UNIT II

SOLAR ENERGY STORAGE AND APPLICATIONS: Different methods, sensible, latent heat and stratified storage, solar ponds, solar applications- solar heating/cooling technique, solar distillation and drying, solar cookers, central power tower concept and solar chimney.

WIND ENERGY: Sources and potentials, horizontal and vertical axis windmills, performance characteristics, betz criteria, types of winds, wind data measurement.

Outcome: Describe the working of a photovoltaic system and wind energy conversion system

Activity: Demonstrating solar applications model and show working of wind turbine to produce power

Energy Storage

"Storage" refers to technologies that can capture electricity, store it as another form of energy (chemical, thermal, mechanical), and then release it for use when it is needed. Although using energy storage is never 100% efficient—some energy is always lost in converting energy and retrieving it—storage allows the flexible use of energy at different times from when it was generated. So, storage can increase system efficiency and resilience, and it can improve power quality by matching supply and demand.

Storage facilities differ in both energy capacity, which is the total amount of energy that can be stored (usually in kilowatt-hours or megawatt-hours), and power capacity, which is the amount of energy that can be released at a given time (usually in kilowatts or megawatts). Different energy and power capacities of storage can be used to manage different tasks. Short-term storage that lasts just a few minutes will ensure a solar plant operates smoothly during output fluctuations due to passing clouds, while longer-term storage can help provide supply over days or weeks when solar energy production is low or during a major weather event, for example.

Advantages of Combining Storage and Solar

1. **Balancing electricity loads** – Without storage, electricity must be generated and consumed at the same time, which may mean that grid operators take some generation offline, or "curtail" it, to avoid over-generation and grid reliability issues. Conversely, there may be other times, after sunset or on cloudy days, when there is little solar

production but plenty of demand for power. Enter storage, which can be filled or charged when generation is high and power consumption is low, then dispensed when the load or demand is high. When some of the electricity produced by the sun is put into storage, that electricity can be used whenever grid operators need it, including after the sun has set. In this way, storage acts as an insurance policy for sunshine.

2. **"Firming" solar generation** – Short-term storage can ensure that quick changes in generation don't greatly affect the output of a solar power plant. For example, a small battery can be used to ride through a brief generation disruption from a passing cloud, helping the grid maintain a "firm" electrical supply that is reliable and consistent.
3. **Providing resilience** – Solar and storage can provide backup power during an electrical disruption. They can keep critical facilities operating to ensure continuous essential services, like communications. Solar and storage can also be used for microgrids and smaller-scale applications, like mobile or portable power units.

What are the benefits of storing solar energy?

Storing this surplus energy is essential to getting the most out of any solar panel system, and can result in cost-savings, more efficient energy grids, and decreased fossil fuel emissions. Storing solar energy has a few main benefits:

- **Balancing electric loads:** If electricity isn't stored, it has to be used at the moment it's generated. Energy storage allows surplus generation to be banked for peak-use. As far as renewable energy is concerned, storing surplus power allows the lights to stay on when the sun goes down or the wind stops blowing. Simply put, energy storage allows an energy reservoir to be charged when generation is high and demand is low, then released when generation diminishes and demand grows.
- **Filling in the gaps:** Short-term solar energy storage allows for consistent energy flow during brief disruptions in generators, such as passing clouds or routine maintenance.
- **Energy resilience:** The energy grid is vulnerable to disruptions and outages due to anything from wildfires to severe weather. Solar energy storage creates a protective bubble during disruptive events by decentralizing where we get our energy from.
- **Savings from electric bills**: If you live in a state that has no solar net energy metering, or policies that don't fairly compensate you for the solar energy you generate, battery storage can help lower your utility bills while consuming more of your own power. So, while you may not be compensated as much for excess energy sent to the grid, any additional solar power generated and stored throughout the day can be discharged from a battery at night or on cloudy days in the place of utility consumption.
- **Reducing carbon footprint:** With more control over the amount of solar energy you use, battery storage can reduce your property's carbon footprint in areas with fossil fuel-based utility power. Large solar batteries can also be used to help charge electric vehicles and turn any appliance in your home into a "solar-powered" device.

Thermal energy storage (TES) technologies

TES is one of the most practiced technologies to store energy in the form of heat to eliminate the gap between the energy supply and demand. As shown in Figure 1, there are three main thermal energy storage technologies: sensible heat storage through a temperature change (sensible heat) of a material, latent heat storage through phase change (latent heat) of a material and thermochemical heat (chemical energy) by thermally inducing changes in materials' chemical states. As compared in Table 1, the choice of TES method depends on a variety of factors such as the storage capacity, cost, temperature range, duration requirement as well as the specific application.

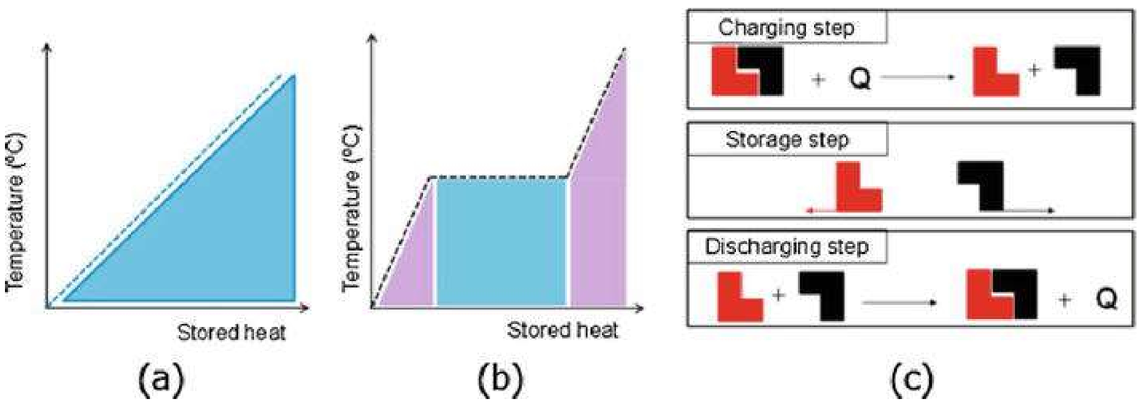


Figure 1. Main approaches of thermal energy storage: (a) sensible heat, (b) latent heat, (c) thermo-chemical reactions.

Sensible heat storage

Solid sensible heat storage is an attractive option for thermal energy storage regarding the investment and maintenance costs. Sensible heat storage stores the thermal energy by varying the temperature of storage materials, without undergoing any form of phase change within the working temperature range. The amount of thermal energy stored or released is proportional to the density ρ, volume V, specific heat cp, and temperature variation of the storage materials:

$$Q_{sen}=\int_{T_i}^{T_f} mcpdT=\rho VcpT_f-T_i$$

where Qsen is the amount of sensible heat stored, dT is the temperature interval, Ti is the initial temperature and Tf the final temperature of storage medium during the storage process. Basically, specific heat cp, density ρ and thermal conductivity k are the key thermal properties of sensible heat storage materials. According to the materials' phase state, sensible heat storage materials can be divided into two main categories: solid and liquid heat storage. Table 2 lists the most common solid and liquid heat storage materials with their thermal properties.

Table 1: Comparison of typical parameters of three TES technologies.

TES technology	Capacity (kWh/t)	Cost (/kWh)	Storage period
Sensible	10–50	0.1–10	Days/months
Phase change materials	50–150	10–50	Hours/months
Chemical reactions	120–150	8–100	Months/seasons

Table 2: Available sensible heat storage materials used in the thermal energy storage systems.

Material	Type	Density (kg/m3)	Thermal conductivity (W/m·K)	Heat capacity (kJ/kg·K)	Cost (€/m3)
Rock	Solid	1500–2800	0.85–3.5	1	64–742
Concrete	Solid	2000	1.35	1	76
Sand and gravel	Solid	1700–2200	2	0.910–1.180	6–8
Ceramic tile	Solid	2000	1	0.8	1600–3500
Gypsum (coating)	Solid	1000	0.4	1	78
Ceramic brick	Solid	1800	0.73	0.92	36–64
Wood	Solid	450	0.12	1.6	404
Water	Liquid	990	0.63	4.19	1.6
Oil	Liquid	888	0.14	1.88	6560
Nitrite salts	Liquid	1825	0.57	1.5	2200
Carbonate salts	Liquid	2100	2	1.8	6050
Liquid sodium	Liquid	850	71	1.3	2000

Solid heat storage

Solid storage materials have been applied in many TES systems for their reliability, low cost, easy implementation and applicability in extensive practical cases. Different from liquid heat storage, there are no vapor pressure or leakage issues in solid heat storage. However, a fluid, usually air or oil, is needed to work as the heat transfer fluid (HTF) to transport the thermal energy that is to be stored into or released from the solid heat storage system. As listed in Table 2, the most frequently used solid heat storage materials include rock, concrete, brick, sand and so on.

Rock is always loosely piled in a packed bed through which the HTF like air or oil can flow. Thermal energy is stored in the packed bed by forcing heated HTF flowing through the rocks and utilized again by recirculating the HTF through the heated rocks. Typically, the characteristic size of rock pieces varies from 1 to 5 cm. There is a large contact surface area available for heat transfer between HTF and rocks which is beneficial for the heat transfer. The amount and temperature level of energy stored in a packed bed storage system with rocks depend on the rock size and shape, packing density, HTF, etc. As a sensible energy storage option, rock has advantages like being non-toxic, non-flammable, cheap and easily available. This type of storage is operated very often for temperatures up to 100°C in conjunction with solar air heaters and thus convenient to be implemented in buildings. The heat storage with rocks can also be used for higher temperature applications, up to 1000°C. When rock is employed as thermal storage material, there are several drawbacks, including the poor thermal conductivity, high pressure drop under large flow rates of HTF.

Concrete is a promising candidate as it has a low cost and is easy to obtain and process directly on site. Concrete is a construction material comprised of cementitious materials and/or calcium aluminate cement, coarse and fine aggregates, water and possibly chemical admixtures. Besides, it has relatively high specific heat and good mechanical properties. The heat exchanger between concrete and HTF is usually designed as the pipes embedded into the concrete block where HTF flows internally. As cracks may form after repeated cycles due to thermal expansion and contraction at high temperatures, research efforts have been devoted to developing appropriate concrete compositions, optimizing chemical–physical and durability performances at high temperatures. Long-term stability of concrete has been proven in oven experiments and through strength measurements up to 500°C. The main challenges to use the concrete as TES materials include: potential cracks, relatively low thermal conductivity, durability after long-term thermal cycling and high costs for heat exchangers to charge/discharge thermal energy.

Sand grains are shown to be a promising low-cost candidate material that is suitable for concentrated solar power (CSP) applications with high-temperature thermal storage. The average size of sand grains is around 0.2–0.5 mm and they are commonly used in the form of packed beds for heat storage with air as HTF. It is possible to use desert sands directly as collected from the field of CSP, removing the need for third-party suppliers. Moreover, they can be used directly in solar receivers to collect solar thermal energy. After absorbing the heat of concentrated solar rays, due to the gravity forces, the sands can fall from the top of solar receiver tower and then they can be collected in an insulated storage tank below. Temperature of hot sands can go up to 700–1000°C which is appropriate for producing steam to drive a Rankine cycle.

Liquid heat storage

Water is the most common liquid material for TES due to its high specific heat, none-toxicity, low-cost and easy-availability. However, due to its high vapor pressure, water requires costly insulation and pressure withstanding containment for high temperature applications from 100 to 700°C (in the form of steam). Water in liquid phase is widely used for low temperature heat storage below 100°C in solar based applications, such as space heating and hot water supply. Water in liquid state can also form thermal stratification or thermocline. Due to density difference caused by heating of liquid, the buoyancy force causes stratification of the water, forming a thermal gradient across the storage. Under such a condition, the hot fluid can be supplied to the upper part of a storage tank during charging, and the cold fluid can be extracted from the bottom part during discharging. Thus, the efficiency of thermal energy store and release process can be improved. In some high temperature applications like CSP plants, water is stored in steam phase in high pressure tanks (steam accumulator) to work as TES systems. In additional, water can be also used in chilled water form or in ice form for cold energy storage, which is useful in refrigeration systems. The main drawbacks for using water as the TES material are its high vapor pressure and corrosiveness to the container above its boiling point.

Molten salt is currently one of the most popular TES materials used in CSP plants. Compared to other liquid heat storage materials, molten salts have relative low costs, high energy storage densities, excellent thermal stabilities, low viscosities and non-flammabilities. Molten salts in liquid state can be operated at high temperatures of several hundred degree centigrade while its vapor pressure is much lower than that of water, so it is very suitable for high temperature CSP plants. The pure molten salt usually has a melting point above 200°C which hampers its further application at low temperatures. It is desirable to have a molten salt with a lower melting point so that it can remain the liquid state when storing the thermal energy. A new series of ternary salt mixtures have been proposed with ultra-low melting temperatures at 76°C, 78°C or 80°C, and they can prevent the solidification at low temperatures to enable the TES systems suitable for a wider applications. Molten salt also has several drawbacks that limit its application: low thermal conductivity, volume change during the melting and corrosivity to the container.

Thermal oil is usually a kind of organic fluid and works as a HTF in many power and energy systems. When using as a thermal storage medium, thermal oil can remain in liquid phase at temperatures of 350–400°C with stable thermal properties, which is much higher than the liquid water. It means that thermal oil can store more thermal energy based on the wider temperature operation range. Compared to water, thermal oil also has a lower vapor pressure, which is beneficial for mechanical designs of relevant pipes and containers. Unlike molten salts, thermal oil does not freeze during the night in pipes so that it doesn't need any antifreeze system. However, the cost of thermal oil is usually higher than water and molten salts.

Pros and cons of sensible heat storage

Sensible heat storage materials are typically based on relatively low cost materials and thus extensively used, except the liquid metals. Due to the relatively good thermal stability, heat transfer performance and transport properties, sensible heat storage materials are the most used TES materials for high temperature applications. Compared to the latent heat storage, specific heat of sensible heat storage materials is 50–100 times smaller, leading to the requirement of large volumes or quantities in order to deliver the amount of energy storage necessary for high temperature thermal energy storage applications. The other main issue of sensible heat storage is that the temperature of the storage medium decreases during discharging process, so the HTF temperature also decreases with time.

Latent heat storage

Latent heat storage utilizing PCMs is an alternative TES technique compared to the sensible heat storage. PCMs are substances which can absorb or release large amount of energy, i.e., so-called latent heat, when they experience phase transitions among solid, liquid and gas states. Although the highest latent heat of phase change is the liquid-gas phase change, it is hard to utilize this due to the enormous volume change associated with material evaporation. While another kind, 'solid-solid' latent heat storage material has its latent heat of transition one order of magnitude smaller than the solid-liquid PCMs, which is commonly applied for latent heat thermal energy storage. Solid-liquid PCMs should have a melting point near the required operation temperature range of the TES system, melt congruently with minimum subcooling, and also is desired to be chemically stable, cost competitive, non-toxic and non-corrosive. The amount of energy storage of the latent heat system with PCMs is calculated as:

$$Q_{lat}=mcp_sT_m-T_i+\alpha Lh+cp_lT_f-T_m$$

where Q_{lat} is the amount of heat stored, cp_s and cp_l are the specific heat of PCMs in solid and liquid state, Lh is the latent heat of fusion, α is the melting fraction, Ti and Tf are the initial and final temperatures of the storage materials, and Tm is the melting temperature. This section briefly introduces the classification of PCMs and the related heat transfer enhancement techniques.

Phase change materials

Solid-liquid PCMs are competitive alternatives to the sensible TES materials. Compared to sensible heat storage materials, PCMs can operate at the phase change temperature with small temperature variations between heat storage (charging) and heat releasing (discharging) as illustrated in Figure 1(b), and Figure 2 shows the classification of PCMs family for TES. Different kinds of PCMs are introduced in the following subsections. Table 3 presents the characteristics of several common PCMs.

Organic PCMs and their eutectic mixtures have been successfully implemented in many commercial applications, such as space heating in buildings, electronic devices, refrigeration and air-conditioning, solar air/water heating, textiles, automobiles, food and space industries. Organic PCMs featured of congruent melting without phase separation usually have relative low melting points. Commonly used organic PCMs are paraffin, fatty acids, esters, alcohols and glycols. Among them, paraffin wax is an excellent heat storage material and has been widely applied for low temperature heat storage applications. It consists of straight n-alkanes chain (CH3-(CH2)-CH3), featuring a high specific heat capacity (2.14–2.9 J/g·K), a low price (∼1 USD/kg) with a moderate heat storage density (200 kJ/kg) and a narrow range of melting temperatures from −10 to 67°C, a small degree of subcooling, chemically stable and non-toxic properties. Due to the purity and specific composition, the organic PCMs show up a remarkable latent heat capacity in narrow temperature ranges. In addition, they are chemically inert and have an unlimited lifetime. However, their low thermal conductivities (0.1–0.35 W/m·K) limit their practical applications.

Inorganic PCMs can be classified into two groups: salt/salt hydrates, and metals and their alloys. In general, inorganic PCMs not only have nearly doubled heat storage densities but also higher thermal conductivities, higher operating temperatures compared to the organic ones. However, inorganic PCMs are corrosive to metals leading to a short service life of the system and a higher maintenance cost. The inorganic PCMs (salt/salt hydrates) can also suffer from phase segregation and supercooling, which would reversibly affect the energy storage capacity. For high temperature applications, however, metal and metallic alloys are potential PCM candidates as they don't suffer from these disadvantages. The inorganic salt means salt or its hydrates, which can be expressed as AxB and AxBy·n(H2O) respectively, where AxB represents metal carbonate, sulfite, phosphate, nitrite, acetate or chloride and n represents number of water molecules. Although the inorganic PCMs show very promising and advantageous characteristics, these materials still face many problems to be commercial products for practical applications: (1) volume change at phase transition, (2) low thermal conductivity (nearly 1 W/m·K), (3) supercooling of salt hydrates, (4) corrosion with metal containers, (5) different melting temperatures of salt hydrates and (6) high cost of some specific salts.

Eutectic PCMs are composites of two or more components, which usually do not interact with each other to form a new chemical compound but at certain ratios, inhabit the crystallization process of one another resulting in a system having a lower melting point than either of the components. The eutectic mixtures can be further classified into organic-organic, organic-inorganic and inorganic-inorganic PCMs. Eutectic PCMs generally melt and freeze congruently and leave no chances of separation of components. Molten salt is one of the best candidates for middle to high temperature applications in the range of 120–1000°C. For solar energy utilization, normally middle-high temperature PCMs are applied and the "middle-high" temperature means the range of 100–300°C. The molten salts offer a favorable density around 1880 kg/m3, a high specific heat around 1.5 kJ/kg·K, a very low chemical reactivity, a low vapor pressure and a low cost about 0.4–0.9 USD/kg. A popular commercial molten salt used in the solar power generation as PCM is called "solar salt", which is a mixture of NaNO3 and KNO3 mixing at a weight ratio of 6:4 with a freezing point of 221°C. Despite its relatively high melting point, the low cost makes it widely utilized in CSP applications. Another similar molten salt product is named "HTEC", which is a ternary salt mixture system of NaNO3, KNO3 and NaNO2, and has a freezing point of 141°C. Different salt combination brings the melting point down but the lack of combination of optimum thermal properties limits its further applications.

Composite PCMs are the mixtures prepared by dispersing the high thermal conductive particles like carbon, graphite or metals into PCMs. One should note that the embedded thermal conductive materials should be compatible with the base PCMs. Although the nano-composite has less ability to store heat, it has higher ability to conduct heat. For example, the graphite based nano-composite has 12 times higher thermal conductivity than that of pure stearic acid [30]. Graphite can be applied as thermal promoters in various forms like graphite flakes (natural graphite), expanded natural graphite or the expanded graphite powder (50–500 nm). Expanded graphene is one of the most suitable PCM support materials due to its extraordinary thermal conductivity. The dispersion of expanded graphene to binary nitrate salts consisting of NaNO3 and KNO3 (6:4) by aqueous solution method adopting ultrasonic and the 2% integration enhanced the thermal conductivity to 4.9 W/m·K but reduced the latent heat by 11%. It is also reported that the use of expanded graphene in molten salts can prevent the liquid leakage after the melting. Different from expanded graphene, a highly conductive additive expanded natural graphite treated with sulfuric acid was introduced into the binary salt, KNO3/NaNO3 nitrate mixture and the additive establishes effective heat transfer matrix for more efficient heat transfer. The results showed that the thermal conductivity has been improved and the highest effective thermal conductivity is about 50.8 W/m·K, almost 110 times larger than the thermal conductivity of the salt powder. A slight decrease of latent heat was observed from the measurements with no obvious variation in the phase change temperature. Another way to enhance the thermal conductivity is to add chloride as addictive into the nitrate salt composite by statical mixing method. It was found that an addition of 5% chlorides into KNO3-NaNO3-NaNO2 composite increased the thermal conductivity, thermal stability with an higher operating temperature from 500 to 550°C. Lower freezing point was obtained and the loss of nitrite content was observed. Those enhanced composite PCMs with enhanced thermal performance and stability can be used to create compact thermal energy storage systems when the space is limited. Not only different nanostructures but also different types of nanoparticles can be applied as the thermal conductivity promoters, such as, the carbon-based nanostructures, metals, metal oxides and silver nanowires. A review of the current experimental studies on variations in thermo-physical properties of PCMs due to the dispersion of nanoparticles is performed in the reference.

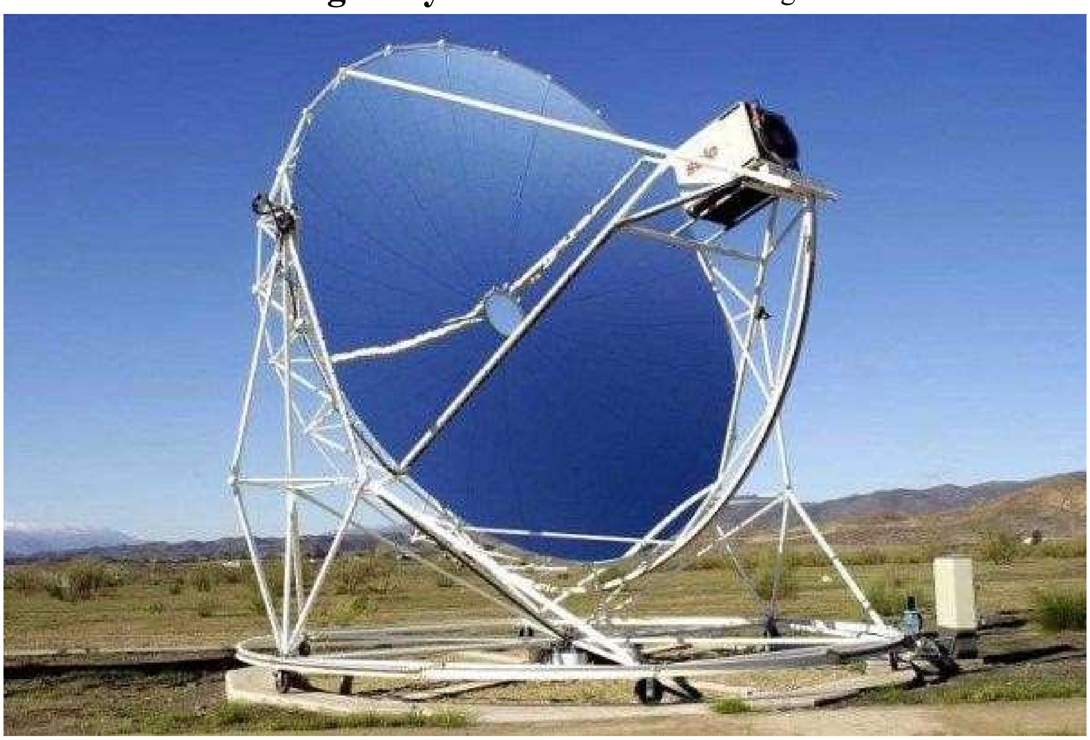
Microencapsulated PCMs (MEPCMs) can be described as particles that contain core PCMs surrounded by a coating or a shell and have diameters in the scale of micrometers. The microencapsulated PCMs usually have required morphologies, uniform diameters, shell mechanical strengths, penetration abilities and thermal stabilities. Pouches, tubes, spheres, panels or other receptacles containing MEPCM can directly act as heat exchangers. They can be incorporated into the building materials for thermal energy storage. The shell can hold the liquid PCM inside and prevent changes in its composition. The encapsulation not only increases the contact surface area for heat transfer but also adds the mechanical stability with the rigid shell. Common encapsulation shell materials include urea-formaldehyde (UF) resin, melamine-formaldehyde (MF) resin and polyurethanes (PU). Specialized techniques to prepare the encapsulation with a polymer cover and a PCM core include coacervation, suspension polymerization, emulsion polymerization, polycondensation and polyaddition. The MEPCMs are widely applied into the building materials and are able to retain or improve the building structural performance, as well as the energy performance (Figure 3).

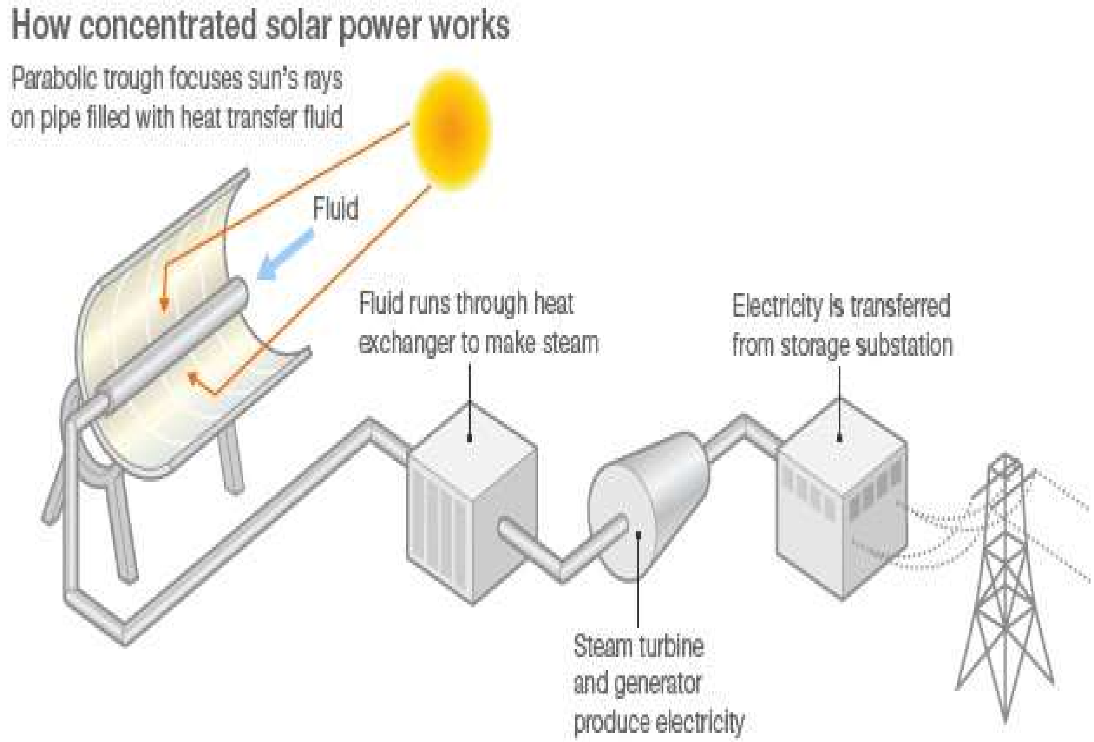
Table 3: Classification of latent heat materials with solid–liquid phase change behavior.

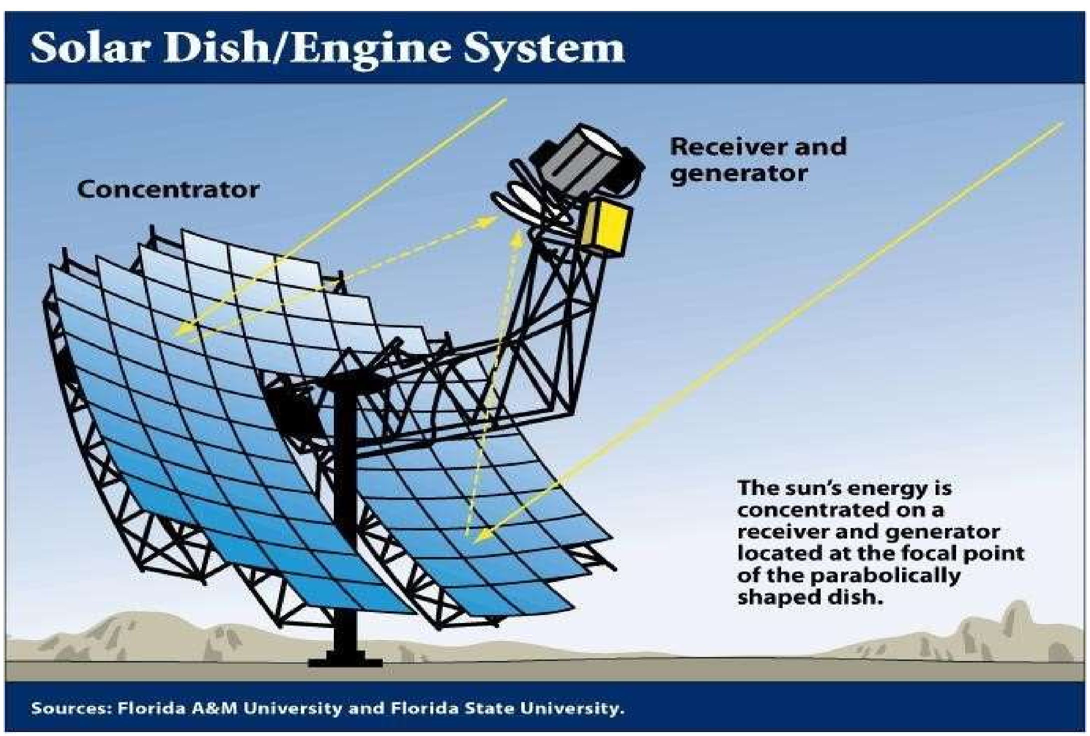
Name	Melting point (°C)	Latent heat (kJ/kg)	Density (kg/m3)	Thermal conductivity (W/m·K)	Heat capacity (kJ/kg·K)
(Organic)					
n-Octadecane	27.7	243.5	865/785	0.19/0.148	2.14/2.66
Paraffin wax	32	251	830	0.514/0.244	1.96/3.26
RT 55	55	172	880/770	0.2	2
RT 70 HC	69–71	260	880/770	0.2	2
(Inorganic)					
CaCl2·6H2O	29.6	190.8	1562	N/A	N/A
Ba(OH)2·8H2O	78	265–280	2070/1937	1.225/0.653	N/A
E117	117	169	1450	0.7	2.61
LiNO3-NaNO3	195	252	N/A	N/A	N/A
NaNO3	306	172	2261	388.9	N/A
KNO3	333	266	2110	N/A	0.5
KOH	380	150	2044	N/A	0.5

Parabolic trough collector

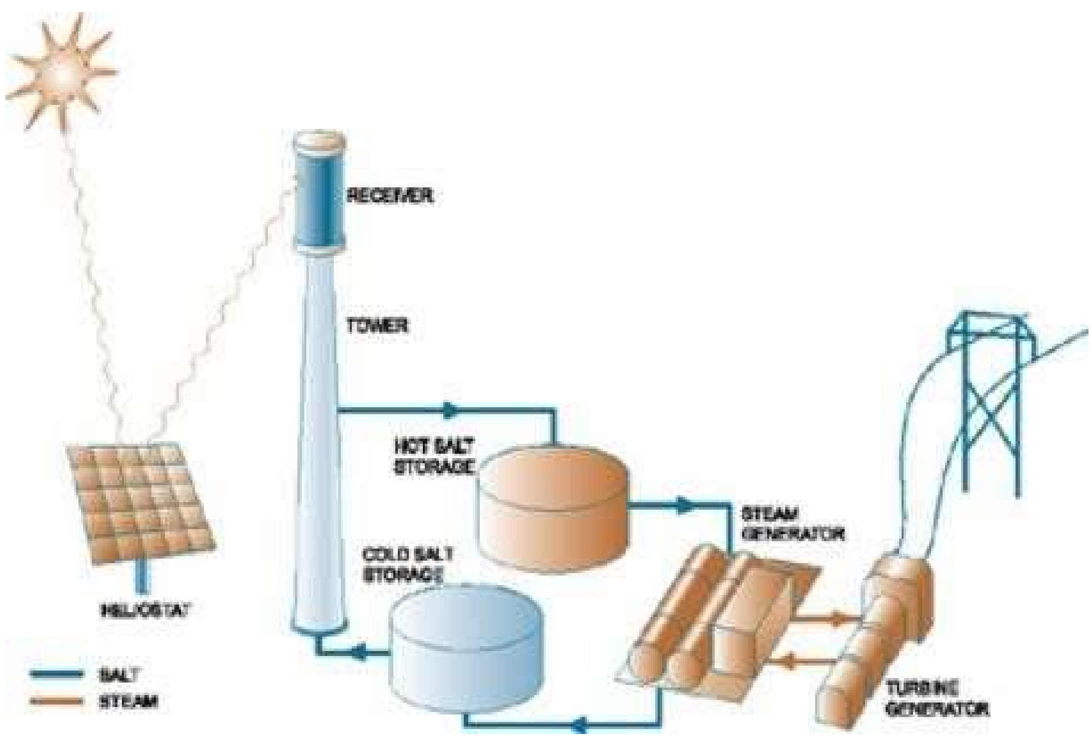
Dish-engine system source: Schlaich Bergermann Solar



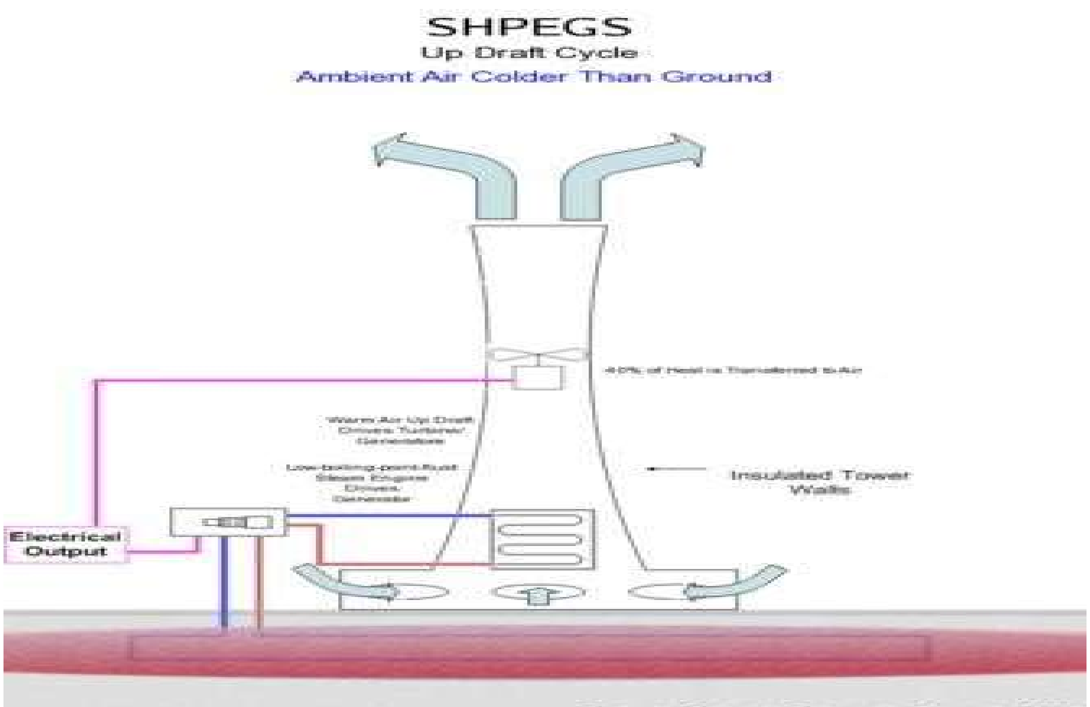

How concentrated solar power works
Parabolic trough focuses sun's rays on pipe filled with heat transfer fluid
Fluid
Fluid runs through heat exchanger to make steam
Electricity is transferred from storage substation
Steam turbine and generator produce electricity


Solar Dish/Engine System
Concentrator
Receiver and generator
The sun's energy is concentrated on a receiver and generator located at the focal point of the parabolically shaped dish.
Sources: Florida A&M University and Florida State University.

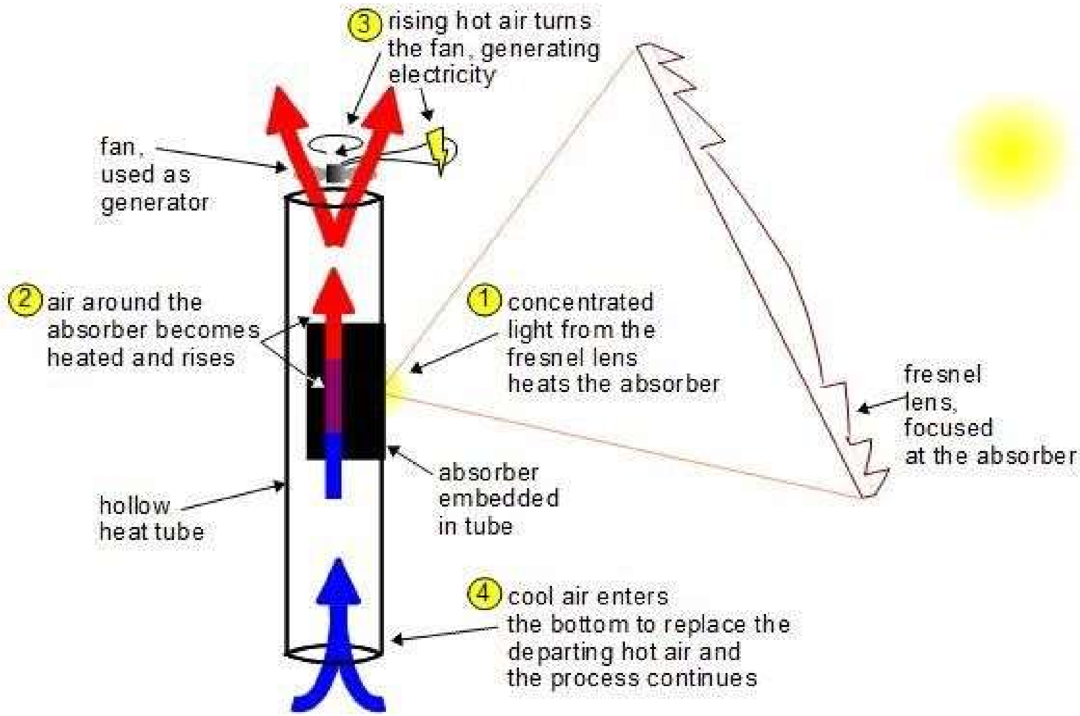
10 MW PS10 central receiver plant in Spain



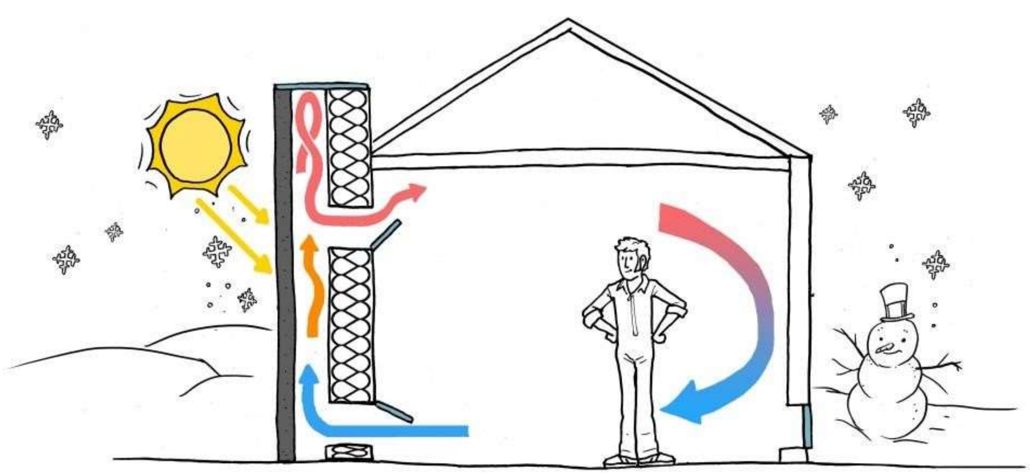
Solar updraft tower originally planned in Australia



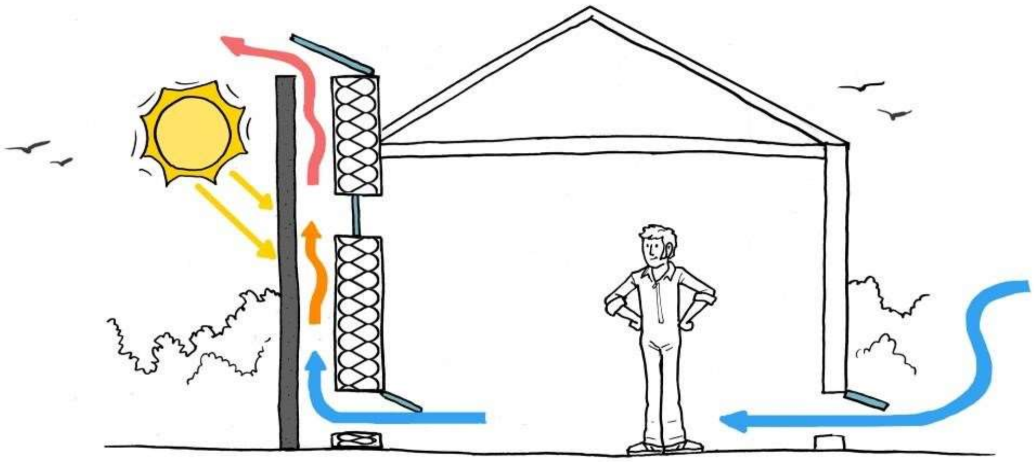
Mini solar tower powered by fresnel lens



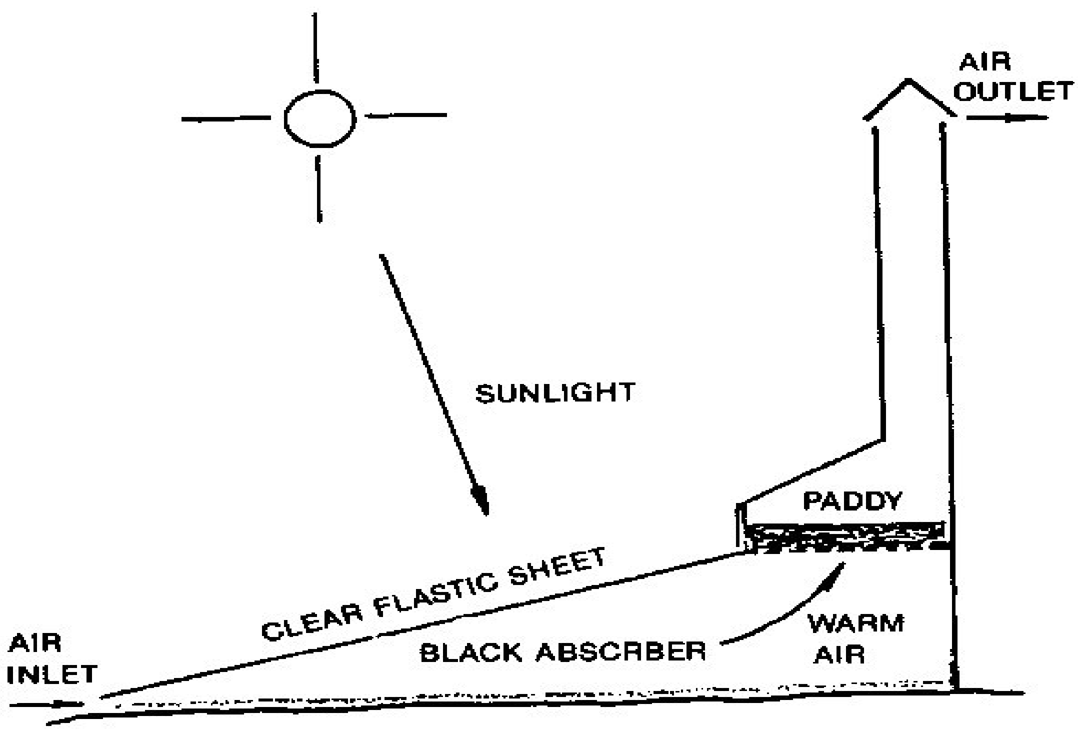
HEATING



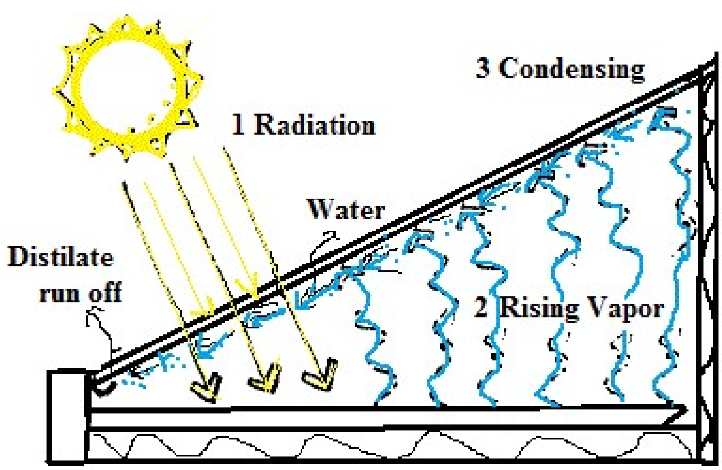
COOLING



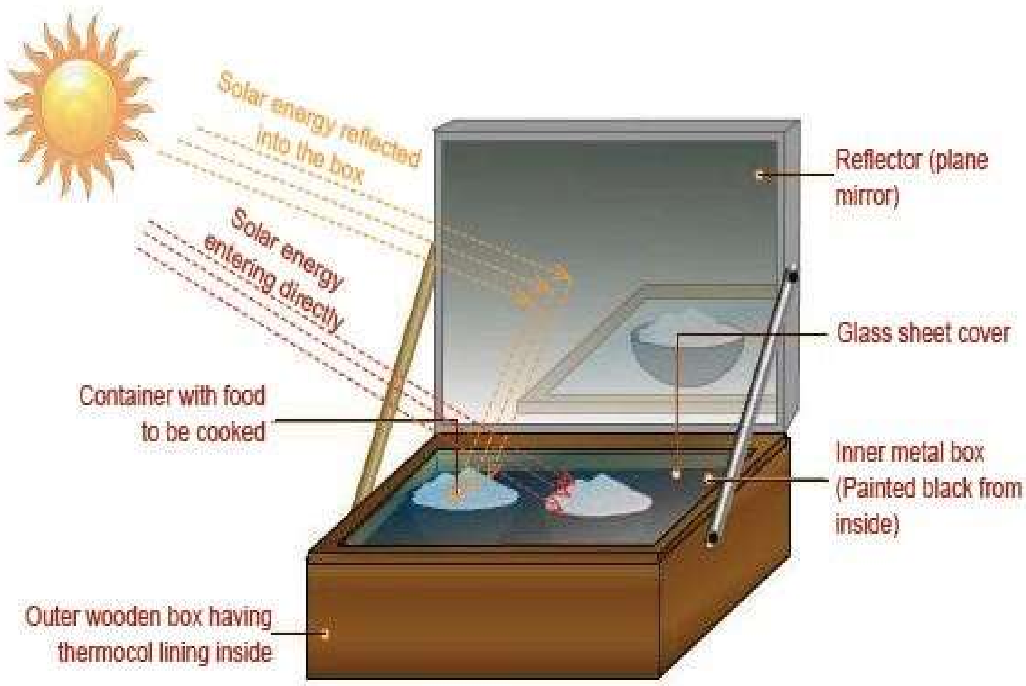
Solar Crop Dryer



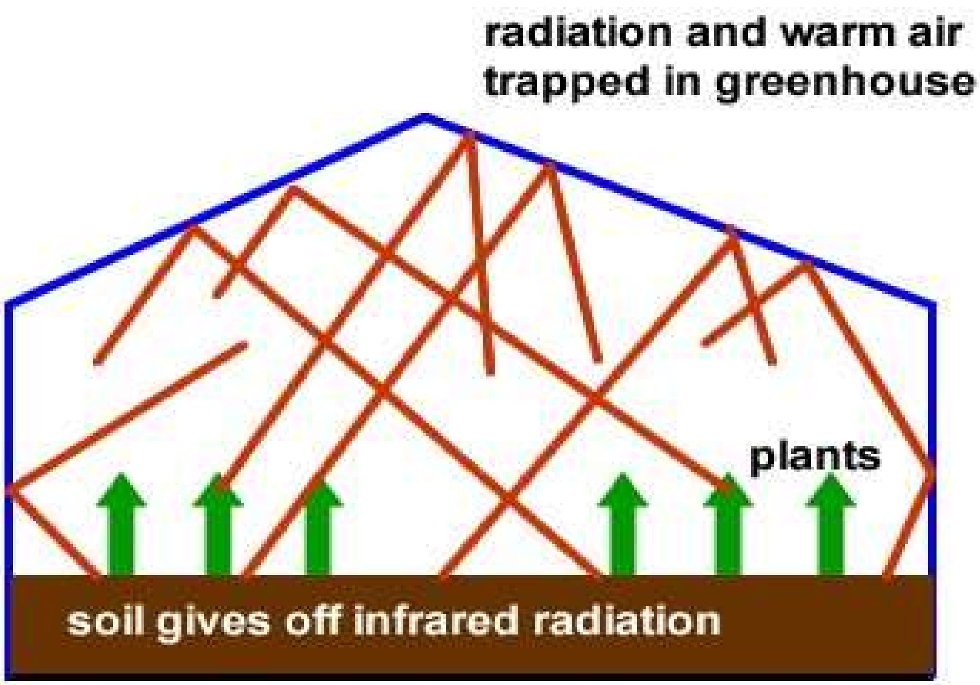
Solar Distillater



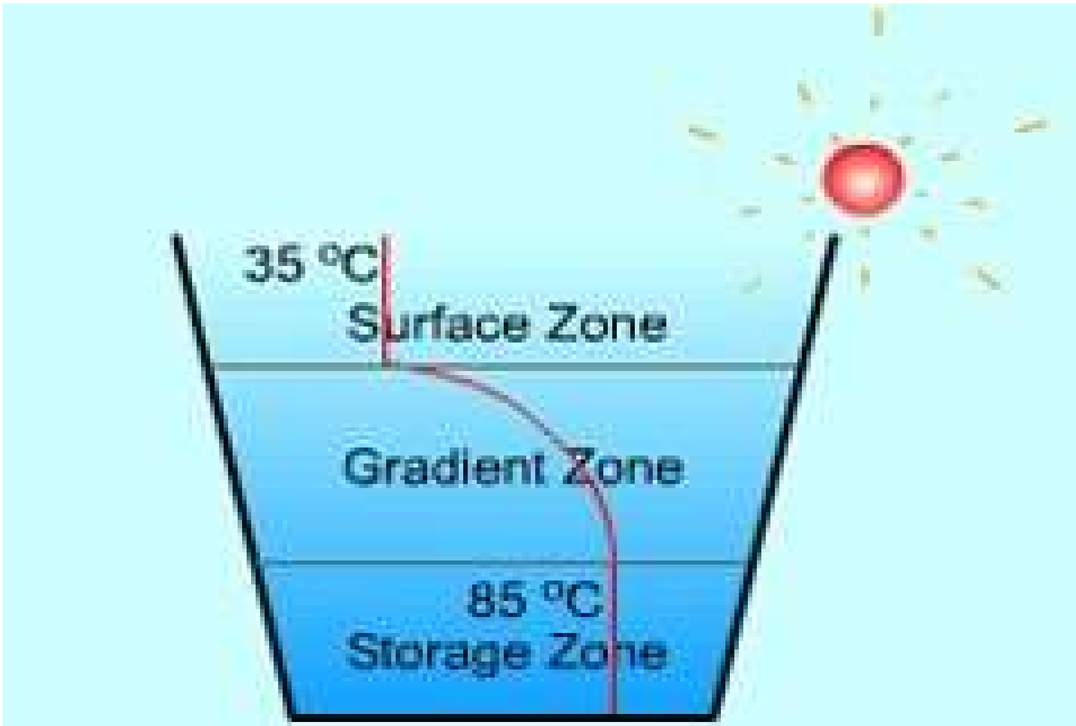
Solar Cooker

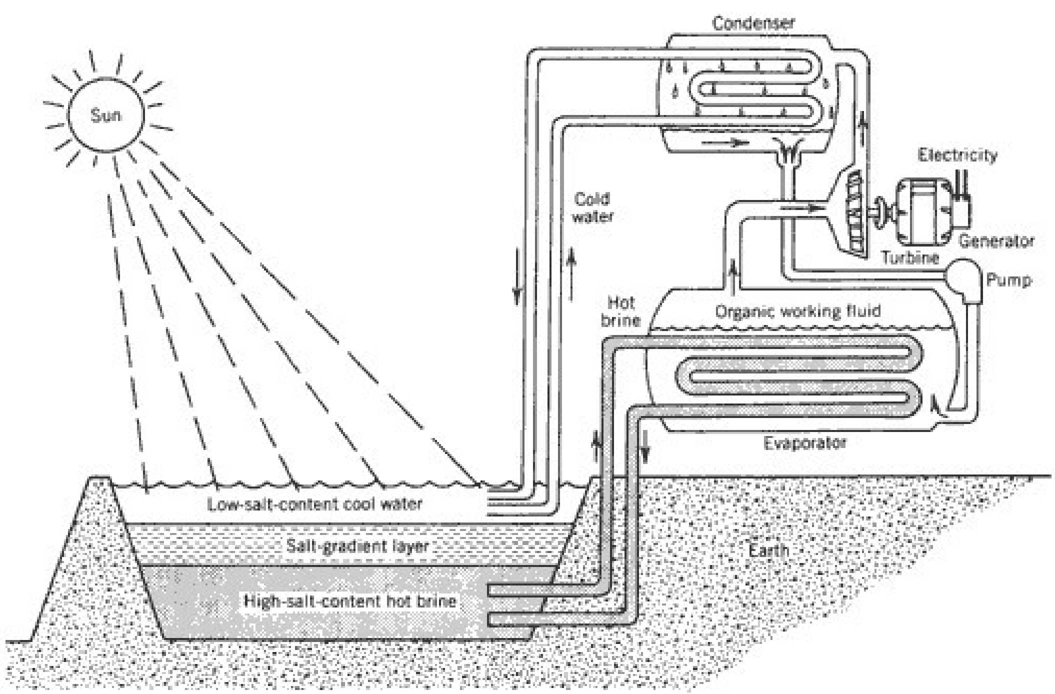


Solar Greenhouse

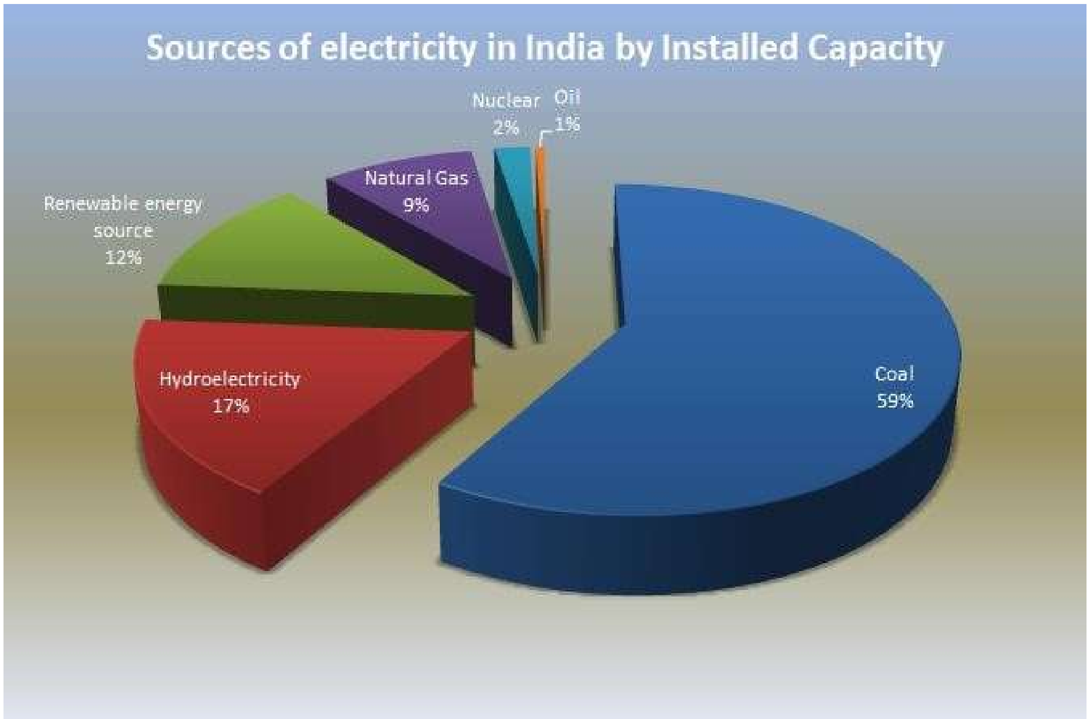


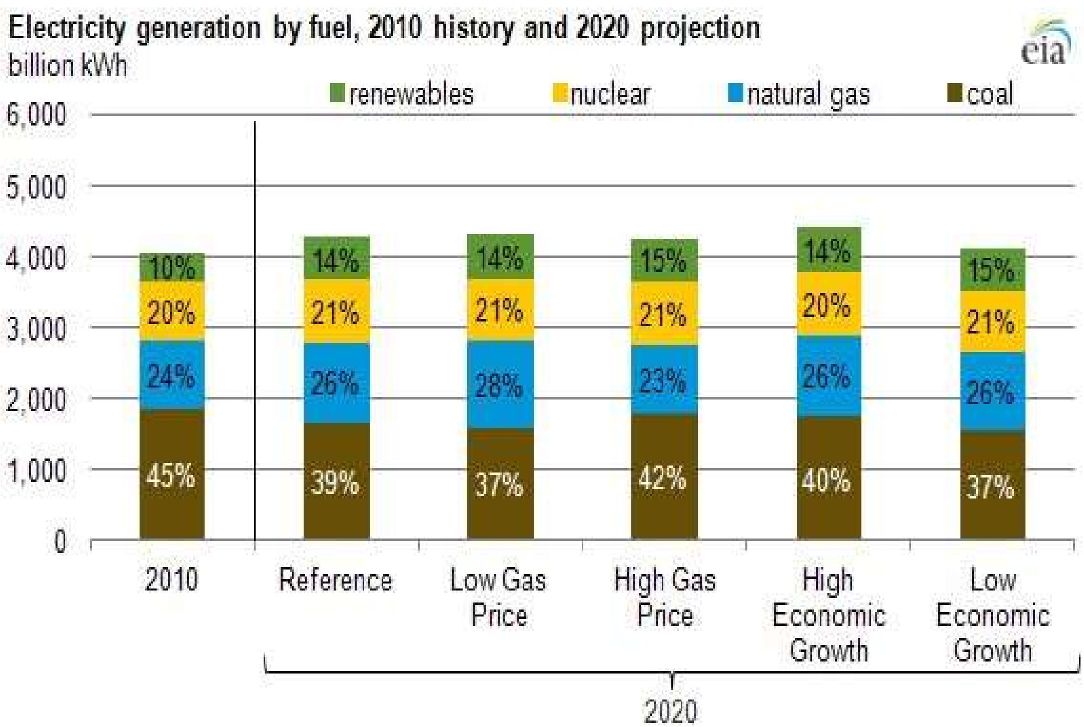
Solar Pond

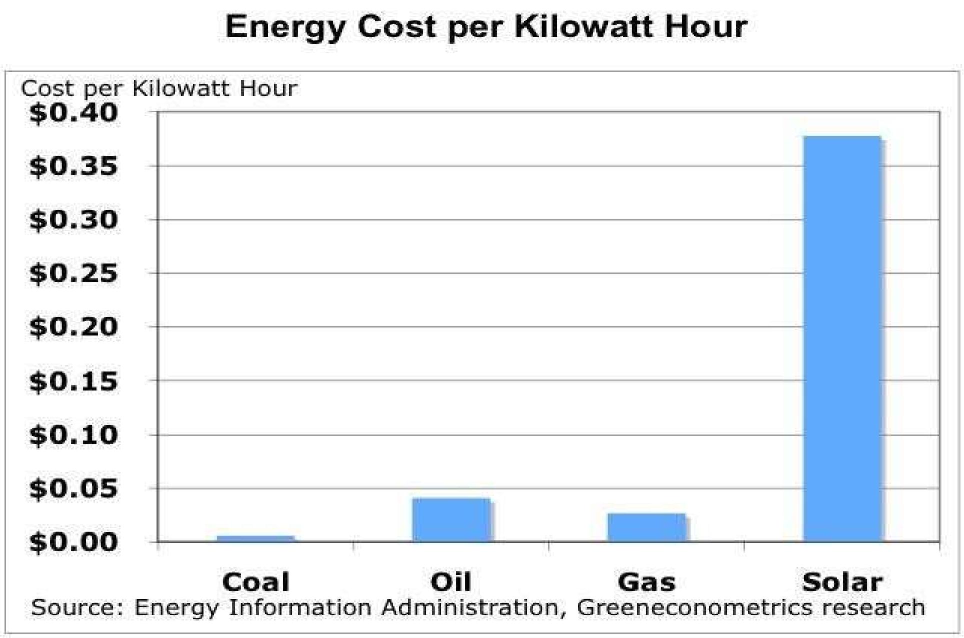

35 °C
Surface Zone
Gradient Zone
85 °C
Storage Zone

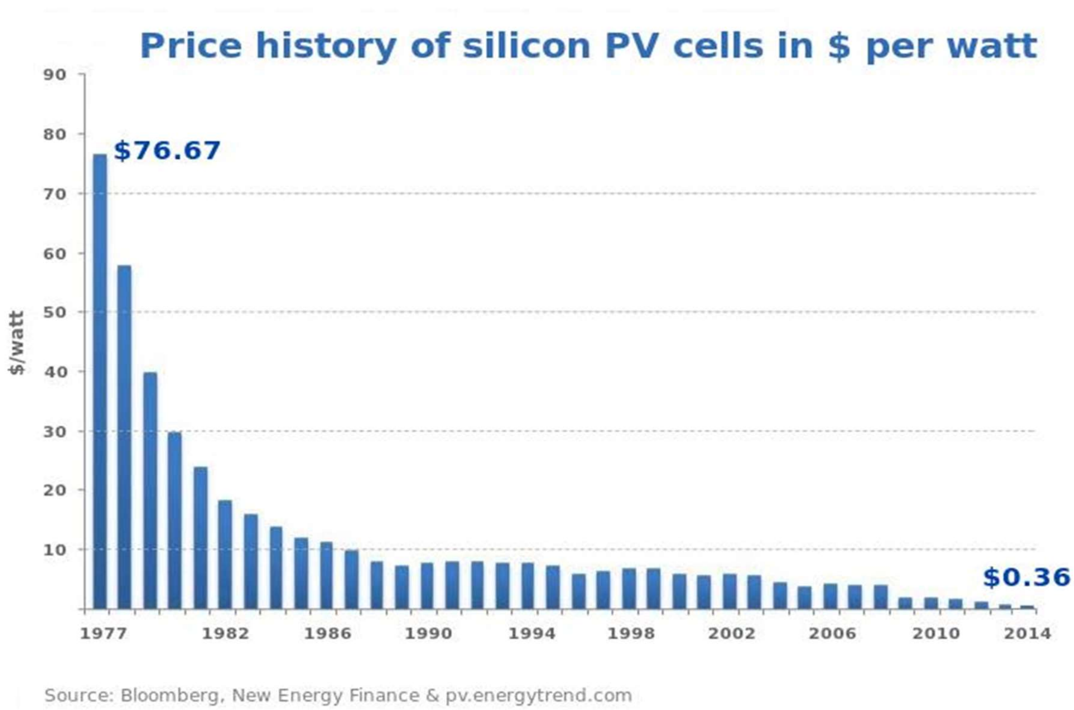

Condenser
Sun
Electricity
Cold water
Generator
Turbine
Pump
Hot brine
Organic working fluid
Evaporator
Low-salt-content cool water
Salt-gradient layer
Earth
High-salt-content hot brine

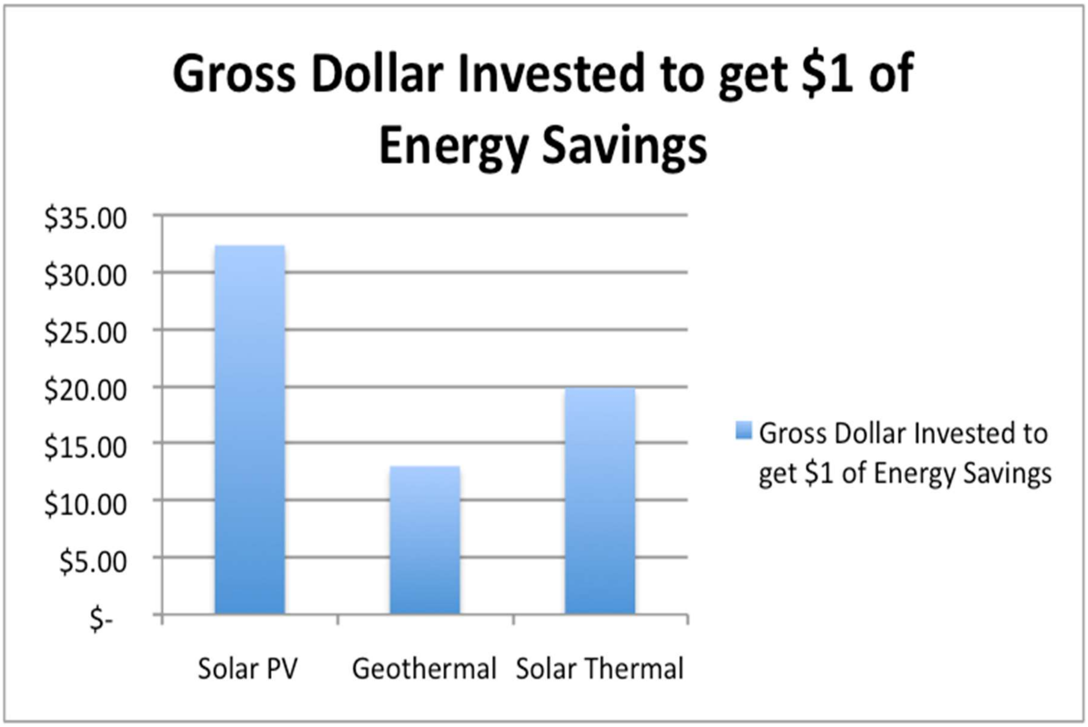
Comparation with other renewable energy






Energy Cost per Kilowatt Hour
Cost per Kilowatt Hour
$0.40
$0.35
$0.30
$0.25
$0.20
$0.15
$0.10
$0.05
$0.00
Coal
Oil
Gas
Solar
Source: Energy Information Administration, Greeneconometrics research


Price history of silicon PV cells in $ per watt
$/watt
90
80
70
60
50
40
30
20
10
$76.67
$0.36
1977
1982
1986
1990
1994
1998
2002
2006
2010
2014
Source: Bloomberg, New Energy Finance & pv.energytrend.com



Question Bank

Short

1. Write the advantages and limitations of wind energy system.
2. Give the disadvantage of wind energy conversion system.
3. Differentiate between sensible and latent heat.
4. List the factors which determine output from a wind energy convertor.
5. What are the main applications of a solar pond? Describe briefly.
6. Write notes on Solar distillation.
7. Write notes on Solar chimney.
8. Write notes on Solar cooking.
9. Discuss about solar drying.

Long

1. What is a solar pond? Explain how energy stored in a solar pond with a suitable diagram?
2. With the help of a schematic diagram, explain a solar passive-space cooling system.

3. What are the various characteristics of the wind? Discuss the advantages and disadvantages of horizontal and vertical axis windmills.
4. What are the different methods available for solar energy storage? Explain the working of any one method.
5. Explain the construction and working of a simple horizontal axis wind mill.
6. Explain the working of horizontal axis wind mill. Write its advantages and disadvantages.
7. Explain how stable density gradient is maintained in a solar pond?
8. Explain with a simple sketch, working of a solar pond with its limitations.
9. Discuss briefly the typical performance characteristics curves of wind machines.
10. What are the general aspects of solar active heating of buildings?
11. What are the design considerations of a horizontal axis wind machine?
12. What is passive heating of buildings?
13. Explain with a simple sketch, working of a typical solar drying bin.
14. Explain the functions of components in a wind electric system.
15. What are the forces on blades and thrust on turbines, explain them in detail?
16. Explain with a simple sketch, working of central power receiving system.
17. Describe the layout and working of a continuous solar cooling system.
18. Discuss the advantages and disadvantages of horizontal and vertical axis windmill.
19. With the help of a neat sketch, describe a solar heating system using water heating solar collectors. What are the advantages and disadvantages of this method?
20. Discuss the methods which are used to overcome the fluctuating power generation of windmill?
21. Describe in brief, the different energy storage methods used in the solar system.
22. What is the basic principle of wind energy conversion? Derive the expression for power developed due to wind.
23. What is the principle in the collection of solar energy used in a non-convective solar pond? Describe a non-convective solar pond for solar energy collection and storage.
24. Describe with a neat sketch the working of a wind energy system with main components.
25. Explain the working of central power tower and solar chimney.
26. Derive the expression to calculate the maximum power that can be generated by using horizontal wind machine (Betz criteria).