UNIT-IV

GEOTHERMAL ENERGY

Introduction

The word geothermal comes from the Greek words *geo* (Earth) and *therme*(heat). Geothermal energy is heat from within the Earth. Geothermal energy is generated in the Earth's **core**, almost 4,000miles beneath the Earth's surface. The double-layered core is made up of very hot **magma** (melted rock) surrounding a solid iron center. Very high temperatures are continuously produced inside the Earth by the slow decay of radioactive particles. This process is natural in all rocks.

Surrounding the outer core is the **mantle**, which is about 1,800 miles thick and made of magma and rock. The outermost layer of the Earth, the land that forms the continents and ocean floors, is called the **crust**. The crust is three to five miles thick under the oceans and15 to 35 miles thick on the continents. The crust is not a solid piece, like the shell of an egg, but is broken into pieces called **plates**. Magma comes close to the Earth's surface near the edges of these plates. This is where volcanoes occur. The lava that erupts from volcanoes is partly magma. Deep underground, the rocks and water absorb the heat from this magma. We can dig wells and pump the heated, underground water to the surface. People around the world use geothermal energy to heat their homes and to produce electricity. Geothermal energy is called a **renewable** energy source because the water is replenished by rainfall and the heat is continuously produced deep within the Earth. We won't run out of geothermal energy.

Geothermal energy is defined as heat from the Earth. It is a clean, renewable resource that provides energy in the United States and around the world. It is considered a renewable energy resource because the heat emanating from the interior of the Earth is essentially limitless. The heat continuously flowing from the Earth's interior is estimated to be equivalent to 42 million megawatts of power.5 One megawatt is equivalent to 1million watts, and can meet the power needs of about 1,000 homes. The interior of the Earth is expected to remain extremely hot for billions of year to come, ensuring an essentially limitless flow of heat. Geothermal power plants capture this heat and convert it to energy in the form of electricity. The picture below shows the source of geothermal electric power production, heat from the Earth. As depth into the Earth's crust increases, temperature increases as well.

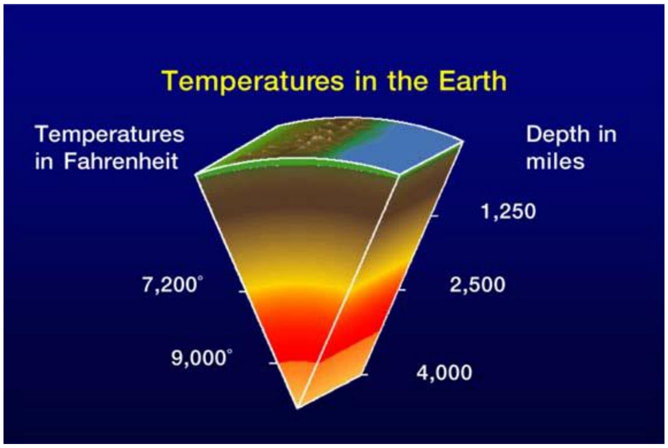


Figure 1: Earth's Temperatures

Like all forms of electric generation, both renewable and non-renewable, geothermal power generation has environmental impacts and benefits. By comparison to other forms of electricity generation, this paper highlights the benefits of choosing geothermal energy over other sources. Topics discussed include air emissions, noise pollution, water usage, land usage, waste disposal, subsidence, induced seismicity, and impacts on wildlife and vegetation. In addition, common environmental myths associated with geothermal energy are addressed throughout the paper. Geothermal energy. whether utilized in a binary, steam, or flash power plant, cooled by air or water systems, is a clean, reliable source of electricity with only minimal environmental impacts, even when compared with other renewable energy sources.

Wherever comparisons with other energy technologies are used, they are intended to provide a context for the reader. Every effort has been made to use comparable data from companies, industry groups, and government agencies. In providing these comparisons, we recognize that energy technologies have many different attributes, all of which should be considered

Converting Geothermal Energy into Electricity

Heat emanating from the Earth's interior and crust generates magma (molten rock).Because magma is less dense than surrounding rock, it rises but generally does not reach the surface, heating the water contained in rock pores and fractures. Wells are drilled into this natural collection of hot water or steam, called a geothermal reservoir, in order to bring it to the surface and use it for electricity production.

The three basic types of geothermal electrical generation facilities are binary, dry steam (referred to as .steam.),and flash steam (referred to as .flash.). Electricity production from each type depends on reservoir temperatures and pressures, and each type produces somewhat different environmental impacts. In addition, the choice of using water or air cooling technology in the power plants has economic and environmental trade-offs.

The most common type of power plant to date is a flash power plant with a water cooling system, where a mixture of water and steam is produced from the wells. The steam is separated in a surface vessel (steam separator) and delivered to the turbine, and the turbine powers a generator. In a dry steam plant like those at The Geysers in California, steam directly from the geothermal reservoir runs the turbines that power the generator, and no separation is necessary because wells only produce steam. Figure 2 shows a flash and dry steam plant.

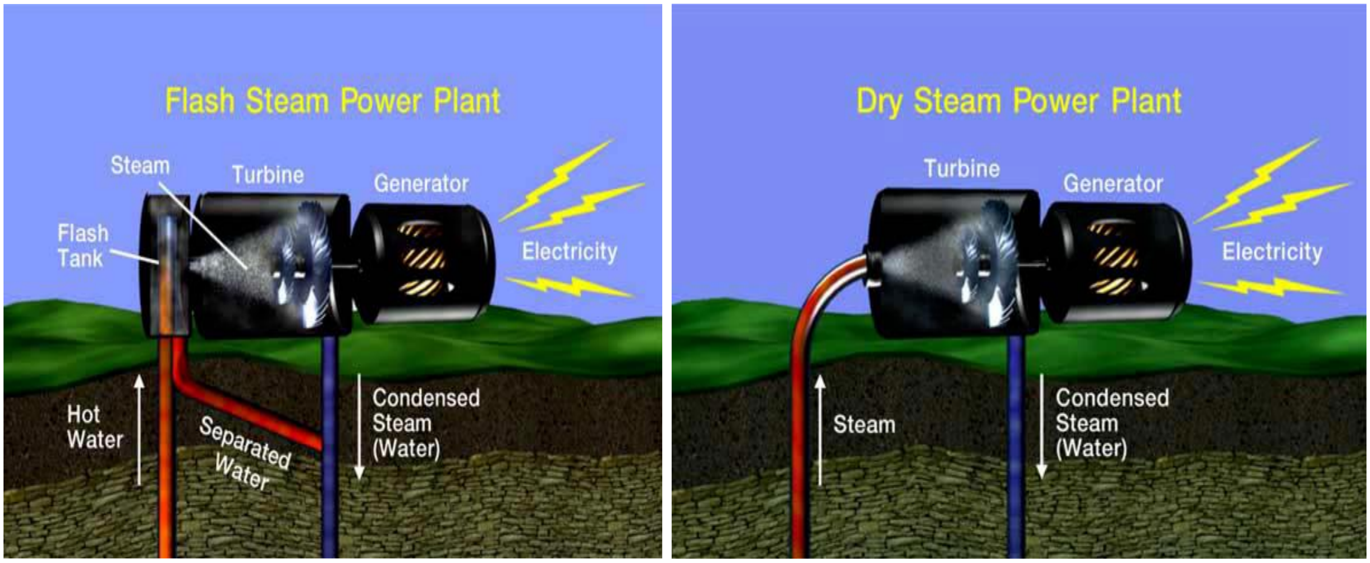


Figure 2: Flash and Dry Steam Power Plant Diagrams

Recent advances in geothermal technology have made possible the economic production of electricity from lower temperature geothermal resources, at 100o C (212o F) to 150o C(302 o F). Known as binary geothermal plants, these facilities reduce geothermal energies already low emission rate to near zero.

In the binary process, the geothermal water heats another liquid, such as isobutane, that boils at a lower temperature than water. The two liquids are kept completely separate through the use of a heat exchanger used to transfer the heat energy from the geothermal water to the .working-fluid." The secondary fluid vaporizes into gaseous vapor and (like steam) the force of the expanding vapor turns the turbines that power the generators. If the power plant uses air cooling (see next paragraph) the geothermal fluids never make contact with the atmosphere before they are pumped back into the underground geothermal reservoir, effectively making the plant emission free.

Developed in the1980s, this technology is already in use in geothermal power plants throughout the world in areas that have lower resource temperatures. The ability to use lower temperature resources increases the number of geothermal reservoirs that can be used for power production. Figure 3 shows a binary power plant.

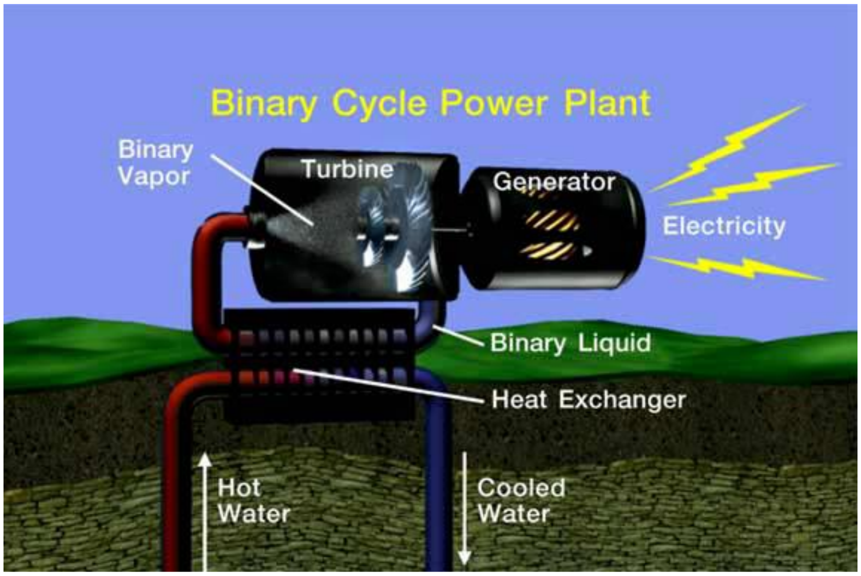


Figure 3: Binary Power Plant

A cooling system is essential for the operation of any modern geothermal power plant. Cooling towers prevent turbines from overheating and prolong facility life. Most power plants, including most geothermal plants, use water cooling systems. Figure 4 below shows a more complex diagram of a geothermal power plant, complete with a water(evaporative) cooling system. Figures 2 and 3 simplify the process of electricity production, while figure 4 shows greater detail and accuracy. Water cooled systems generally require less land than air cooled systems, and are considered overall to be effective and efficient cooling systems.

The evaporative cooling used in water cooled systems, however, requires a continuous supply of cooling water and creates vapor plumes. Usually, some of the spent steam from the turbine (for flash- and steam-type plants) can be condensed for this purpose. Air cooled systems, in contrast to the relative stability of water cooled systems, can be extremely efficient in the winter months, but are less efficient in hotter seasons when the contrast between air and water temperature is reduced, so that air does not effectively cool the organic fluid. Air cooled systems are beneficial in areas where extremely low emissions are desired, or in arid regions where water resources are limited, since no fluid needs to be evaporated for the cooling process.

Air cooled systems are preferred in areas where the view shed is particularly sensitive to the effects of vapor plumes, as vapor plumes are only emitted into the air by wet cooling towers and not air cooling towers. Most geothermal air cooling is used in binary facilities.

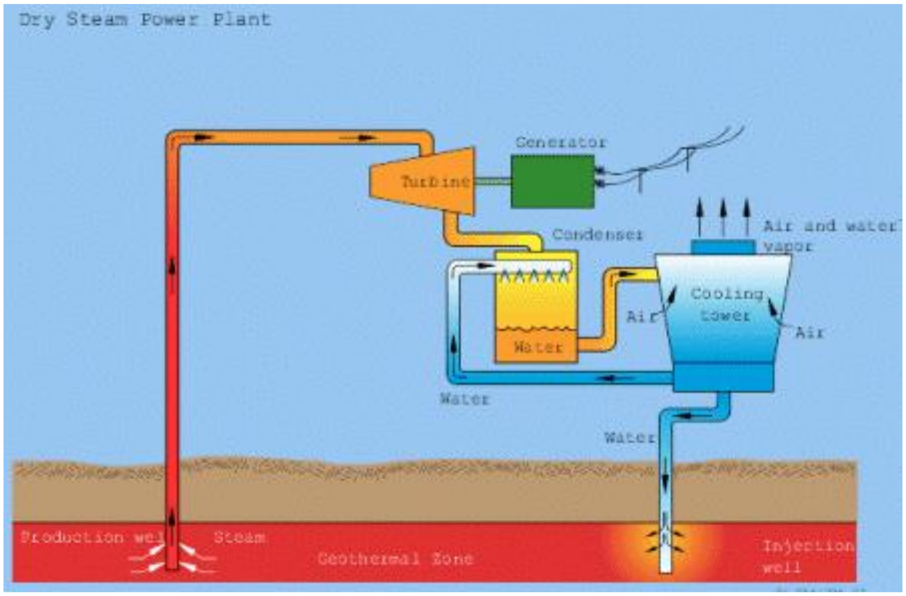


Figure 4: Geothermal Power Plant with Water Cooling System

A combination of flash and binary technology, known as the flash/binary combined cycle, has been used effectively to take advantage of the benefits of both technologies. In this type of plant, the flashed steam is first converted to electricity with a back pressure steam turbine, and the low-pressure steam exiting the backpressure turbine is condensed in a binary system. This allows for the effective use of air cooling towers with flash applications and takes advantage of the binary process. The flash/binary system has a higher efficiency where the well-field produces high pressure steam, while the elimination of vacuum pumping of non condensable gases allows for 100 percent injection.

OCEAN ENERGY

OTEC

Ocean thermal energy conversion (OTEC) generates electricity indirectly from solar energy by harnessing the temperature difference between the sun-warmed surface of tropical oceans and the colder deep waters. A significant fraction of solar radiation incident on the ocean is retained by seawater in tropical regions, resulting in average year-round surface temperatures of about 283C. Deep, cold water, meanwhile, forms at higher latitudes and descends to Show along the sea shoor toward the equator. The warm surface layer, which extends to depths of about 100}200m, is separated from the deep cold water by a thermo cline. The temperature difference, *T*, between the surface and thousand-meter depth ranges from 10 to 253C, with larger differences occurring in equatorial and tropical waters is that a differential of about 203C is necessary to sustain viable operation of an OTEC facility.

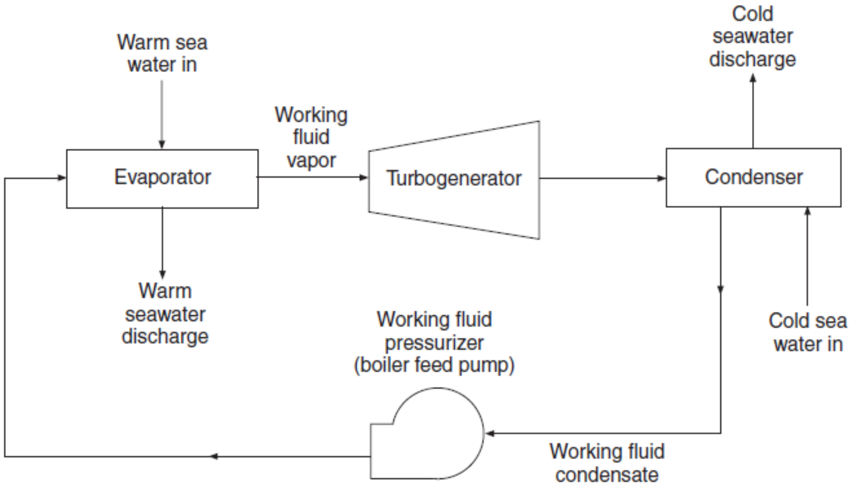
Since OTEC exploits renewable solar energy, recurring costs to generate electrical power are minimal. However, the fixed or capital costs of OTEC systems per kilowatt of generating capacity are very high because large pipelines and heat exchangers are needed to produce relatively modest amounts of electricity. These high fixed costs dominate the economics of OTEC to the extent that it currently cannot compete with conventional power systems, except in limited niche markets. Considerable effort has been expended over the past two decades to develop OTEC by-products, such as fresh water, air conditioning, and mariculture, that could offset the cost penalty of electricity generation

OTEC power systems operate as cyclic heat engines. They receive thermal energy through heat transfer from surface sea water warmed by the sun, and transform a portion of this energy to electrical power. The Second Law of Thermodynamics precludes the complete conversion of thermal energy in to electricity. A portion of the heat extracted from the warm sea water must be rejected to a colder thermal sink. The thermal sink employed by OTEC systems is sea water drawn from the ocean depths by means of a submerged pipeline. A steady-state control volume energy analysis yields the result that net electrical power produced by the engine must equal the difference between the rates of heat transfer from the warm surface water and to the cold deep water. The limiting (i.e., maximum) theoretical Carnot energy conversion efficiency of a cyclic heat engine scales with the difference between the temperatures at which these heat transfers occur. For OTEC, this difference is determined by *T* and is very small; hence, OTEC efficiency is low. Although viable OTEC systems are characterized by Carnot efficiencies in the range of 6-8%, state-of-the-art combustion steam power cycles, which tap much higher temperature energy sources, are theoretically capable of converting more than 60% of the extracted thermal energy into electricity.

The low energy conversion efficiency of OTEC means that more than 90% of the thermal energy extracted from the ocean's surface is 'wasted' and must be rejected to the cold, deep sea water. This necessitates large heat exchangers and seawater Sow rates to produce relatively small amounts of electricity. In spite of its inherent inefficiency, OTEC, unlike conventional fossil energy systems, utilizes a renewable resource and poses minimal threat to the environment. In fact, it has been suggested that widespread adoption of OTEC could yield tangible environmental benefits through avenues such as reduction of greenhouse gas CO2 emissions; enhanced uptake of atmospheric CO2 by marine organism populations sustained by the nutrient-rich, deep OTEC sea water; and preservation of corals and hurricane amelioration by limiting temperature rise in the surface ocean through energy extraction and artificial upwelling of deep water. Carnot efficiency applies only to an ideal heat engine. In real power generation systems, ir-reversibilities will further degrade performance. Given its low theoretical efficiency, successful implementation of OTEC power generation demands careful engineering to minimize ir-reversibilities. Although OTEC consumes what is essentially a free resource, poor thermodynamic performance will reduce the quantity of electricity available for sale and, hence, negatively affect the economic feasibility of an OTEC facility. An OTEC heat engine may be configured following designs by J.A. D'Arsonval, the French engineer who first proposed the OTEC concept in 1881, or G. Claude, D'Arsonval's former student. Their designs are known, respectively, as closed cycle and open cycle OTEC.

Closed Cycle OTEC

D'Arsonval's original concept employed a pure working fluid that would evaporate at the temperature of warm sea water. The vapor would subsequently expand and do work before being condensed by the cold sea water. This series of steps would be repeated continuously with the same working fluid, whose Sow path and thermodynamic process representation constituted closed loops and hence, the name 'closed cycle.' The specific process adopted for closed cycle OTEC is the Rankine, or vapor power, cycle. **Figure 1** is a simplified schematic diagram of a closed cycle OTEC system. The principal components are the heat exchangers, turbo generator, and seawater supply system, which, although not shown, accounts for most of the parasitic power consumption and a significant fractionof the capital expense. Also not included are ancillary devices such as separators to remove residual liquid downstream of the evaporator and subsystems to hold and supply working fluid lost throughleaks or contamination.



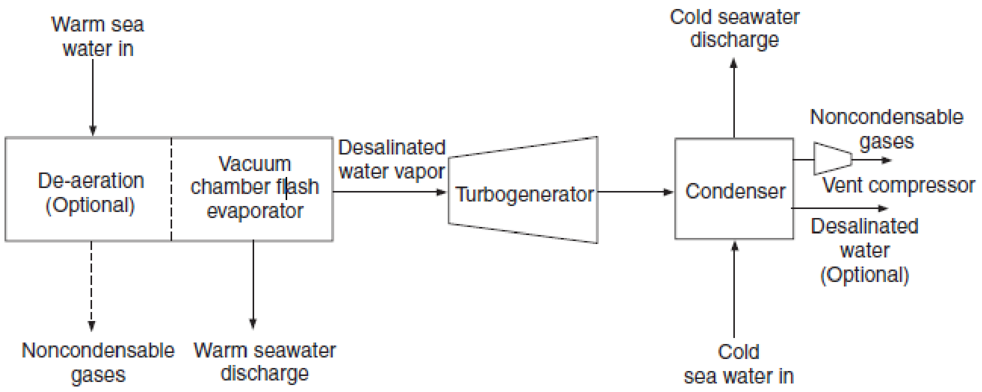
In this system, heat transfer from warm surface sea water occurs in the evaporator, producing a saturated vapor from the working fluid. Electricity is generated when this gas expands to lower pressure through the turbine. Latent heat is transferred from the vapor to the cold sea water in the condenser and the resulting liquid is pressurized with a pump to repeat the cycle. The success of the Rankine cycle is a consequence of more energy being recovered when the vapor expands through the turbine than is consumed in re-pressurizing the liquid. In conventional (e.g., combustion) Rankine systems, this yields net electrical power. For OTEC, however, the remaining balance may be reduced substantially by an amount needed to pump large volumes of sea water through the heat exchangers. (One misconception about OTEC is that tremendous energy must be expended to bring cold sea water up from depths approaching 1000 meters. In reality, the natural hydrostatic pressure gradient provides for most of the increase in the gravitational potential energy of a fluid particle moving with the gradient from the ocean depths to the surface.)

Irreversibilities in the turbo machinery and heat exchangers reduce cycle efficiency below the Carnot value. Irreversibilities in the heat exchangers occur when energy is transferred over a large temperature difference. It is important, therefore, to select a working fluid that will undergo the desired phase changes at temperature established by the surface and deep sea water. Insofar as a large number of substances can meet this requirement (because pressures and the pressure ratio across the turbine and pump are design parameters), other factors must be considered in the selection of a working fluid including: cost and availability, compatibility with system materials, toxicity, and environmental hazard. Leading candidate working fluids for closed cycle OTEC applications are ammonia and various fluorocarbon refrigerants. Their primary disadvantage is the environmental hazard posed by leakage; ammonia is toxic in moderate concentrations and certain fluorocarbons have been banned by the Montreal Protocol because they deplete stratospheric ozone.

The Kalina, or adjustable proportion fluid mixture (APFM), cycle is a variant of the OTEC closed cycle. Whereas simple closed cycle OTEC systems use a pure working fluid, the Kalina cycle proposes to employ a mixture of ammonia and water with varying proportions at different points in the system. The advantage of a binary mixture is that, at a given pressure, evaporation or condensation occurs over a range of temperatures; a pure fluid, on the other hand, changes phase at constant temperature. This additional degree of freedom allows heat transfer-related irreversibilities in the evaporator and condenser to be reduced. Although it improves efficiency, the Kalina cycle needs additional capital equipment and may impose severe demands on the evaporator and condenser. The efficiency improvement will require some combination of higher heat transfer coefficients, more heat transfer surface area, and increased seawater Sow rates. Each has an associated cost or power penalty. Additional analysis and testing are required to confirm whether the Kalina cycle and assorted variations are viable alternatives.

Open Cycle OTEC

Claude's concern about the cost and potential bio-fouling of closed cycle heat exchangers led him to propose using steam generated directly from the warm sea water as the OTEC working fluid. The steps of the Claude, or open, cycle are: (1) flash evaporation of warm sea water in a partial vacuum; (2) expansion of the steam through a turbine to generate power; (3) condensation of the vapor by direct contact heat transfer to cold sea water; and (4) compression and discharge of the condensate and any residual non condensable gases. Unless fresh water is a desired by-product, open cycle OTEC eliminates the need for surface heat exchangers. The name 'open cycle' comes from the fact that the working fluid (steam) is discharged after a single pass and has different initial and final thermodynamic states; hence, the Sow path and process are 'open.' The essential features of an open cycle OTEC system are presented in **Figure 2**.



The entire system, from evaporator to condenser, operates at partial vacuum, typically at pressures of 1-3% of atmospheric. Initial evacuation of the system and removal of non condensable gases during operation are performed by the vacuum compressor, which, along with the sea water and discharge pumps, accounts for the bulk of the open cycle OTEC parasitic power consumption. The low system pressures of open cycle OTEC are necessary to induce boiling of the warm sea water. Flash evaporation is accomplished by exposing the sea water to pressures below the saturation pressure corresponding to its temperature.

This is usually accomplished by pumping it into an evacuated chamber through spouts designed to maximize heat and mass transfer surface area. Removal of gases dissolved in the sea water, which will come out of solution in the low-pressure evaporator and compromise operation, may be performed at an intermediate pressure prior to evaporation.

Vapor produced in the flash evaporator is relatively pure steam. The heat of vaporization is extracted from the liquid phase, lowering its temperature and preventing any further boiling. Flash evaporation may be perceived, then, as a transfer of thermal energy from the bulk of the warm sea water of the small fraction of mass that is vaporized. Less than 0.5% of the mass of warm sea water entering the evaporator is converted into steam.

The pressure drop across the turbine is established by the cold seawater temperature. At 43C, steam condenses at 813 Pa. The turbine (or turbine diffuser) exit pressure cannot fall below this value. Hence, the maximum turbine pressure drop is only about 3000Pa, corresponding to about a 3:1 pressure ratio. This will be further reduced to account for other pressure drops along the steam path and differences in the temperatures of the steam and seawater streams needed to facilitate heat transfer in the evaporator and condenser.

Condensation of the low-pressure steam leaving the turbine may employ a direct contact condenser (DCC), in which cold sea water is sprayed over the vapor, or a conventional surface condenser that physically separates the coolant and the condensate. DCCs are inexpensive and have good heat transfer characteristics because they lack a solid thermal boundary between the warm and cool fluids. Surface condensers are expensive and more difficult to maintain than DCCs; however, they produce a marketable freshwater by-product

Effluent from the condenser must be discharged to the environment. Liquids are pressurized to ambient levels at the point of release by means of a pump, or, if the elevation of the condenser is suitably high, can be compressed hydrostatically. As noted previously, non condensable gases, which include any residual water vapor, dissolved gases that have come out of solution, and air that may have leaked into the system, are removed by the vacuum compressor. Open cycle OTEC eliminates expensive heat exchangers at the cost of low system pressures.

Partial vacuum operation has the disadvantage of making the system vulnerable to air in-leakage and promotes the evolution of non condensable gases dissolved in sea water. Power must ultimately be expended to pressurize and remove these gases. Furthermore, as a consequence of the low steam density, volumetric flow rates are very high per unit of electricity generated. Large components are needed to accommodate these flow rates. In particular, only the largest conventional steam turbine stages have the potential for integration into open cycle OTEC systems of a few megawatts gross generating capacity. It is generally acknowledged that higher capacity plants will require a major turbine development effort.

The mist lift and foam lift OTEC systems are variants of the OTEC open cycle. Both employ the sea water directly to produce power. Unlike Claude's open cycle, lift cycles generate electricity with a hydraulic turbine. The energy expended by the liquid to drive the turbine is recovered from the warm sea water. In the lift process, warm seawater is flash evaporated to produce a two-phase, liquid}vapor mixture and either a mist consisting of liquid droplets suspended in a vapor, or a foam, where vapor bubbles are contained in a continuous liquid phase. The mixture rises, doing work against gravity. Here, the thermal energy of the vapor is expended to increase the potential energy of the fluid. The vapor is then condensed with cold sea water and discharged back into the ocean. Flow of the liquid through the hydraulic turbine may occur before or after the lift process. Advocates of the mist and foam lift cycles contend that they are cheaper to implement than closed cycle OTEC because they require no expensive heat exchangers, and are superior to the Claude cycle because they utilize a hydraulic turbine rather than a low pressure steam turbine.

Hybrid Cycle OTEC

Some marketing studies have suggested that OTEC systems that can provide both electricity and water may be able to penetrate the marketplace more readily than plants dedicated solely to power generation. Hybrid cycle OTEC was conceived as a response to these studies. Hybrid cycles combine the potable water production capabilities of open cycle OTEC with the potential for large electricity generation capacities offered by the closed cycle.

Several hybrid cycle variants have been proposed. Typically, as in the Claude cycle, warm surface seawater is flash evaporated in a partial vacuum. This low pressure steam flows into a heat exchanger where it is employed to vaporize a pressurized, low-boiling-point fluid such as ammonia. During this process, most of the steam condenses, yielding desalinated potable water. The ammonia vapor flows through a simple closed-cycle power loop and is condensed using cold sea water. The uncondensed steam and other gases exiting the ammonia evaporator may be further cooled by heat transfer to either the liquid ammonia leaving the ammonia condenser or cold sea water. The non condensables are then compressed and discharged to the atmosphere. Steam is used as an intermediary heat transfer medium between the warm sea water and the ammonia; consequently, the potential for bio-fouling in the ammonia evaporator is reduced significantly. Another advantage of the hybrid cycle related to freshwater production is that condensation occurs at significantly higher pressures than in an open cycle OTEC condenser, due to the elimination of the turbine from the steam flow path. This may, in turn, yield some savings in the amount of power consumed to compress and discharge the non condensable gases from the system.

These savings (relative to a simple Claude cycle producing electricity and water), however, are offset by the additional back work of the closed-cycle ammonia pump. One drawback of the hybrid cycle is that water production and power generation are closely coupled. Changes or problems in either the water or power subsystem will compromise performance of the other. Furthermore, there is a risk that the potable water may be contaminated by an ammonia leak. In response to these concerns, an alternative hybrid cycle has been proposed, comprising decoupled and water production components.

The basis for this concept lies in the fact that warm sea water leaving a closed cycle evaporator is still sufficiently warm, and cold seawater exiting the condenser is sufficiently cold, to sustain an independent freshwater production process. The alternative hybrid cycle consists of a conventional closed-cycle OTEC system that produces electricity and a downstream Sash-evaporation-based desalination system. Water production and electricity generation can be adjusted independently, and either can operate should a subsystem fail or require servicing. The primary drawbacks are that the ammonia evaporator uses warm seawater directly and is subject to bio fouling; and additional equipment, such as the potable water surface condenser, is required, thus increasing capital expenses.

Tidal and Wave Energy

Tidal Power is the power of electricity generation achieved by capturing the energy contained in moving water mass due to tides. Two types of tidal energy can be extracted: **kinetic energy** of currents between ebbing and surging tides and **potential energy** from the difference in height between high and low tides.

All coastal areas experience high and low tide. If the difference between high and low tides is more than 16 feet, the differences can be used to produce electricity. There are approximately 40 sites on earth where tidal differences are sufficient. Tidal energy is more reliable than wave energy because it based on the moon and we can predict them. It is intermittent, generating energy for only 6-12 hours in each 24 hour period, so demand for energy will not always be in line with supply.

Types of Tidal Energy

Kinetic energy from the currents between ebbing and surging tides
>This form is considered most feasible
>Potential energy from height differences between high and low tide

Density of water is much higher than air, so ocean currents have much more energy than wind currents.

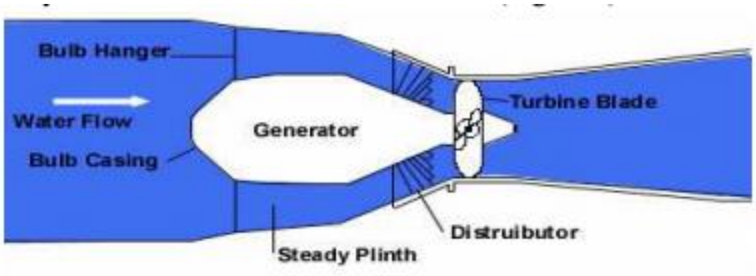
- Barrage or Dam
  Using a dam to trap water in a basin, and when reaches appropriate height due to high tide, release water to flow through turbines that turn an electric generator.
- Tidal Fence
  Turnstiles built between small islands or between mainland and islands. The turnstiles spin due to tidal currents to generate energy.
- Tidal turbine
  Look like wind turbines, often arrayed in rows but are under water. Tidal currents spin turbines to create energy

Like wave energy, tidal energy is used for electricity, with the ultimate goal of connecting to local utility grids. A single 11-meter blade tidal turbine outside of Britain's Devon coast will be capable of generating300 kW of electricity (enough to power approximately 75 homes)

Tidal turbine

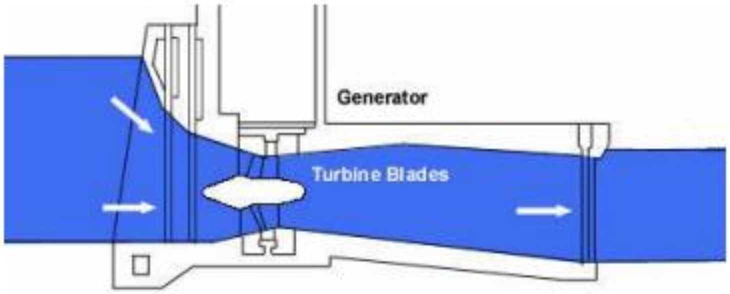
Tidal turbines look like wind turbines. They are arrayed underwater in rows, as in some wind farms. The turbines function best where coastal currents run at between 3.6 and 4.9 knots (4 and 5.5 mph). In currents of that speed, a 15-meter (49.2-feet) diameter tidal turbine can generate as much energy as a 60-meter (197-feet) diameter wind turbine. Ideal locations for tidal turbine farms are close to shore in water depths of 20–30 meters (65.5–98.5 feet).

There are different types of turbines that are available for use in a tidal barrage. A bulb turbine is one in which water flows around the turbine. If maintenance is required then the water must be stopped which causes a problem and is time consuming with possible loss of generation. The La Rance tidal plant near St Malo on the Brittany coast in France uses a bulb turbine.



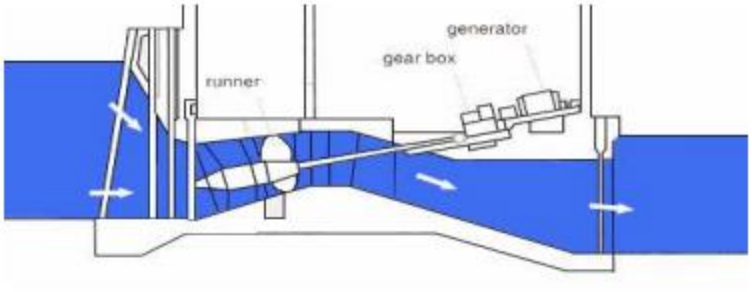
Bulb Turbine

When rim turbines are used, the generator is mounted at right angles to the to the turbine blades, making access easier. But this type of turbine is not suitable for pumping and it is difficult to regulate its performance. One example is the Straflo turbine used at Annapolis Royal in Nova Scotia.



Rim Turbine

Tubular turbines have been proposed for the UK's most promising site, The Severn Estuary, the blades of this turbine are connected to a long shaft and are orientated at an angle so that the generator is sitting on top of the barrage. The environmental and ecological effects of tidal barrages have halted any progress with this technology and there are only a few commercially operating plants in the world, one of these is the La Rance barrage in France.



Tubular turbines

Category of generation

Ebb generation

The basin is filled through the sluices and freewheeling turbines until high tide. Then the sluice gates and turbine gates are closed. They are kept closed until the sea level falls to create sufficient head across the barrage and the turbines generate until the head is again low. Then the sluices are opened, turbines disconnected and the basin is filled again. The cycle repeats itself. Ebb generation (also known as outflow generation) takes its name because generation occurs as the tide ebbs.

Flood generation

The basin is emptied through the sluices and turbines generate at tide flood. This is generally much less efficient than Ebb generation, because the volume contained in the upper half of the basin (which is where Ebb generation operates) is greater than the volume of the lower half (the domain of Flood generation).

Two-way generation

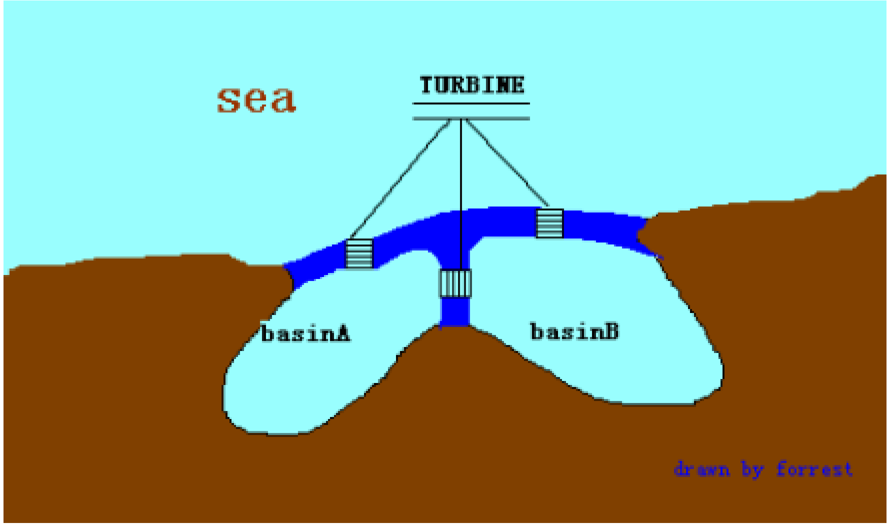
Generation occurs both as the tide ebbs and floods. This mode is only comparable to Ebb generation at spring tides, and in general is less efficient. Turbines designed to operate in both directions are less efficient.

Pumping

Turbines can be powered in reverse by excess energy in the grid to increase the water level in the basin at high tide (for Ebb generation and two-way generation). This energy is returned during generation.

Two-basin schemes

With two basins, one is filled at high tide and the other is emptied at low tide. Turbines are placed between the basins. Two-basin schemes offer advantages over normal schemes in that generation time can be adjusted with high flexibility and it is also possible to generate almost continuously. In normal estuarine situations, however, two-basin schemes are very expensive to construct due to the cost of the extra length.



Schematic diagram of double basin tidal power generation

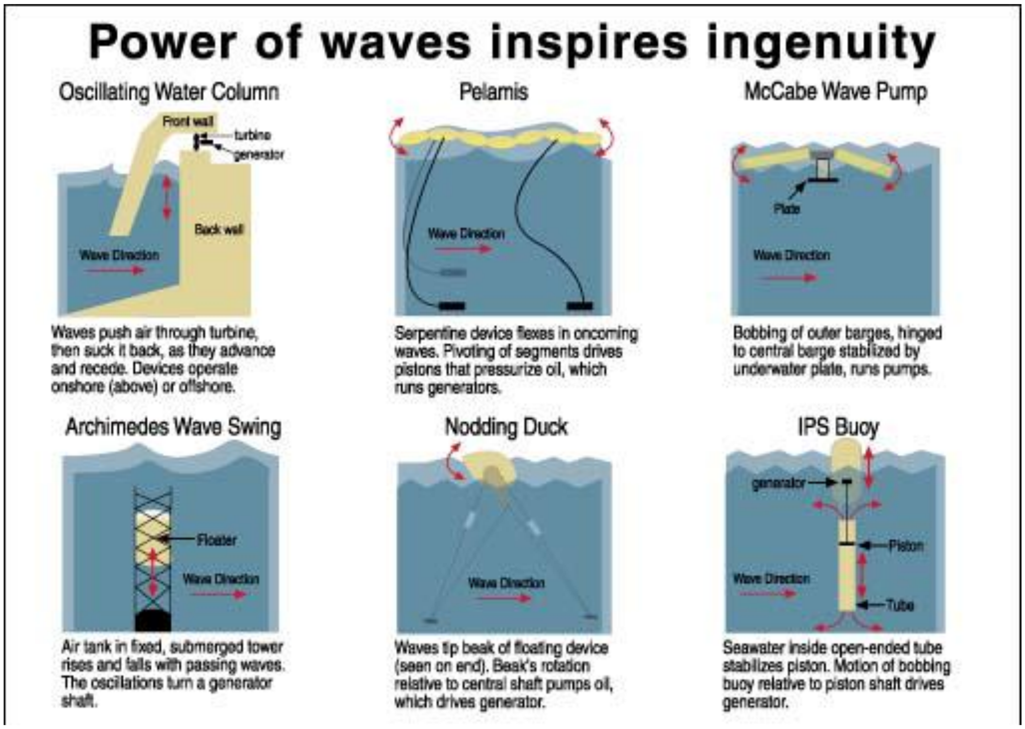
Wave Energy

Wave energy is an irregular and oscillating low frequency energy source that can be converted to a 50 Hertz frequency and can then be added to the electric utility grid. Waves get their energy from the wind, which comes from solar energy. Waves gather, store, and transmit this energy thousands of kilometers with very little loss. Though it varies in intensity, it is available twenty four hours a day all round the year. Wave power is renewable, pollution free and environment friendly. Its net potential is better than wind, solar, small hydro or biomass power. Wave energy technologies rely on the up-and-down motion of waves to generate electricity. There are three basic methods for converting wave energy to electricity.

1. **Float or buoy systems** that use the rise and fall of ocean swells to drive hydraulic pumps. The object can be mounted to a floating raft or to a device fixed on the ocean bed. A series of anchored buoys rise and fall with the wave. The movement is used to run an electrical generator to produce electricity which is then transmitted ashore by underwater power cables.

2. **Oscillating water column devices** in which the in-and-out motion of waves at the shore enters a column and force air to turn a turbine. The column fills with water as the wave rises and empties as it descends. In the process, air inside the column is compressed and heats up, creating energy. This energy is harnessed and sent to shore by electrical cable.

3. **Tapered channel** rely on a shore mounted structure to channel and concentrate the waves driving them into an elevated reservoir. Water flow out of this reservoir is used to generate electricity using standard hydropower technologies.



The advantages of wave energy are as follows:

1. Because waves originate from storms far out to sea and can travel long distances without significant energy loss, power produced from them is much steadier and more predictable day to day and season to season.
2. Wave energy contains about 1000 times the kinetic energy of wind.
3. Unlike wind and solar energy, energy from ocean waves continues to be produced round the clock.
4. Wave power production is much smoother and more consistent than wind or solar resulting in higher overall capacity factors.
5. Wave energy varies as the square of wave height whereas wind power varies with the cube of air speed. Water being 850 times as dense as air, this result in much higher power production from waves averaged over time.
6. Because wave energy needs only 1/200 the land area of wind and requires no access roads, infrastructure costs are less.