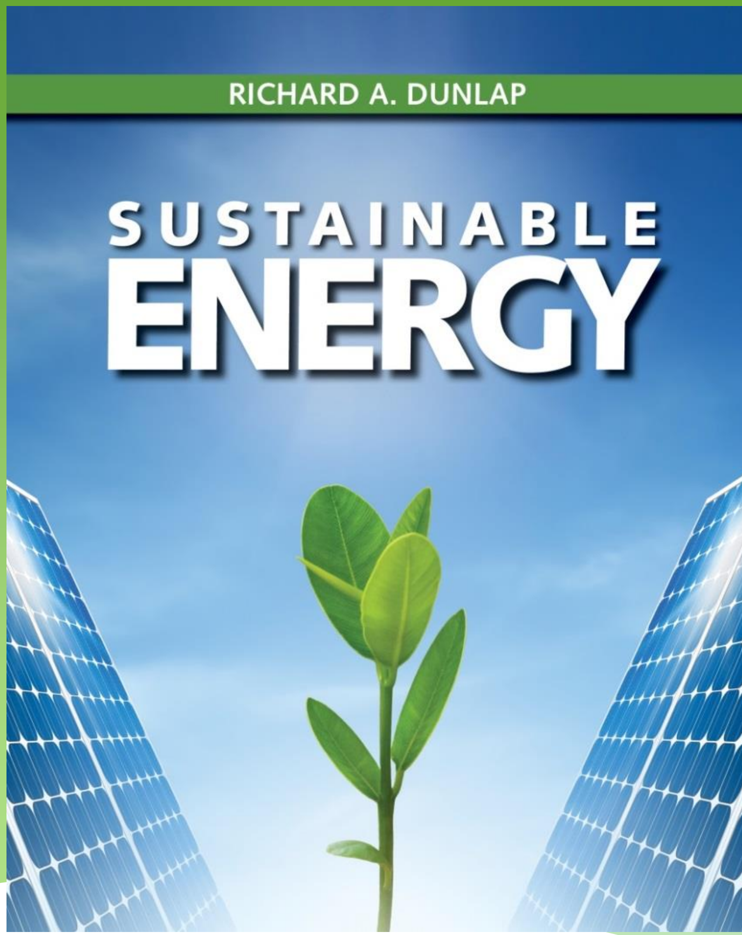
Sustainable Energy



Chapter 14

* Ocean Thermal Energy Conversion
* and
* Ocean Salinity Gradient Energy

CENGAGE Learning

Learning Objectives

- The distribution of thermal energy in the oceans.
- The use of a heat engine to extract energy from the oceans and convert it into electricity.
- The design of the different types of OTEC systems.
- Experimental OTEC facilities and their performance.
- The basic principles of osmotic energy production.
- Experimental facilities for osmotic energy production.

Basics of Ocean Thermal Energy Conversion (OTEC)

A heat engine may be constructed using the temperature difference between the cold water deep in the ocean and the warm surface water.

Below about 1000 m depth ocean water is a fairly constant temperature of about 4 °C.

To maximize efficiency of heat engine it is necessary to maximize the temperature difference.

This means maximizing the surface temperature - so tropical regions are appropriate.

Depth dependence of ocean temperature

typical thermocline in tropical regions

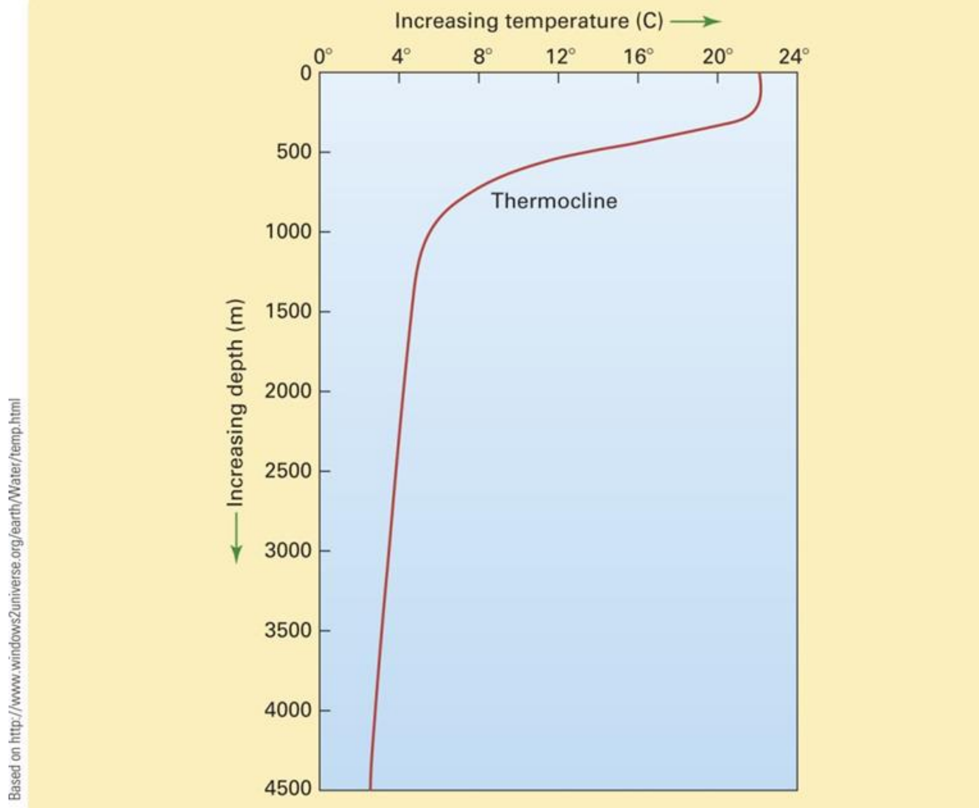


Figure 14.1: Typical depth variation of the ocean temperature in a tropical region.

Ocean surface temperature worldwide

Based on 2010 Survey of Energy Resources, http://www.worldenergy.org/documents/ser_2010_report_1.pdf

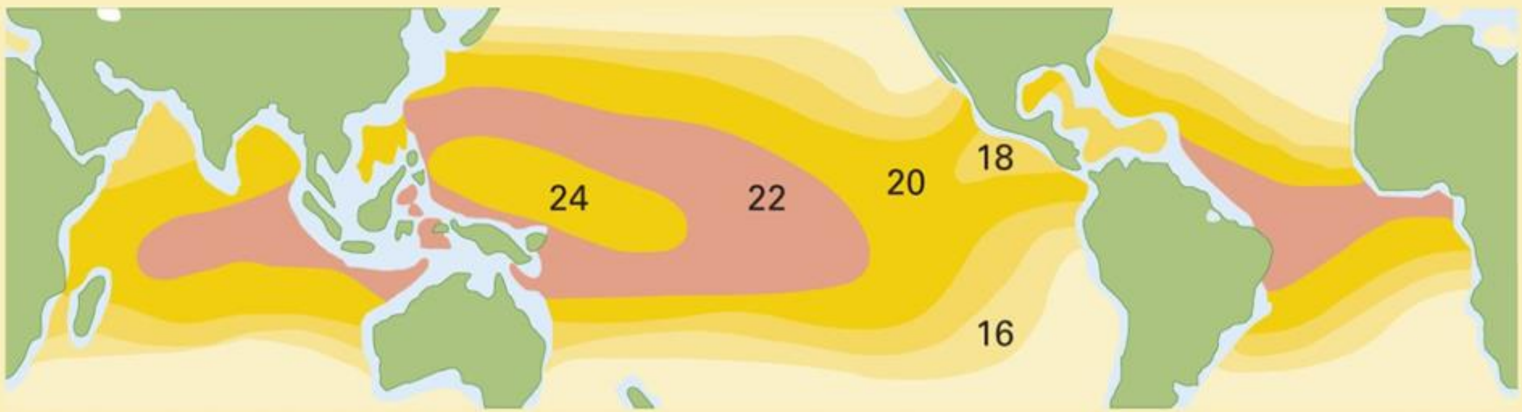


Figure 14.2: Temperature differences between the ocean surface and water at a depth of 1000 m measured in °C.

Types of OTEC systems

Three different systems designs exist

- Open cycle
- Closed cycle
- Hybrid systems

Open cycle OTEC system design

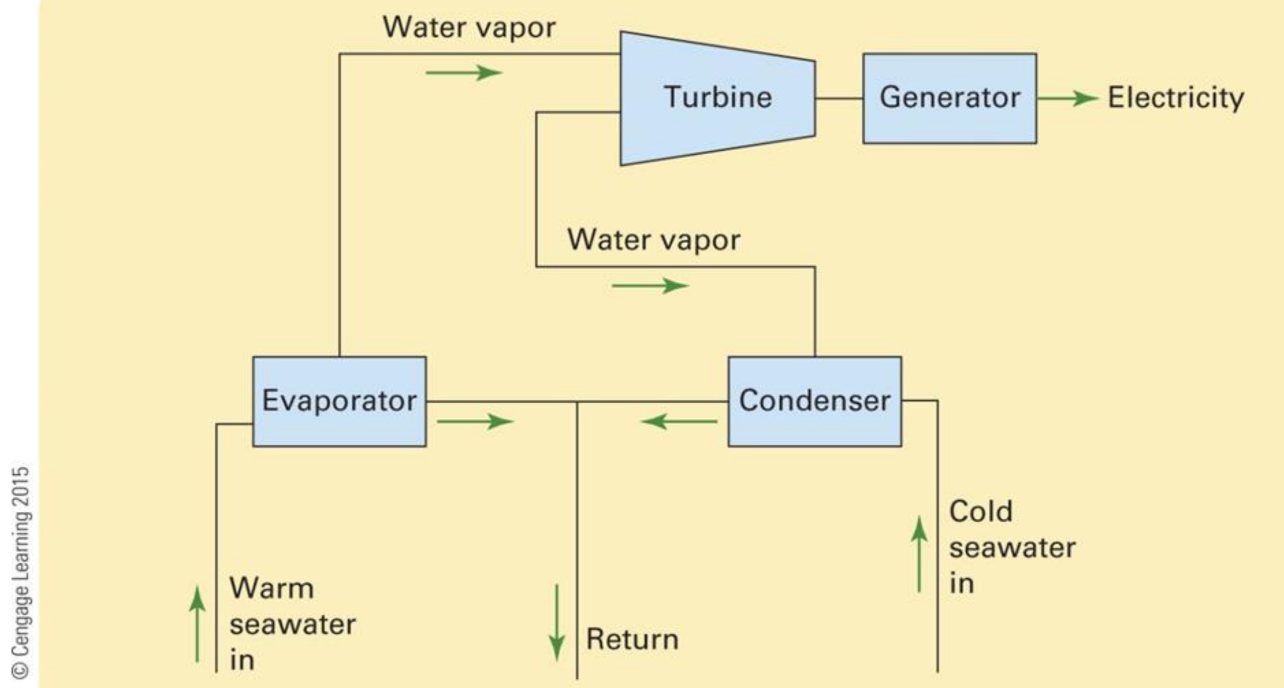


Figure 14.3: Schematic of an open-cycle OTEC plant.

Operation of an open cycle OTEC system

Warm surface water is vaporized in the evaporator by lowering its vapor pressure.

The vaporized water is used to run a turbine and is then condensed by cooling it with cold sea water pumped from deep in the ocean.

Phase diagram of water

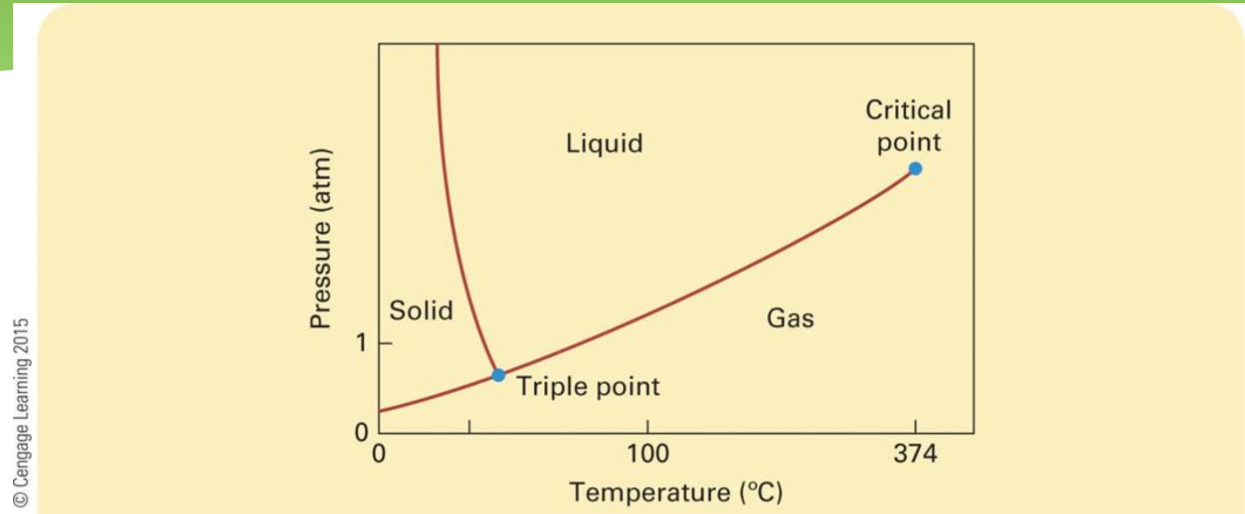


Figure 14.4: The phase diagram of water (not to scale).

Above the triple point, lowering the pressure causes a transition from the liquid to gaseous state - This is what happens in the evaporator.

Lowering the temperature of a gas causes a transition back to the liquid state - This is what happen in the condenser.

Closed cycle OTEC system

A closed cycle OTEC system uses a working fluid (other than water) to drive the turbine.

Heat is transferred to the working fluid by a heat exchanger (evaporator).

Heat is extracted from the working fluid by a heat exchanger.

Schematic of a closed cycle OTEC system

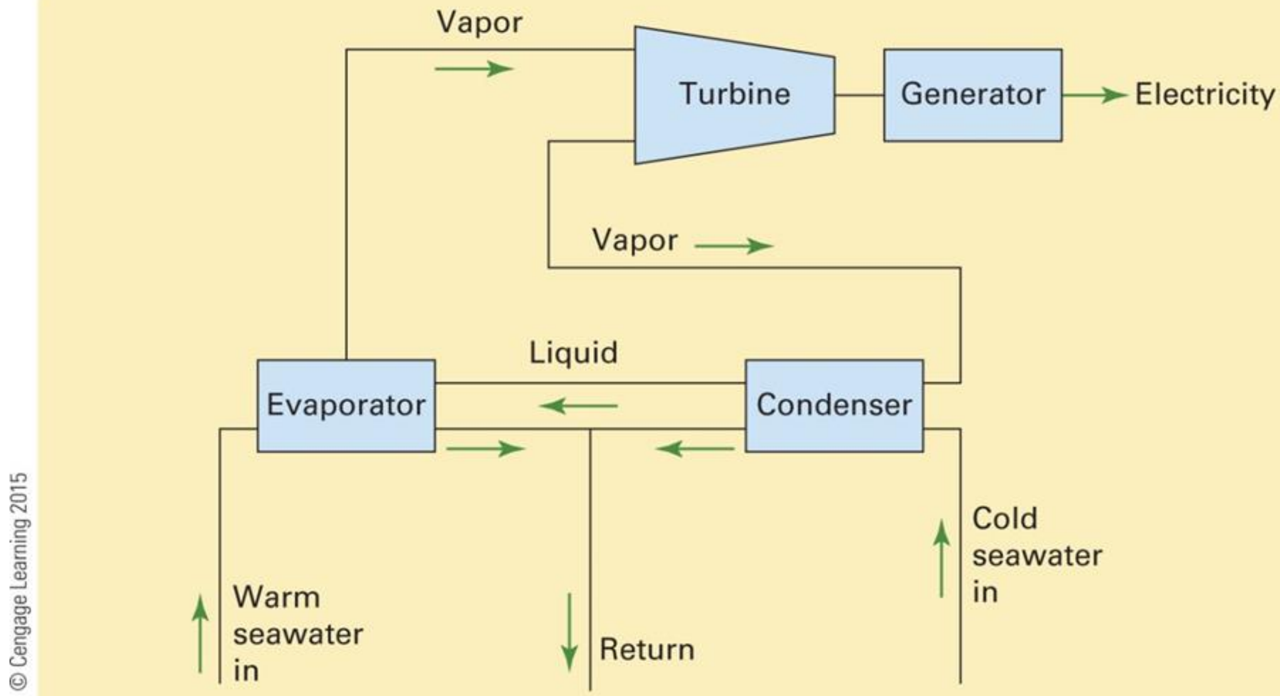


Figure 14.6: Schematic of a closed-cycle OTEC plant.

Hybrid OTEC systems

Hybrid systems vaporize both the warm sea water and the working fluid.

The vaporized working fluid is used to drive the turbine.

The vaporized sea water is condensed to provide a source of fresh water.

Analysis of OTEC energy output

The thermal energy available is the difference in thermal energy associated with warm water and the cold water.

The mechanical energy is the available thermal energy times the Carnot efficiency of the heat engine.

The Carnot efficiency is determined by the absolute temperature difference between the evaporator and condenser.

The electrical energy is the mechanical energy times the efficiency of the generator (high).

Comparison with coal fired generating station

The thermal energy available in a coal fired generating station is the energy produced by the combustion of the coal.

The mechanical energy is the available thermal energy times the Carnot efficiency of the heat engine.

The Carnot efficiency is determined by the absolute temperature difference between the boiler and the cold reservoir.

The electrical energy is the mechanical energy times the efficiency of the generator (high).

Limitations of OTEC

Compared to the coal generating station the energy output of the OTEC system is affected by the following factors:

- Small available energy due to small temperature differences between the warm and cold seawater
- Low Carnot efficiencies due to small temperature differences between evaporator and condenser
- Net energy also reduced because of large amount of energy needed to pump seawater from deep in the ocean

An experimental OTEC facility

Keahole Point, Hawaii

Figure 14.9: Land-based 250-kW open-cycle OTEC demonstration plant at Keahole Point, Hawaii.

OTEC facility locations

Facilities may be

- on (or near) shore in which case cold water will need to be pumped onshore
- offshore in which case electricity will need to be transported onshore

Success limited by

- Low efficiencies
- Complications due to adverse marine environment
- Transport of electricity to users

1980 prediction of OTEC capacity

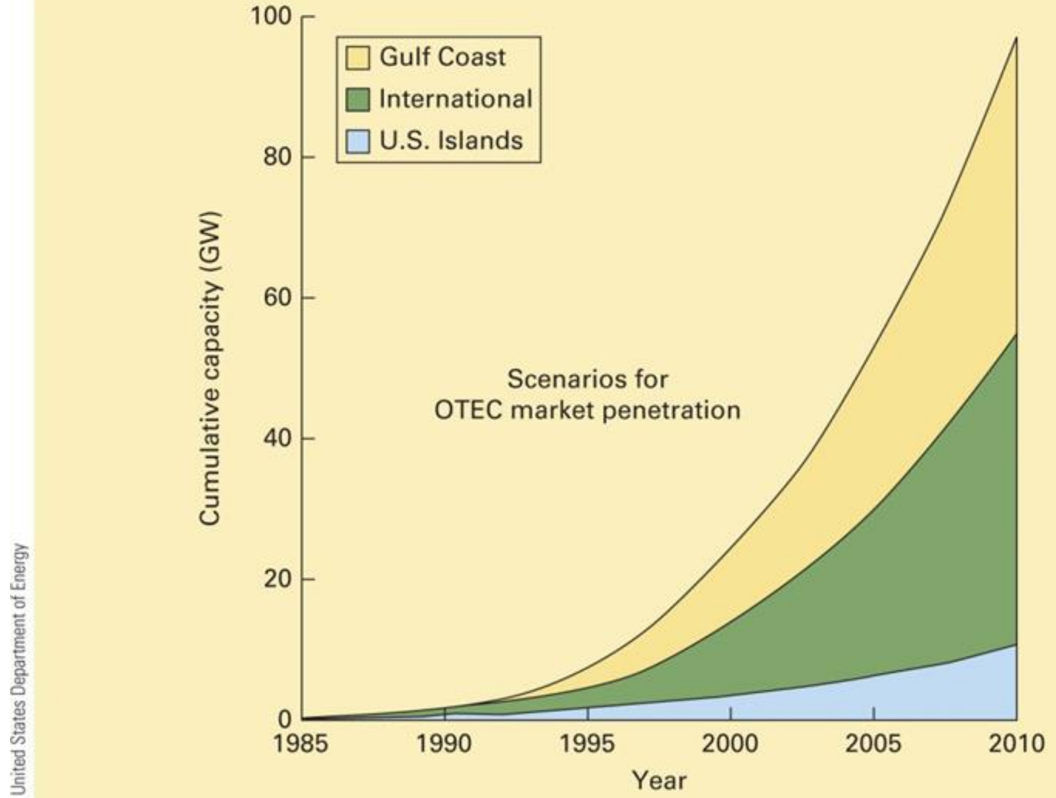


Figure 14.10: Predicted production of electricity by OTEC.

Actual OTEC capacity

No current commercial OTEC energy production

May be most useful as a source of

- fresh water for domestic use
- cold water to replace air conditioning

Ocean salinity gradient energy

Two solutions (i.e. salt water and fresh water) are separated by a membrane that allows the flow of water but not the solutes.

Driving force tries to equals concentration gradients by allowing water to flow from the concentrated side to the dilute side.

Osmotic cell

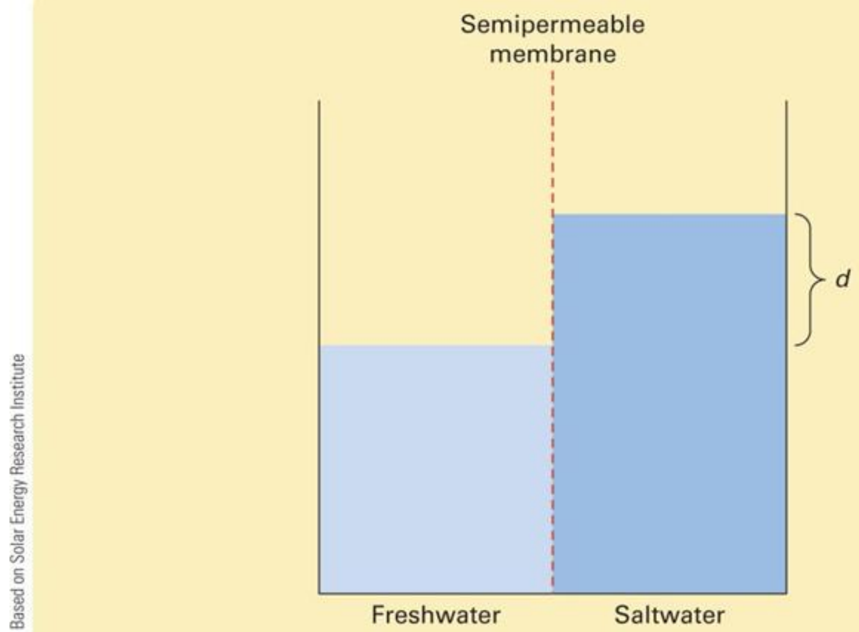


Figure 14.11: Height difference between freshwater and saltwater on two sides of a semipermeable membrane as a result of osmotic pressure.

Driving force cases height difference on the two sides of the membrane

Osmotic pressure

The osmotic pressure is

$$p = iRMT \qquad (14.2)$$

i = solute dependent constant (2.0 for NaCl)
R = gas constant
M = molarity
T = temperature

Pressure is related to gravitational force due to height difference (*d*) across the membrane is

$$p = mg/A = \frac{dA\rho g}{A} = d\rho g \qquad (14.4)$$

Production of electricity from osmotic pressure

Two approaches:

- pressure retarded osmosis (PRO)
- reverse electrodialysis (RED)

Pressure retarded osmosis

Water flowing across the membrane is used to drive turbines (to generate electricity) so as to keep the height on both sides of the membrane approximately equal.

Reverse electrodialysis

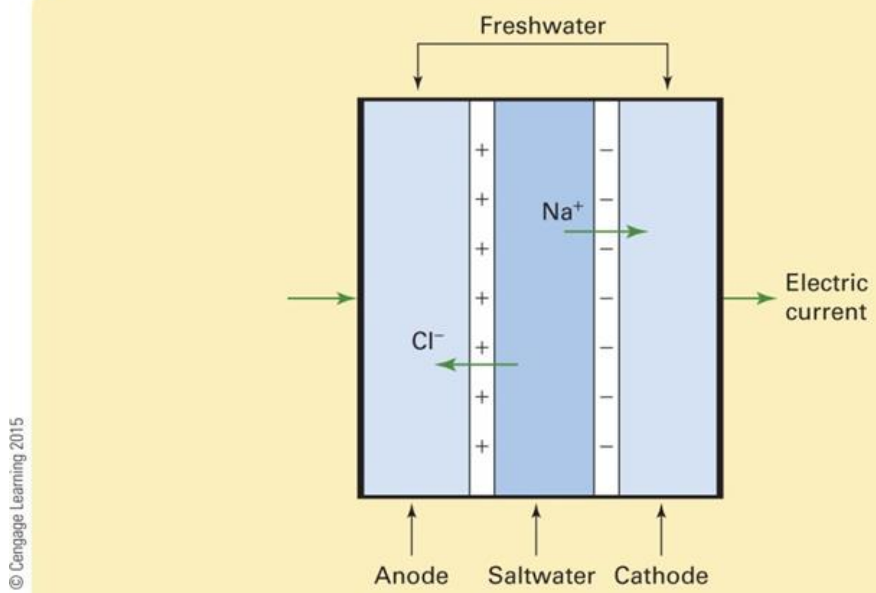


Figure 14.12: Schematic of reverse electrodialysis production of electricity.

Charges associated with the dissolved ions contribute directly to the flow of current

Applications of osmotic energy

Potential viability where sources of seawater (ocean) and fresh water are in proximity

(i.e. mouths of large rivers that empty into the sea)

No commercial applications at present

Economic viability remains to be determined

Pilot PRO facility in Norway

Based on http://www.yalescientific.org/2013/02/the-elixir-of-life-generating-electricity-from-water/; http:// pre.docdat.com/docs/index-219628.html; http://www.theengineer.co.uk/news/osmotic-power/302450.article

Pressure-retarded osmosis generating station in Norway.

Summary

- Energy can be obtained from the temperature gradients in the oceans and converted into electricity

- The small temperature difference combined with low Carnot efficiency make this approach difficult.

- Ocean salinity gradient available where large rivers empty into the ocean.

- Two approaches:
  - Pressure retarded osmosis
  - Reverse electrodialysis

- Viability of both OTEC and salinity gradient technologies needs to be established