ENE 101:
Introduction to Energy Engineering

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Week 9: Energy conversion cont.

- Solar energy
- Geo-energy

Solar Power Generation

There are two main ways of generating energy from sun:

Photovoltaic (PV)	Concentrating Solar Thermal (CST)
Converts sunlight directly into electricity.	Generate electricity indirectly
	

Solar thermal power generation systems use mirrors to collect sunlight and produce steam by solar heat to drive turbines for generating power.

This system generates power by rotating turbines like thermal and nuclear power plants, and therefore, is suitable for large-scale power generation.

Solar Thermal Energy Conversion

- Solar thermal energy applications such as space and water heating have been known for a long time.
- **Solar Water-Heating Systems** represent the most common application of solar energy at the present time. Small systems are used for domestic hot water applications while larger systems are used in industrial process heat applications.
- Researchers over the past few decades have developed a number of additional solar thermal applications, such as

  industrial process heat,

  refrigeration and air-conditioning,

  drying and curing of agricultural products,

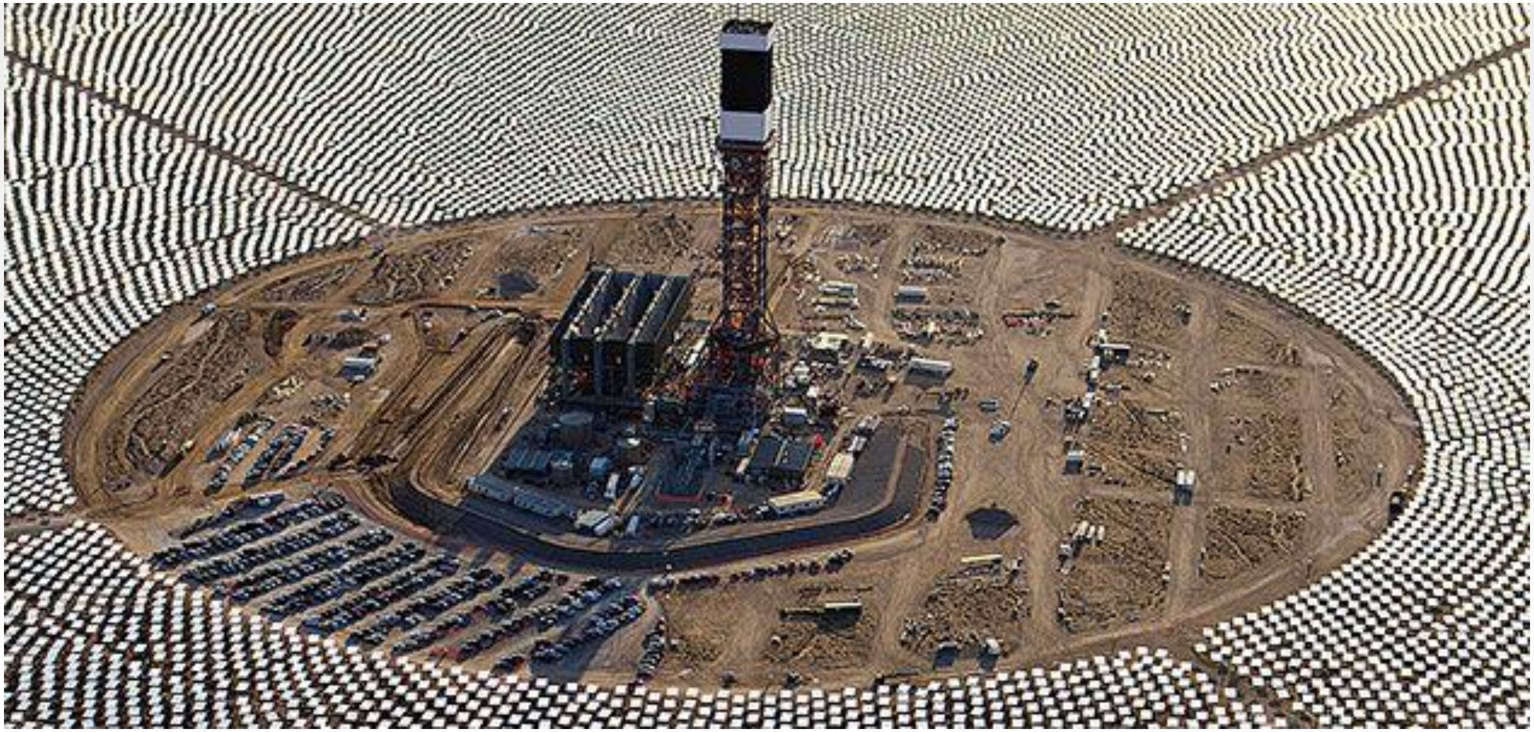
  and electric power production by solar thermal conversion.

History of Solar Thermal Power Generation

- In 1866, Auguste Mouchout used a parabolic trough to produce steam for the first solar steam engine.
- In 1886, The first patent for a solar collector was obtained by the Italian Alessandro Battaglia in Genoa, Italy.
- In 1913, Frank Shuman finished a 55 HP parabolic solar thermal energy station in Maadi, Egypt for irrigation.
- In 1929, The first solar-power system using a mirror dish was built by American Scientist Dr. R.H. Goddard.
- In 1968, The first concentrated-solar plant, which entered into operation in Sant'Ilario, near Genoa, Italy.
- in 1981, The 10 MW Solar One power tower was developed in Southern California.
- In 1984, The parabolic-trough technology of the Solar Energy Generating Systems (SEGS) begun its combined capacity is 354 MW.
- In 2014, The world's largest solar thermal plant (392 MW) achieves commercial operation in Ivanpah, California, USA.

Take a Look at the World's Largest Solar Thermal Farm

When completed in 2013, this series of 170,000 mirrors will power 140,000 California homes



When completed in late 2013, the $2.2 billion Ivanpah Solar Electric Generating System will power 140,000 California homes. (Gilles Mingasson)

Solar Thermal Systems

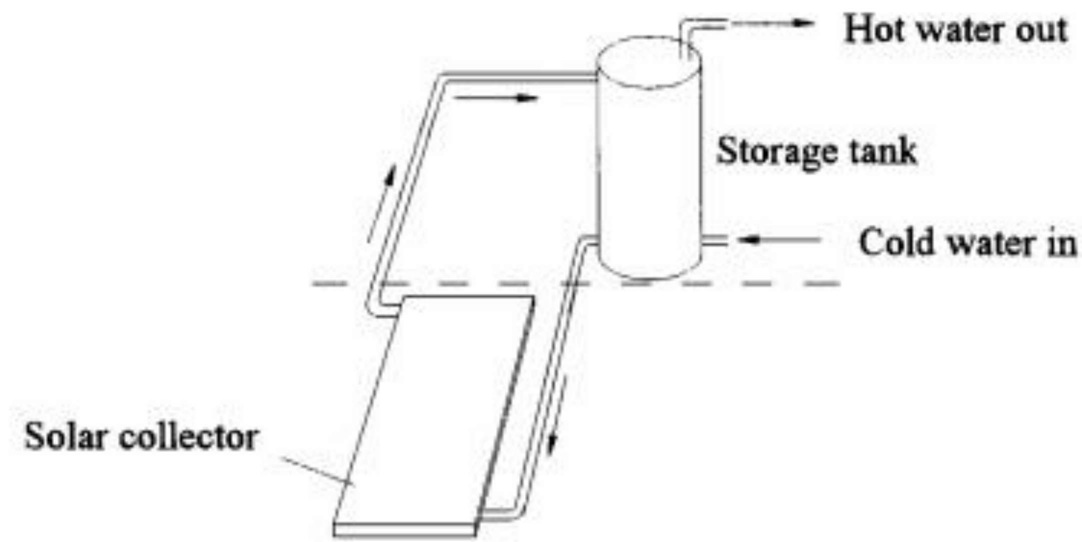
There are basically two types of water-heating systems:

natural circulation or passive solar system : A system requires no equipment, like when heat builds up inside your car when its left parked in the sun.
Example: Thermal Chimneys, thermosyphon

forced circulation or active solar system : An active system requires some way to absorb and collect solar radiation and then store it.
Example: Solar power plants

Passive Solar System

Natural Circulation



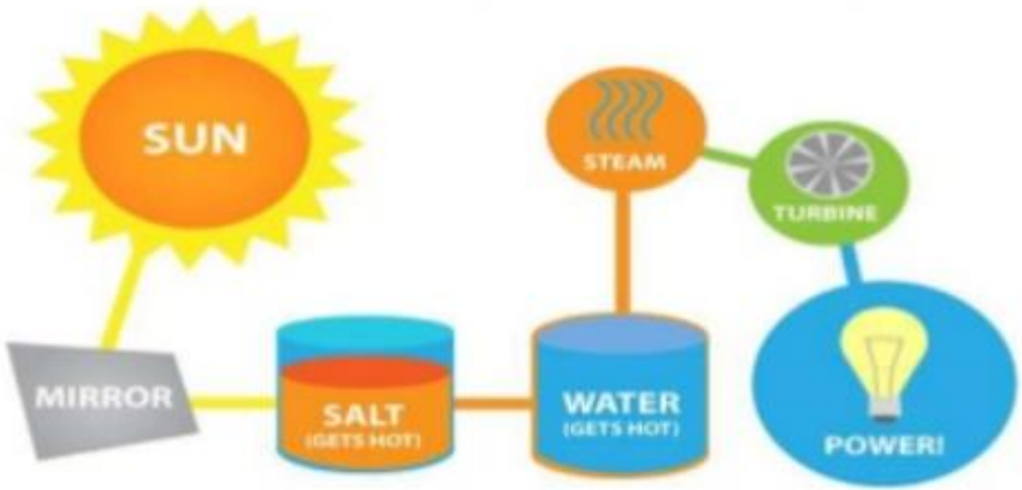
FIGURES 8.10.5 Schematic of a thermosyphon solar water-heating system.

It is also called a ***thermosyphon*** or ***passive solar water heater*** because it does not require a pump to circulate water. The storage tank is located above the collector. When the water in the collector gets heated, it rises into the tank, because of density change, setting up a circulation loop.

Active Solar System

Basic Working Principle Active Solar Thermal Systems

- Mirrors reflect and concentrate sunlight.
- Receivers collect that solar energy and convert it into heat energy.
- A generator can then be used to produce electricity from this heat energy.



Solar Thermal Collectors

A simple **solar thermal collector** consists of (1) an absorber surface (usually a dark, thermally conducting surface), (2) some insulation behind the surface to reduce heat loss, (3) a trap for thermal reradiation from the surface such as glass, which transmits the shorter-wavelength solar radiation but blocks the longer-wavelength radiation from the absorber, and (4) a heat-transfer medium such as air, water, etc. High-temperature collectors require reflectors of sunlight that concentrate solar radiation on the absorber. The technology of solar collectors is developed to achieve temperatures as high as 1000°C or even higher. The design of a solar collector and the choice of working fluids depend on the desired temperature and the economics of the application. Table 8.10.1 lists the types of solar thermal collectors based on their temperature range.

TABLE 8.10.1 Types of Solar Collectors and Their Typical Temperature Range

Type of Collector	Concentration Ratio	Typical Working Temperature Range (°C)
Flat plate collector	1	≤70
High-efficiency flat plate collector	1	60–120
Fixed concentrator	2–5	100–150
Parabolic trough collector	10–50	150–350
Parabolic dish collector	200–2000	250–700
Central receiver tower	200–2000	400–1000

Source: Compiled from Goswami, D.Y., *Alternative Energy in Agriculture*, Vol. 1, CRC Press, Boca Raton, FL, 1980.

Flat Plate Collector

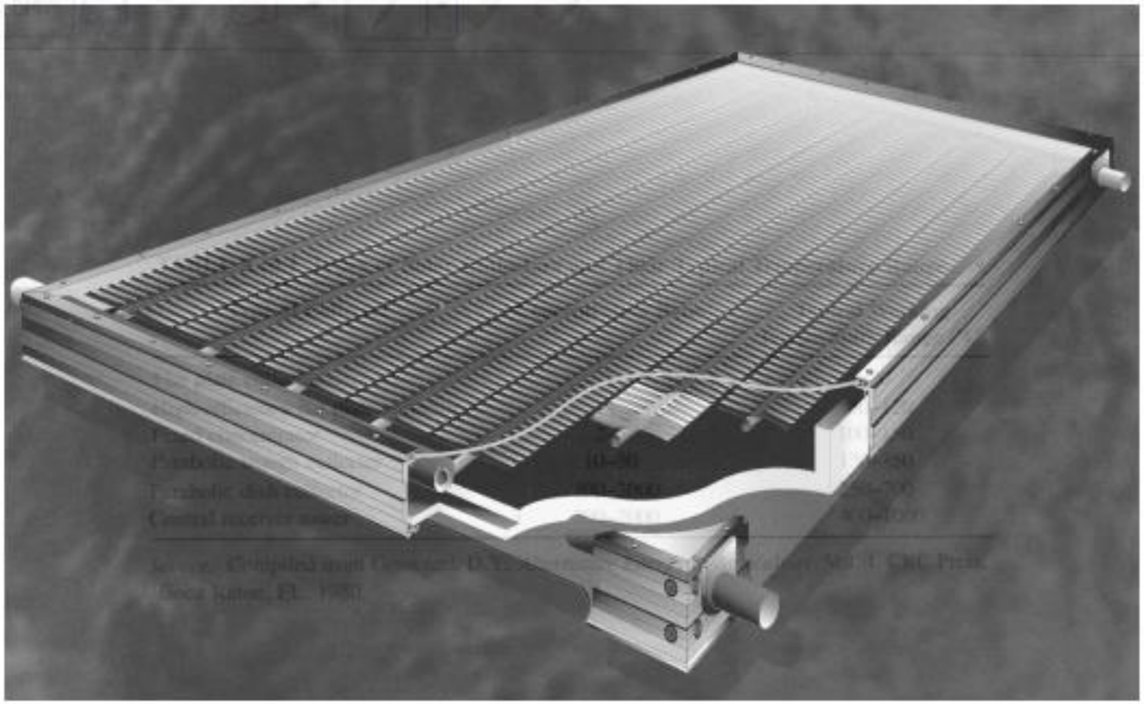


FIGURE 8.10.1 A typical liquid flat plate collector. (Courtesy of American Energy Technologies, Green Cove Springs, FL.)

Flat plate collectors may be designed to use liquids (water, oil, etc.) or air as the heat-transfer fluid.

Flat Plate Collector

Glazing. The purpose of **glazing** is to

(1) transmit the shorter-wavelength solar radiation, but block the longer-wavelength reradiation from the absorber plate, and

(2) reduce the heat loss by convection from the top of the absorber plate.
Glass is the most widely used glazing material. Transmittance of low iron glass in the visible and near infrared wavelength range can be as much as 91%, while for the longer wavelength radiation (>3 mm) its transmittance is almost zero.
Other materials than can be used as glazings include certain plastic sheets such as ***polycarbonates*** (transmittance ~75%), ***acrylic***s (Plexiglass¨ transmittance ~92%), and thin plastic films such as ***polyethylen****e*.
A major advantage of the plastics is that they are shatterproof; however, they scratch easily and lose transparency over time.

Absorbers. Copper is the most common material used for absorber plates and tubes because of its ***high thermal conductivity*** and ***high corrosion resistance***. For low-temperature applications such as swimming pool heating, a plastic material called ethylene propylene polymer can be used to provide inexpensive absorber material.

To compensate for low thermal conductivity of these materials, a large surface area is provided for heat transfer. In order to increase the absorption of solar radiation and to reduce the emission from the absorber, the metallic absorber surfaces are painted or coated with flat black paint or some selective coating.

TABLE 8.10.2 Absorptivity and Emissivity of Common Selective Surfaces

Surface	Absorbtivity	Emissivity
Black chrome	0.95	0.1
Black nickel	0.9	0.08
Copper oxide	0.9	0.17
Lead sulfide	0.89	0.2
Flat black paint	0.98	0.98

Source: Compiled from Duffie, J.A. and Beckman, W.A., *Solar Engineering of Thermal Processes*, John Wiley and Sons, New York, 1980.

Evacuated Tube Collectors.

- Evacuated tube collectors have essentially a vacuum between the absorber and the glazing tube.
- This eliminates most of the heat loss by conduction and convection.
- Therefore, these collectors give a very high efficiency at higher temperatures. Evacuated tube collectors are typically used in the temperature range of 80 to 140°C.

Concentrating Collectors. Concentrating collectors use reflectors or lenses to focus solar radiation from a large area onto a small area, thereby creating higher temperatures. Such collectors are usually used for temperatures higher than 100°C. Figure 8.10.2 shows schematics of some of the concentrating collectors.

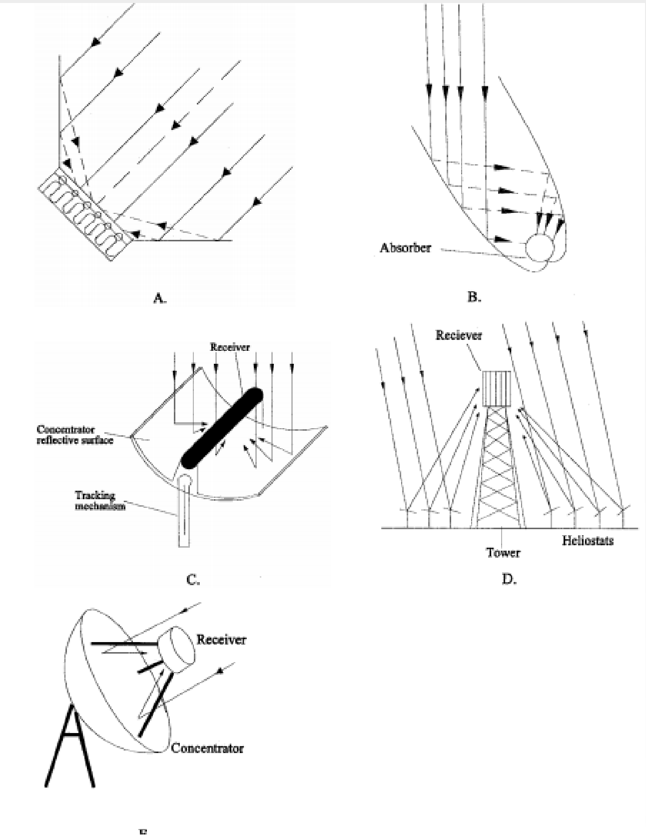


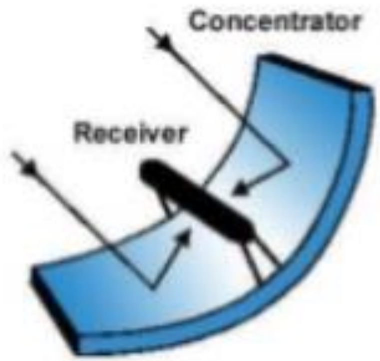
FIGURE 8.10.2 Types of concentrating collectors.
(A) Flat plate collector with reflective wings;
(B) Compound parabolic concentrator;
(C) parabolic trough;
(D) central receiver;
(E) parabolic dish.

Nontracking Concentrators. The simplest concentrating collector can be made by using flat wall reflectors to concentrate the solar radiation on a flat plate collector. Concentration ratios of two to three can be achieved this way. For slightly higher concentration ratios, a novel design, called a compound parabolic concentrator (CPC) can be used.

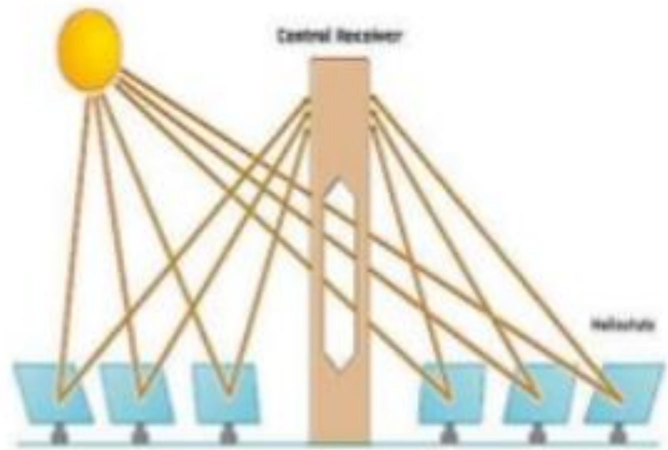
Tracking Concentrators. For temperatures up to 350°C, cylindrical parabolic trough collectors are used. These collectors focus solar radiation on a line focus where the absorber is located. These collectors usually require tracking on one axis only with seasonal adjustment on the other axis. A reflecting spherical or paraboloidal bowl is used when temperatures of the order of 250 to 500°C are needed. **These collectors require two-axis tracking**. In some cases, the dish is kept stationary while the receiver is moved to track the focus of the reflected solar radiation.

Finally, for extremely high temperatures (500 to 1000°C) needed for large-scale thermal power generation, a large field of tracking flat mirrors (called heliostats) is used to concentrate solar radiation on a receiver that is located on top of a central tower.

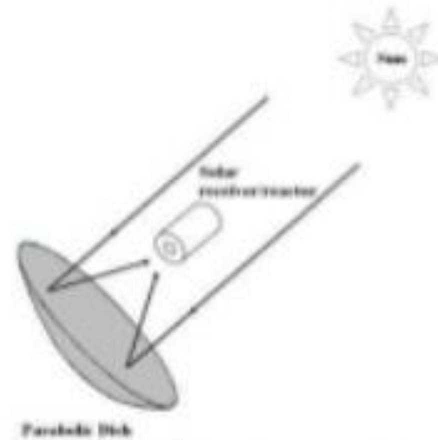
Types of Solar Thermal Power Plants



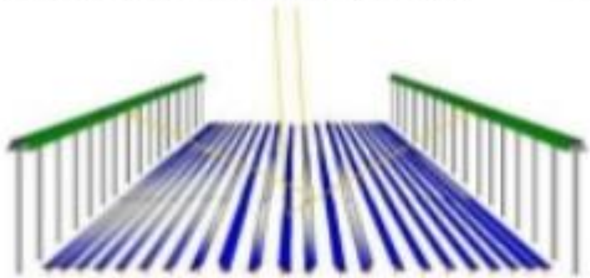
Parabolic trough system



Solar power tower systems



Solar dish/engine system



Compact linear Fresnel reflector

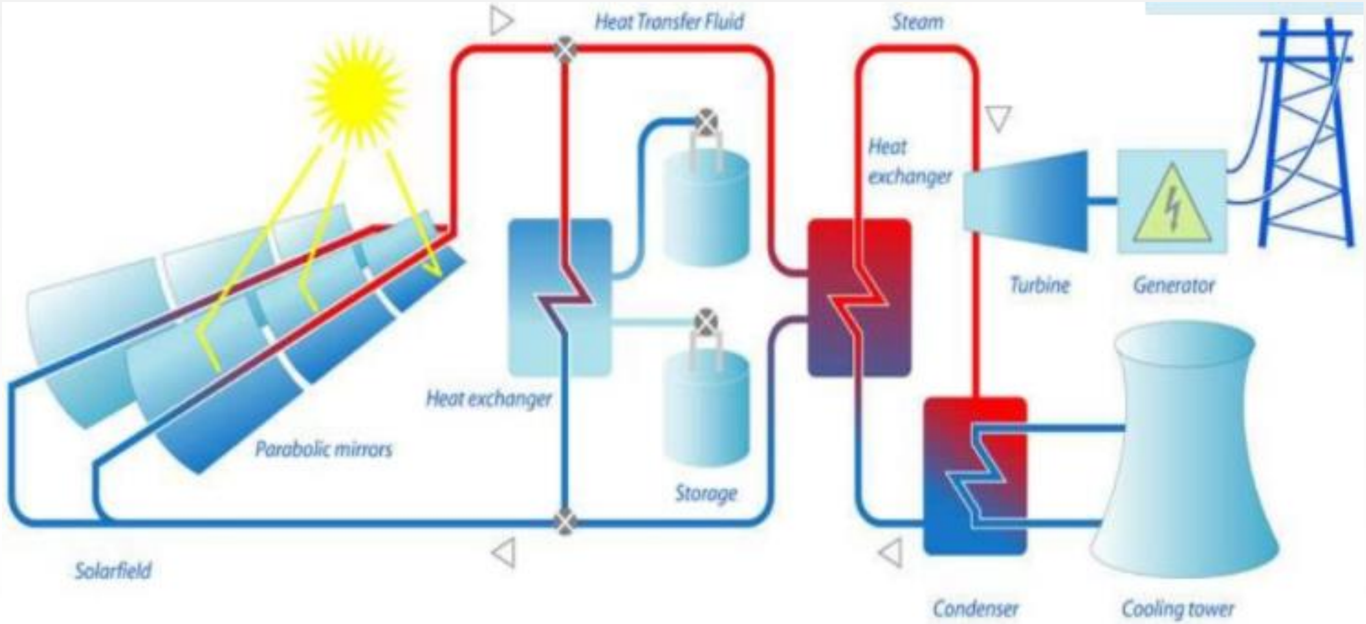
Parabolic Trough System

A parabolic trough consists of a linear parabolic reflector that concentrates light onto a receiver positioned along the reflector's focal line.

The receiver is a tube positioned directly above the middle of the parabolic mirror and filled with a working fluid.

The reflector follows the sun during the daylight hours by tracking along a single axis.

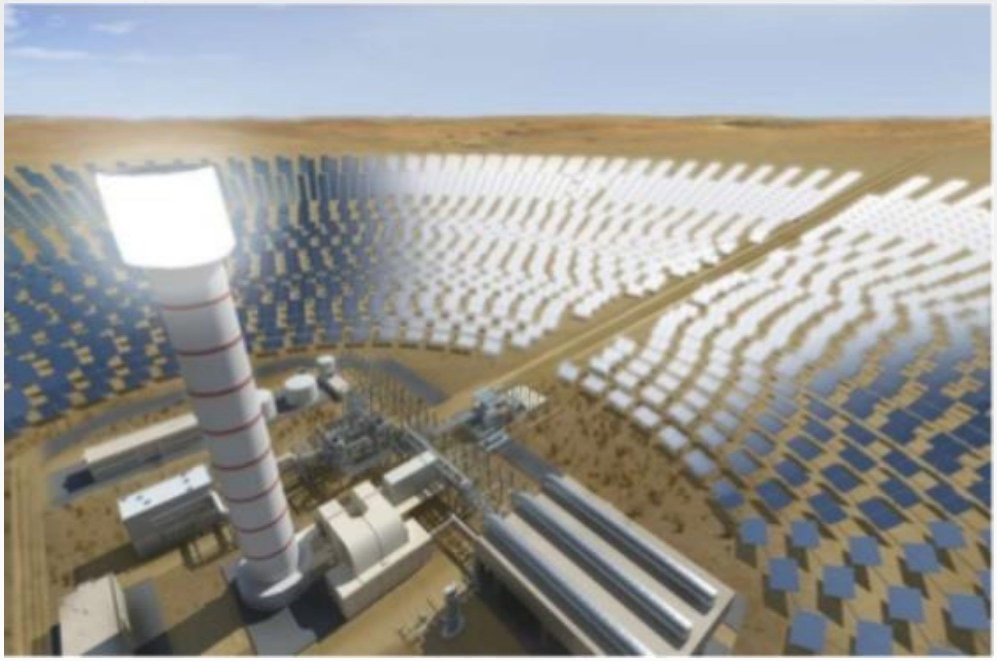
A working fluid (e.g molten salt) is heated to 150-350 oC as it flows through the receiver and is then used as a heat source for a power generation system.



Parabolic Trough System

Solar Power Tower Systems

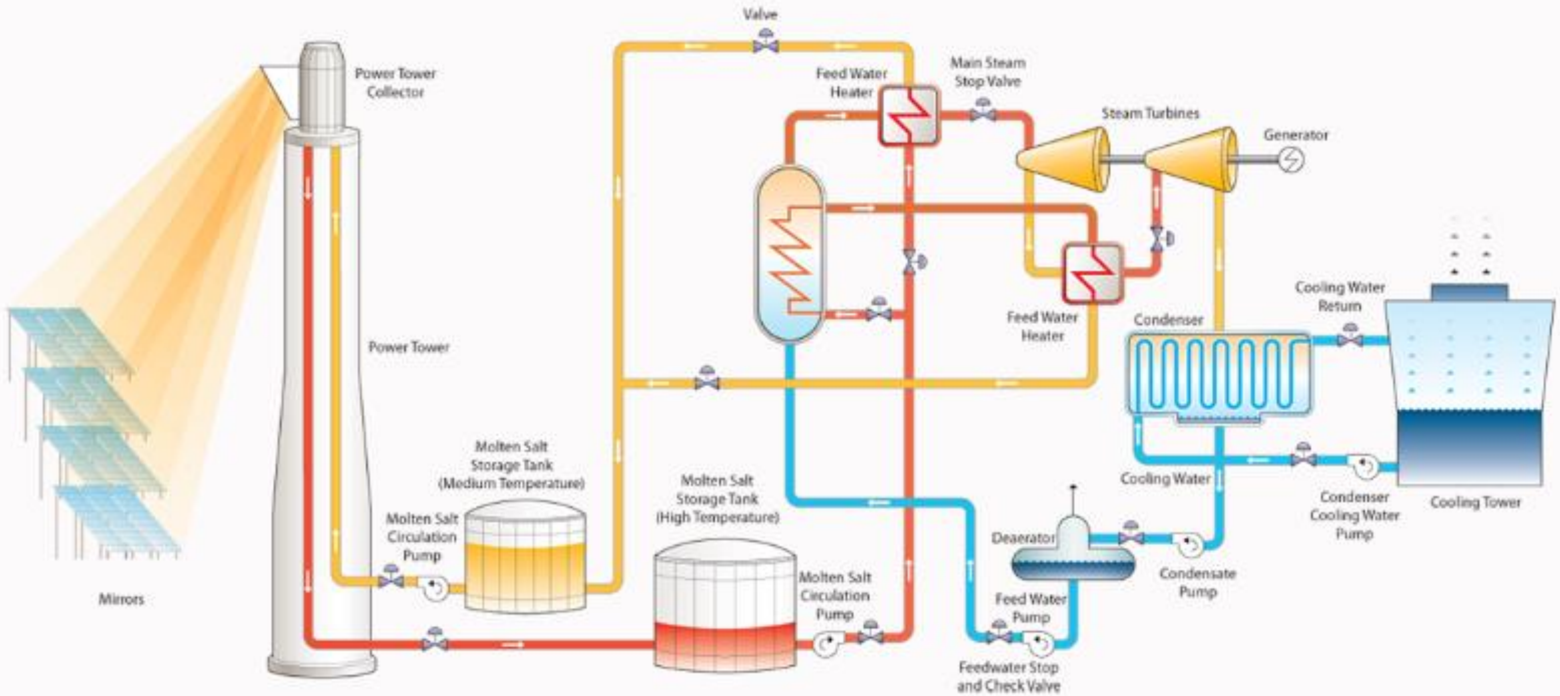
Solar power towers are one of the most reliable source of electrical energy and high temperature industrial process heat. The central receiver technology is highly efficient, because it concentrates and converts direct solar radiation to heat a fluid to a high temperature which can be used for a variety of end uses.



- Power towers (also known as 'central tower' power plants or 'heliostat' power plants).

Solar Power Tower Systems

- These designs capture and focus the sun's thermal energy with thousands of tracking mirrors (called heliostats) in roughly a two square mile field.
- A tower resides in the center of the heliostat field. The heliostats focus concentrated sunlight on a receiver which sits on top of the tower.
- Within the receiver the concentrated sunlight heats molten salt to over 1,000 °F (538 °C).
- The heated molten salt then flows into a thermal storage tank where it is stored, maintaining 98% thermal efficiency, and eventually pumped to a steam generator.
- The steam drives a standard turbine to generate electricity.



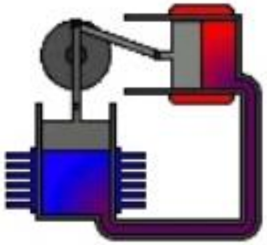
Solar Dish/Engine System

The system consists of a stand-alone parabolic reflector that concentrates light onto a receiver positioned at the reflector's focal point.

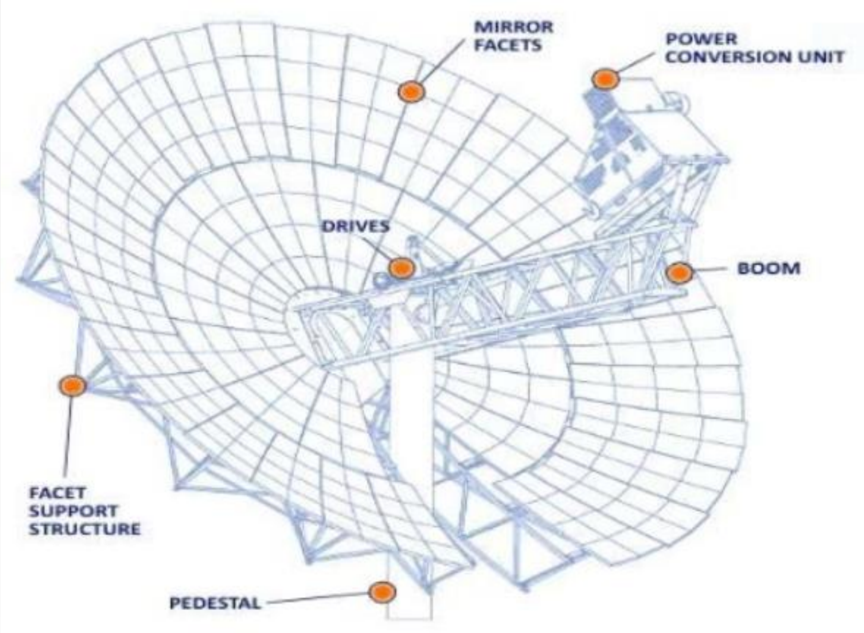
The working fluid in the receiver is heated to 250–700 °C (523–973 K (482–1,292 °F)) and then used by a Stirling engine to generate power.

Parabolic-dish systems have the highest efficiency of all solar technologies provide solar-to-electric efficiency between 31–32%.

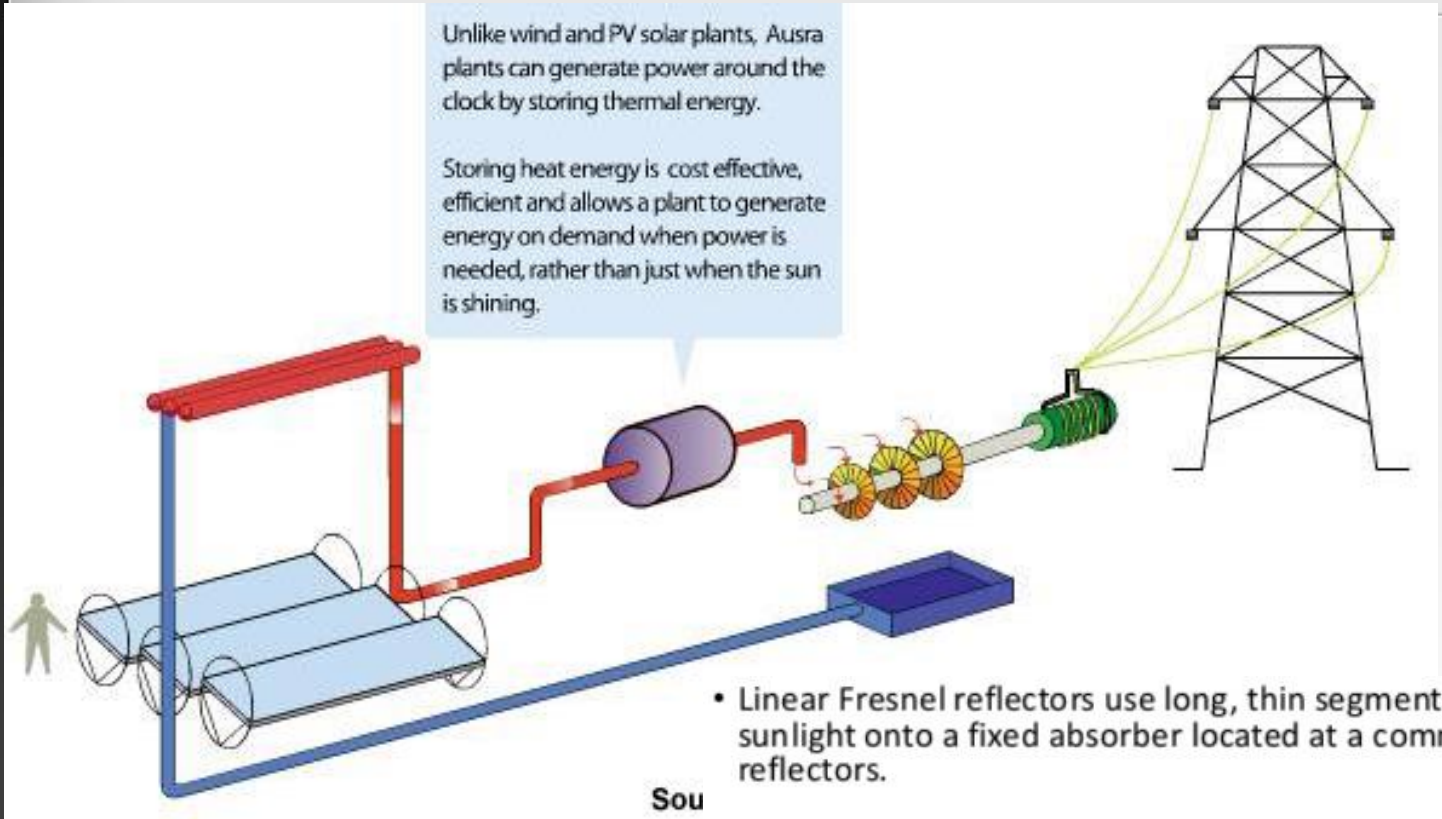
Stirling Engine →



Solar Dish/Engine System



Compact Linear Fresnel Reflector



Sou

- Linear Fresnel reflectors use long, thin segments of mirrors to focus sunlight onto a fixed absorber located at a common focal point of the reflectors.
- These mirrors are capable of concentrating the sun's energy to approximately 30 times its normal intensity.
- This concentrated energy is transferred through the absorber into some thermal fluid.
- The fluid then goes through a heat exchanger to power a steam generator.

Compact Linear Fresnel Reflector

Enclosed Parabolic Trough System

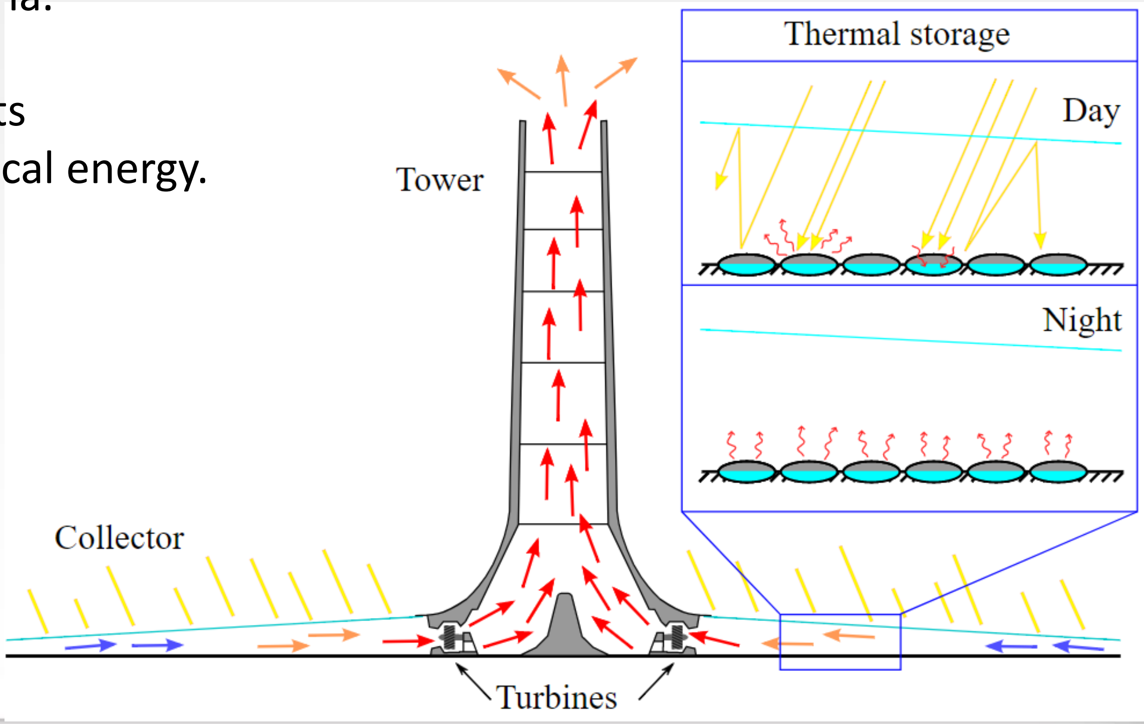
- The enclosed parabolic trough solar thermal system encapsulates the components within a greenhouse-like glasshouse.
- The glasshouse protects the components from the elements that can negatively impact system reliability and efficiency.
- Lightweight curved solar-reflecting mirrors are suspended from the ceiling of the glasshouse by wires.
- A single-axis tracking system positions the mirrors to retrieve the optimal amount of sunlight.
- The mirrors concentrate the sunlight and focus it on a network of stationary steel pipes, also suspended from the glasshouse structure.
- Water is pumped through the pipes and boiled to generate steam when intense sun radiation is applied. y steel pipes, also suspended from the glasshouse structure.

Enclosed Parabolic Trough System

Further Development-Thermal Chimneys

- Passive Solar Ventilation systems, which means they are non-mechanical.
- Typically made of a black, hollow thermal mass with an opening at the top for hot air to exhaust.
- Inlet openings are smaller than exhaust outlets and are placed at low to medium height in a room.
- When hot air rises, it escapes through the exterior exhaust outlet, either to the outside or into an open stairwell or atria.
- Turbines similar to those

used in hydroelectric power plants
convert the air flow into mechanical energy.



Collector Thermal Performance

The instantaneous efficiency of a collector is given by

$$\eta = \frac{\text{Useful energy collected}}{\text{Incident solar energy}} = \frac{Q_u / A}{I}$$

where

$$Q_u = mC_p(T_o - T_i)$$

A = area of the collector,
I = incident solar energy per unit area,
m, Cp, *Ti*, and *To* are the mass flow rate, specific heat, and inlet and outlet temperatures of the heat-transfer fluid.

The efficiency of a flat plate solar collector can also be written by the Hottel Whillier Bliss equation :

$$\eta = F_R(\tau\alpha)_e - F_R U_L \frac{(T_i - T_{amb})}{I}$$

where F_R, called the collector heat-removal factor, is a convenient parameter that gives the ratio of the actual useful energy gain of a flat plate collector to the useful gain if the whole collector surface were at the inlet fluid temperature; (ta)*e* = effective transmittance absorptance product; and U_L = collector heat-loss coefficient

Pros and Cons of Thermal Energy

Pros

No Fuel cost

Predictable, 24/7 power

No pollution and Global Warming Effects

Using Existing Industrial Base

Cons

High Cost

Future Technology has a high probability of making CSP Obsolete

Ecological and Cultural Issues

Limited Locations and Size Limitations

Long Gestation Time leading to cost overruns

Major challenges

Installation cost and energy storage

The costs are still far higher than fossil fuel plants based on units of energy produced.

The hot water storage products are often stretched to their limits.

Alternatives could be phase change materials or thermochemical materials.

Conclusion

- In the face of global warming, rising fuel costs and an ever-growing demand for energy, energy needs are expected to increase by nearly the equivalent of 335 million barrels of oil per day, mostly for electricity.
- By concentrating solar energy with reflective materials and converting it into electricity, modern solar thermal power plants, if adopted today as an indispensable part of energy generation, may be capable of sourcing electricity to more than 100 million people in the next 20 years. All from one big renewable resource: THE SUN.

Defining Terms

Forced circulation or active solar system: A solar thermal system that uses active means, such as pumps, for fluid flow and heat transfer .

Glazing: A material used in a solar collector that transmits short-wavelength solar radiation and blocks longer-wavelength reradiation from the absorber plate.

Natural circulation passive solar system: A solar thermal system that uses natural means, such as the thermosyphon effect, for fluid flow and heat transfer.

Salt gradient solar pond: A solar pond that uses high salt concentration in the lowest layer and a concentration gradient in the middle layer to make those layers nonconvective.

Selective surface: A surface that has high absorptance in short wavelengths and low emittance in longer wavelengths.

Solar hybrid combined cycle: A hybrid of solar and natural gas turbine combined cycle.

Solar thermal collector: A solar collector that absorbs sunlight and converts it to heat.

GEOTHERMAL ENERGY

Geothermal power plants use hydrothermal resources that have both water (hydro) and heat (thermal).
Geothermal power plants require high-temperature (300°F to 700°F) hydrothermal resources that come from either dry steam wells or from hot water wells.
People use these resources by drilling wells into the earth and then piping steam or hot water to the surface.
The hot water or steam powers a turbine that generates electricity. Some geothermal wells are up to two miles deep.

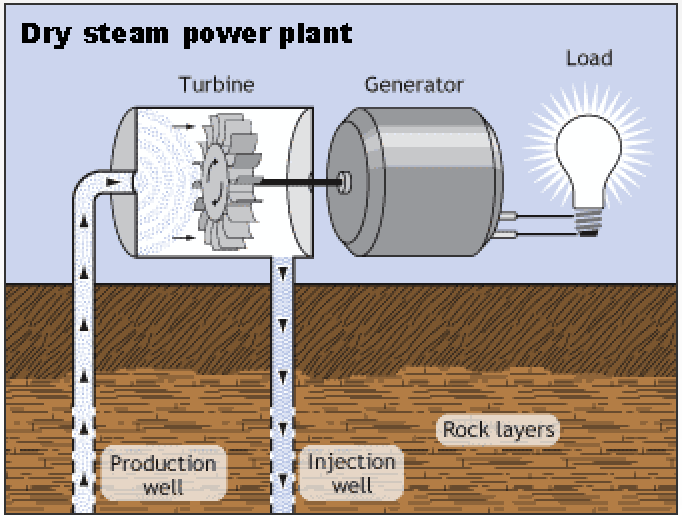
There are three basic types of geothermal power plants:

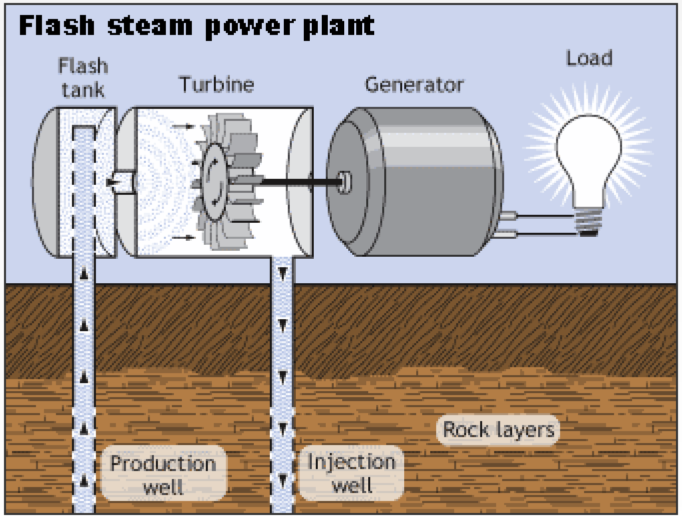
- **Dry steam plants**
- **Flash steam plants**
- **Binary cycle power plants**

Types of Geothermal Power Plants

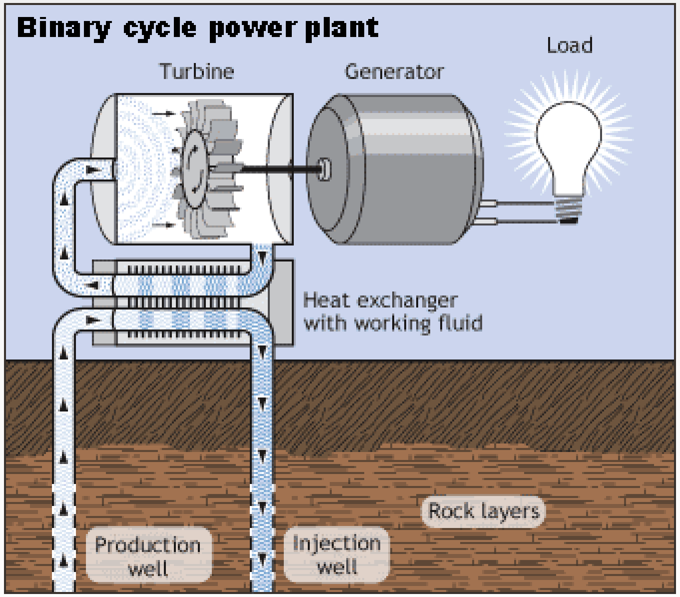
•**Dry steam plants** use steam directly from a geothermal reservoir to turn generator turbines. The first geothermal power plant was built in 1904 in Tuscany, Italy, where natural steam erupted from the earth.

•**Flash steam plants** take high-pressure hot water from deep inside the earth and convert it to steam to drive generator turbines. When the steam cools, it condenses to water and is injected back into the ground to be used again. Most geothermal power plants are flash steam plants.





•**Binary cycle power plants** transfer the heat from geothermal hot water to another liquid. The heat causes the second liquid to turn to steam, which is used to drive a generator turbine.



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