# EET435
# RENEWABLE ENERGY SYSTEMS

MODULE 1

# SYLLABUS

**Module 1**

Introduction, Classification of Energy Resources- Conventional Energy Resources - Availability and their limitations- Non-Conventional Energy Resources – Classification, Advantages, Limitations; Comparison.

SOLAR THERMAL SYSTEMS- Principle of Conversion of Solar Radiation into Heat – Solar thermal collectors. – Flat plate collectors. Solar concentrators (parabolic trough, parabolic dish, Central Tower Collector).

SOLAR ELECTRIC SYSTEMS- Solar Thermal Electric Power Generation – Solar Photovoltaic – Solar Cell fundamentals - characteristics, classification, .construction. Solar PV Systems – stand-alone and grid connected- Applications .

# INTRODUCTION

- Energy is defined as the capacity to do work by a body or a substance
- Energy transfer strictly follows the Law of conservation of energy
- Energy is a key input in the economic growth
- The invention of steam engine (1785, James Watt), internal combustion engine ($19^{th}$ Cent.) and later on electrical machines along with commercial availability of electrical power started the new electrical age

# Classification of Energy Sources

## 1. Based on Usability of Energy

### ❑ Primary resources

- Available in raw forms : raw energy resources
- Located, explored, extracted, processed and are converted to a form as required by the consumer
- Energy is spent during extraction process (E.Y.R should be high for utilisation)

$$\text{Energy Yield Ratio} = \frac{\text{Energy received from raw energy source}}{\text{Energy spent to obtain raw energy source}}$$

- Example: Fossil fuels (coal, crude oil, gas), sunlight, wind, running rivers, uranium

# Classification (Contd...)

## ❑ Secondary resources

- Resources in usable energy form
- Supplied directly to consumer for utilization after one or more steps of transformation
- Primary resources are often processed to get secondary resources
- Example : electrical energy, thermal energy, steam, hot water, petrol, diesel, LNG, CNG

# Classification (Contd…)

## 2. Based on Traditional Use

### ❑ Conventional

- Resources that are traditionally used for many years, widely used and likely to be depleted
- Examples: fossil fuels, nuclear fuels, hydro resources

### ❑ Non-Conventional

- Alternate energy sources to Conv. Resources (will be depleted in 50- 60 years)
- Examples: solar, wind, biomass etc..

# Classification (Contd…)

| *Conventional resources* | *Non-conventional resources* |
|---|---|
| Traditional | Non-traditional |
| These have been in use for many years | These are not in routine use at present |
| These resources can be easily converted into mechanical energy | These resources require some costly method to be converted into mechanical energy |
| These are likely to be depleted, that is, these have limited availability | These are non-depletable or may be available in vast quantities |
| Coal, petrol, diesel, nuclear fuels CNG and LPG are conventional energy resources | Solar, wind, tidal geothermal and biogas are non-conventional energy resources |

# Classification (Contd...)

## 3. Based on Long-Term Availability

### ❑ Non-renewable

- Finite and do not get replenished after their consumption
- Likely to deplete with time
- Examples: fossil fuels, uranium, etc.

### ❑ Renewable

- Infinite or renewed by nature again and again
- can be harnessed without the release of harmful pollutants
- Examples: wind power, solar, geothermal, tidal and hydroelectric power

# Classification (Contd…)

| *Renewable resources* | *Non-renewable resources* |
|---|---|
| These are inexhaustable resources | These are exhaustable resources |
| These are non-traditional in use | These are traditional in use |
| New methods are being developed to use these resources | Widely used used as energy resources |
| Efforts are taken to make vast use of these resources | Efforts are taken to conserve these resources |
| Hydel, solar, wind, tidal and geothermal resources are renewable energy resources | Fossil fuels, nuclear fuels and natural gases are non-renewable resources |

# Classification (Contd…)

## 4. Based on Commercial Application

### ❑ Commercial Energy Resources

- available in the market for a definite price
- forms the basis of industrial, agricultural, transport and commercial development
- commercialized fuels are used for economic production
- for many household tasks of general population
- Examples: electricity, coal and refined petroleum products etc.

# Classification (Contd...)

## ❑ Non-commercial Energy

- Energy that are derived directly from nature
- Can be used directly without passing through any commercial outlet
- Not available in the commercial market for a definite price
- Examples: fuels such as firewood, cattle dung and agricultural wastes etc.

## 5. Based on origin

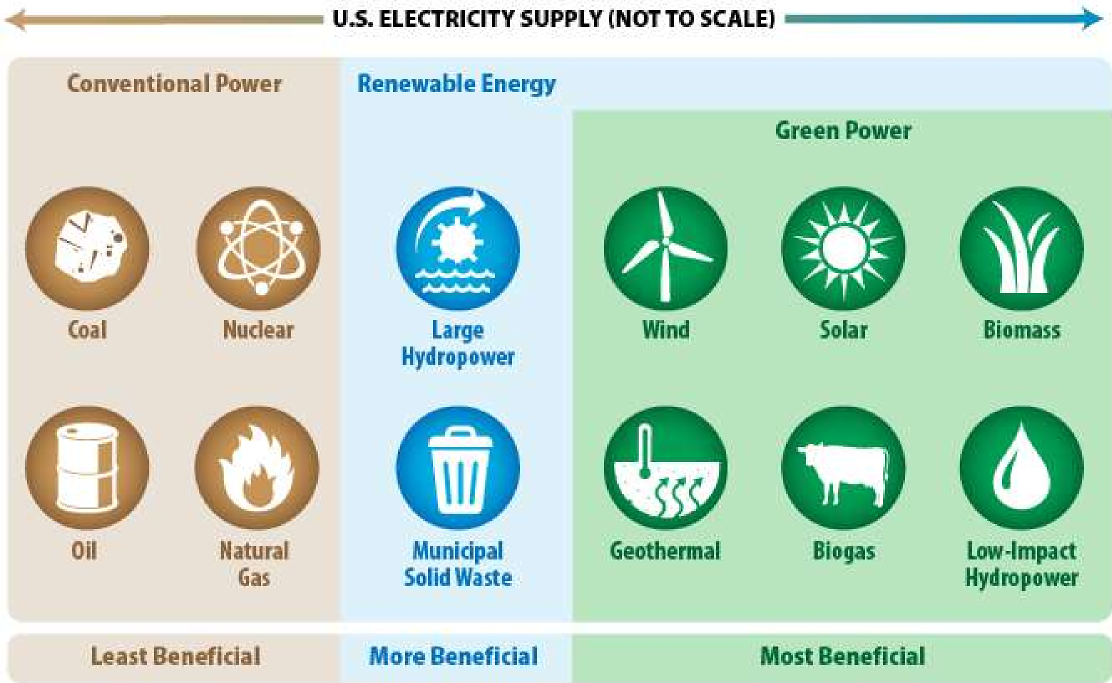
- (a) Fossil fuel energy, (b) Nuclear energy, (c) Hydro energy, (d) Solar energy, (e) Wind energy, (f) Biomass energy, (g) Geothermal energy, (h) Tidal energy (i) Ocean thermal energy, (j) Ocean wave energy

# Green Power

Subset of renewable energy.

Represents those renewable energy resources & technologies that provide the greatest environmental benefit.

Electricity produced from solar, wind, geothermal, biogas, eligible biomass, and low-impact small hydroelectric sources.




- Zero-emissions profile and carbon footprint reduction.

US Environmental Protection Agency

# Power Sector in Kerala

Installed Capacity as of 27-04-2022 (in MW)

| KSEB | |
|---|---|
| Hydro | 2058.761 |
| Diesel | 159.96 |
| Wind | 2.025 |
| Solar | 17.521 |
| Total | 2238.267 |

| IPP | |
|---|---|
| Thermal | 359.58 |
| Hydro | 33 |
| Wind | 58.25 |
| Solar | 185.065 |

| Captive Power | |
|---|---|
| Hydro | 33 |
| Solar | 32.70 |
| Thermal | 10 |
| Wind | 10 |

| Cogeneration | |
|---|---|
| Thermal | 10 |
| **Total** | **2969.862** |

Source: kseb.in

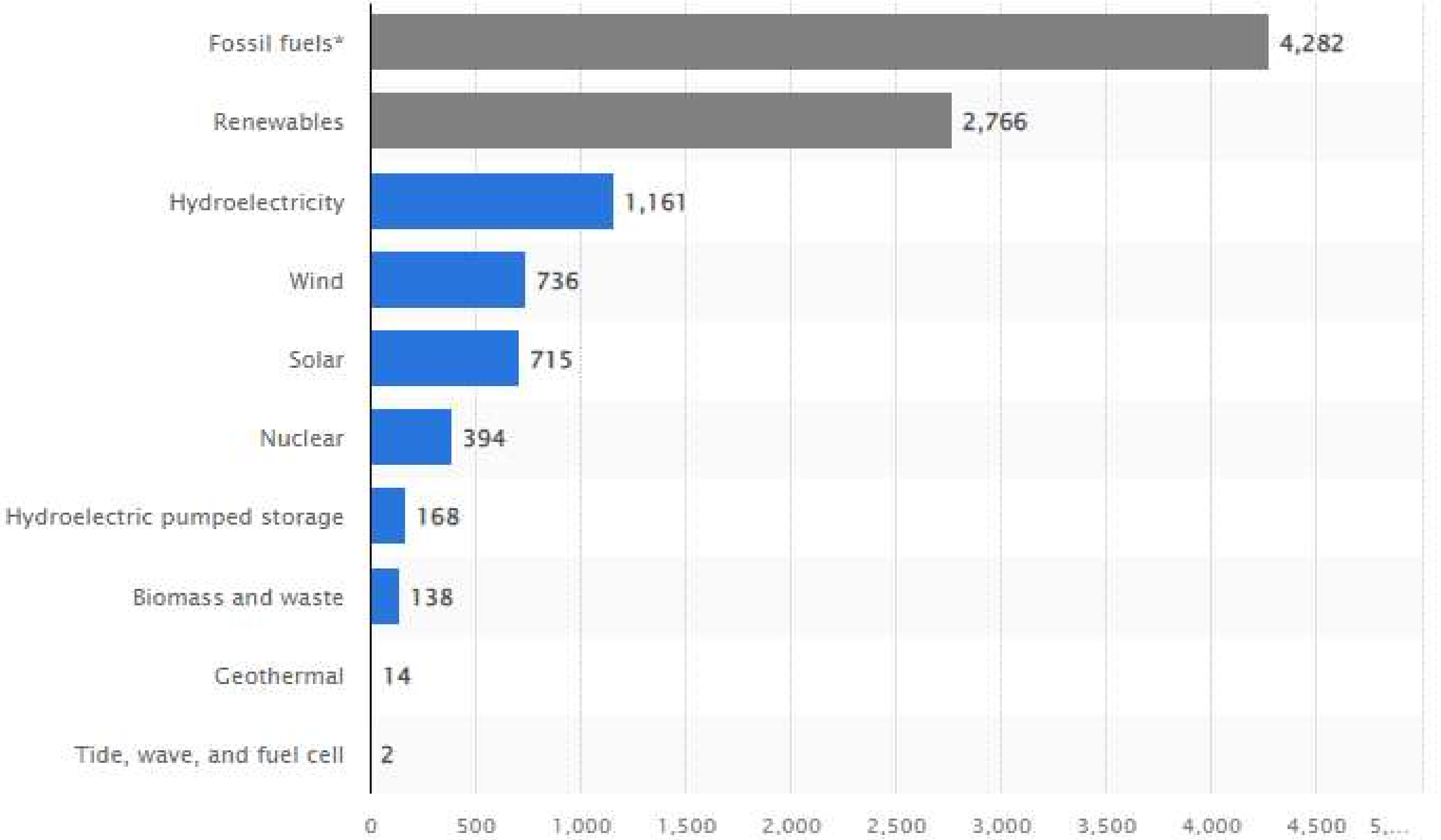
# Power Sector in India

Installed Capacity (fuel wise) as of 31-03-2022  (in MW)

| CATAGORY | INSTALLED GENERATION CAPACITY(MW) | % of SHARE IN Total |
|---|---|---|
| **Fossil Fuel** | | |
| Coal | 2,04,080 | 51.1% |
| Lignite | 6,620 | 1.7% |
| Gas | 24,900 | 6.3% |
| Diesel | 510 | 0.1% |
| **Total Fossil Fuel** | **2,36,109** | **59.1%** |
| **Non-Fossil Fuel** | | |
| **RES (Incl. Hydro)** | **1,56,608** | 39.2% |
| Hydro | **46,723** | **11.7 %** |
| Wind, Solar & Other RE | 1,09,885 | 27.5 % |
| Wind | 40,358 | 10.1 % |
| Solar | 53,997 | 13.5 % |
| BM Power/Cogen | 10,206 | 2.6 % |
| Waste to Energy | 477 | 0.1 % |
| Small Hydro Power | 4,849 | 1.2 % |
| **Nuclear** | 6,780 | 1.7% |
| **Total Non-Fossil Fuel** | **1,63,388** | 40.9% |
| **Total Installed Capacity** | **3,99,497** | **100%** |

# Power Sector in World

Installed Capacity as 2020



# Drawbacks of Conventional Energy Sources

Non-Renewable

Pollution

Global Warming

Safety Issues

Increasing fossil fuel cost

# Non-Conventional Energy Resources

**Classification:**

1. Solar Energy
2. Wind Energy
3. Biomass Energy
4. Geothermal Energy
5. Ocean Tidal Energy
6. Ocean Wave Energy
7. Ocean Thermal Energy Conversion

# Solar Energy

Advantages of solar energy are as follows:

(i) Solar energy is available freely in nature.
(ii) It is a renewable energy resource.
(iii) It does not pollute the environment.
(iv) It can be directly converted into electricity by employing photovoltaic cells.

Disadvantages of solar energy are as follows:

(i) It is available only during daytimes and clear days.
(ii) Solar energy obtainable also depends on seasonal variations.
(iii) It requires a large area to entrap appreciable solar energy for the generation of an economical amount of electricity.

# Wind Energy

Advantages of wind energy are as follows:

(i) It is freely and abundantly available in nature.
(ii) It is a renewable energy source.
(iii) It does not cause pollution to environment.
(iv) Windmills require minimal maintenance and operating cost.

Disadvantages of wind energy are as follows:

(i) It cannot produce steady and consistent power.
(ii) It can generate only low power.

# Ocean Tidal Energy

Advantages of tidal energy are as follows:

(i) It is free from pollution.
(ii) It is superior to hydel energy as it does not depend on rains.
(iii) The tidal basin can also be used for fish farming.
(iv) It is best suited to meet peak power demands.

Disadvantages of tidal energy are as follows:

(i) Tidal power plant is costly compared to thermal and hydel power plants.
(ii) Limited locations are available for the construction of tidal power stations.
(iii) Power generation is not continuous and depends on the capacity of tidal basin.

# Geothermal Energy

Advantages of geothermal energy as follows:

(i) Energy is continuously available. It is more reliable.
(ii) It has a good potential to meet the power requirement.
(iii) Capital cost is low in comparison to nuclear and thermal power plants.

Disadvantages of geothermal energy are as follows:

(i) Components of the plants are liable to be corroded.
(ii) Gaseous effluent creates nuisance at the site for the workers.
(iii) Gaseous effluent also creates thermal pollution to the environment.
(iv) Groundwater is likely to be polluted from gaseous effluents.

# Ocean Thermal Energy Conversion

Advantages of OTEC are as follows:

(i) Power generation is continuous throughout the year.
(ii) Energy is available from nature at no cost.

Disadvantages of OTEC are as follows:

(i) It has a small temperature gradient which gives a small thermodynamic efficiency.
(ii) Capital cost is high due to necessity of heat exchanger, boiler and condenser.

# Features of Renewable Energy

- ✓ Environmental Friendly
- ✓ Low Running Cost
- ✓ Less Maintenance
- ✓ Energy for Future Needs
- ✓ Energy Security
- x Abundant but Diluted
- x Intermittent in Nature
- x Affected by Climate
- x High Capital Cost
- x Low Rated Generators

# Renewable Energy Potential in India

| Source | Installed Capacity (MW) | Estimated Potential (MW) |
|---|---|---|
| Wind | 40358 | 102772 |
| Small Hydro | 4849 | 19749 |
| Biomass/Cogen | 10206 | 17538 |
| Waste to Energy | 477 | 2556 |
| Solar | 53997 | 748000 |

https://cea.nic.in/wp-content/uploads/installed/2022/03/installed_capacity.pdf

As of 31 March 2022
Source: powermin.nic.in, www.mospi.gov.in

# Solar Energy

The Sun, having a diameter of $1.39 \times 10^9$ m, is at an average distance of $1.495 \times 10^{11}$ m from the Earth.

It is a sphere of intensely hot gaseous matter.

90 % of the Sun's energy is generated in a innermost spherical region (core) having a radius 0.23 times the Sun's radius.

The average density (ρ) and the temperature (T) in this region are $10^5$ kg/m$^3$ and approximately $(8 - 40) \times 10^6$ K, respectively.

The Sun has an effective black-body temperature of 5777K (~6000) K.

Energy generated in this region is due to continuous fusion reactions.

$$H_2 + H_2 = He + 25 \text{ MeV}$$

# Solar Energy

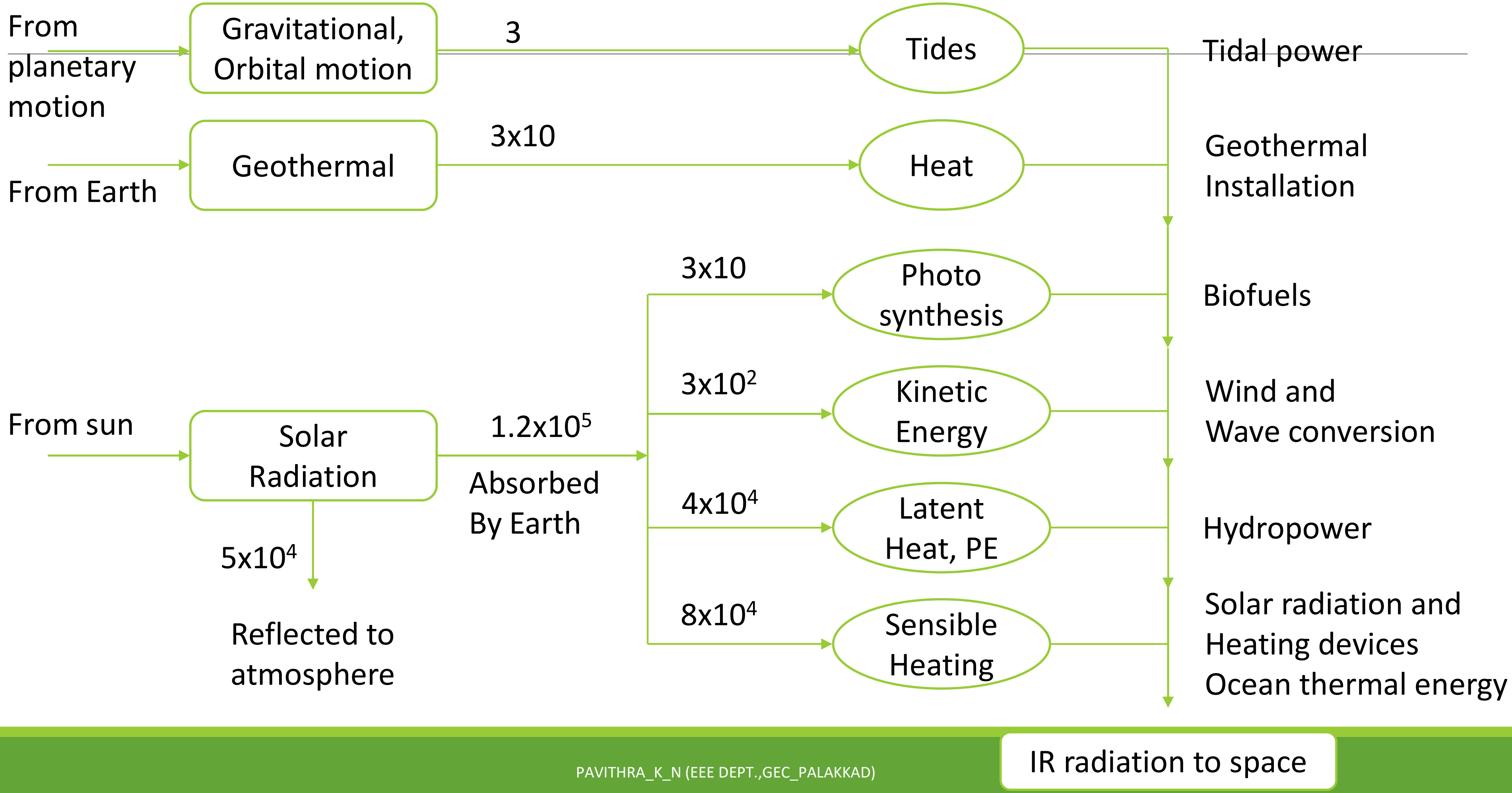
Solar energy from the Sun can be classified as a heat (electromagnetic waves) and light (photons), respectively.

Basically, the Sun is responsible to produce directly most of the renewable energy sources.

It is also responsible for providing indirect sustenance for nonrenewable sources such as fossil fuels.

- Fossil fuels are actually solar energy stored millions and millions of years ago.

# Source of Energy



# Depletion of Solar Radiation

A part of scattered radiation is lost (reflected back) to space while remaining is directed downwards to the earth's surface from different directions as diffused radiation.

Scattered sunlight makes the sky blue.

In cloudy atmosphere,

i. a major part of the incoming solar radiation is reflected back into the atmosphere by the clouds.

ii. another part is absorbed by the clouds and

iii. the rest is transmitted downwards to the earth surface as diffused radiation.

# Depletion of Solar Radiation

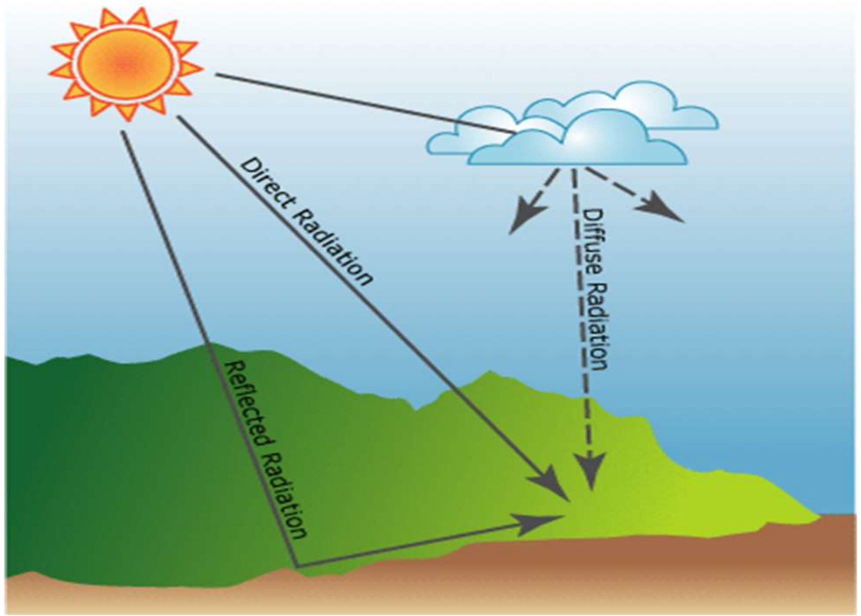
The portion of solar energy is reflected back to the space by

i. Reflection from clouds
ii. Scattering by the atmospheric gases and dust particles
iii. Reflection from the earth’s surface

Has a value of about 30 percent of the incoming solar radiation for the earth as a whole.

# Solar Radiation

1. **Direct Radiation/Beam Radiation/ Direct Beam Radiation:** Passes directly through the atmosphere to the earth surface.
2. **Diffused Radiation:** Scattered by cloud, aerosols, dust particles and molecules in the atmosphere, but finally reaches the earth surface.




3. **Global Radiation:** Total amount of solar radiation falling on specific horizontal surface.

Global Radiation = Direct radiation + Diffused radiation

# Solar Radiation

Solar Irradiation (Solar irradiance): The terrestrial radiation expressed as energy per unit time per unit area (i.e. $W/m^2$).

Irradiance is an instantaneous measurement of solar power over some area.

Solar Insolation: Solar radiation energy received on a given surface area in a given time (in $J/m^2$ or $kWh/m^2$).

Insolation is a measurement of the cumulative energy measured over some area for a defined period of time.

Irradiance is a measure of solar power whereas insolation is a measure of solar energy.

Solar radiation data are measured mainly by following instruments: pyranometer, Pyrheliometer and Sunshine Recorder

# Factors Affecting Solar Radiation

Latitude and longitude of geographical location

Climatic conditions- presence of cloud, water vapour etc.

Time of the day

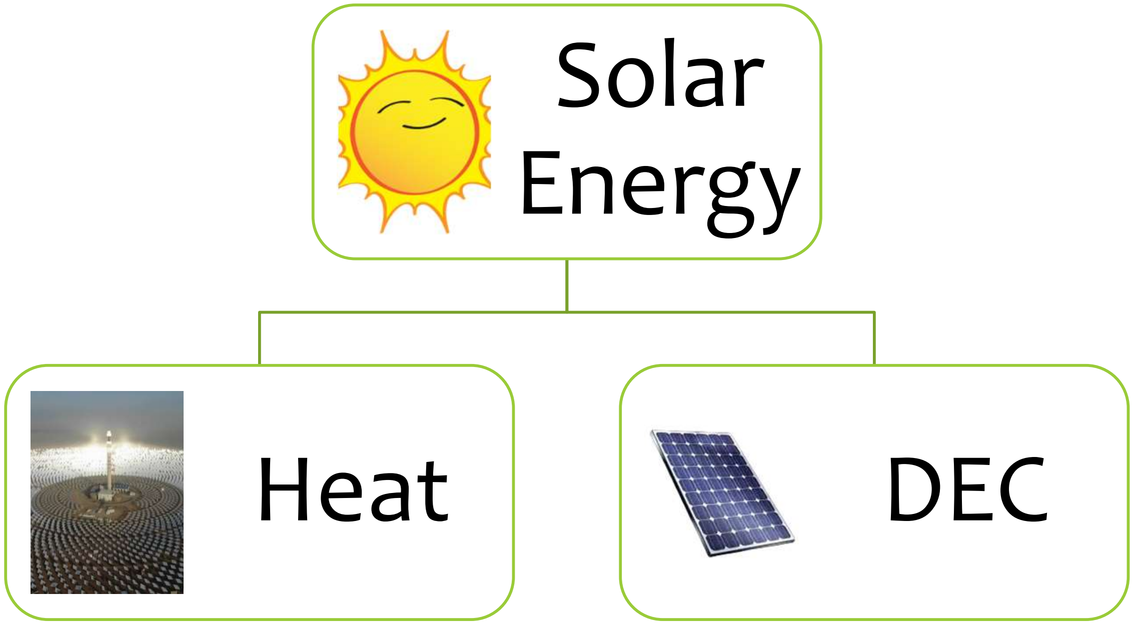
Time of the year

Angle of tilt

Note:

- Even on clear days, there will be some diffused radiation depending upon the amount of dust particles, ozone and water vapour present in the atmosphere.
- On overcast days when the sun is not visible, all the radiation reaching the ground will be diffused radiation.

# Extraction of Solar Energy




Solar Thermal

Solar Photovoltaic

# Solar Thermal Energy

Solar energy can be utilized directly by two technologies: namely (i) Solar Thermal and (ii) Solar Photovoltaic

Uses:

- low-grade thermal applications, Drying and process industries
- In cold climate regions this low-grade thermal energy is required
  - Room heating, hot water for washing, cleaning and other domestic and industrial needs
- Solar distillation, desalination, Solar food dryers and Solar water heating
- In high temperature heating applications, fuel can be saved by using solar energy for preheating (up to about 180 °C)

# Solar Thermal Systems

Rooftop solar water heater

Domestic space heating

Solar thermal engines and electricity generation

Solar concentrators

Solar ponds

OTEC

Solar chimneys

Solar cooker

# Thermal Energy Storage

- Thermal energy is stored by virtue of heat capacity and the change in temperature of the material during the process of charging and discharging.
- The temperature of storage material rises when energy is absorbed and drops when energy is withdrawn.
- The charging and discharging operations, in a sensible heat storage system, can be expected to be completely reversible for an unlimited number of cycles, over the life span.
- On the basis of heat storage media, it can be classified as: (a) liquid media storage, (b) solid media storage and (c) dual media storage

# Thermal Energy Storage

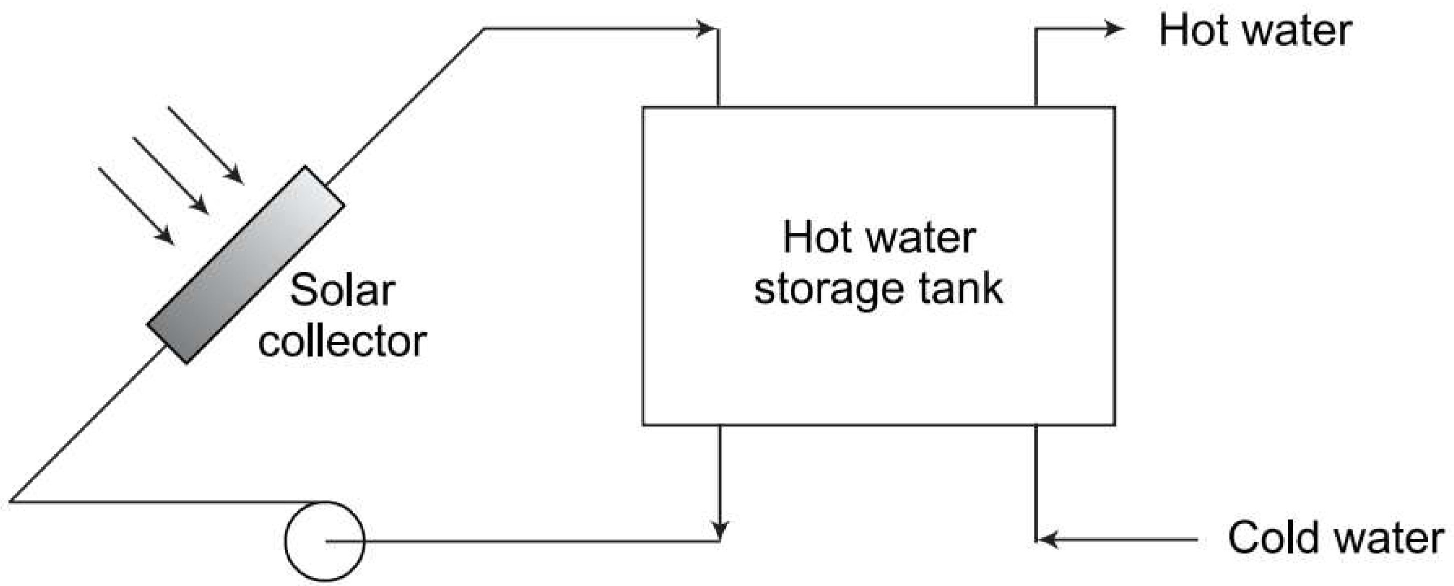



**Figure 3.9** Short term thermal energy storage in water

# Heat Transfer Principles

There are three basic physical ways that heat moves...

1. Conduction 2. Convection

3. **Radiation:**

- Radiation is a process by which heat flows from a body at a higher temperature to a body at a lower temperature when the bodies are separated in space or even a vacuum exists between them.
- The heat energy transmitted by radiation is called radiant heat.
- Radiation is the mode of heat transfer by which the Sun transfer energy to the Earth.
- The quantity of energy leaving a surface as radiant heat depends on the absolute temperature and the nature of the surface.

# Solar thermal heat systems

- Solar thermal heat systems are installations converting solar radiation into heat in order to heat swimming pools, produce domestic hot water, cover the demand for space heating or supply other heat consumers.
- Physical principles of energy conversion: Absorption, emission, reflection and transmission
- The basic principle of solar thermal utilization is the conversion of short-wave solar radiation into heat (photo thermal conversion process).
- If radiation incidences on material a certain part of the radiation is absorbed.
- A body's capacity to absorb radiation is called absorbing capacity or absorption α
- An ideal black body absorbs radiation at every wavelength and therefore has an absorption coefficient equal to one.

# Solar thermal heat systems

•**Emission ε** represents the power radiated by a body.
•The relationship between **absorption α and emission ε** is defined by Kirchhoff's law . For all bodies the ratio of specific radiation and the absorption coefficient is constant at a given temperature, and in terms of its amount, equal to the specific radiation of the black body at this temperature.
•This ratio is exclusively a functionality of *temperature and wavelength*.
•Matter with **a high absorption capacity** within a defined wave range also has a high emission capacity within that same wave range.

**Reflection and transmission:**
•The reflection coefficient *ρ describes the ratio of the reflected to the incident* radiation.
•The transmission coefficient *τ defines the ratio of the radiation transmitted* through a given material to the entire radiation incident

# Solar thermal heat systems

There are two main types of solar thermal systems for energy production: active and passive.

- Active systems require moving parts like fans or pumps to circulate heat-carrying fluids.
- Passive systems have no mechanical components and rely on design features only to capture heat .
- The technologies are also grouped by temperature – low, medium and high
- **Low-temperature (<100°C)** app. : use solar thermal energy for hot water or space heating: Active systems often consist of a roof-mounted flat plate collector through which liquid circulates.

# Solar thermal heat systems

- The collector absorbs heat from the sun and the liquid carries it to the desired destination, for example a swimming pool or home heating system.
- Passive heating systems involve intelligent building design practices, which cut back on the need for heating or cooling systems by better capturing or reflecting solar energy.
- **Medium-temperature (100-250°C) systems:** Solar oven, which uses a specially-shaped reflector to focus the sun's rays on a central cooking pot.
- **High-temperature (250°C >) Systems:** Solar thermal systems that use groups of mirrors to concentrate solar energy onto a central collector. These concentrated solar power (CSP) systems can reach temperatures high enough to produce steam, which then turns a turbine, driving a generator to produce electricity.

# Solar Collectors

Solar power has low density per unit area – Need to be collected by covering large ground area by solar thermal collectors.

**Solar Collectors:** Device for collecting solar radiation and transfer the energy to a fluid.

- Essentially forms the first unit in a solar thermal system.
- Absorbs solar energy as heat and then transfers it to heat transport fluid efficiently.
- The heat transport fluid delivers this heat to thermal storage tank / boiler / heat exchanger, etc., to be utilized in the subsequent stages of the system.

# Classification of Solar Collectors

- Solar Collectors
  - Non – concentrating type
    - a. Liquid flat-plate collector
    - b. Flat-plate air-heating collector
  - Concentrating type
    - a. Line Focus Type
    - b. Point Focus type
    - c. Non-Focus Type

# Classification of Solar Collectors

## Concentrating Type

### Line Focus Type

a. Cylindrical parabolic trough concentrator
b. Fixed mirror solar concentrator
c. Linear Fresnel lens collector

### Point Focus Type

a. Parabolic dish collector
b. Hemispherical bowl mirror concentrator
c. Circular Fresnel lens collector
d. Central tower receiver

### Non-Focus Type

a. Modified flat plate collector
b. Compound parabolic concentrating type

# Performance Indices of Solar Collectors

Collector Efficiency: Ratio of the energy actually absorbed and transferred to heat transporting fluid by the collector (useful energy) to the energy incident on the collector.

Concentration Ratio (CR): Ratio of the area of aperture of the system to the area of the receiver. The aperture of the system is the projected area of the collector facing (normal) the beam.

Temperature Range: Range of temperature to which the heat transport fluid is heated up by the collector.

In flat plate collectors – CR = 1 and temperature range < 100 °C.

Line focus collectors – CR up to 100 and temperature range of the order of 150 °C to 300 °C.

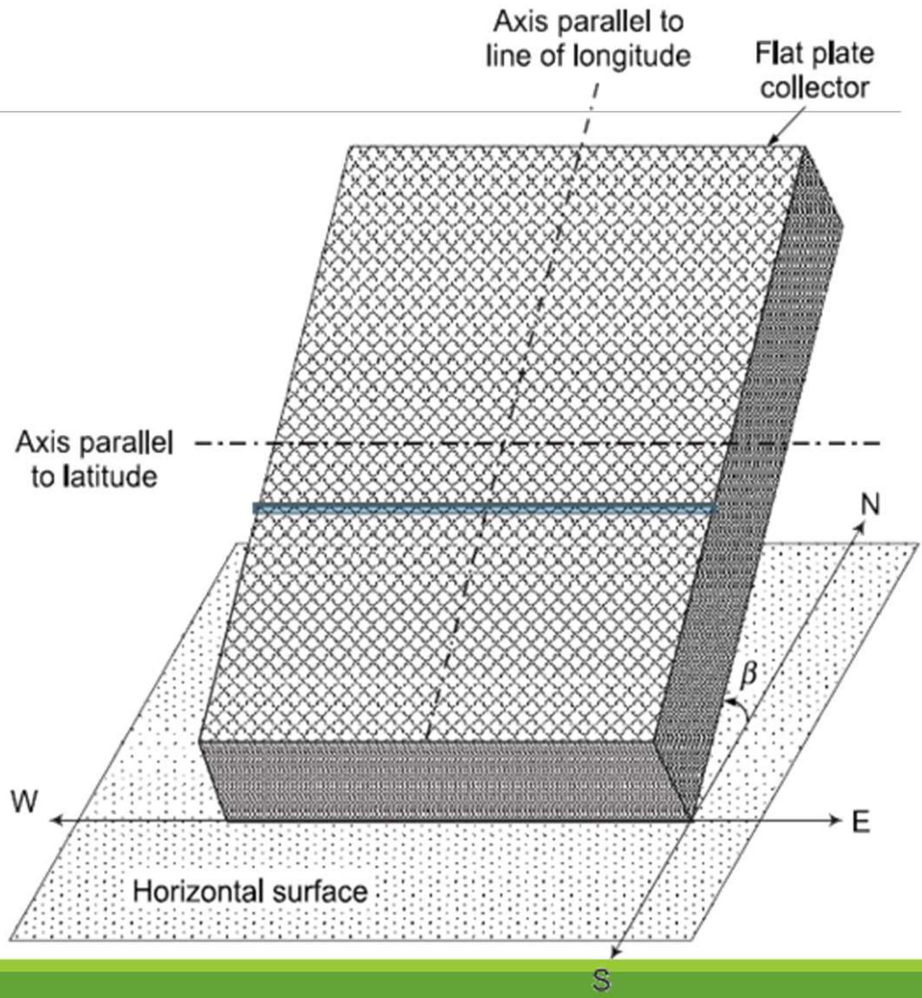
Point focus collectors – Concentration ratio of the order of thousands and temperature range of 500 °C to 1000 °C.

# Flat Plate Collectors

- The FPC is the heart of any solar energy–collection system.
- Flat plate can absorb both beam and diffused radiations.
- Designed for operation in the low and medium temperature range between 60 °C and 100 °C.
- Used to absorb both the beam and the diffuse solar radiation after transmission from the glass cover.
- The absorber converts it into thermal energy (heat) and then transfers the absorbed thermal energy (heat) into a stream of liquid or gas.
- Does not require tracking of the Sun.
- Requires little operation and maintenance.
- The flat-plate–collector assembly is inclined at the optimum angle (depending on the location of installation) to receive the maximum solar radiation throughout the year.

# Flat Plate Collectors

- A flat plate collector is placed at a location in a position such that its length aligns with line of longitude and suitably tilted towards south to have maximum collection.
- Does not require sun tracking.
- Can be properly secured on a rigid platform- mechanically stronger than those collectors requiring tracking.



# Components of Flat Plate Collectors

a. Glazing: This is transparent material for the short wavelength range (0.23–2.6 μm) and opaque for the long wavelength range ≥2.6 μm
   * single layer or double layer
   * transmits radiation to absorber and prevents radiative & convective heat loss
   * Eg: Polyvinyl fluride, crystal glass, polycarbonate etc..

b. Tubes and fins: The fluid is allowed to pass through tubes and fins for conducting or directing the heat transfer from absorber to the flowing fluid.

c. Absorber plate: This is a blackened conducting flat plate, corrugated or grooved, with tubes and fins for the absorption of short-wavelength solar radiation. Eg: Copper or steel plates

d. Header or manifolds: There are two headers, namely, the lower header, which allows fluid to pass through, and upper header, which is used to discharge hot water after heating.

e. Insulation: This is a non-conducting material at the bottom of tube and fins to minimize heat loss from the back and sides of the FPC.

f. Container or casing: This surrounds the various components and protects them from dust and moisture, etc.

# Flat Plate Collectors

## Heat Transfer Process

The critical component of the FPC is to act as the absorber and tubes/duct for the flow of liquid/gas.

In case of the water collector, water flowing in the tubes receives thermal energy from the absorber plate.

The role of absorber of FPC is:

i. to absorb the maximum possible solar radiation incident on it through the glazing;

ii. to minimize heat losses from the absorber to the atmosphere from the top, bottom, and sides of the FPC; and

iii. to transfer maximum heat to the fluid.

# Flat Plate Collectors

## Heat Transfer Process

A liquid, most commonly, water is used as heat transport medium from collector to next stage of the system.

However, sometimes mixture of water and ethylene glycol (antifreeze mixture) are also used if the ambient temperatures are likely to drop below 0°C during nights.

As solar radiation strikes on specially treated metallic absorber plate, it is absorbed and raises its temperature.

The absorber plate is usually made from a metal sheet ranging in thickness from 0.2 to 1 mm.

Materials generally used for collector absorber plates are copper, aluminum, and steel.

# Flat Plate Collectors

## Heat Transfer Process

The selective surface coating of the absorber plate must ensure high absorptivity ($\alpha$) and low emissivity ($\epsilon$) to retain maximum thermal energy.

The solar energy absorbed by the absorber plate heats the absorber plate.

The thermal energy from the absorber plate is transferred to the fluid circulating in the tubes in thermal contact with the absorber plate; or fluid can directly extract the heat if it is flowing on the absorbing plate.

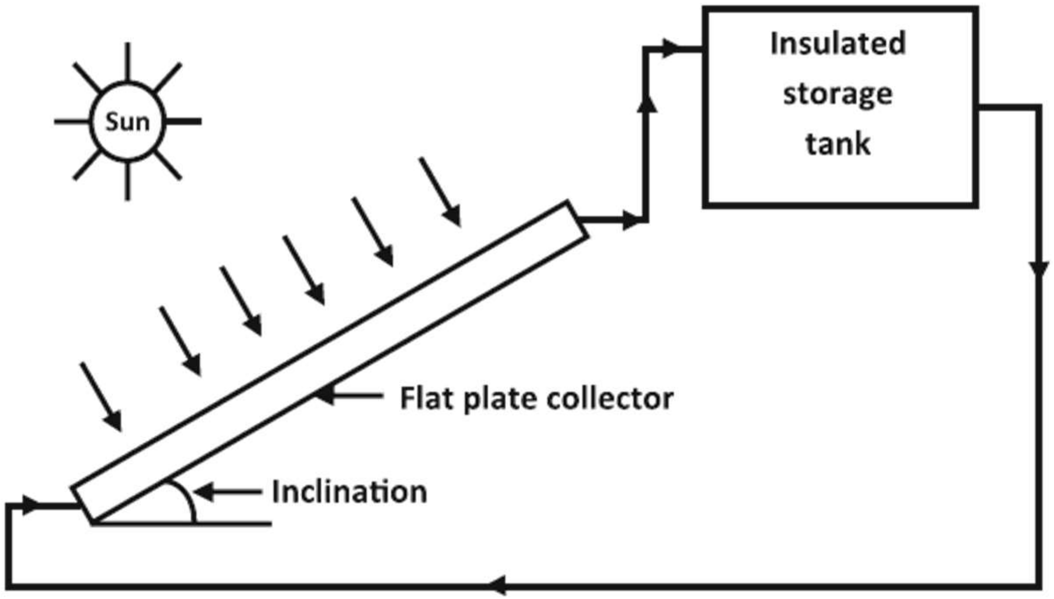
Heat remains trapped in the airspace between the absorber plate and glass cover in a manner similar to green house.

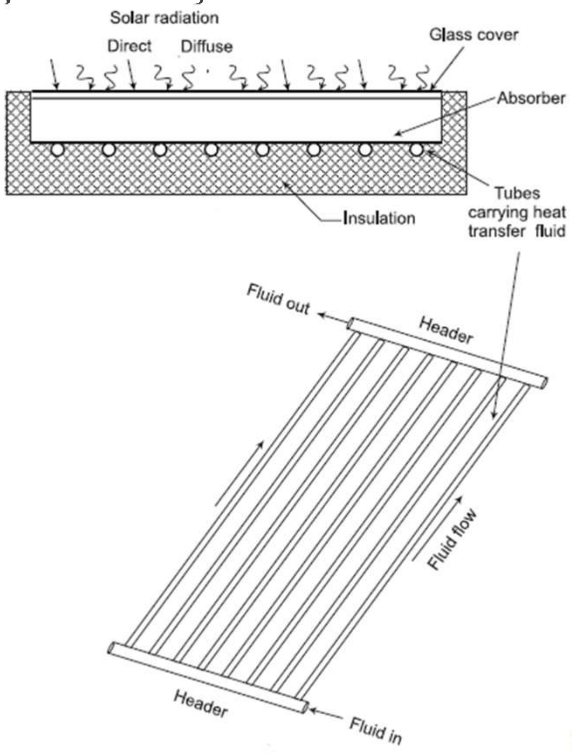
The sides and bottom of the FPC are properly insulated to reduce losses from the bottom- and sides.

# Flat Plate Collectors

Heat Transfer Process

The flat-plate–collector assembly is inclined at the optimum angle (depending on the location of installation) to receive the maximum solar radiation throughout the year.



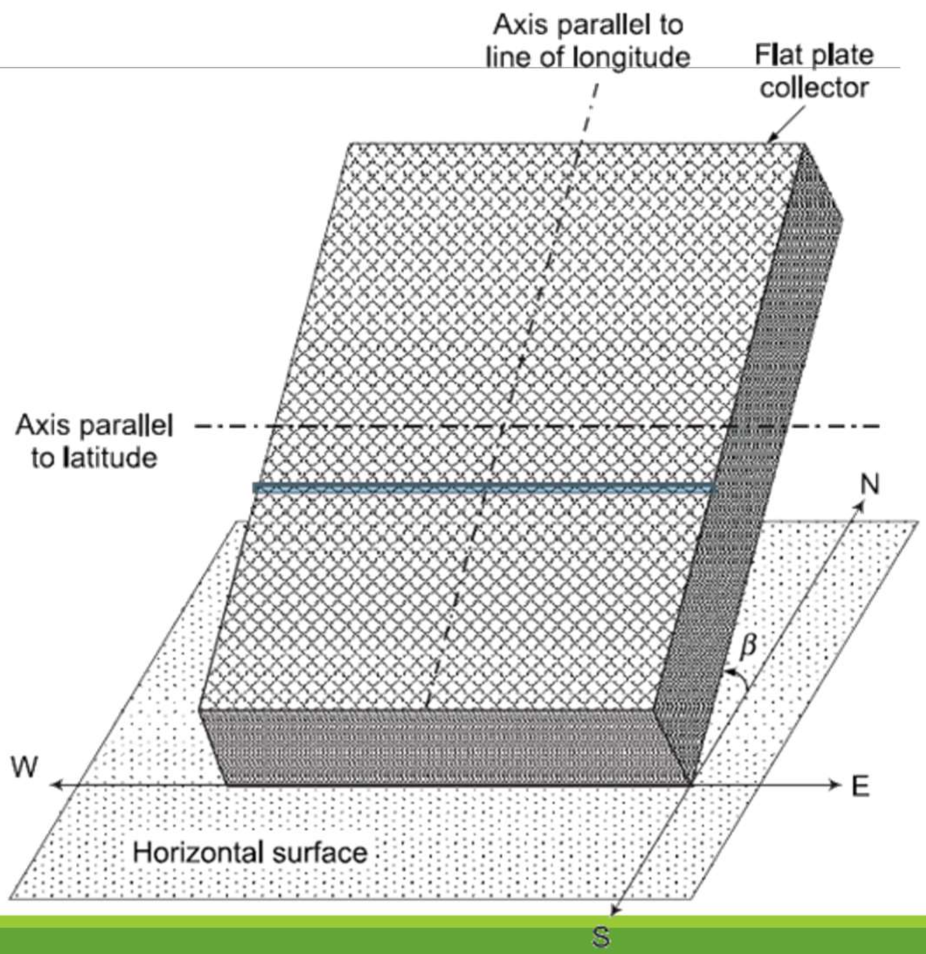
# Flat Plate Collectors

## Positioning of the Collector

A flat plate collector is placed at a location in a position such that its length aligns with line of longitude and suitably tilted towards south to have maximum collection.

Does not require sun tracking.

Can be properly secured on a rigid platform- mechanically stronger than those collectors requiring tracking.



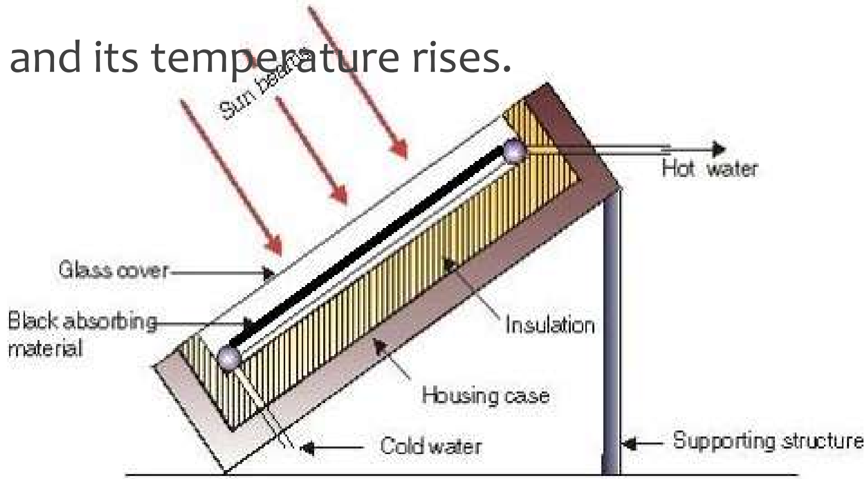
# Liquid Flat Plate Collectors

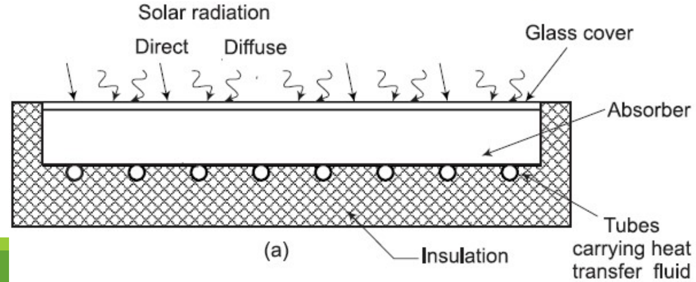
Flat plate can absorb both beam and diffused radiations.

Metallic absorber plate absorbers the solar radiation and its temperature rises.

Consists of

i. Absorber plate
ii. Tubes, channels or passages
iii. Weather tight insulated container
iv. Transparent cover of glass



# Liquid Flat Plate Collectors

Heat is transferred to water circulating in the tube, beneath the absorber plate.

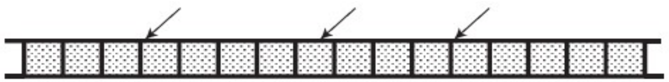
Tubes are either welded, soldered or pressure bonded.

Water is moved either forcefully or naturally by placing it inclined.

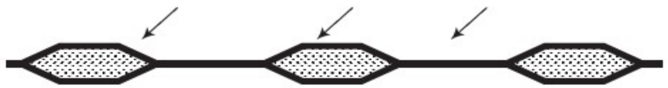
Absorber plate and tubes is made of copper.

At bottom and along side walls thermal insulation.

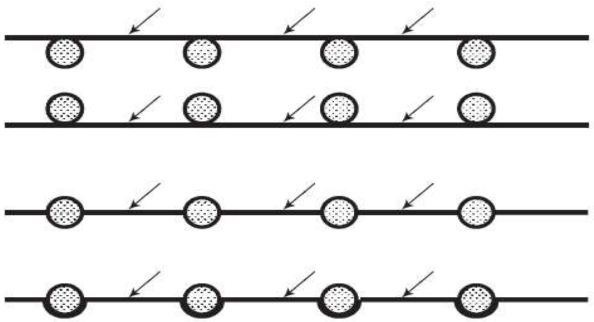
Types: Pipe and fin, Full water sandwich, Semi-water sandwich.



(b) Water sandwich type



(c) Semi water sandwich type (roll-bond)



(a) Pipe and fin type

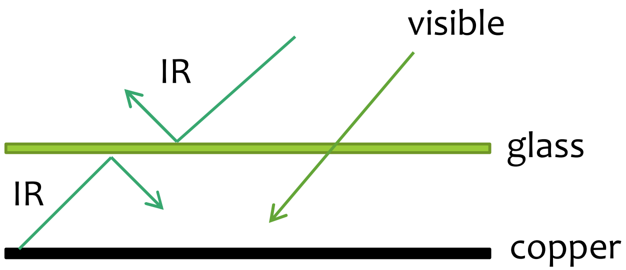
# Liquid Flat Plate Collectors

Heated plate will lose heat as radiation, conduction and convection.

Glass: allow visible range to pass through it and block infrared.

Reflection of incoming radiation reduced by anti reflective coating.

After heating the plate will radiate in infrared range, glass will not allow to radiate out.



# Liquid Flat Plate Collectors

Convection can take place: Air in contact with copper plate will heat up and creates convection current.

Glass act as a convection shield & reduce heat losses.

One or two sheets of Glass cover of thickness 4- 5 mm usually used.

Heat is trapped in air space between the cover and the absorber plate.

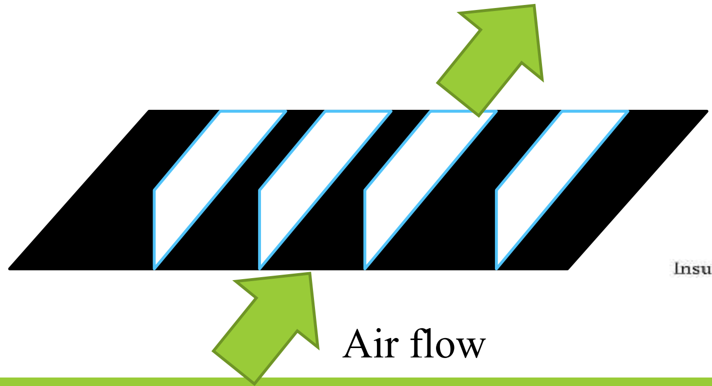
GREEN HOUSE EFFECT: Allowing visible range to come in and not allowing IR to go out.

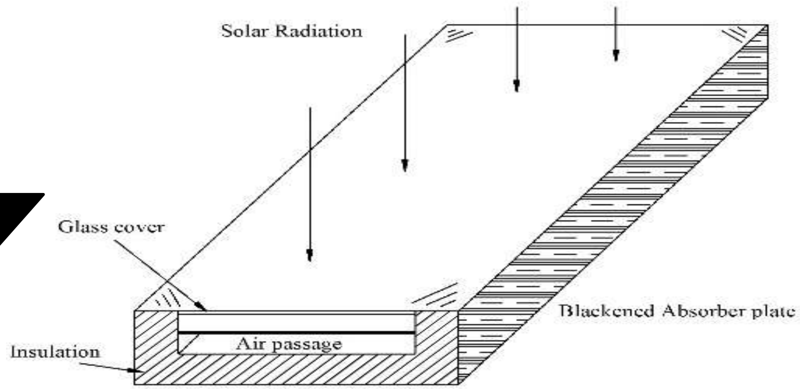
# Flat-plate Air-heating Collector

Similar to liquid flat plate with a change in configuration of absorber and tube.

Heat transfer coefficient is low.

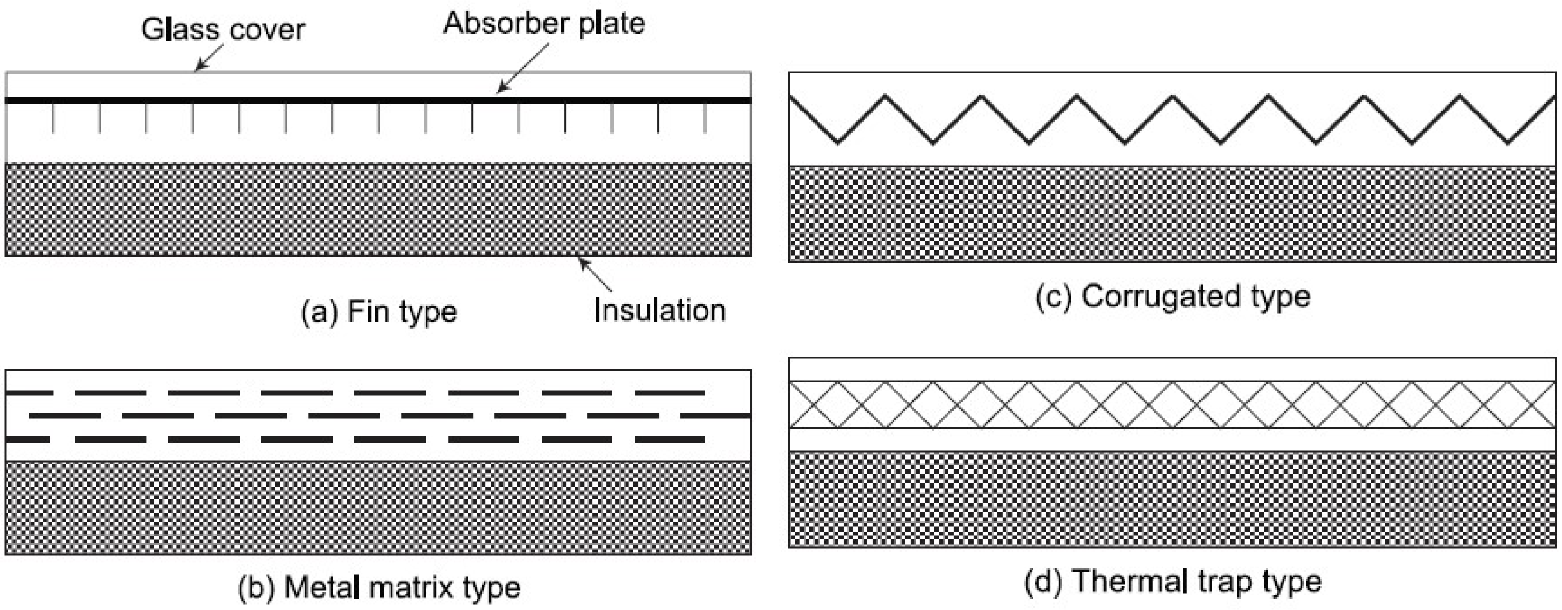
Application: Drying for agricultural and industrial purpose and space heating.



# Flat-plate Air-heating Collector

Fin Type, Metal Matrix Type, Corrugated Type, Thermal Trap type



# Flat-plate Air-heating Collector

Advantages over liquid flat plate collector

- ✓ Need to transfer energy from one working fluid to another is eliminated.
- ✓ Corrosion is eliminated.
- ✓ Leakage of air from duct is less severe.
- ✓ Freezing is eliminated.
- ✓ Pressure inside collector does not become high.

Disadvantages

- X Large amount of fluid is to be handled.
- X Heat transfer is poor.
- X Less storage of thermal energy due to low heat capacity.

# Evacuated Tube Collector (ETC)

To reduce heat lost by conduction and convection - vacuum is provided around absorber.

Glass tube  to withstand the stress introduced by the pressure difference due to vacuum.

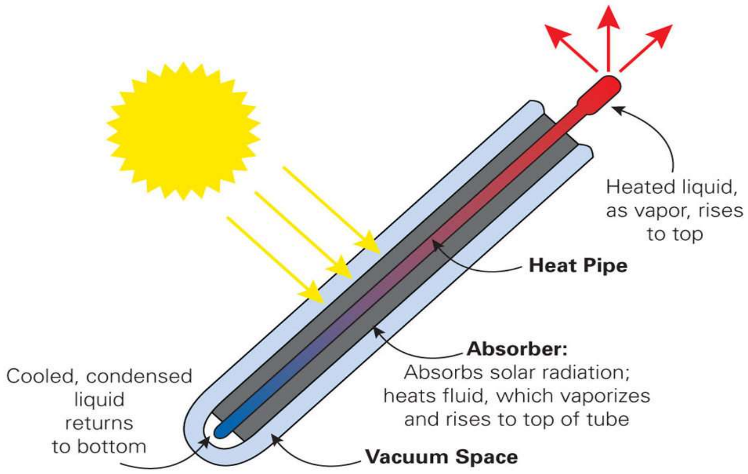
Collector consist of a no of long tubular modules.

Absorber plate has a selective surface coating.

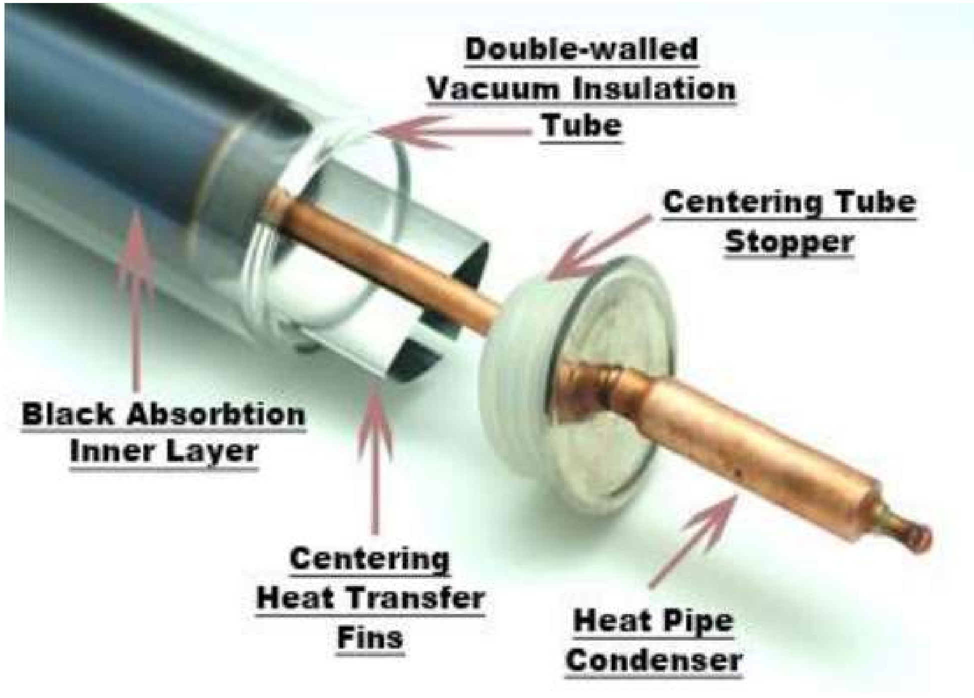
Temperature: 100 – 130°C.

Two types:

- Flat Plate type ETC
- Concentric tube type ETC



# Evacuated Tube Collector (ETC)



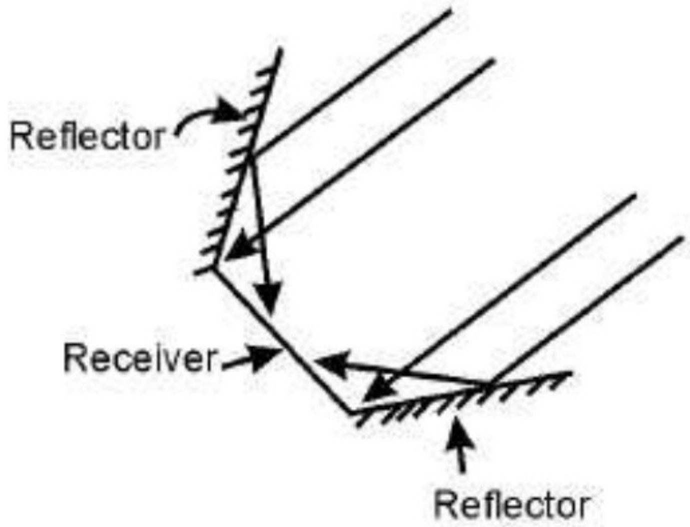

# Modified Flat Plate Collector (V-Trough)

Booster mirrors are provided at the edges reflects additional radiation to receiver.

It is aligned in the east- west direction

Requires  periodic tilt adjustment.

Concentration ratio : 4 max



# Compound Parabolic Concentrator (CPC)

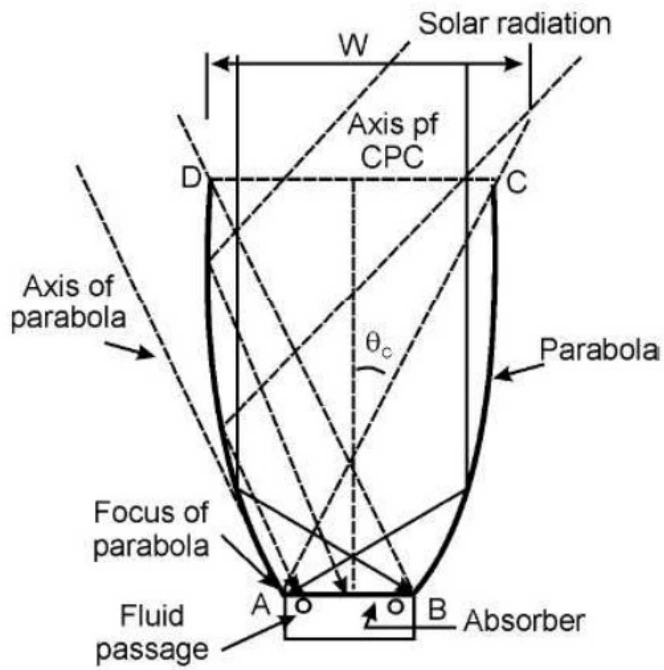
Consist of two parabolic mirror attached to flat receiver.

Acceptance angle is large and need to be adjusted.

Rays from central region reach directly.

Rays from edges undergo reflection.

Concentration ratio: 3-7

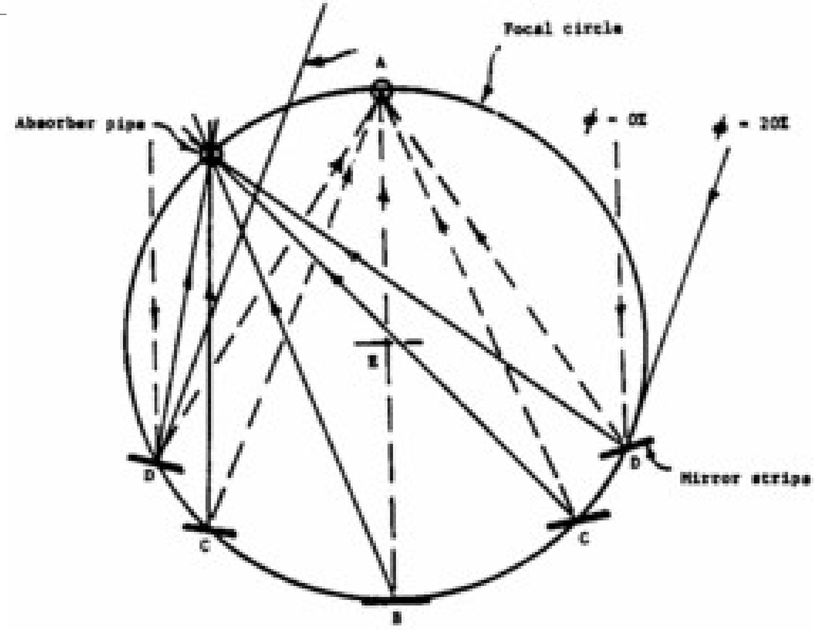


# Fixed Mirror Solar Concentrator

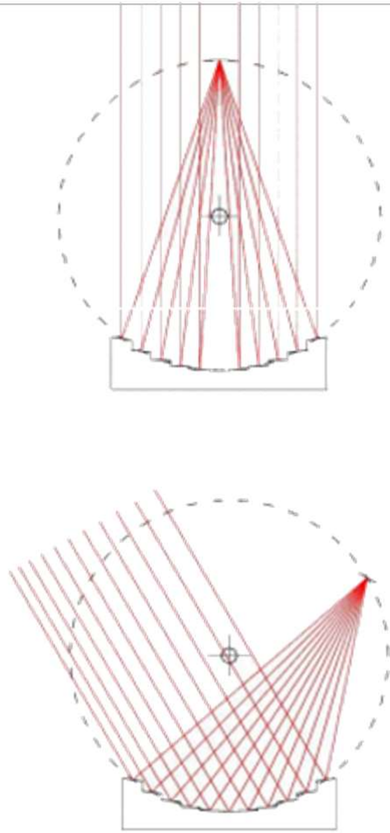
Consist of fixed mirror strips arranged on a circular reference cylinder with tracking receiver tube.

Receiver tube rotated about center of curvature to track the sun.

Concentration ratio same as no of mirror strips.



# Fixed Mirror Solar Concentrator



# Cylindrical Parabolic Concentrator

Consist of cylindrical parabolic trough reflector and a metal tube receiver at focal point.

Receiver tube is blacked at outer surface.

Rotated about one axis to track the sun.

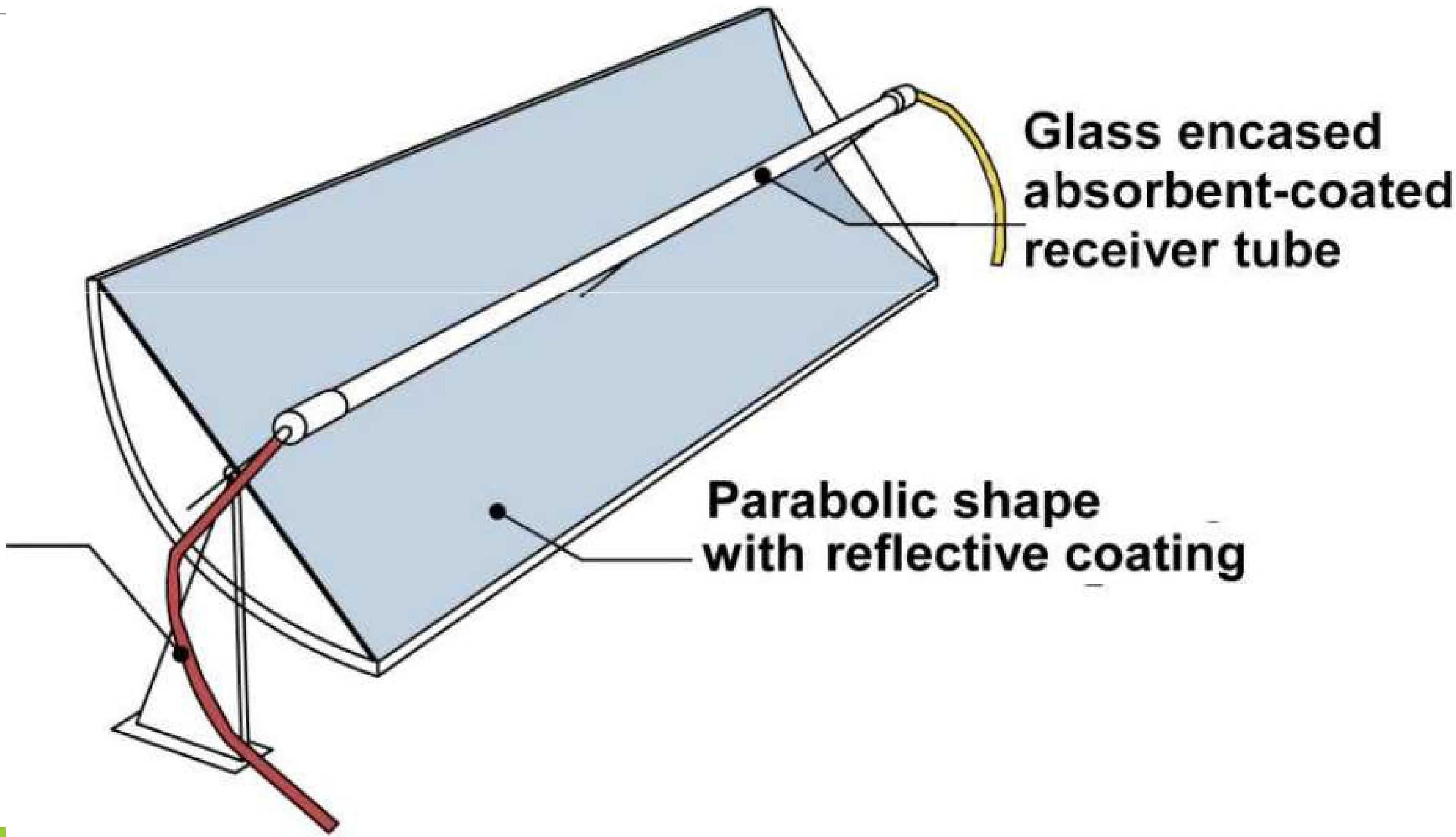
Fluid flows through the receiver tube.

Orientation: East-west, north –south or polar.

Single axis sun tracking mechanism needed.

Concentration ratio: 5- 30.

# Cylindrical Parabolic Concentrator



# Linear Fresnel Lens Collector

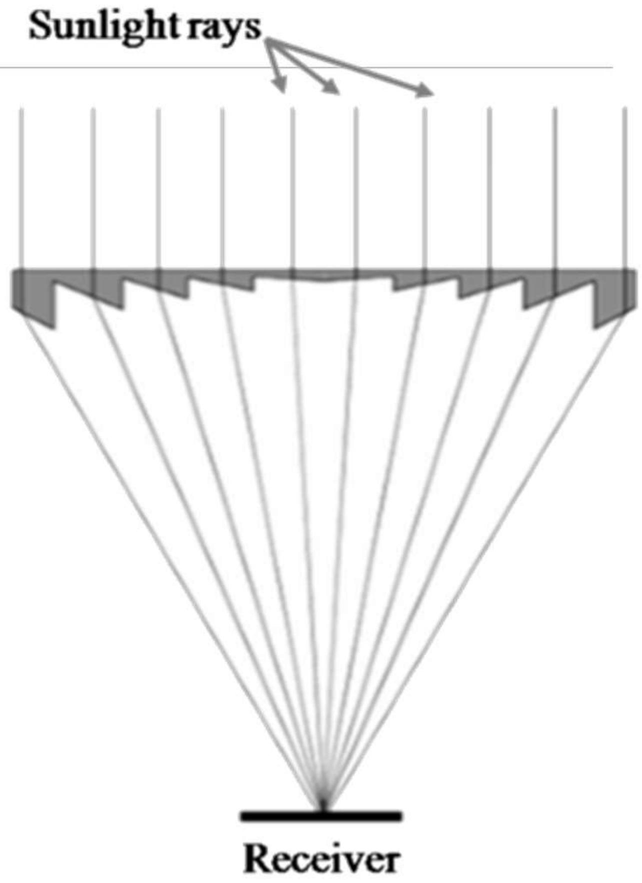
Fresnel lens consist of fine, linear grooves on the surface of refracting material on one side and other side is flat.

Optical behavior similar to spherical lens.

Beam radiation converges on the focal line where receiver tube is provided.

Concentration ratio : 10 to 30.

Temperature: 150 -300°C.



# Parabolic Dish Collector

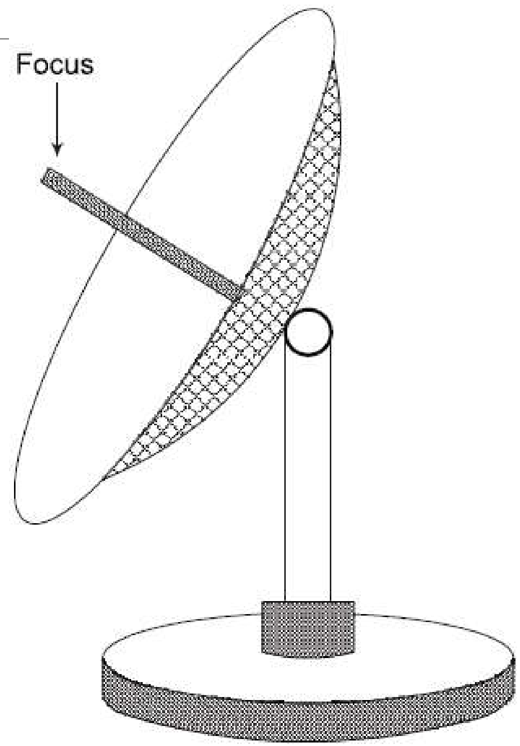
Parabolic shape: A parabola is rotated about its optical axis

Beam radiation is focused on a point in the paraboloid.

Requires two axis tracking.

Concentration ratio: 10 to few 1000s.

Temperature: Upto 3000ºC.



# Parabolic Dish Collector

# Hemispherical Bowl Mirror Concentrator

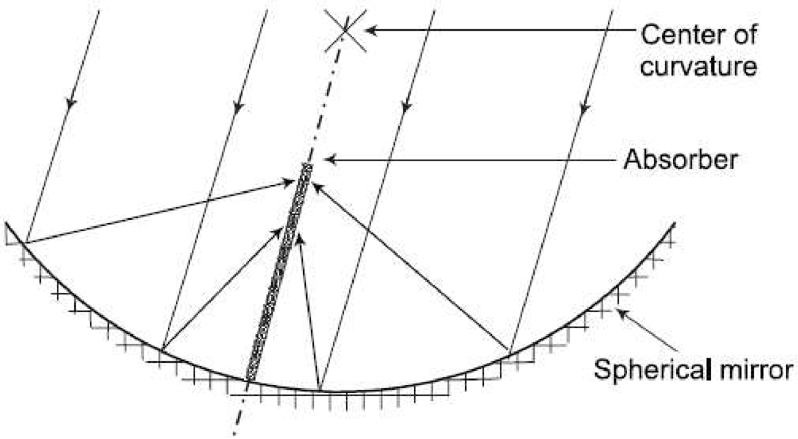
Consist of hemispherical mirror and a tracking absorber.

Rays entering the hemisphere after reflection cross the paraxial line.

Linear absorber pivoted about the center of curvature of hemisphere, intercepts reflected rays.

Absorber moved so that, axis aligned with solar rays.

Requires two axis tracking.



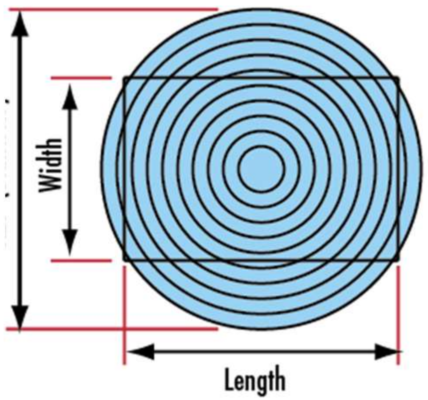
# Circular Fresnel Lens Concentrator

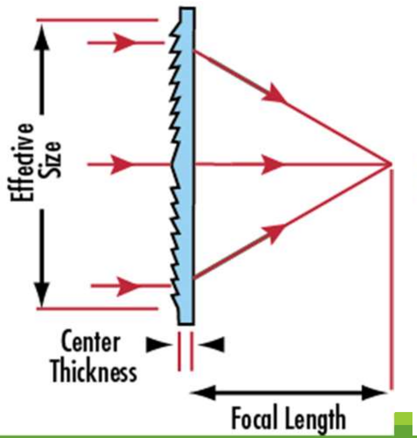
This is used where high flux is desired, such as silicon solar cells.

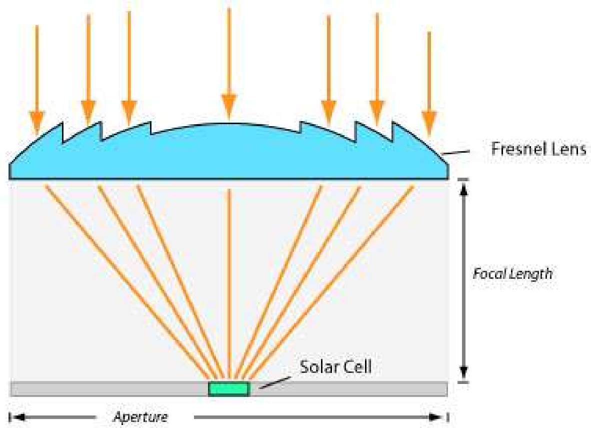
Divided into a number of thin circular zones.

Tilt of each zone is so adjusted that it approximates a thin  spherical lens.

Concentration ratio : 2000



# Parabolic Dish Collector

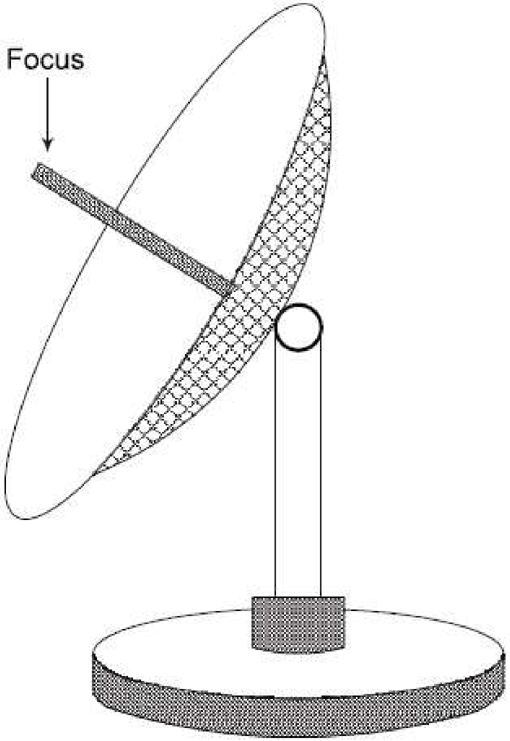
Parabolic shape: A parabola is rotated about its optical axis

Beam radiation is focused on a point in the paraboloid.

Requires two axis tracking.

Concentration ratio: 10 to few 1000s.

Temperature: Upto 3000ºC.



# Central Tower Receiver

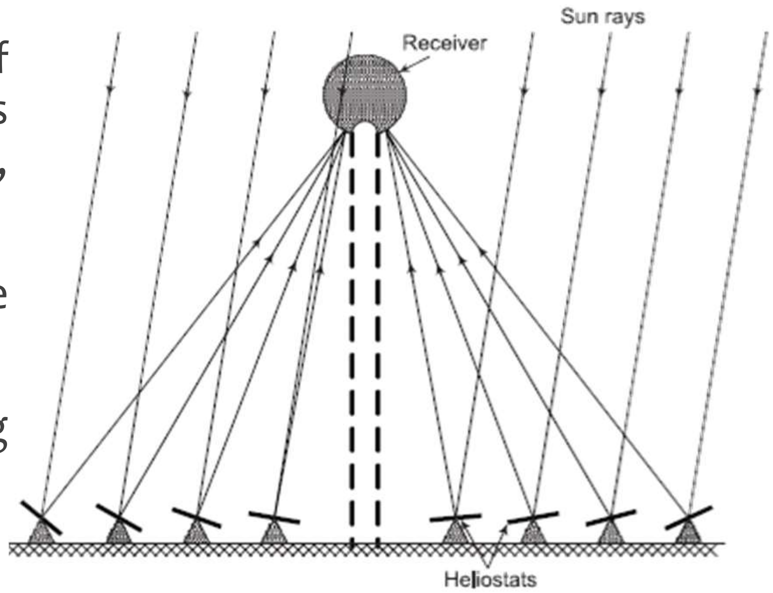
Receiver is located at the top of a tower.

Beam radiation is reflected on it from a large number of independently controlled; almost flat mirrors, known as heliostats, spread over a large area on the ground, surrounding the tower.

Thousands of such heliostats track the sun to direct the radiation on the receiver from all sides.

The heliostats, together act like a dilute paraboloid of very big size.

Concentration ratio: 3000



# Solar Thermal Power Plants

Concentrating systems

Solar tower power plants

Dish/Stirling engine power plants

Parabolic trough power plants

Non-concentrating systems

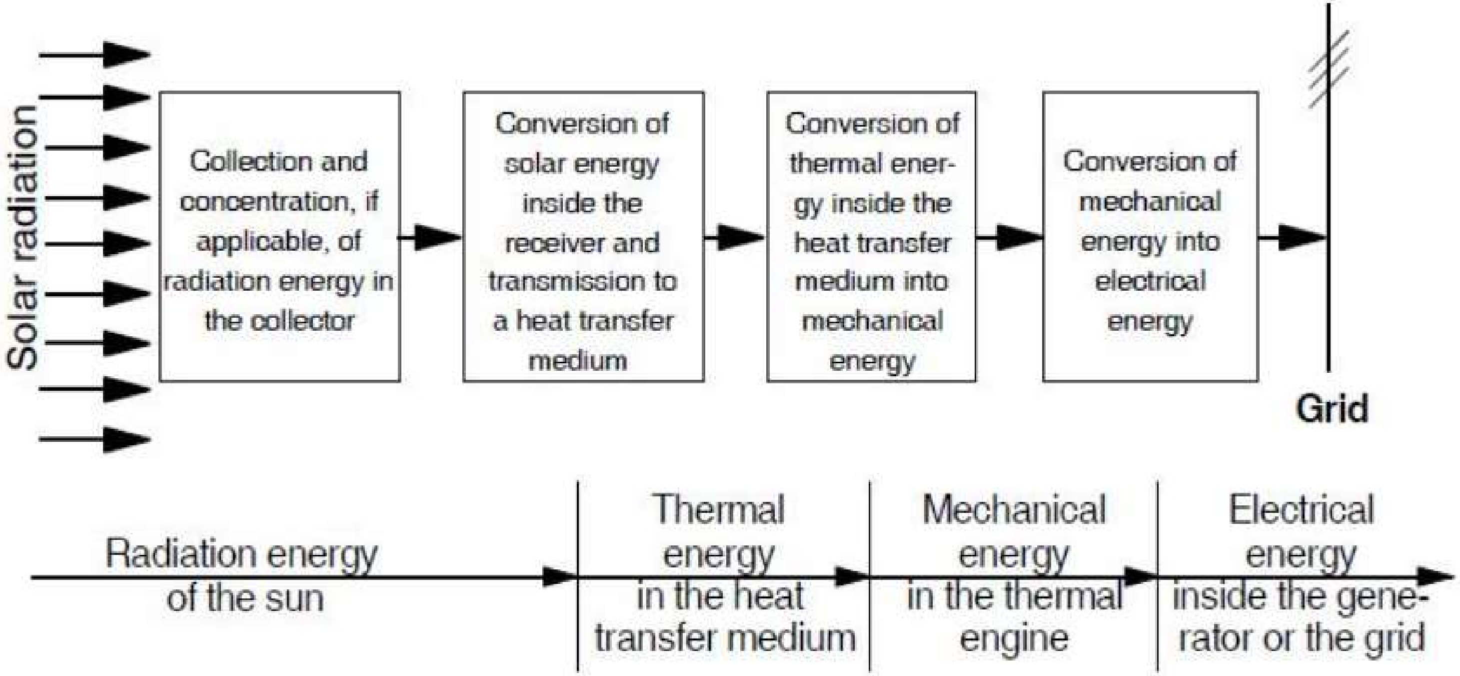
Solar pond power plants

Flat Plate collector power plant

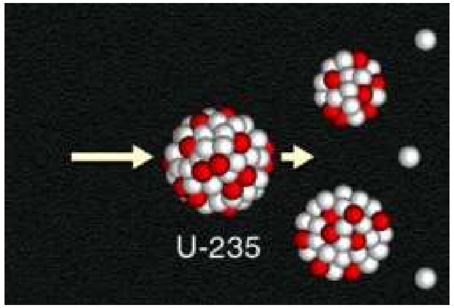
Solar concentrators (Parabolic trough, Parabolic dish, Central Tower Collector) in syllabus

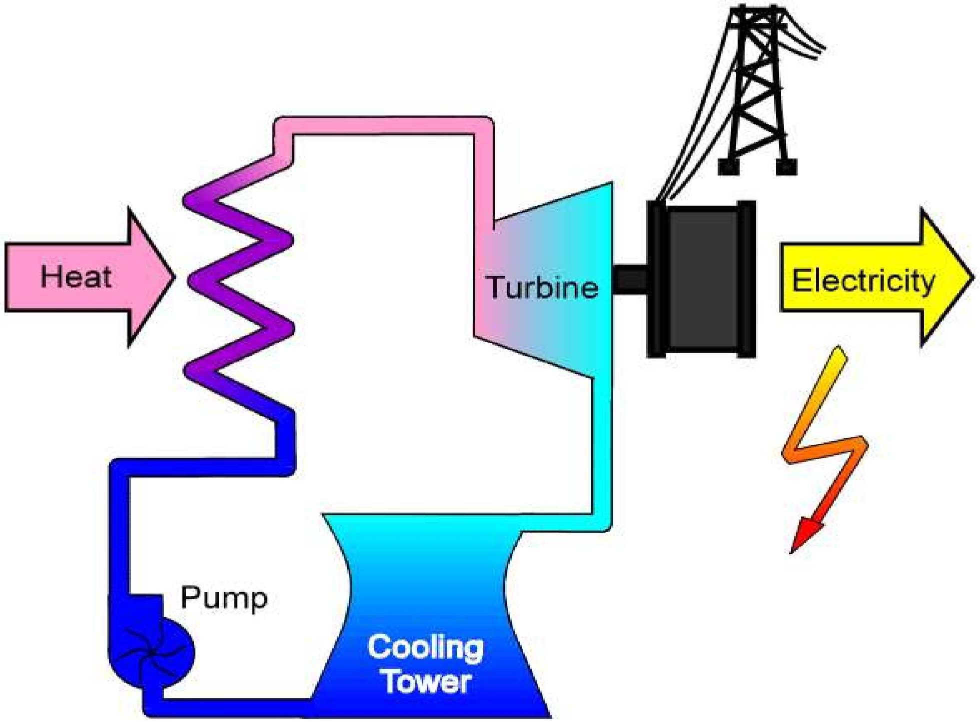
# Solar Thermal Power Plants

Power plants which first convert solar radiation into heat. The resulting thermal energy is subsequently transformed into mechanical energy by a thermal engine, and then converted into electricity.

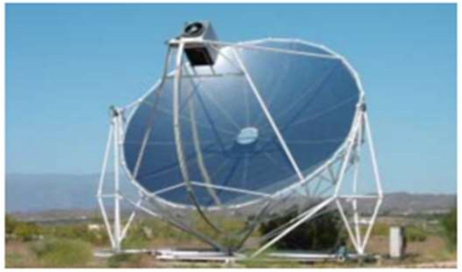


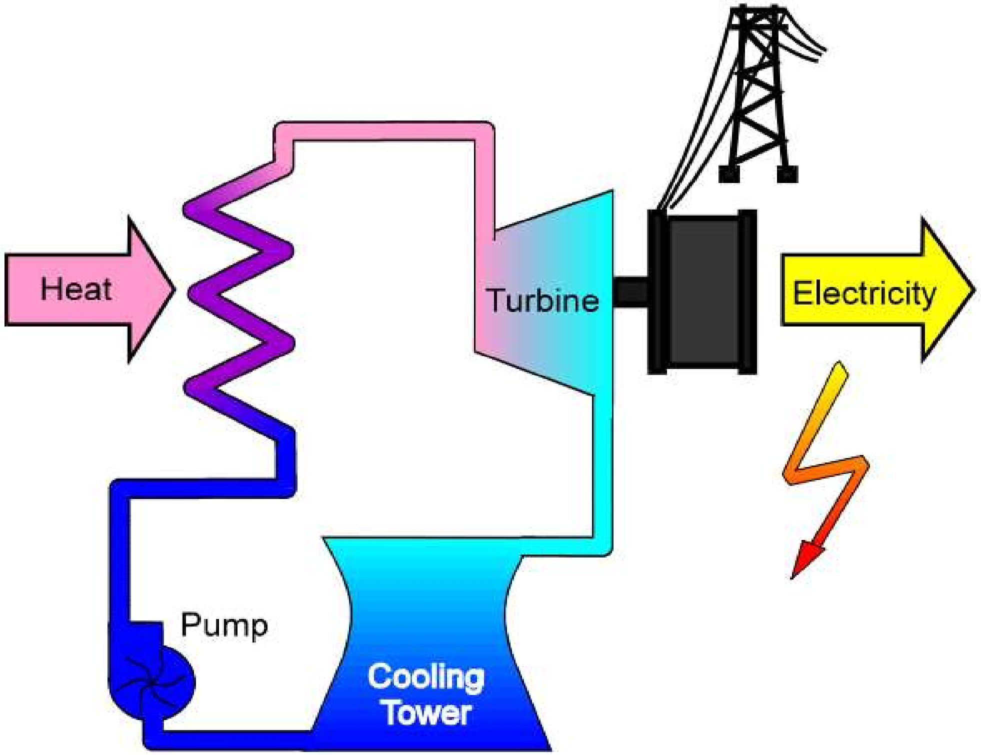
# Conventional Thermal Power Generation



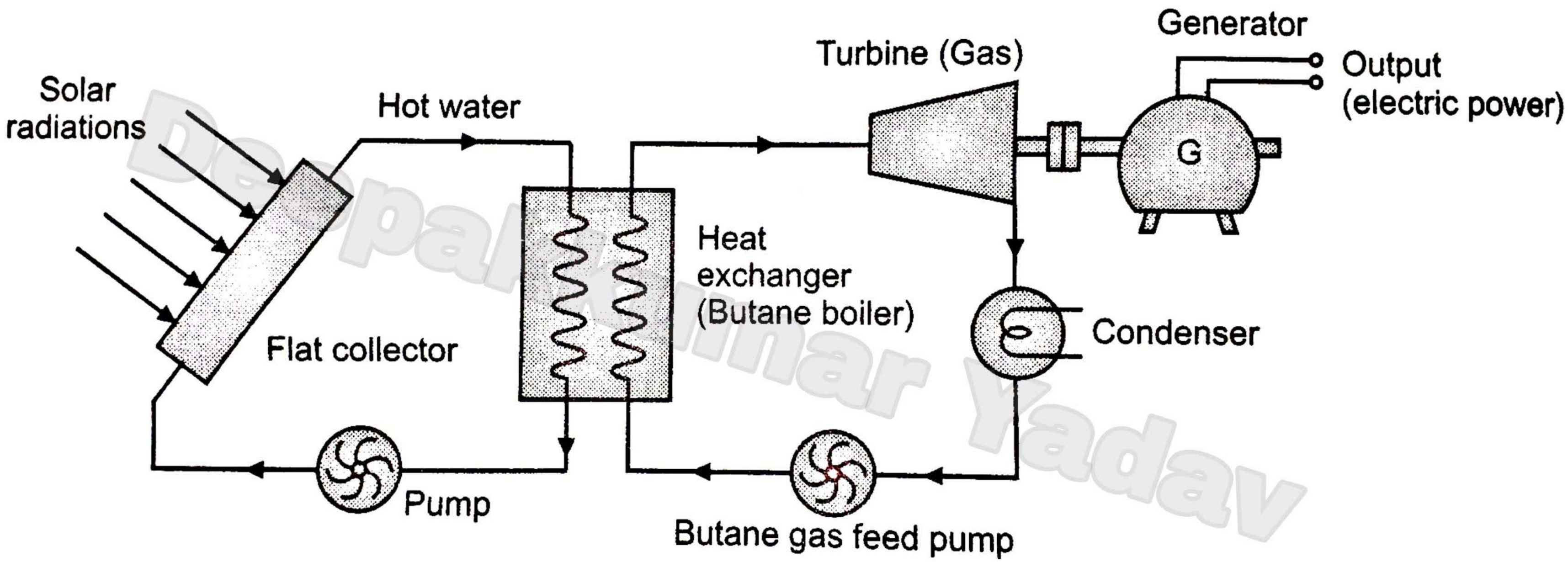



# Solar Thermal Power Generation



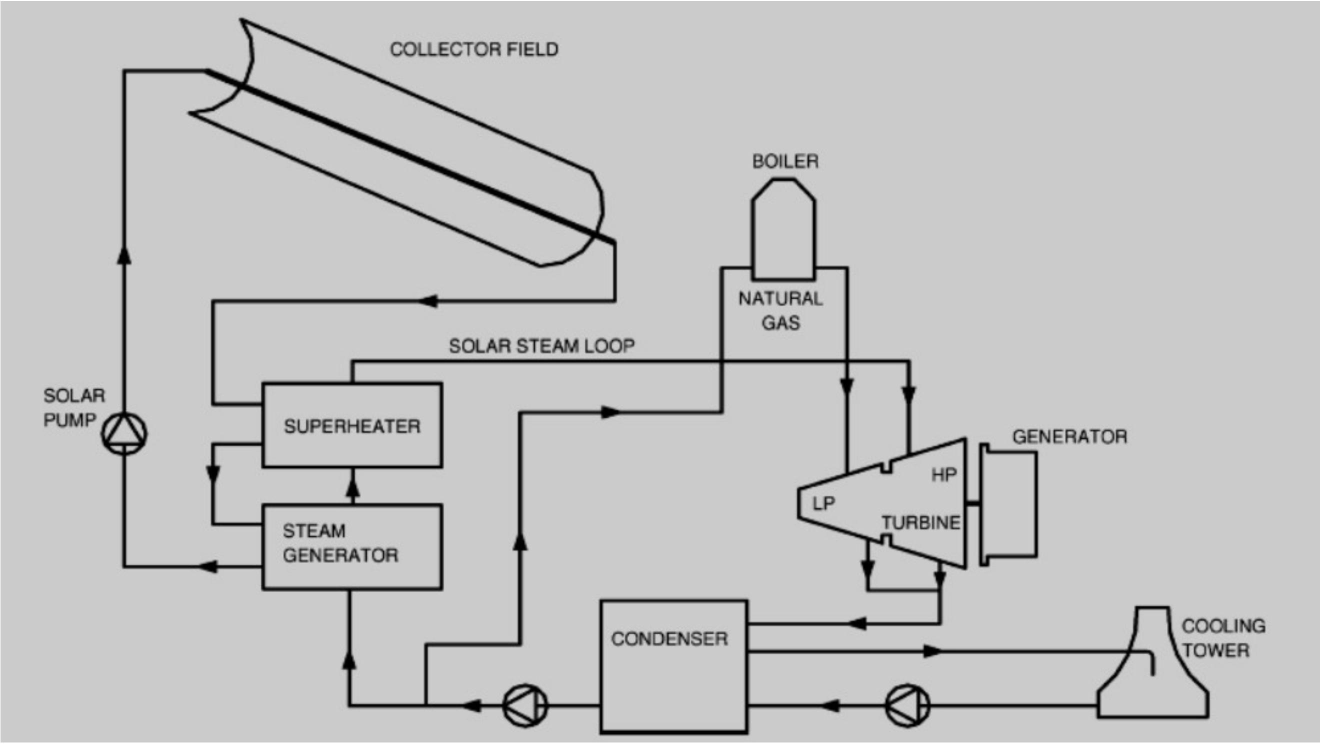



# Flat plate collector based Solar TPP

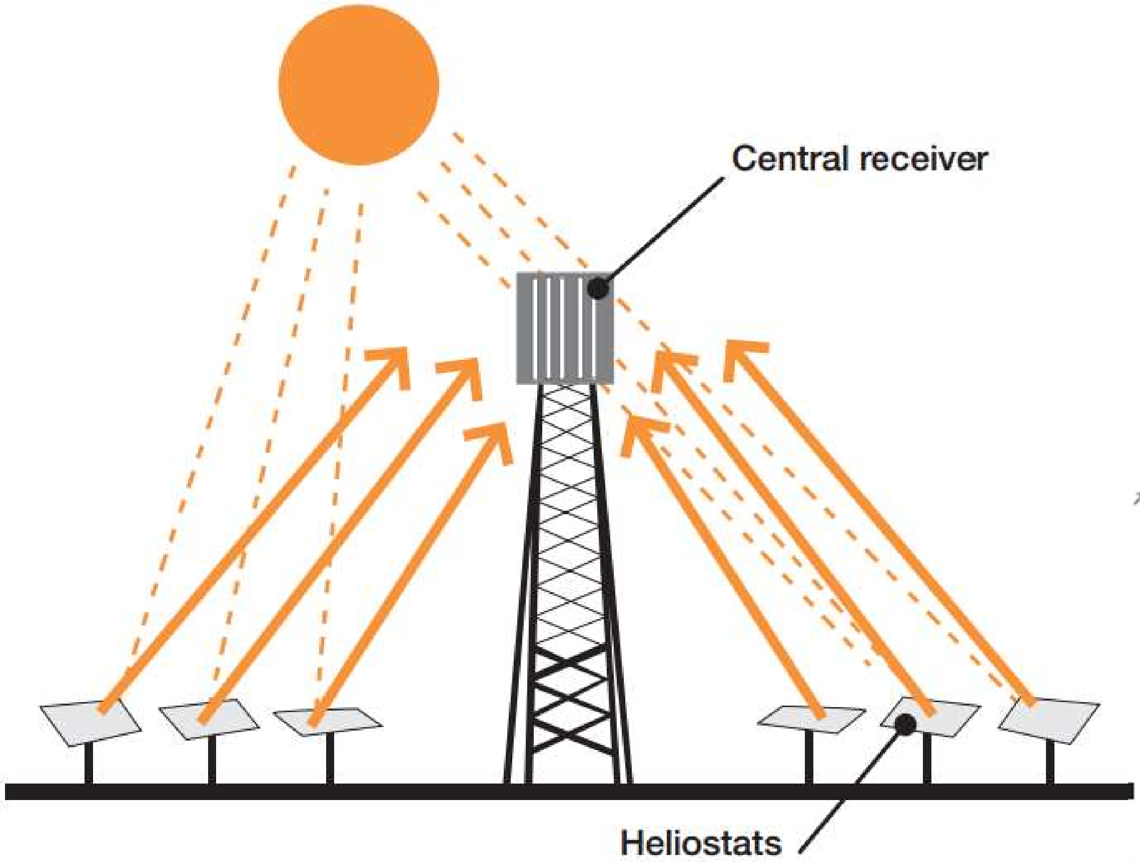


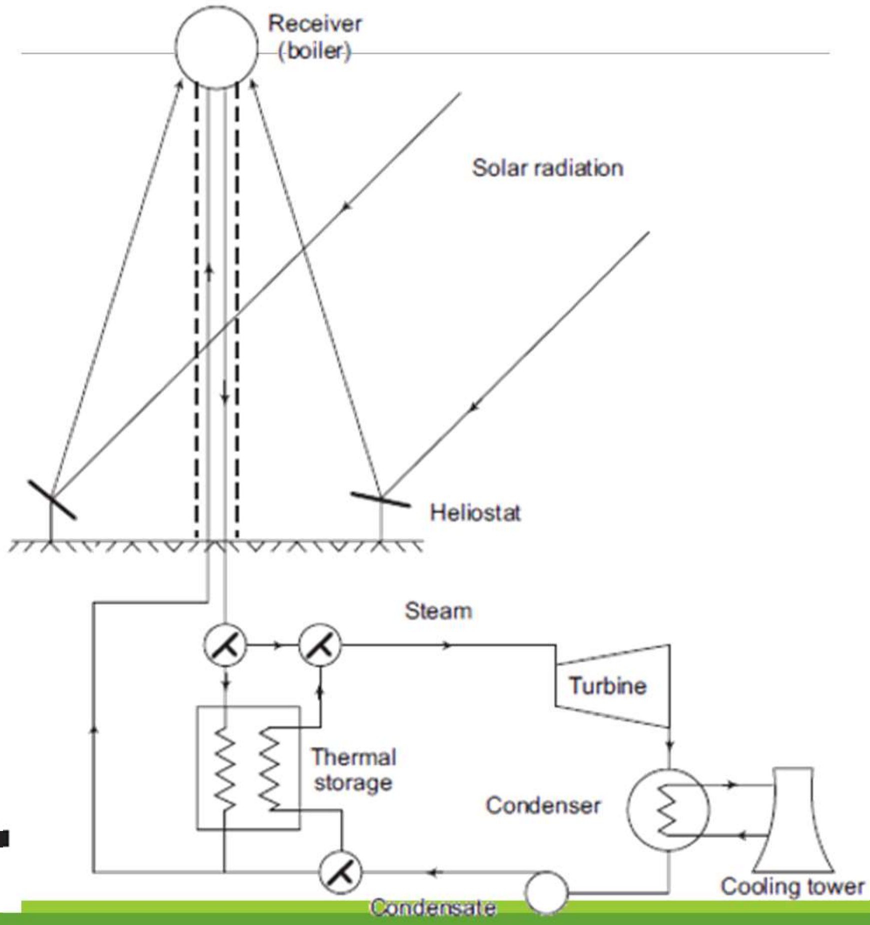

**Low Temperature Solar Power Plant**

# Parabolic Trough collector based Solar TPP

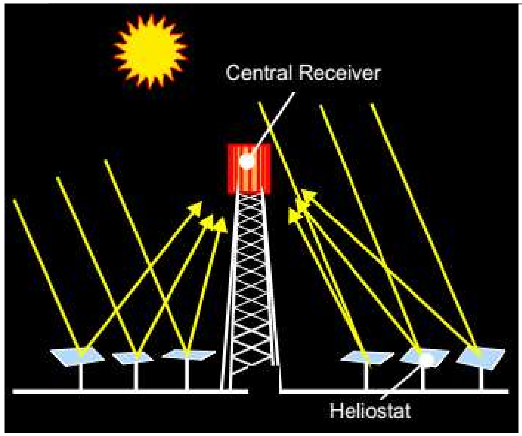


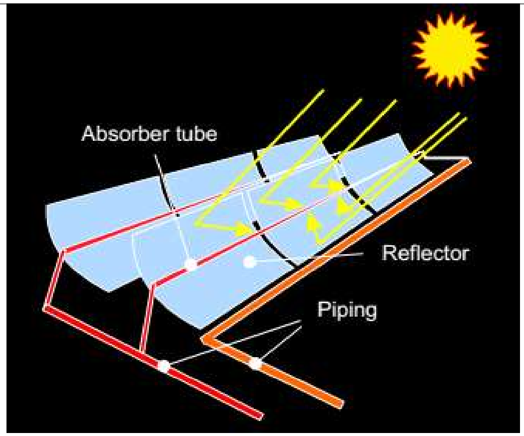
# Central Tower Receiver Solar Power Plants

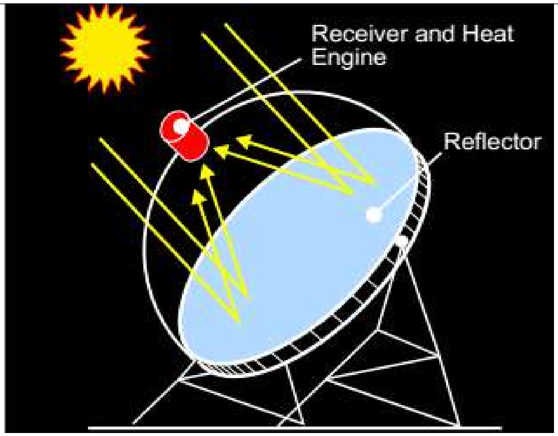


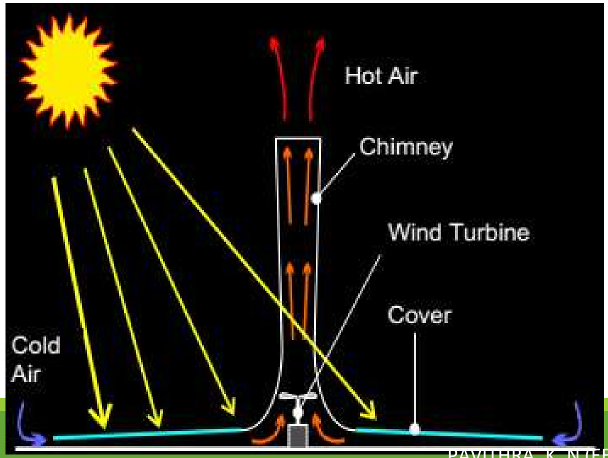



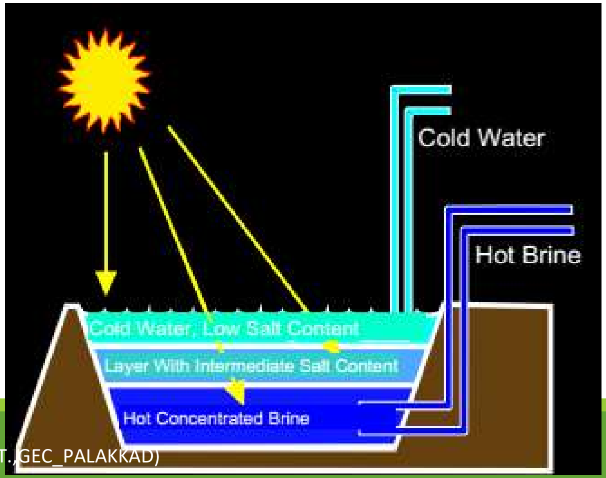
# Solar Thermal Power Plants



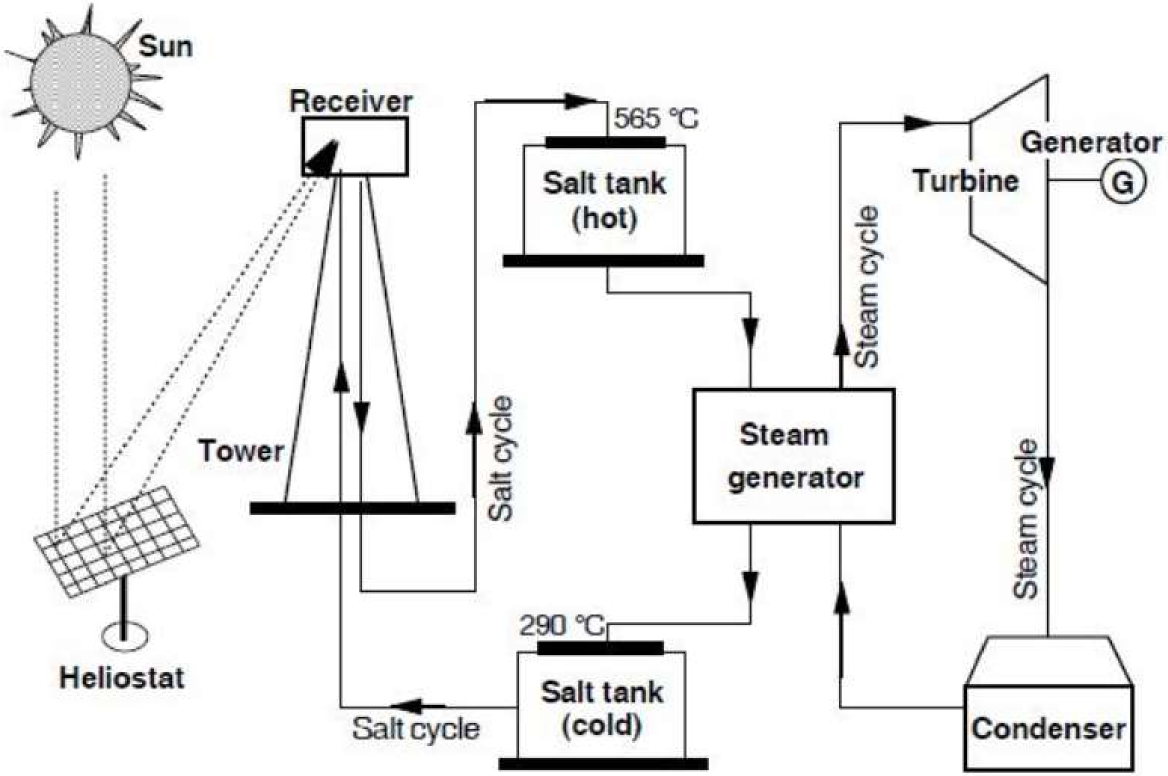



# Central Tower Receiver Solar Power Plants



# Central Tower Receiver Solar Power Plants

- Device that includes a mirror, usually a plane mirror, which turns so as to keep reflecting sunlight toward a predetermined target, compensating for the sun's apparent motions in the sky.

Main Components:

- Central receiver system
- Reflector surface (e.g. mirrors, mirror facets, polymer reflectors) or Mirrors tracking the course of the sun in two axes (Heliostats)
- Sun-tracking system provided with drive motors.
- Foundations and control electronics.
- Working fluid storage system
- Steam generator
- Turbine
- Generator
- Condenser

# Central Tower Receiver Solar Power Plants

- Heliostats reflect the direct solar radiation onto a receiver, centrally positioned on a tower.
  - Higher towers are generally more favorable, since bigger and denser heliostat fields presenting lower shading losses may be applied.
  - Common towers have a height of 80 to 150 m.
  - Transforms the radiation energy, diverted and concentrated by the heliostat field, into thermal energy.
- Receiver is located at the top of the tower. Receiver's classification according to the applied heat transfer medium
  - Water/steam receiver, Molten salt receiver, Open volumetric air receiver, Closed (pressurized) air receivers
- In the receiver, radiation energy is converted into heat and transferred to a heat transfer medium (working fluids such as salts, butane or water itself)
- This heat is used to generate steam within a steam generator.
- The steam is used to drive the turbine and there by a generator which produces electricity
- To ensure continuous supply of energy at times of varying solar radiation, either a heat storage can be incorporated into the system or additional firing using fossil fuel can be used.

# Solar One, California (7 MW)

# PS10 Solar Power Tower, Spain

# PS10 and PS20, Spain

# Solar PV Systems : Solar Cell

Direct conversion of solar energy into electrical energy (DC) using semiconductors that exhibits photovoltaic effect.

A photovoltaic (PV) cell transforms the solar energy incident on it directly into electricity due to the photovoltaic effect.

Light, which is pure energy, enters a PV cell and imparts enough energy to some electrons to free them.

Light energy incident on the cell surface in the form of photons generates electron–hole pairs as current carriers at the p-n junction.

# Solar Cell : Working Principle

A built-in-potential barrier in the cell acts on these electrons to produce a voltage (photo-voltage), which can be used to drive a current through a circuit.

Photocurrent produced by a PV cell is directly related to its surface area, incident irradiance and ambient temperature. Generated voltage is limited by the forward voltage drop across the p-n junction.

Voltage and current output of a single cell are very small - a large number of cells are arranged in series– parallel combination to produce PV modules or arrays of higher voltage and power rating.

# Solar Cell : Working Principle

- Silicon p-type is doped with some trivalent atom like boron, and while n-type is doped with some pentavalent atoms like phosphorous.
- n-type silicon has excess electrons and p-type has excess holes.
- When these materials are joined together, excess electrons from the n-type diffuse to recombine with the holes in the p-type, creating a depletion layer with barrier potential.
- When photons of sun rays that has energy greater than the band gap energy is incident in this pn junction, an electron hole pair is generated within the depletion region.
- The electron move towards n region and hole move towards p region, thereby an external terminal voltage is generated due to the presence of excess majority carriers in p and n region.

# Solar Cell : Working Principle

- When a load or external conducting path is provided, these terminal voltage causes a flow of current (photo current) through the path.
- This photo current will be proportional to the number of electron hole pairs generated, which in turn depend upon the intensity of illumination.
- Thus an illuminated pn junction becomes a photovoltaic cell with positive on the P side.
- If the electron hole pairs are formed outside the depletion region, the minority carriers must reach the edge of depletion region, to be able to contribute to photo current.
- A solar Cell must be made of material which can absorb the energy associated with the photons in the sunlight.

# Solar Cell : Working Principle

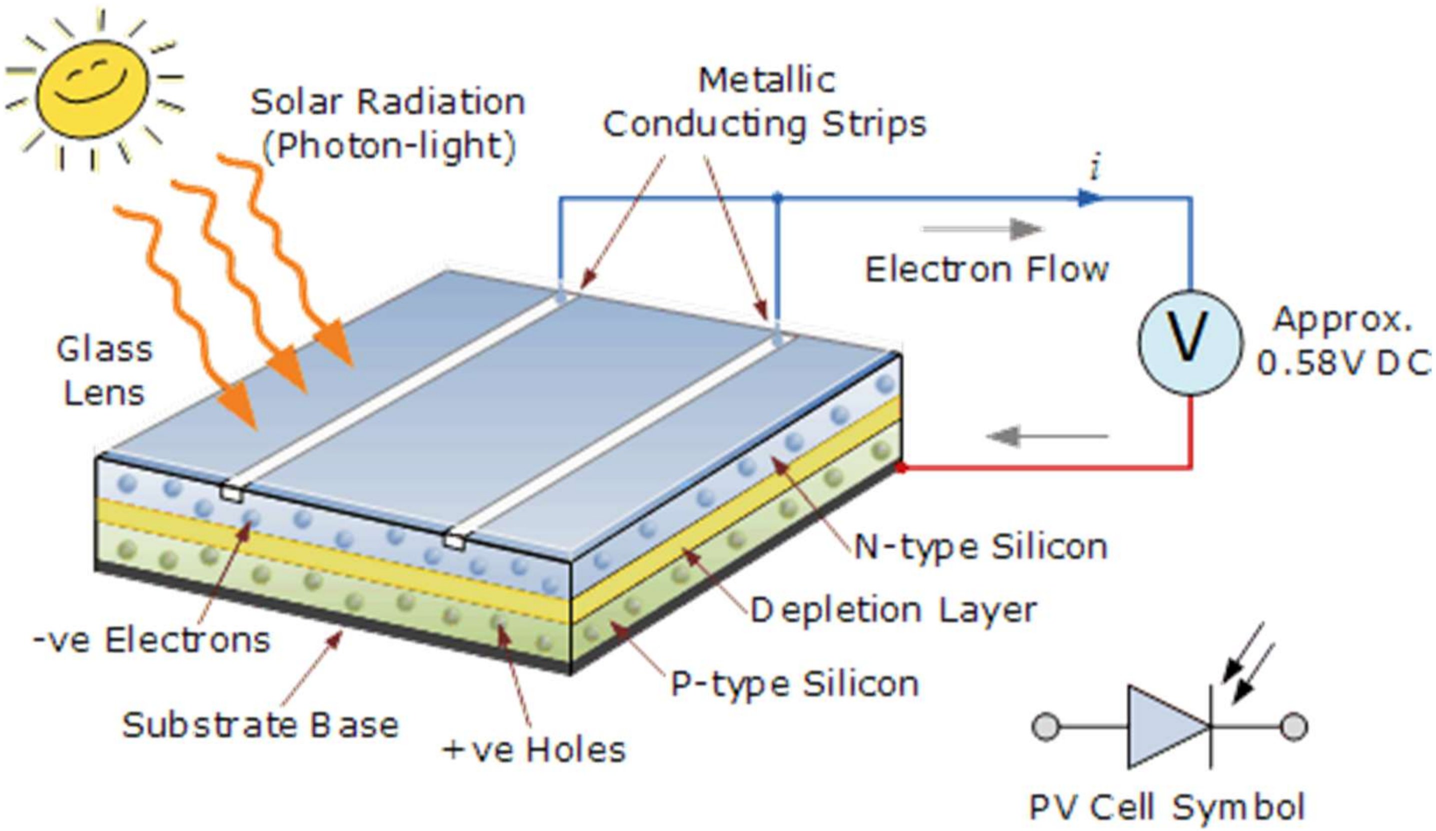
The electron–hole pairs, generated in the depletion region due to the absorption of solar radiation, are driven by the internal electric fields producing a photo current ($I_L$).

The direction of the photocurrent is in a direction opposite that of the forward current.

Absorption of more light produces more electron–hole pairs; hence, this current depends linearly on the light intensity. This effect is known as the photovoltaic effect.

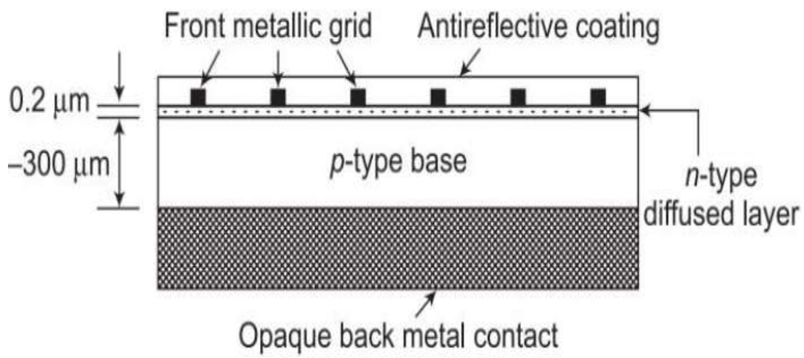
The p–n junction with this effect is referred to as a **solar cell.**

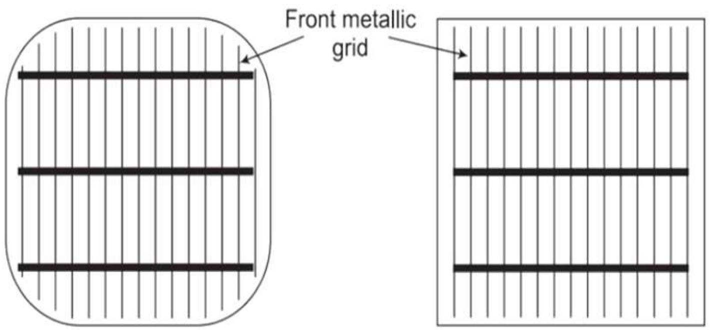
# Basic Principle of Solar PV



# Solar Cell construction

- The bulk material of P-type silicon with thickness 100 to 350 microns, with a thin layer of N-type silicon formed at the top surface.
- The top active surface of the N layer has an ohmic contact with metallic grid structure to collect the current produced by impinging photons.
- The metallic grid covers minimum possible top surface area to leave enough uncovered surface area for incoming photons.
- Bottom inactive surface has an ohmic metallic contact over the entire area.

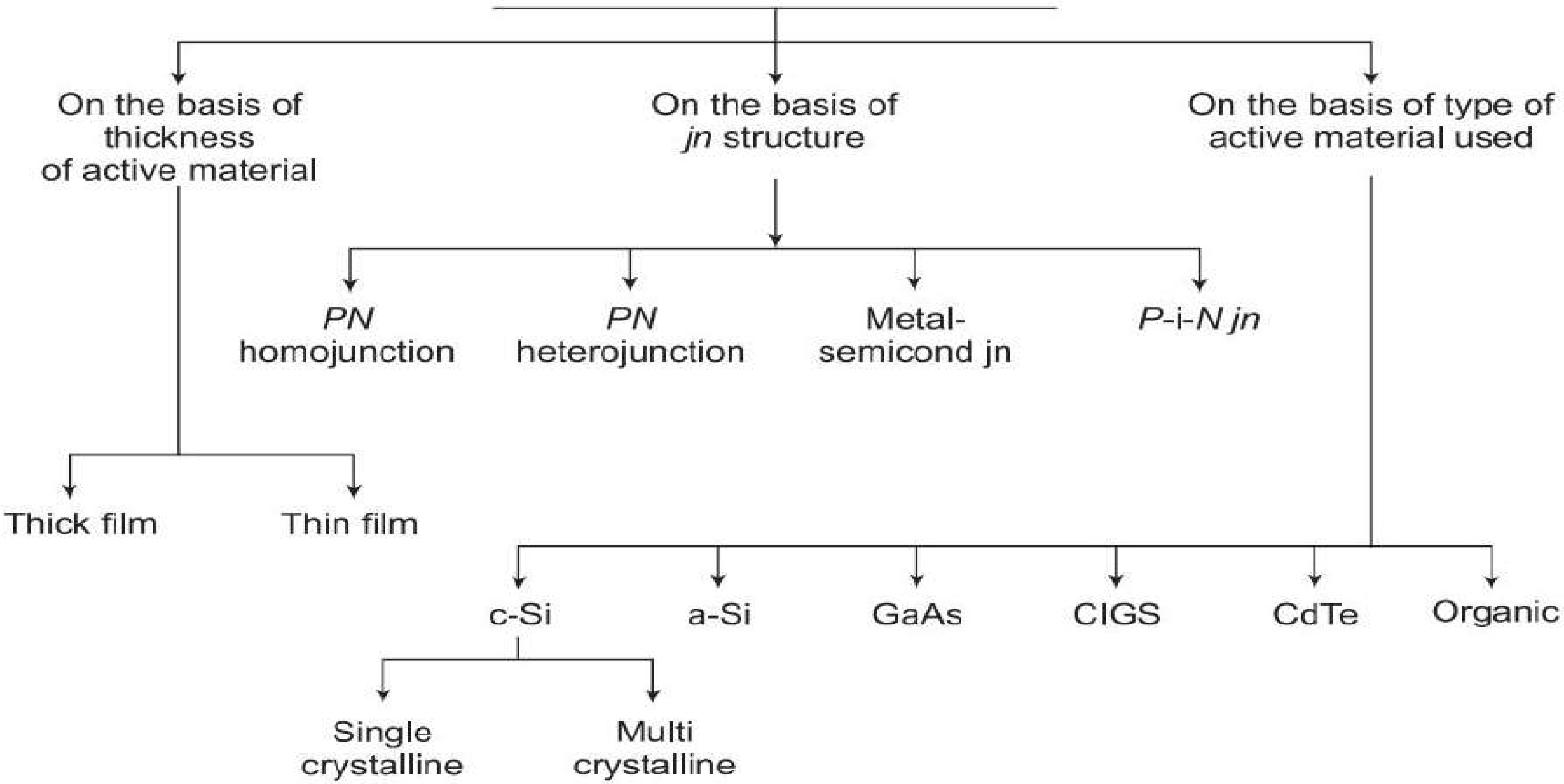


# Solar Cell construction

- These two metallic contacts on P and N layers respectively form the positive and negative terminals of the solar cell.
- Anti-reflective coating, textured finish of the top surface and reflective, textured rear surface, to capture maximum photons and direct them toward the junction are also provided.

# Classification of Solar Cells (refer text)



# Solar Cell (Photovoltaic) Materials

- There are various types of solar cell materials, namely, (a) single crystal, (b) polycrystalline, (c) amorphous silicon, (d) compound thin-film material, as well as other semiconductor absorbing layers, which give highly electrical-efficient solar cells for specialized applications.
- Crystalline silicon cells (c-Si) are expensive. However, they are most popular due to their easy availability.
- Amorphous silicon thin-film solar cells are less expensive. The amorphous silicon layer is used with both hydrogen and fluorine incorporated into the structure.
- The a-Si:F:H alloys are produced by the glow-discharge decomposition of Si $F_4$ in the presence of hydrogen. The efficiency of a-Si module lies between 6 and 8 %.

# Solar Cell (Photovoltaic) Materials

- Thin-film solar cells can be manufactured by using a variety of compound semiconductors.
- These compound materials include (a) copper–indium selenide ($CuInSe_2$), (b) cadmium sulphide (CdS), (c) cadmium telluride (CdTe), (d) copper sulphide ($Cu_2S$), and (e) indium phospate (InP). The stability of the copper– indium selenide ($CuInSe_2$) solar cell appears to be excellent.
- Combinations of different band-gap materials in the tandem configurations lead to photovoltaic generators with greater efficiencies.

# Characteristics of Solar Cell

- Characteristic of an ordinary silicon PN junction

$$I = I_o\left\{\exp\left(\frac{V}{V_T}\right) - 1\right\}$$

- Where $I_o$ is reverse saturation current, $V_T$ is known as voltage equivalent of temperature and is given as $V_T = kT/q$.
  - k is Boltzmann's constant (in J/K), T is temperature in Kelvin and q is charge of an electron in coulombs.
  - At room temperature (20°C), value of $V_T$ is 25.283 mV.

# Characteristics of Solar Cell

- When the PN junction is illuminated, the characteristics gets modified in shape and shifts downwards as photon-generated component ($I_L$) is added with reverse leakage current

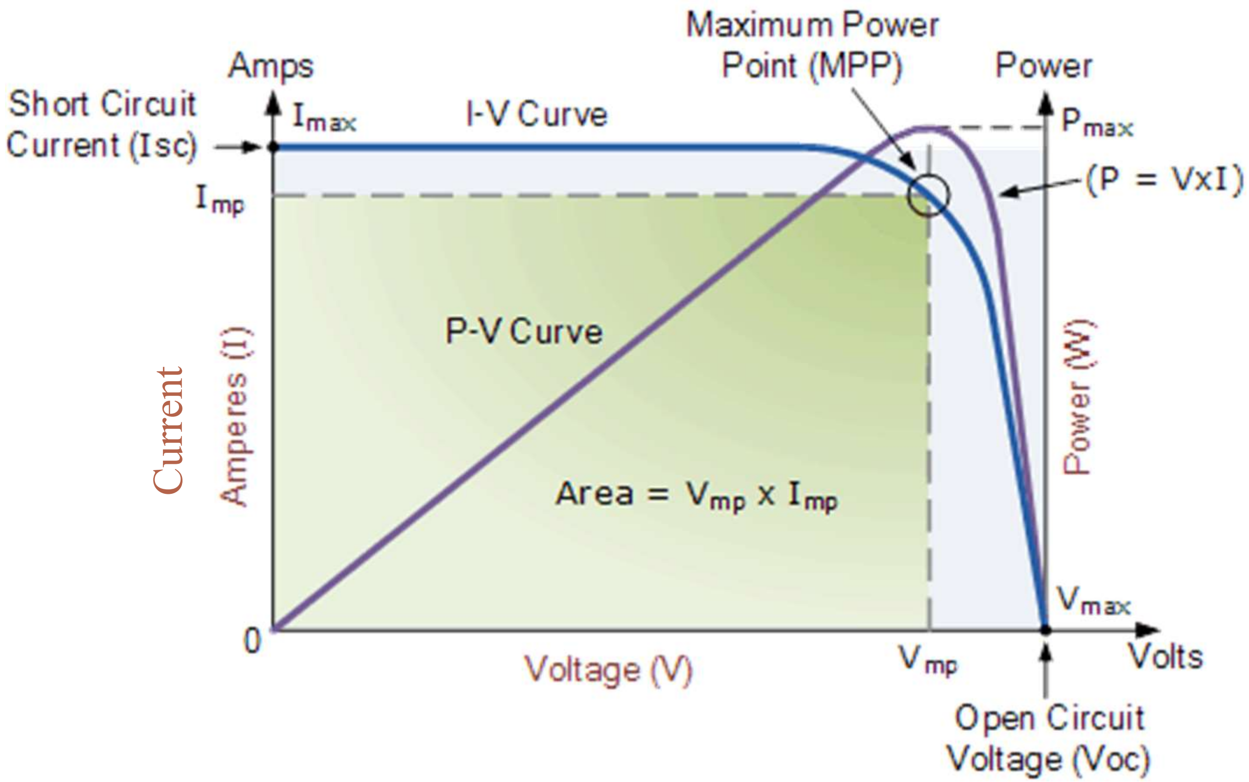
$$I = -I_L + I_o\left\{\exp\left(\frac{V}{V_T}\right) - 1\right\}$$

- $I_L$ is known as light generated current and its magnitude will depend on solar insolation.
- When the junction is short-circuited at its terminals, V becomes zero and a finite current $I_{sc} = -I_L$ flows through the external path.
- When the junction is left open at its terminals and no load is connected across the terminals, no current can flow, therefore, I = 0, the voltage available across the terminals, $V_{oc}$ is known as open circuit voltage.

{Typically for $I_{sc}$ = 2A, $I_o$ = 1 nA and at room temperature, $V_{oc}$ is 0.54 V}

# Characteristics of Solar Cell

## I-V Characteristics and P-V Characteristics



# Characteristics of Solar Cell

## Basic Parameters of the Solar Cell

### 1. Overall Current (I)

The overall current (I) flowing through a solar cell is given by

$$I = I_D - I_L$$

$$I = I_0 \left[ exp\left(\frac{eV}{kT}\right) - 1 \right] - I_L$$

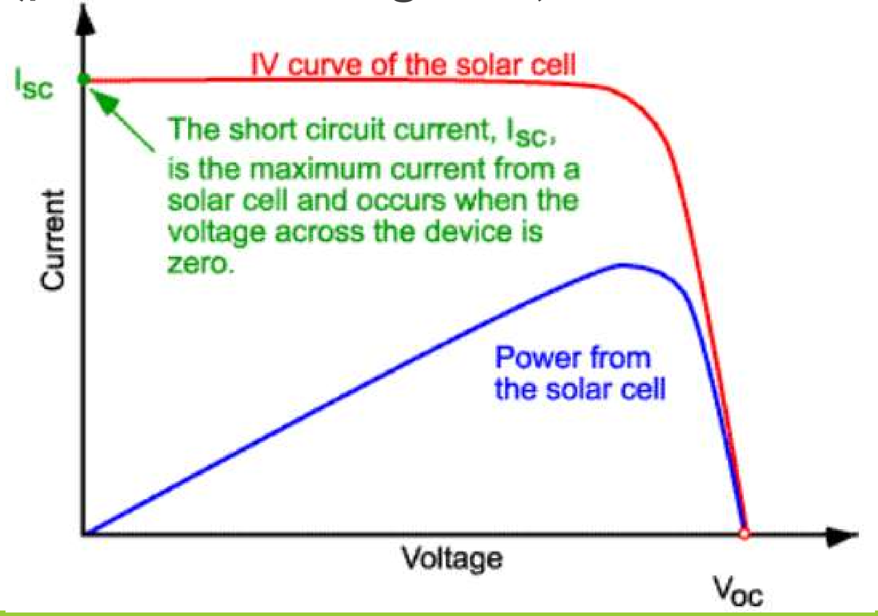
Where $I_D$ is the diode dark current; $I_L$ is the light induced current; $I_o$ leakage current.

# Characteristics of Solar Cell

## Basic Parameters of the Solar Cell

### 2. Short Circuit Current ($I_{SC}$)

The short-circuit current is the light-induced current that occurs when the load in the circuit is zero, i.e., both terminals (positive and negative) of the solar cell are connected together.



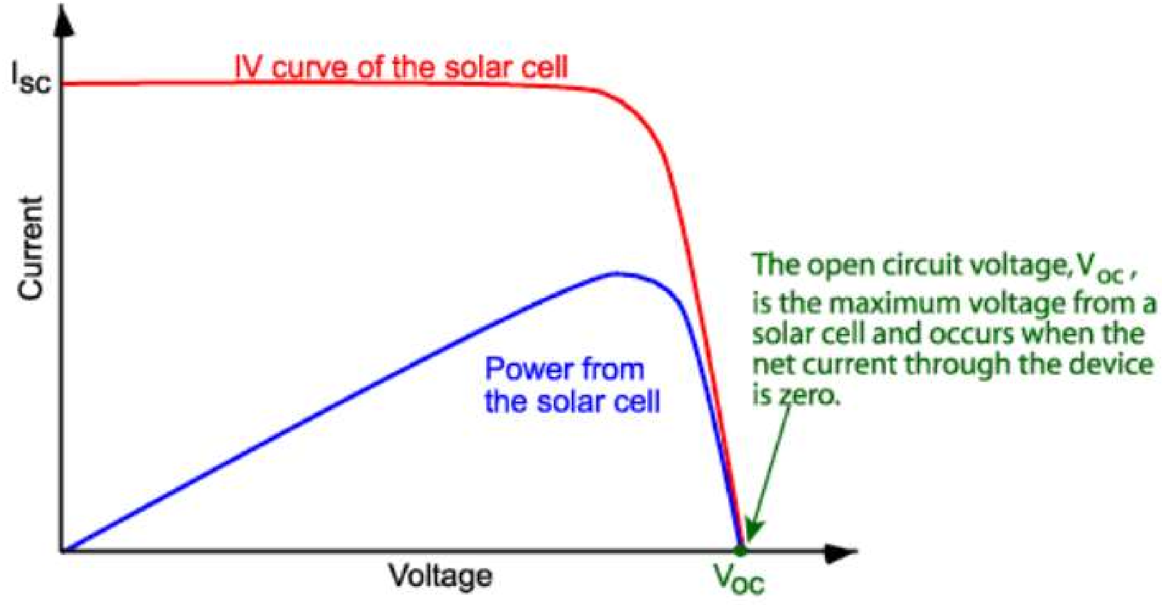
# Characteristics of Solar Cell

## Basic Parameters of the Solar Cell

### 3. Open-circuit voltage (Voc)

The open-circuit voltage is the voltage across the solar cell when there is no current flowing in the circuit, i.e., there is infinite resistance between the terminals of the solar cell.

$$V_{oc} = V_T \ln\left\{\left(\frac{I_L}{I_o}\right) + 1\right\}$$

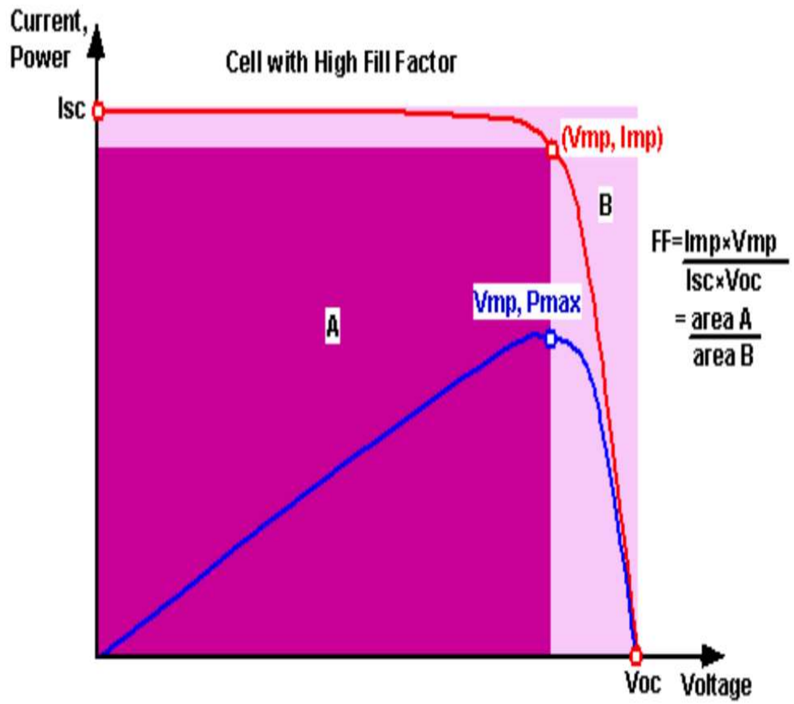


# Characteristics of Solar Cell

## Basic Parameters of the Solar Cell

### 4. Fill Factor (FF)

- The Closeness of the characteristics to rectangular shape measures the quality of the cell.
- The fill factor gives an idea of the maximum power output withdrawn from the solar cell for a given $V_{oc}$ and $I_{sc}$.
- The value of FF under ideal conditions is unity.
- Deviation from the ideal value is due to defects and contact resistance. The lower the value of the FF, the less sharp will be the I–V curve.
- For an Si solar cell, the maximum value of FF is 0.88.




$$FF = \frac{P_{\max}}{V_{oc} \times I_{sc}} = \frac{I_{\max} \times V_{\max}}{V_{oc} \times I_{sc}}$$

# Characteristics of Solar Cell

## Basic Parameters of the Solar Cell

### 5. Efficiency

Ratio of maximum electric power output to the power in incident solar radiation

$$Efficiency, \eta = \frac{Electrical\ power\ output}{Solar\ power\ input} = \frac{P}{\varphi} = \frac{P}{I_T \times A}$$

Where *P* = *V* x *I* is the power delivered by the PV generator; $\varphi = I_t \times A$ is the solar radiation falling on the PV generator; $I_T$ is the solar intensity; *A* is the surface area irradiated.

$$\eta_{max} = \frac{V_{mpp} I_{mpp}}{Solar\ Power} \times 100 = \frac{FF * V_{OC} * I_{SC}}{Solar\ Power} \times 100 = \frac{FF \times V_{OC} * I_{SC}}{A \times I_T} \times 100$$

Highest efficiency ≈ 25%, Commercial cells ≈ 12-15%

# Solar PV Module

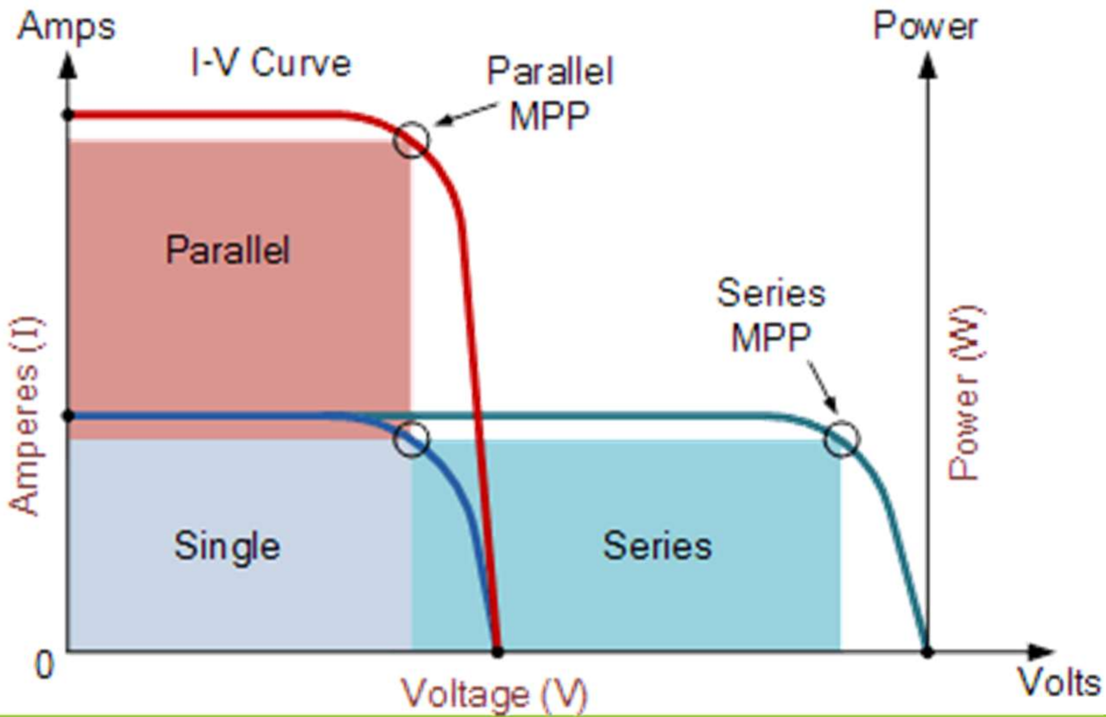
- Individual solar cells electrically connected together to increase their power output.
- These interconnected cells are also sandwiched between top transparent and bottom opaque/transparent covers to prevent mechanical damage to the solar cells, to prevent water or water vapour from corroding the electrical contacts, to prevent dust, moisture and protect against outdoor harsh conditions.
- This inter-connected packaged solar cells are known as **PV modules.**
- Available in different sizes and shapes depending on the required electrical output (36 cells most common).

# Solar PV Module

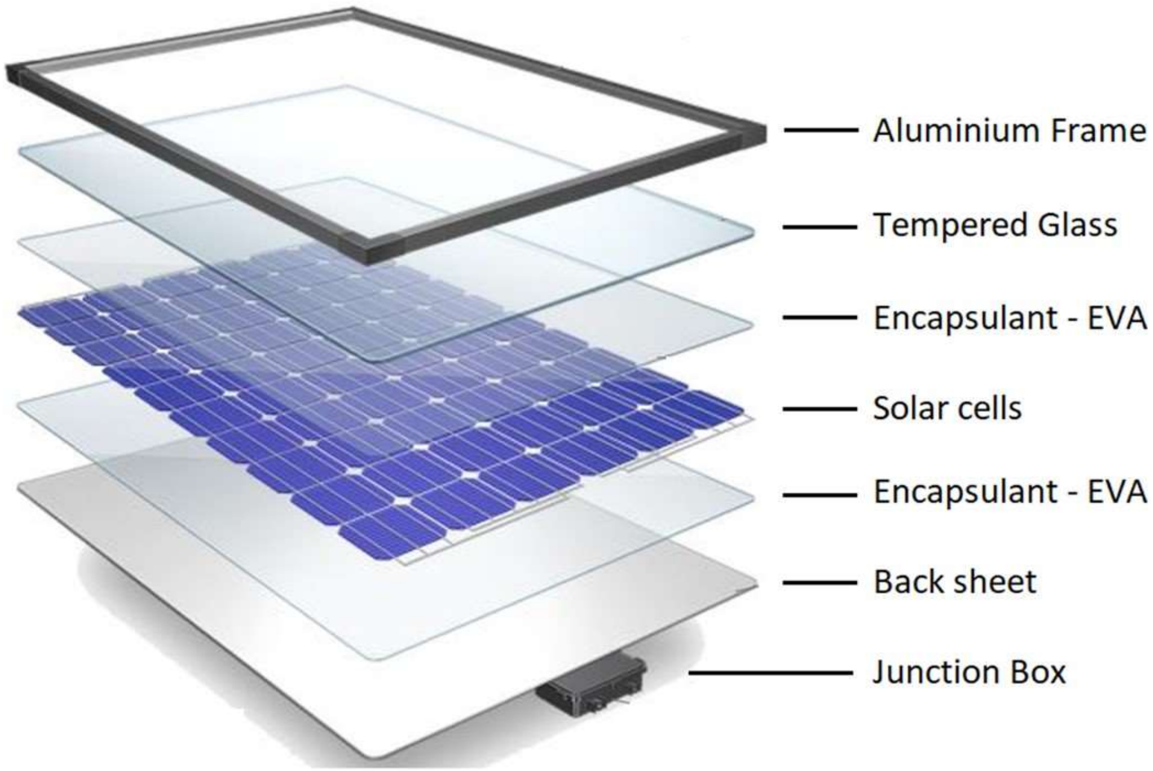
- The number and size of series-connected solar cells primarily decides the output of the PV module.
- The electrical interconnections as well as weather and climatic conditions are some other factors that affect the output of a PV module.
- Most of the modules are rigid, but thin-film solar cell–based modules are flexible.
- The positive and negative terminals for interconnections are provided on the backside of PV module.
- PV modules are rated in terms of peak watts (Wp), which is the power produced at 1000 W/m$^2$.

# Solar PV Module

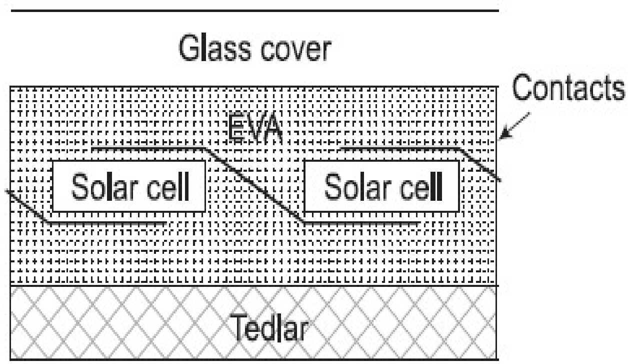
Cells are connected in series to get higher voltage, while in parallel to get higher current.



# Solar PV Module




- PVF



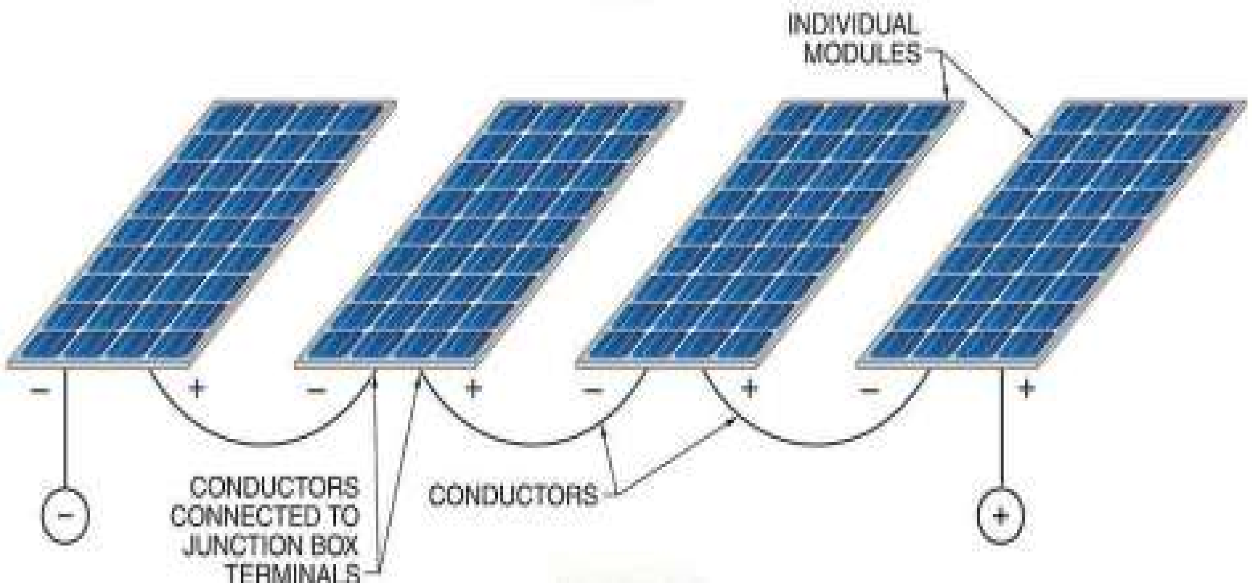
# Series and Parallel Combination of PV Modules

- PV modules are connected in series or in parallel to increase voltage and current ratings.
- When PV modules are connected in series/parallel, it is desired to have the maximum power production at the same current/voltage.
- Modules connected in series : Output voltage increases with same current.
- Modules connected in parallel: Output current increases with same voltage.

# Solar PV Panel

- Several solar modules are connected in series/parallel to increase the voltage/current ratings.
- When modules are connected in series, it is desirable to have each module's maximum power production occur at the same current.
- When modules are connected in parallel, it is desirable to have each module's maximum power production occur at the same voltage.
- Solar panel is a group of several modules connected in series-parallel combination in a frame that can be mounted on a structure.

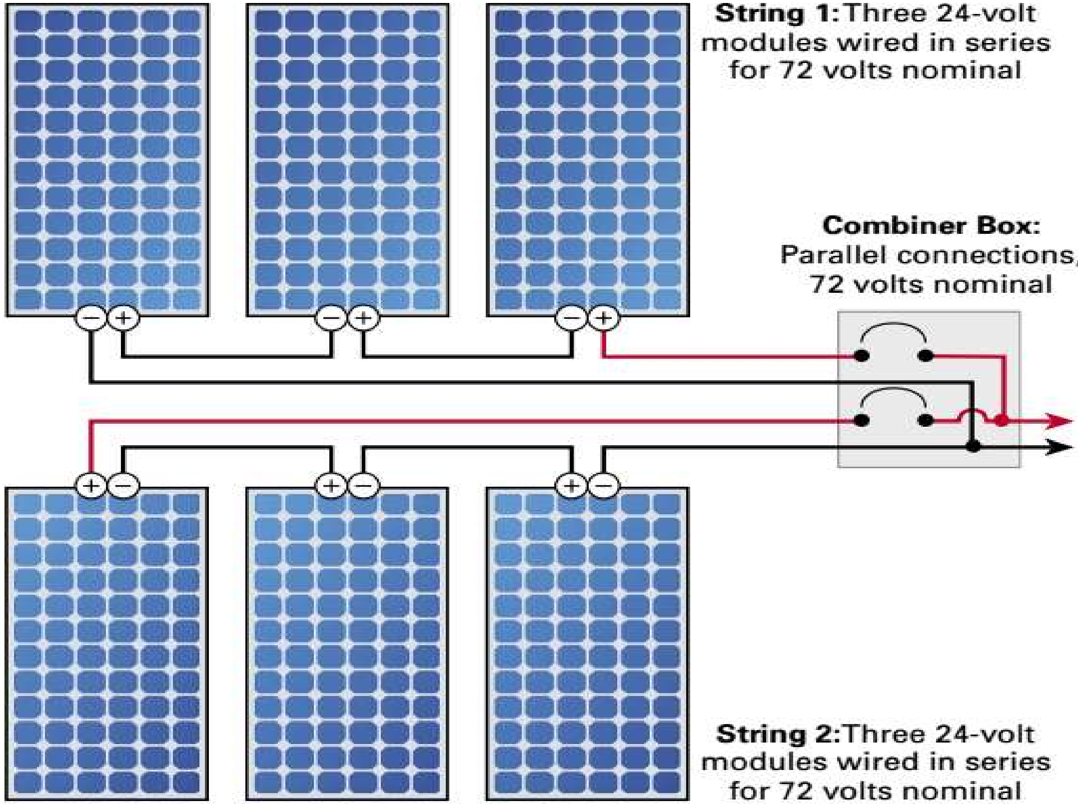
# Solar PV Panel



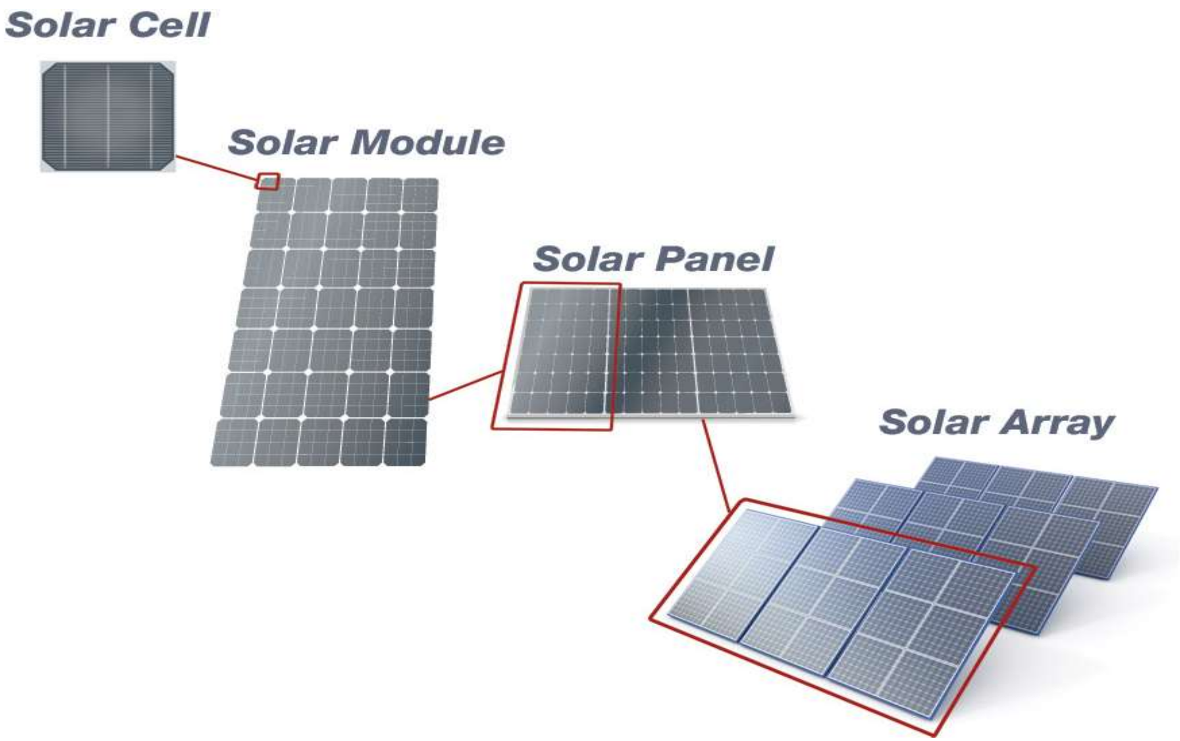

# Solar PV Array

- **Solar PV Array:** Large number of interconnected solar panels.
- The size of a PV array depends on the requirement of electrical power.
- Panels are connected in series to achieve the desired voltage; then such series-connected strings are connected in parallel to enhance the current and hence power output from the array.
- Panels may be installed as stationary or with sun tracking mechanism. It is important to ensure that an installed panel does not cast its shadow on the surface of its neighboring panels during a whole year.
- The layout & mechanical design of the array (tilt angle, height of panels, clearance among the panels, etc.) are carried out taking into consideration the local climatic conditions, ease of maintenance, etc.

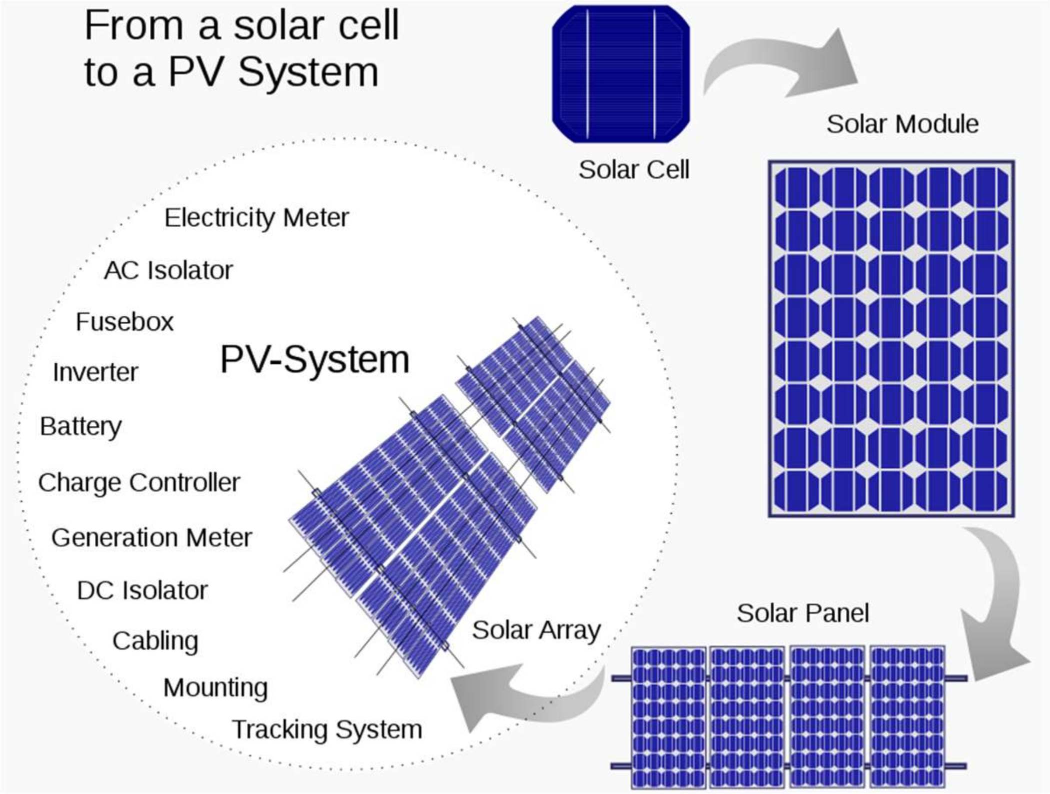
# Solar PV Array



# Cell-Module-Panel-Array



# Solar PV System



# Solar PV System : Classification

1. Central Power Station System

2. Distributed System

(a) Stand Alone or Off Grid

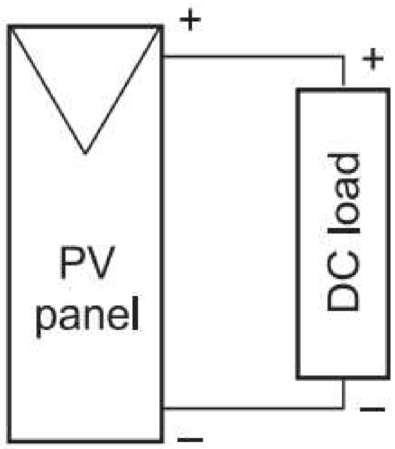
(b) Grid-Interactive or Grid Tied

(c) Hybrid PV System

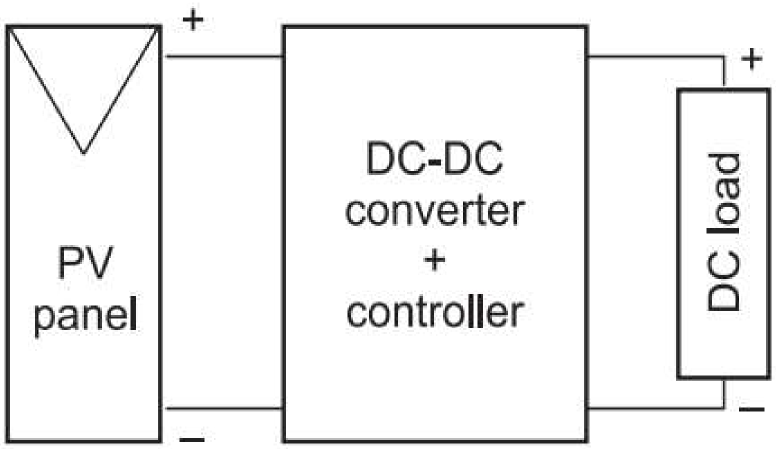
(d) Small System for Consumer Applications

# Solar PV System

## Stand alone PV system



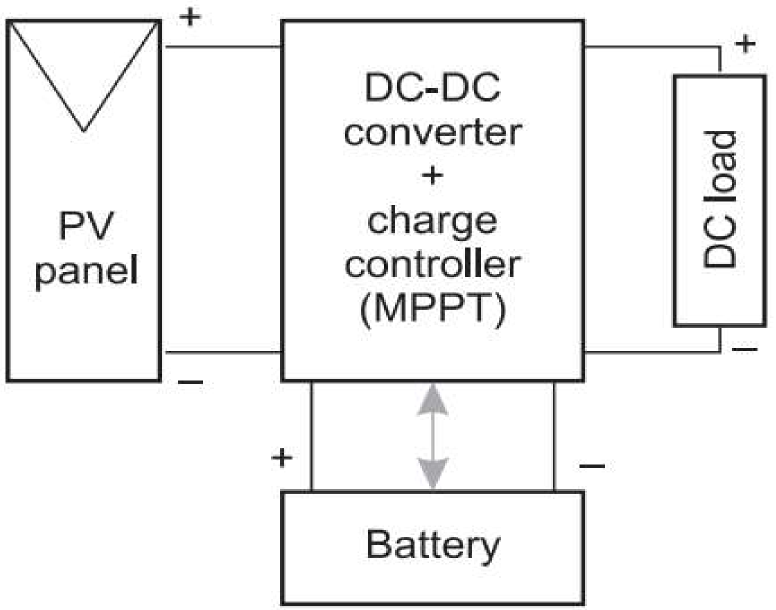

Config. 1: Unregulated system with dc load



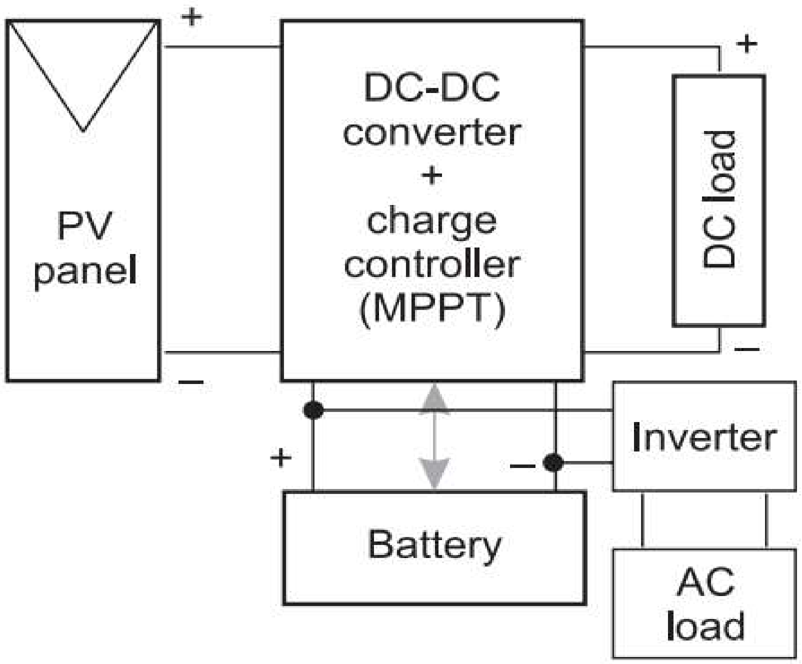

Config. 2: Regulated system with dc load

# Solar PV System

## Stand alone PV system



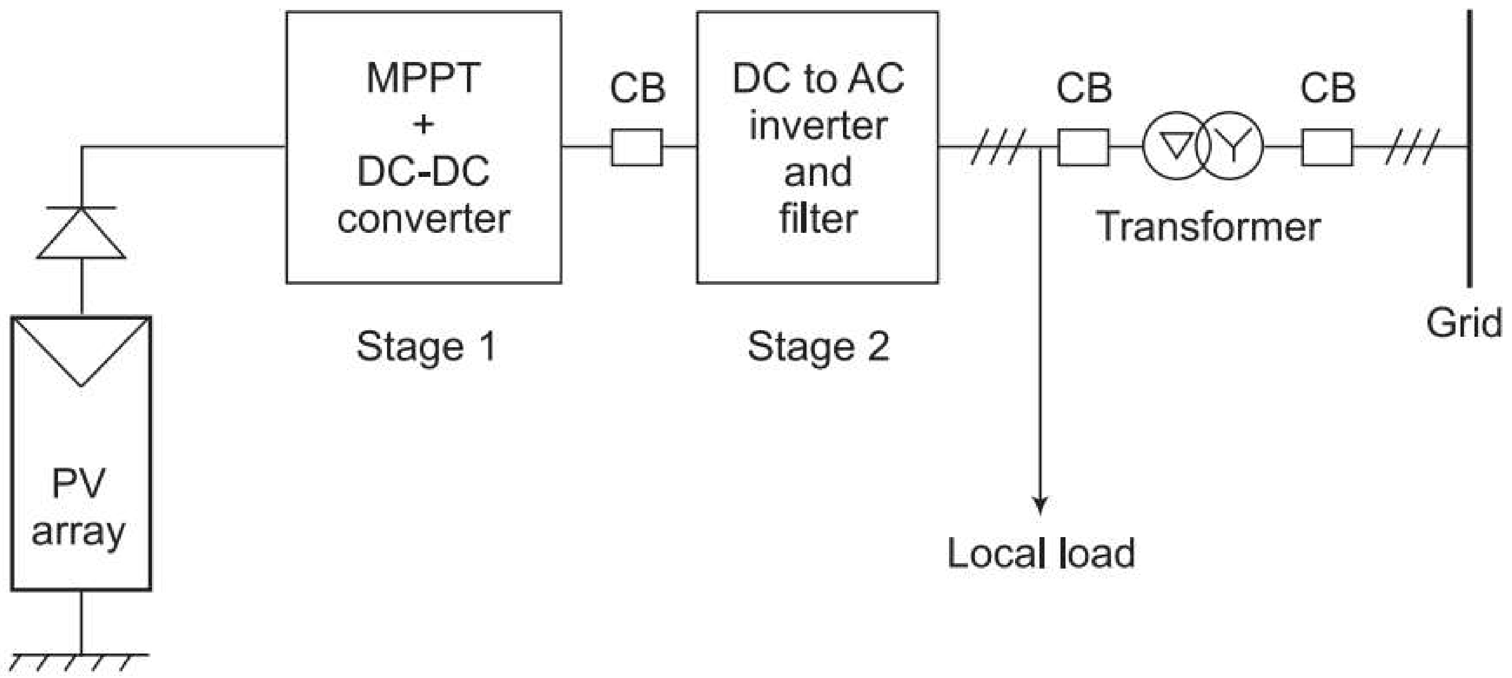

Config. 3: Regulated system with battery and dc load




Config. 4: Regulated system with battery and dc/ac load

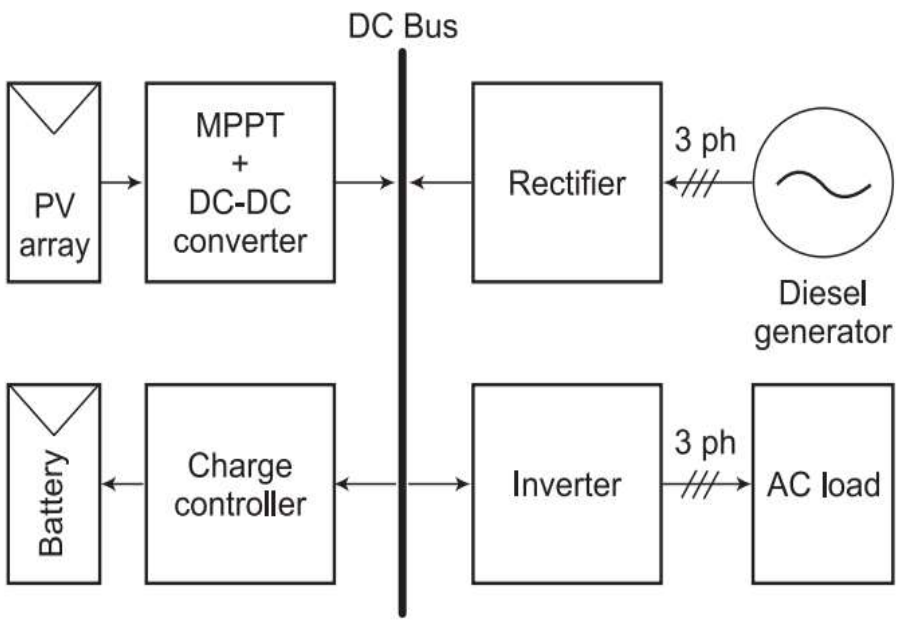
# Solar PV System

## Grid connected PV system

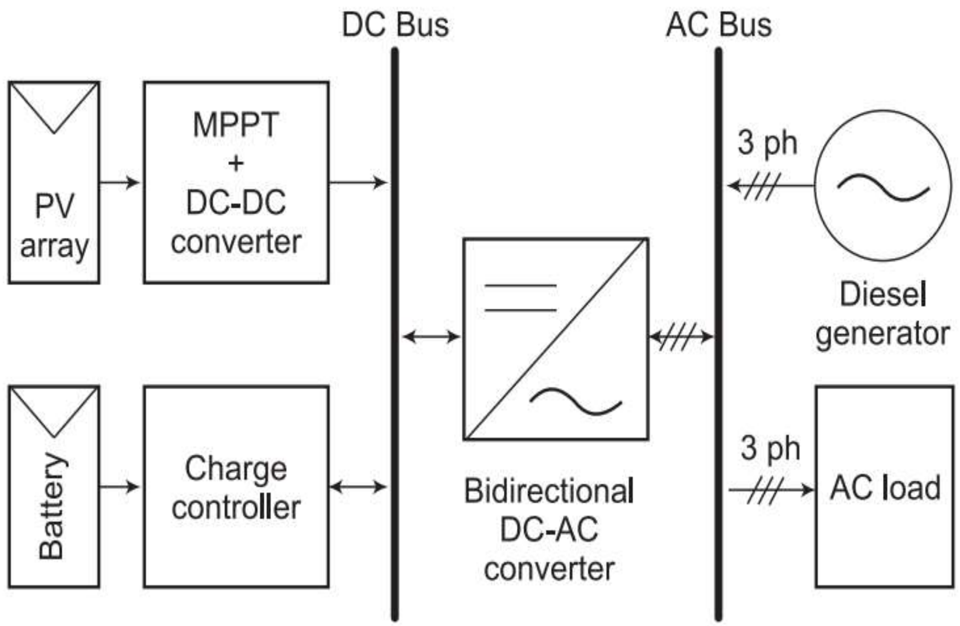


# Solar PV System

## Solar Hybrid PV system




(a) Series configuration




(b) Parallel configuration