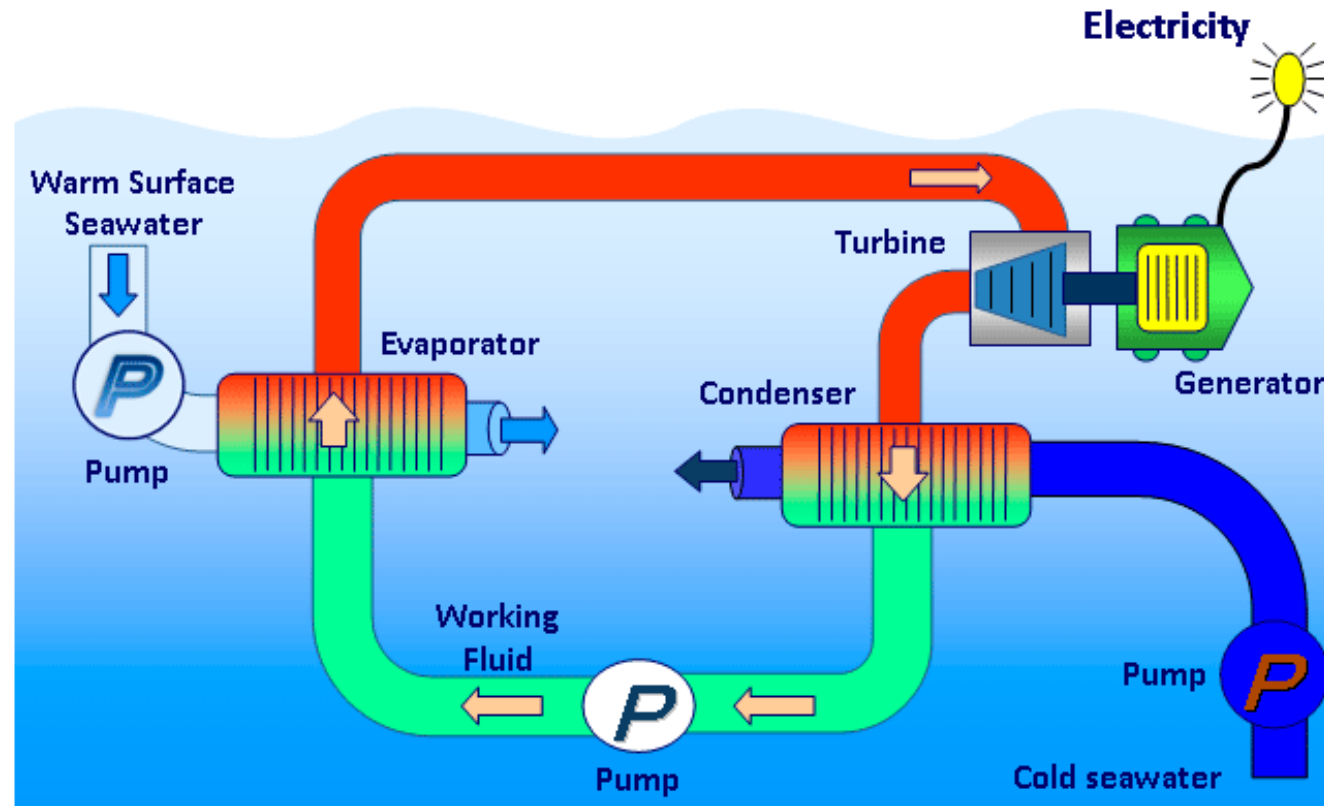
- The cold deep sea water used in the OTEC system is also rich in nutrients, and it can be used to cultivate plant and marine organism near the shore or on land.

Principle of Ocean Thermal Energy Conversion

The basic principle of ocean thermal energy conversion (OTEC) is explained as follows:

- The warm water from the ocean surface is collected and pumped through the heat exchanger to heat and vapourized a working fluid, and it develops pressure in a secondary cycle.
- Then, the vapourized working fluid expands through a heat engine (similar to a turbine) coupled to an electric generator that generates electrical power.
- Working fluid vapour coming out of heat engine is condensed back into liquid by a condenser.
- Cold deep ocean water is pumped through condenser where the vapour is cooled and returns to liquid state.

- The liquid (working fluid) is pumped again through heat exchanger and cycle repeats, It is known as closed-cycle OTEC.
- If ocean surface water is high, enough propane or similar material is used as working fluid; otherwise, for low-temperature surface water, fluid such as ammonia with low boiling point is used.
- In an open-cycle OETC, warm ocean surface water is pumped into a low-pressure boiler to boil and produce steam.
- Then, the steam is used in steam turbine to drive an electrical generator for producing electrical power.
- The cold deep sea water is used in condenser to condense steam.



1. Warm seawater and Cold seawater are pumped to the evaporator and condenser.
2. The cold working fluid is pumped to the evaporator
3. The evaporator uses the warm sea water to vaporise the working fluid
4. The vapor rotates the turbine thereby generating electricity
5. The vapor then enters the condenser where the cold seawater cools it to a fluid
6. The fluid returns to the pump and the cycle is repeated

Open Cycle, Closed Cycle and Hybrid Cycle

There are three types of OTEC cycle designs, namely open cycle, closed cycle, and hybrid cycle.

- In an open cycle, warm sea water is pumped into a flash evaporator as working fluid where it boils at low pressure and converts into steam.
- This steam expands through low-pressure turbine which drives an electrical generator and generates electricity.
- The steam released from turbine condensed in a condenser by deep sea cold water as non-saline water.
- When non-condensable gases are separated and exhausted, the non-saline water is either pumped in marine culture ponds for freshwater applications or finally discharged in sea surface water.

- In closed cycle, organic fluid flows in a separate closed-cycle loop called **organic Rankine cycle**.
- Warm sea surface water pumped through another pipe vapourized working fluid in heat exchangers to drive turbine generator, The fluid vapour condenses into liquid form by deep sea water pumped in condenser by a separate pumping system, The process of pumping liquid fluid in an evaporator cycle is repeated.
- A hybrid cycle is a combination of both closed and open cycle.

Open-Cycle OTEC

The working principles of open-cycle OTEC plants are explained as follows with the help of Figure 5.3.

- The warm ocean surface water is pumped into flash evaporator where it is partially flashed into steam at a very low pressure.
- The remaining warm sea water is discharged into the sea.
- The low-pressure vapour (steam) expands in turbine to drive a coupled electrical generator to produce electricity.
- A portion of electricity generated is consumed in plants to run pumps and for other work, and the remaining large amount of electricity is stored as net electrical power.

Warm sea water inlet

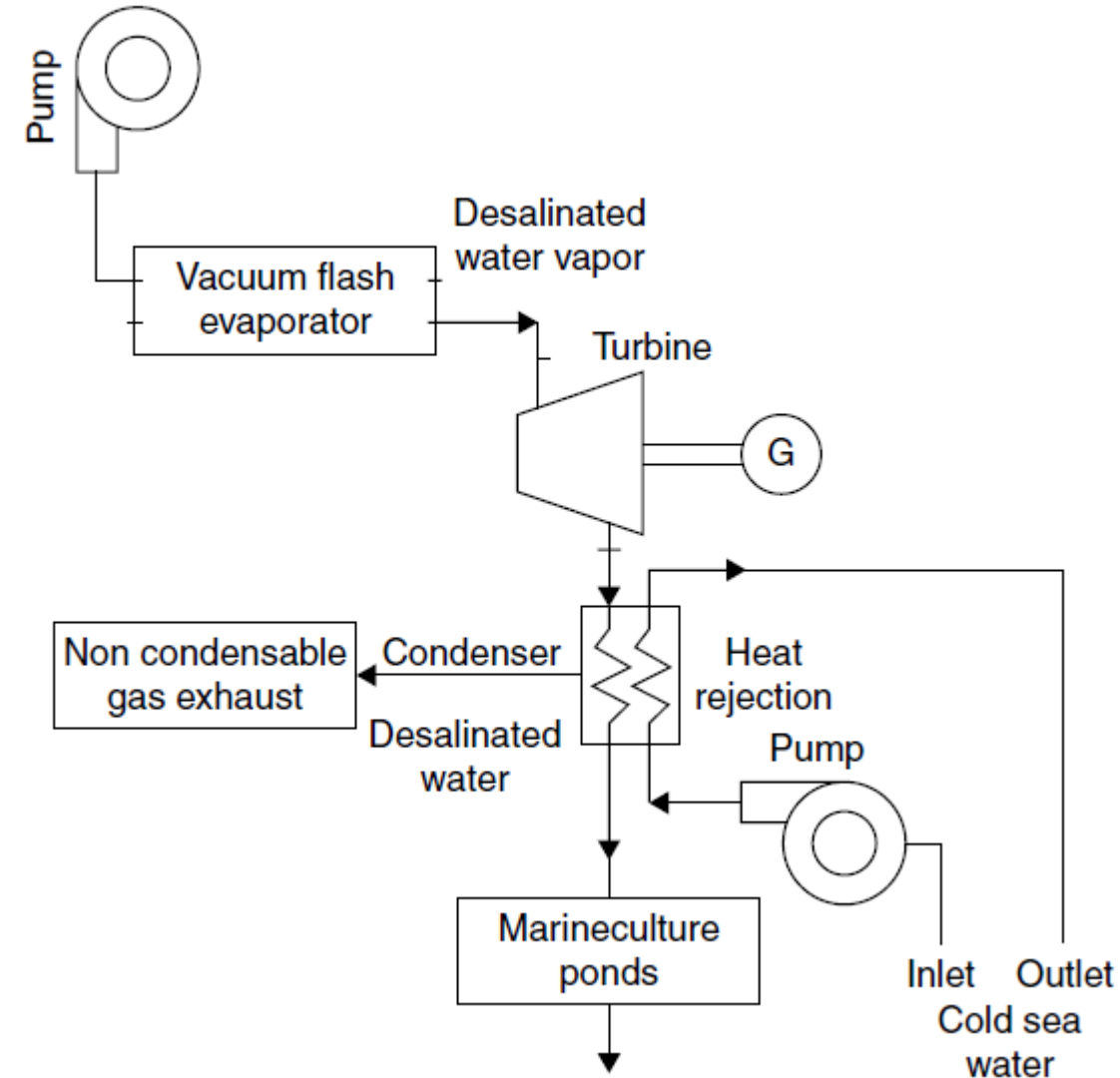


Figure 5.3 Open-cycle OTEC

- The steam with many gases (such as oxygen, nitrogen, and carbon dioxide) released from the turbine separated from sea water in an evaporator is pumped into condenser.
- The steam is cooled in a condenser by cold deep sea water.
- The condensed non-saline water is discharged either directly in deep sea cold water or through the marine culture pond.
- The non-condensable gases are compressed to pressure and exhausted simultaneously.
- The warm ocean surface water is continuously pumped into evaporator and cycle repeats.

Closed-Cycle OTEC

- The schematic of closed-cycle OTEC is shown in Figure 5.4.
- It has different arrangement when compared to open-cycle OTEC.

Working principles of closed-cycle OTEC are as follows:

- Working fluid is pumped through heat exchangers in a closed loop cycle which is perfectly leakage proof.
- Warm sea surface water is pumped through separate pipe in heat exchanger in close contact with fluid closed loop cycle

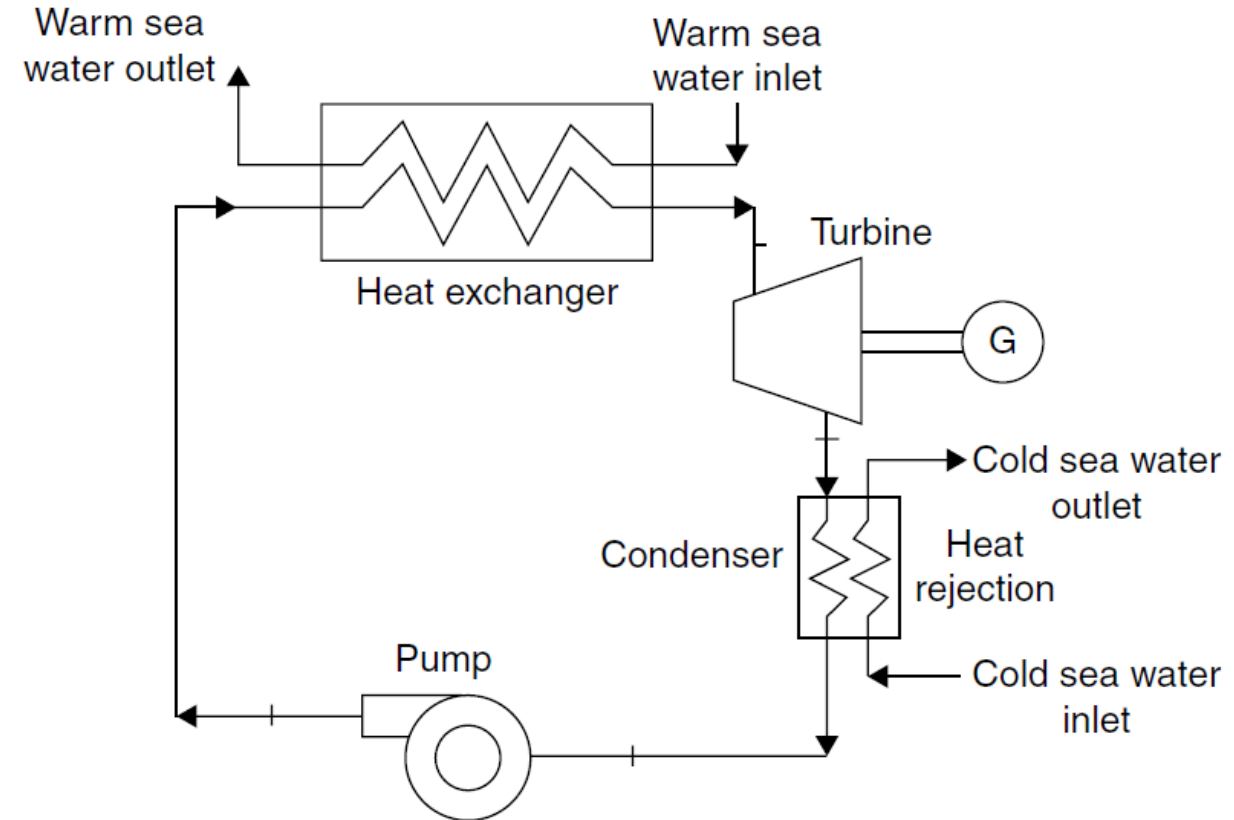


Figure 5.4 Closed-cycle OTEC plant

- Warm sea water transfer its heat energy to working fluid in heat exchanger and working fluid vapourized.
- The fluid vapour makes the turbine to rotate and drive an electrical generator to produce electricity.
- Fluid vapour leaving the turbine is cooled and condensed as liquid fluid and is pumped again to repeat cycle.
- Cold deep sea water is pumped through a separate pipe in condenser for providing efficient cooling of working fluid.

OTEC Hybrid Cycle

- As shown in Figure 5.5, a hybrid cycle combines the features of both closed-cycle and open-cycle systems.
- Warm sea water is pumped into a vacuum chamber where it is used to flash and produces steam.
- Working fluid in another closed cycle loop is evaporated and vapourized by steam in vacuum chamber.
- The fluid vapour rotates the turbine and drive an electric generator to produce electricity.

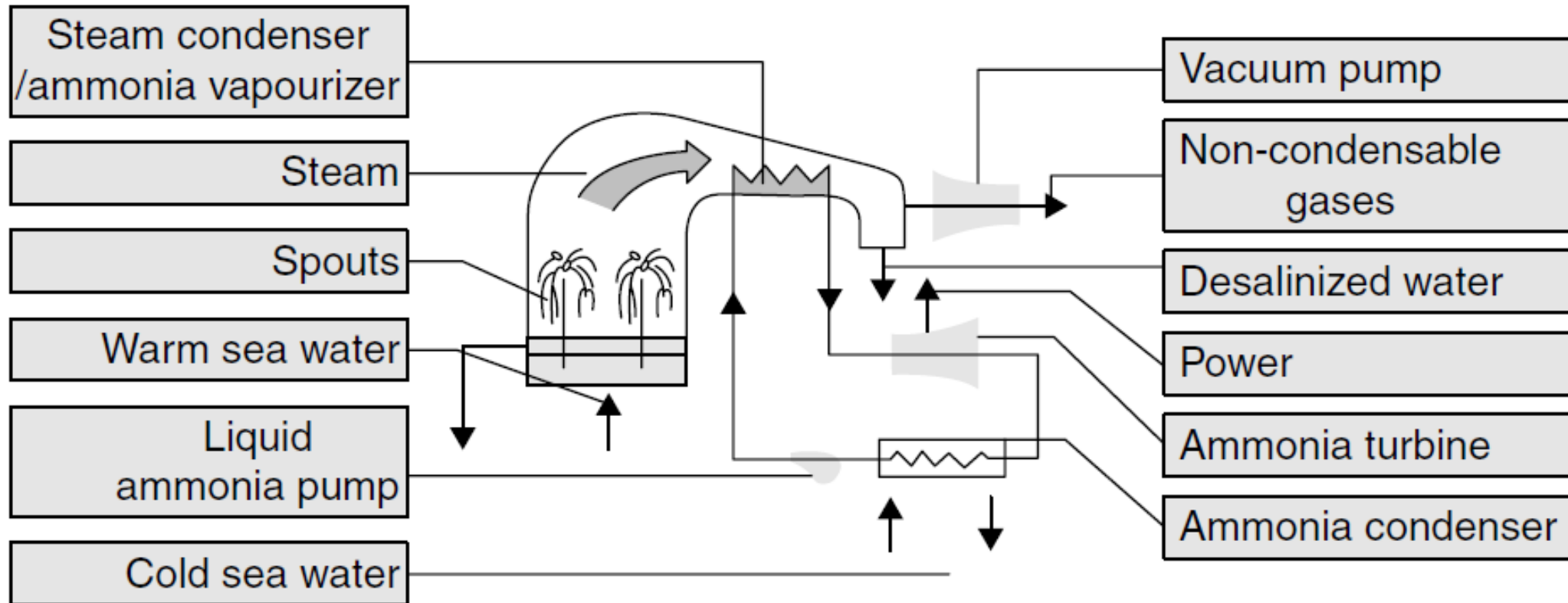


Figure 5.5 OTEC Hybrid Cycle

CARNOT CYCLE

- The Carnot cycle is the most efficient thermodynamical cycle by exploiting the warm sea surface water and cold deep sea water.

*Adiabatic process, in thermodynamics, change occurring within a system as a result of transfer of energy to or from the system in the form of work only.

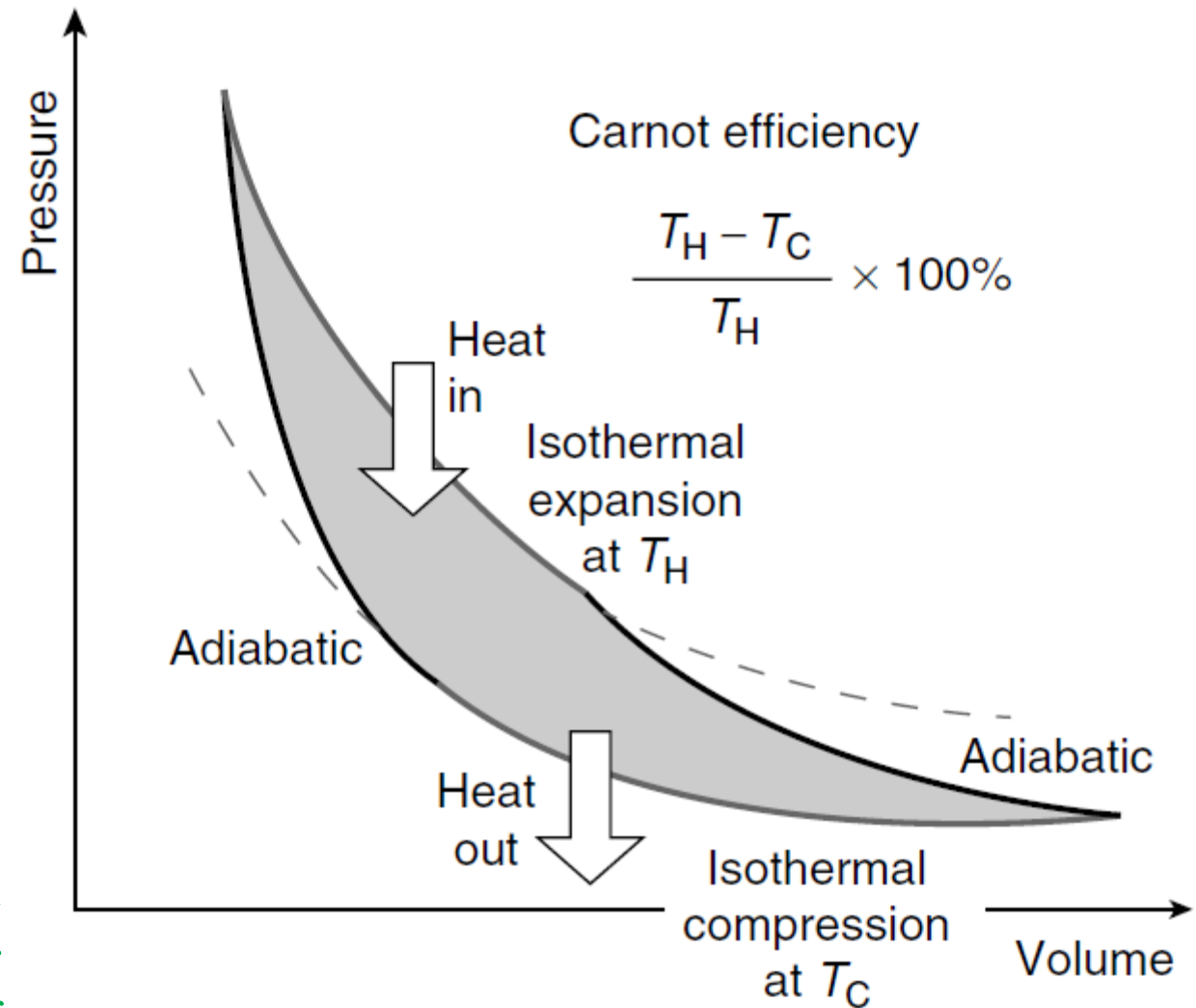


Figure 5.6 Carnot efficiency P–V diagram

- Let W be the work done by the system (energy exiting the system as work).
- Q_H be the heat put into the system (heat energy entering the system),
- T_C be the absolute temperature of the sea surface and
- T_H be the absolute temperature of the deep sea water hot reservoir.

Carnot efficiency (η) is given by the following equation:

$$\eta = W/Q_H = 1 - T_C/T_H$$

APPLICATION OF OTEC IN ADDITION TO PRODUCE ELECTRICITY

- OTEC schematic diagram and applications are shown in Figure 5.7.
- Ocean thermal converting plants provide several products for use by mankind.

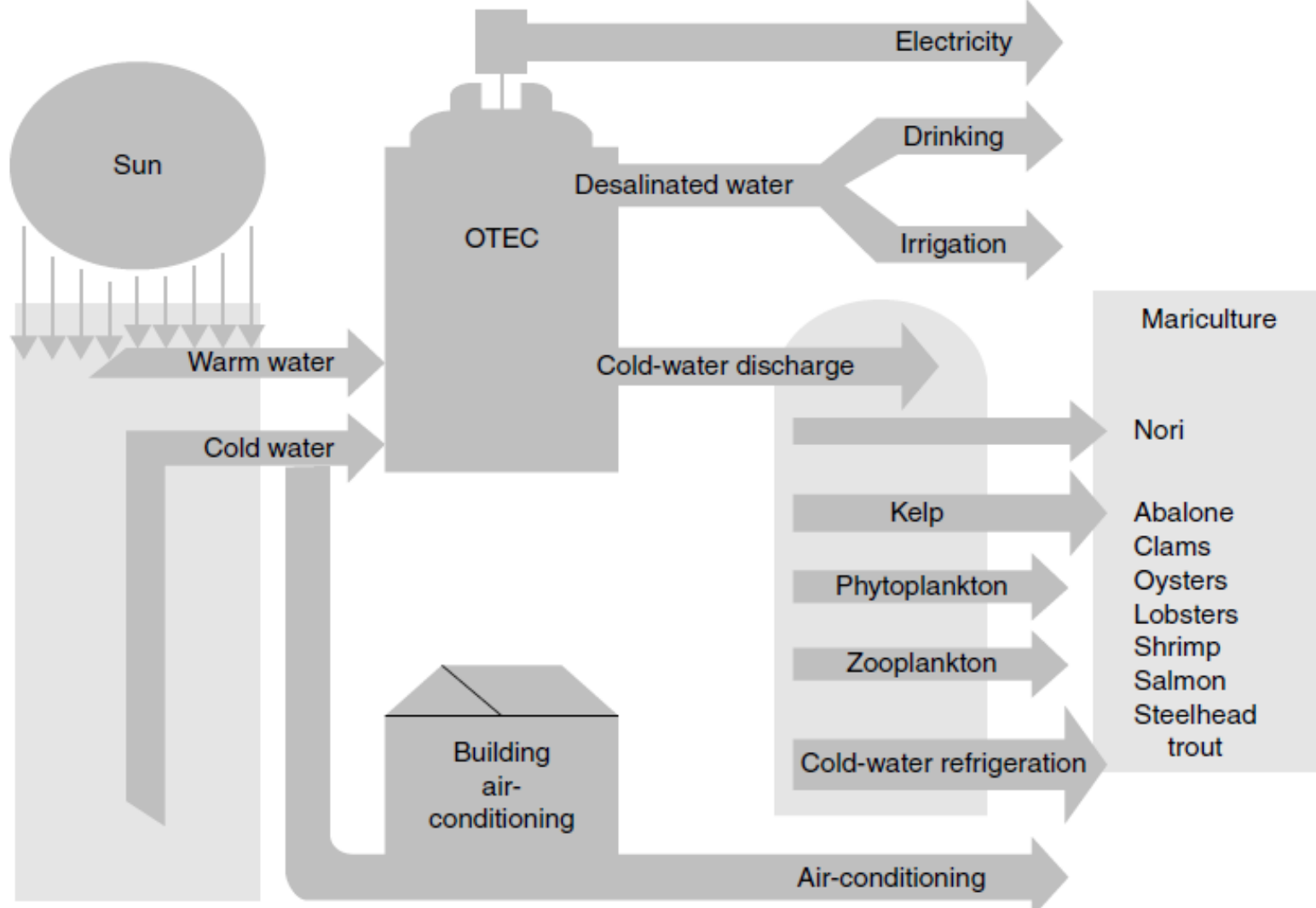


Figure 5.7 OTEC plant and applications

Electricity:

- Electrical energy is the primary product of OTEC plants.
- Laying down long transmission and distribution cables up to the sea shore for domestic and industrial applications is not practical from economic view point.
- OTEC plants are, therefore, considered for other products and applications.

Hydrogen production:

- Electricity produced from OTEC plants is used for separating water in hydrogen and oxygen by the method of electrolysis of water.
- Hydrogen is considered as the second best usable form of energy after electricity.
- Use of deep sea cold water and OTEC electricity for hydrogen production signifies the important applications of OTEC plants.

Ammonia and methanol production:

- OTEC electricity can be used to obtain by-products, such as ammonia and methanol, that can be transported either by tankers or through pipe lines to on shore applications.

Desalinated water:

- Desalinated water is produced in an open-cycle and hybrid-type OTEC plants through surface condenser.
- It is freshwater and widely used as water resource for drinking, agriculture, and industry.

Aquaculture:

- Nutrient-rich cold deep sea water provides sufficient environment for fish farming which may create a profitable business activities.

Air conditioning:

- Because the temperature is only a few degrees, cold water can be used as a fluid in air condition systems.

Chilled soil agriculture:

- Chilled soil agriculture is another application of OTEC plants.
- Cold deep sea water flowing through underground pipes chills the surrounding soil.
- The temperature difference is maintained between plant roots in the cool soil and plant leaves in the warm air, and thus, the tree and plants grows.
- The amount of food that can be produced in this way is very large, larger in market value than the electric power produced by the plant.

ADVANTAGES, DISADVANTAGES AND BENEFITS OF OTEC

Advantages

1. Ocean thermal energy is a renewable, clean natural resource available in abundance.
2. It is pollution-free and has no greenhouse effects.
3. It is a good source of freshwater and portable water.

Disadvantages

1. **High cost:** Electricity generated by OTEC plants is more expensive than electricity produced by chemical and nuclear fuels.
2. **Complexity:** OTEC plants must be located where a difference of about 20°C occurs year round. Ocean depths must be available fairly close to shore-based facilities for economic operation. Floating plant ships could provide more flexibility.
3. **Acceptability:** For the large-scale production of electricity and other products, OTEC plants are poorly acceptable due to their high costs.

- 4. *Ecosystem damage:* It is obvious by setting OTEC plants.
- 5. *Lower efficiency:* A higher temperature difference between ocean surface warm water and cold deep ocean water is required for highly efficient operation of plant.

Benefits as a Measure of the Value of OTEC

Economic and other benefits are the value of OTEC plants.

These include the following:

1. It is a clean, renewable natural resource available in plenty.
2. It has no environmental problems and greenhouse effects.
3. It is a source of base load electricity and fuels such as hydrogen, methanol, and ammonia.
4. It provides freshwater for drinking, agriculture, and industry.
5. It encourages chilled agriculture and aquaculture.
6. Self-sufficiency, no environmental effects, and improved sanitation and nutrition are the added benefits for island.

Summary of Module-5

- Basic thinking behind ocean thermal energy conversion (OTEC) was first suggested in 1881 by a French physicist Jacques d'Arsonval which involves extracting useful energy from the solar heat stored in the oceans.
- Ocean thermal energy conversion is a potential source of renewable energy that creates no emissions.
- It uses the ocean's temperature difference between warm surface water and cold deep seawater to generate both electricity and potable water.
- OTEC is an energy technology that converts solar radiation to electric power.
- These systems use the ocean's natural thermal gradient.
- As long as the temperature difference between warm surface water and cold deep sea water below 600 meters by about 20°C, an OTEC system can produce a significant amount of power.

- The cold sea water used in the OTEC process is also rich in nutrients, and it can be used to cultivate both marine organisms and plant life near the shore or on land.
- Sea water air conditioning (SWAC) is a clean method of air conditioning buildings, using cold deep sea water in place of polluting standard refrigerants.
- The main advantages of OTEC are that the method is fuel-free, has a low environmental impact, can supply pure water for both drinking and agriculture, can supply refrigeration and cooling, and can provide a coastal community with reliable energy.
- The disadvantages include high capital cost, potential for hostile ocean environment during construction and use, and an overall lack of familiarity with OTEC technology.
- There have been several analyses of the feasibility of full-scale implementation of OTEC.
- While some of these investigations are contradictory to each other, research with actual mini OTEC plants is proving that OTEC systems will one day become a feasible, efficient, and renewable source of energy.

THANK YOU