# RENEWABLE ENERGY SOURCES AND APPLICATIONS
## (Subject Code: 21MEO112T)


Dr. Vivek Kumar Pathak

***Course Outcomes (CO):***

CO-1: Recognize solar energy systems and current applications

CO-2: Describe knowledge on wind energy conversion systems

CO-3: Discuss the ocean, hydro and geothermal energy theories and concept

CO-4: Enumerate the use biologically degradable resources and its energy conversion processes

CO-5: Identify renovate future energy need towards renewable energy

**Unit-1 - Solar Energy**

Introduction to Energy Science & Technology, Forms of Energy, Nature of solar radiation - spectrum - constant - extra-terrestrial radiation on a horizontal surface, attenuation of solar radiation, beam, diffuse and global radiation. Measurement of global - diffuse - beam radiation. Principle of working of solar water heating systems - cookers- desalination systems - ponds - chimney power plant, central power tower power plants. Classification of solar concentrators, Basic definitions - concentration ratio, angle of acceptance, Drawbacks/Real field issues in solar thermal systems, sensible and latent heat thermal energy storage systems, Solar photovoltaic systems: basic working principle, components, and its applications.

## Introduction to Energy Science & Technology



**Energy Science and Technology** is an interdisciplinary field that explores the production, conversion, storage, transmission, and utilization of energy in various forms with least pollution and with highest economy.

It forms the foundation for understanding how energy is harnessed and used in different systems, with a particular focus on sustainable and renewable energy sources.

## Energy ?

- ❖ Energy is the capability to produce motion; force, work; change in shape, change in form, etc.

## Importance of Energy

- ❖ Energy is the important part of modern civilization.
- ❖ It powers : homes, industries, transportation, and communication.
- ❖ With growing global population and technological advancements, the demand for energy is steadily increasing.

*At the same time, environmental concerns and the depletion of fossil fuels have led to an urgent need for cleaner and renewable energy alternatives.*

# Forms of Energy

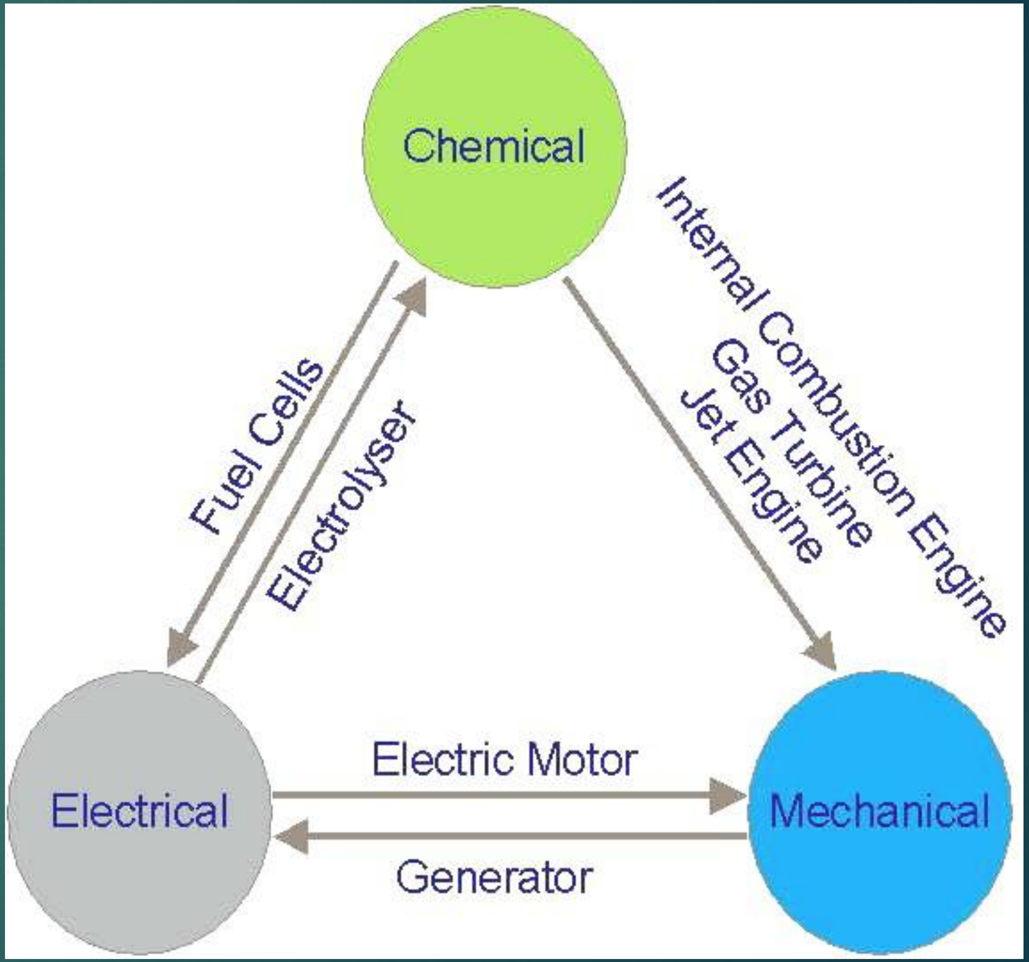
- **Kinetic Energy** – Energy due to motion
- **Potential Energy** – Stored energy due to position
- **Thermal Energy** – Energy related to temperature
- **Chemical Energy** – Stored in chemical bonds (e.g., fuels)
- **Electrical Energy** – Flow of electric charge
- **Radiant Energy** – Carried by electromagnetic waves (e.g., solar radiation)
- **Nuclear Energy** – Stored in the nucleus of atoms

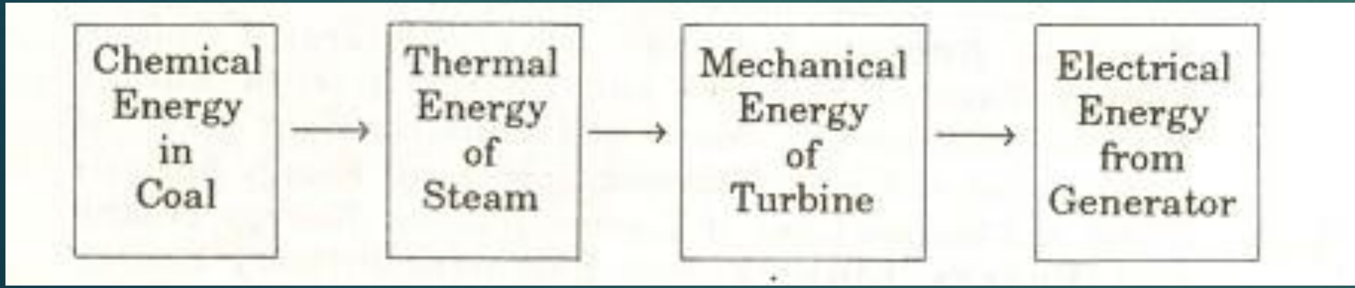
*Energy can be converted from one form to another, but according to the **First Law of Thermodynamics or Law of Conservation of Energy**, it cannot be created or destroyed.*

# Law of conservation of Energy



- Energy can neither be created nor destroyed but can be transformed from one form to another form.



# Mechanical Energy



Mechanical energy is the **sum of kinetic and potential energy** in a system.

- **Kinetic Energy (KE)**: Energy possessed by a body in motion.
  - **Formula**: $KE=1/2(mv^2)$
  - **Example**: Wind moving turbine blades, flowing water in hydroelectric power.

- **Potential Energy (PE)**: Stored energy due to position or configuration.
  - **Formula**: $PE=mgh$
  - **Example**: Water stored in a dam has gravitational potential energy.

# Thermal (Heat) Energy

Thermal energy is due to the motion of particles within a substance; it determines temperature and heat flow.

- **Source**: Solar radiation, geothermal energy, combustion.
- **Example**:
  - Solar thermal collectors use sunlight to heat water.
  - Geothermal plants tap Earth's internal heat.
  - Biomass combustion releases thermal energy.

# Chemical Energy

Stored in **chemical bonds** of molecules. When these bonds break during chemical reactions, energy is released.

**Examples**:

- **Fossil Fuels**: Coal, oil, natural gas.
- **Biomass**: Organic material used in gasification or fermentation.
- **Hydrogen Fuel**: Used in fuel cells to produce electricity.

# Electrical Energy

Results from the movement of **electric charges (electrons)** through a conductor.

- **Example**:
  - ❖ Generated in wind turbines, hydropower plants, solar PV cells.
  - ❖ Stored in batteries and transmitted via power lines.

# Radiant (Solar) Energy

Carried by **electromagnetic waves**, particularly from the sun.

- **Wavelength range**: UV, visible, infrared.

**Example**:

- Solar PV cells convert sunlight into electricity.
- Solar thermal systems convert sunlight into heat for heating or desalination.

## Nuclear Energy

Stored in the **nucleus of atoms**; released during nuclear fission (splitting atoms) or fusion (joining atoms).

- **Example**:
  - Nuclear power plants use uranium fission.
  - Fusion is the process powering the sun (still experimental on Earth).

# Energy Conversion Examples in Renewable Systems



| Energy Source | Input Energy Form | Output Energy Form | Application Example |
|---|---|---|---|
| **Solar PV** | Radiant (solar) | Electrical | Rooftop solar panels |
| **Wind Turbine** | Kinetic (wind) | Mechanical → Electrical | Wind farms |
| **Hydropower** | Potential (water) | Kinetic → Electrical | Dams |
| **Biomass** | Chemical | Thermal/Electrical | Biomass power plant |
| **Geothermal** | Thermal (Earth's heat) | Thermal → Electrical | Geothermal station |
| **Fuel Cell** | Chemical ($H_2$) | Electrical | Fuel-cell vehicles |

## Conventional vs. Non-Conventional Energy Sources



- **Conventional sources**: Fossil fuels like coal, petroleum, and natural gas; nuclear energy.
- **Non-conventional (Renewable) sources**: Solar, wind, hydro, geothermal, ocean, and biomass energy. These sources are sustainable, eco-friendly, and often regionally available.

## Renewable and Non-Renewable Energy Resources

- Renewables are those which are renewed by the nature again and again and their supply is not affected by rate of consumption (Eg. Solar , geothermal, Tidal , wind, biomass etc)
- Non-renewable resources cannot be replaced once they are used. (Eg. Coal, Oil, Gas etc.)

# Energy Technology



Energy technology encompasses the tools, systems, and processes used to:

- **Harvest energy** (e.g., solar panels, wind turbines)
- **Convert energy** to usable forms (e.g., generators, inverters)
- **Store energy** (e.g., batteries, hydrogen storage)
- **Distribute energy** (e.g., power grids)
- **Utilize energy** efficiently in applications (e.g., electric vehicles, LED lighting)

# What is solar energy?



- Solar energy is radiant light and heat from the Sun that is harnessed using a range of ever-evolving technologies such as solar heating, photovoltaics, solar thermal energy, solar architecture, and molten salt power plants.


Orchid Solar Systems

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# Solar energy can be utilized directly in two ways:

(i) by collecting the radiant heat and using it in a thermal system (‘Solar Thermal’ system )

or

(ii) by collecting and converting it directly to electrical energy using Photovoltaic system. (‘Solar Photovoltaic’ (SPV) system)

*The output of sun is $2.8 \times 10^{23}$kW. The energy reaching the earth is $1.5 \times 10^{18}$ kWh/year.

*The earth reflects about 30% of the sunlight that fall on it. This is known as earth’s albedo.

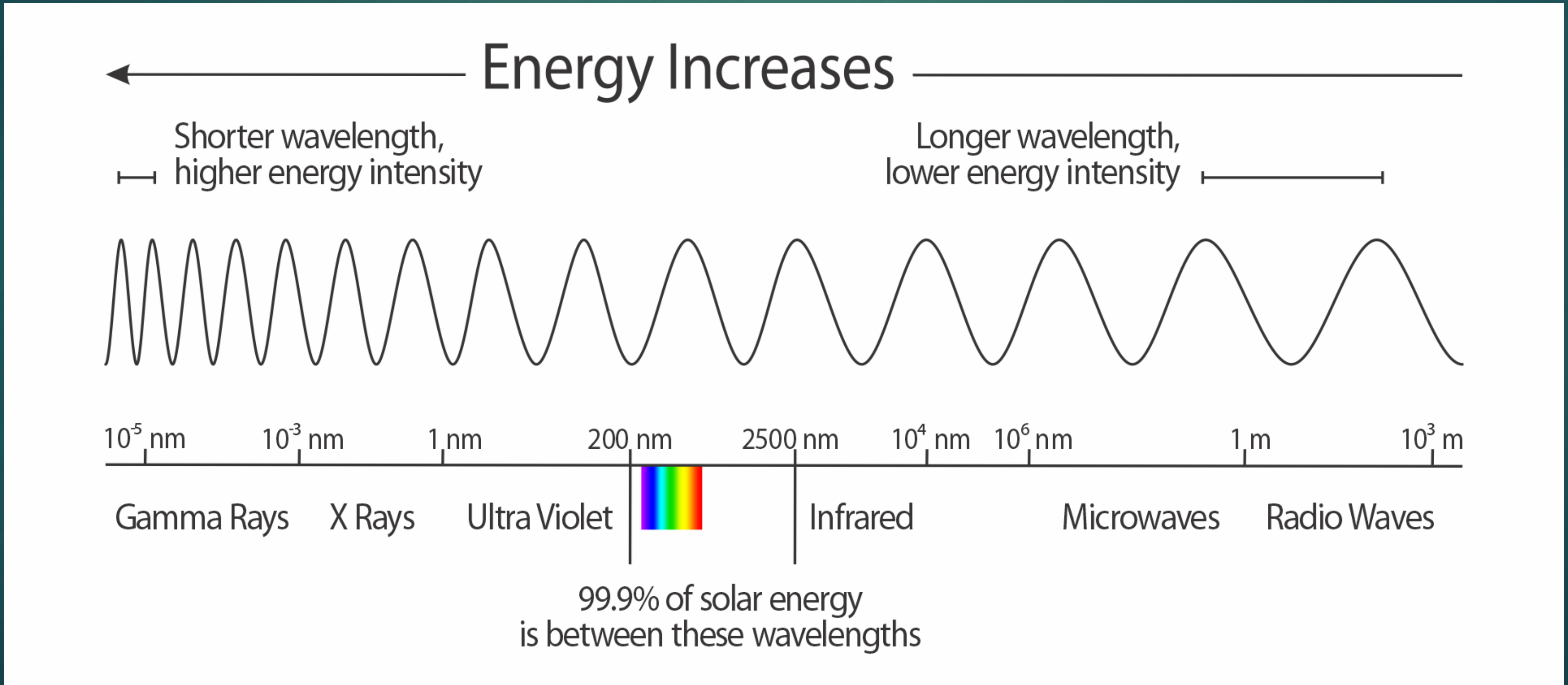
# Nature of Solar Radiation

- Solar radiation is radiant energy emitted by the sun from a nuclear fusion that converts electromagnetic energy.
- Solar radiation= Thermal radiation + electromagnetic radiation
- The units to measure solar radiation is watt/$m^2$.
- One of the main cause of climate changes due to solar radiation.

# Electromagnetic spectrum

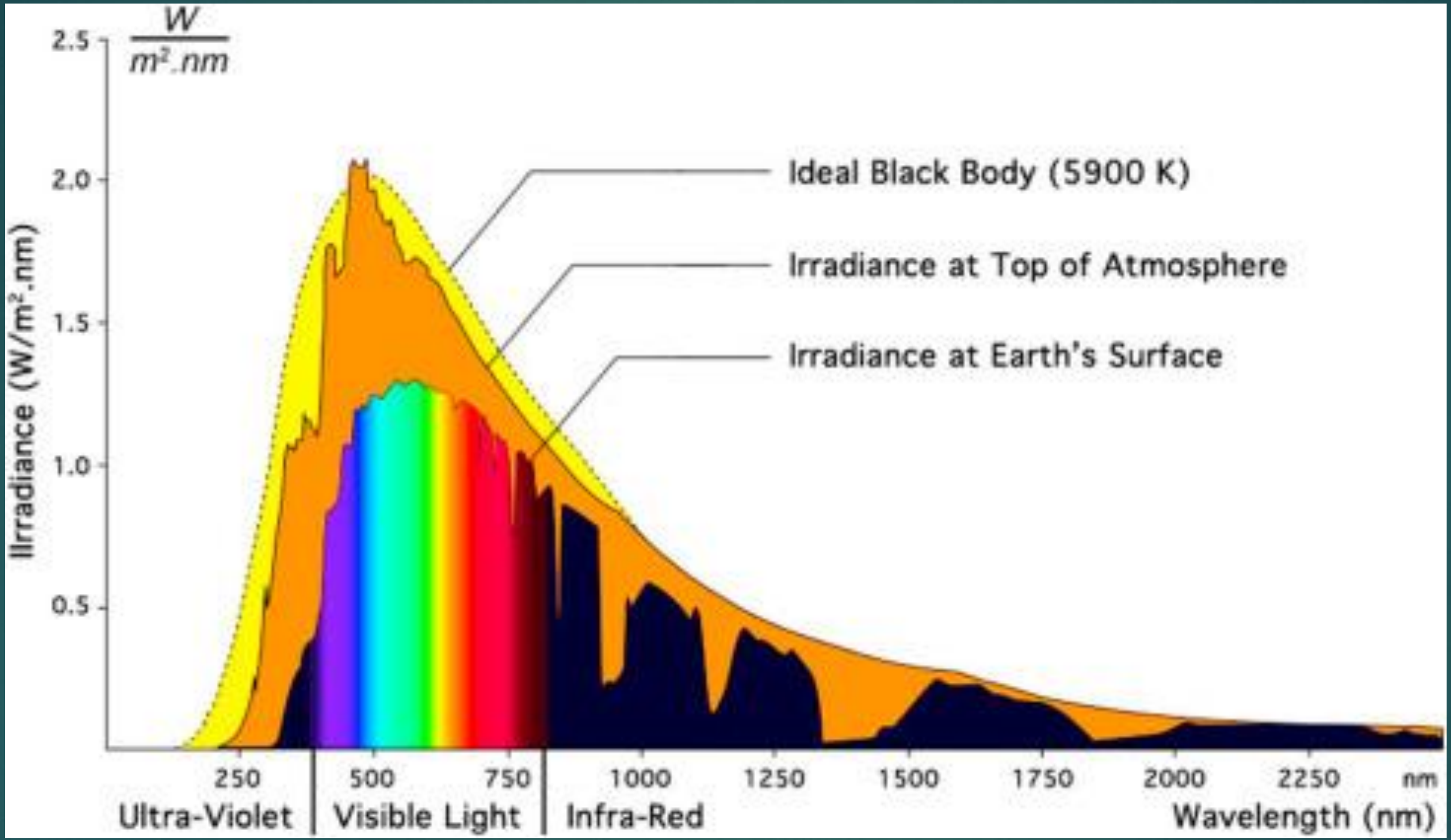


The solar radiation spectrum encompasses the entire range of electromagnetic radiation emitted by the sun, extending from gamma rays to radio waves. While the sun emits across this vast spectrum, the portion that reaches Earth's surface is primarily composed of ultraviolet (UV), visible, and infrared (IR) light.



# Solar Spectrum

- Distribution of solar energy across wavelengths
- Range: 0.29 µm – 3.0 µm
- Ultraviolet, Visible, Infrared regions
- Peak in visible range (~0.5 µm)



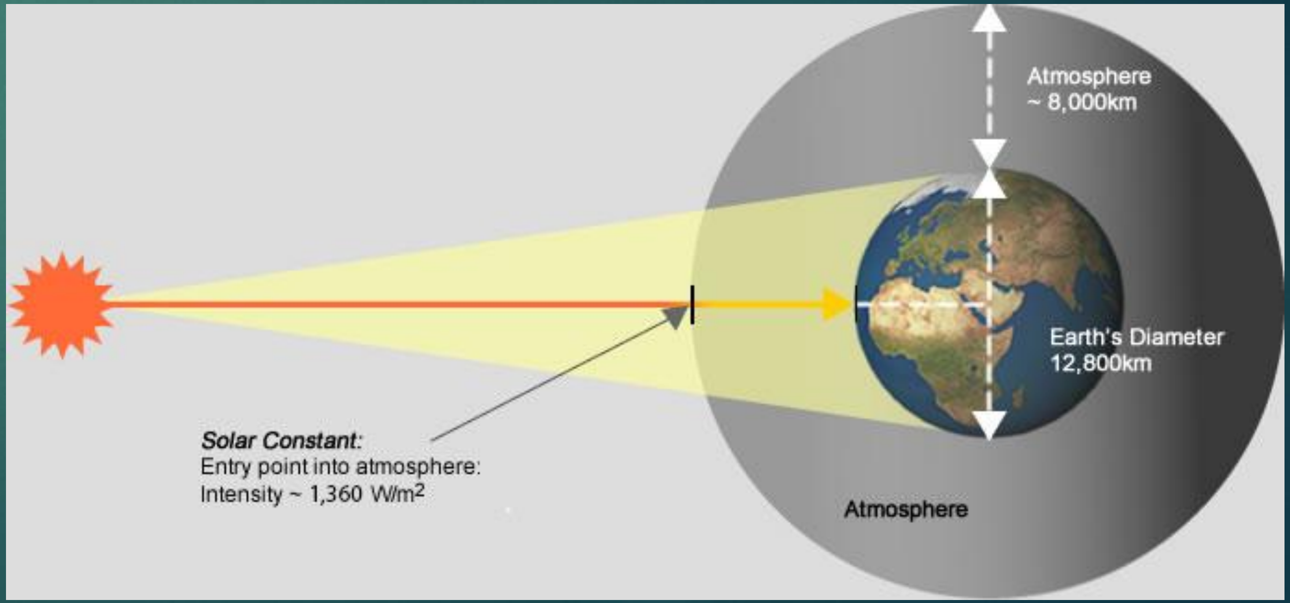
W / m².nm
2.5
2.0
1.5
1.0
0.5
Irradiance (W/m².nm)
Ideal Black Body (5900 K)
Irradiance at Top of Atmosphere
Irradiance at Earth's Surface
250
500
750
1000
1250
1500
1750
2000
2250
nm
Ultra-Violet
Visible Light
Infra-Red
Wavelength (nm)


**8%** **46%** **46%**

# Solar Constant

- The rate at which the solar energy arrived at the top of the atmosphere is called solar constant $I_{cs}$.
- This is the amount of energy received in unit time on unit area perpendicular to the sun's direction at the mean distance of the earth from the sun.
- Definition: Amount of solar energy received outside Earth's atmosphere on a surface normal to the Sun's rays
- Value: approx. 1360 $W/m^2$
- Importance in energy calculations

$$I_{ext} = I_{sc}\left[1 + 0.033\cos\left(\frac{360n}{365}\right)\right]$$



# Extraterrestrial and Terrestrial Radiation

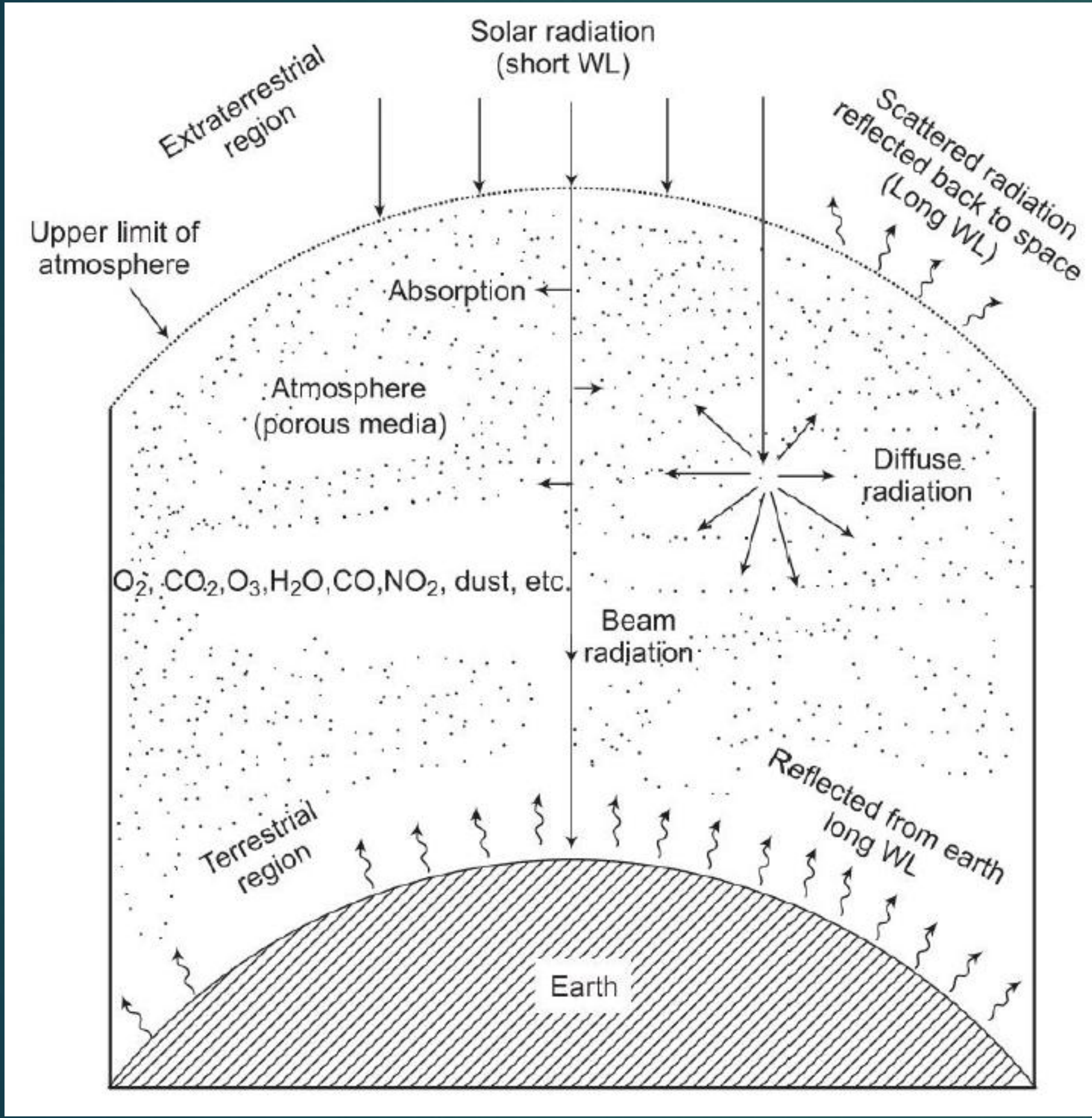


- Solar radiation incident on the outer atmosphere of the earth is known as Extraterrestrial Radiation, $I_{ext}$.
- The extraterrestrial radiation, being outside the atmosphere, is not affected by changes in atmospheric conditions.
- Solar radiation that reaches earth surface after passing through the earth's atmosphere is known as Terrestrial Radiation.

# *Attenuation of solar radiation*



- The reduction in the solar radiation reaching to the Earth's surface outside the atmosphere is due to Absorption and Scattering in the atmosphere.
- Absorption: Shorter wavelengths (UV) are absorbed by the oxygen or Ozone in the atmosphere. The longer Wavelength are absorbed by carbon dioxide and moisture in the atmosphere. This results in narrowing the bandwidth.
- Scattering: The portion of solar radiation passing though the atmosphere scattered by components such as the water vapour dust. The portion of scatter radiation always reach the earth surface as diffuse radiation.
- Radiation finally reached at the earth surface consists partly Beam radiation and partly defuse radiation




- **Beam radiation (direct radiation)**: solar radiation that travels directly from the sun to the Earth without being scattered or reflected.
- **Diffuse radiation**: solar radiation that has been scattered or reflected by the atmosphere.
- The sum of direct and diffuse radiation is called <u>total (or) global solar radiation</u>.

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

The term Solar Insolation (incident solar radiation) is defined as total solar radiation energy received on a given surface area in a given time (in $J/m^2$ or $kWh/m^2$).

Sun at Zenith: Position of the sun directly over head.

# *Measurement of global - diffuse - beam radiation.*

Solar radiation data are measured mainly by following instruments:

- (i) Pyranometer: A pyranometer is designed to measure global (total) radiation, usually on a horizontal surface but can also be used on an inclined surface. When shaded from beam radiation by using a shading ring, it measures diffuse radiation only.
- (ii) Pyrheliometer: An instrument that measures beam radiation by using a long and narrow tube to collect only beam radiation from the sun at normal incidence.
- (iii) A sunshine recorder measures the sunshine hours in a day.

# Pyranometer

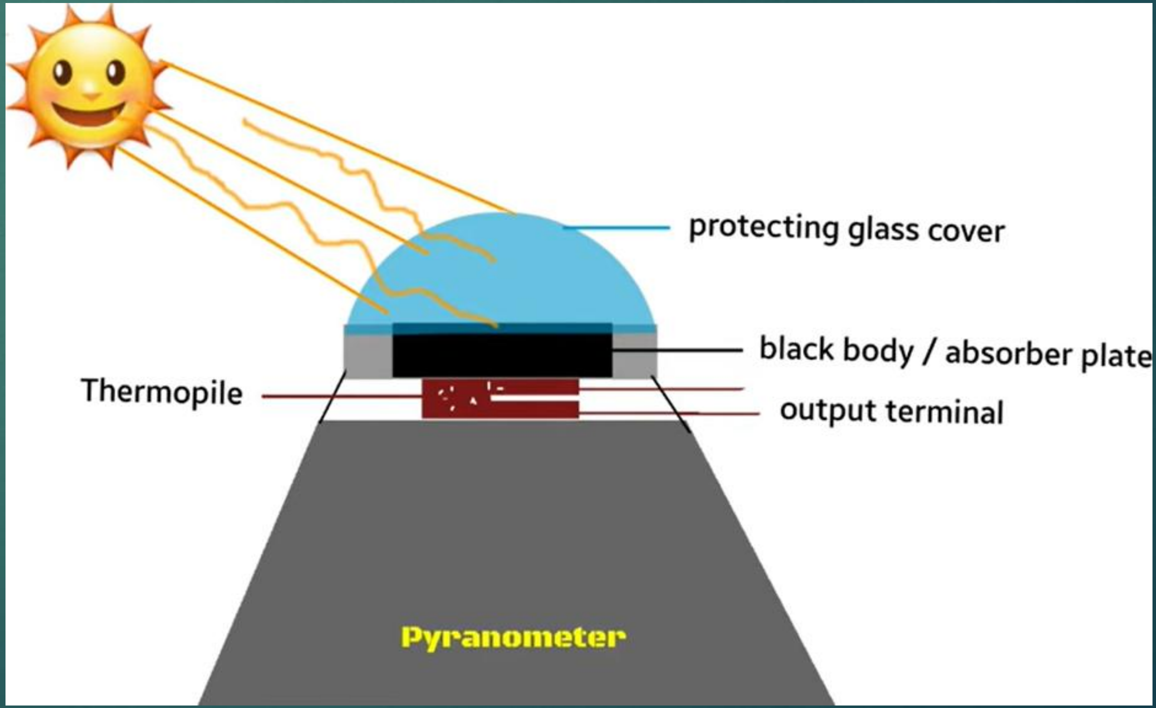


Pyranometer
(Courtesy: Eppley Laboratory)

A pyranometer with shadow band
(Courtesy: Eppley Laboratory)

**Working Principle of a Pyranometer**

Pyranometers operate based on the principle of thermopiles or photodiodes. When solar radiation strikes the sensor surface, it generates heat or produces an electric current proportional to the radiation intensity. This signal is then amplified and converted into irradiance units using calibration factors.

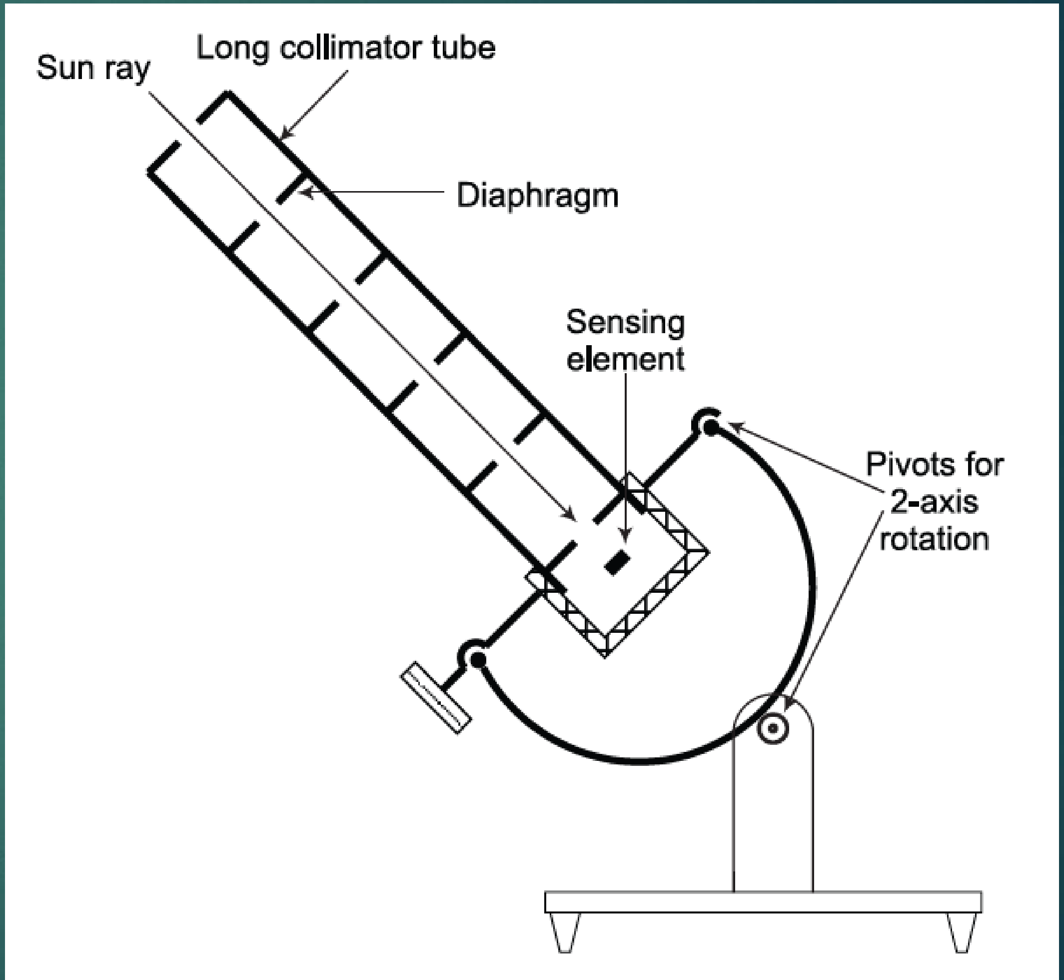


**How works**

1. **Sensor Design**: The heart of a pyranometer is a sensor that's typically made of thermopiles or photodiodes. These sensors are designed to convert solar radiation into an electrical signal proportional to the solar irradiance.
2. **Absorption of Solar Radiation**: The surface of the pyranometer is designed to absorb incoming solar radiation. This surface is often treated to minimize reflection and maximize absorption.
3. **Thermopiles or Photodiodes**: In thermopile-based pyranometers, the absorbed radiation heats up a set of thermocouples, which generate a voltage proportional to the temperature difference. In photodiode-based pyranometers, photons from the incoming solar radiation create electron-hole pairs in semiconductor materials, generating a current or voltage.
4. **Calibration**: Pyranometers need to be carefully calibrated to ensure accuracy. This involves comparing the electrical output of the sensor to known standards under various conditions.
5. **Data Processing**: The electrical signal generated by the sensor is processed by associated electronics. This may involve amplification, filtering, and conversion to digital form for further processing or display.
6. **Output**: The output of the pyranometer typically represents the solar irradiance measured in watts per square meter ($W/m^2$) or equivalent units.

# Pyrheliometer





Principle & working: The external structure of the Pyrheliometer instrument looks like a telescope. The lens can be pointed in the direction of the sun & the solar radiation will flow throughout the lens. The irradiance of solar enters into this device through a crystal quartz window and directly reaches onto a thermopile. So this energy can be changed from heat to an electrical signal that can be recorded. A calibration factor can be applied once changing the mV signal to a corresponding radiant energy flux, and it is calculated in $W/m^2$ .

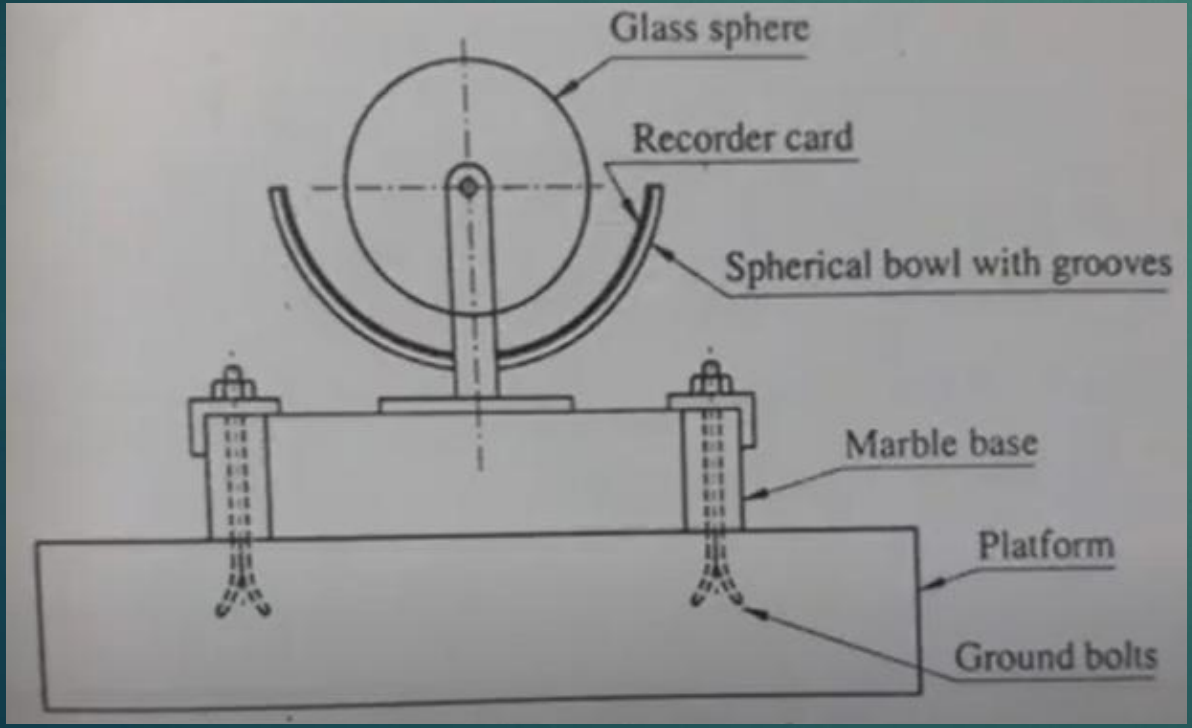
Differences: Pyrometer measures diffuse solar irradiance, while pyrheliometer measures direct sun’s irradiance. Pyrometer used the technique of visual comparison between a calibrated light source and the targeted object’s surface. Pyrheliometer used to measure direct sun’s irradiance with the help of thermopile.

A thermopile is an electronic device that converts thermal energy into electrical energy.

# Sunshine recorder



A sunshine recoder is a device that records the amount of sunshine at a given location. The results provide information about the weather and climate as well as the temperature of the geographical area.




A Campbell-Stokes sunshine recorder concentrates sunlight through a glass sphere onto a recording card placed at its focal point. The length of the burn trace left on the card represents the sunshine duration.

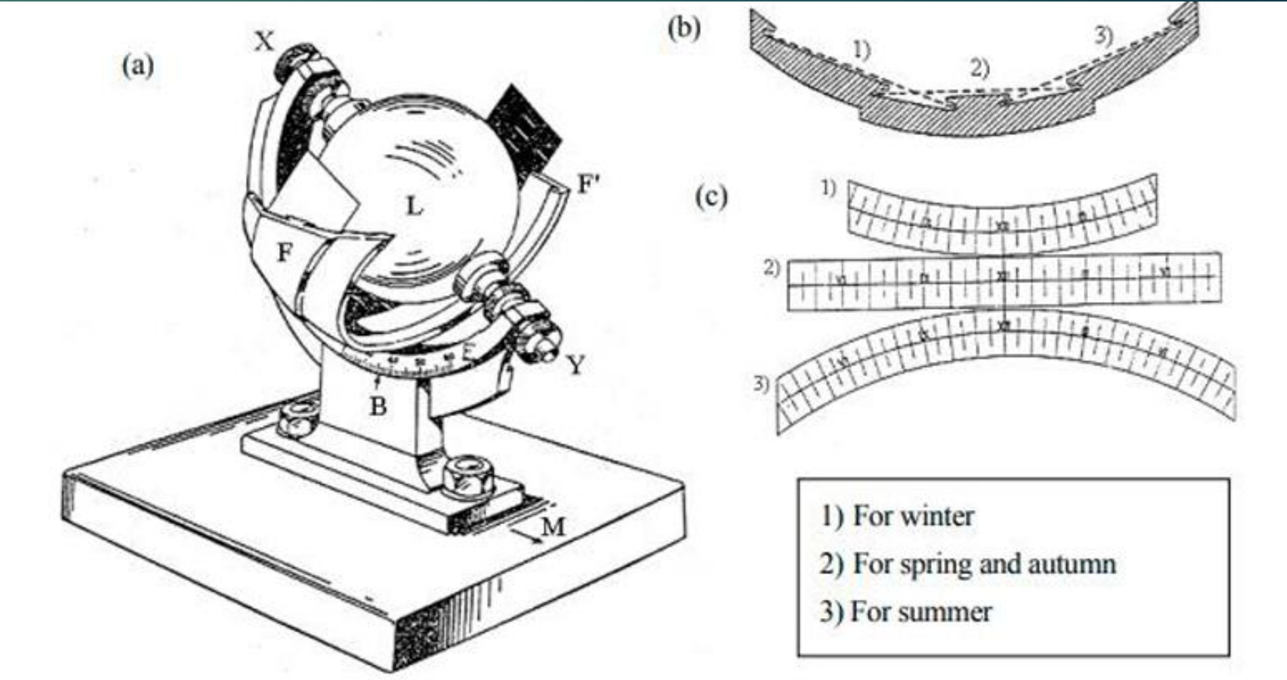



**Figure 7.1 Campbell-Stokes sunshine recorder**

**(a) Structure**

**(b) Cross section of bowl and grooves**

**(c) Recording cards**

Solar collector :

- A solar collector absorb Incident solar radiation and convert it to useful heat which is used for heating Fluid Such as water Oil Or air.
- The surface of a solar collector is designed for high absorption and low emission
- It can be two type : Flat Collector and Concentrated Collector

Flat collector: used where temperature below 100° are required. (liquid heating or air heating)

Concentrating collect : Reflect the radiation from reflector and concentrate the radiation on the point of absorbing surface.

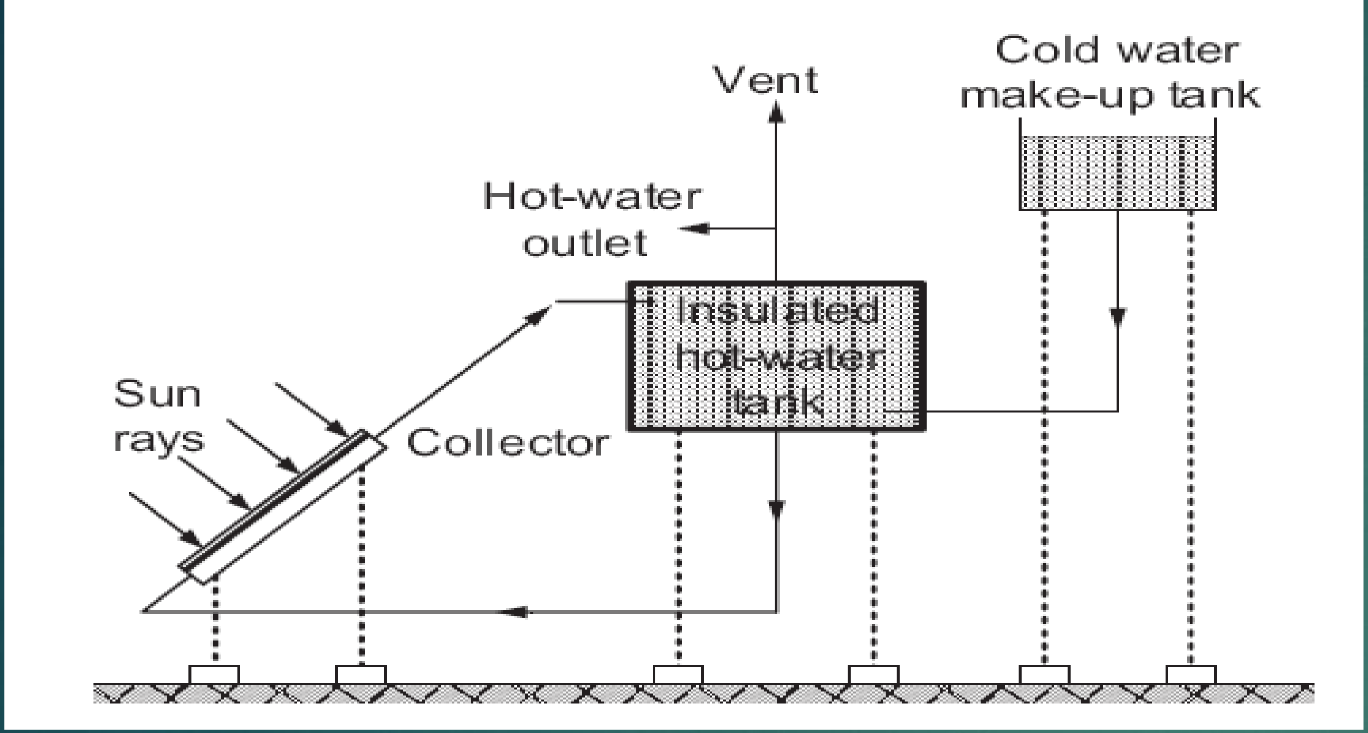
*Principle of working of solar water heating systems - cookers- desalination systems - ponds - chimney power plant.*

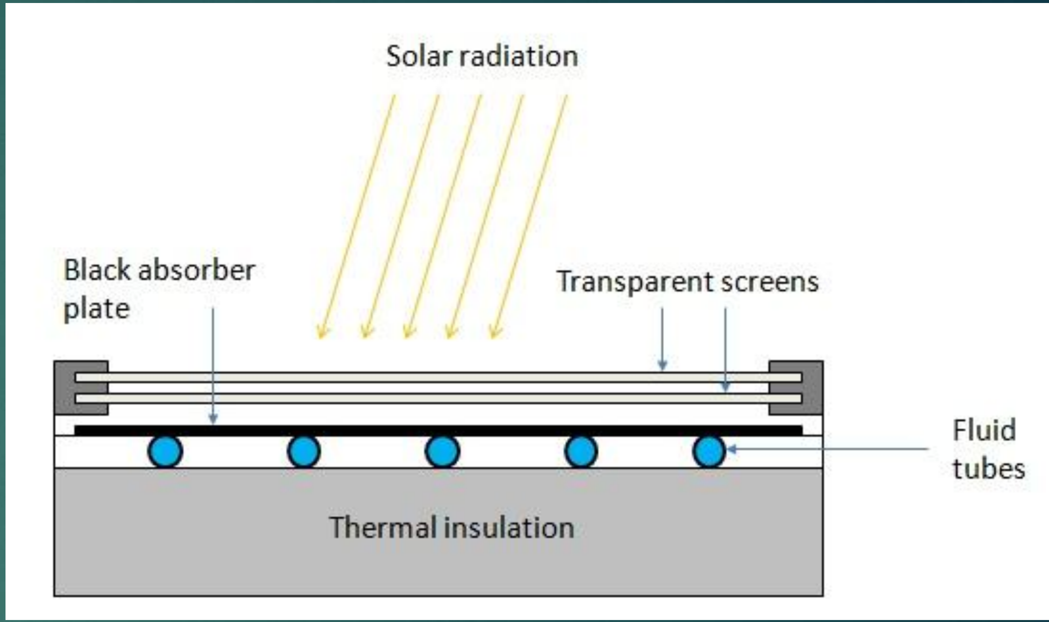
# SOLAR WATER HEATER

- A solar water heater consists of a collector to collect solar energy and an insulated storage tank to store hot water.
- The solar energy incident on the absorber panel coated with selected coating transfers the heat to the riser pipes underneath the absorber panel.
- The water passing through the risers get heated and is delivered to the storage tank.
- The re-circulation of the same water through absorber panel in the collector raises the temperature to about 80° C (Maximum) in a good sunny day.
- The total system with solar collector, storage tank and pipelines is called solar hot water system.

# *Solar water heating systems:*






Working : Solar radiation passes through the transparent cover of flat plate collector and is absorbed by collector plate. Water flowing in contact with the collector is heated and the heat from the water is extracted for use. The circulating pump keeps a continuous circulation of water through the collector and storage tank.

# Solar Coockers :



Working Principles:

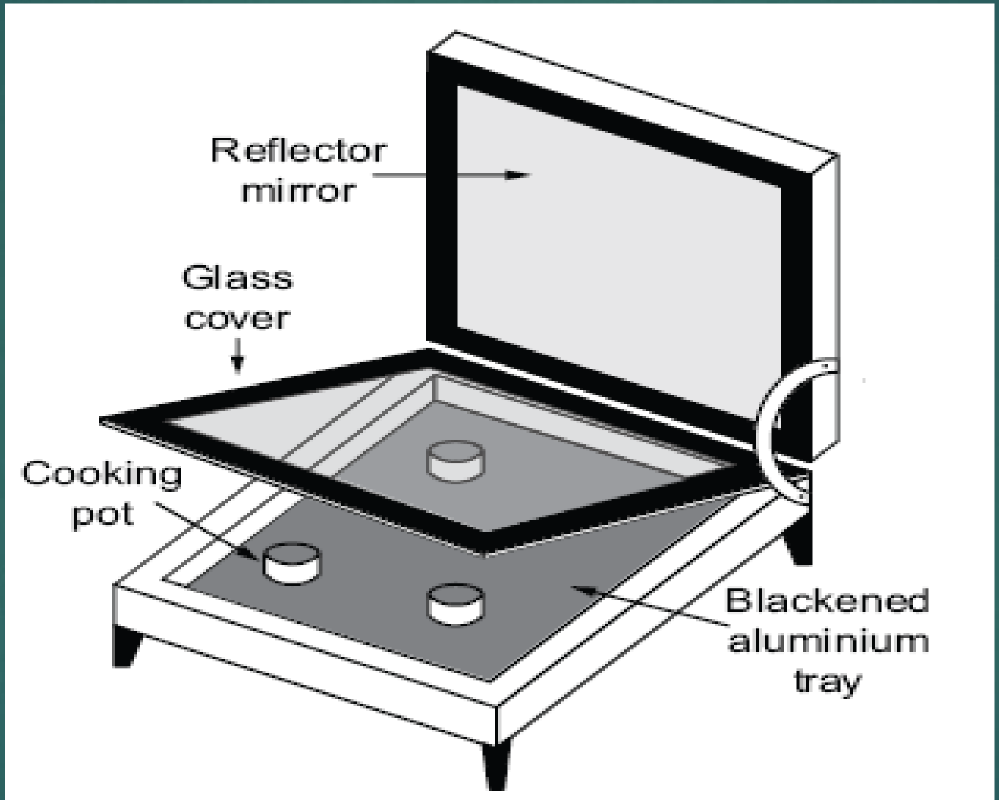
Converting Sunlight – In some cookers mirror or some type of reflective metal used to concentrate light and heat from the sun into small cooking area.

Converting light to heat : Any black colour in side the solar cooker improve the effectiveness of the turning light into heat. A black pan will absorb all of the sun's light and turn into heat, and improve the effectiveness of coocker.

Trapping heat :

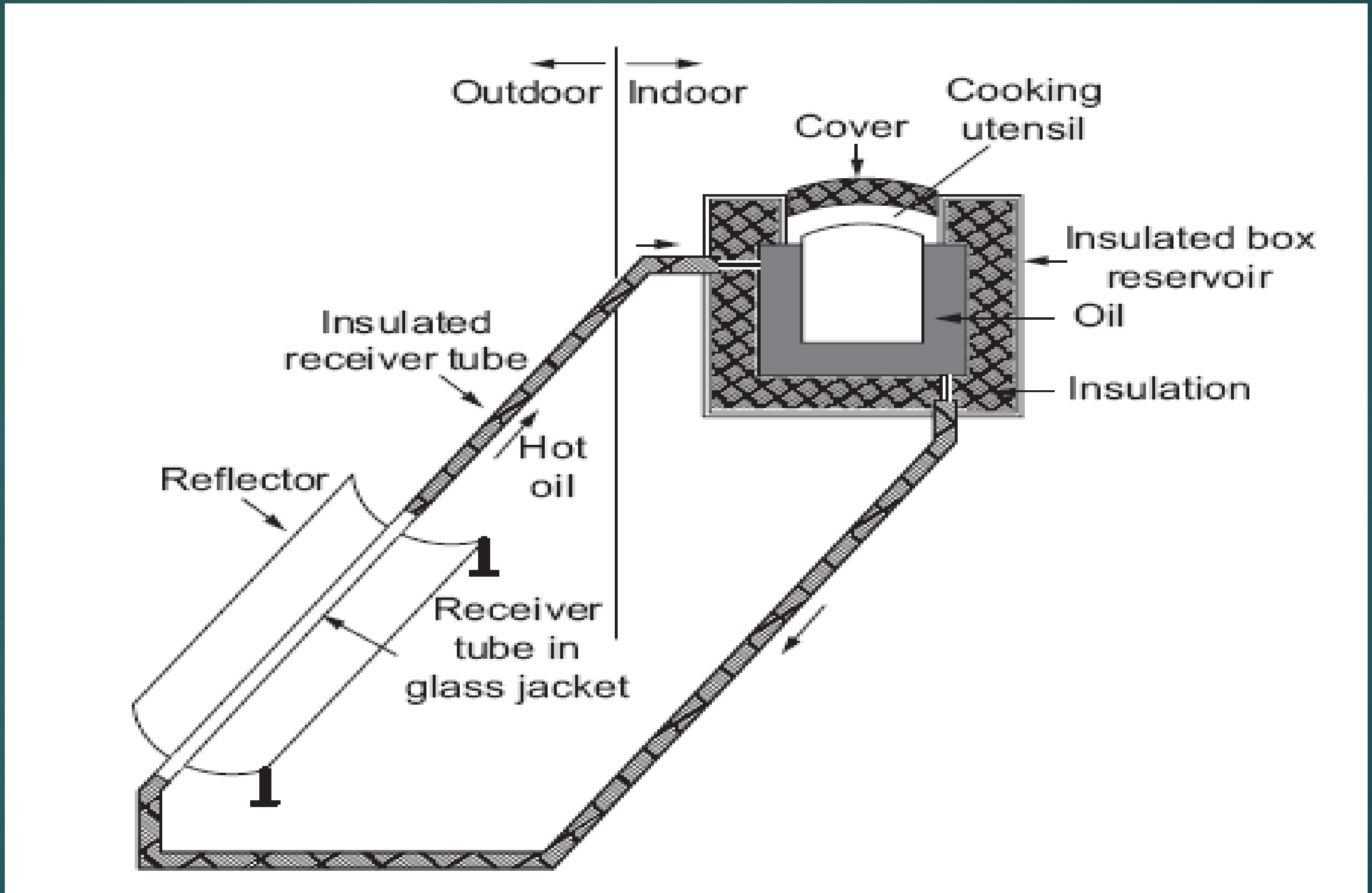
Using glass cover , plastic bag as isolation it will allow light to enter, but once the light is absorbed and converted to heat , it will show greenhouse effect. Isolating the air inside the coocker from the air outside the make greenhouse effect, it will help to increase the temperature inside the coocker during windy and cold days.

# Box-type Solar Cooker



# Paraboloidal Dish-type (Direct Type) Solar Cooker

# Advanced Solar Cooker



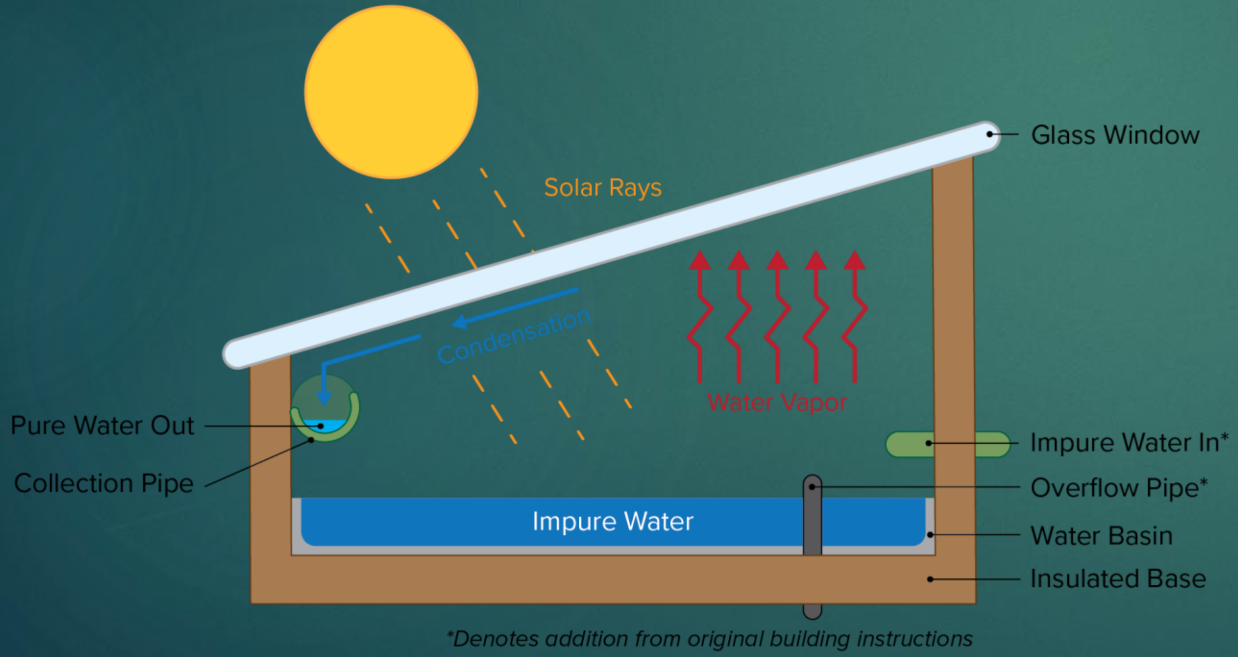
# *Solar desalination systems*

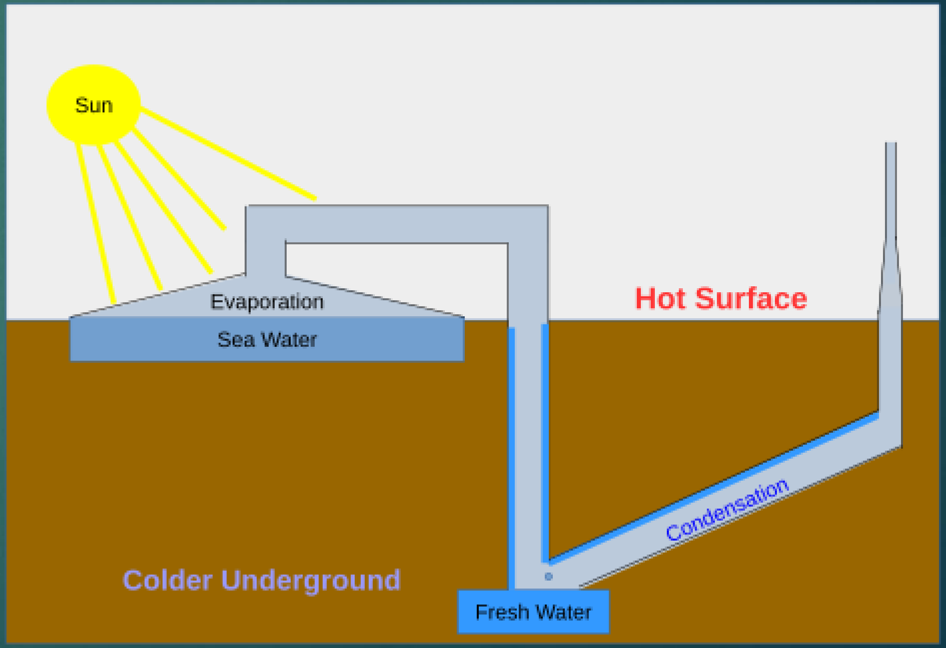


- Solar desalination systems utilize solar energy to convert saline water into freshwater, mimicking (evaporation, condensation, and precipitation ) the natural water cycle.
- These systems can be broadly categorized into direct and indirect methods:
- direct methods involving solar stills where water evaporates and condenses within the same unit, and
- indirect methods using solar collectors to heat water and drive conventional desalination processes like reverse osmosis.

**Direct :**

In the direct (distillation) method, a solar collector is coupled with a distilling mechanism. Solar stills of this type are described in survival guides, provided in marine survival kits, and employed in many small desalination and distillation plants.



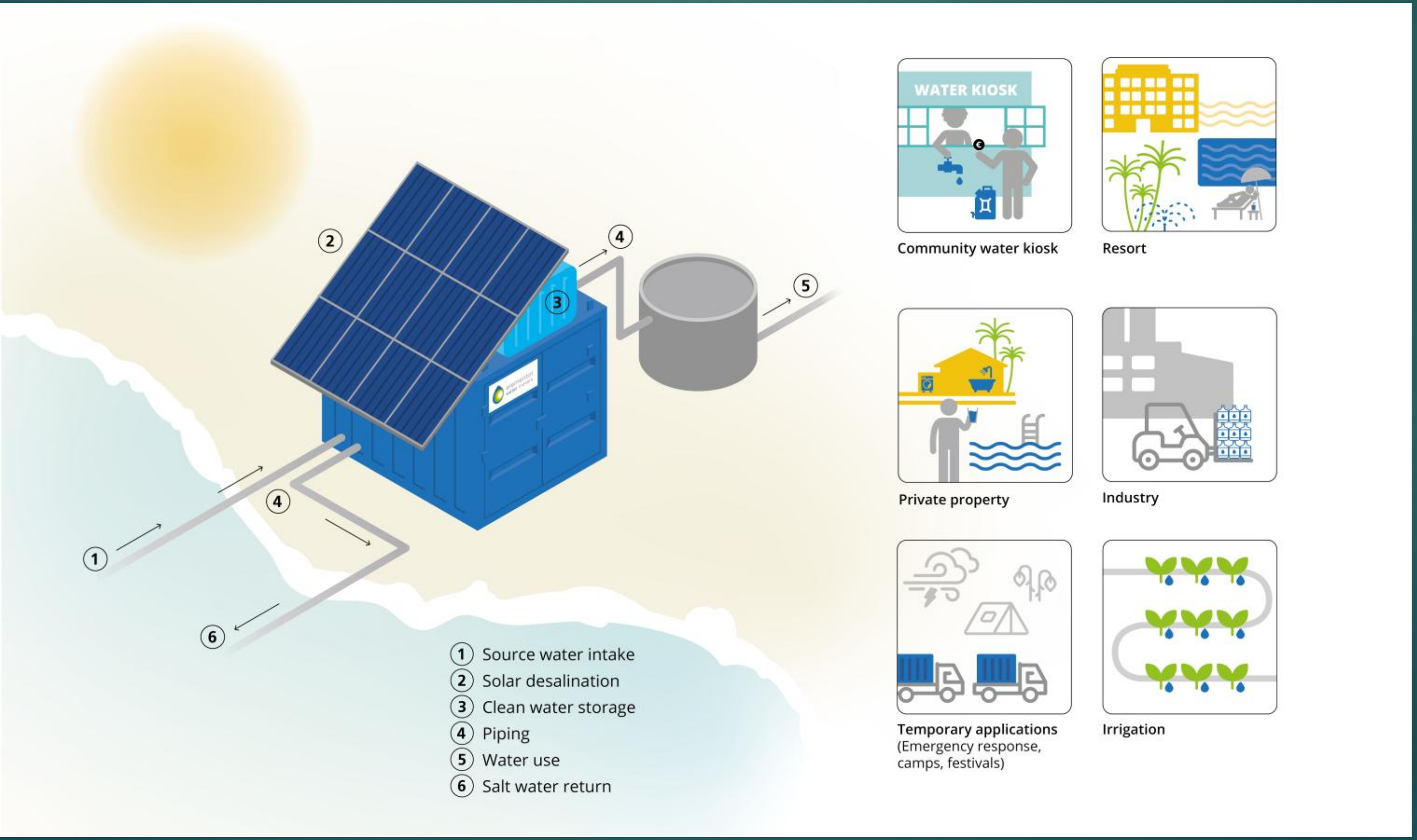
# SODIS, or solar disinfection




This is a method for purifying water using sunlight to kill harmful microorganisms. It's a simple, inexpensive, and effective way to make contaminated water safer to drink, particularly in developing countries.

## Indirect :

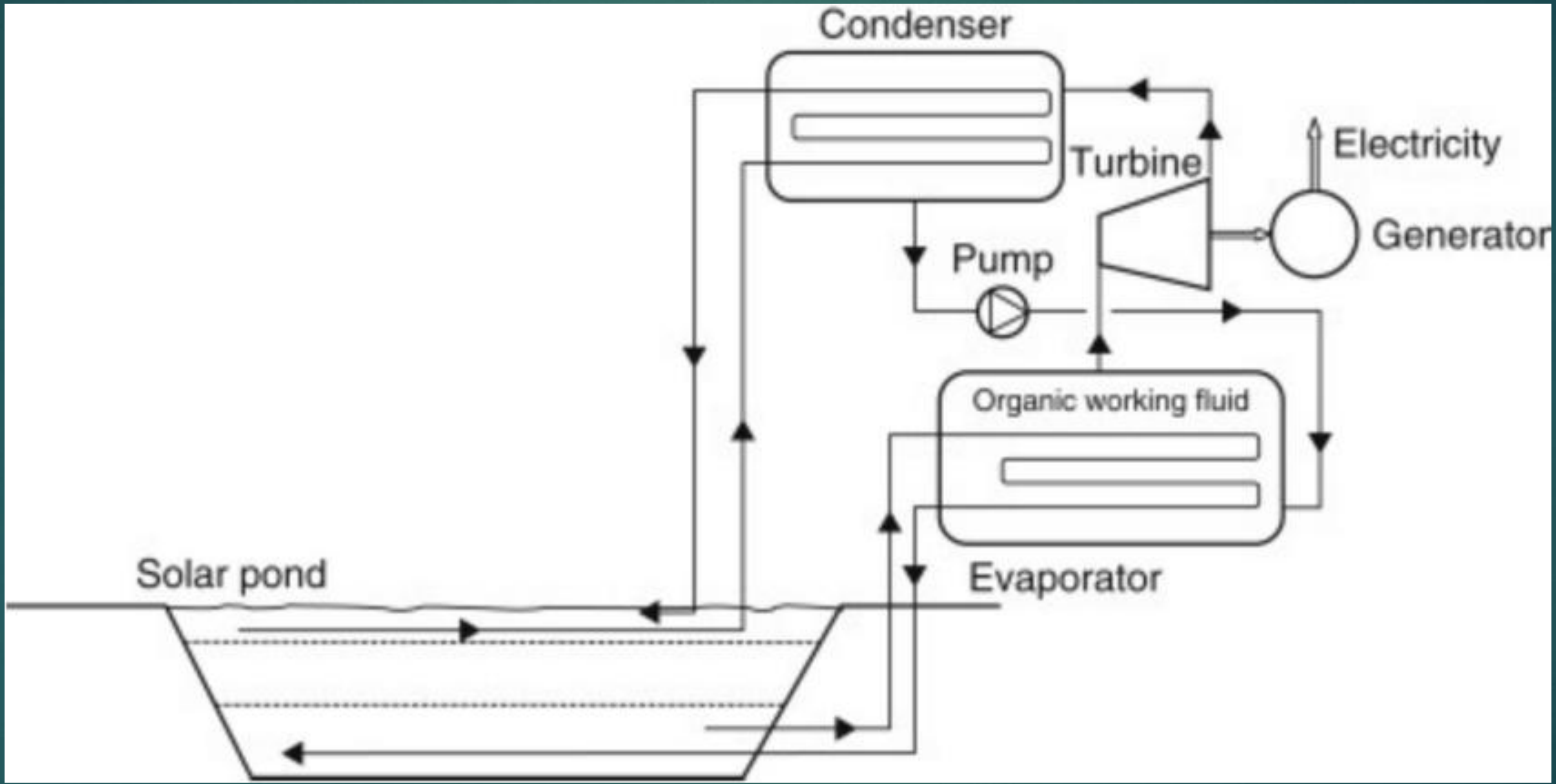
**Indirect desalination employs a solar collection array, consisting of photovoltaic and/or fluid-based thermal collectors, and a separate conventional desalination plant. Many arrangements have been analyzed, experimentally tested and deployed.**



# *Solar ponds :*

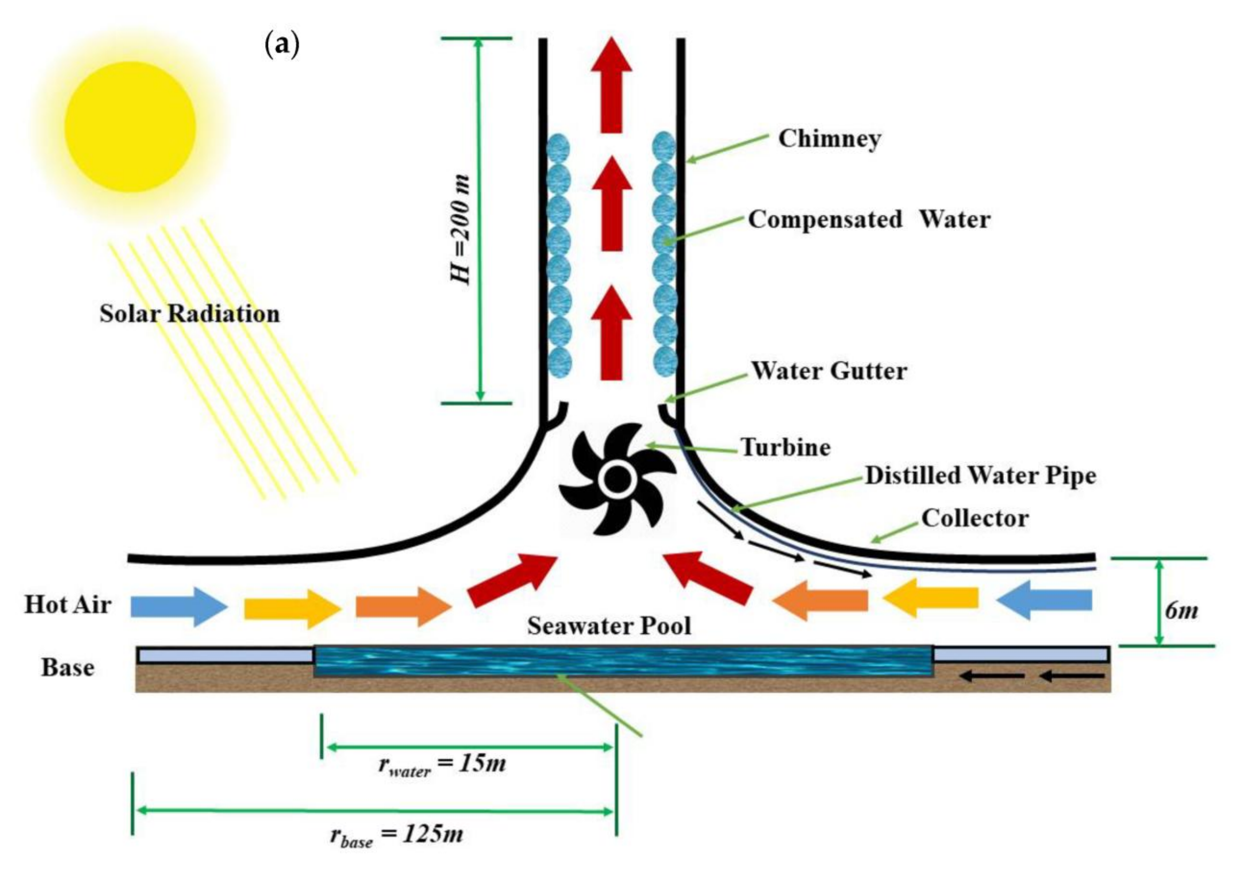


- Non-convective solar ponds have been suggested for collecting solar energy on a large scale.
- A solar pond is a shallow body of water, about 1 m deep containing dissolved salts to generate a stable density gradient (fresh water on top and denser salt water at bottom).
- Solar radiation passes through the upper layer to the bottom layer. The upper layer provides thermal insulation. Convection of water particles is prevented by the graded salt concentration. Temperature of water in upper layers is lower. Heat from lower layers of water is exchanged with the working fluid in the heat exchanger.
- In a well designed solar pond, the bottom layer can reach temperature of about 95°C, whereas the cold water in the upper layer may have nearly atmospheric temperature 20°C.
- The use of solar ponds has been suggested for salt production, space heating electricity generation (by using rampine cycle etc


Condenser
Turbine
Electricity
Generator
Pump
Organic working fluid
Evaporator
Solar pond

# Solar chimney power plant:






# Solar chimney power plant



- Consists of solar collector, chimney and turbine. The solar radiations are used to convert into electricity with the help of solar chimney plant.

- Direct and diffuse radiation strikes the glass roof collector, where specific fraction of energy is reflected, absorbed and transmitted. The transmitted solar radiations through the roof strike the ground surface where part of radiated energy is absorbed by the surface and part is reflected.

- The reflected radiations are used to heat the air under roof. Hot air under roof rises up into the chimney of the plant, thereby drawing in more air at the collector perimeter and thus initiating forced convection which heats the collector air more rapidly.

- As the air flows from the collector perimeter towards the chimney its temperature increases while the velocity of the air approximately constant because of the increasing height of the collector.

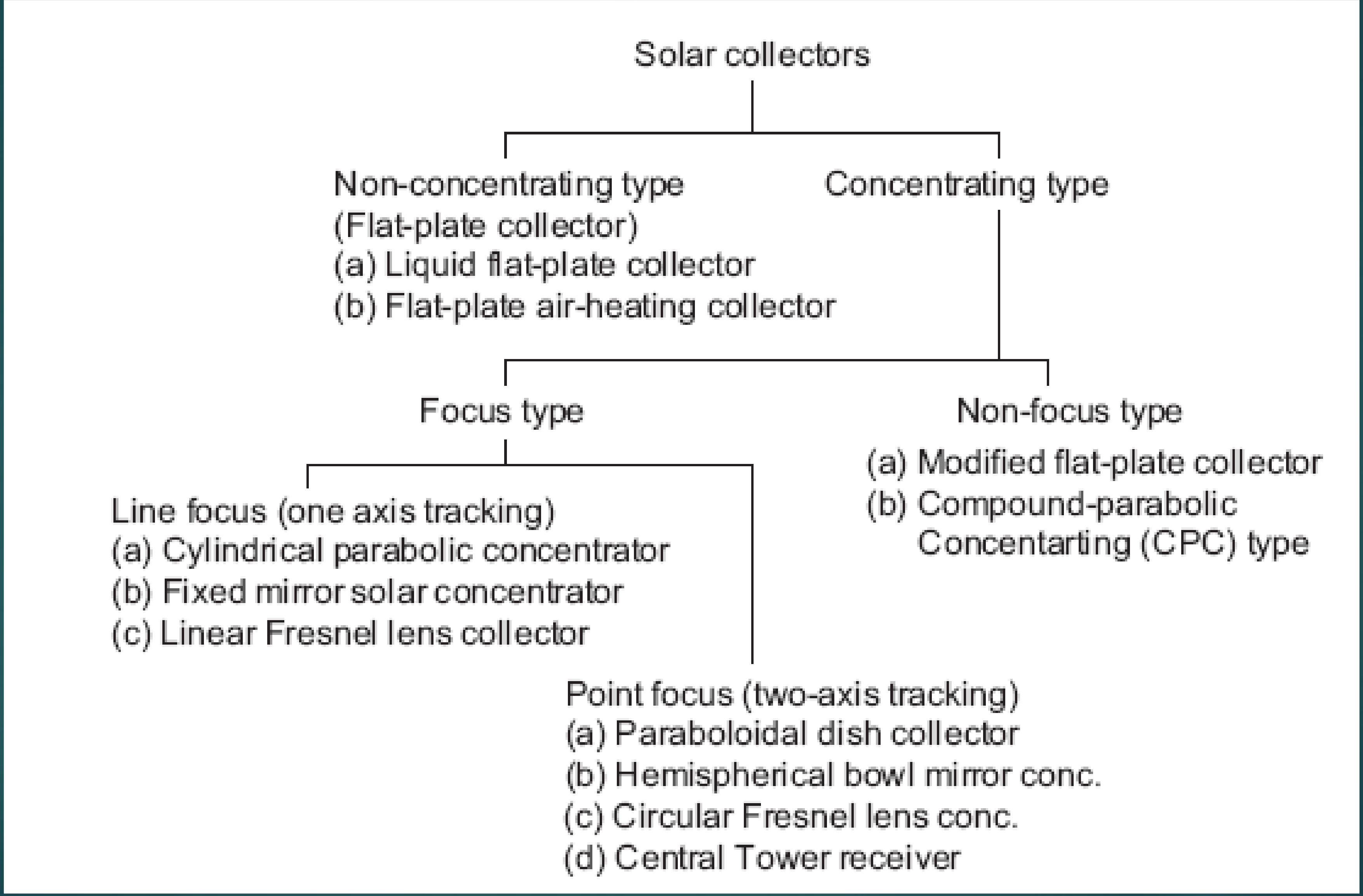
- The heated air travels up the chimney causing to create pressure difference at the inlet ant outlet of the chimney thus the air flowing through the chimney is used to drive the generator to generate the electricity.

Concentration ratio (CR) is defined as the 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.

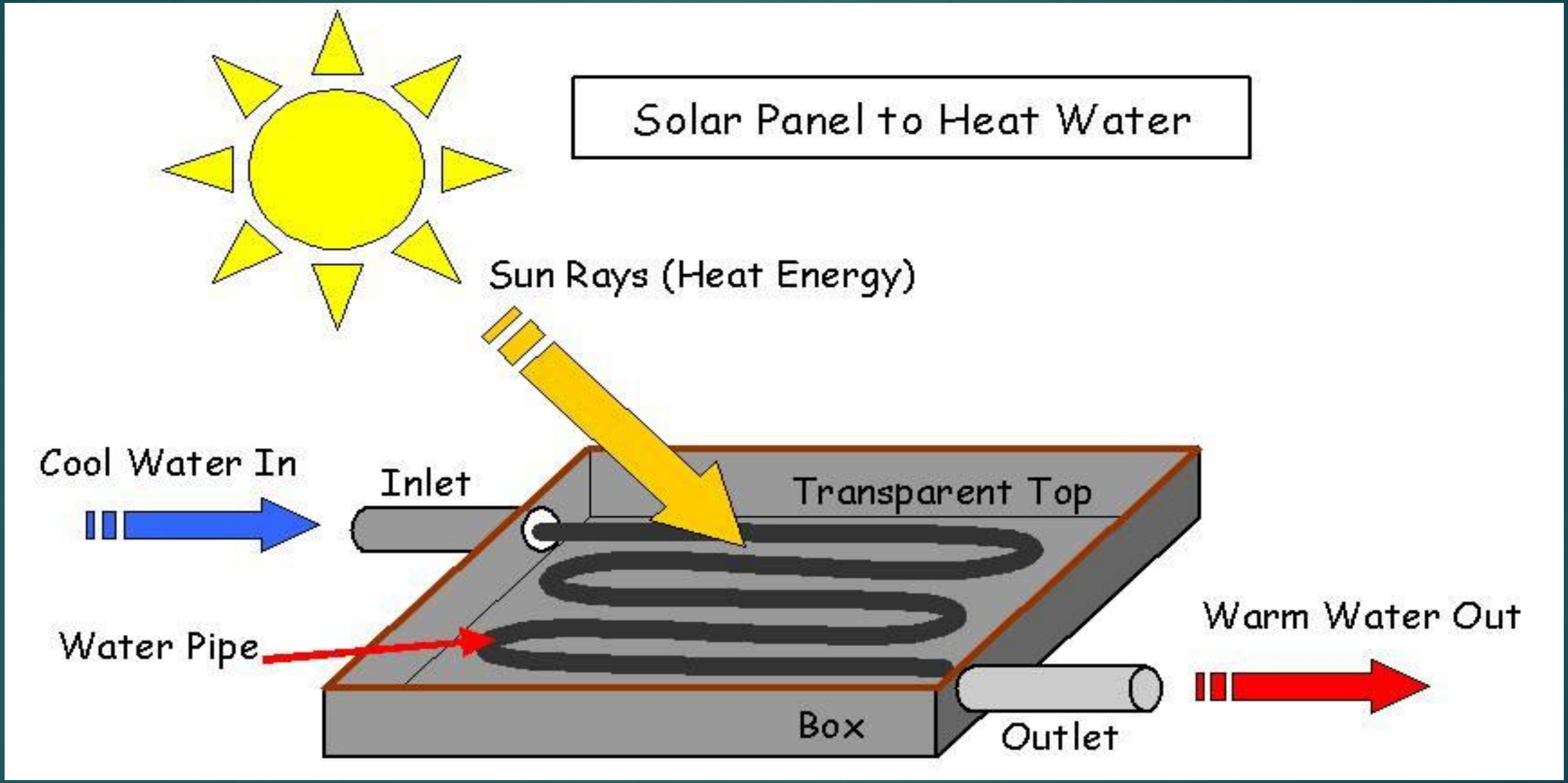
Temperature range is the range of temperature to which the heat transport fluid is heated up by the collector.

- In flat plate collectors no optical system is utilized to concentrate the solar radiation and hence the concentration ratio is only 1 and temperature range is less than 100 °C.
- Line focus collectors have CR up to 100 and temperature range of the order of 150 °C to 300 °C.
- Concentration ratio of the order of thousands and temperature range of 500 °C to 1000 °C can be obtained by using point focus collectors.

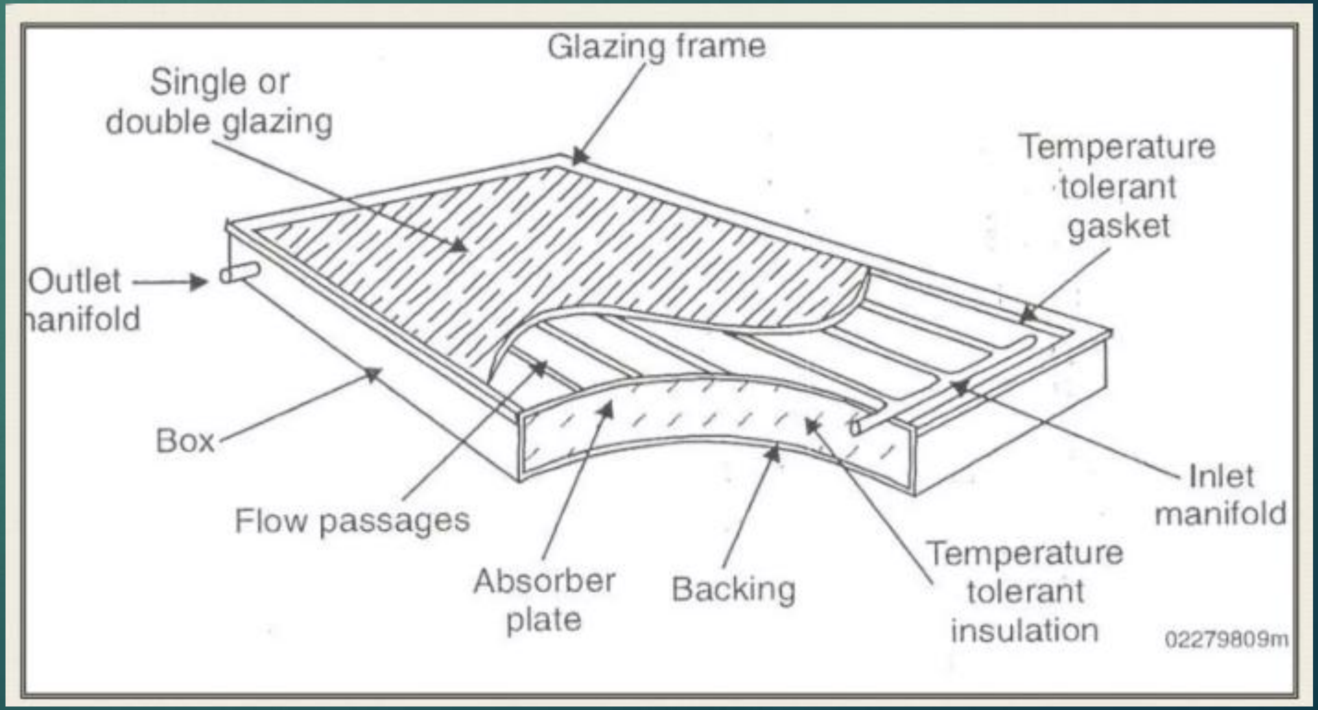
# CLASSIFICATION



# SOLAR FLAT PLATE COLLECTOR

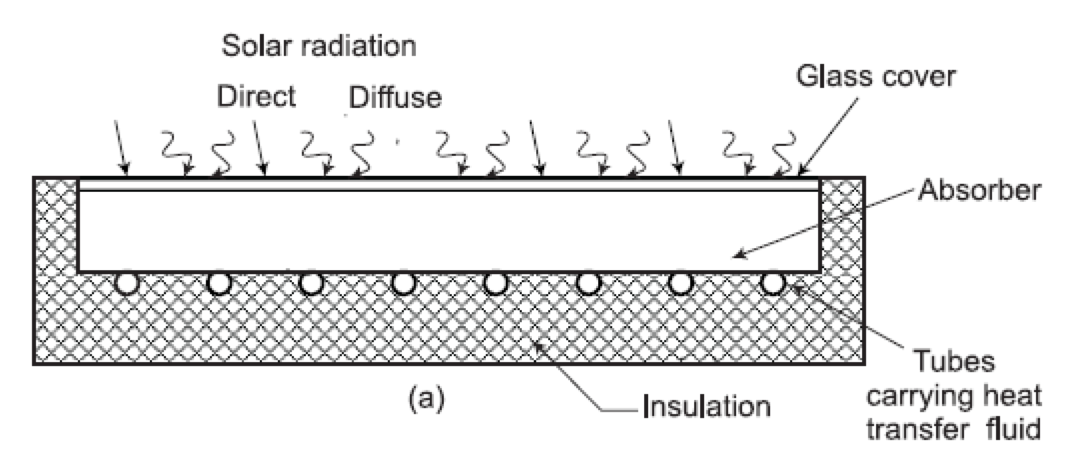


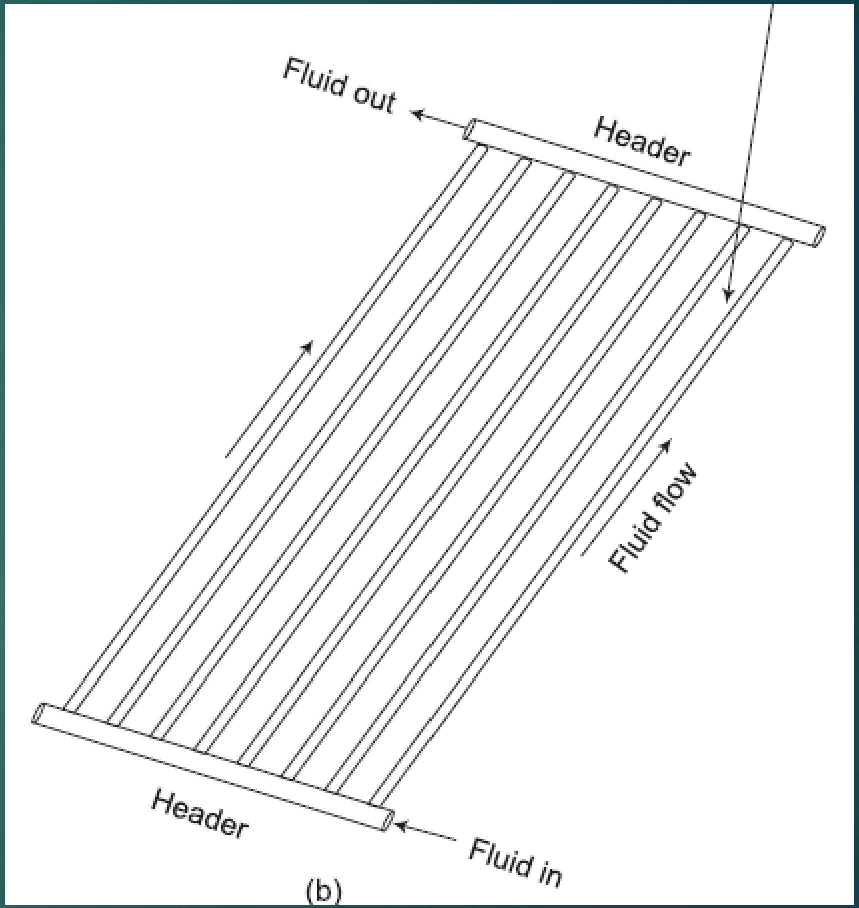
- A flat plate collector is simple in construction and does not require sun tracking. As the collector is installed outdoors and exposed to atmospheric disturbances (rain, storm, etc.), the flat plate type is more likely to withstand harsh outdoor conditions.
- Also because of simple stationary design, a flat plate collector requires little maintenance.



# Basic elements of collector:





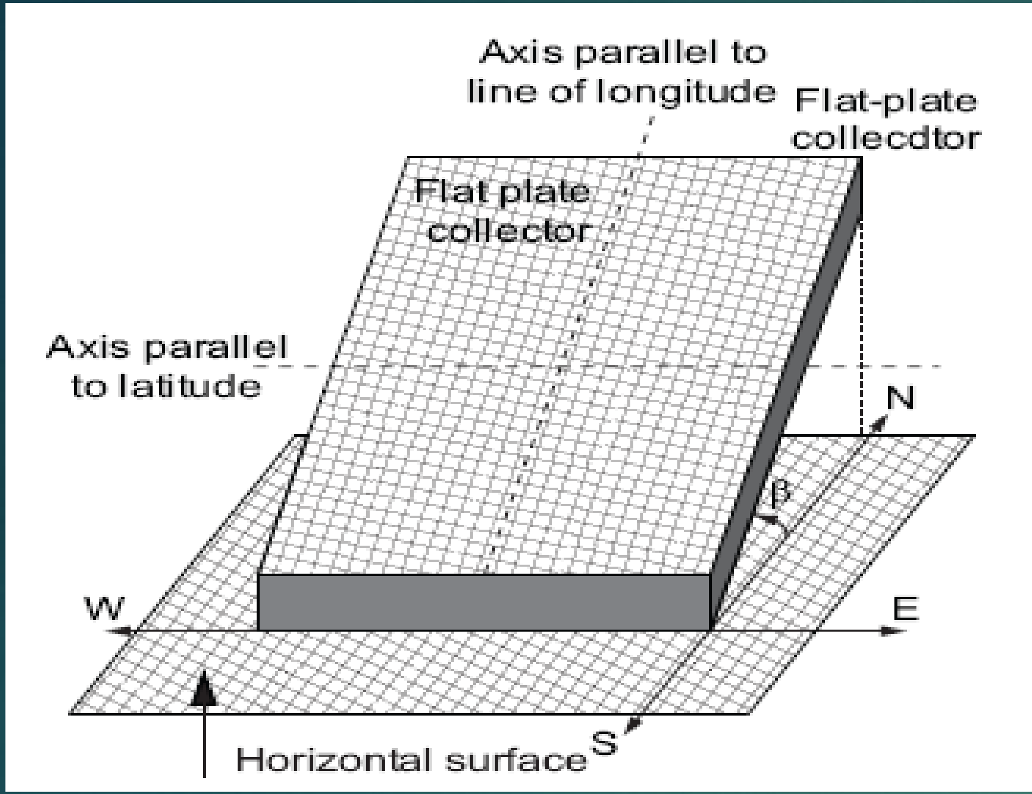

The basic elements in a majority of these collectors are:

(i) transparent cover (one or two sheets) of glass or plastic

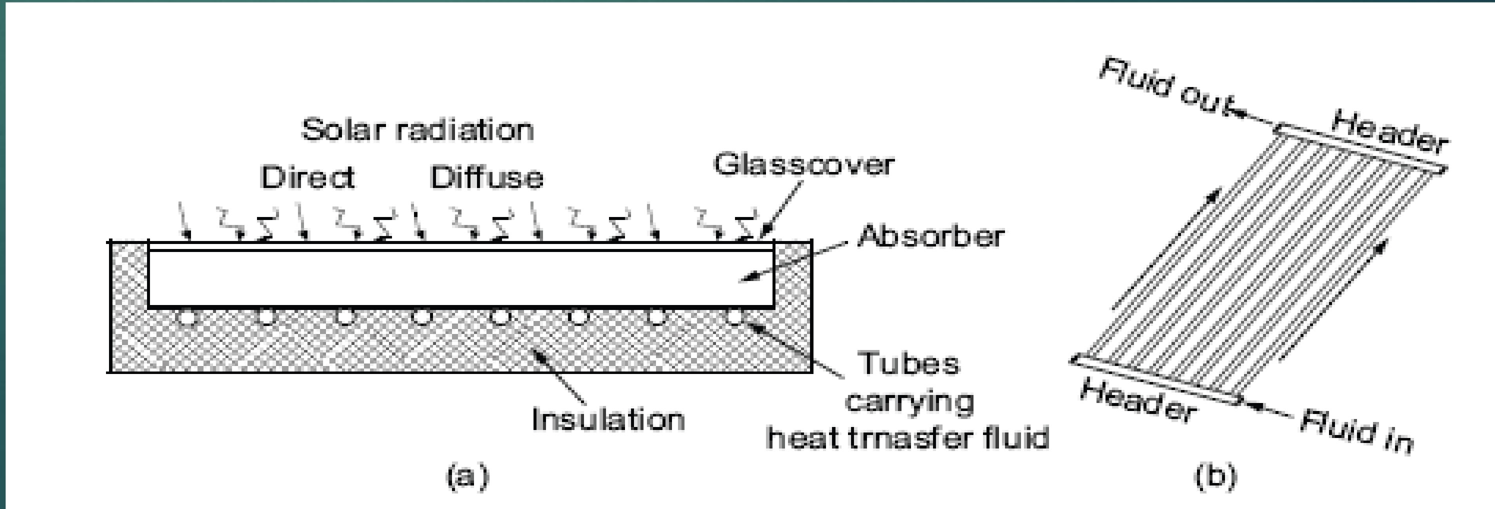
(ii) blackened absorber plate usually of copper, aluminium or steel,

(iii) tubes, channels or passages, in thermal contact with the absorber plate. In some designs, the tubes form integral part of absorber plate.

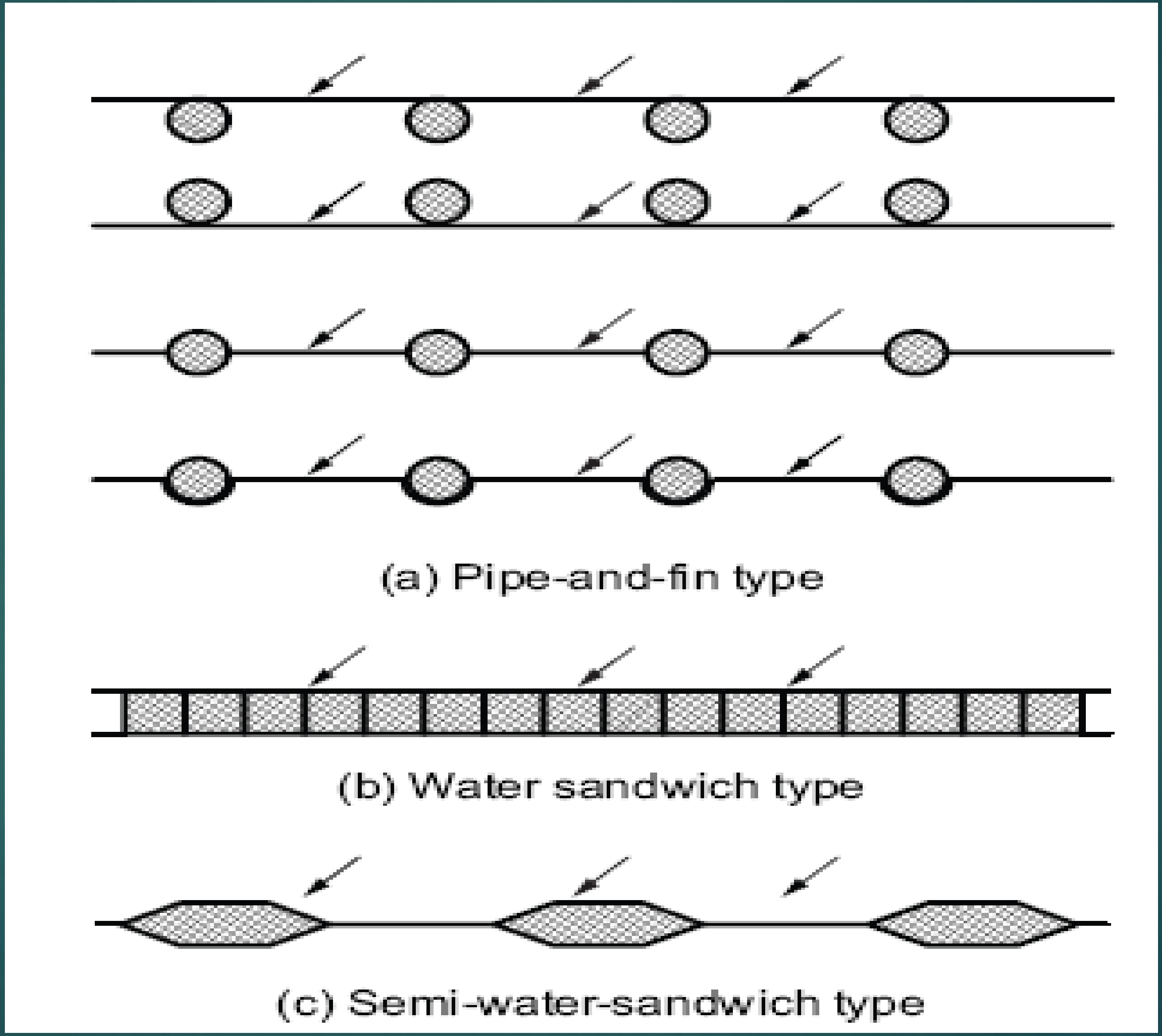
(iv) weather tight, insulated container to enclose the above components



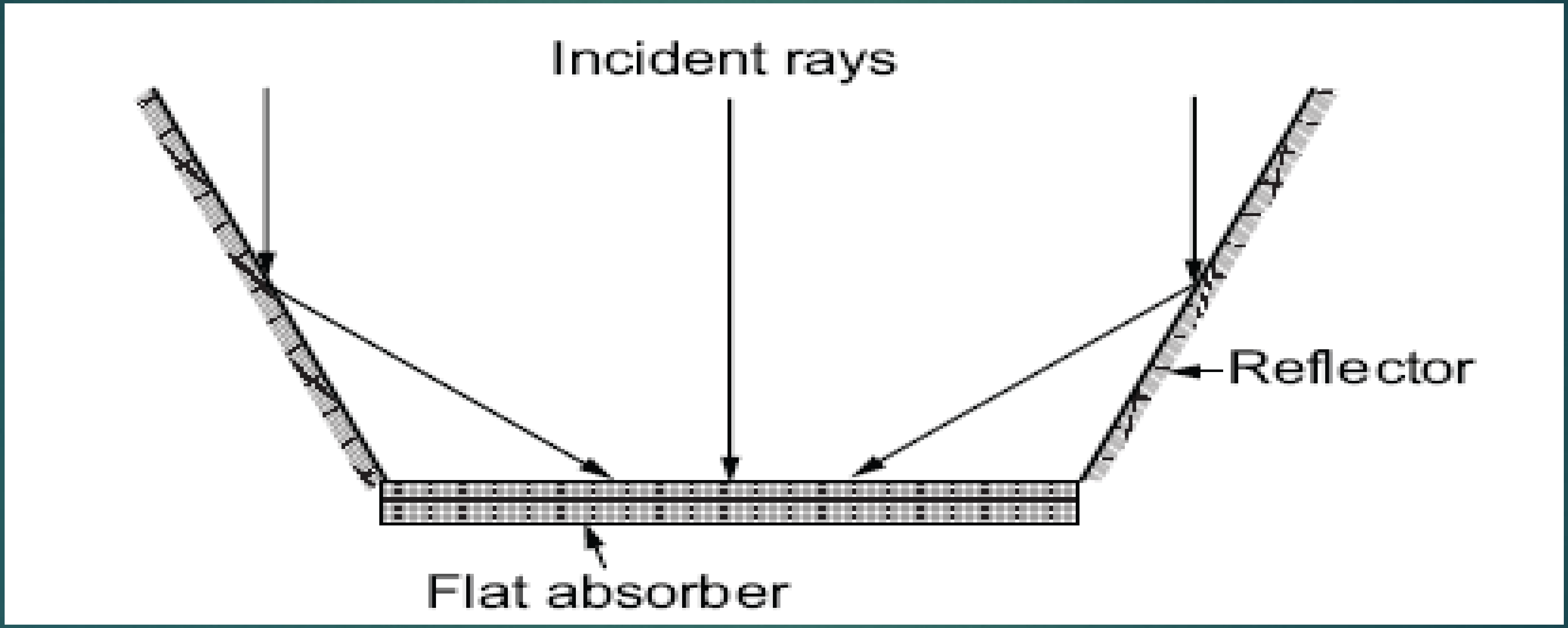

- It can easily achieve a temperature 60-80$^{o}$C above ambient temperature.
- It uses both beam and diffuse radiation.
- Does not require tracking.
- Requires little maintenance.
- Efficiency: ~ 45% at 80$^{o}$C
- Applications: air heating, water heating, industrial process heating, passive air conditioning.



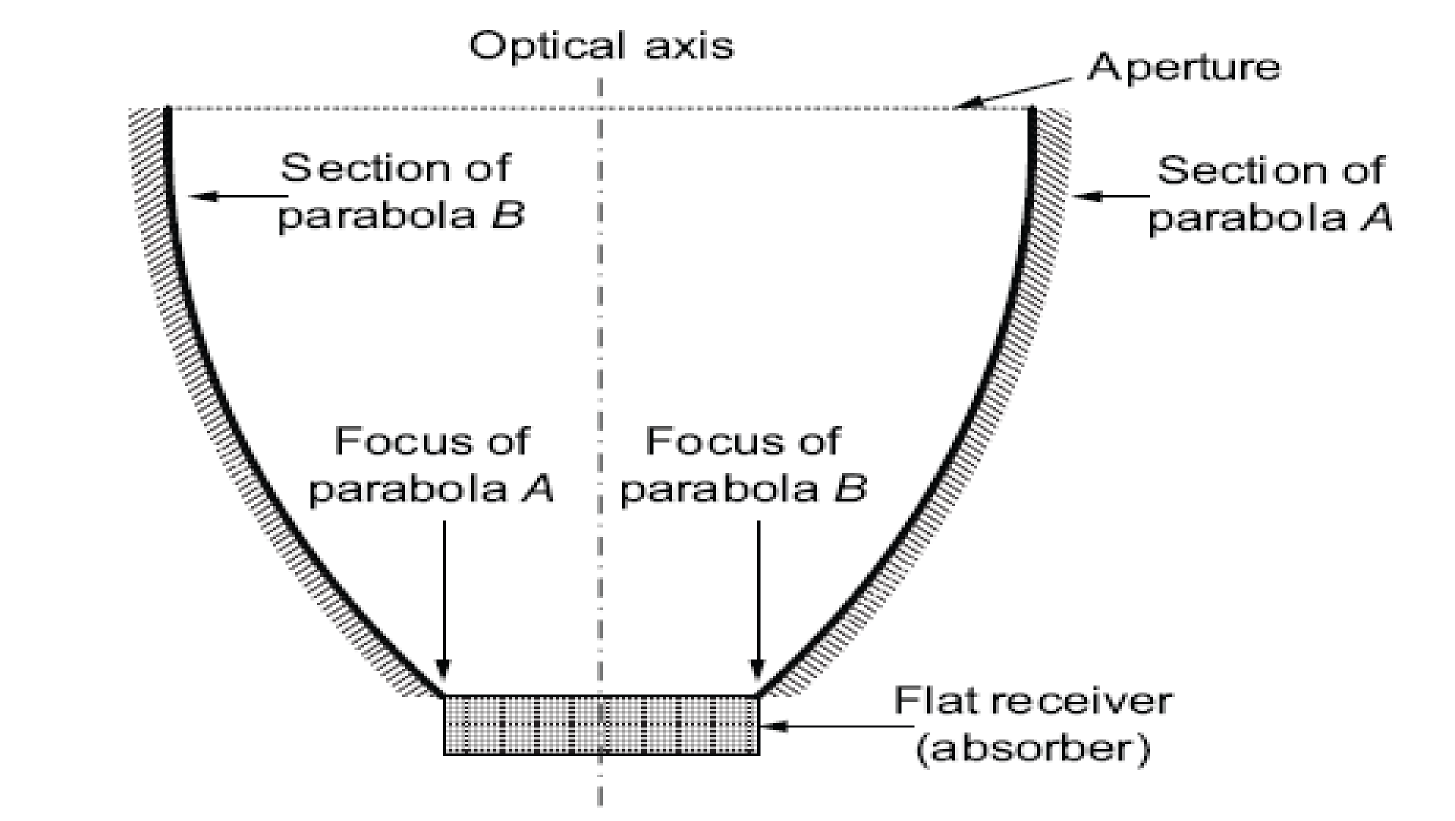
# ABSORBER-PLATE DESIGNS



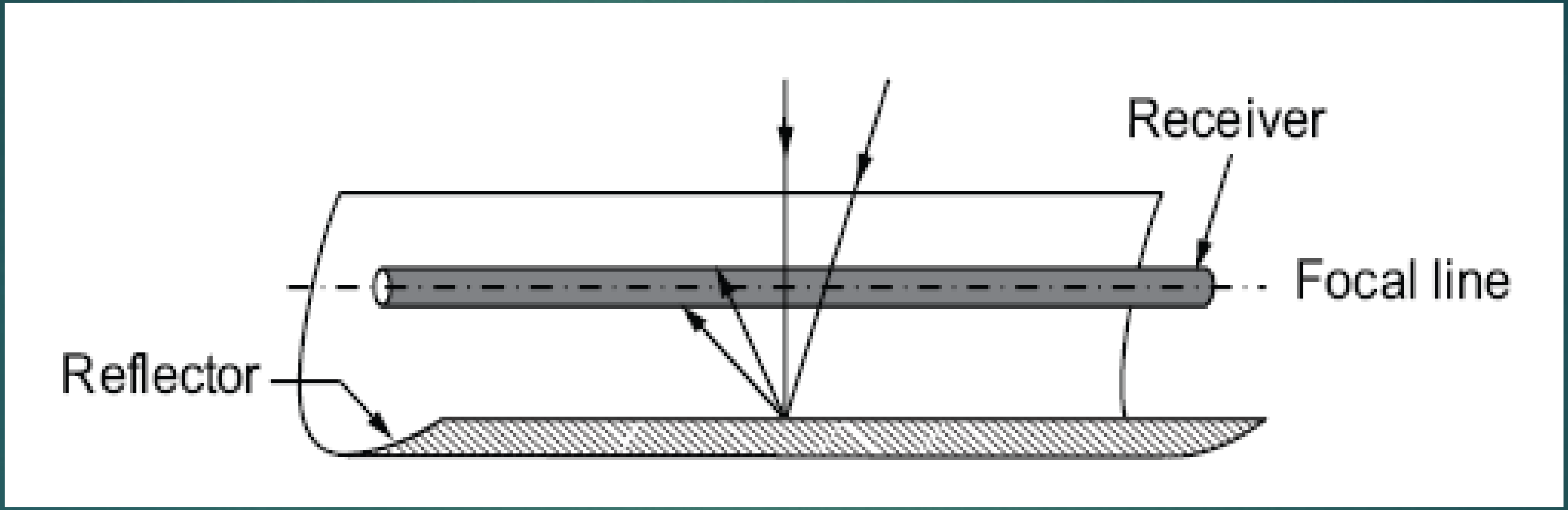
# FLAT-PLATE COLLECTOR WITH BOOSTER MIRRORS



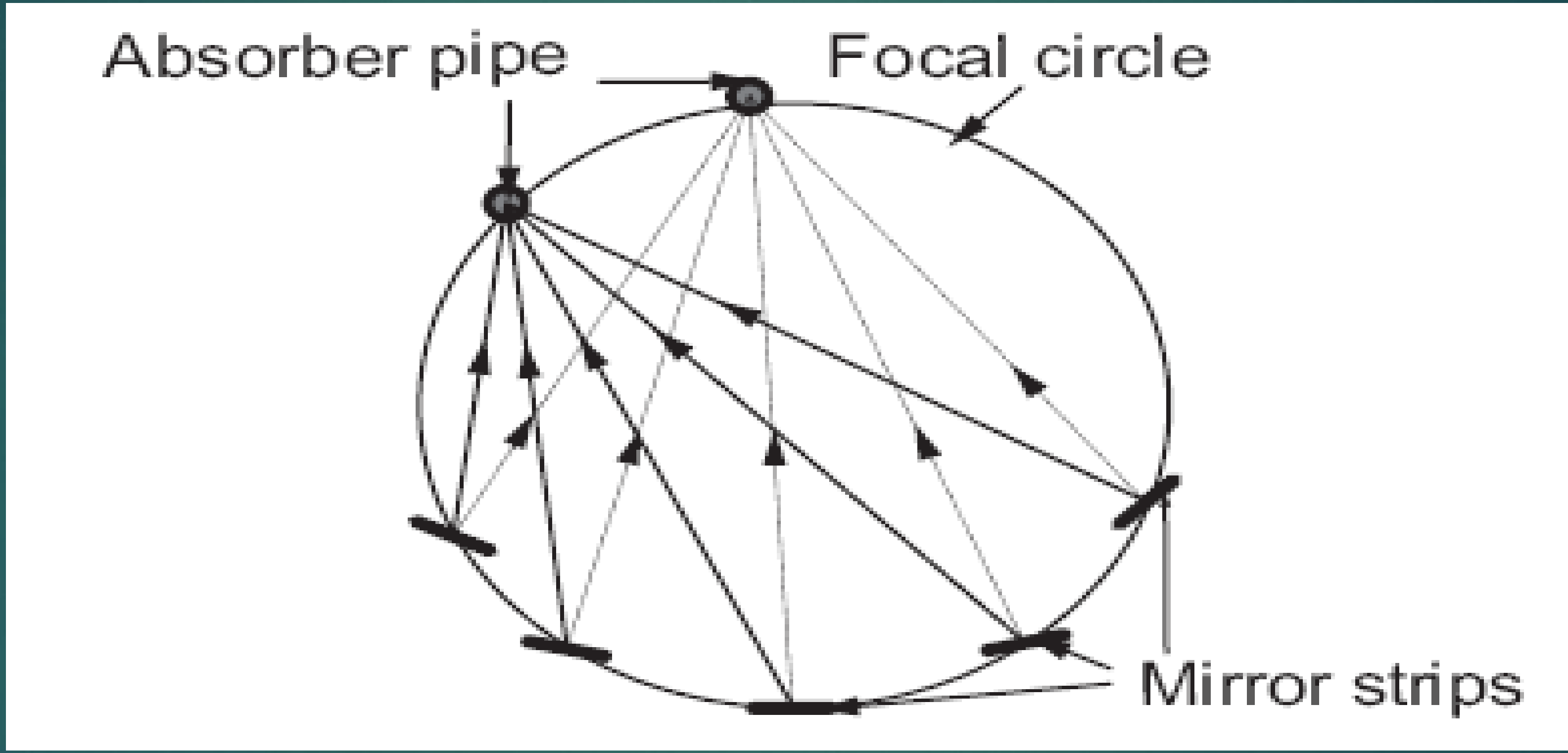
# COMPOUND PARABOLIC CONCENTRATOR (CPC)



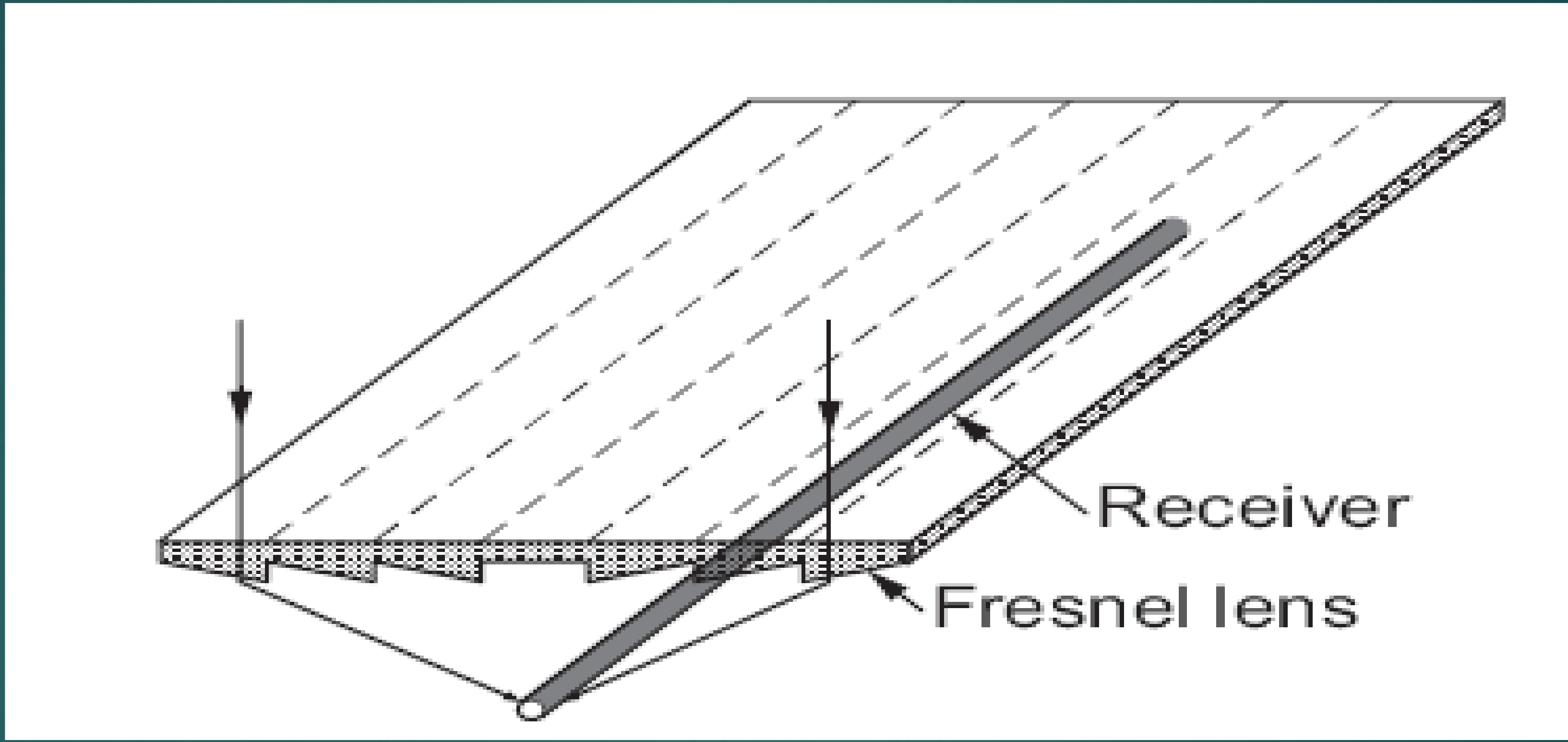
# CYLINDRICAL PARABOLIC CONCENTRATOR



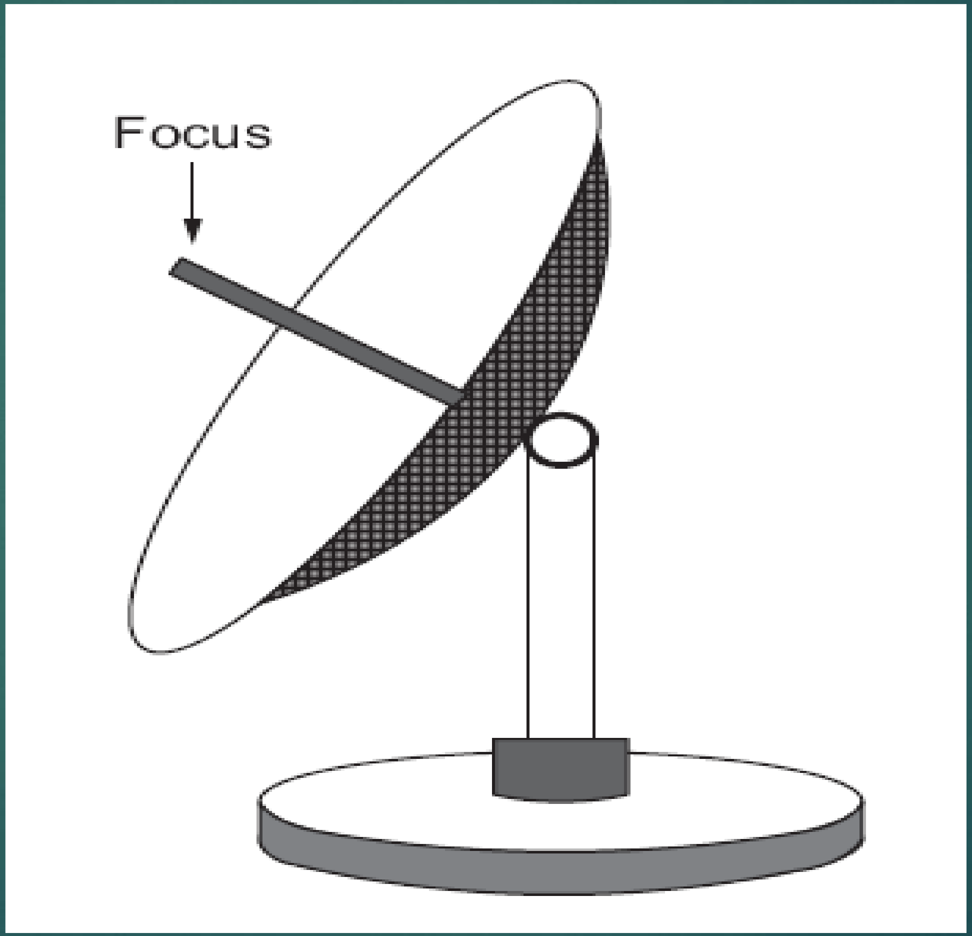
# FIXED-MIRROR SOLAR CONCENTRATOR



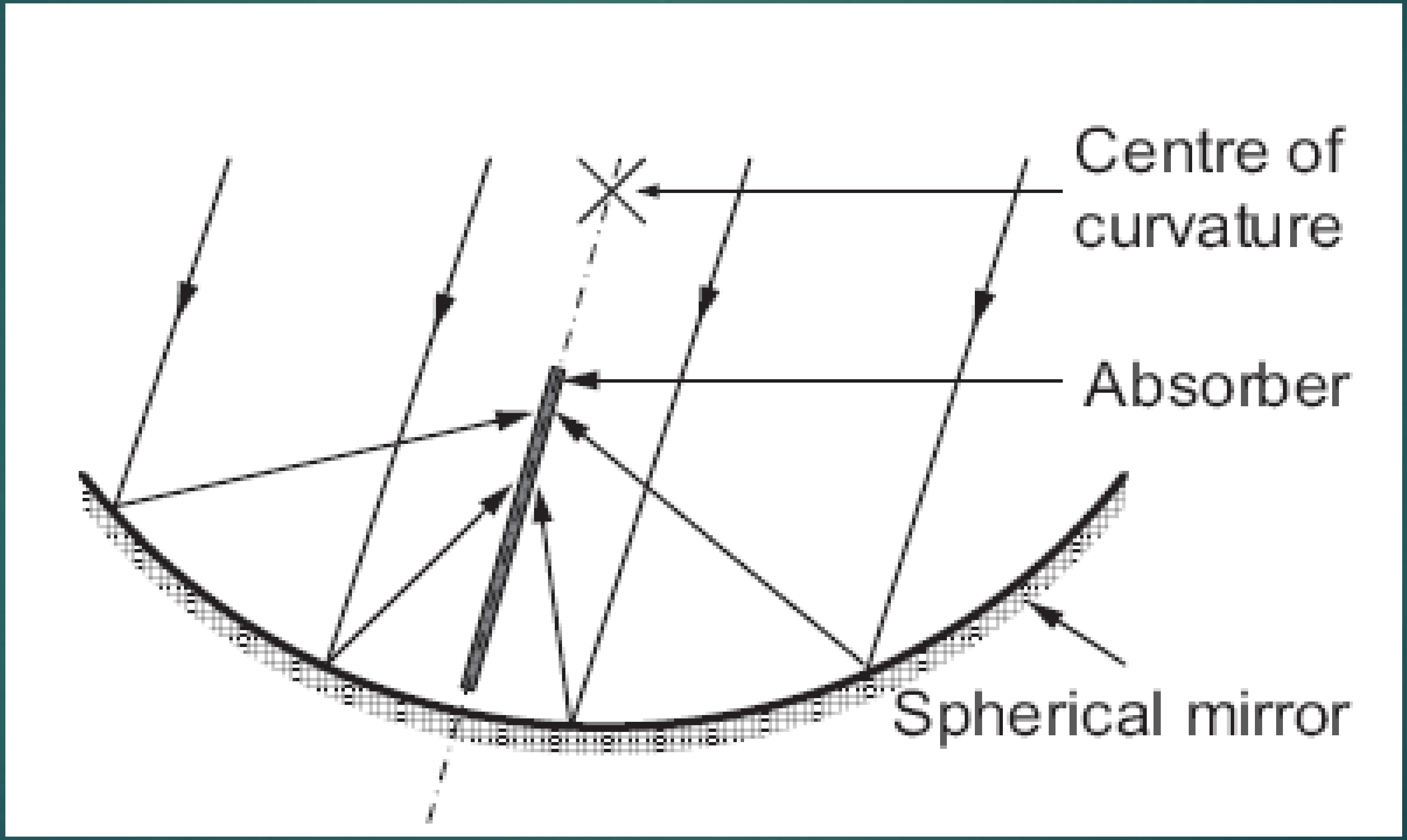
# LINEAR FRESNEL LENS COLLECTOR



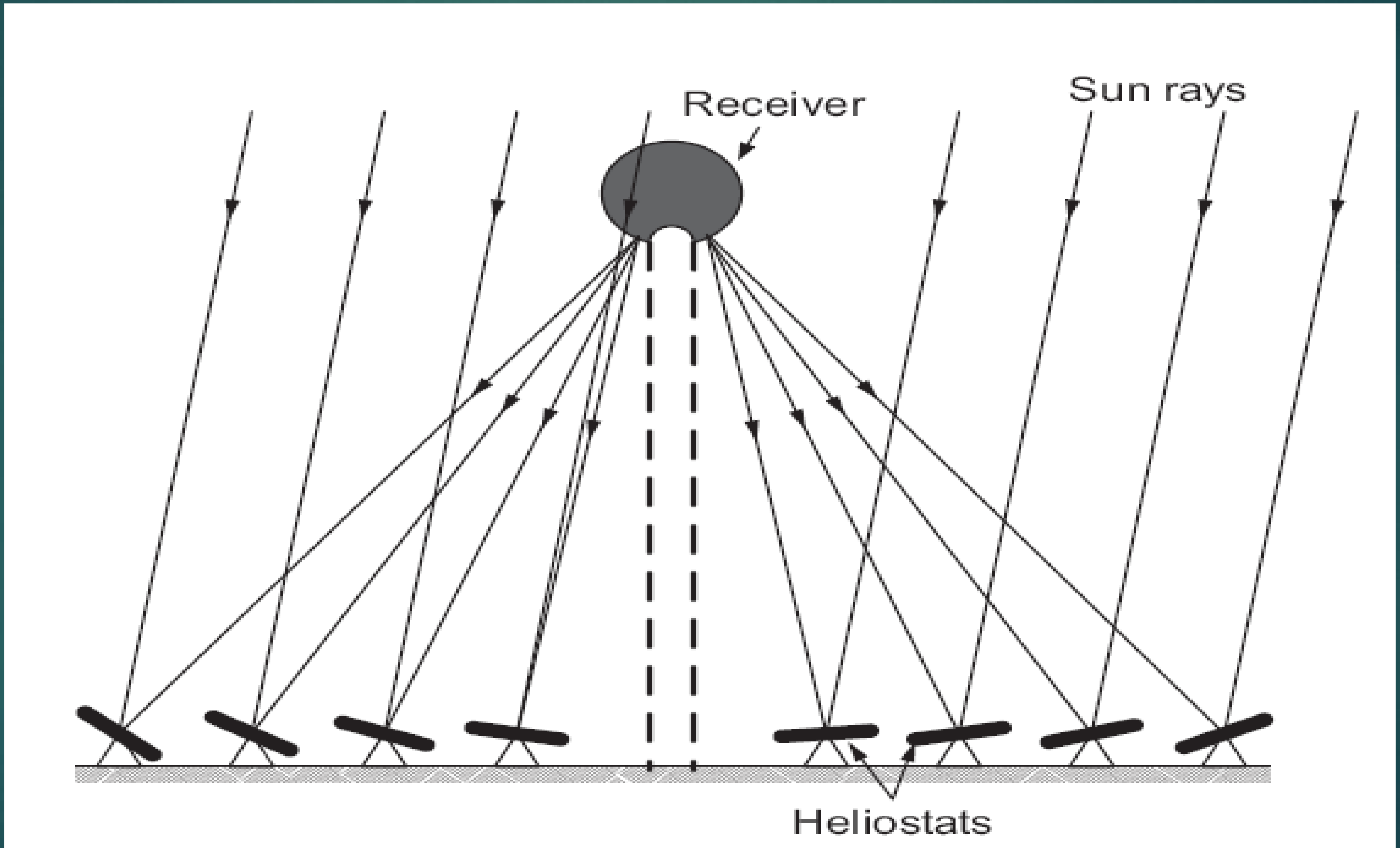
# PARABOLOIDAL DISH COLLECTOR



# HEMISPHERICAL BOWL MIRROR CONCENTRATOR



# CENTRAL TOWER RECEIVER



# What is a Solar Cell?



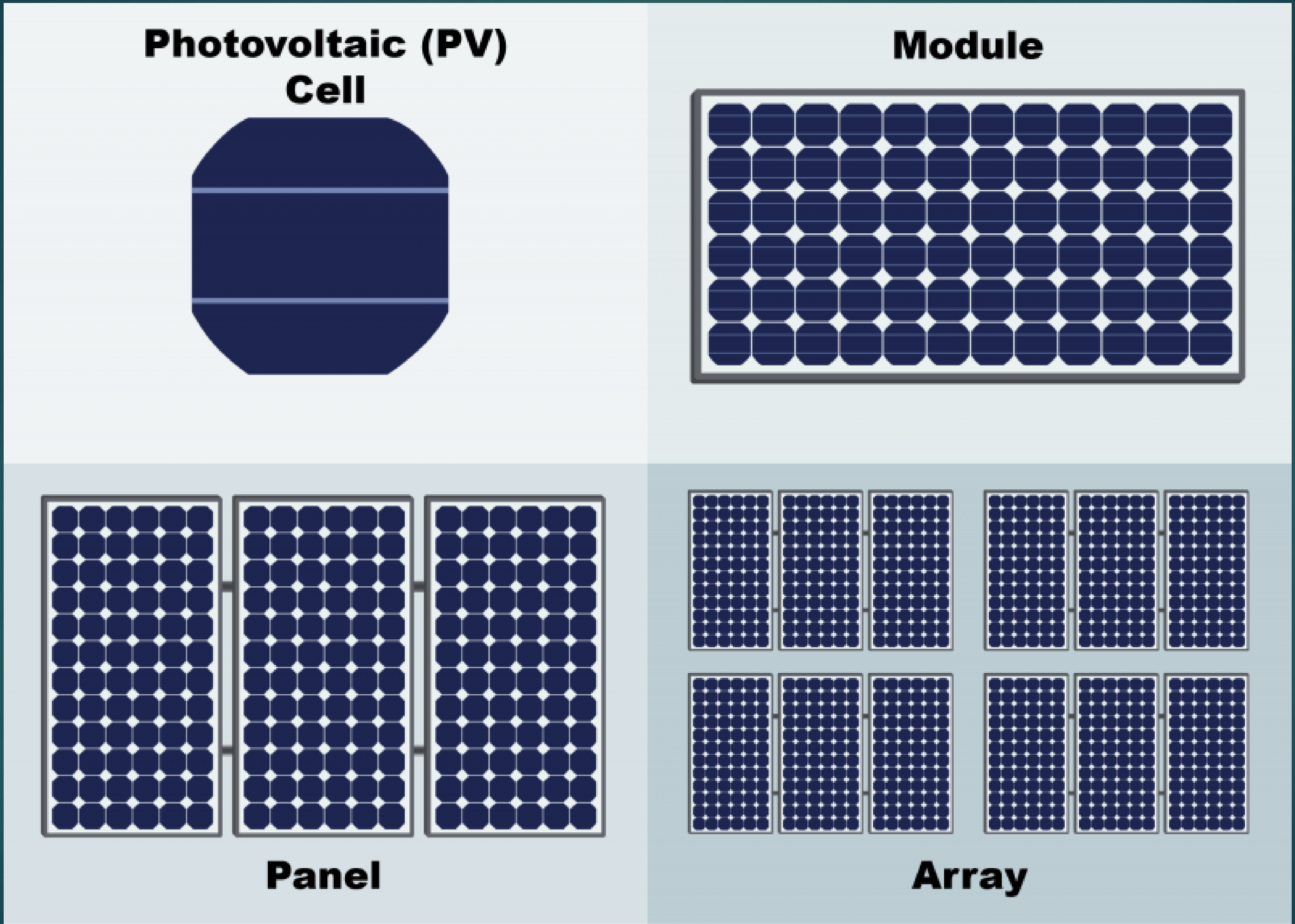
A **solar cell** (also known as a photovoltaic cell or PV cell) is defined as an electrical device that converts light energy into electrical energy through the photovoltaic effect. A solar cell is basically a p-n junction diode.

Solar cells are a form of photoelectric cell, defined as a device whose electrical characteristics – such as current, voltage, or resistance – vary when exposed to light.

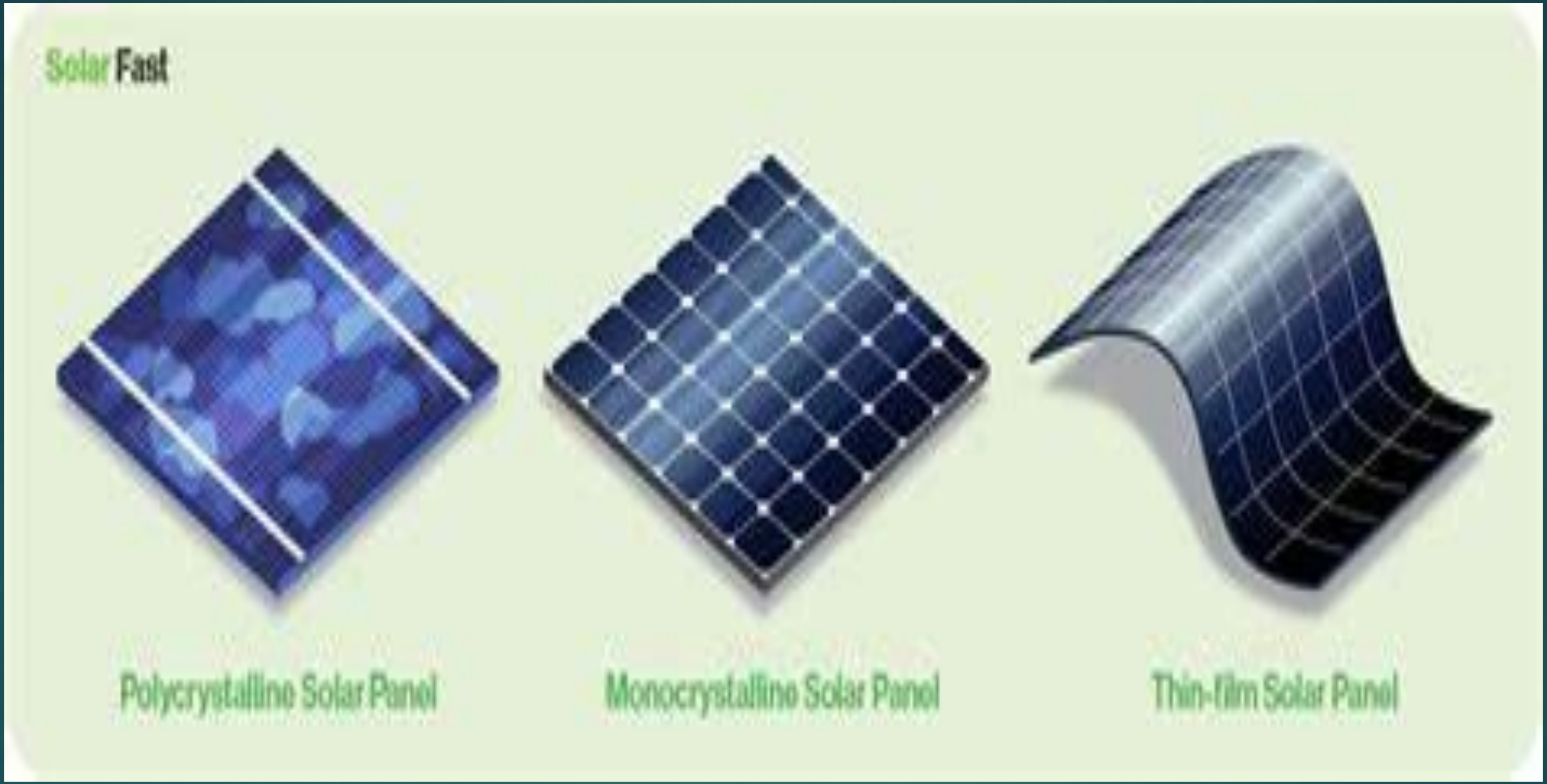
- Individual solar cells can be combined to form modules commonly known as solar panels.

- The common single junction silicon solar cell can produce a maximum open-circuit voltage of approximately 0.5 to 0.6 volts.

- Solar cells are tiny. When combined into a large solar panel, considerable amounts of renewable energy can be generated.


Photovoltaic (PV) Cell
Module
Panel
Array

# Solar Park

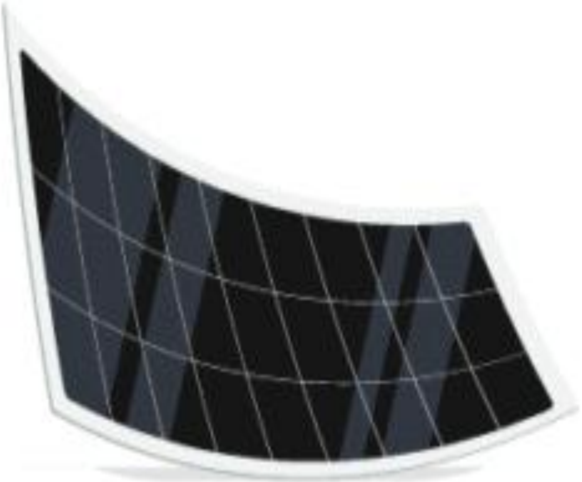

Solar Fast
Polycrystalline Solar Panel
Monocrystalline Solar Panel
Thin-film Solar Panel

## Monocrystalline

- Highest price
- Typically over **19%** efficiency
- Excellent choice when you have limited roof space

## Polycrystalline

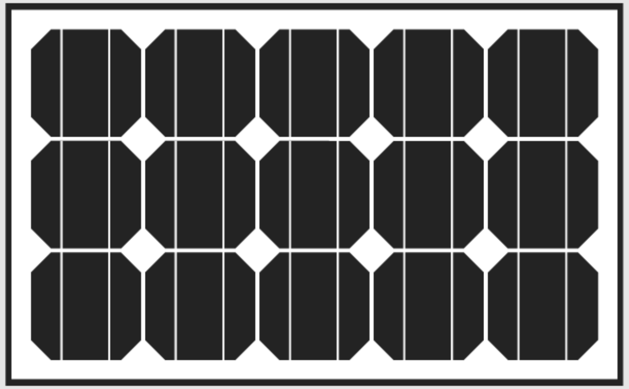
- Intermediate price
- Typically **15-17%** efficiency
- Great choice if space is not a limitation



## Thin-film

- Lowest price
- Typically below **15%** efficiency
- Best for large commercial and industrial rooftops

## MONOCRYSTALLINE
### SOLAR PANEL



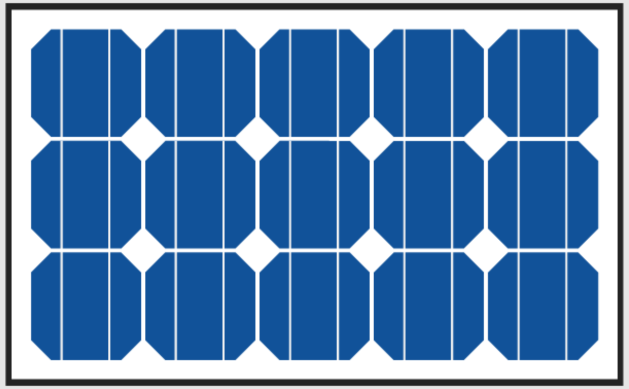
Single Crystal of Silicon

Less Space + More Efficent

More Expensive

Black Hue

## POLYCRYSTALLINE
### SOLAR PANEL

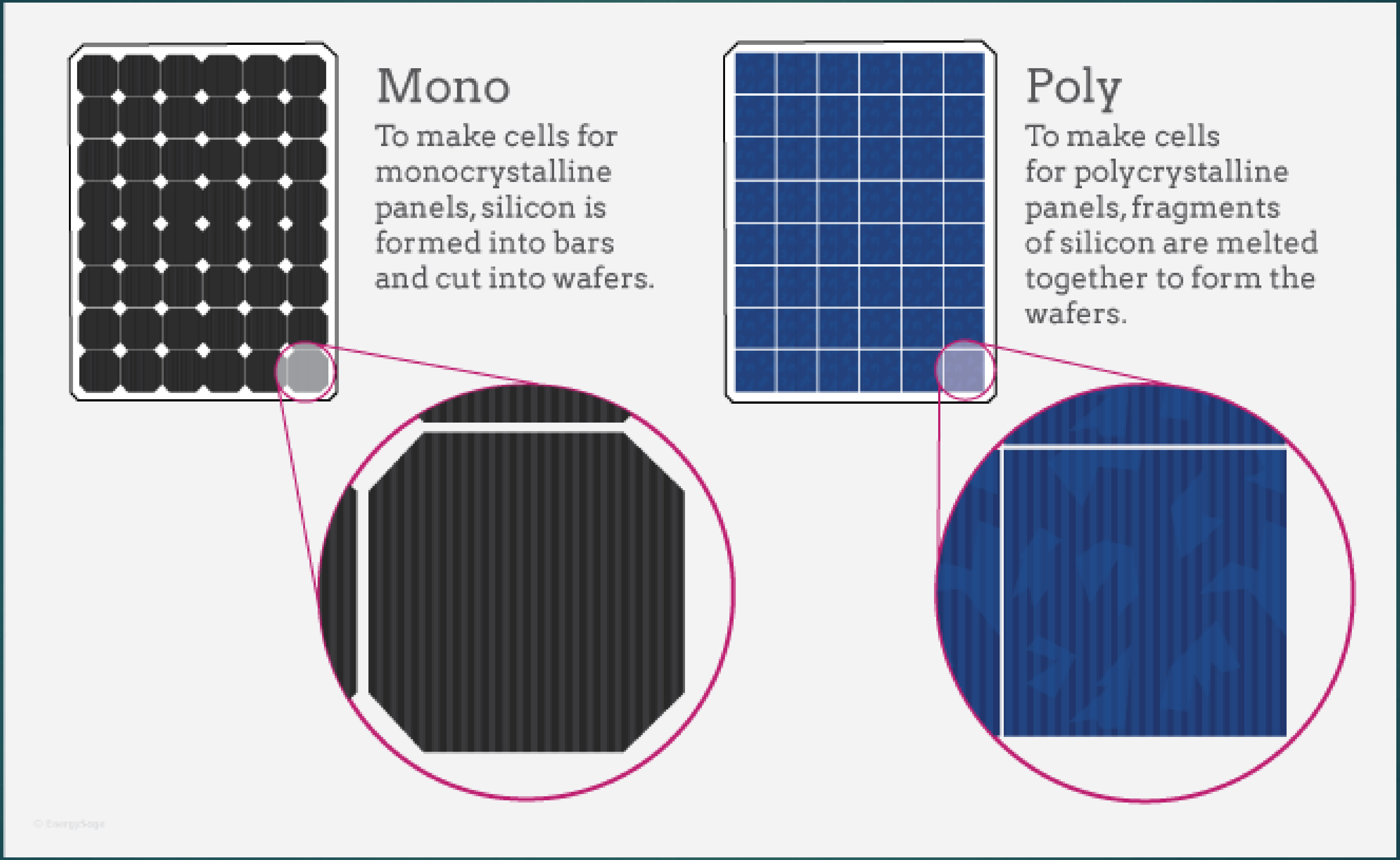


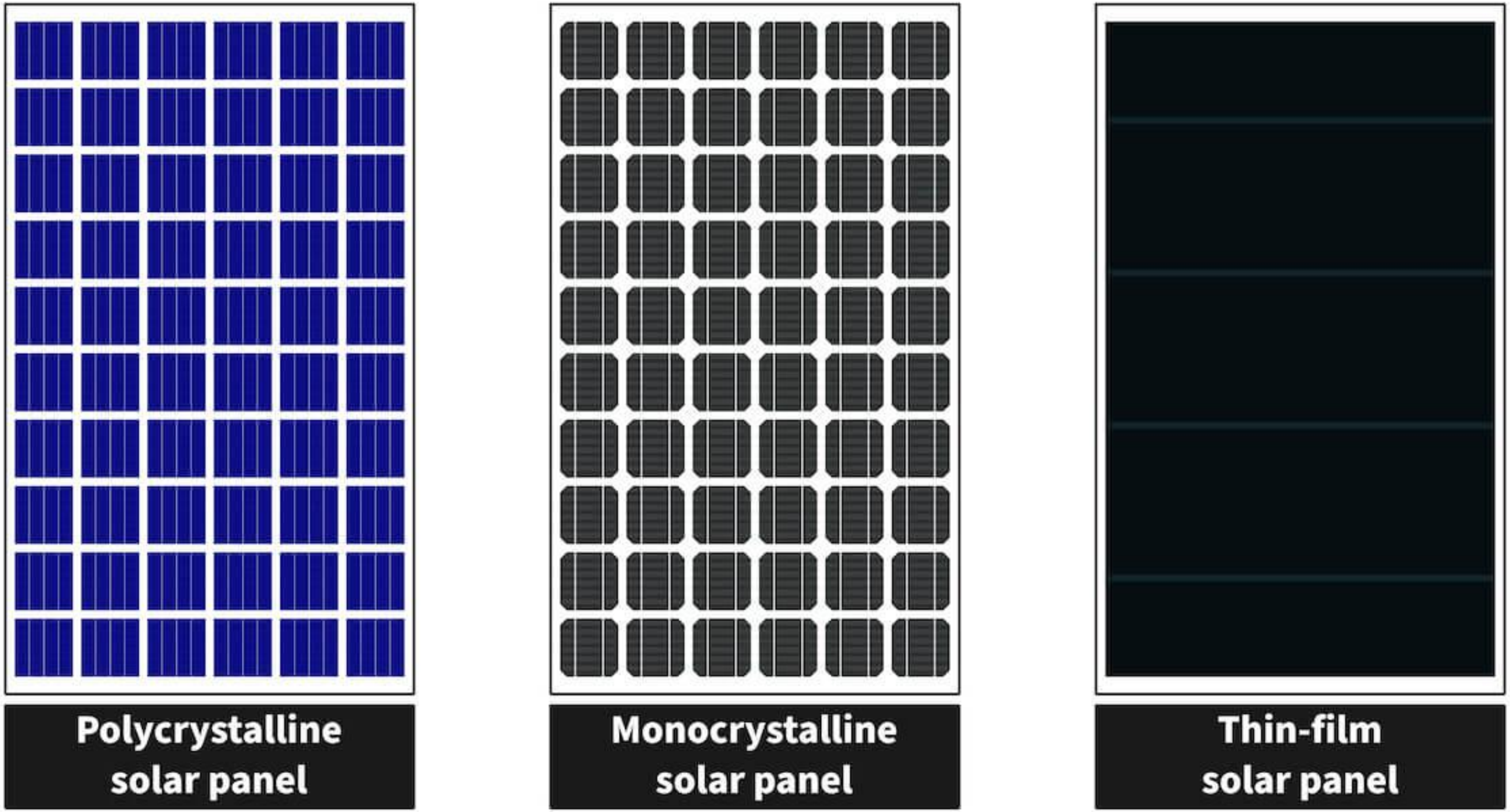
Multiple Silicon Fragments

More Space + Less Efficent

Less Expensive

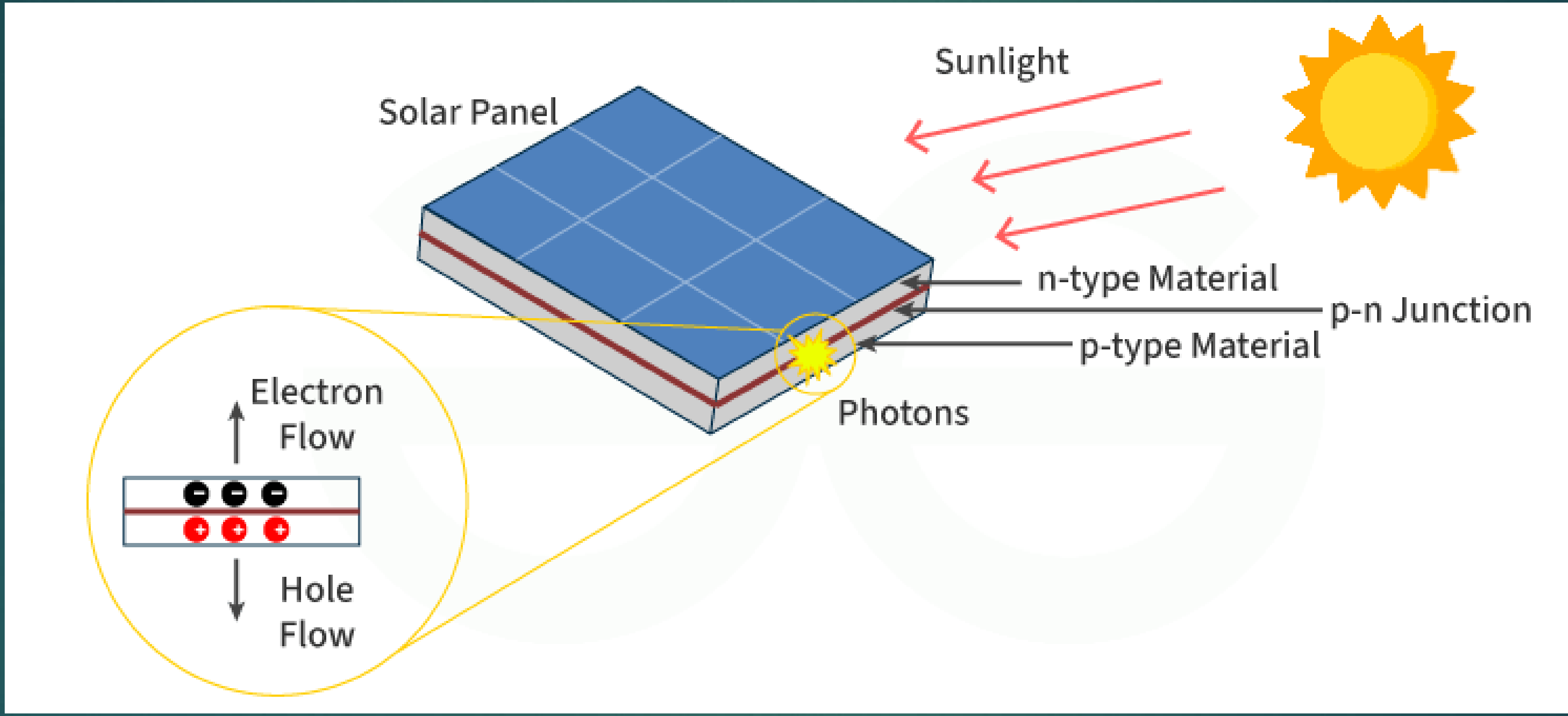
Blue Hue


Mono
To make cells for monocrystalline panels, silicon is formed into bars and cut into wafers.
Poly
To make cells for polycrystalline panels, fragments of silicon are melted together to form the wafers.


Polycrystalline solar panel
Monocrystalline solar panel
Thin-film solar panel

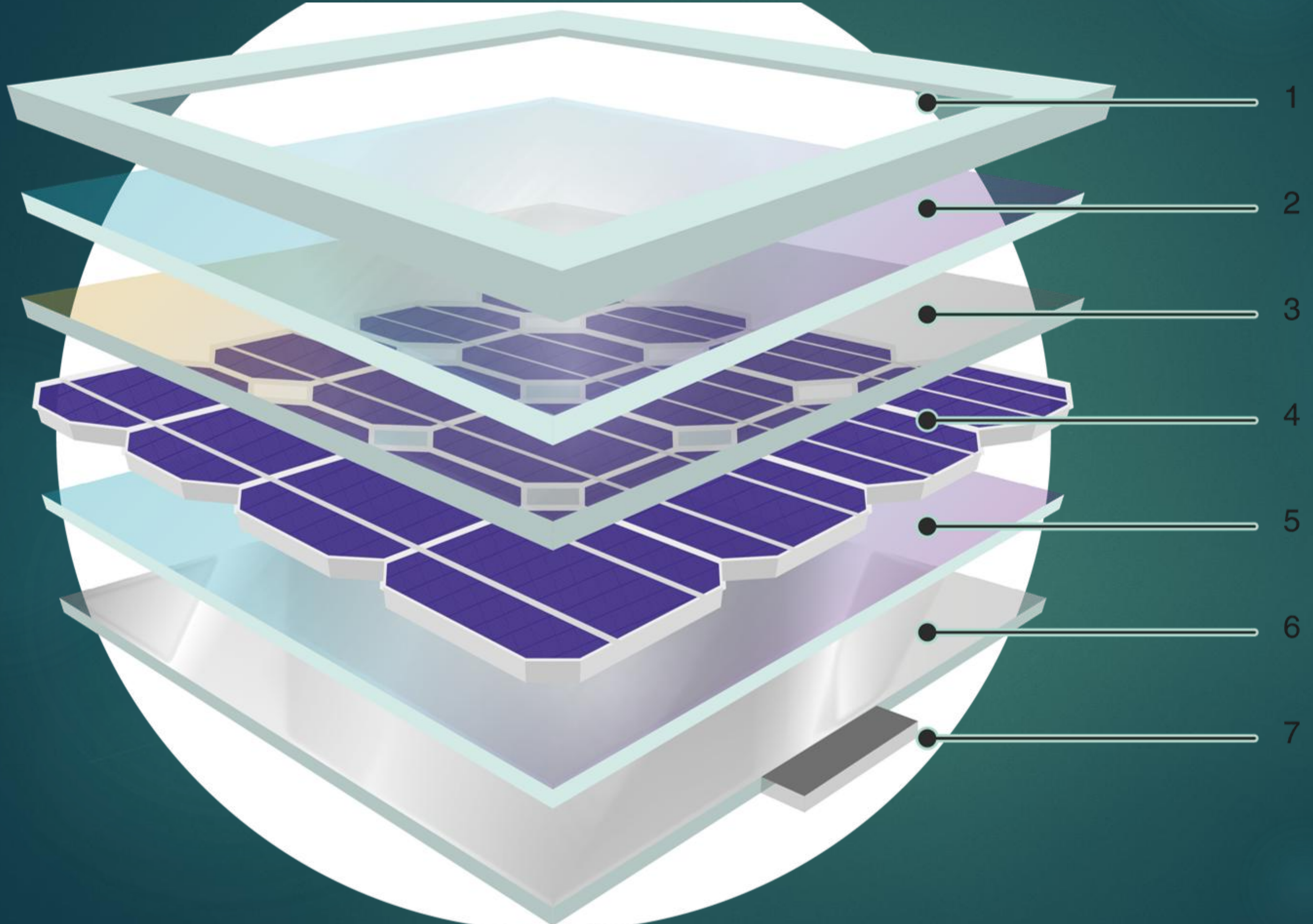
# Photovoltaic Cell or Solar Cell





# Component parts of a solar module






1 = Frame

2 = Glass

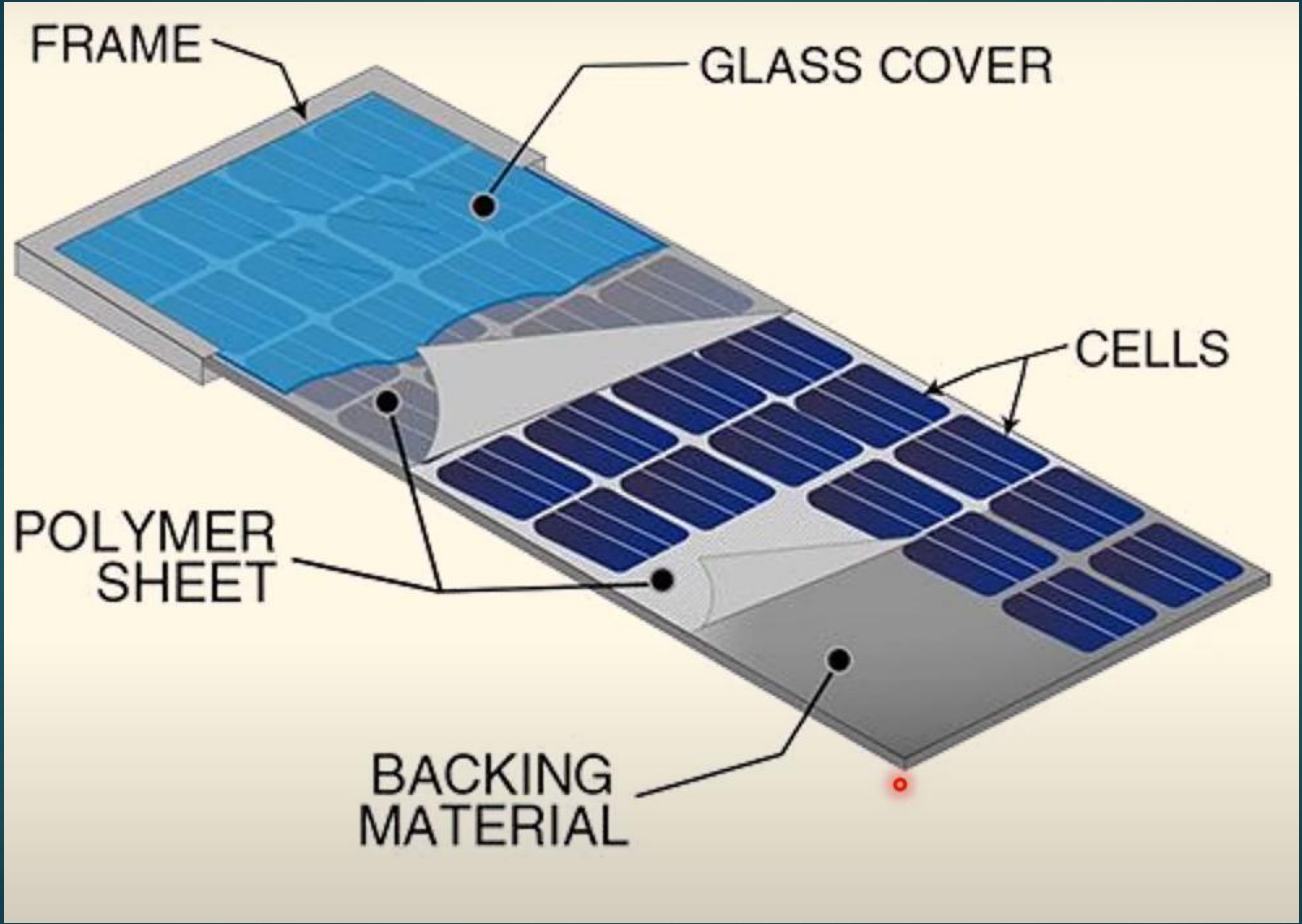
3 = Encapsulant

4 = Solar cells

5 = Encapsulant

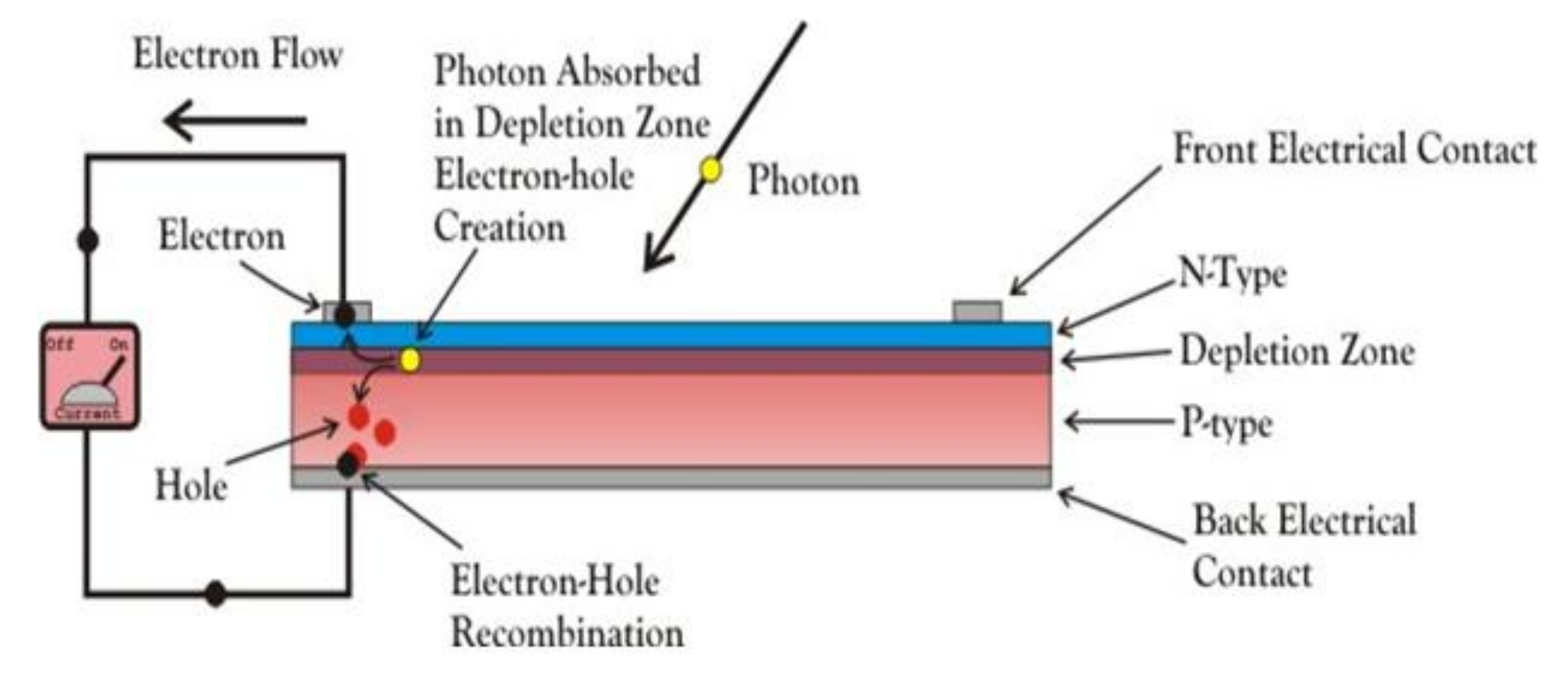
6 = Backsheet

7 = Junction box

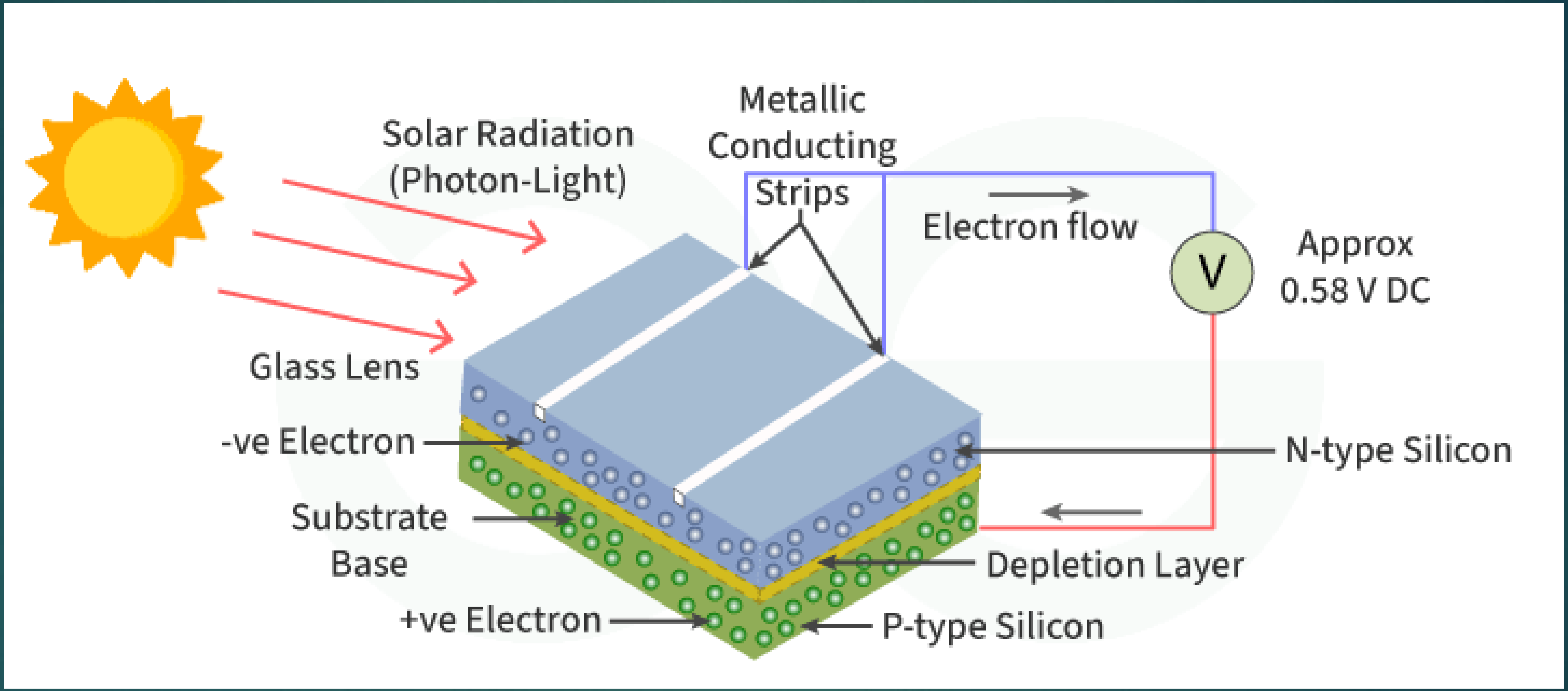

FRAME
GLASS COVER
CELLS
POLYMER SHEET
BACKING MATERIAL

# Construction of Solar Cell






A solar cell functions similarly to a junction diode, but its construction differs slightly from typical p-n junction diodes. A very thin layer of n-type semiconductor is grown on a relatively thicker p-type semiconductor.


Solar Radiation
(Photon-Light)
Metallic
Conducting
Strips
Electron flow
V
Approx
0.58 V DC
Glass Lens
-ve Electron
N-type Silicon
Substrate
Base
Depletion Layer
+ve Electron
P-type Silicon

# Working Principle of Solar Cell



The working principle of a photovoltaic (PV) cell involves the conversion of sunlight into electricity through the photovoltaic effect.

**Absorption of Sunlight:** When sunlight (which consists of photons) strikes the surface of the PV cell, it penetrates into the semiconductor material (usually silicon) of the cell.

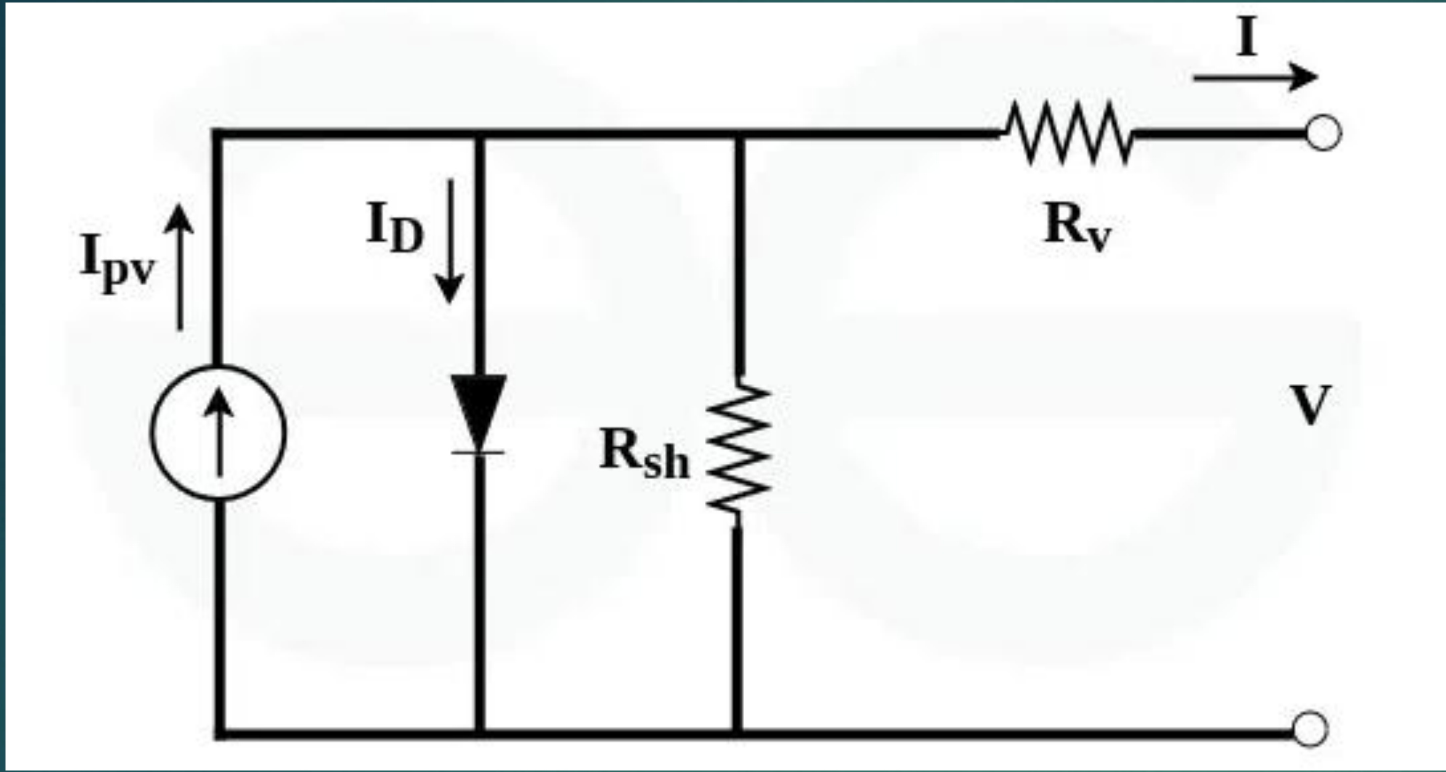
**Generation of Electron-Hole Pairs:** The energy from the absorbed photons is transferred to electrons in the semiconductor material, allowing them to break free from their atomic bonds and create electron-hole pairs. Electrons are negatively charged and move freely, while the holes are positively charged.

**Separation of Charges:** Due to the built-in electric field within the PV cell (created by the junction between different semiconductor layers), the newly generated electron-hole pairs are separated. Electrons are pushed towards the n-type (negative) side of the cell, while holes are pushed towards the p-type (positive) side.

**Flow of Electrons:** The separated electrons are collected by metal contacts on the surface of the cell, forming an electric current. This current can be harnessed for external use.

**External Load:** When an external electrical load (such as a light bulb or a battery) is connected to the PV cell, the flow of electrons through the load generates electrical power, which can be used to power various devices or stored in batteries for later use.

# Equivalent Circuit of a Photovoltaic Cell




**Photovoltaic Current Source (Ipv):** the current generated by the PV cell when exposed to light. It is proportional to the intensity of incident light and the efficiency of the cell.

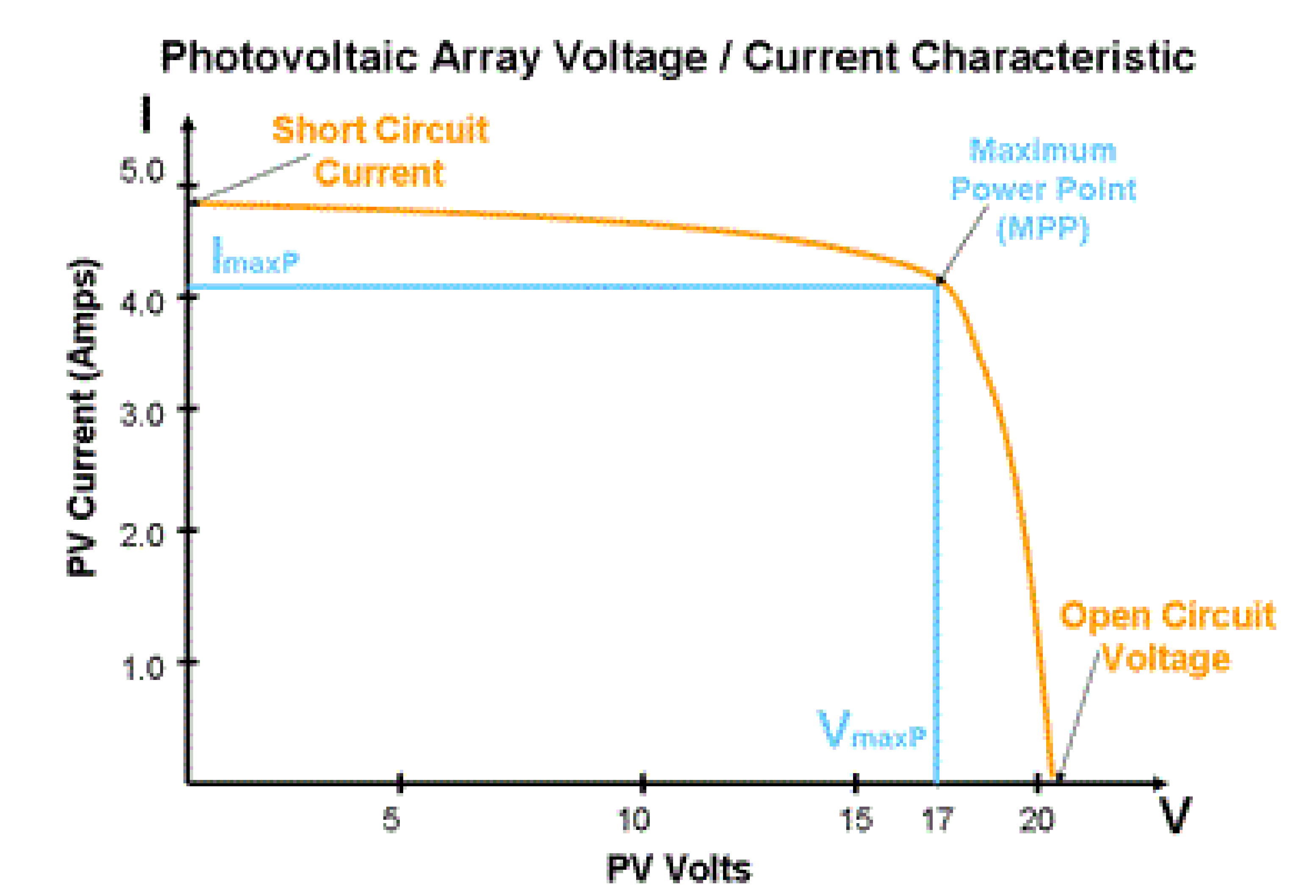
**Diode:** The diode represents the behavior of the p-n junction within the PV cell.

**Series Resistance (Rs):** This represents the internal resistance of the PV cell, including the resistance of the semiconductor material and the metal contacts.

**Shunt Resistance (Rsh):** This represents any parallel paths for current flow within the cell, such as surface leakage or defects in the semiconductor material.

# V-I Characteristics of a Photovoltaic Cell





**Short Circuit Current**: This is the highest current a solar cell can provide under optimal conditions without being damaged.

**Open Circuit Voltage**: The voltage across the solar cell's terminals when there is no load connected, typically around 0.5 to 0.6 volts.

**Maximum Power Point of Solar Cell**

The maximum electrical power one solar cell can deliver at its standard test condition.

**Current at Maximum Power Point:** The current at which maximum power occurs.

**Voltage at Maximum Power Point:** The voltage at which maximum power occurs.

**Fill Factor of Solar Cell:** The ratio between product of current and voltage at maximum power point to the product of short circuit current and open circuit voltage of the solar cell

$$Fill\ Factor = \frac{P_m}{I_{sc} \times V_{oc}}$$

**Efficiency of Solar Cell:** the ratio of the maximum electrical power output to the input radiation power, expressed as a percentage. On Earth, the radiation power is about 1000 watts per square meter. If the cell's exposed surface area is A, the total radiation power on the cell will be 1000 A watts.

$$Efficiency(\eta) = \frac{P_m}{P_{in}} \approx \frac{P_m}{1000A}$$

# Materials Used in Solar Cell



Materials used in solar cells must possess a band gap close to 1.5 ev to optimize light absorption and electrical efficiency. Commonly used materials are-

1. Silicon
2. GaAs (Gallium arsenide)
3. CdTe (cadmium telluride)
4. $CuInSe_2$ (Copper indium diselenide)

# Criteria for Materials to be Used in Solar Cell



1. Must have band gap from 1ev to 1.8ev.
2. It must have high optical absorption.
3. It must have high electrical conductivity.
4. The raw material must be available in abundance and the cost of the material must be low.

## Advantages of Solar Cell

1. No pollution associated with it.
2. It must last for a long time.
3. No maintenance cost.

## Disadvantages of Solar Cell

1. It has high cost of installation.
2. It has low efficiency.
3. During cloudy day, the energy cannot be produced and also at night we will not get solar energy.

# Applications of solar energy

1.Heating and Cooling of buildings

2. Solar water and air heating

3. Salt production by evaporation of seawater

4. Solar distillation

5. Solar drying of agricultural products

6. Solar cookers

7. Solar water pumping

8. Solar refrigeration

9. Electricity generation through Photo voltaic cells

10. Solar furnaces

11. Industrial process heat

12. Solar thermal power generation

# Application of solar energy



**Electricity Generation**

- **Solar Photovoltaic (PV) Systems**: Convert sunlight directly into electricity using solar panels.
  - Used in homes, offices, and solar farms.
- **Concentrated Solar Power (CSP)**: Uses mirrors/lenses to focus sunlight to produce steam and drive turbines.

# Application of solar energy

(a) Solar water heating

(b) Solar heating of buildings

(c) Solar distillation

(d) Solar pumping

(e) Solar drying of agricultural and animal products

(f) Solar furnaces

(g) Solar cooking

(h) Solar electric power generation

(i) Solar thermal power production

(j) Solar green houses.

Solar water heating

Solar heating of buildings

Solar distillation

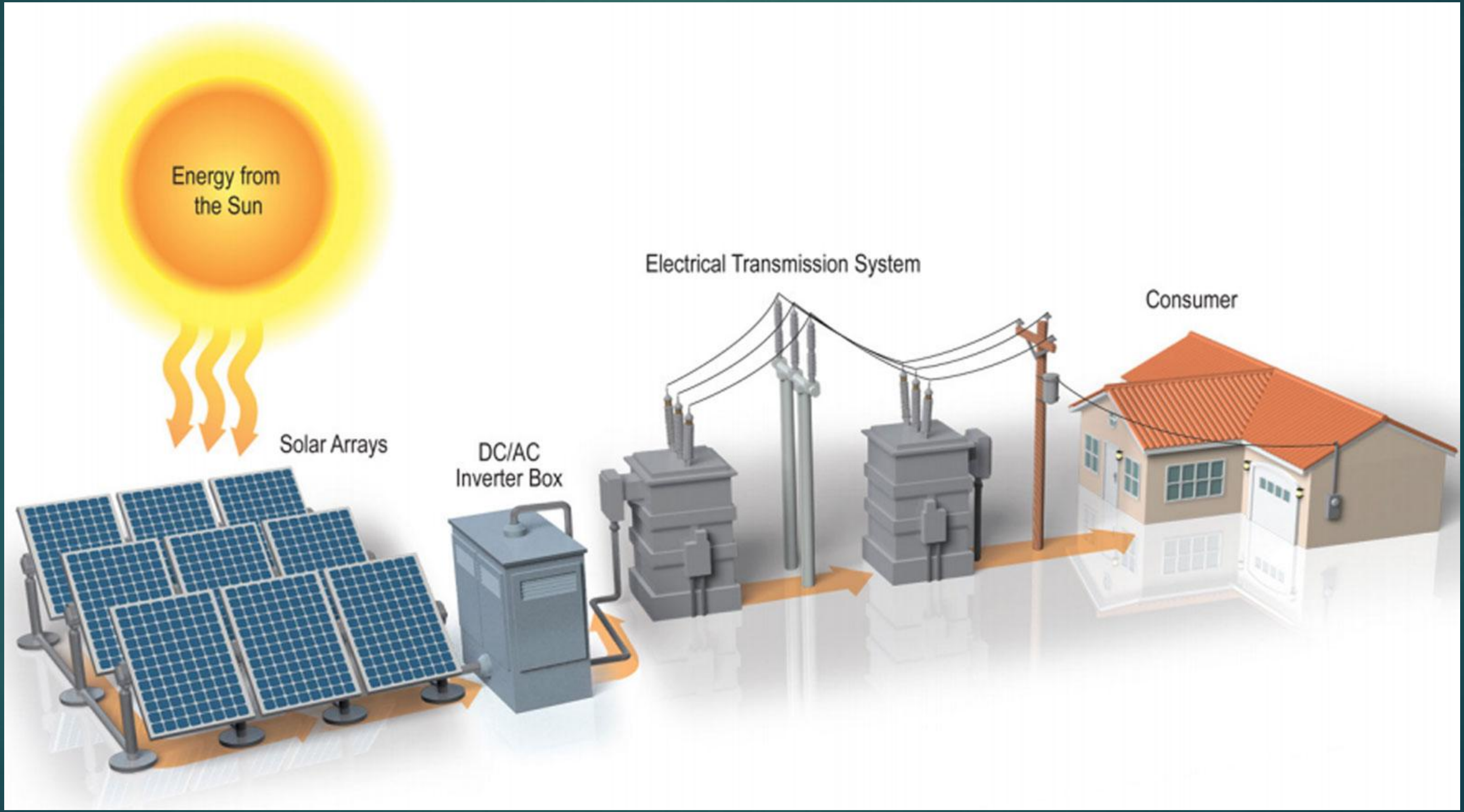
Solar pumping

**Solar drying of agricultural and animal products**

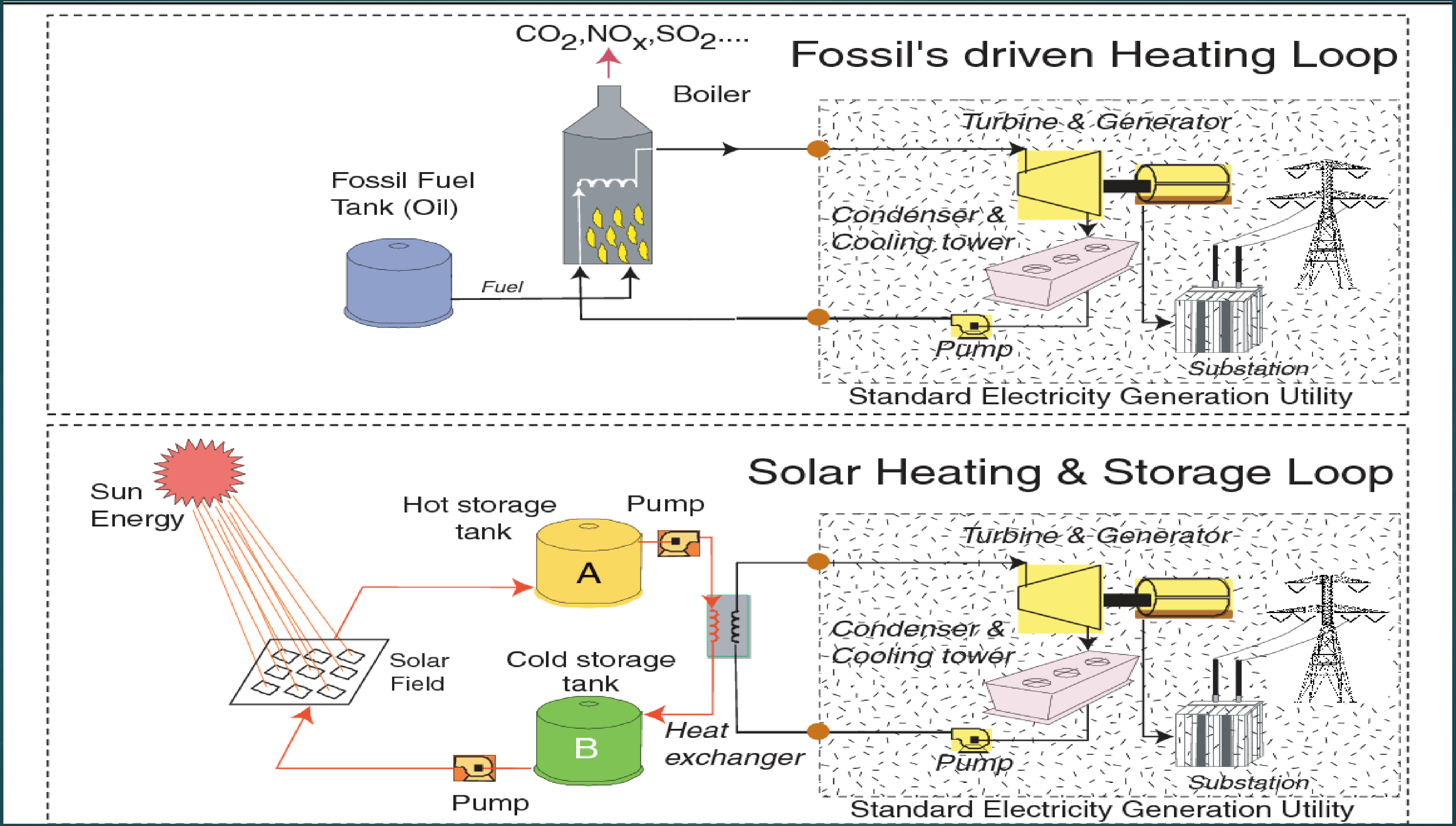
**Solar furnaces**


**Solar cooking**

## Solar electric power generation



# Solar thermal power production



## Solar green houses

# Solar Lighting


# Transportation

# Transportation


# Remote Power Supply

## Remote telecommunication towers

**Solar powered weather stations**



# Solar powered border outposts

# EV Charging Infrastructure

# Transformation of Solar Energy

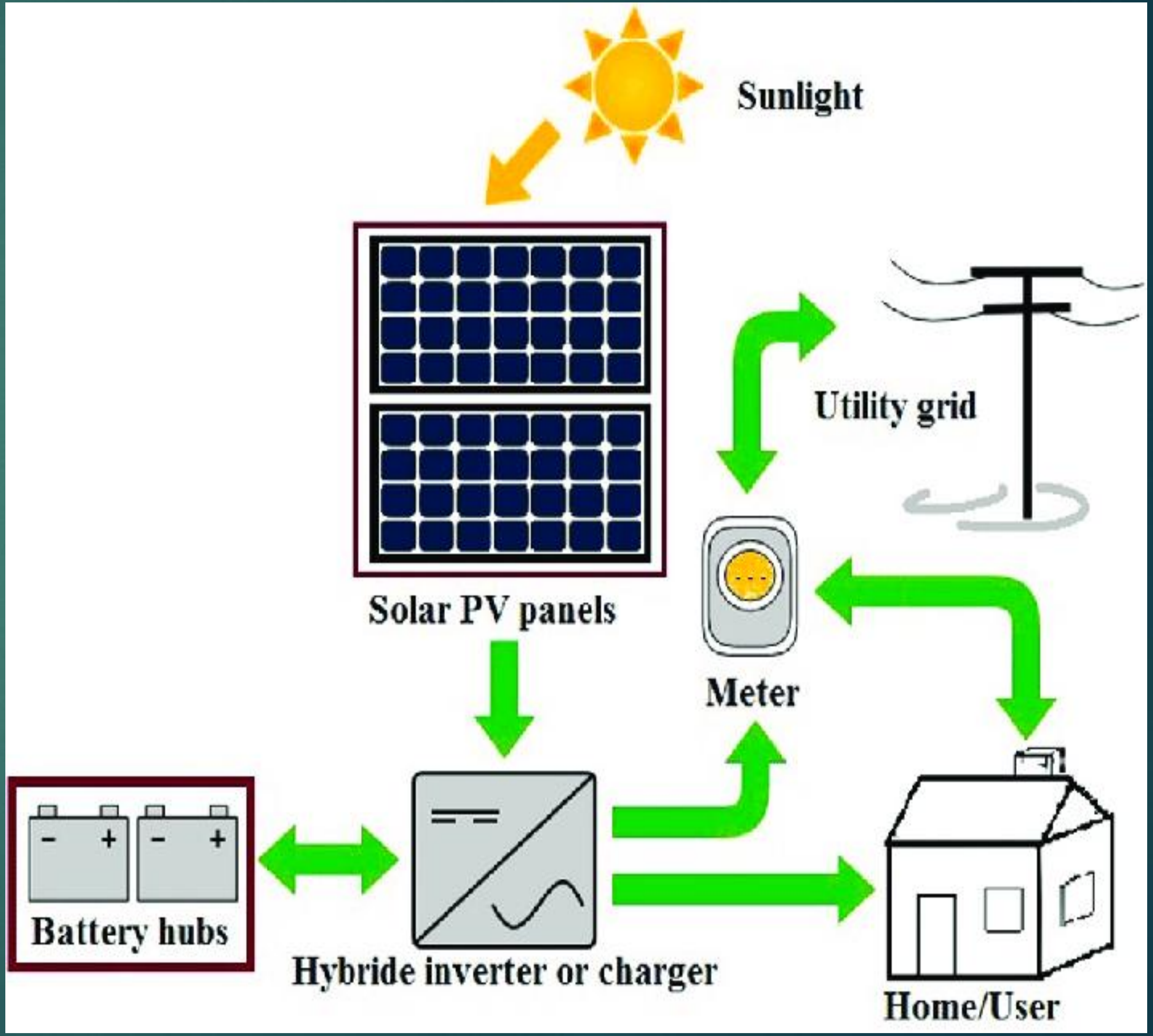


**The process of converting sunlight into usable forms of energy such as electricity, heat, or chemical energy.**

- **Photovoltaic (PV) Conversion – *Solar to Electricity***
- **Solar Thermal Conversion – *Solar to Heat***
- **Photosynthesis (Natural Transformation) – *Solar to Chemical Energy***
- **Solar to Mechanical Energy (Indirect)**
- **Solar to Chemical Energy (Artificial Transformation)**

## Photovoltaic (PV) Conversion – *Solar to Electricity*

**Process**: Solar panels made of semiconductor materials (like silicon) absorb sunlight and convert it into direct current (DC) electricity via the **photovoltaic effect**.




**Application**: Homes, industries, solar power plants.

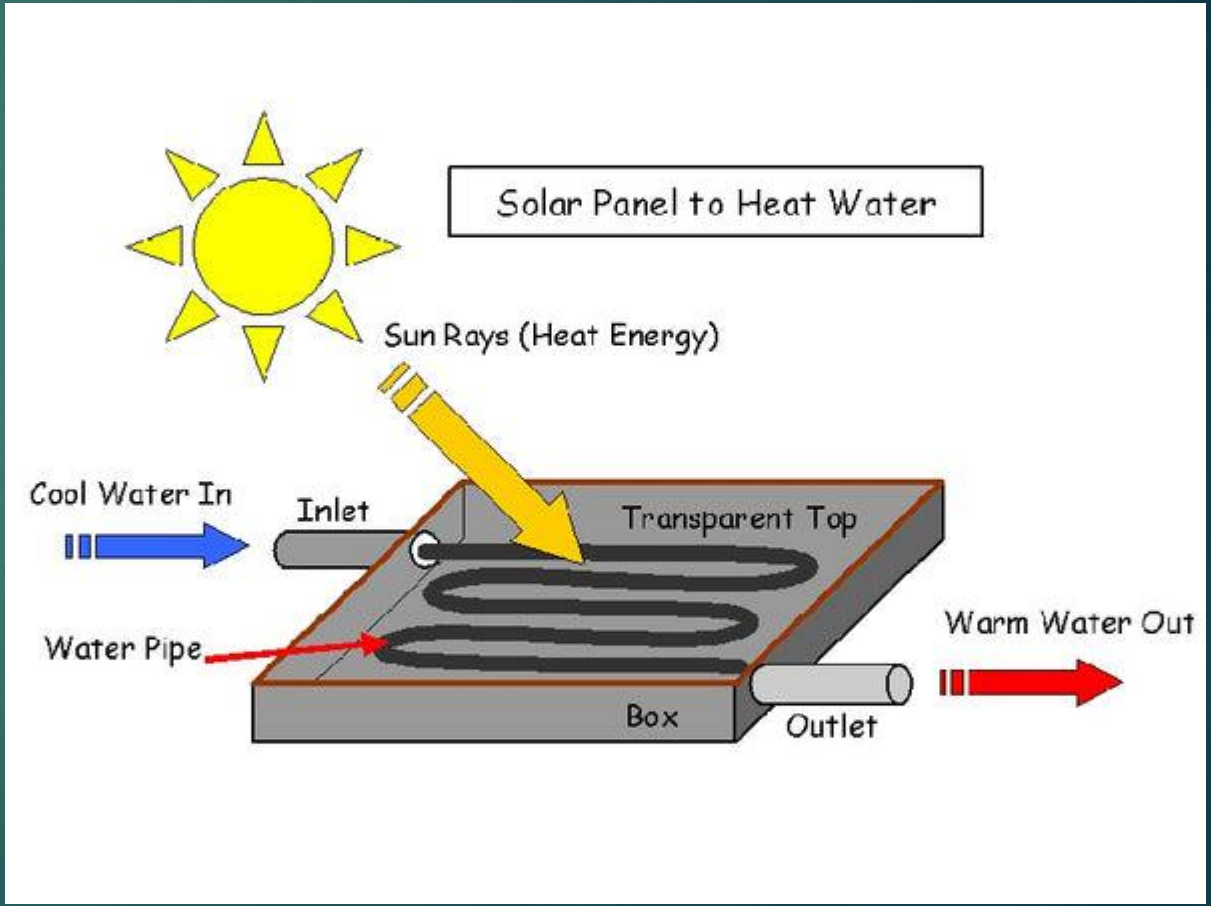
# Solar Thermal Conversion – *Solar to Heat*



**Process**: Solar collectors absorb solar radiation and convert it into thermal energy (heat).

**Types**:
**Low-temperature collectors** (e.g., flat plate): Used for water heating.

**Medium to high-temperature collectors** (e.g., parabolic troughs, solar towers): Used for power generation through steam turbines

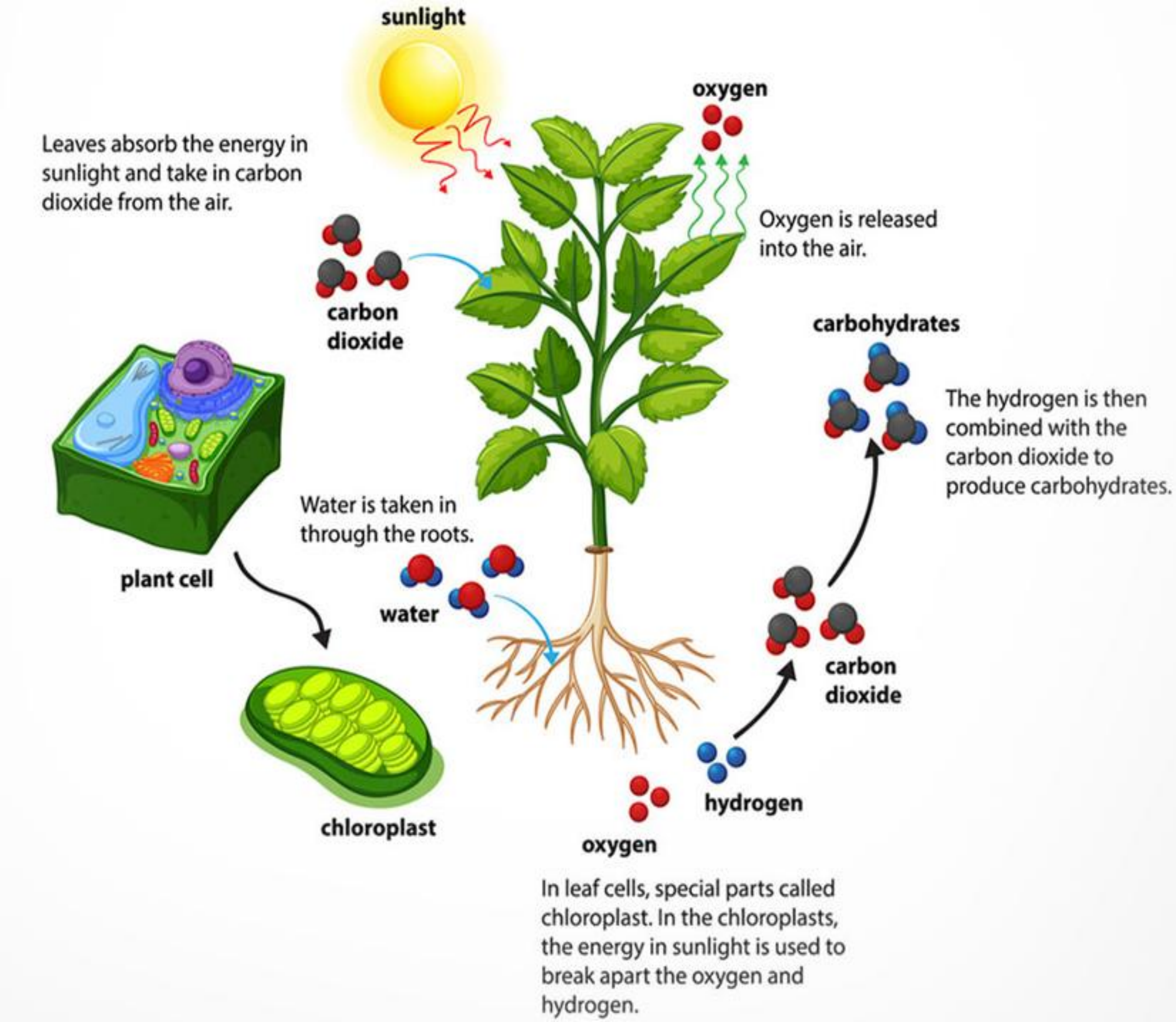


# **Photosynthesis (Natural Transformation)** – *Solar to Chemical Energy*



**Process**: Green plants absorb sunlight and convert carbon dioxide and water into glucose (chemical energy) and oxygen via **photosynthesis**.

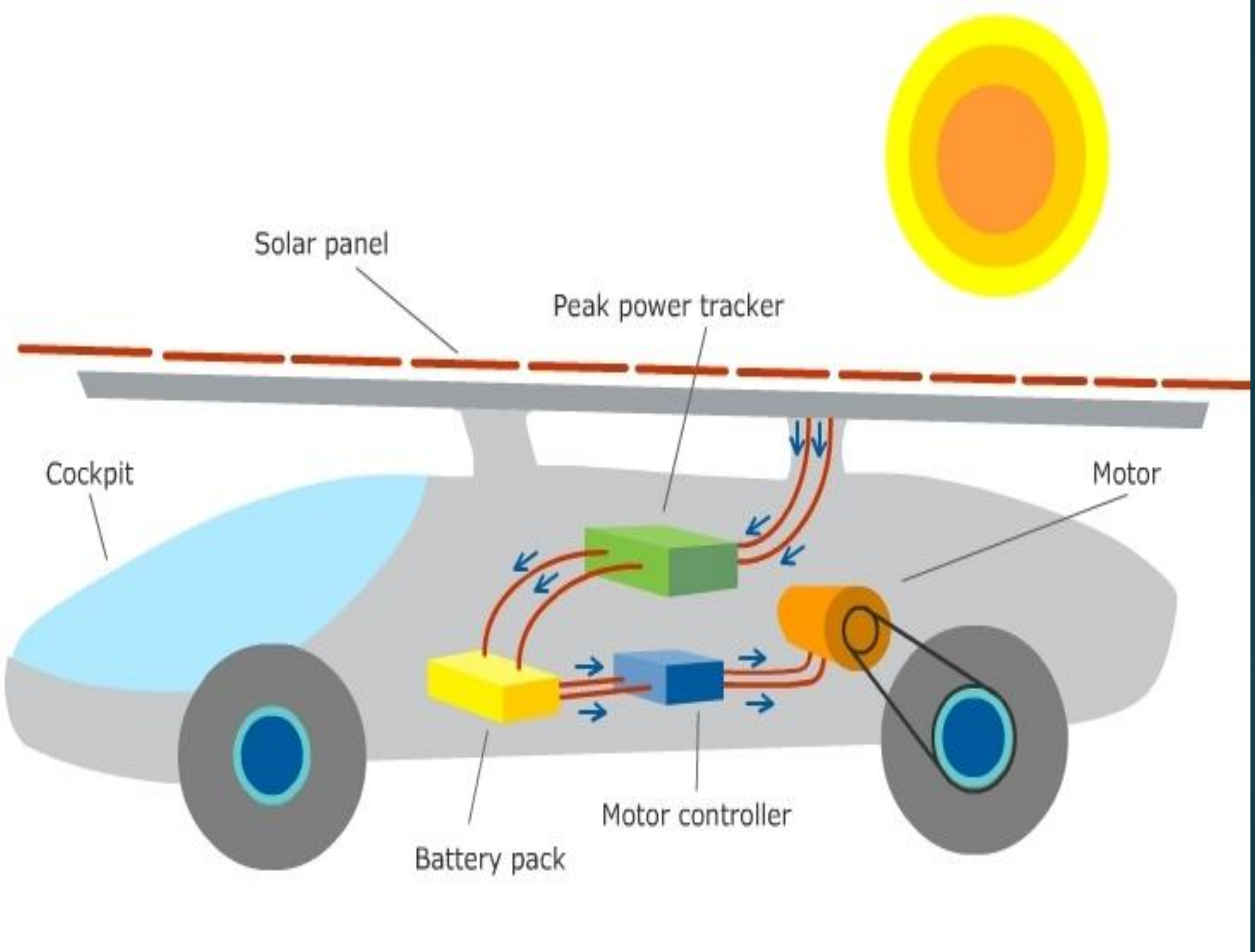
**Application**: Basis of the food chain; biomass energy source.



# Solar to Mechanical Energy (Indirect)



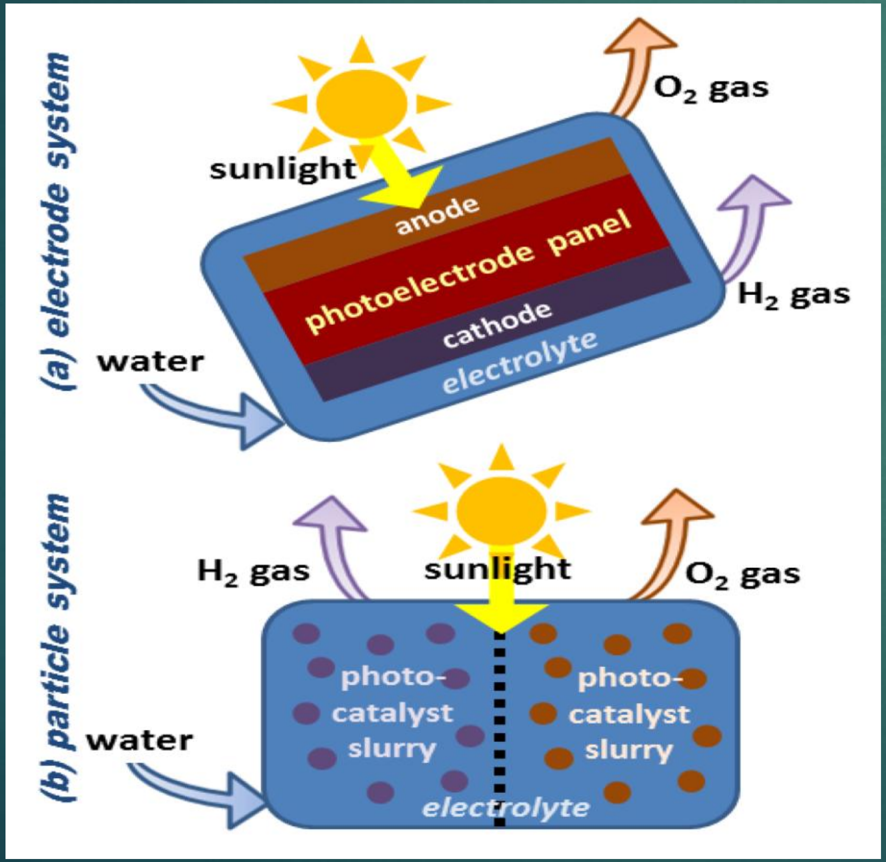
In **solar-powered engines** or **solar cars**, solar energy is first converted to electricity or heat, which then powers mechanical systems like motors or turbines

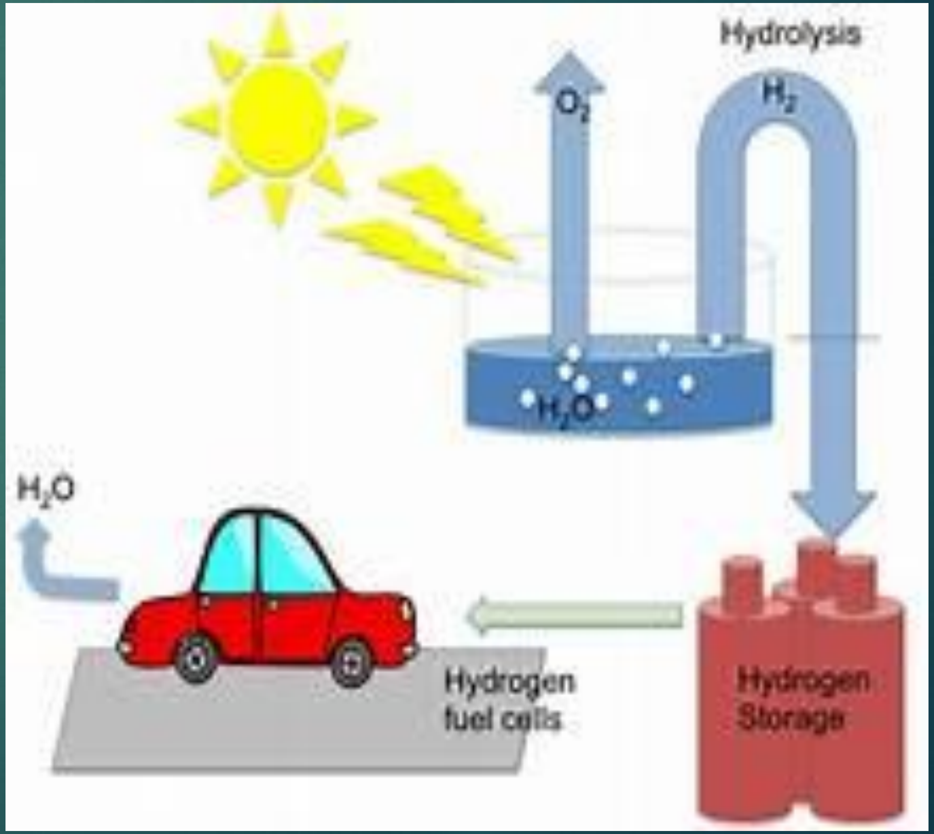


# Solar to Chemical Energy (Artificial Transformation)



**Solar Fuel Production**: Techniques like **photoelectrochemical cells** use sunlight to split water into hydrogen and oxygen, storing solar energy as **hydrogen fuel**.



| Form of Transformation | Energy Output | Technology Used |
|---|---|---|
| Solar → Electricity | Electrical Energy | Photovoltaic cells |
| Solar → Heat | Thermal Energy | Solar thermal collectors |
| Solar → Chemical | Chemical Energy (e.g., fuel) | Photosynthesis, hydrogen cells |
| Solar → Mechanical | Motion/Work | Solar engines, turbines |

*Solar energy transformation is essential for harnessing the sun's potential in various forms, contributing to clean and sustainable energy systems.*

# Solar Heat Collectors

**Solar heat collectors** are devices that **capture and convert solar radiation into thermal energy (heat)**, which can then be used for applications like **water heating**, **space heating**, **drying**, and **power generation**.

## Types of Solar Heat Collectors

- ❖ Flat Plate Collectors (FPC)
- ❖ Evacuated Tube Collectors (ETC)
- ❖ Concentrating Collectors (High-Temperature)

# Flat Plate Collectors (FPC)



**Structure**: A flat, insulated box with a dark absorber plate and transparent cover (glass/plastic).

**Working**: Sunlight heats the absorber plate, and the heat is transferred to a fluid (usually water or air) passing through tubes.

**Uses**: Domestic hot water systems, solar cookers, building heating.

**Efficiency**: Moderate, works well in moderate climates.

# Evacuated Tube Collectors (ETC)

**Structure**: Rows of glass tubes with vacuum insulation; inside each tube is an absorber.

**Working**: The vacuum reduces heat loss, increasing efficiency even in cold climates.

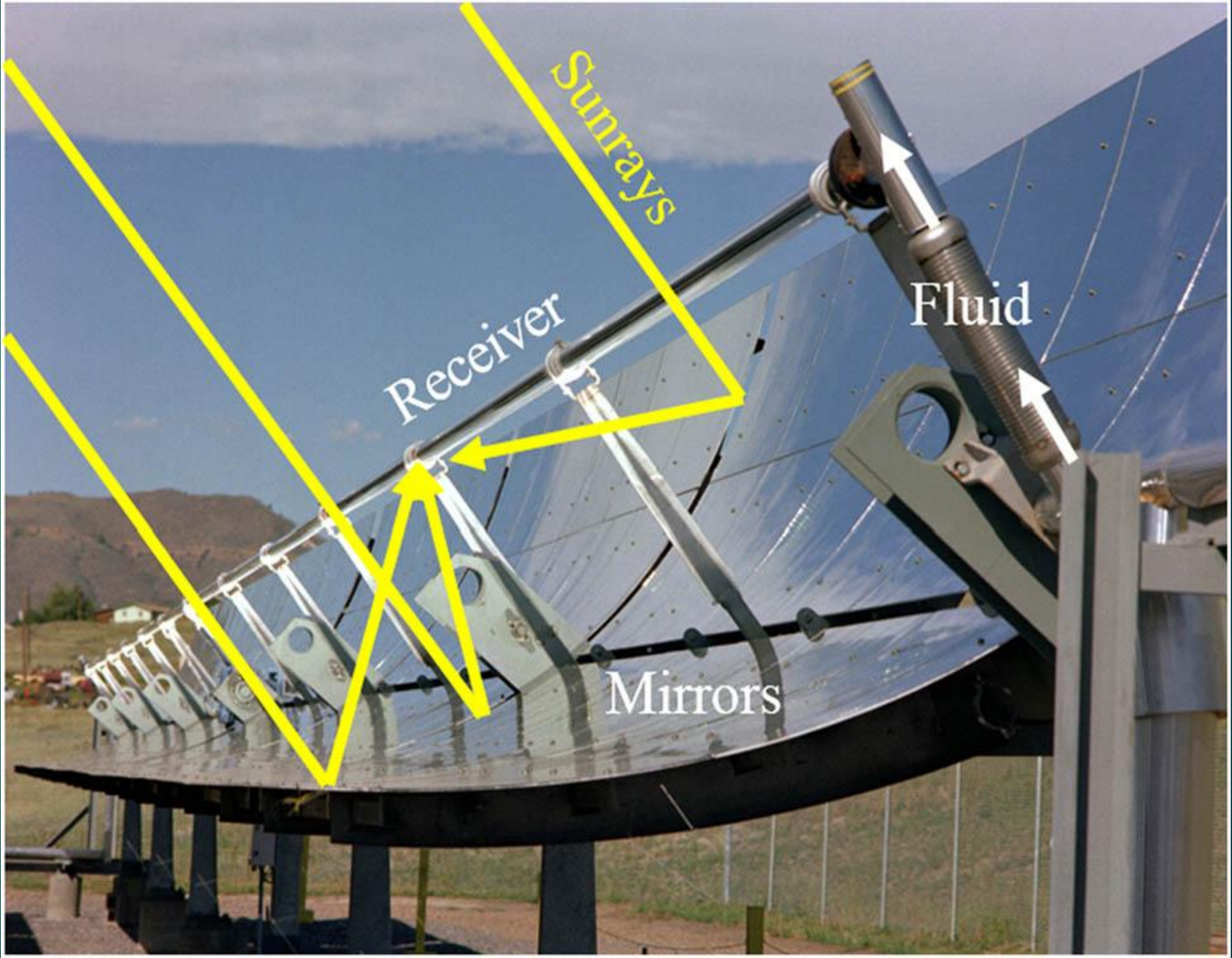
**Uses**: Residential and commercial water heating, hospitals, and hotels.

**Efficiency**: Higher than flat plate collectors; good for colder areas.

# Concentrating Collectors (High-Temperature)



These collectors **concentrate sunlight onto a small area** to generate high temperatures.




**Parabolic Trough Collectors**
Shaped like a parabola; focus sunlight onto a receiver pipe at the focal line.

Fluid in the pipe gets heated to 150–400°C.

Used in solar thermal power plants.

# Parabolic Dish Collectors



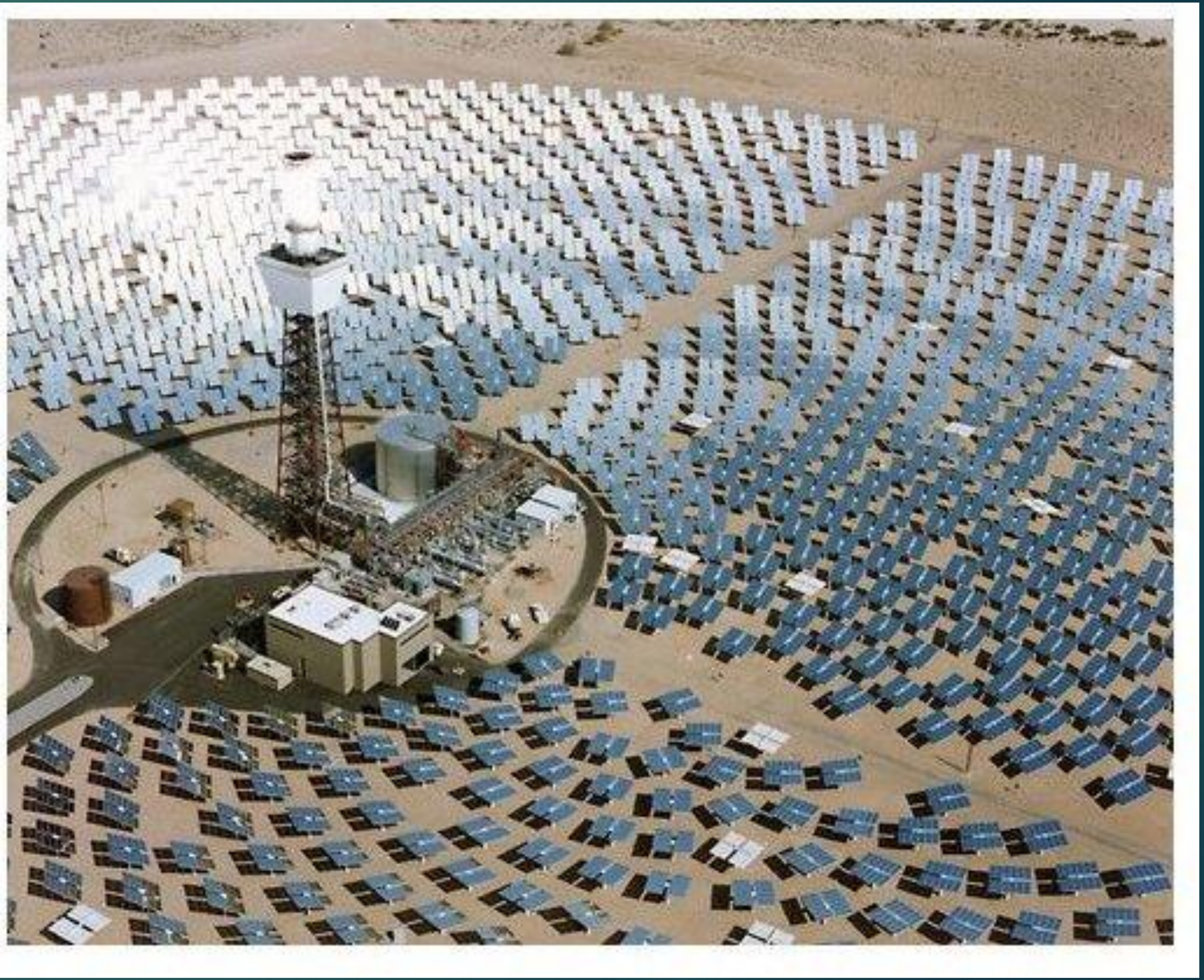
- Focus sunlight to a single point; used for very high temperatures.

- Can generate power using Stirling engines.

# Heliostat/Power Tower Systems

- A field of mirrors (heliostats) focuses sunlight on a central receiver atop a tower.

- Used in large-scale electricity generation (CSP – Concentrated Solar Power).



| Type | Temperature Range | Efficiency | Applications |
|---|---|---|---|
| Flat Plate Collector | 30–80°C | Moderate | Water heating, space heating |
| Evacuated Tube Collector | 50–150°C | High | Water heating in cold climates |
| Parabolic Trough | 150–400°C | Very High | Industrial heating, power generation |
| Parabolic Dish | Up to 1000°C | Very High | Power generation with engines |
| Heliostat/Power Tower | 300–1000°C+ | Very High | Large-scale solar thermal power plants |

*Solar heat collectors are vital for harnessing solar energy efficiently for thermal applications. The choice of collector depends on the* ***temperature requirement****,* ***budget****, and* ***location****.*

# Solar Photovoltaic (PV) Collectors



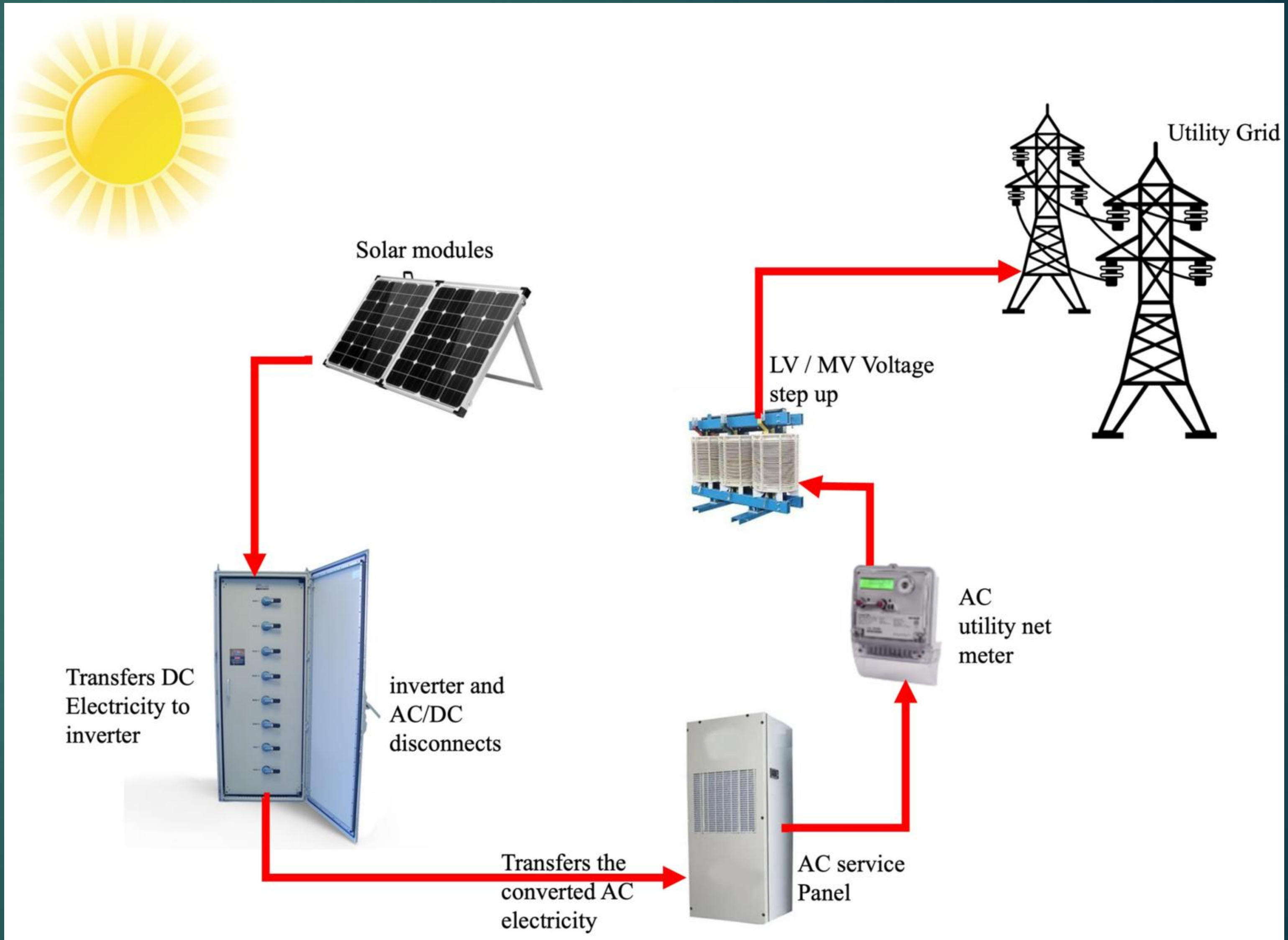
**Solar photovoltaic (PV) collectors** are devices that **convert sunlight directly into electricity** using the **photovoltaic effect**.

| Type | Description | Efficiency | Cost |
|---|---|---|---|
| **Monocrystalline Silicon** | Made from single-crystal silicon; black in appearance | High (~20–24%) | High |
| **Polycrystalline Silicon** | Made from multiple silicon crystals; blue in appearance | Moderate (~15–20%) | Moderate |
| **Thin-Film (e.g., CdTe, a-Si)** | Made by layering thin semiconductor materials on glass or plastic | Lower (~10–13%) | Low |
| **Bifacial Panels** | Capture sunlight from both front and back surfaces | High | High |
| **Perovskite Solar Cells** | Emerging technology with high potential and flexibility | Experimental | Low to moderate |

# Solar Power Plant

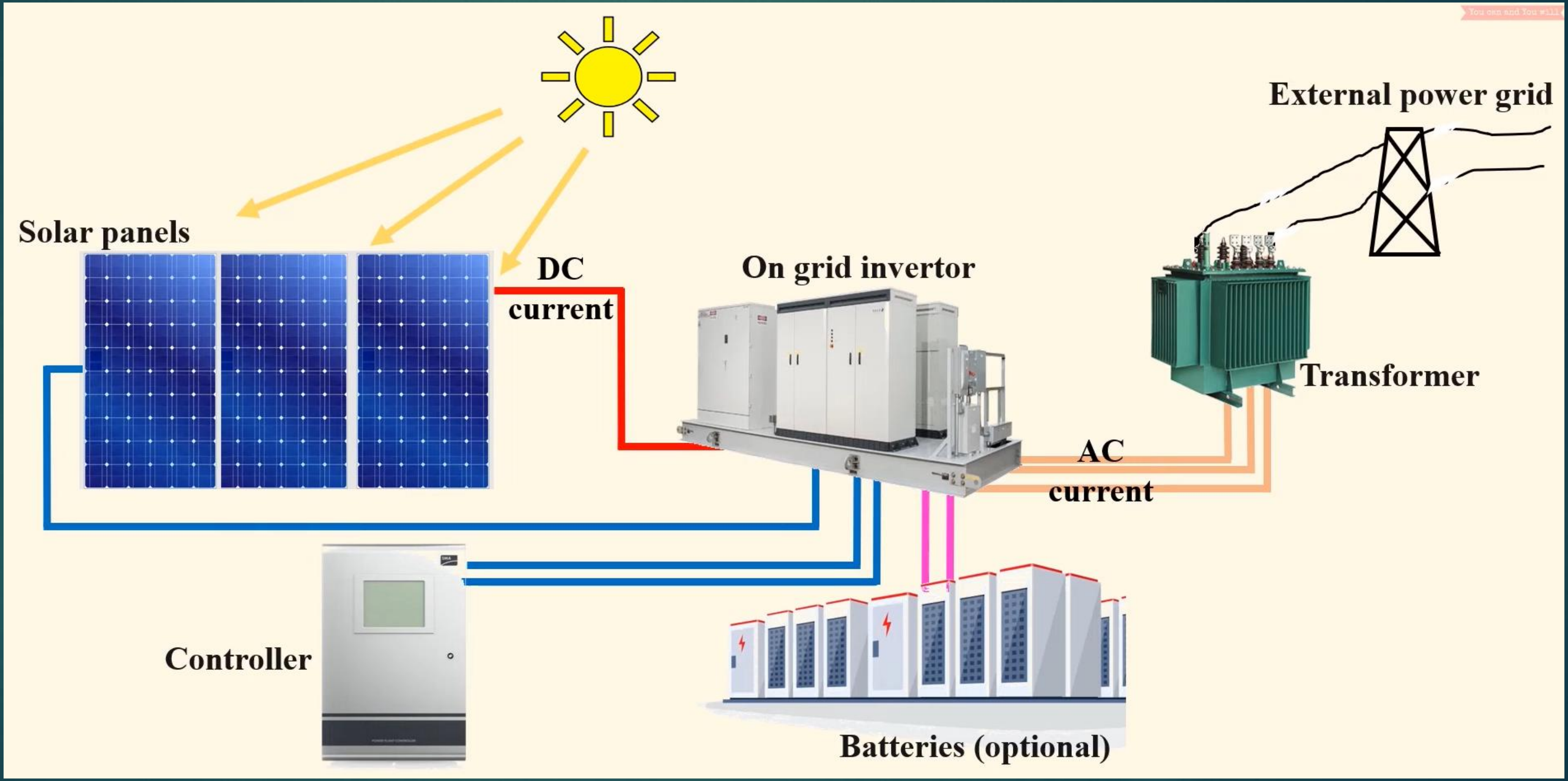
**Main Components of a Solar Power Plant**

- **Solar Panels or Collectors** (PV modules or reflectors)
- **Mounting Structures** (fixed or tracking systems)
- **Inverters** (convert DC to AC)
- **Batteries** (optional, for energy storage)
- **Transformers & Grid Interface** (for transmission to the utility grid)



# Solar Power Plant





# Examples of Major Solar Power Plants



| Name | Location | Capacity |
|---|---|---|
| Bhadla Solar Park | Rajasthan, India | 2,245 MW |
| Pavagada Solar Park | Karnataka, India | 2,050 MW |
| Tengger Desert Solar Park | China | 1,547 MW |
| Noor Solar Complex | Morocco | ~580 MW (CSP) |

# Economic study



An **economic study of solar energy** evaluates the **cost-effectiveness**, **financial viability**, and **long-term economic benefits** of using solar energy for electricity or heat production compared to conventional sources like coal, gas, or diesel.

**Capital Cost (Initial Investment)**

- Includes:
  - Cost of **solar panels** or **collectors**
  - **Inverter**, **batteries** (if used), and **installation**
  - **Land acquisition** and **mounting structures**

- Capital cost has **dropped significantly** in recent years due to technology improvements and mass production.

# Example (India, 2024 Estimates):

| System Type | Approx. Cost per kW |
| --- | --- |
| Rooftop PV System | ₹40,000 – ₹60,000 |
| Utility-scale Solar Plant | ₹35,000 – ₹50,000 |

**Operating & Maintenance Cost**

- Very **low** compared to fossil fuel plants.
- Includes cleaning, inverter replacement (after ~10 years), minor repairs

**Levelized Cost of Electricity (LCOE)**

- **LCOE** is the cost per unit of electricity over the system's lifetime.
- Solar power's LCOE is **increasingly competitive** with coal and gas.
- In India, utility-scale solar LCOE ≈ ₹2.5–₹3.5 per kWh (cheaper than coal in many cases).

**Payback Period**

- Time taken to recover the initial investment.
- Depends on:
  - Solar irradiance
  - Electricity tariffs
  - Subsidies and incentives

Typically **3–7 years** for rooftop systems, after which power is virtually free

**Government Incentives**

- **Capital subsidies** for rooftop systems (e.g., 20%–40%)
- **Net metering policies** to sell surplus electricity to the grid
- **Tax benefits** (Accelerated Depreciation for commercial users)

**Environmental and Social Cost Savings**

- Reduced **carbon emissions**
- Less **air pollution**, **water usage**, and **health hazards**
- Creates **green jobs** in manufacturing, installation, and maintenance

**Economic Benefits Over Time**

- Long lifespan (20–30 years)
- Shield from rising electricity tariffs
- Increased property value for homes and businesses with solar systems

# Trends in Solar Energy Utilization



### Rapid Growth in Solar Installations

- **Global solar capacity** is expanding every year, with many countries adding **gigawatts of new capacity annually**.
- India, China, the USA, and Europe are leading in large-scale solar deployments.
- Rooftop solar adoption is growing among **residential, commercial, and industrial users**.

### Declining Cost of Solar Technology

- The **cost of solar panels** has dropped by more than 80% in the last decade.
- **Levelized cost of electricity (LCOE)** for solar is now often **cheaper than coal or gas**.
- Improvements in **manufacturing efficiency** and economies of scale continue to drive prices down.

**Rise of Grid-Connected and Hybrid Systems**

- Shift from **off-grid** to **grid-tied systems** with net metering allows users to feed excess electricity into the grid.
- **Hybrid systems** combining solar with wind, batteries, or diesel generators ensure continuous power supply.

**Integration with Energy Storage**

- **Battery storage systems** (like lithium-ion) are increasingly paired with solar PV to store excess energy.
- **Solar + Storage** improves energy reliability and grid independence, especially in remote or disaster-prone areas.

**Smart Solar and IoT Integration**

- Use of **smart inverters**, **real-time monitoring**, and **IoT-based control systems** for performance tracking and optimization.
- Integration with **home automation** and **smart grids**.

**Development of Floating Solar Farms**

- Installation of **solar panels on water bodies** (lakes, reservoirs) saves land and reduces panel heating, improving efficiency.
- Floating solar is gaining popularity in countries with limited land availability.

**Growth of Solar in Transportation**

- Development of **solar-powered vehicles**, **charging stations for EVs**, and **solar panels on electric buses and trains**.

**Innovations in Solar Technology**

- **Bifacial solar panels** (capture sunlight from both sides)
- **Perovskite solar cells** (low-cost and flexible, with high efficiency potential)
- **Building Integrated PV (BIPV)**: Solar panels integrated into windows, facades, or roofs.

**Policy Support and Incentives**

- Many governments offer **tax benefits**, **subsidies**, and **net metering policies** to promote solar adoption.
- International initiatives like **IRENA** and **Mission Innovation** push for global solar expansion.

**Focus on Sustainable Development**

- Solar energy plays a major role in achieving **UN Sustainable Development Goals (SDG 7 – Affordable and Clean Energy)**.
- Solar adoption is crucial in **rural electrification**, reducing energy poverty.

*The trends in solar energy utilization reflect a clear shift towards a* ***clean, sustainable, and technology-driven energy future****. As innovations continue and costs fall, solar energy will increasingly become a* ***mainstream power source*** *globally.*

# *THANK YOU*