

Unit 2:- Solar Energy



Syllabus...Unit 2

- Solar radiation, Flat plate collectors, solar concentration, thermal applications of solar energy, photovoltaic technology and applications, energy storage.

Books ...

- Gilbert M. Masters, *Renewable and Efficient Electrical Power Systems*, Wiley - IEEE Press, August 2004.
- Godfrey Boyle, *Renewable Energy*, Third edition, Oxford University Press, 2012.
- Chetan Singh Solanki, *Solar Photovoltaics-Fundamentals, Technologies and Applications*, PHI Third Edition, 2015.

Supplementary Reading:

- D.P.Kothari, K.C.Singal, Rakesh Rajan, *Renewable Energy Sources and Emerging Technologies*, PHI Second Edition, 2011.

Introduction

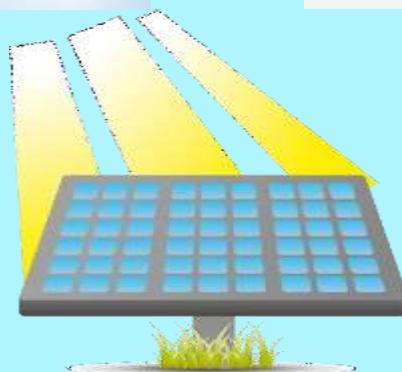
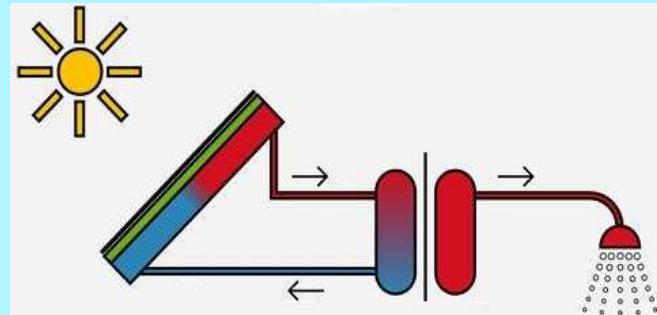
- India is nearly **17% of world population (with an growth rate of 1.2%)**
 - Land area of 3.2 million Sq km, is 2.4% of the world, 0.01 sq million Kms is required to meet complete demand of country
- We have **ONLY 6.7% of coal, 0.3% of oil and 0.6% of gas reserves of world**
- **Capital cost per MW for coal based power plant is 7.75 cr. and for solar plant is 3.5 cr.**

Solar energy...

Solar Thermal Passive Energy



Solar Thermal Active Energy

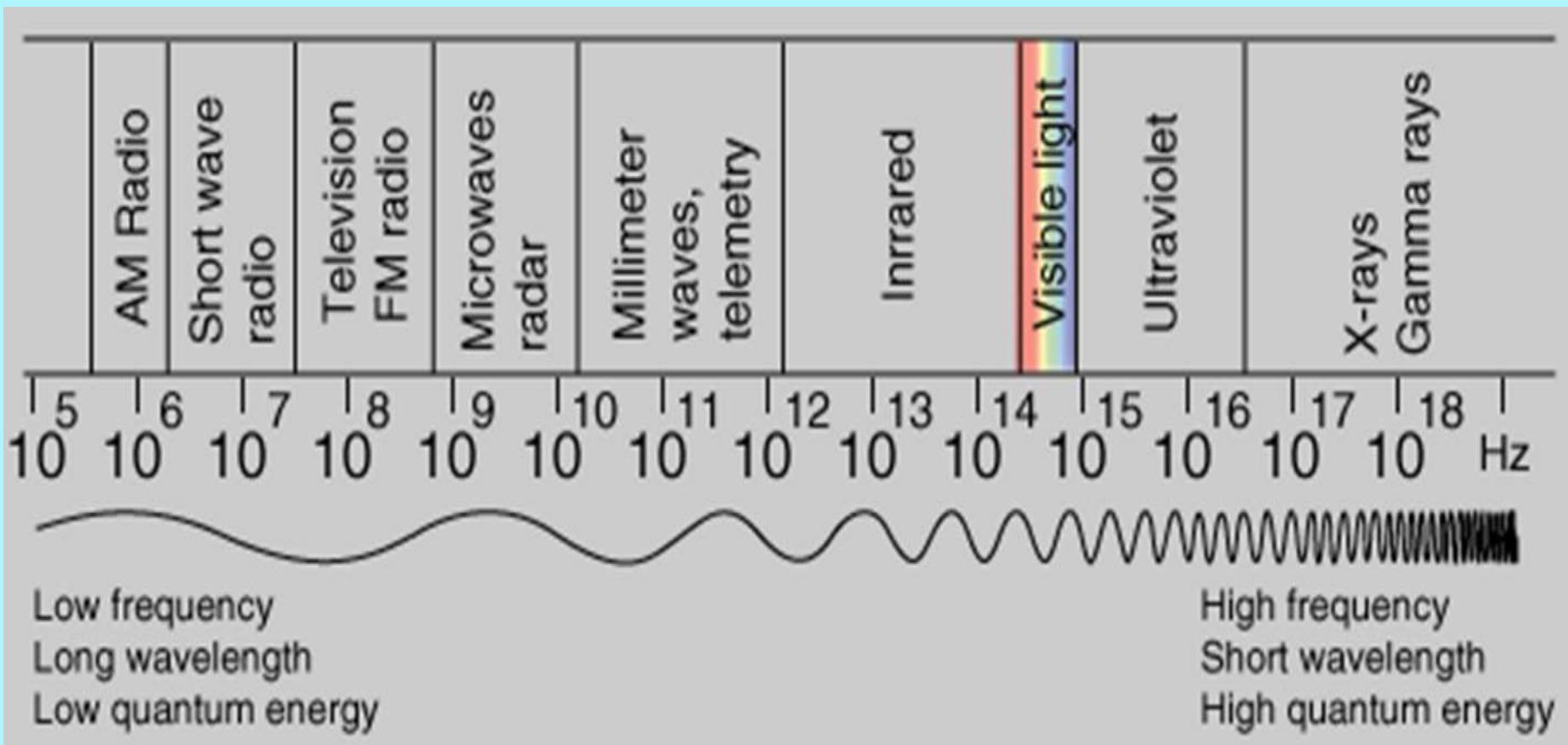


**Solar Photovoltaic
Energy**

Solar energy...

- ✿ The sun generates its energy by **nuclear fusion** which is emitted as radiation
- ✿ Radiation emitted by sun is in the form of Gamma rays, Visible rays, Infrared rays etc.
- ✿ Sun's total energy is composed of **7% UV radiation, 47% Visible radiation, 46% Infrared radiation**
- ✿ Photovoltaic cells primarily uses irradiation of wavelength **300-3000 nm**, the range for SPV (Solar Photo Voltaic)
- ✿ SPV plants utilizes **only light component of sunlight to generate electricity**

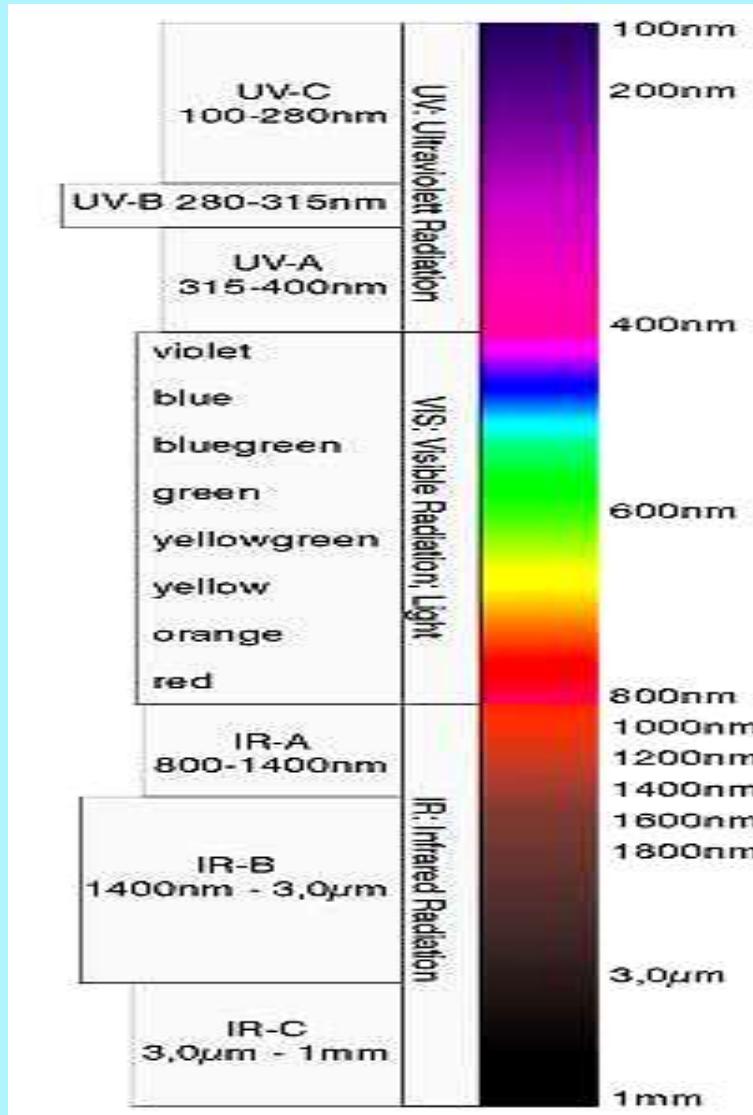
Solar Radiation..



Low frequency
Long wavelength
Low quantum energy

High frequency
Short wavelength
High quantum energy

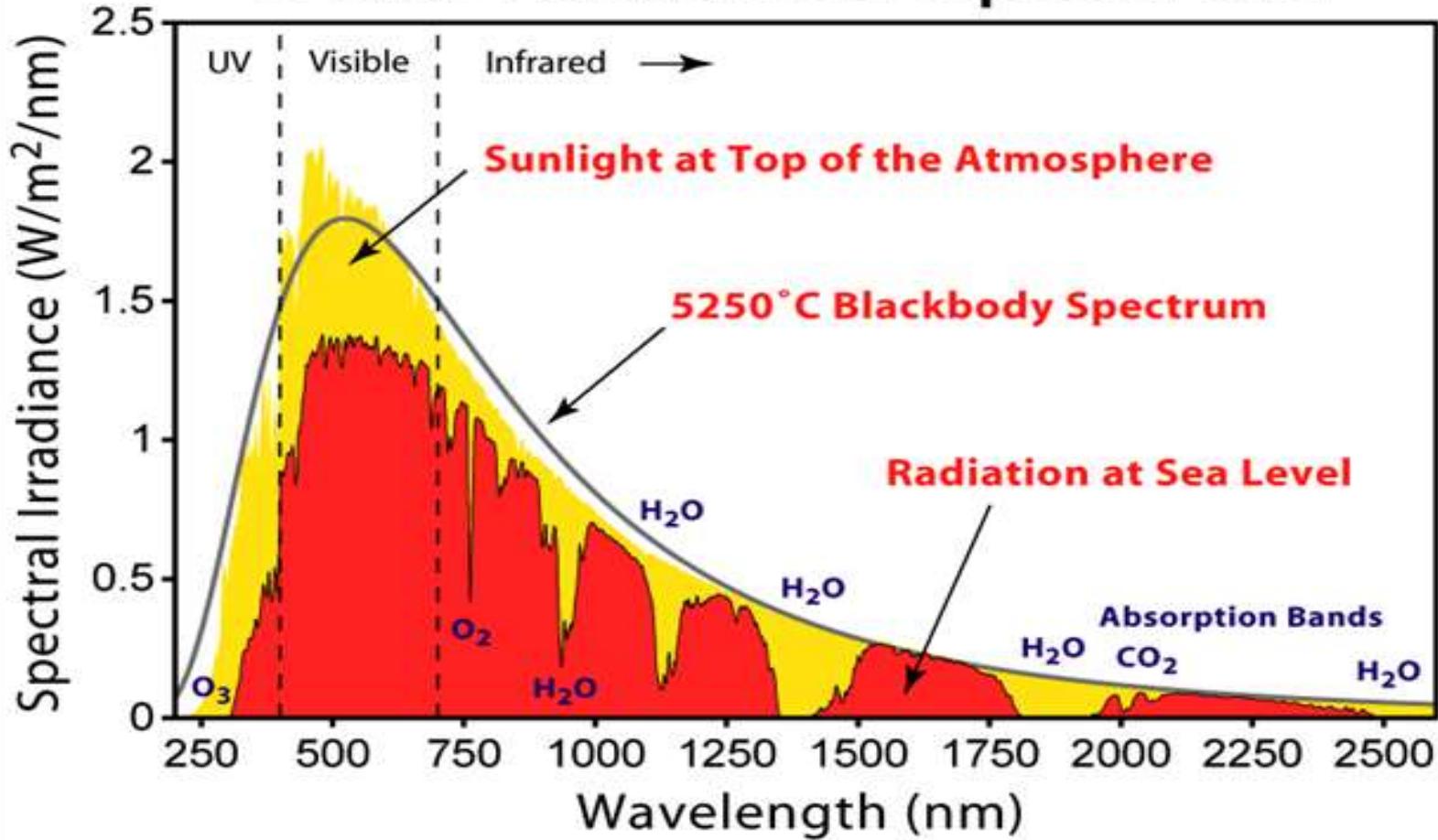
Solar Radiation..



Light is small portion of electromagnetic spectrum
380nm to 760nm visible range
Light is radiant energy

Solar Radiation..

Solar Radiation Spectrum

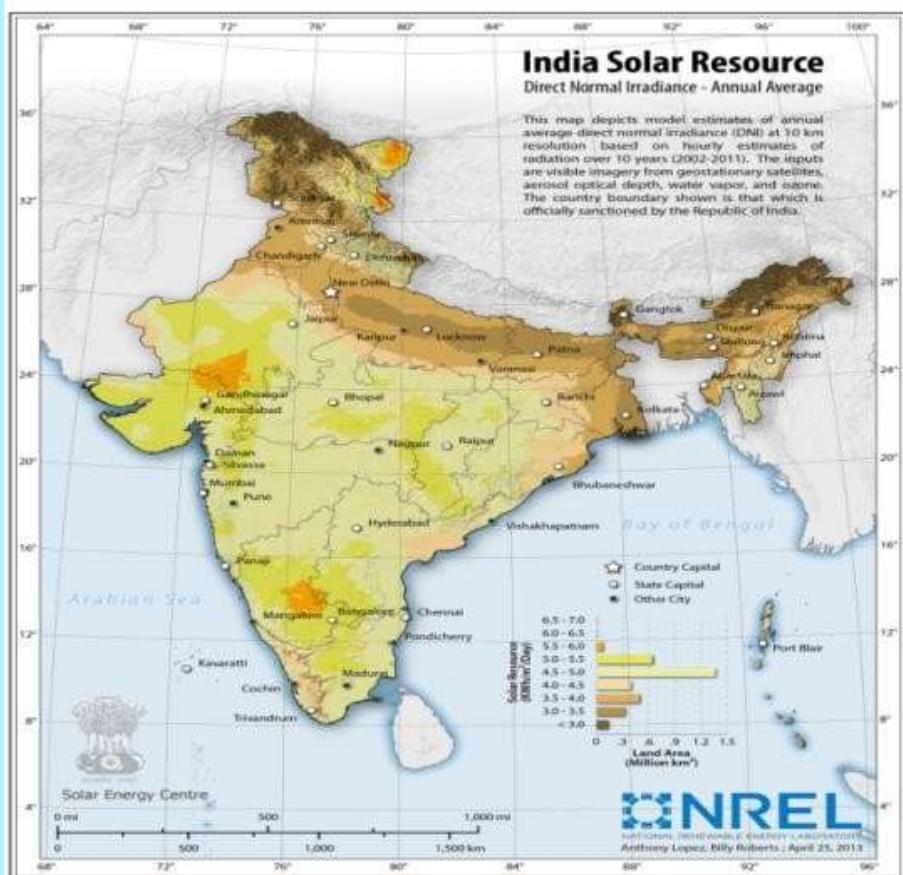


Solar irradiance Global Horizontal irradiance & Direct normal irradiance ...

Global (total) **Horizontal** solar **irradiance** is all radiation that strikes a flat surface that faces the sun,

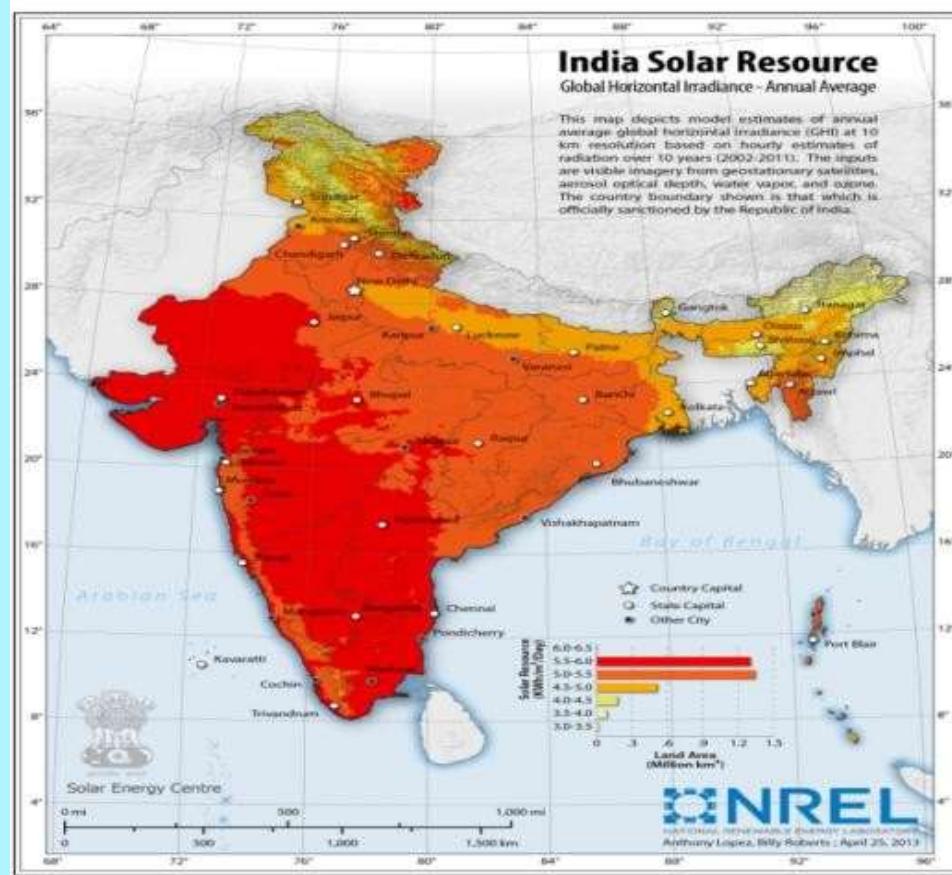
while **Direct normal** solar **irradiance** excludes all radiation that does not come from the direction of the sun **in the sky**.

Solar irradiance



DN

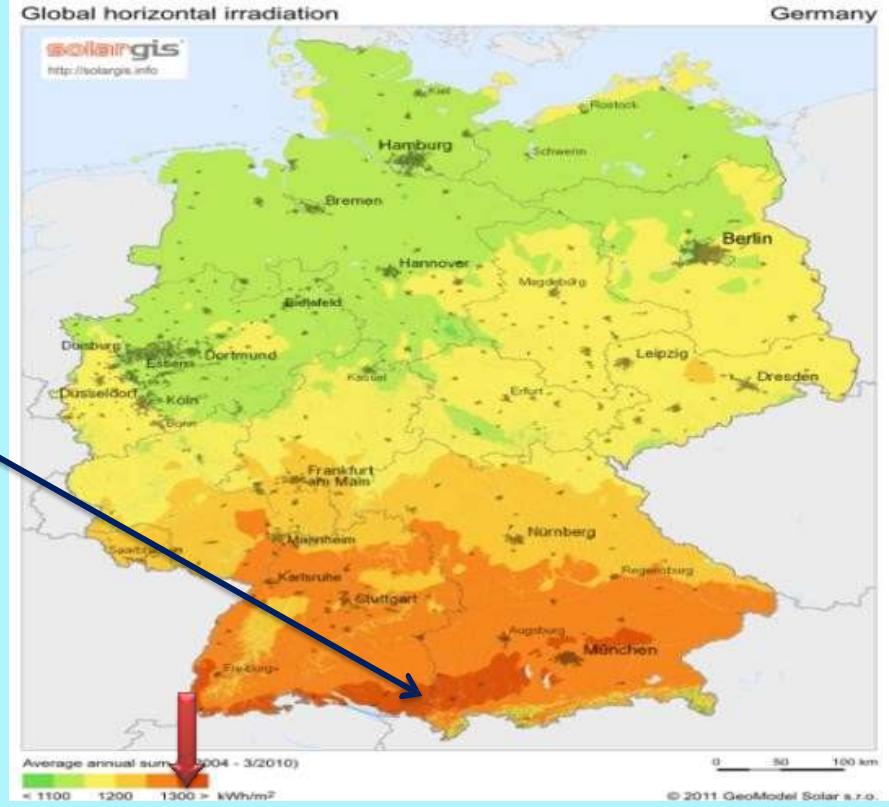
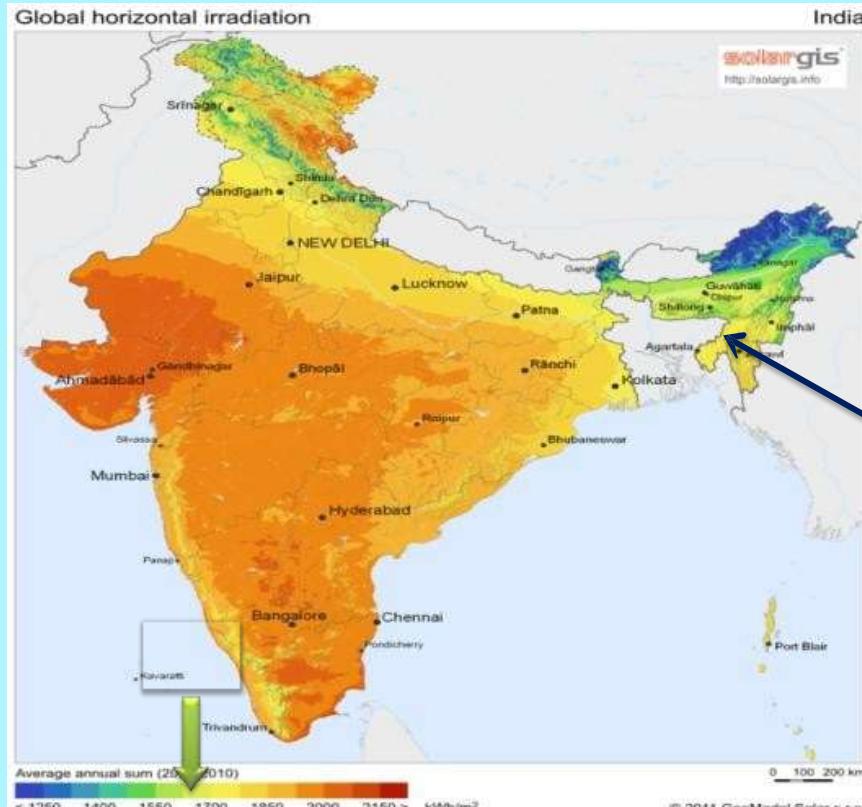
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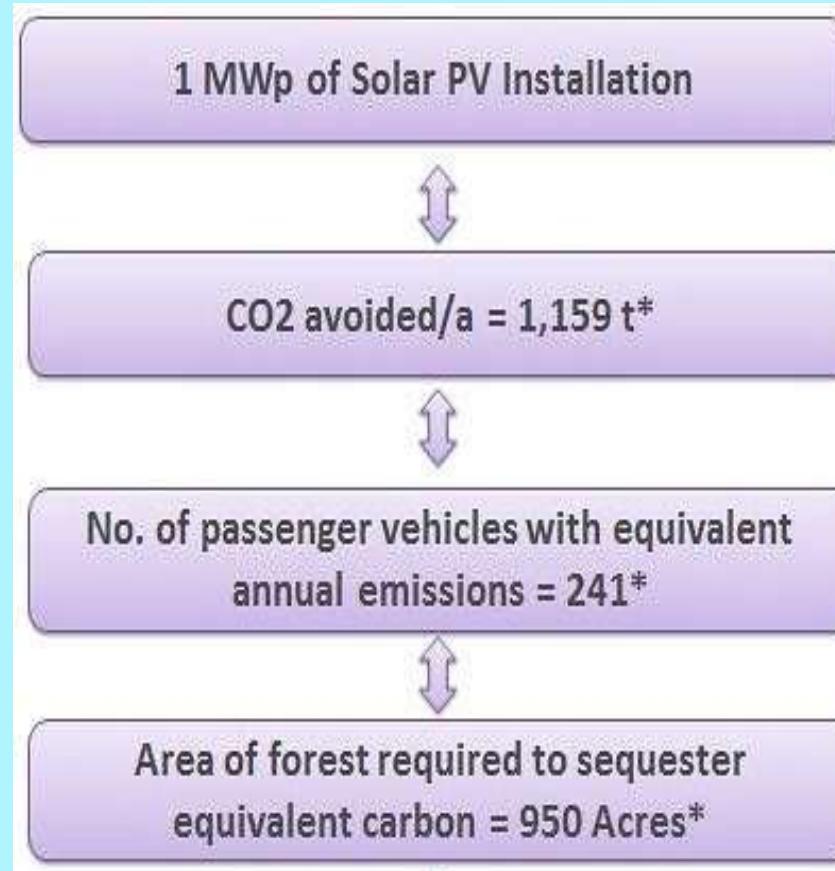
L-1 Unit 2

Solar irradiance



The average solar irradiation in India is roughly double than in Germany

Why? Solar Energy as a Renewable...



All data is calculated as per US environmental protection agency green house gas equivalence calculator

Why? Solar Energy as a Renewable...

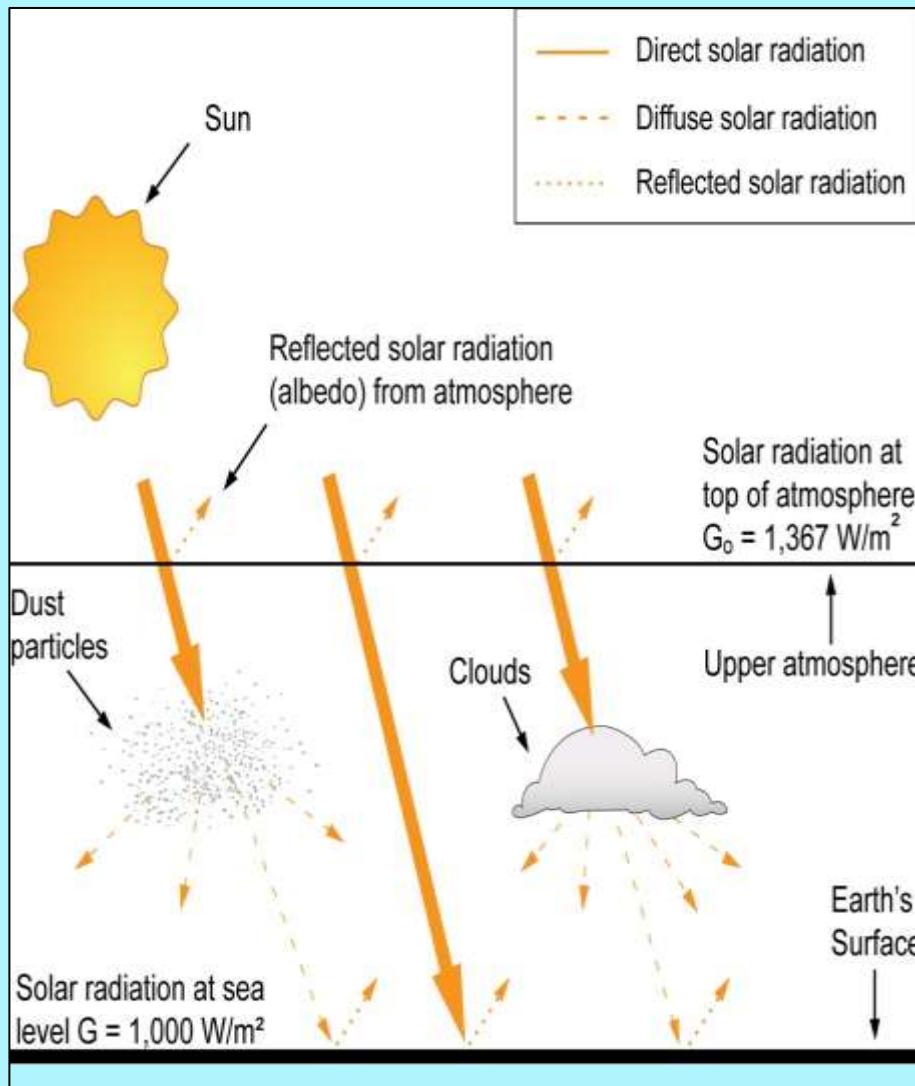
- SPV is very fast to install
- Consumer as well as utility friendly
- Good for off grid & On grid App
- Can be hybridized with any other IPP
- Fuel is free
- Sizable KWp to MWp
- Economically viable
- Virtually No recurring cost

Difference between Lumens Lux and Watts...

- Lumens (LM) are a measurement unit, which determines the total amount of light emitted.
- Lux is a unit of light measurement where the area is also taken into account. 1 lux is equals to the 1 Lumen/m²,
- In other words - light intensity in a specific area



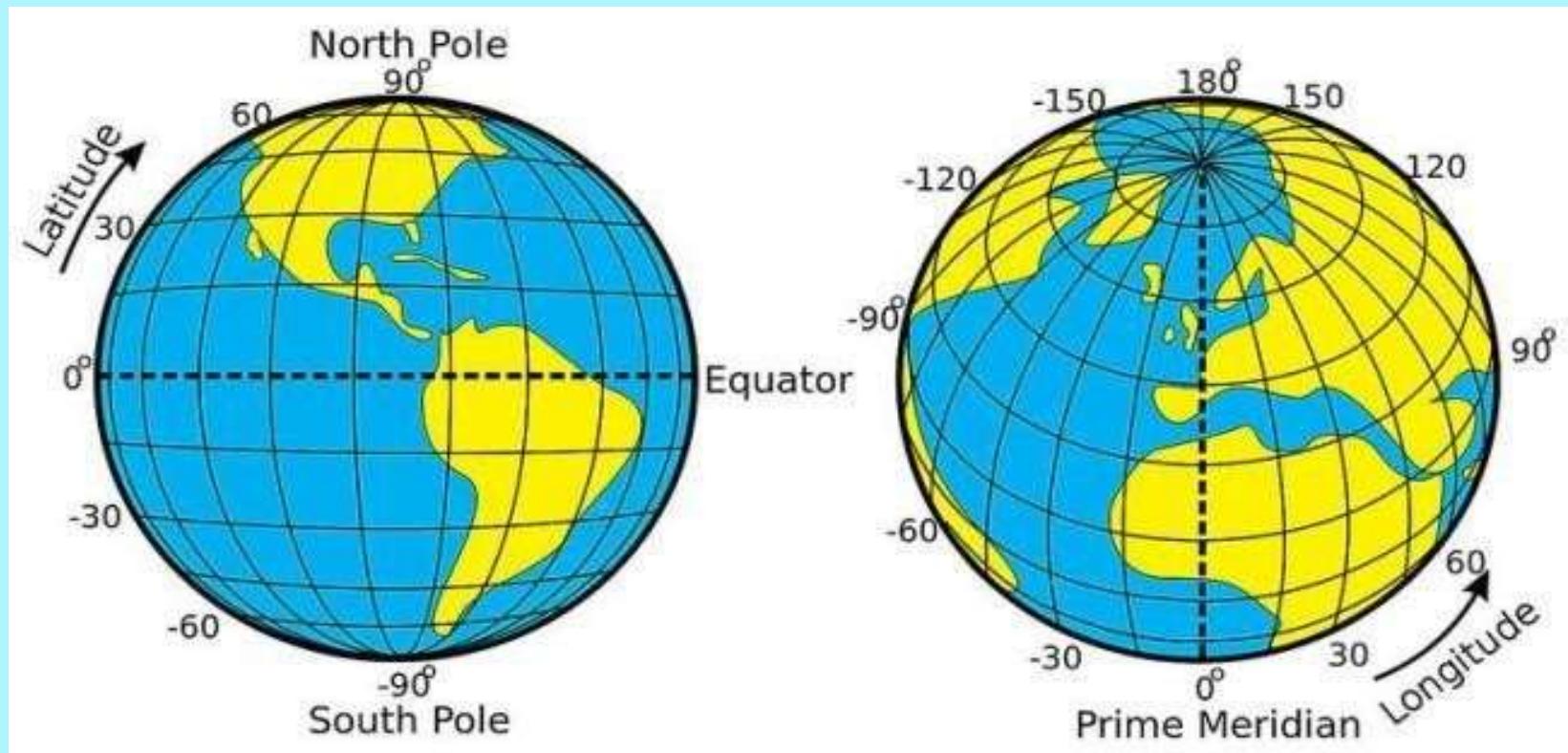
Solar Radiation...



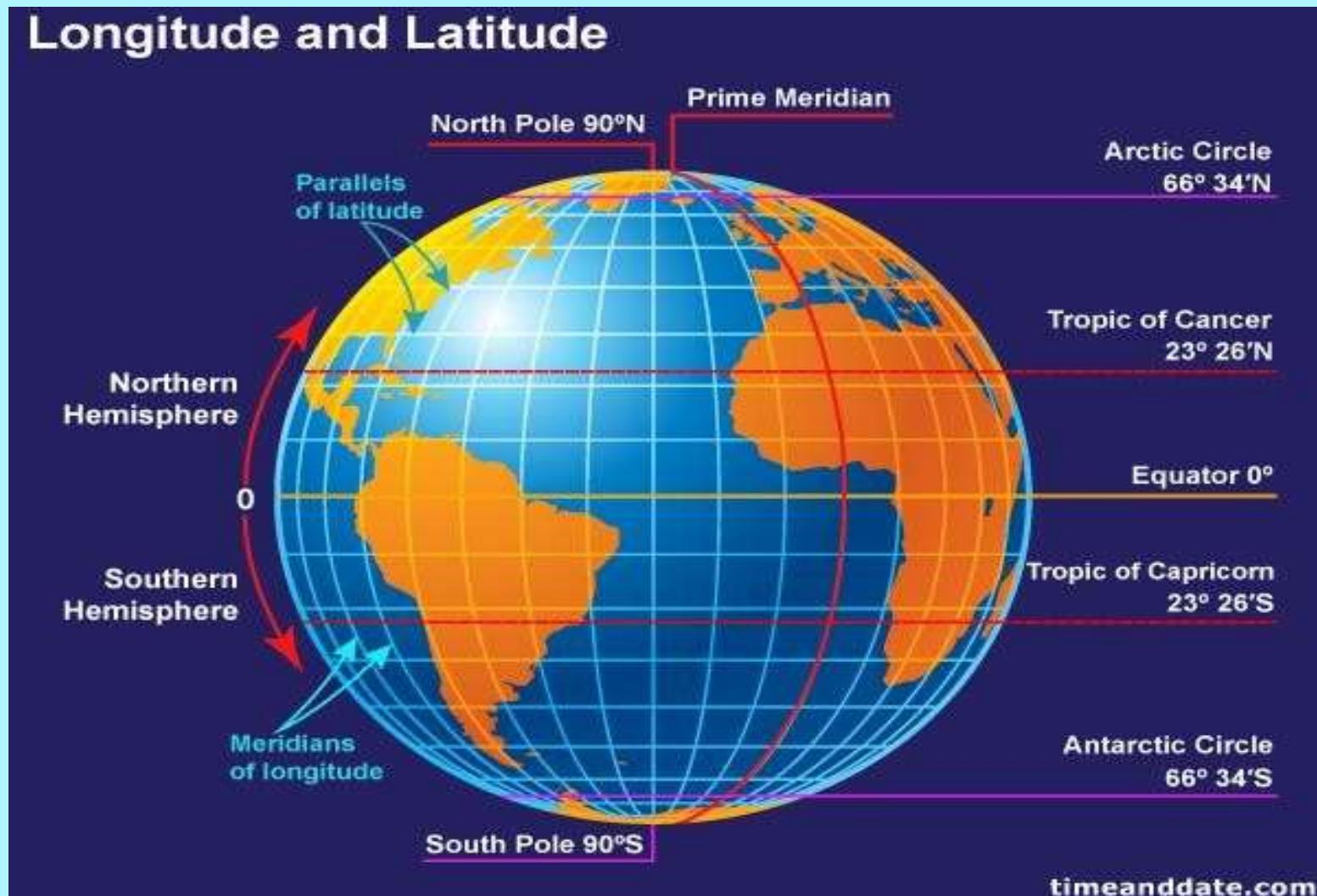
The radiation from sun is received by earth in form of:

- ★ **Direct beam:** The radiation beams which reach the earth's surface directly
- ★ **Diffuse beam:** The radiation beams which hit the earth's surface after being scattered by clouds, dust etc.
- ★ **Albedo:** Albedo is the measure of the diffuse reflection of solar radiation out of the total solar radiation
- ★ **Global Irradiation = Direct + Diffuse + albedo**

Longitude & Latitude

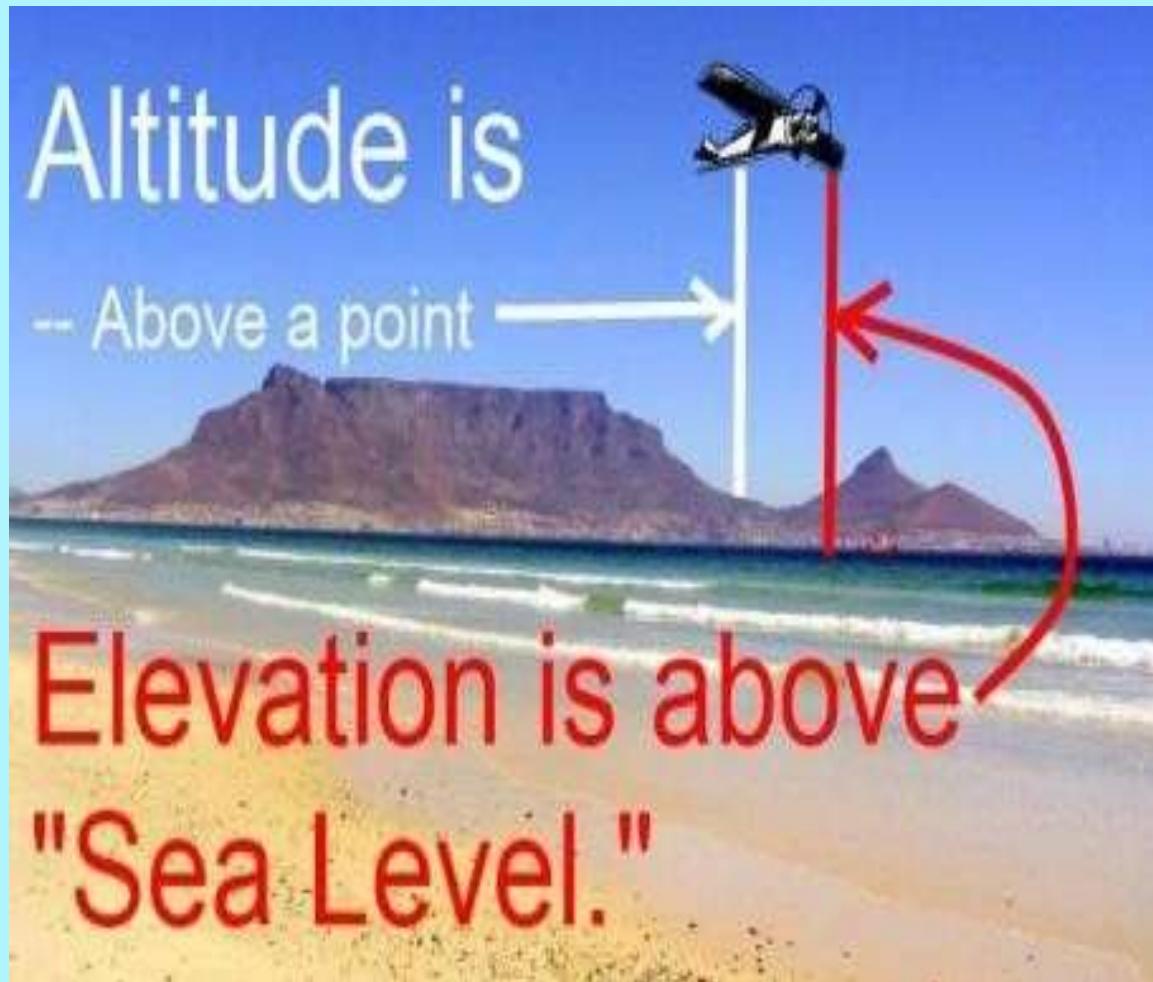


Longitude & Latitude



Altitude & Temperature

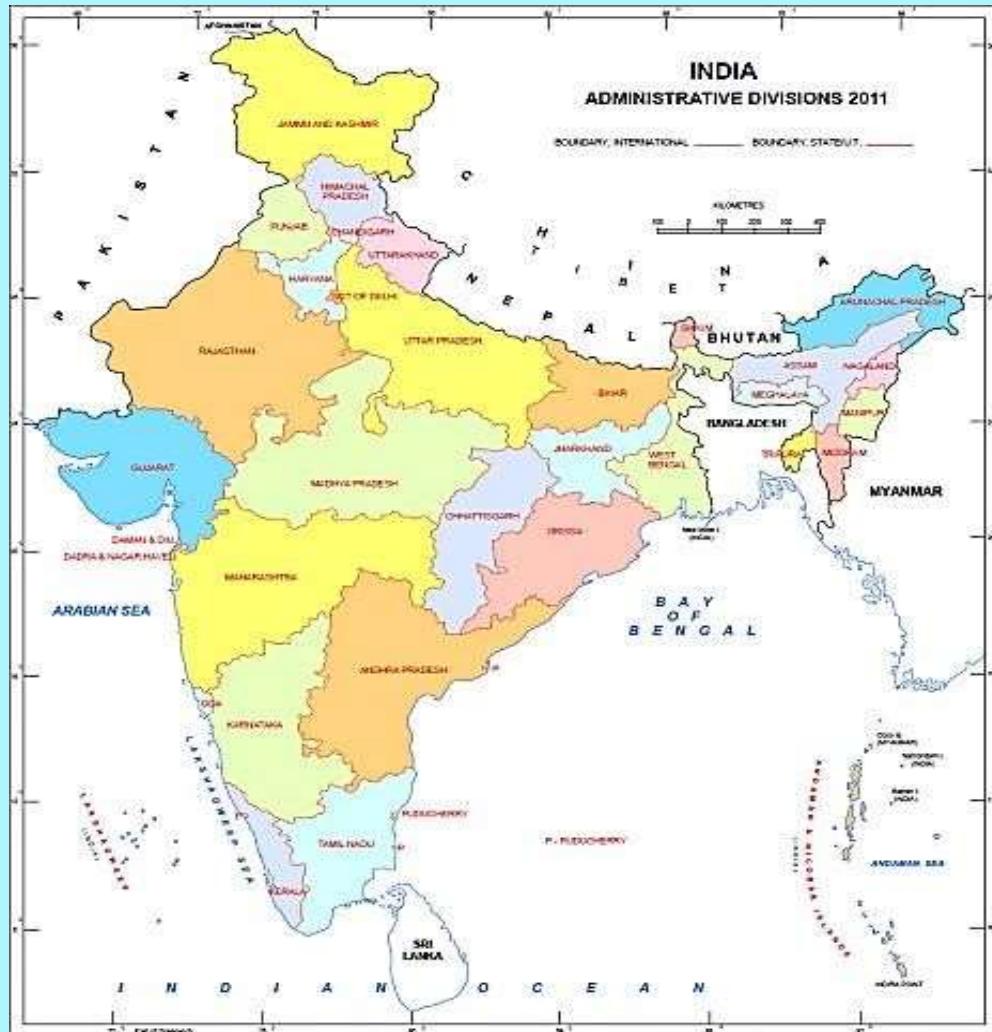
- The term *altitude* or *elevation* is commonly used to mean **the height above sea level** of a location, in *geography* the term *elevation* is often preferred for this usage.
- The rate of decrease of temperature is 6.5 degrees C for each 1 km altitude change.



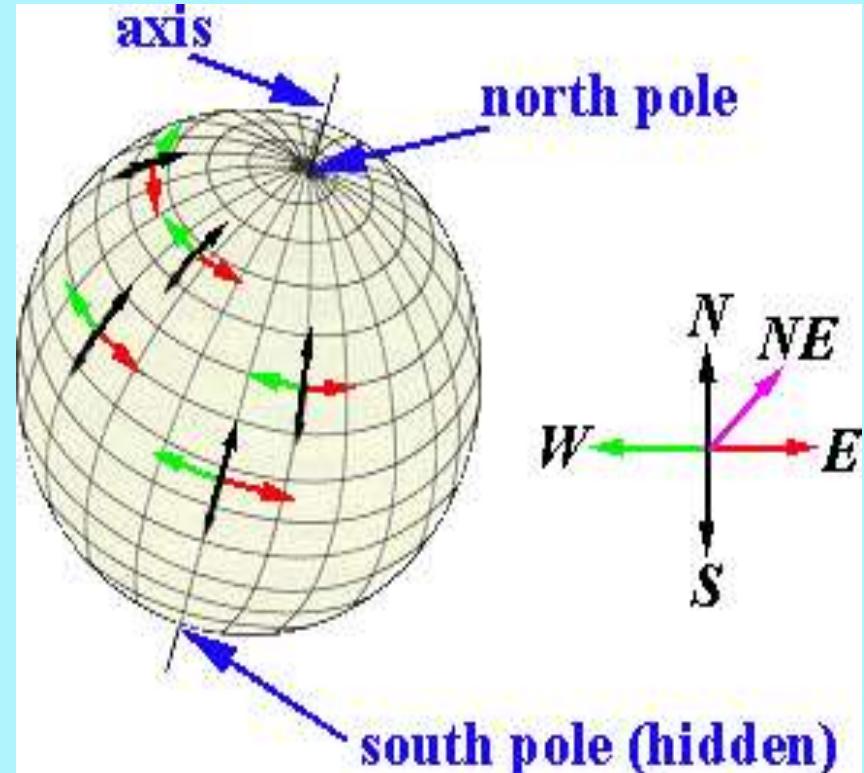
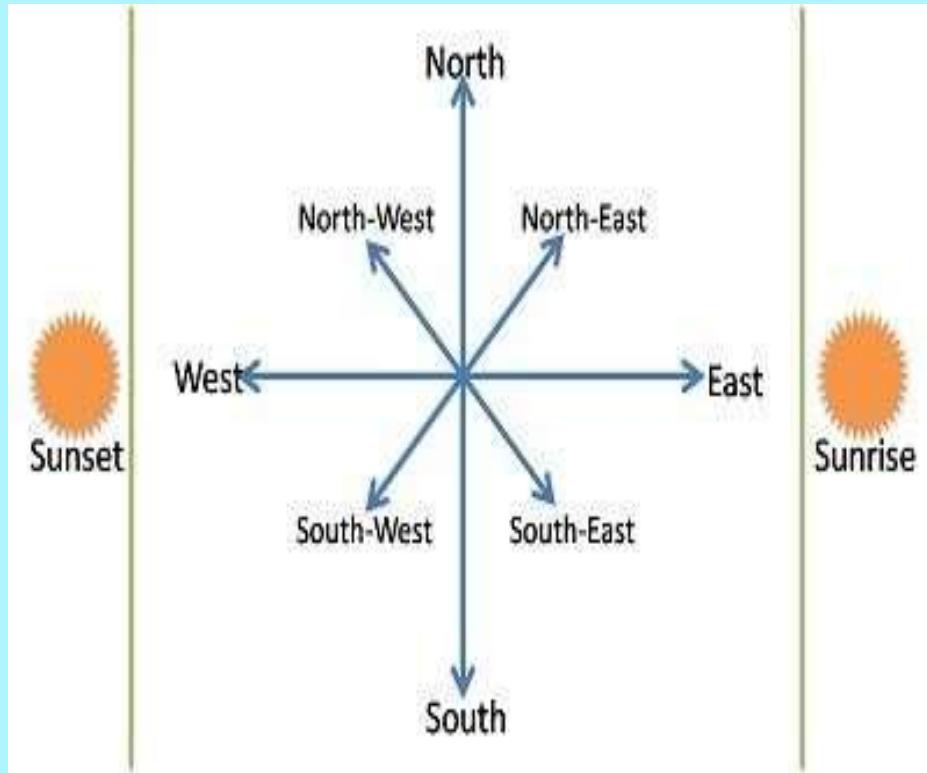
Coordinates and elevation

India is in between
latitude of
8 to 36 degrees N

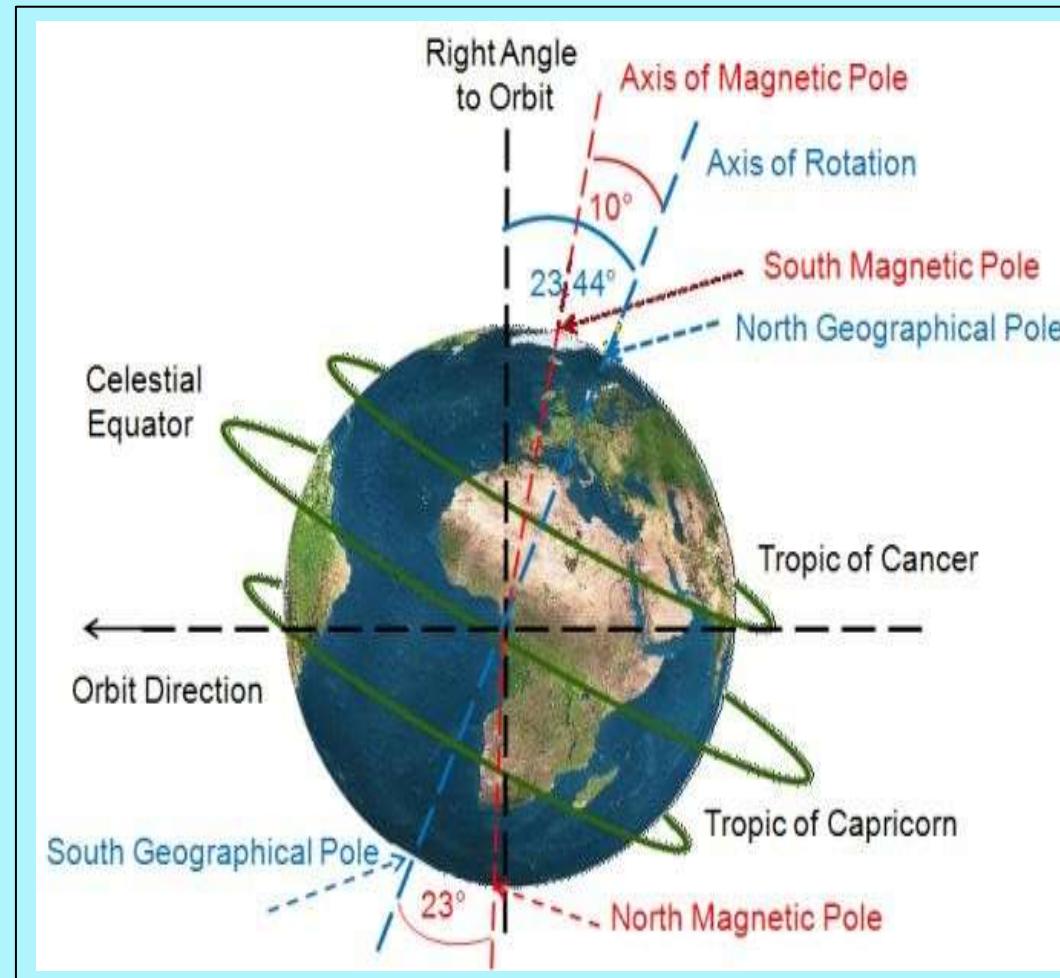
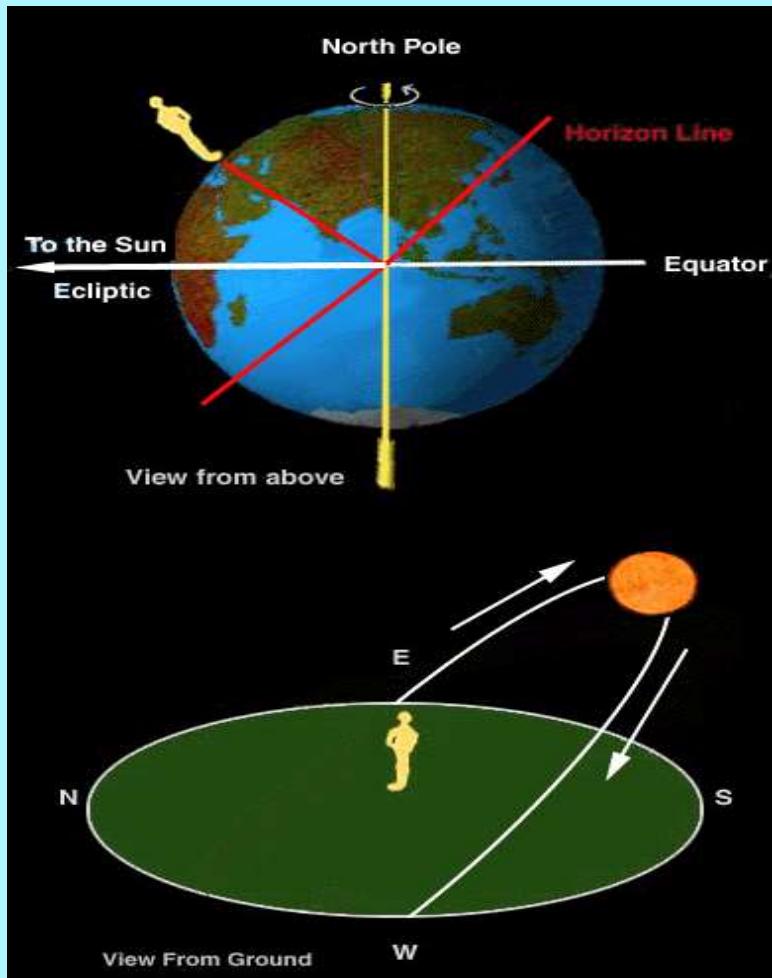
Pune
18.5204 Deg. N
73.8567 Deg. E
560m Elevation



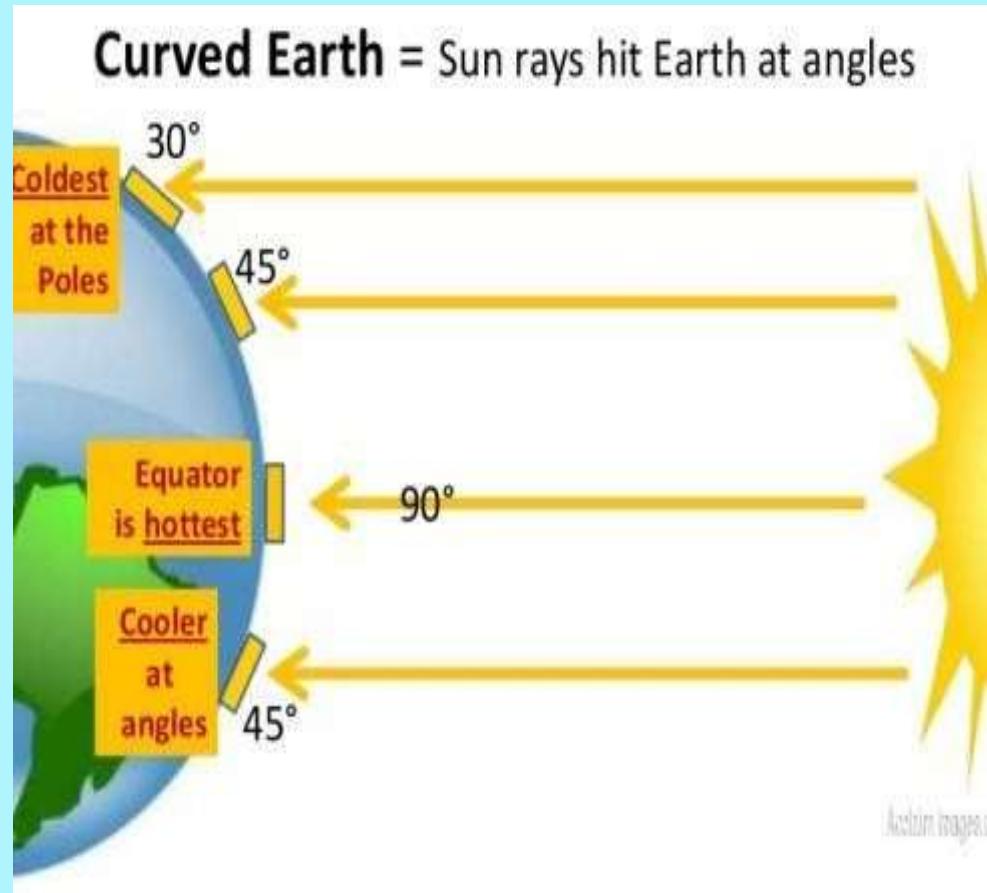
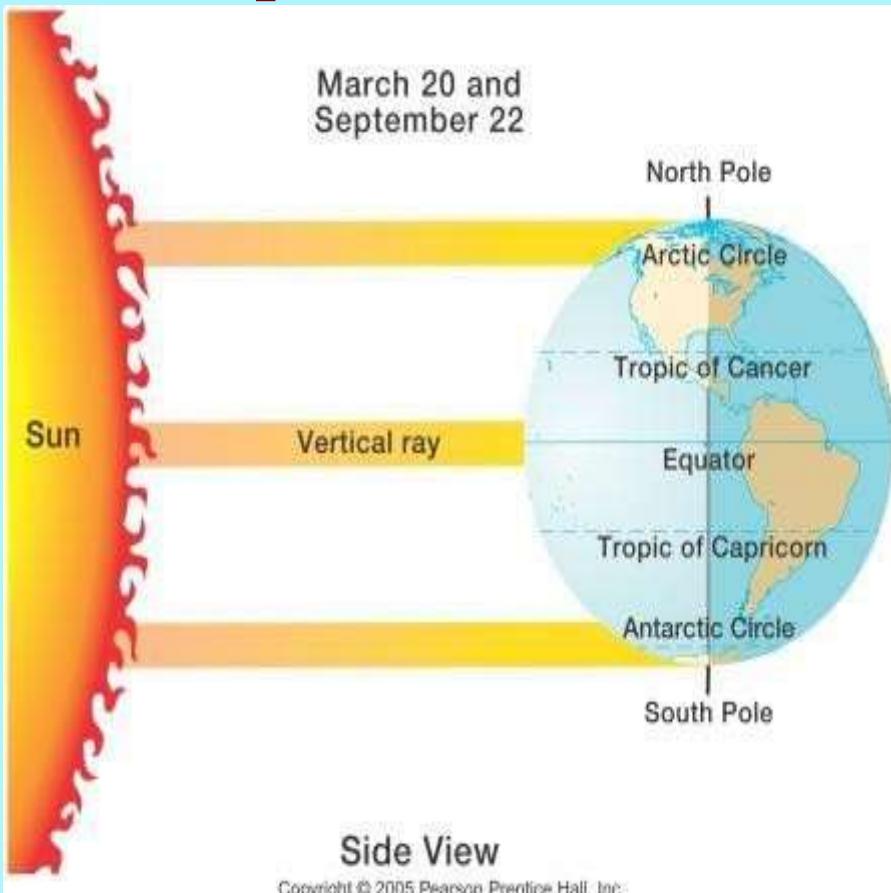
Direction and Orientation...



Earth & its Rotation...

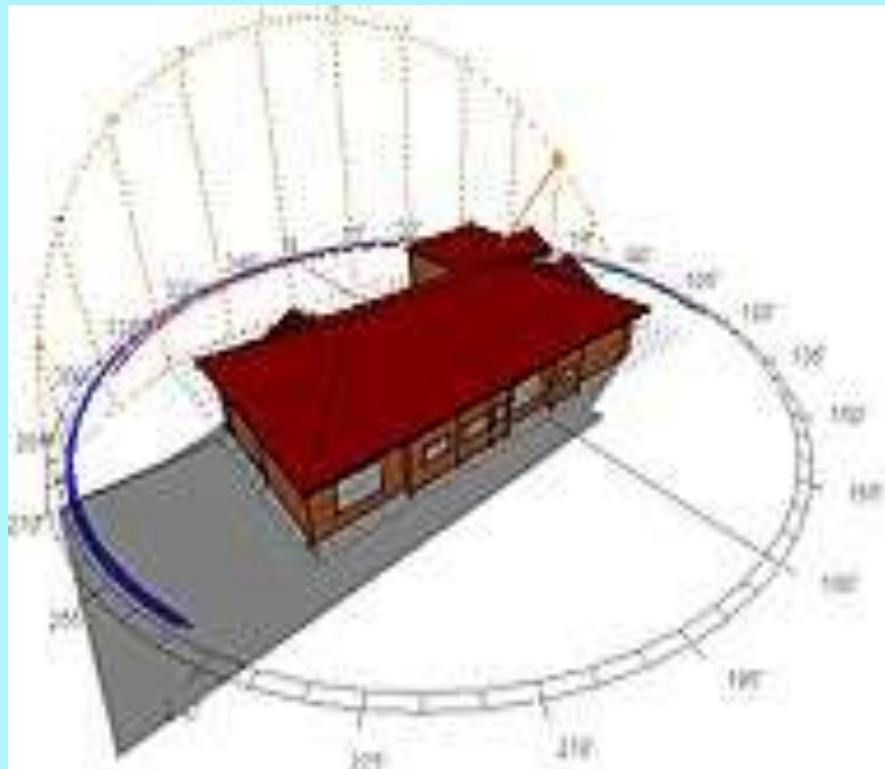


Change In Sunlight Density As Spherical Shape...

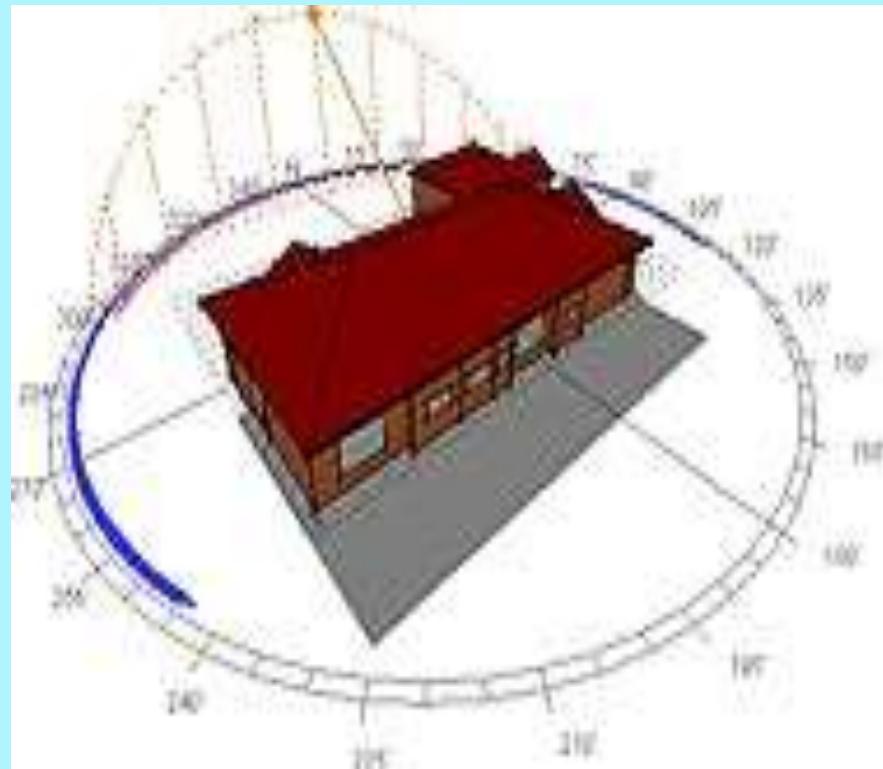


Due to the earth shape on a given day different places are receiving different intensity

Change In Sun Position



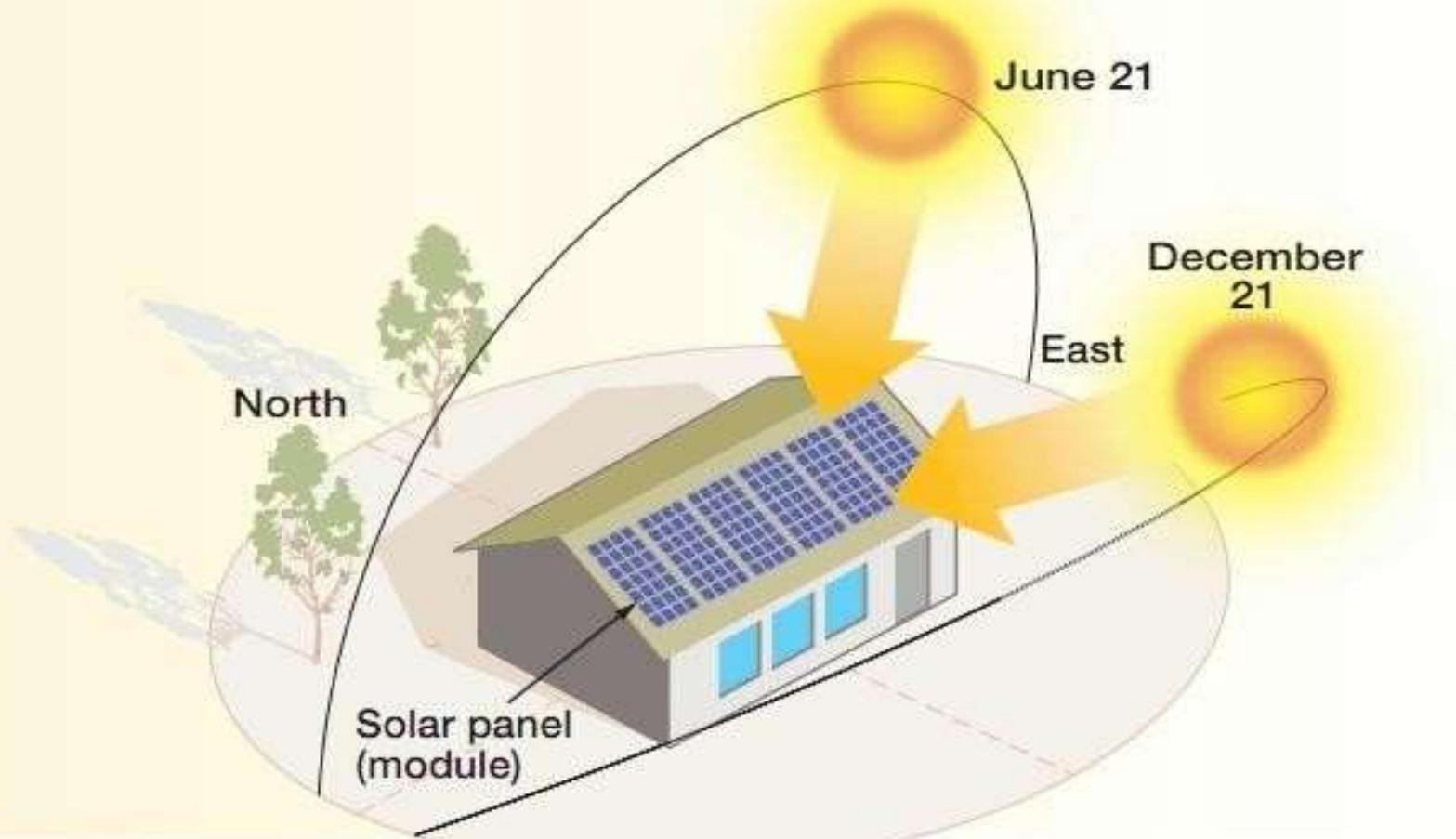
Over a Day



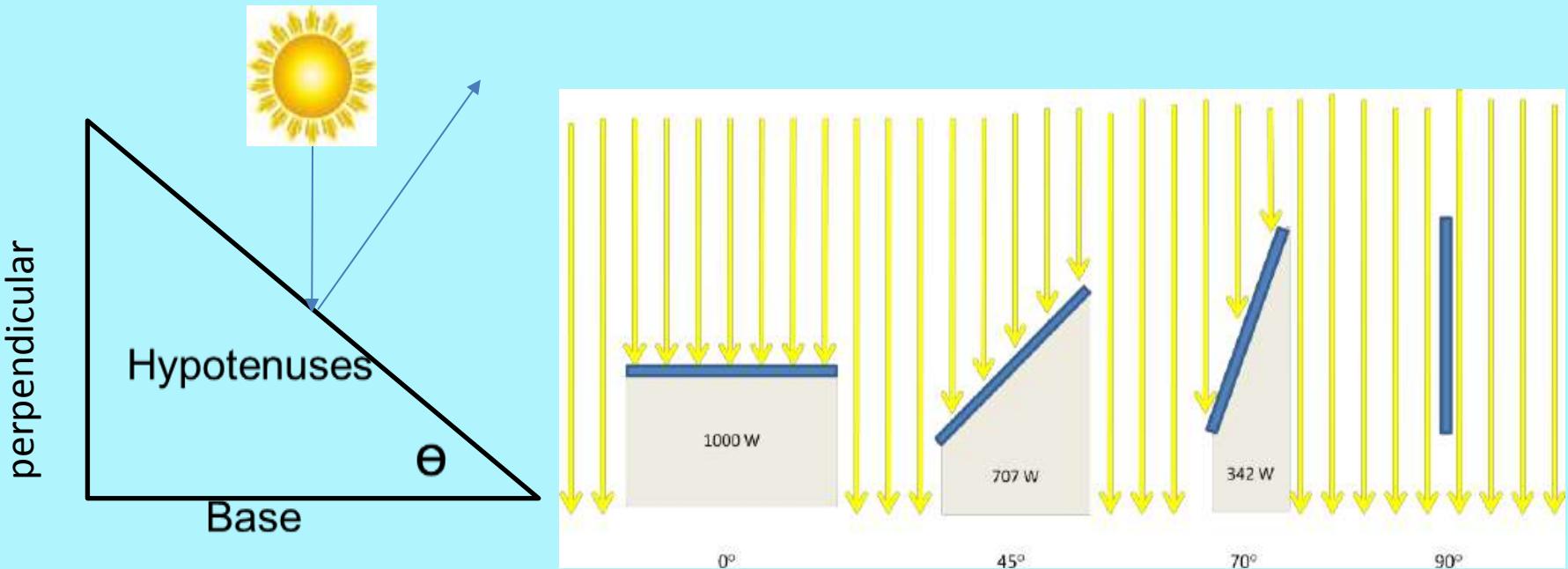
Over a Year

Declination Angle...

Sun's Path During Summer and Winter

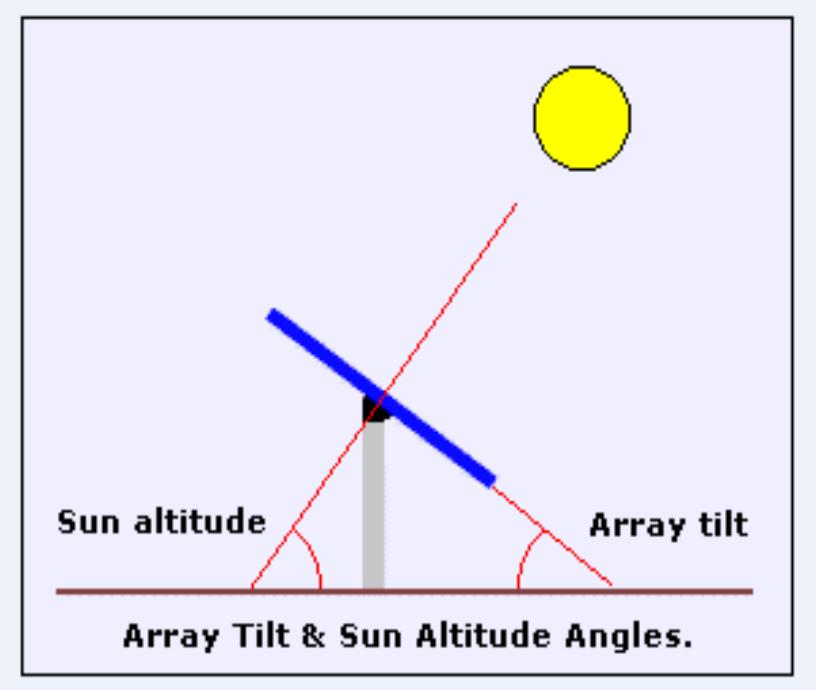
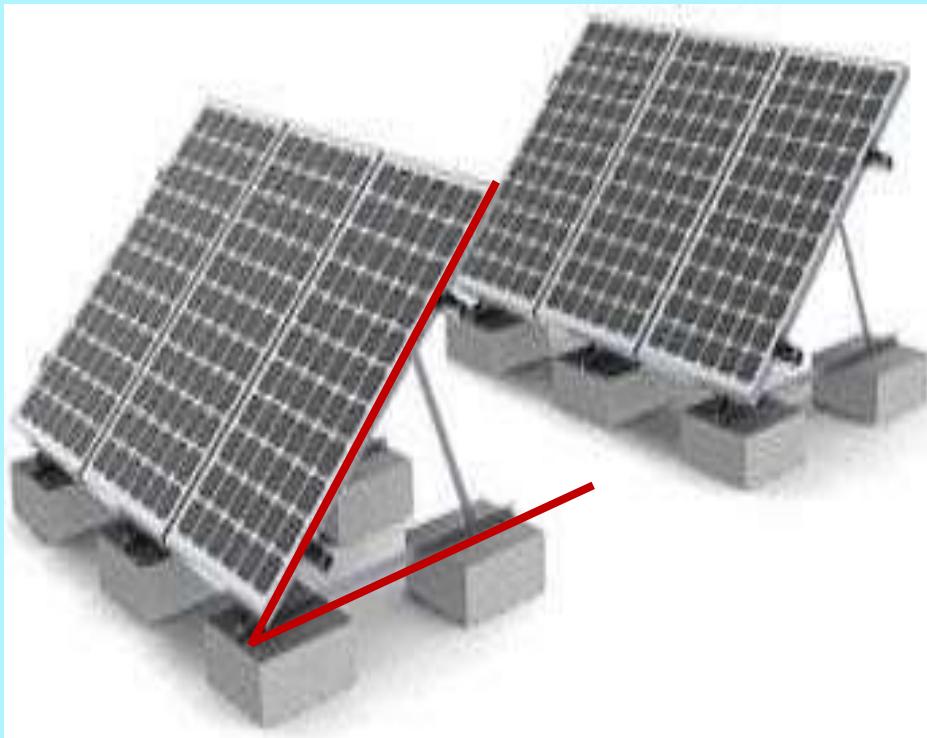


Sun Intensity Vs Power Output



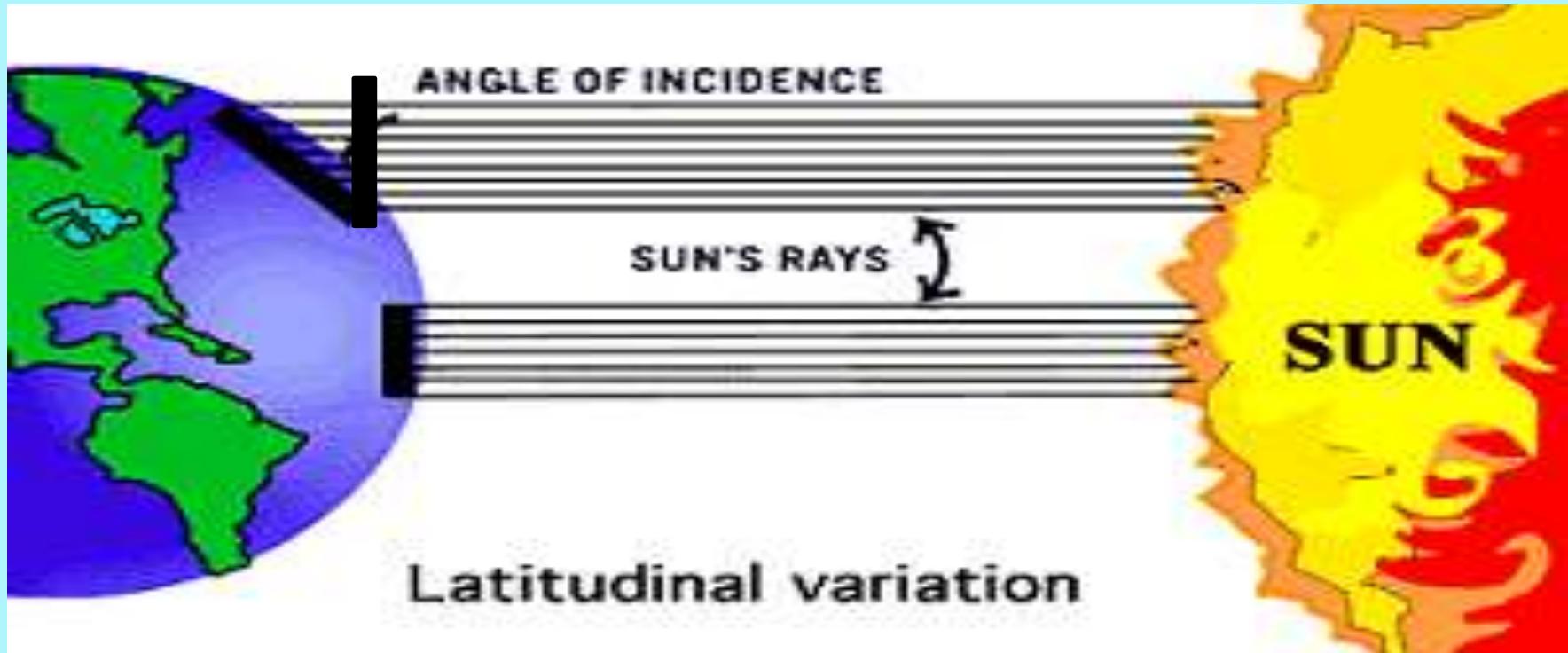
- Sun collector Angle and sun rays that varies the output of the solar panels,
- Reduction of radiation by the cosine of the angle between the solar radiation and a surface normal is called the **cosine effect**.

Optimum Tilt Angle



Tilt Angle, It is the optimum angle, between Solar array and horizontal surface, which gives maximum solar irradiation through out the year

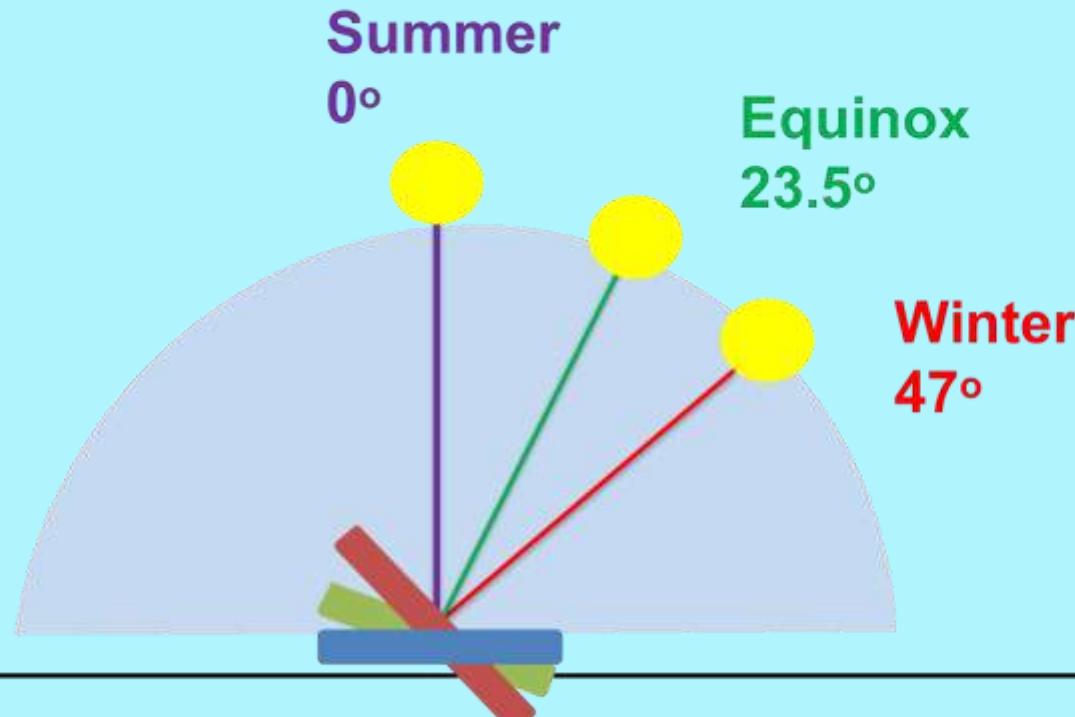
Optimum Tilt Angle



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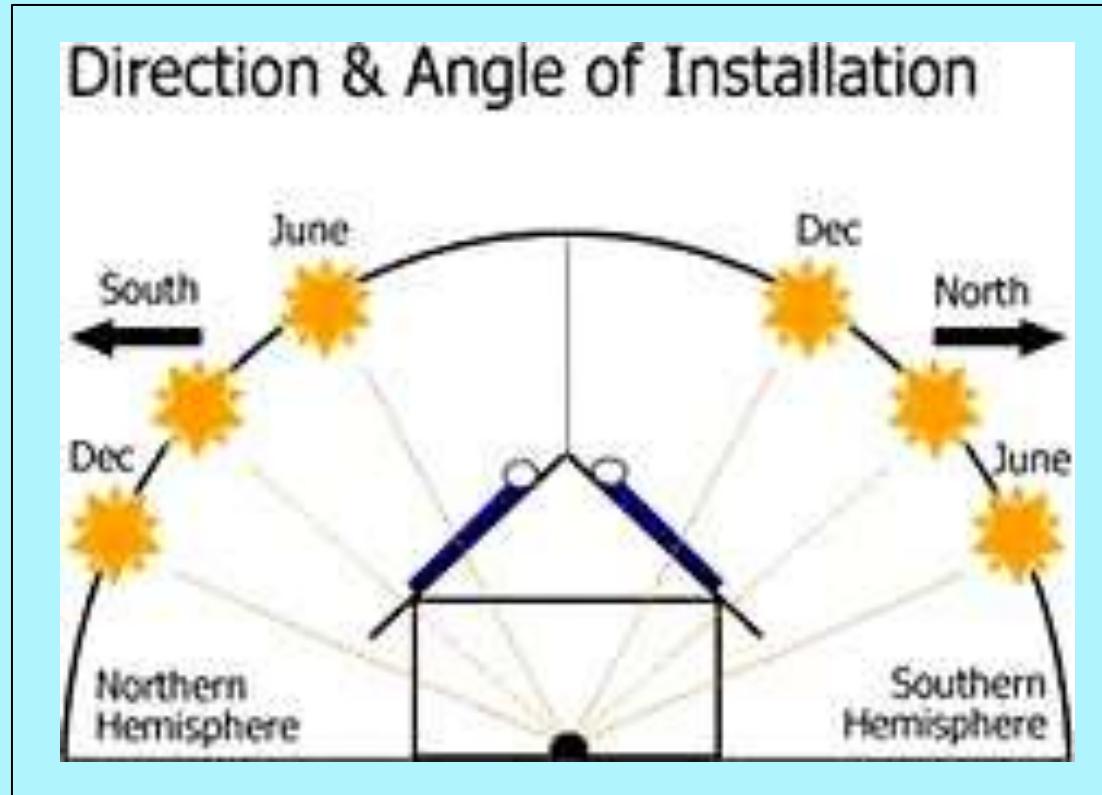
Sun Declines in a Year

Eg. Jabalpur



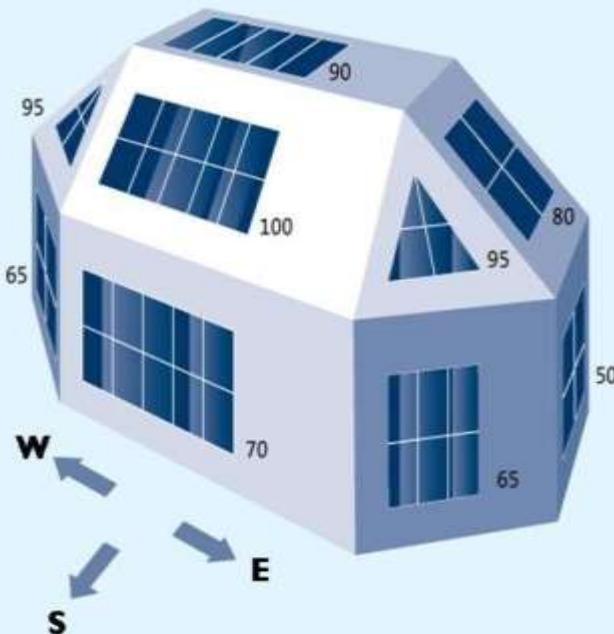
- ☀ Solar radiation available at a particular location keeps changing during the day and also during the year
- ✿ The amount of solar radiation received by a solar array is not same during all the time of the day and it is also not the same in different months of a year

Sun Declines in a Year



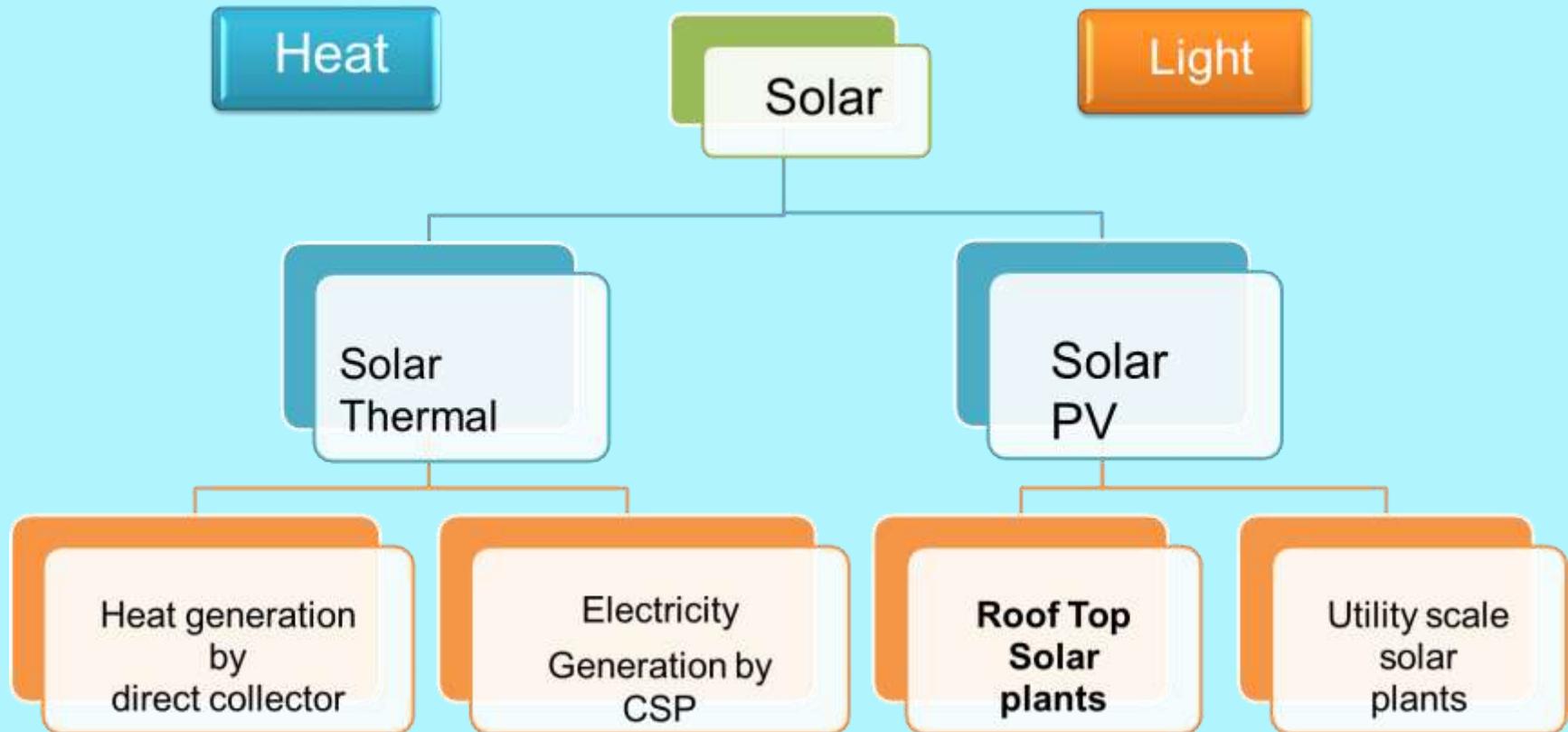
Solar panels should always face true south if you are in the northern hemisphere, or true north if you are in the southern hemisphere a photovoltaic system. SPV array need geographical south not the magnetic

Effect of Orientation Angle

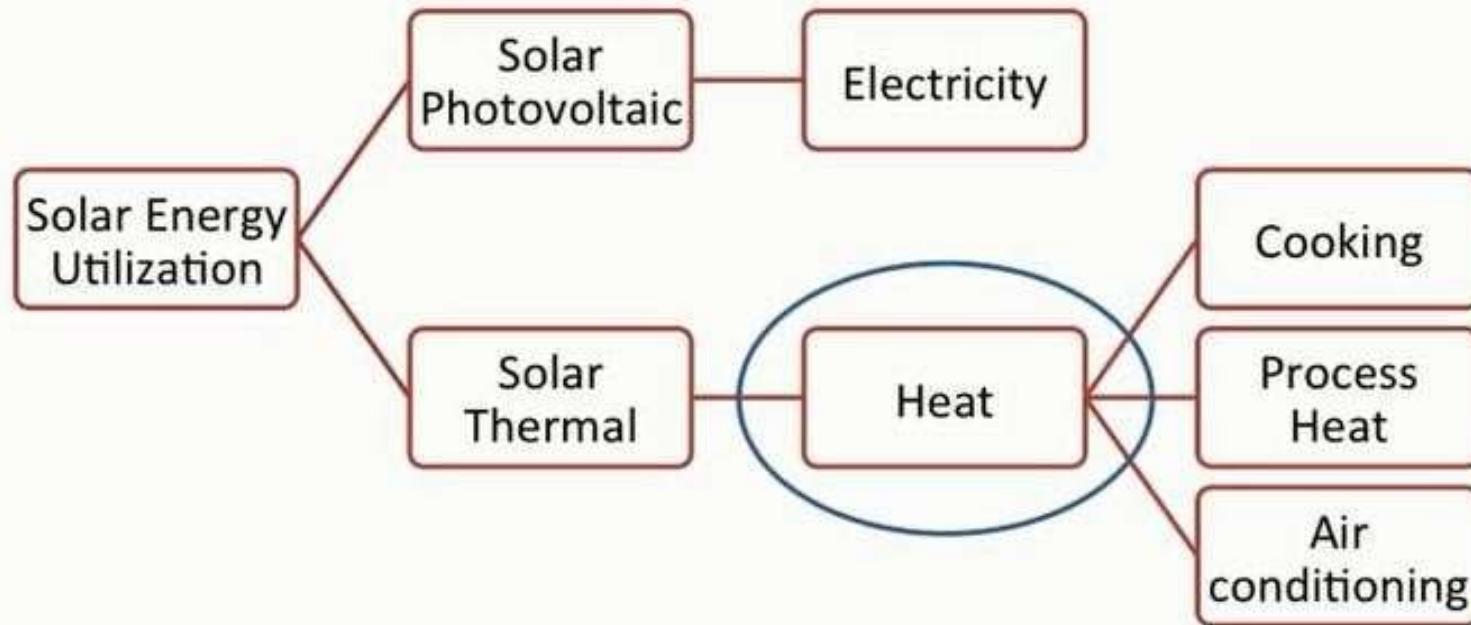


Horiz	West			SW			South			SE			East	
	270°	255°	240°	225°	210°	195°	180°	165°	150°	135°	120°	105°	90°	
0°	90	90	90	90	90	90	90	90	90	90	90	90	90	
10°	89	91	92	94	95	95	95	95	95	94	93	91	90	
20°	87	90	93	96	97	98	98	98	97	96	94	91	88	
30°	86	89	93	96	98	99	100	100	98	96	94	90	86	
40°	82	86	90	95	97	99	100	99	98	96	92	88	84	
50°	78	84	88	92	95	96	97	97	96	93	89	85	80	
60°	74	79	84	87	90	91	93	93	92	89	86	81	76	
70°	69	74	78	82	85	86	87	87	86	84	80	76	70	
80°	63	68	72	75	77	79	80	80	79	77	74	69	65	
90°	56	60	64	67	69	71	71	71	71	69	65	62	58	
Vertical														

Solar Power Utilization



Solar Power Utilization

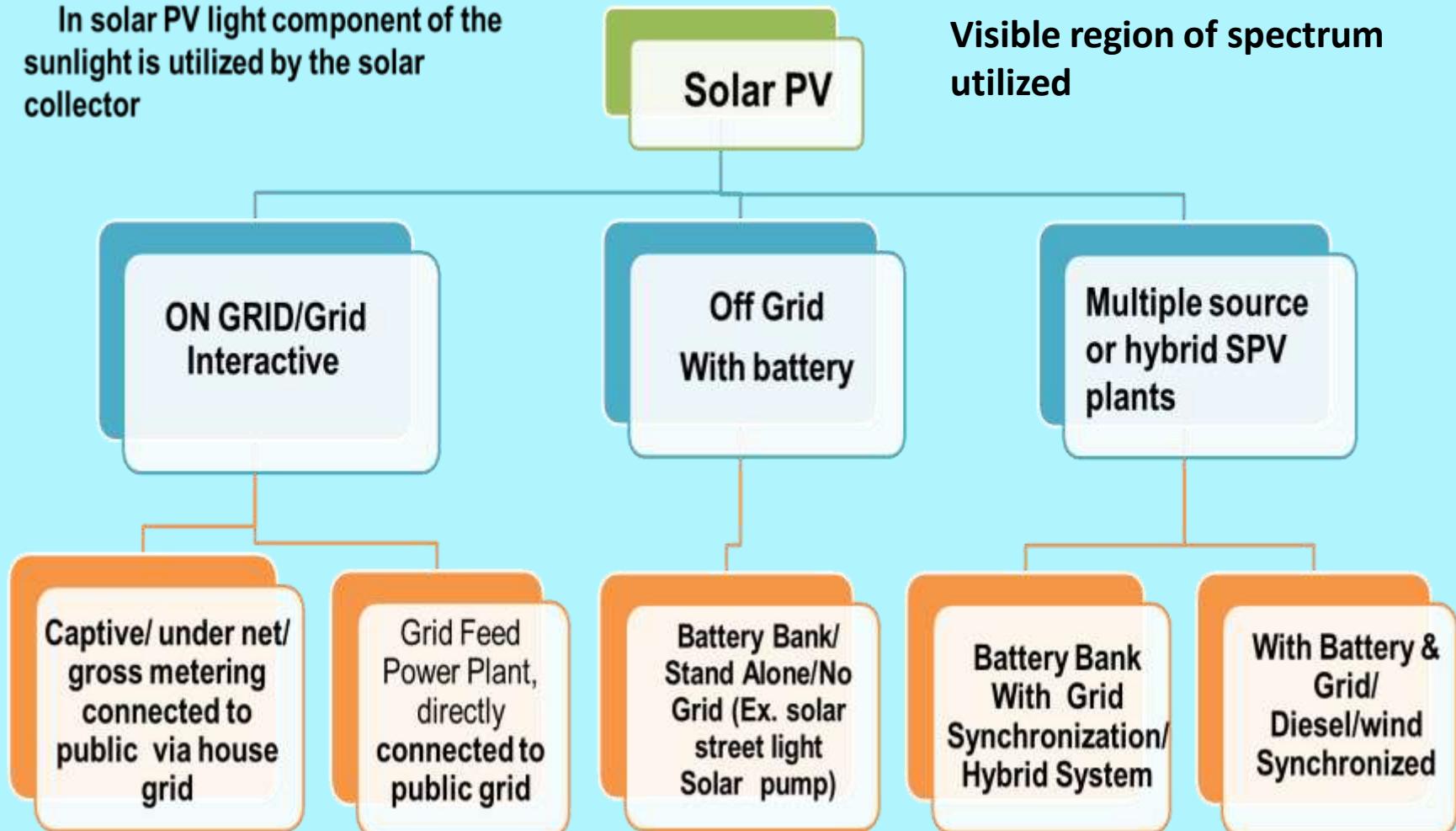


- In solar thermal heat component of the sunlight is utilized by the solar collector i.e. Infrared region of spectrum

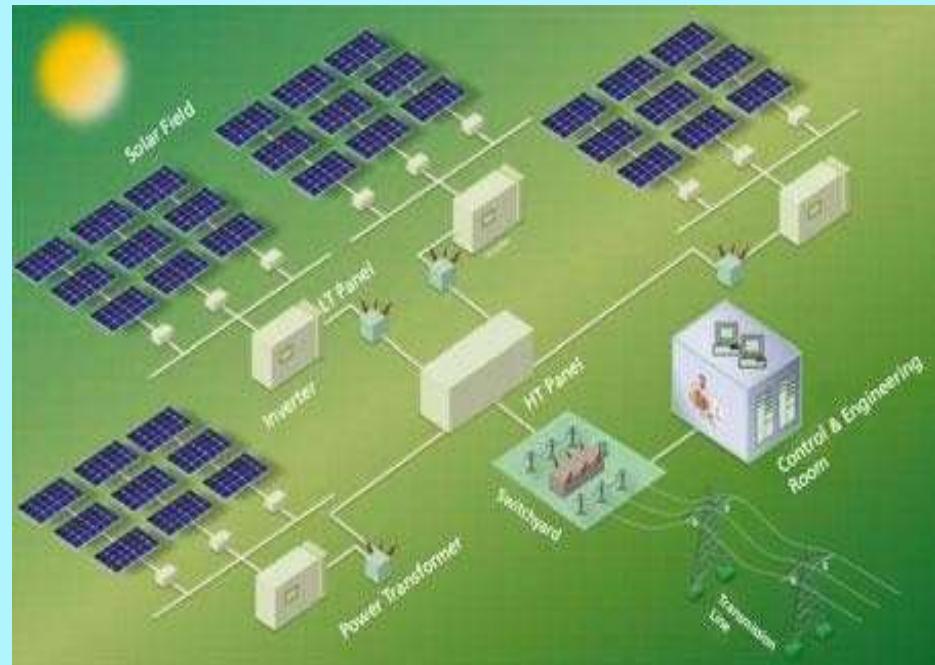
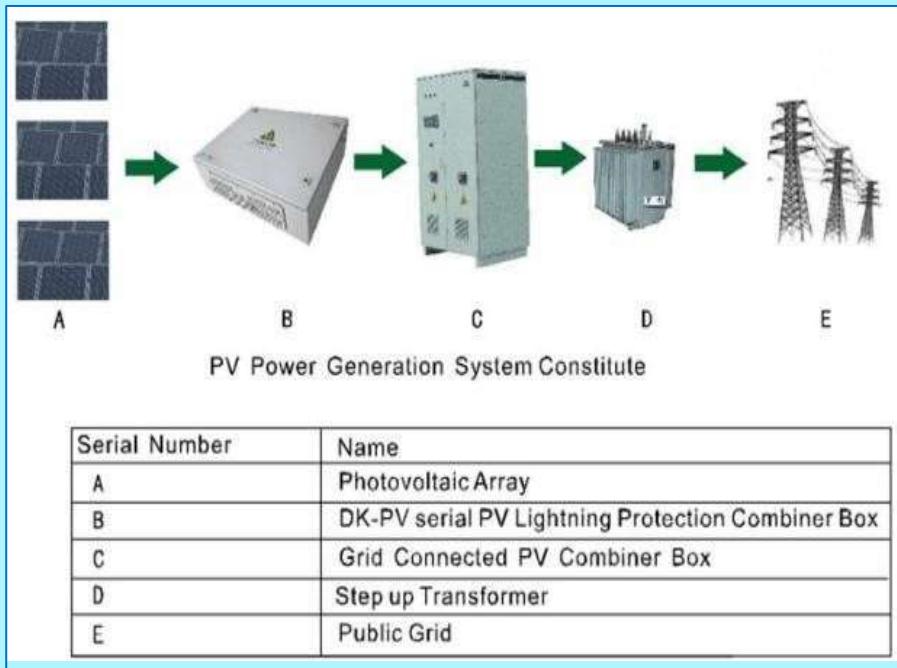
Solar Power Utilization

In solar PV light component of the sunlight is utilized by the solar collector

Visible region of spectrum utilized



Grid-connected photovoltaic power systems



Grid-connected photovoltaic power systems are energized by photovoltaic solar panels, which are connected directly to the utility grid.

Solar Power Utilization



12MWp Solar Plant at Cochin International Airport[720P].MP4

Floating SPV Plant

- First Implemented in Japan,
- Effective use of the available space & no buying or leasing the land,
- Non-metallic, non toxic and high-density polyethylene material
- Resistant to both corrosion and the sun's ultraviolet rays
- Ensures zero loss in power output due to shadow cover,
- Naturally cooled by the constant winds and the evaporation of water
- Strong enough to withstand storms and even typhoons,
- Cleaning frequency is less and there are no trees for leaves to fall

Roof Top SPV Plant



Roof Integrated SPV



BIPV (Building Integrated)



Terrace Garden SPV

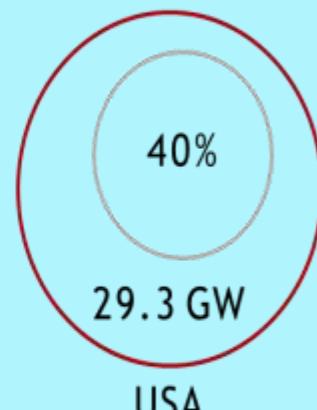
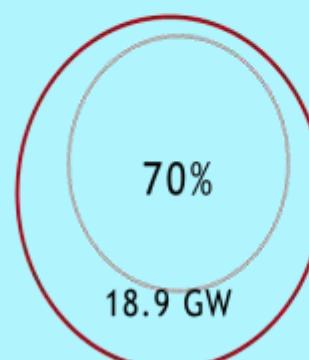
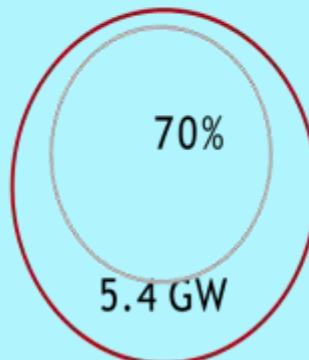
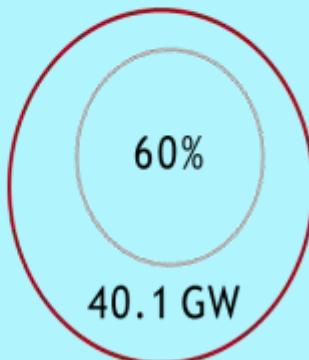
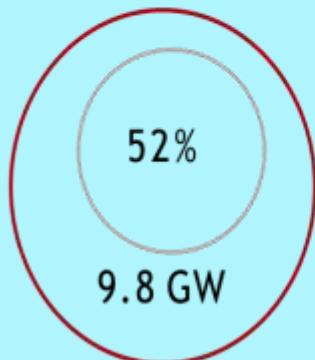
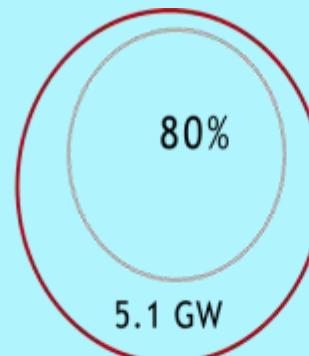
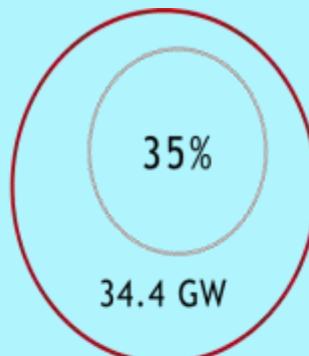
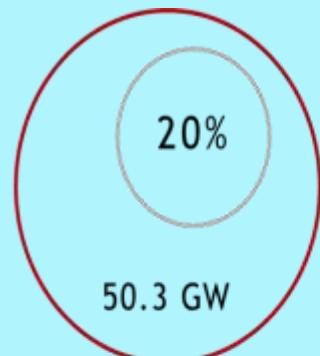


Roof Top SPV Plant

Solar Deployment areas/ benefits	Land Requirement	T&D losses	Investments	Optimal utilization of infrastructure
Large ground mounted solar projects	Need dedicated land for 25 years	High losses similar to conventional power projects (15-30%)	Need large investments	Need new transmission lines & enhanced grid capacity
Large solar rooftop projects (industrial/commercial/institutional)	Un-utilized roofs can be put to use	Minimal losses due to consumption at generation point	Medium investments Can be mobilized from small to medium investors	Infrastructure expansion needs can be minimized
Small rooftops projects (residential)			Small investments Can be mobilized from retail investors	

Roof Top SPV Plant Share Global

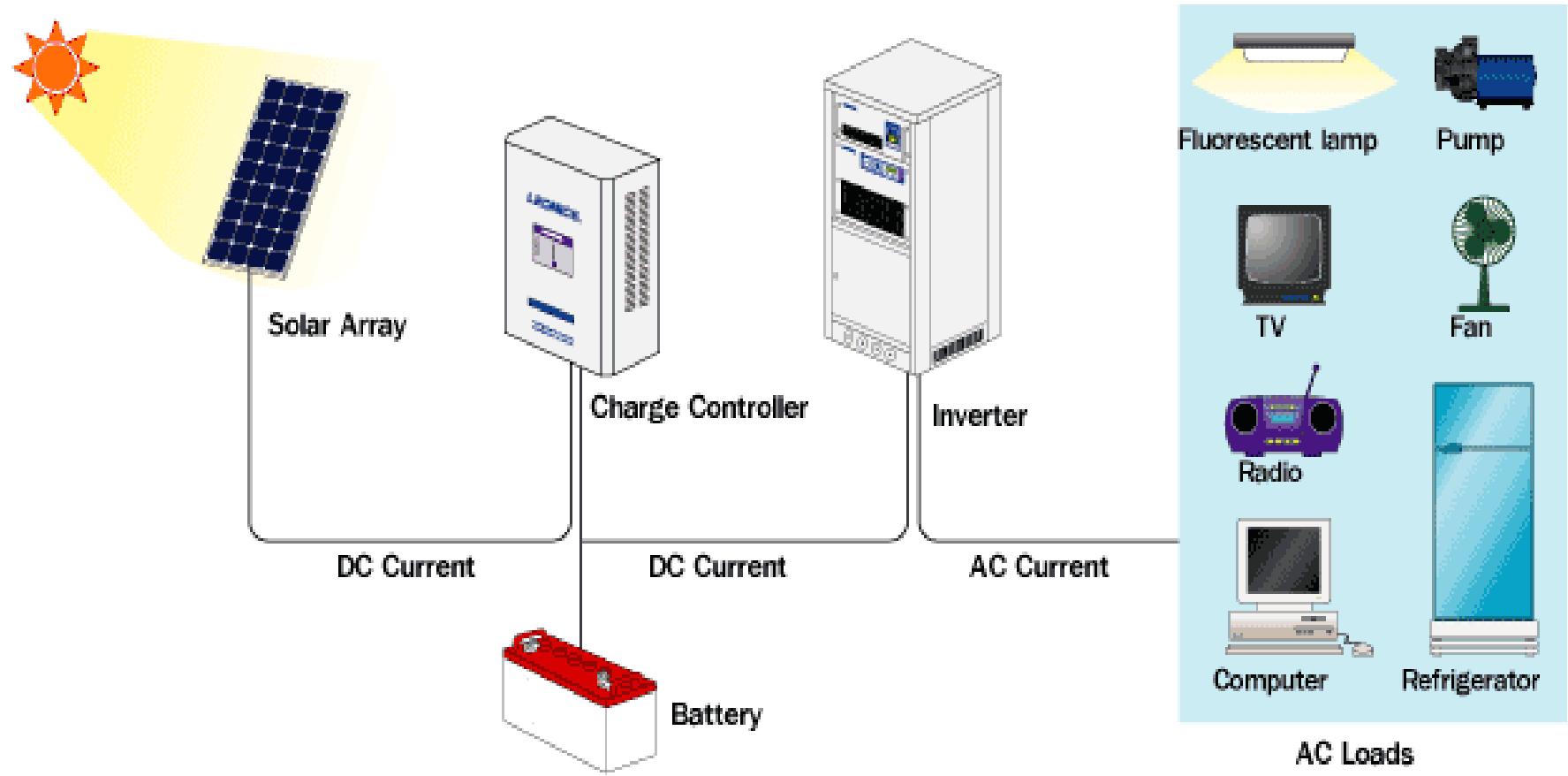
Source: REN21 / Wikipedia



- Total Solar Output
- Share of Rooftop

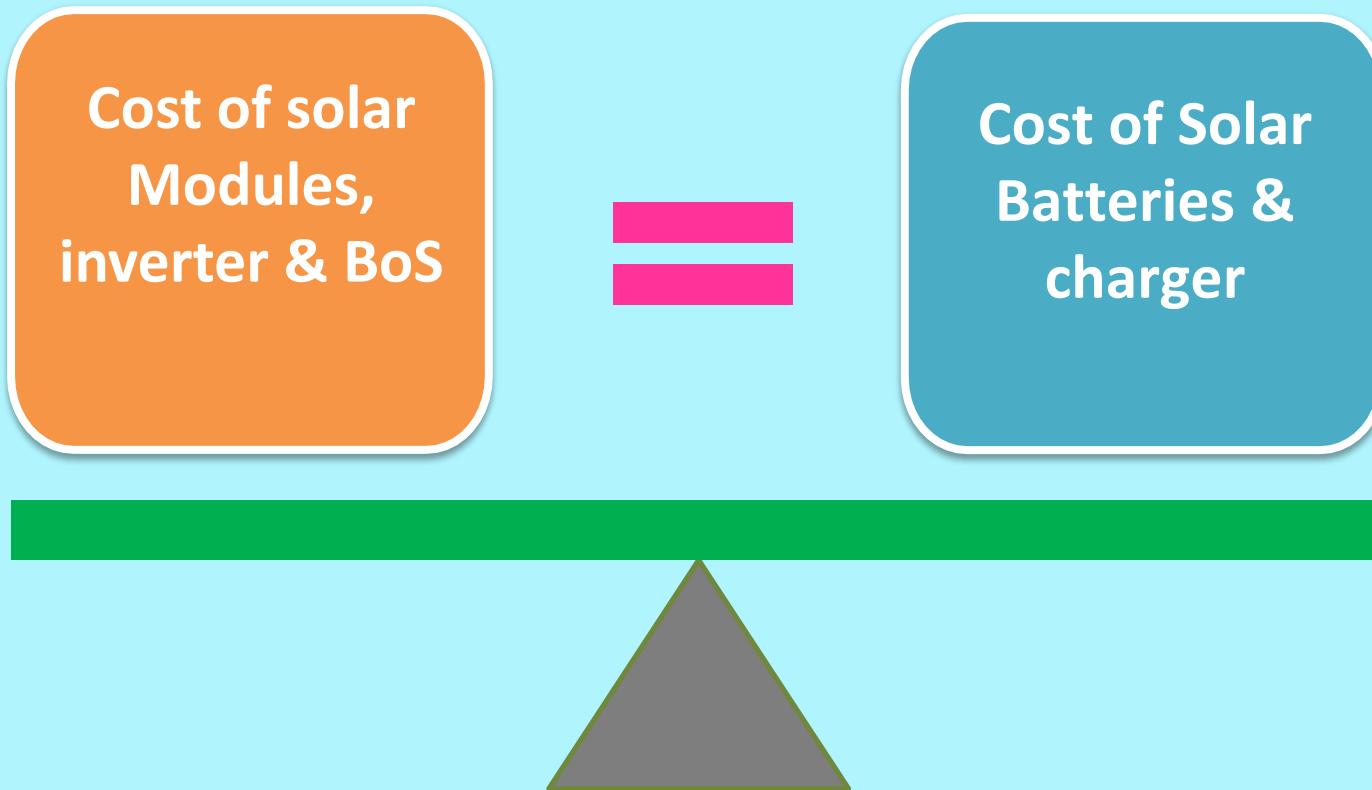
1st Generation Solar PV Plant

With Battery Bank/ Stand Alone/No Grid



1st Generation Solar PV Plant

Issue of cost



BOS: Balance of Solar System components

2nd Generation Solar PV Plant

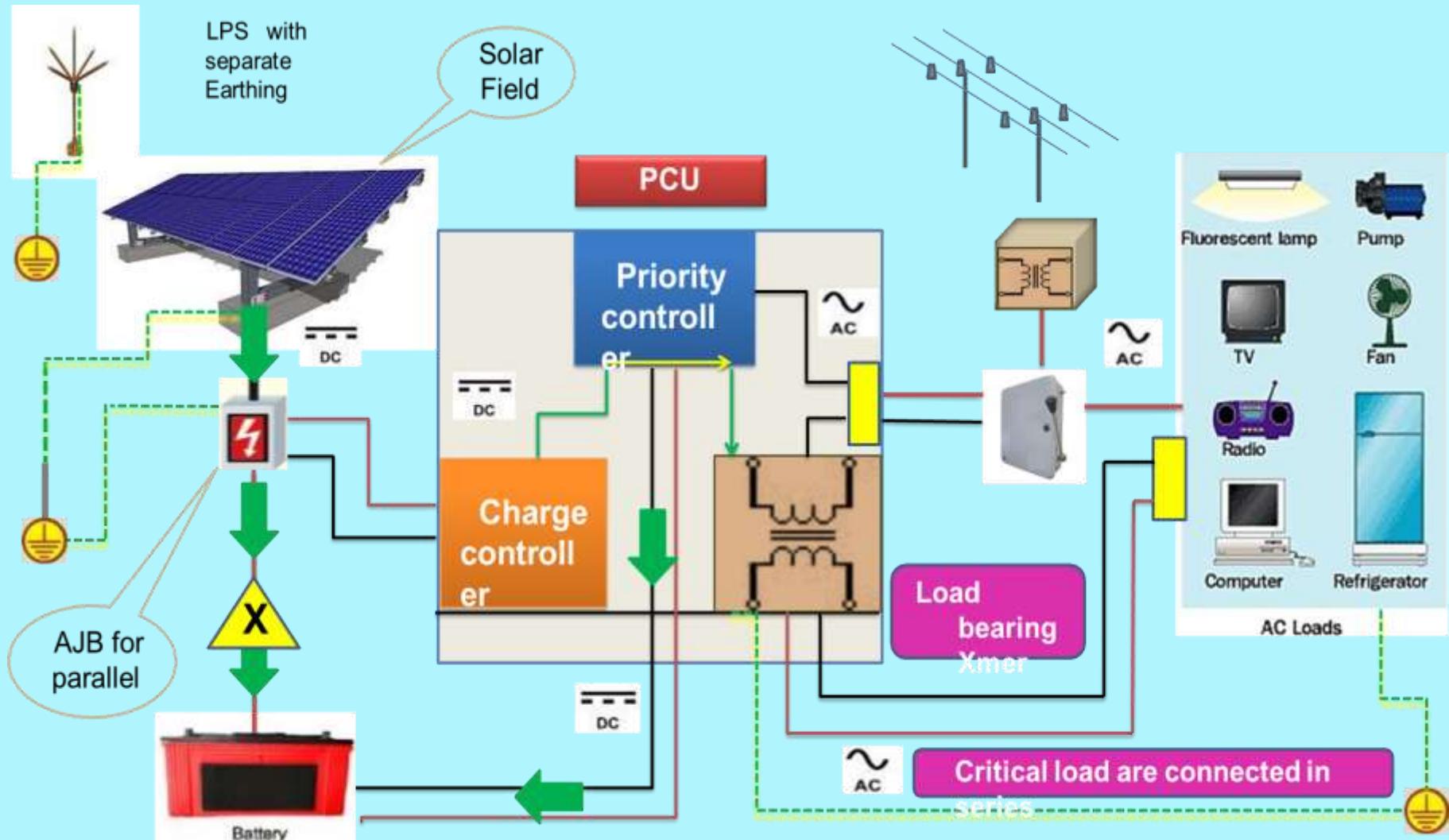


Smaller size of the batteries used to reduce the cost of the plants

Wind & Solar Hybrid Plant



2nd Generation Solar Plant



3rd Generation Grid Connected Solar Plant

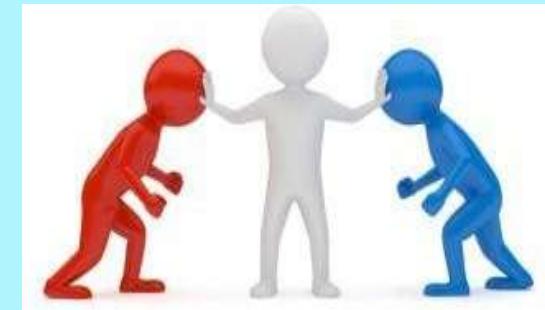
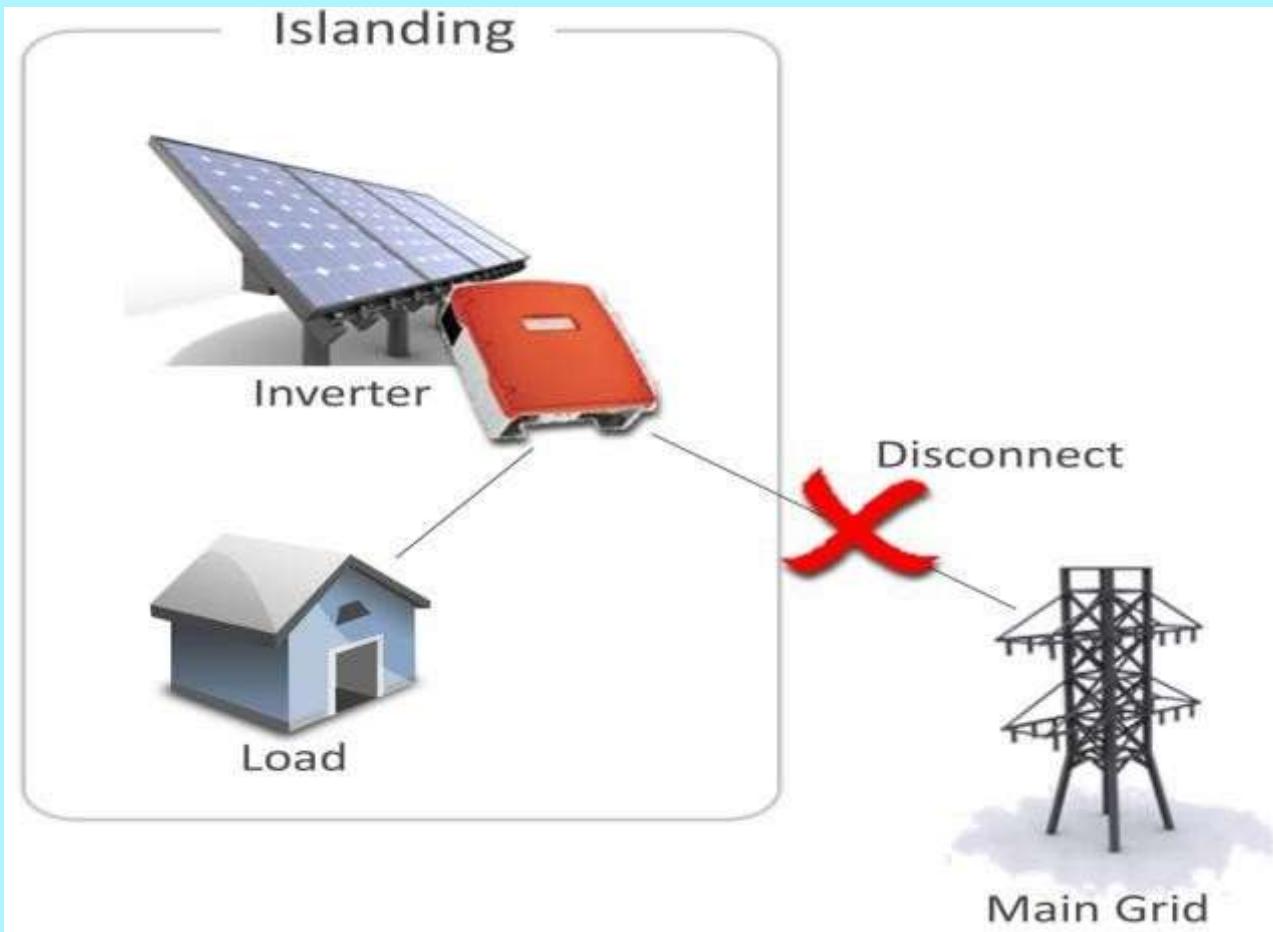
1. Solar Panels
2. Solar inverter
3. Solar meter
4. Connected Load
5. Net meter
6. Grid Synchronization

V, f, Phase sequence & wave form



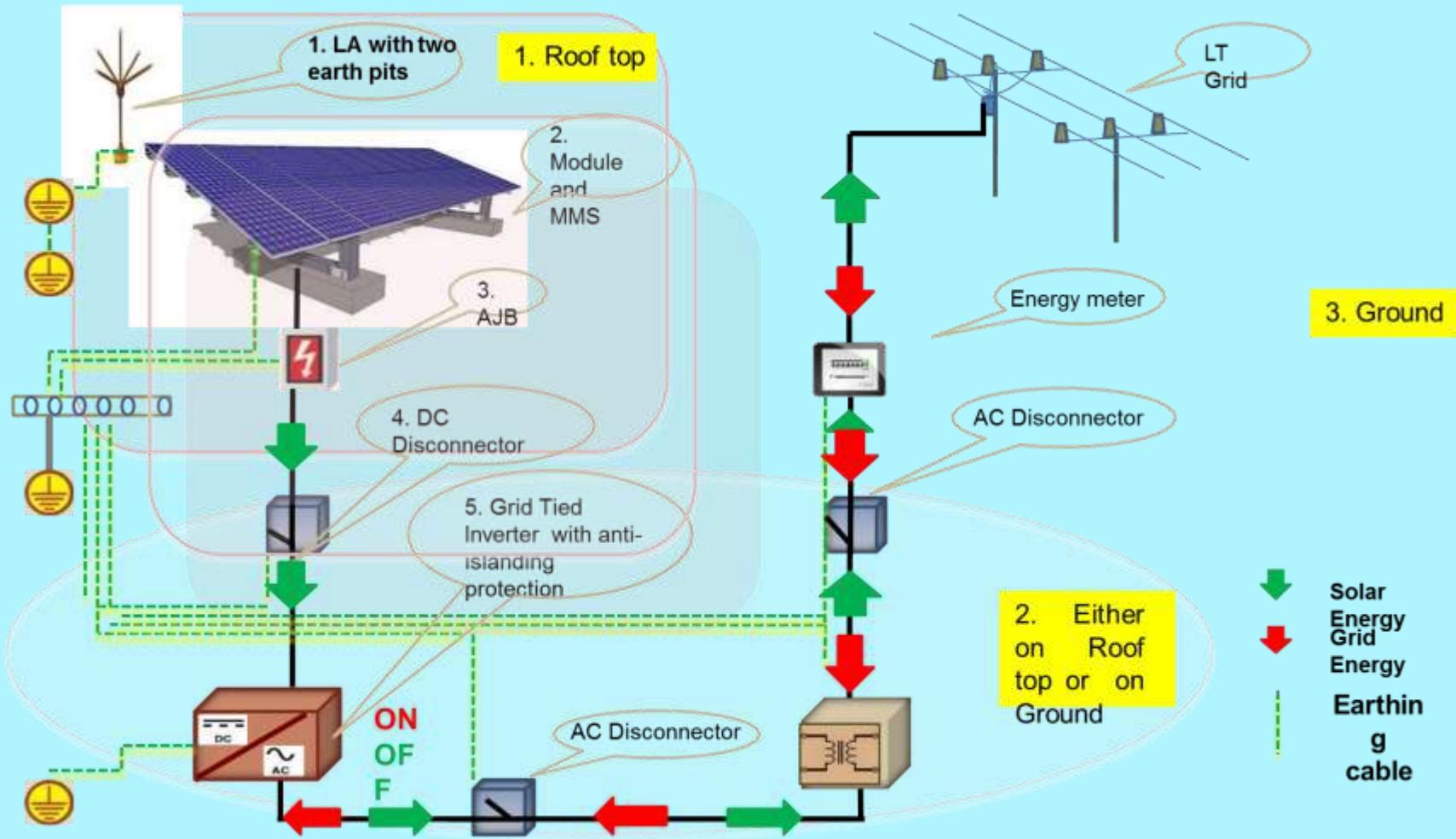
Completely battery less system
to minimize the cost of RTSPV & to connect in
load sharing mode

Grid Connected Solar Plant Working



No grid power No AC electricity from inverter

Grid Connected Solar Plant Working



Grid Connected Solar Plant Working

- On-grid plants needs **reference voltage (AC power)** from Grid
- It gets **synchronized with the grid usually in 1 min** with the grid
- Afterwards start converting DC power coming from SPV in to AC
- The **AC voltage generated by the solar inverter is slightly higher than Grid voltage** Due to this solar power will get the **first priority** for connected loads
- On-grid plant is **connected in parallel** hence it is a **load independent system**
- On-grid plant act as a **load sharing device in the electric circuit**
- **It has inbuilt Anti islanding feature**, which provide **immediate (0.2 seconds) isolation** from the grid and **complete isolation in 2 seconds** when there is loss of reference from the grid

Solar PV cell Classification

Classification of PV Solar Cell

First generation PV solar cell

- Mono-crystalline
- Poly-crystalline



Second generation PV solar cell

- Amorphous silicon
- Cadmium telluride/cadmium sulphide
- Copper indium gallium diselenide



Third generation PV solar cell

- Copper zinc tin sulfide PV Cell
- Dye-sensitized PV cell
- Organic PV cell
- Perovskite PV cell
- Polymer PV cell
- Quantum dot PV cell



4th Generation Solar Plant



Grid Connected Solar Plant with Battery Bank



Micro - Grid Applications



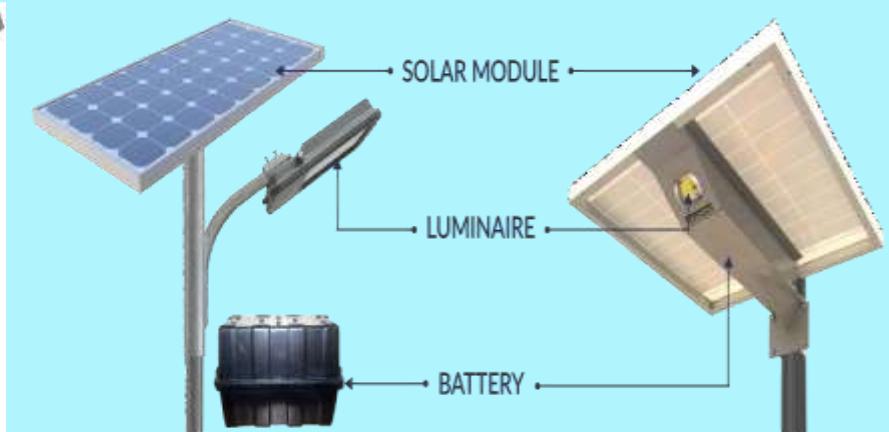
- Usually micro grids constructed, where the grid availability is not economically viable
- In India many remote location are best suited for this type of solutions
- It may use more than one source of the electricity
- The power generation can be increase or decrease as per the requirement of the village.

Solar Home Applications



Complete solution for household electrical appliances and also can provide battery back up for critical load

Solar Street light Applications



Solar street lights comprise of the SPV module, which absorb the solar energy during daytime & convert solar energy into electrical energy, which is stored in the battery. At the night time the lamp starts automatically and it consumes the electricity already stored in the battery. During the day time the battery gets recharged and the process keeps on repeating every day

Solar Street light Applications



1. solar panel



2. Battery with maintenance free



3. Solar Controller



4. LED Lamp



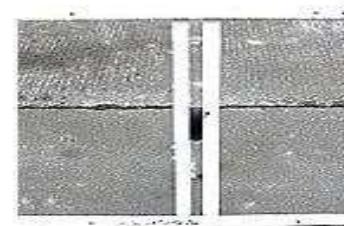
5. Battery Case



6. Premium Lamp-Post

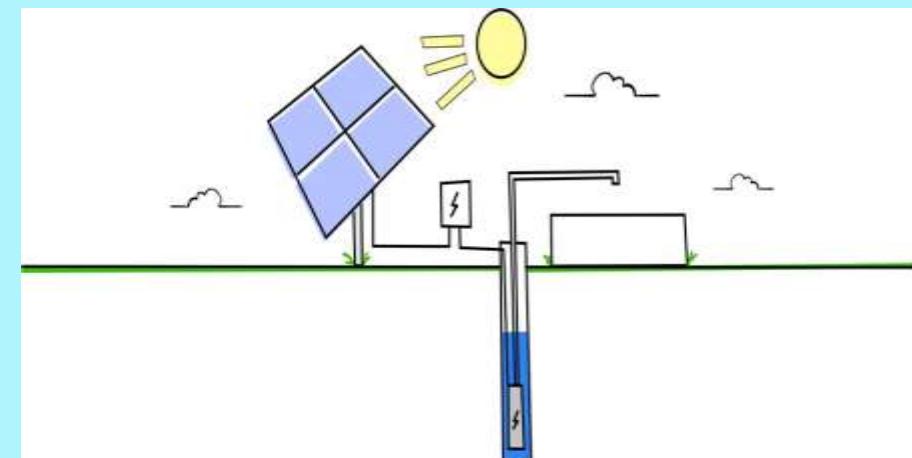
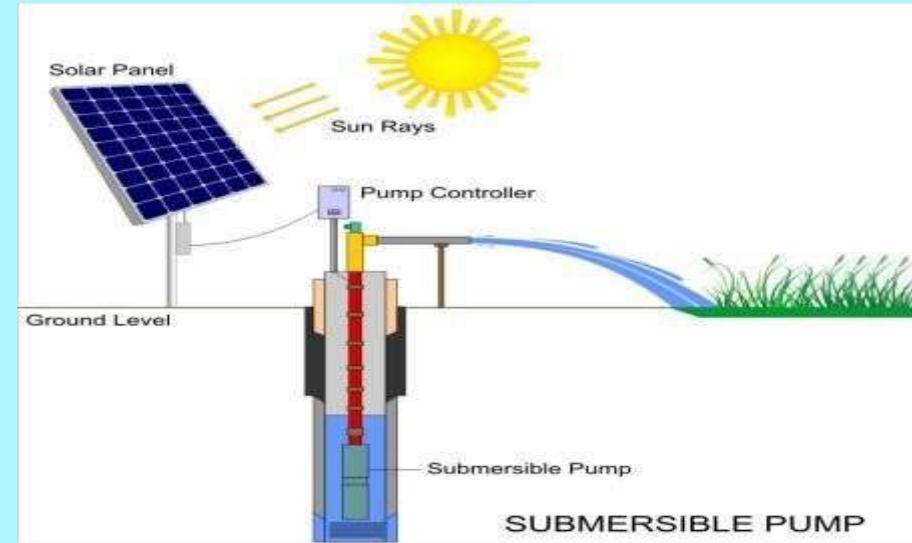
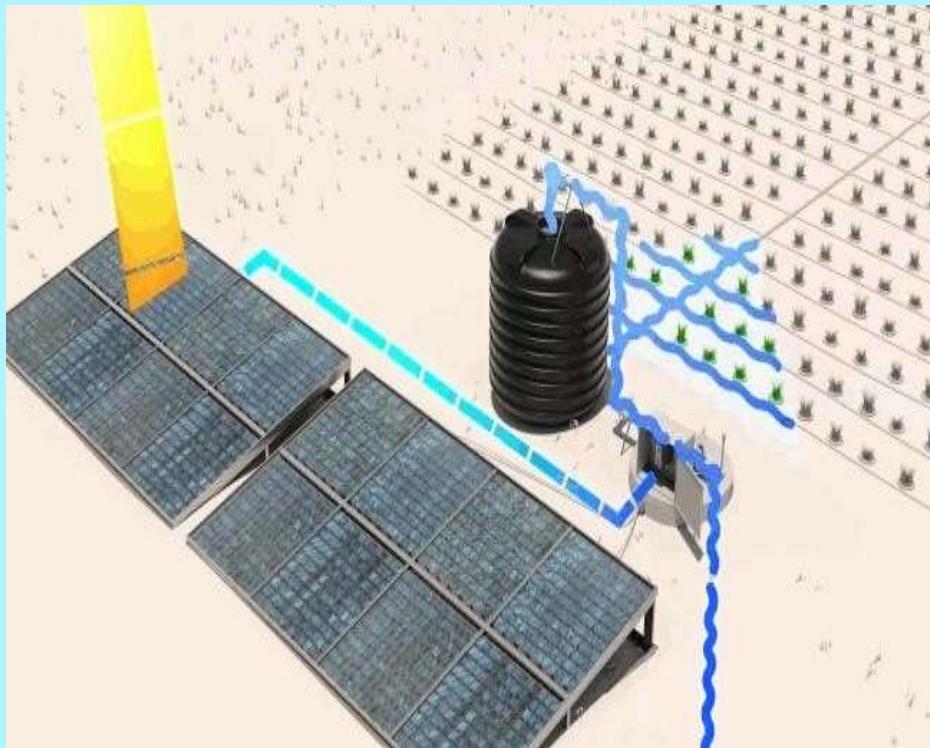


7. Land Foot Bracket



8. Bracket for solar panel

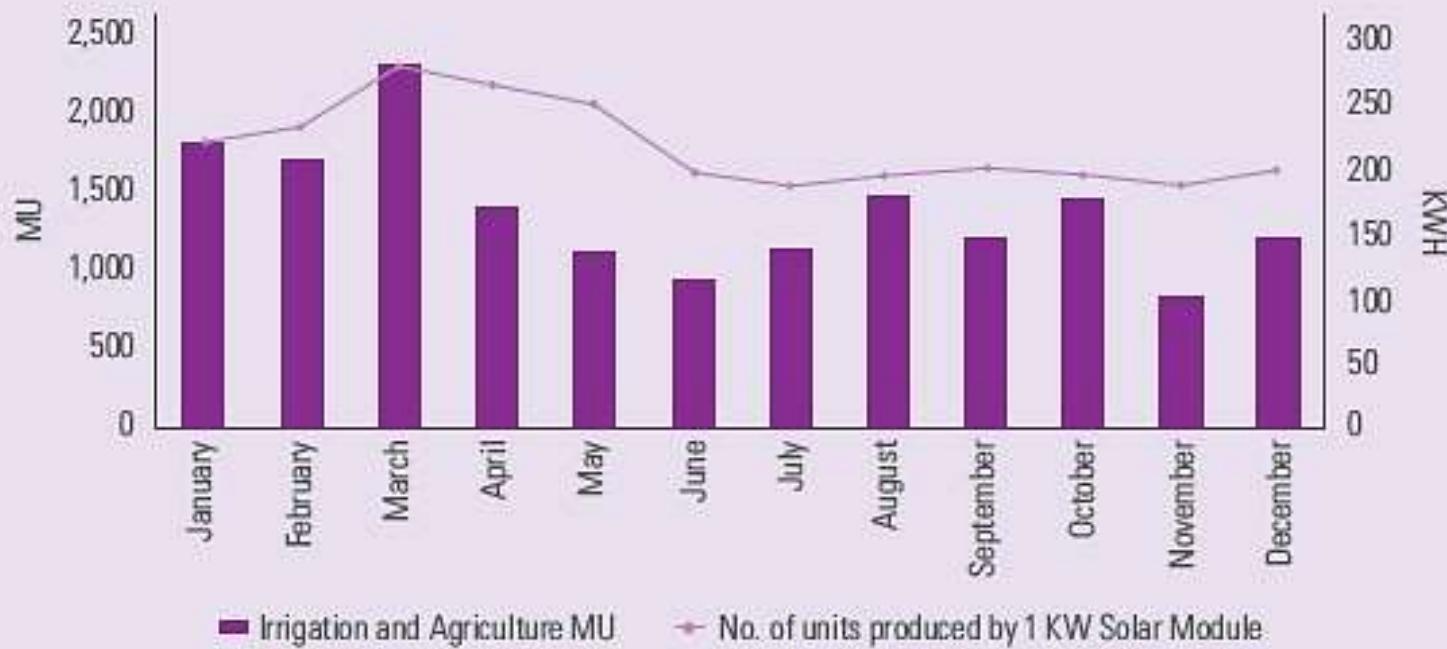
1st Generation Solar Pumps



Can be Integrated with Drip Irrigation System

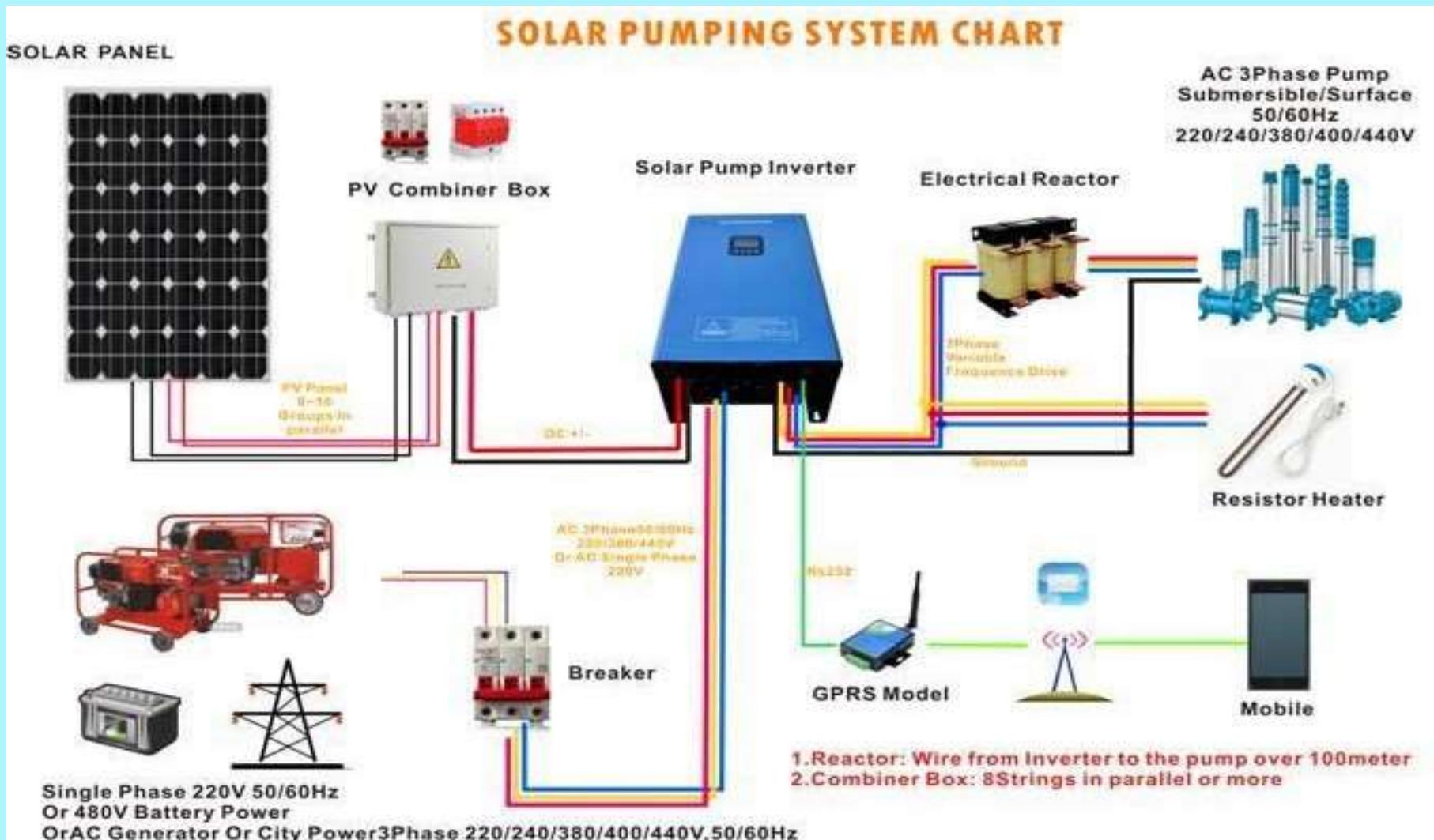
Why Solar Pumps?

Correlation of agriculture power consumption & solar power production in the state of A.P.



In 2014, Government of India announced a target to install 1 million solar water Pumps, a INR 415 Crore package equivalent to approximately 3,000 MW, for irrigation and drinking water by 2021

Grid Connected Solar Pumps

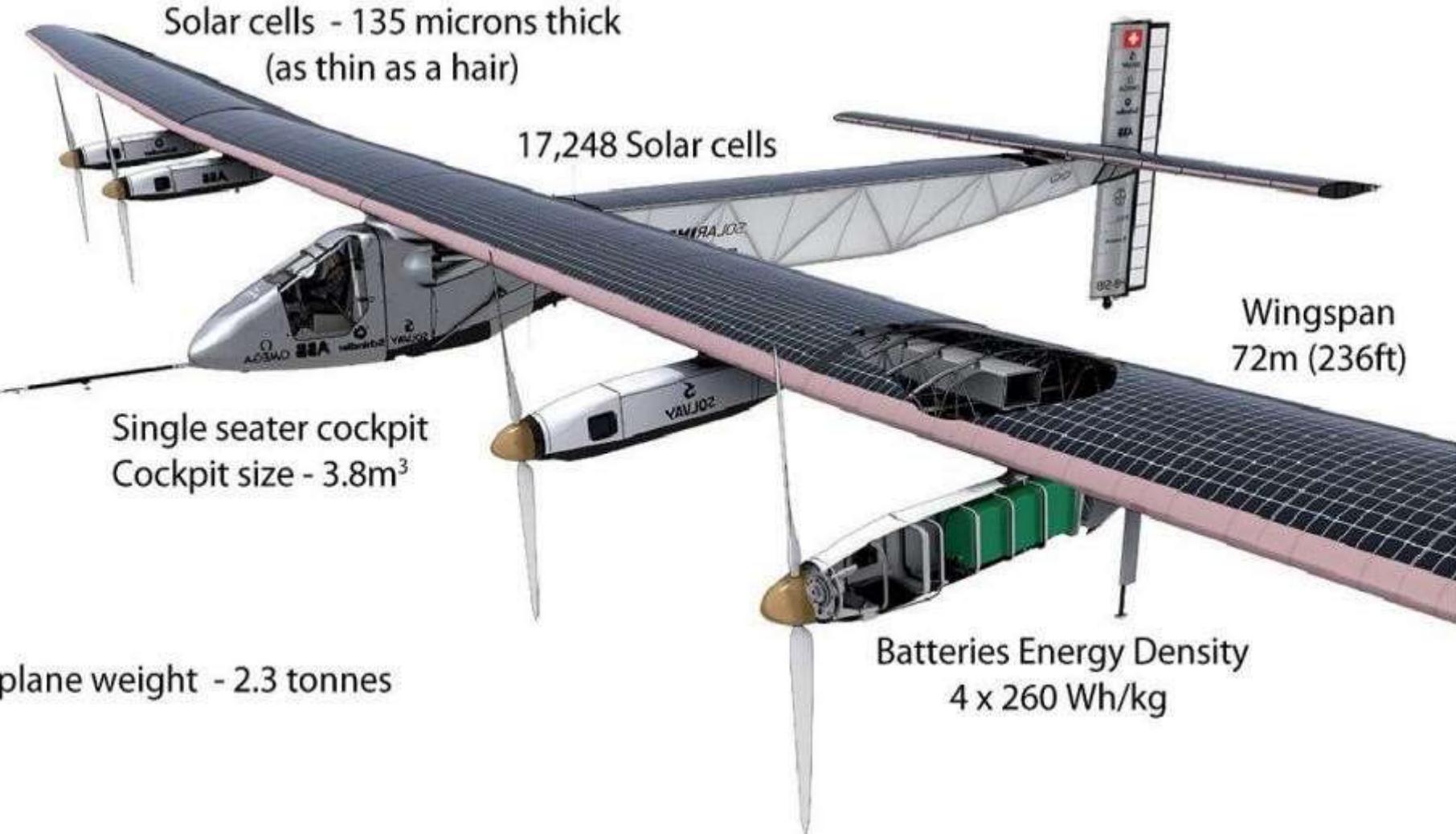


Off Grid Solar Mobility Applications

Solar PV technology - Off-grid mobility applications



Solar Impulse



Solar Impulse

Solar Impulse is a Swiss long-range experimental solar-powered aircraft project, and also the name of the project's two operational aircraft. [Wikipedia](#)

Top speed: 140 km/h

Introduced: 26 June 2009

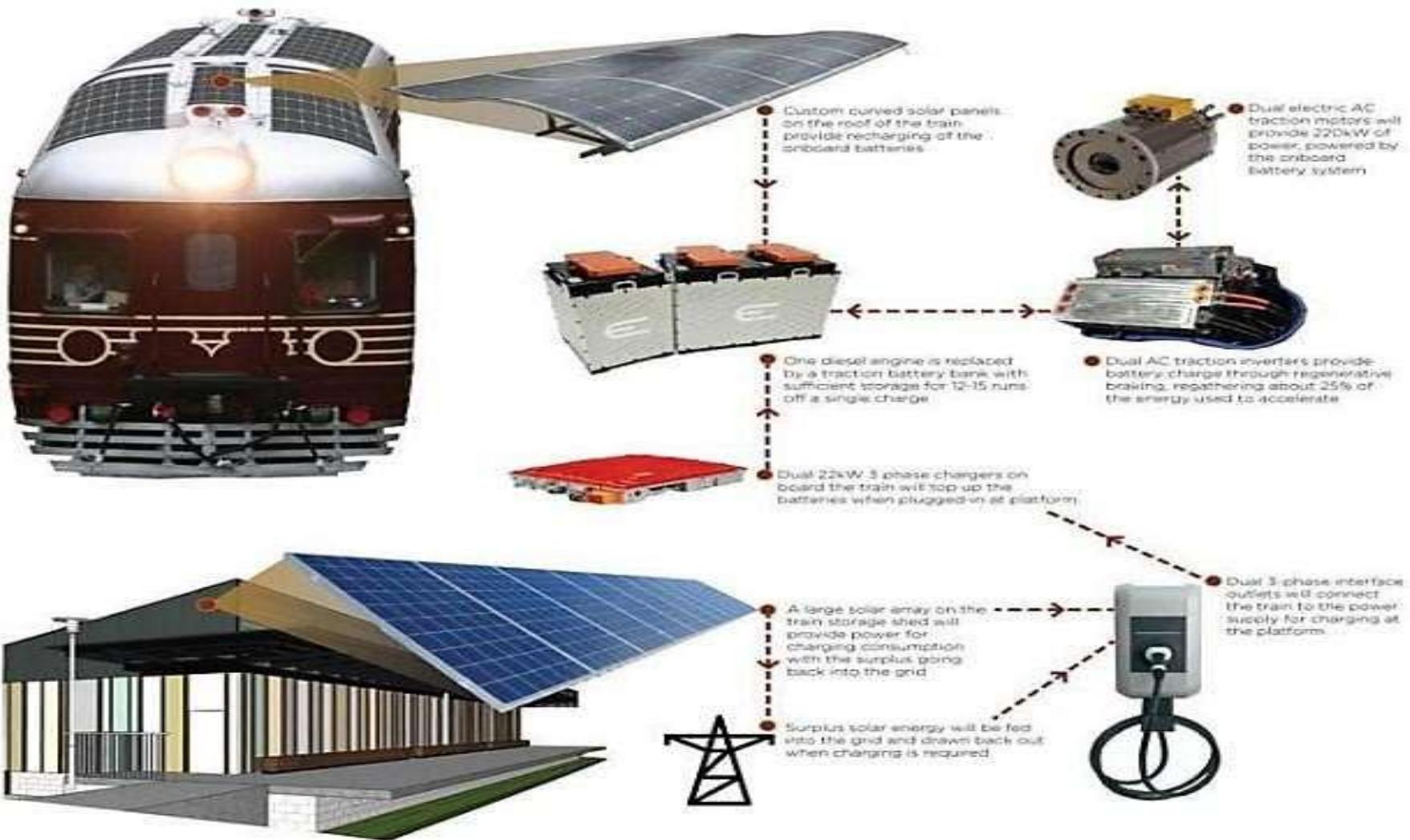
First flight: 3 December 2009

Manufacturer: [Swiss Federal Institute of Technology](#)

[Lausanne](#)

Engine type: Electric motor

Solar Train



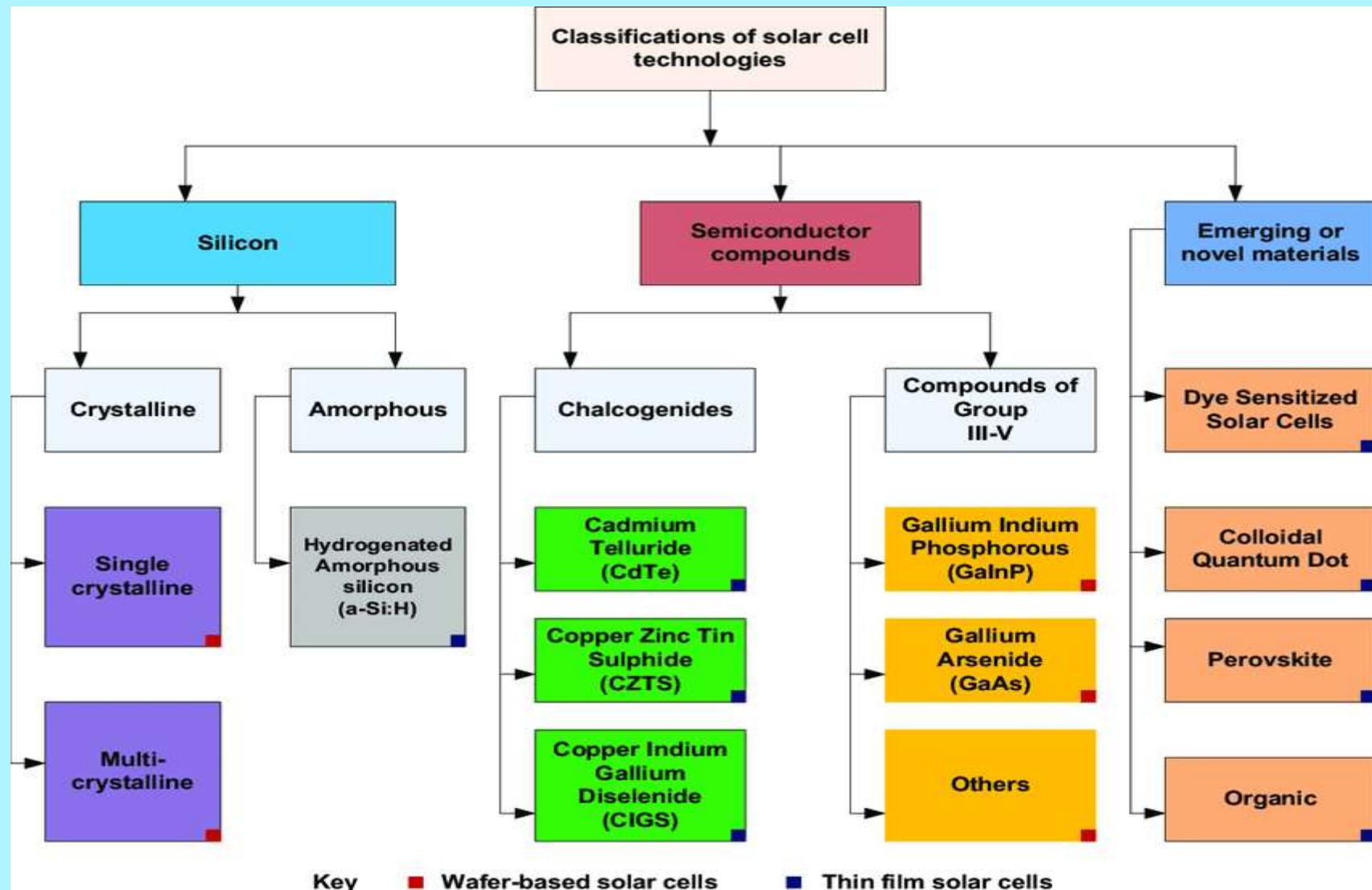
Solar Trains in India



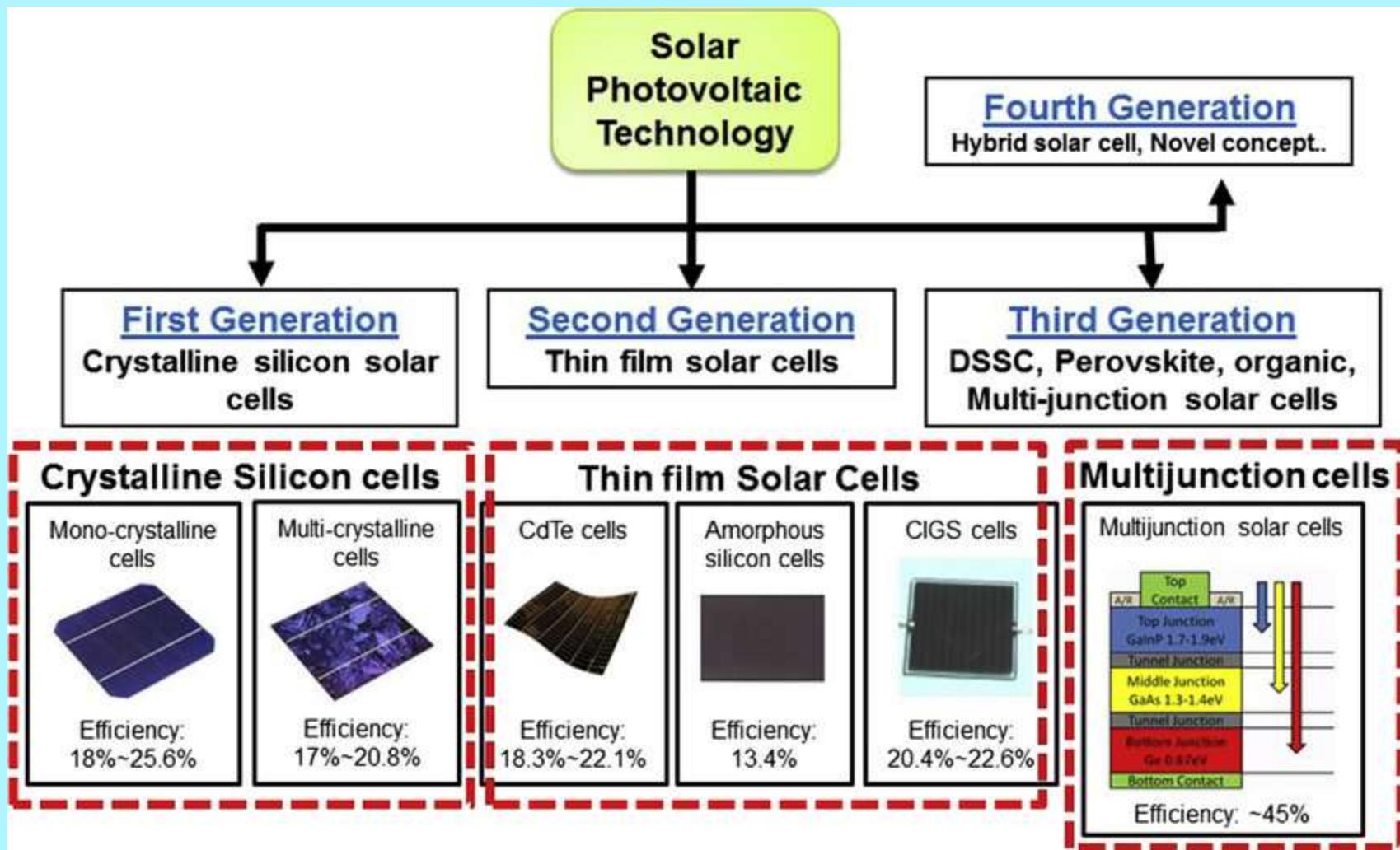
Solar Fence in India



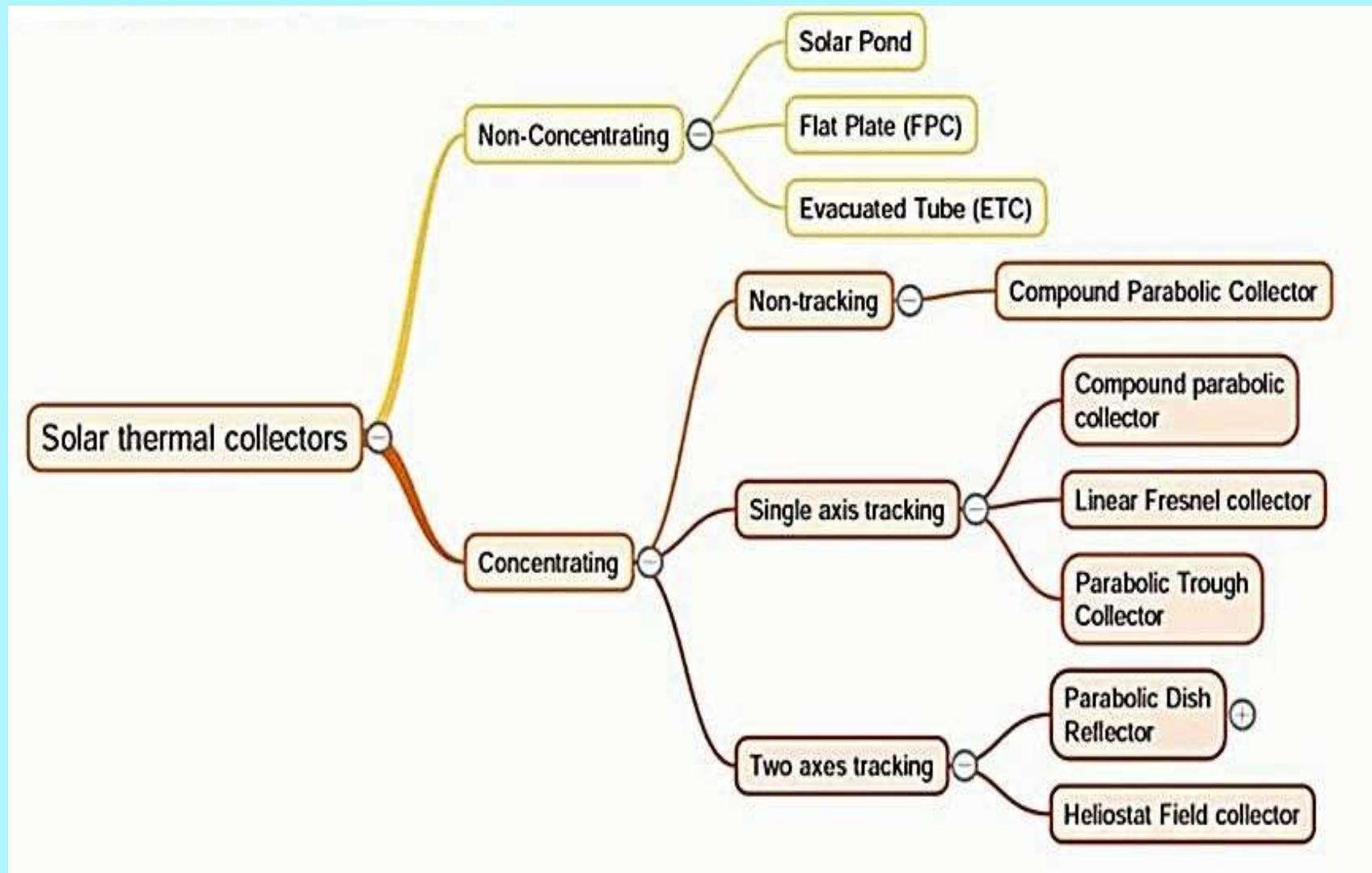
Solar Cell Technologies



Solar Cell Technologies



Solar Thermal Power



Solar Water Heater Comparative Study

- The approximate savings per day for 125 LPD solar hot water system are given below:
 - Electricity: 6 units
 - Diesel: 2 liters
 - Kerosene: 3 liters
 - LPG: 0.44 kg. 5
 - Firewood: kg.

Solar Thermal Water Heater



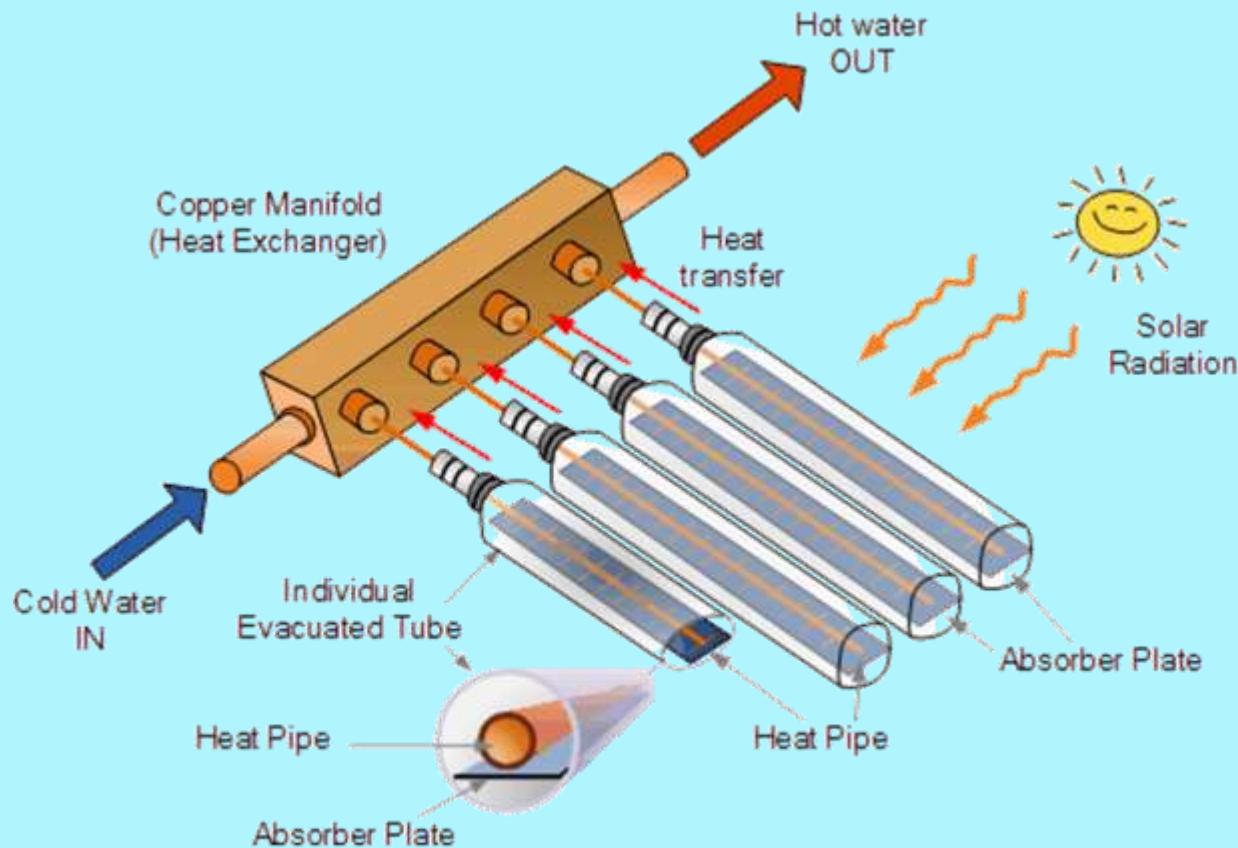
- It consists of a solar collector and an overhead tank
- Water circulates naturally by thermo-syphon effect.
- 125 ltrs per day system will be sufficient for 3-4 persons.
- Heats water up-to 70°C
- The storage tank and piping of the system are well insulated.
- Electrical heater backup can be provided for cloudy days.

Solar Hot Water System



Flat plate, cu tube , pressurized solar water heater

Evacuated Type Collector

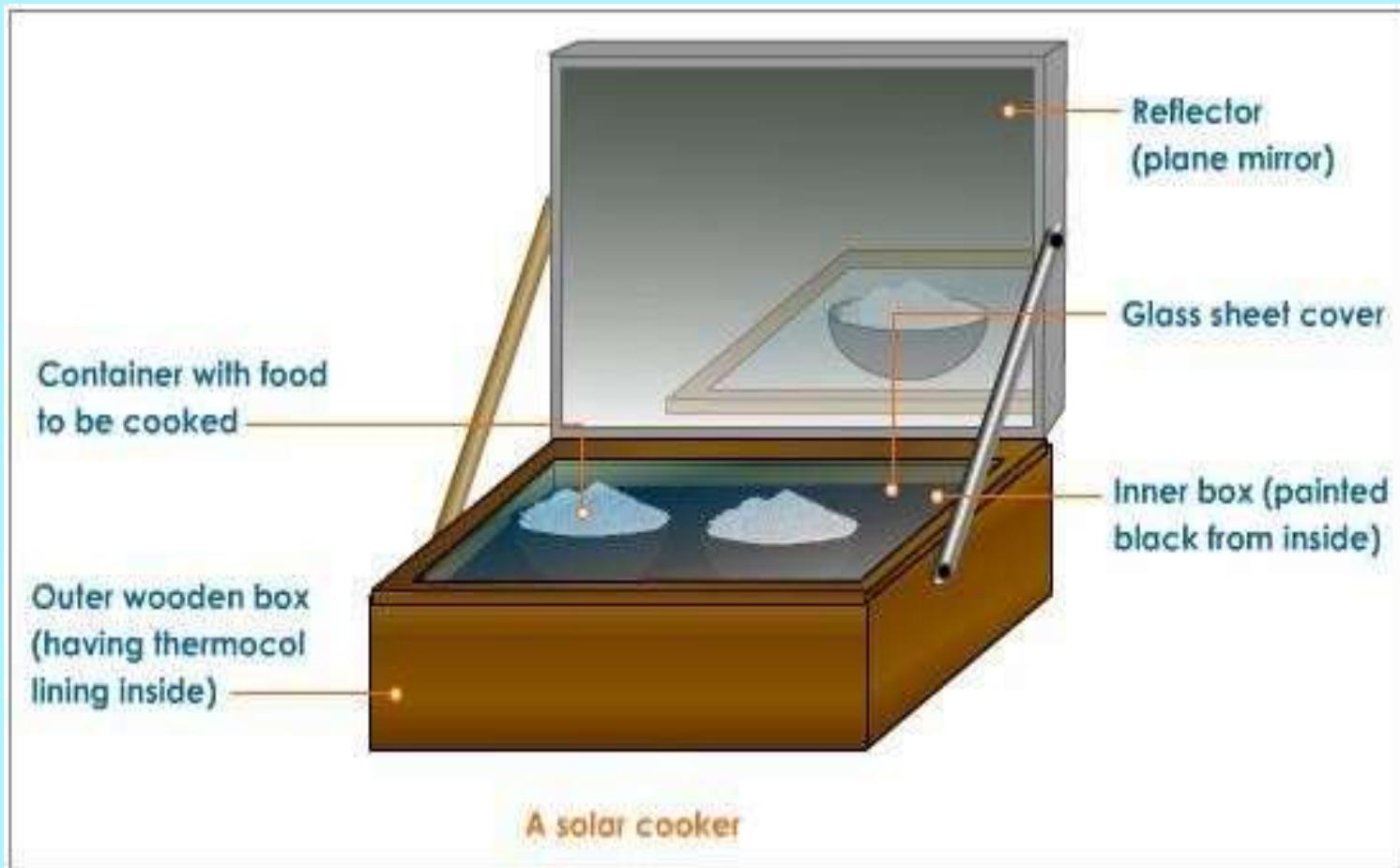


- Evacuated tube collectors are the most efficient collectors available. Each evacuated tube is similar to a thermos in principle.
- A glass or metal tube containing the water or heat transfer fluid is surrounded by a larger glass tube.
- The space between them is a vacuum, so very little heat is lost from the fluid.

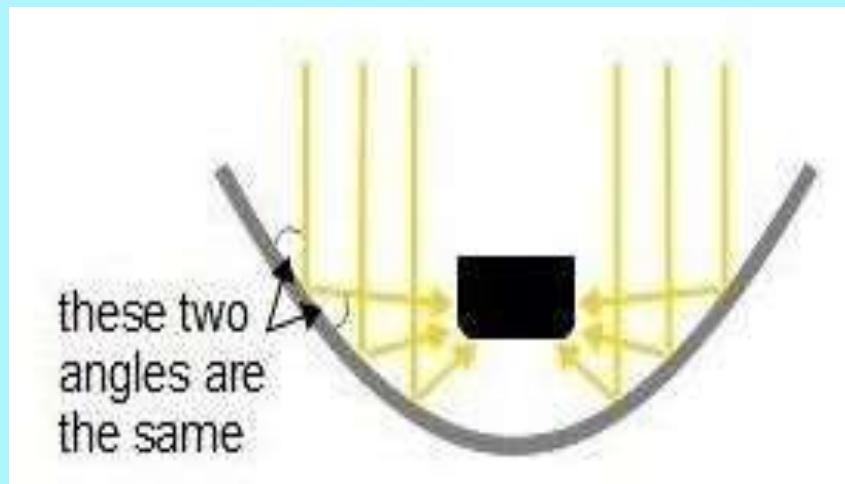
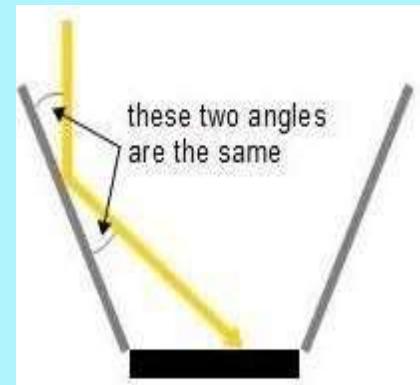
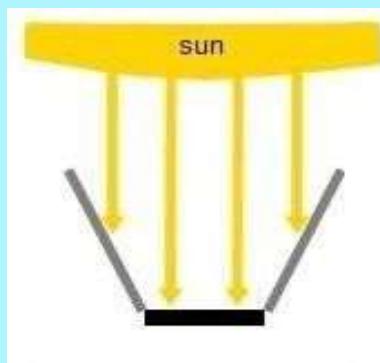
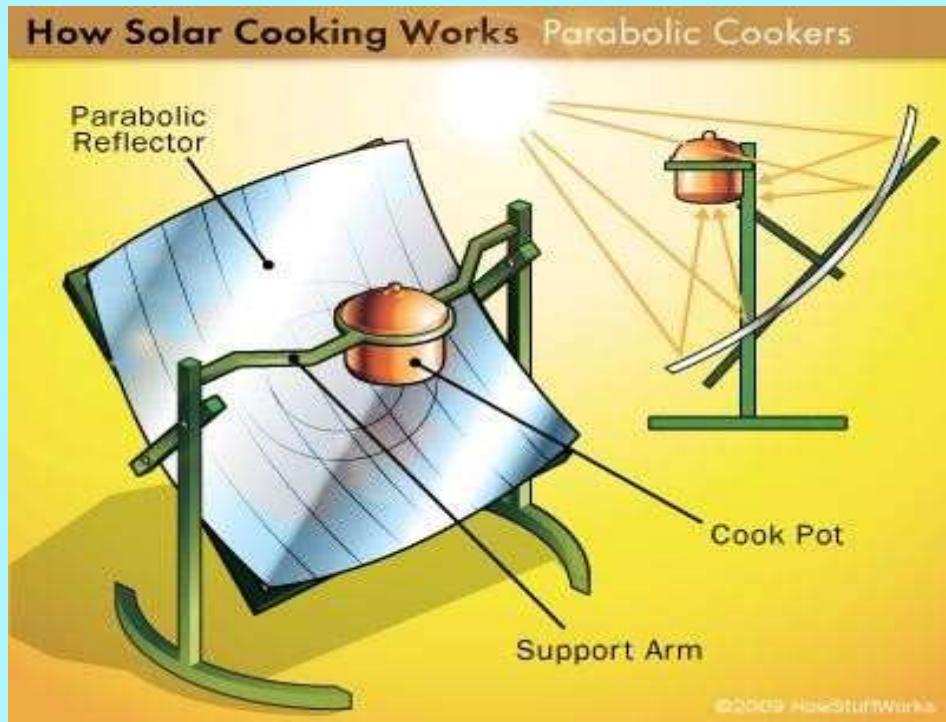
Solar Water Heater for Low Radiation



Box Type Solar Cooker



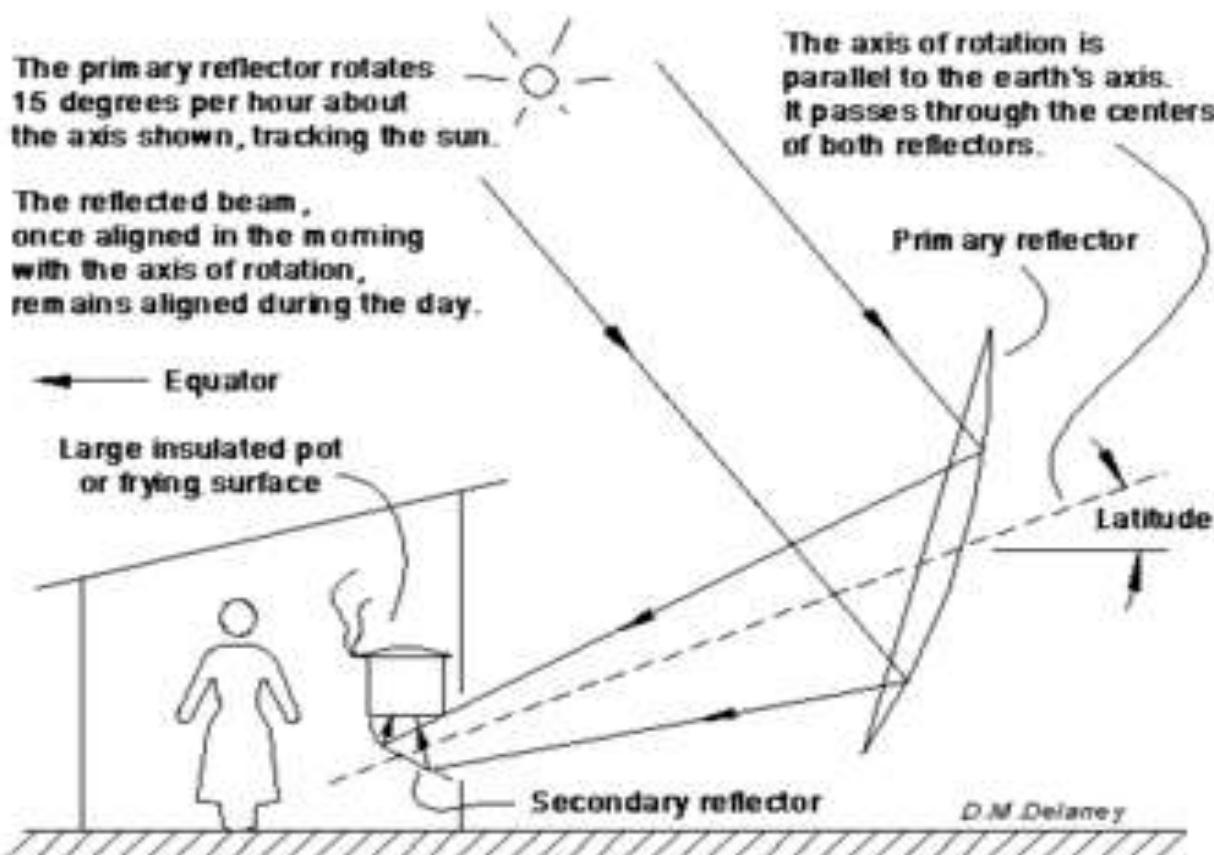
Parabolic Solar Cooker



Parabolic Solar Cooker



Scheffler Cooker



How a Scheffler reflector used for cooking keeps its focus on the cooking place as the sun moves.



Scheffler Cooker



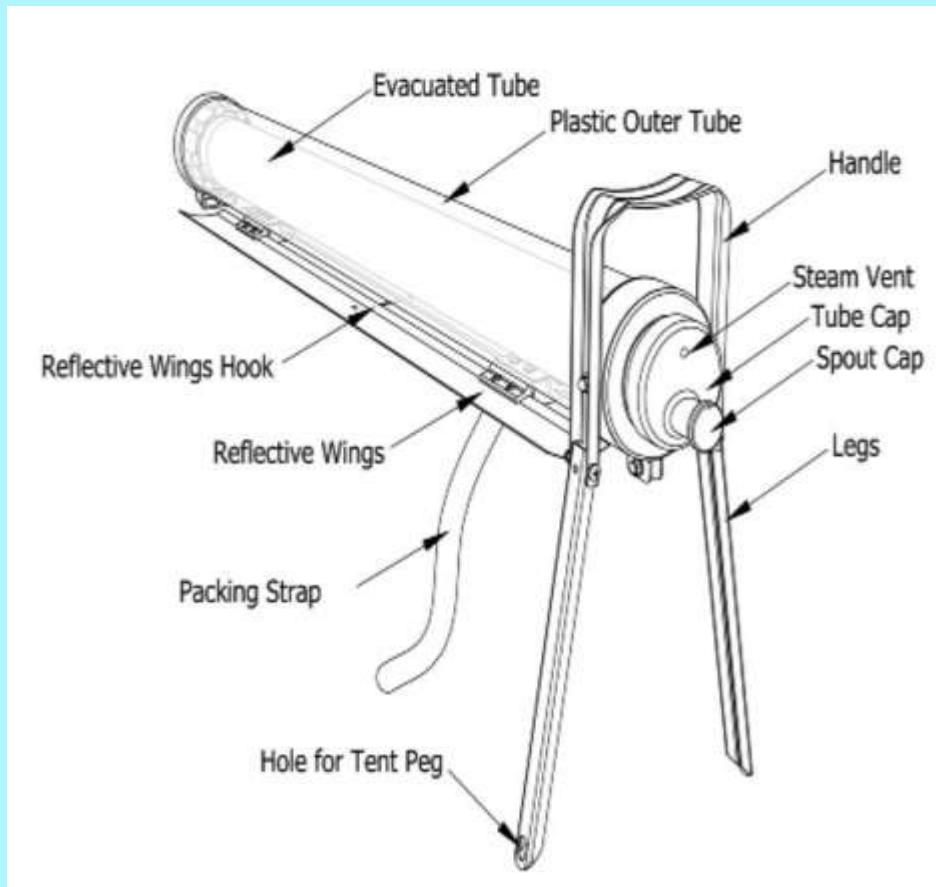
Primary Reflector (Motorized)

Receiver

- Fixed and out side the rotating reflector



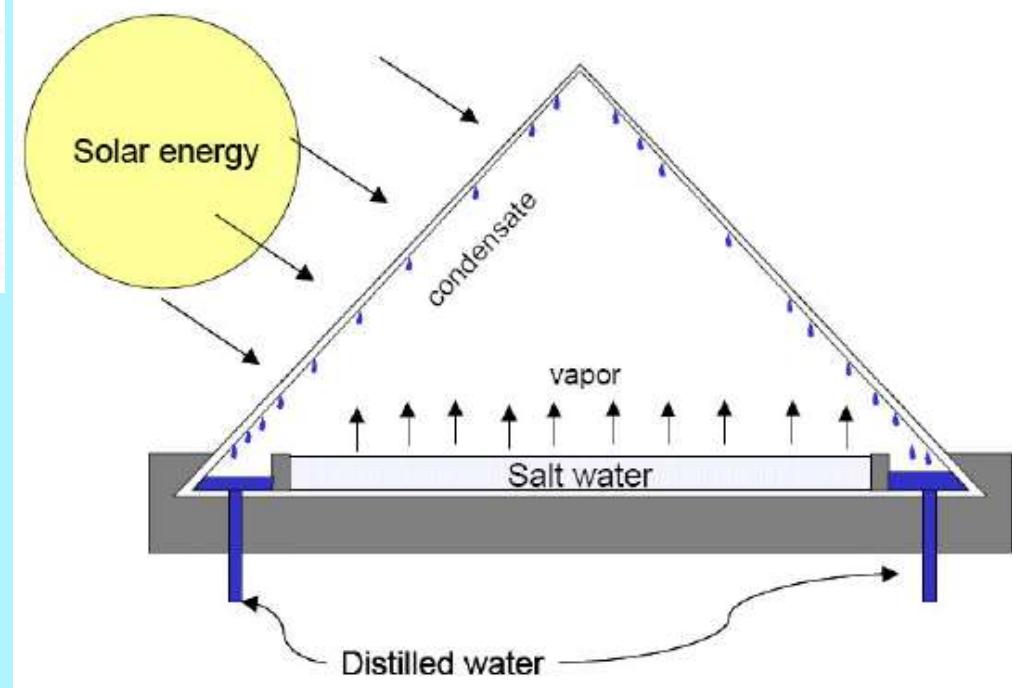
Evacuated Tube Solar Cooker



Community Solar



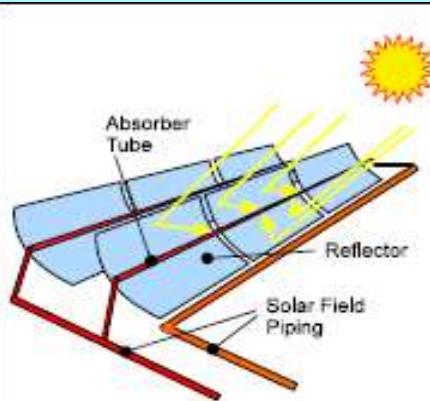
Solar Distillation Plant



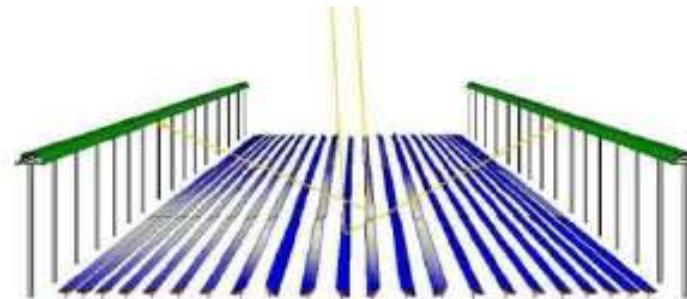
Solar Dryer



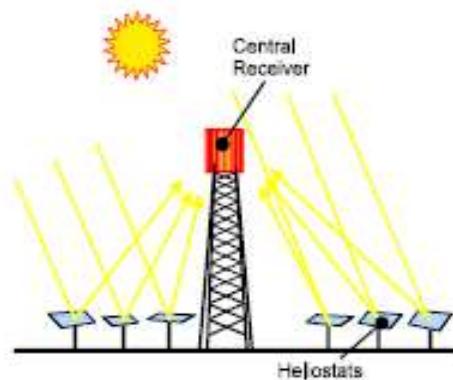
Concentrated Solar Power



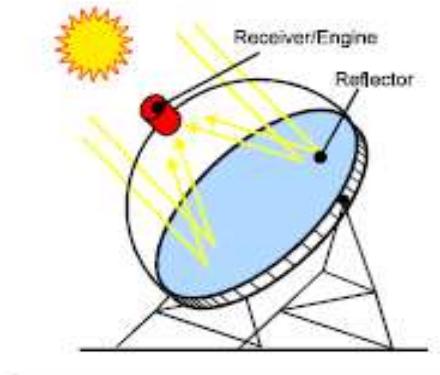
Parabolic troughs



Linear Fresnel Reflectors

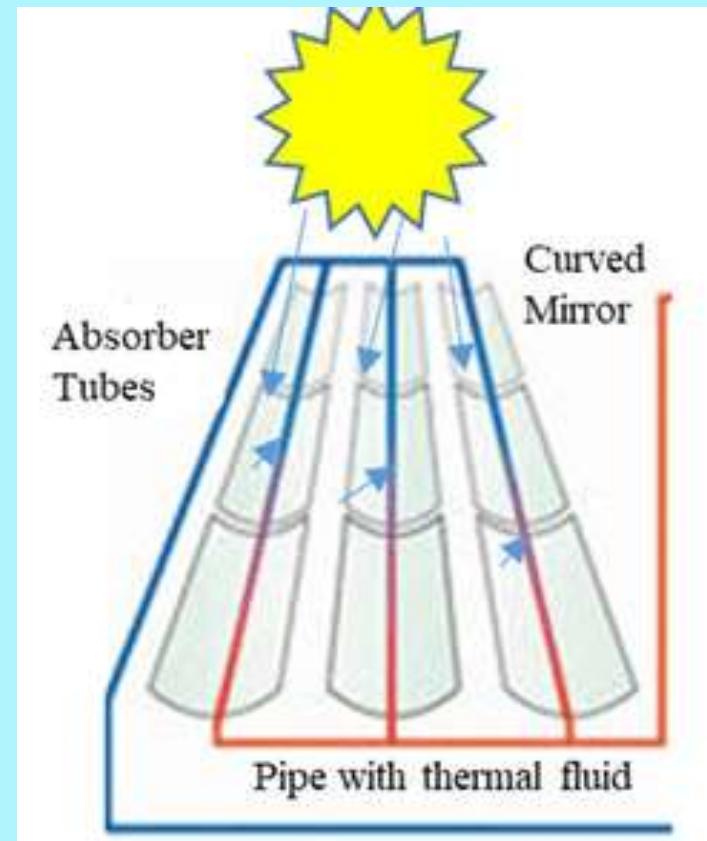


Central Receiver / Heliostats

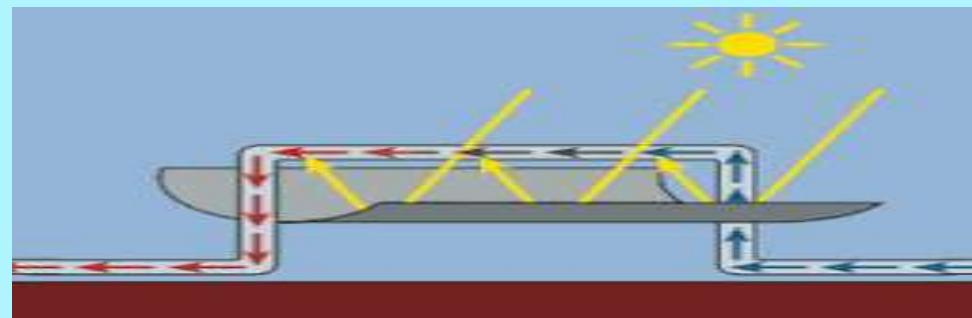
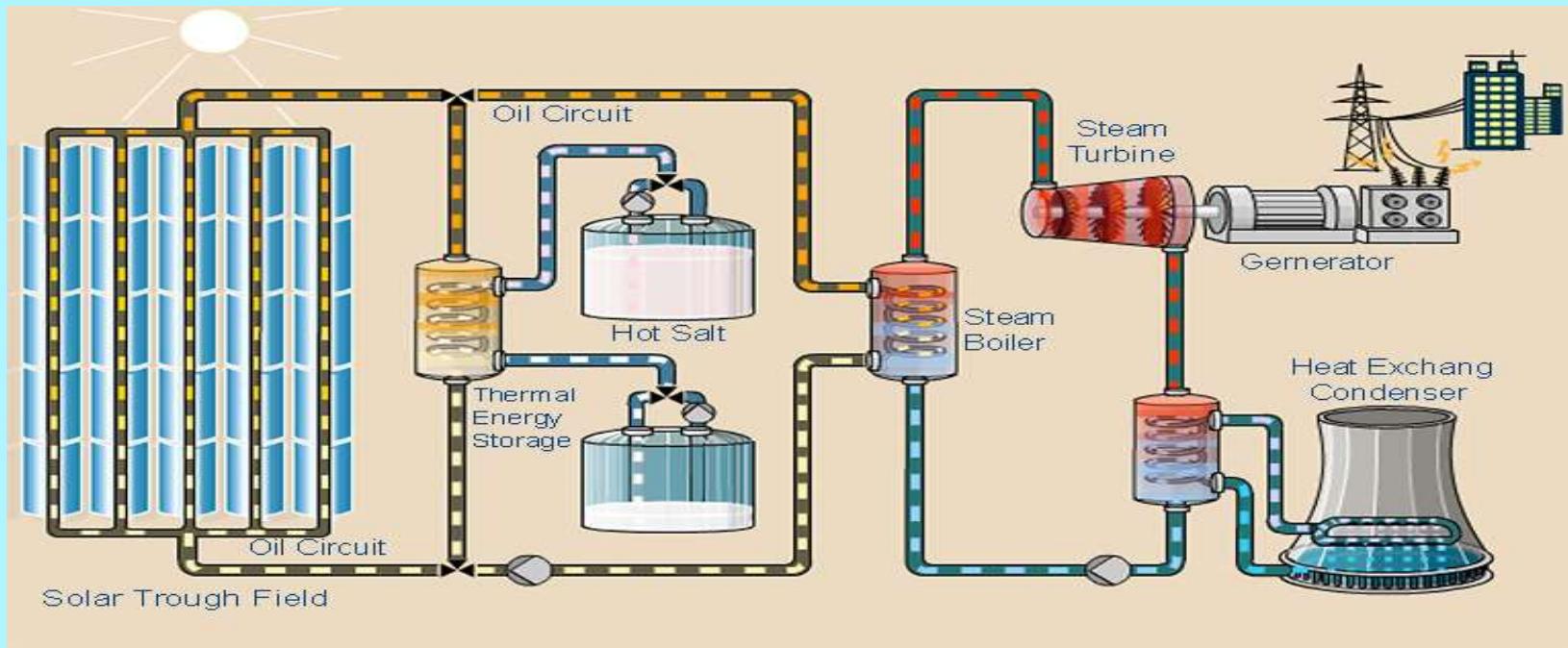


Parabolic dishes

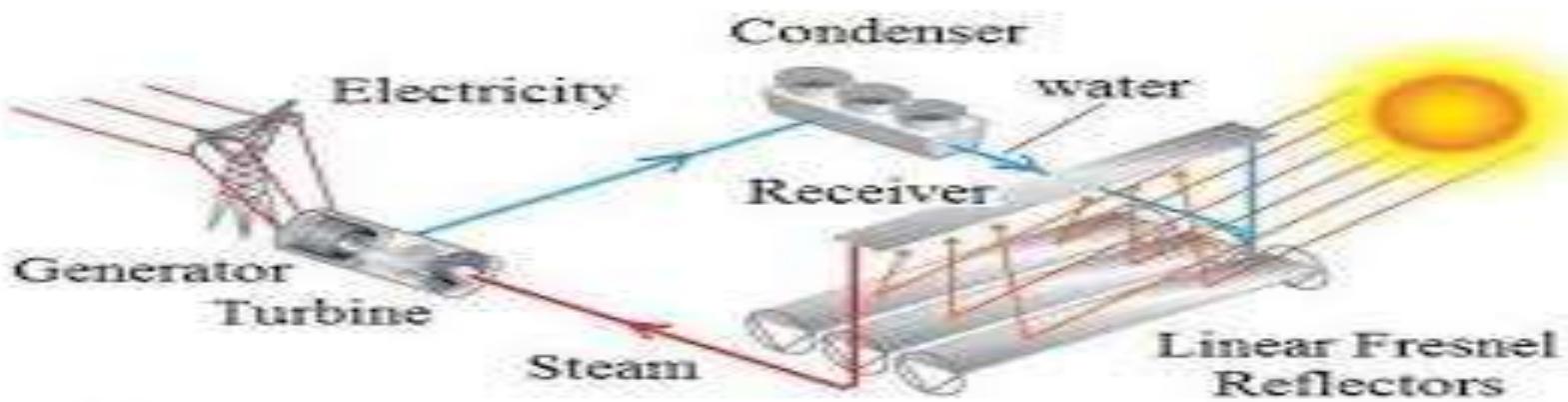
Solar Thermal flat Panels



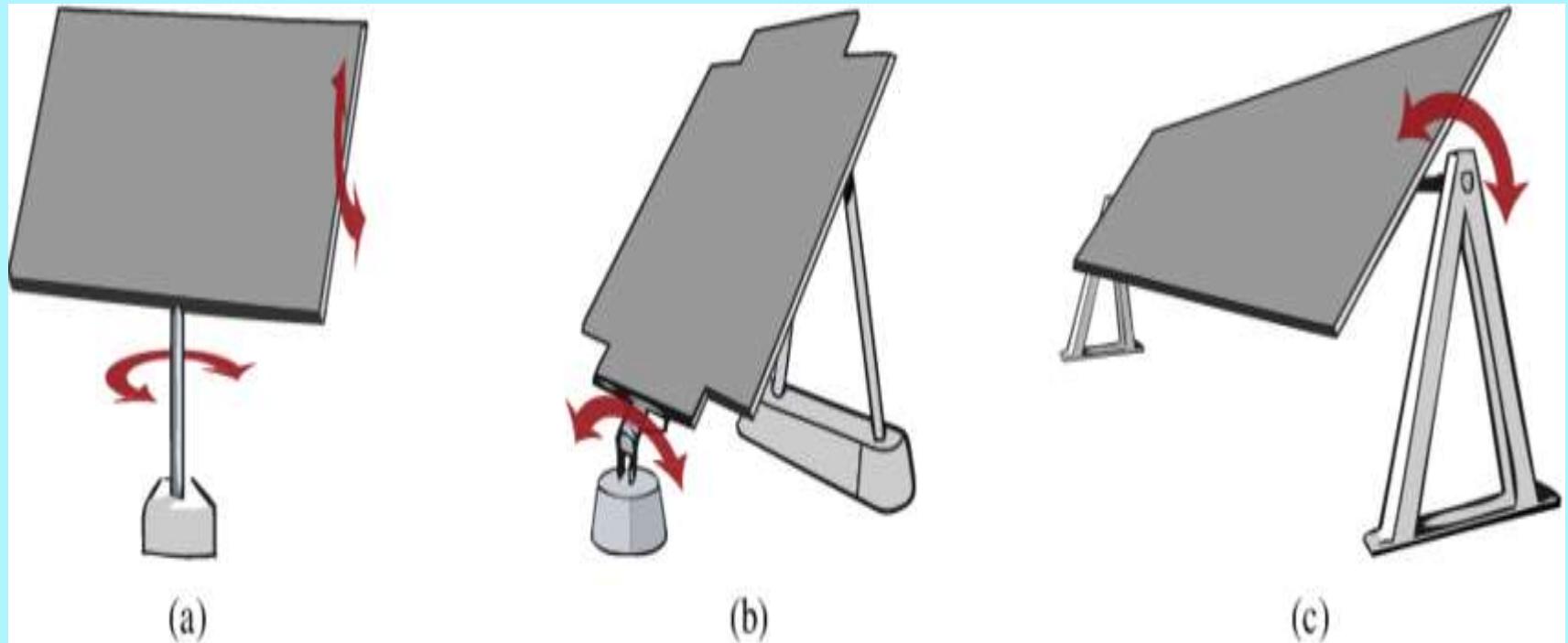
Parabolic Trough Solar Power Plant



Linear Fresnel Reflectors



Single and Two Axis Solar Tracking



Shown are different solar trackers used in both PV and CPV; (a) dual-axis tracker, (b) polar aligned single-axis tracker, and (c) horizontal single-axis tracker.

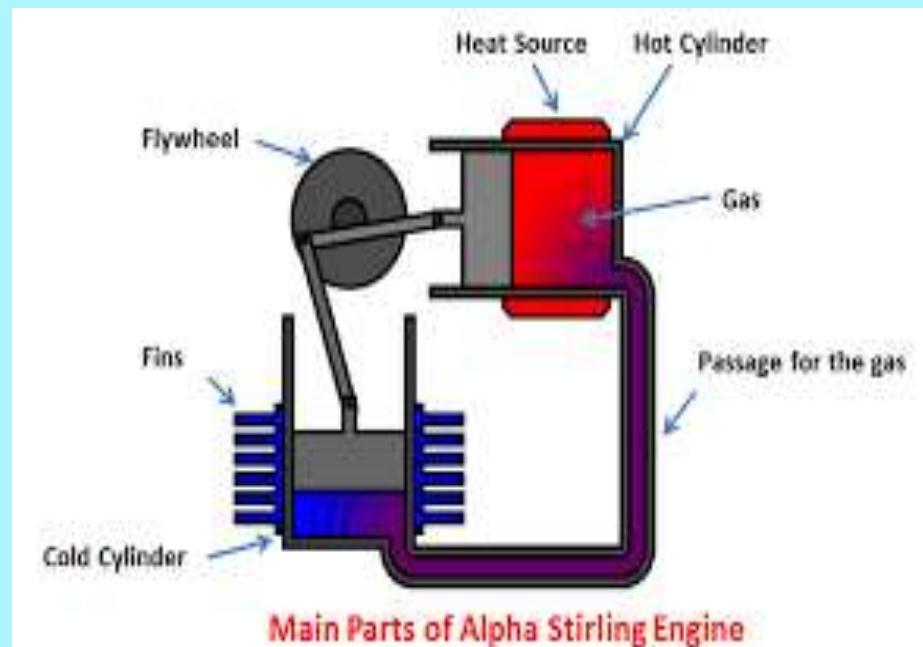
Two Axis Solar Tracking



Dual-axis Tracker



Parabolic Dish Sterling Engine

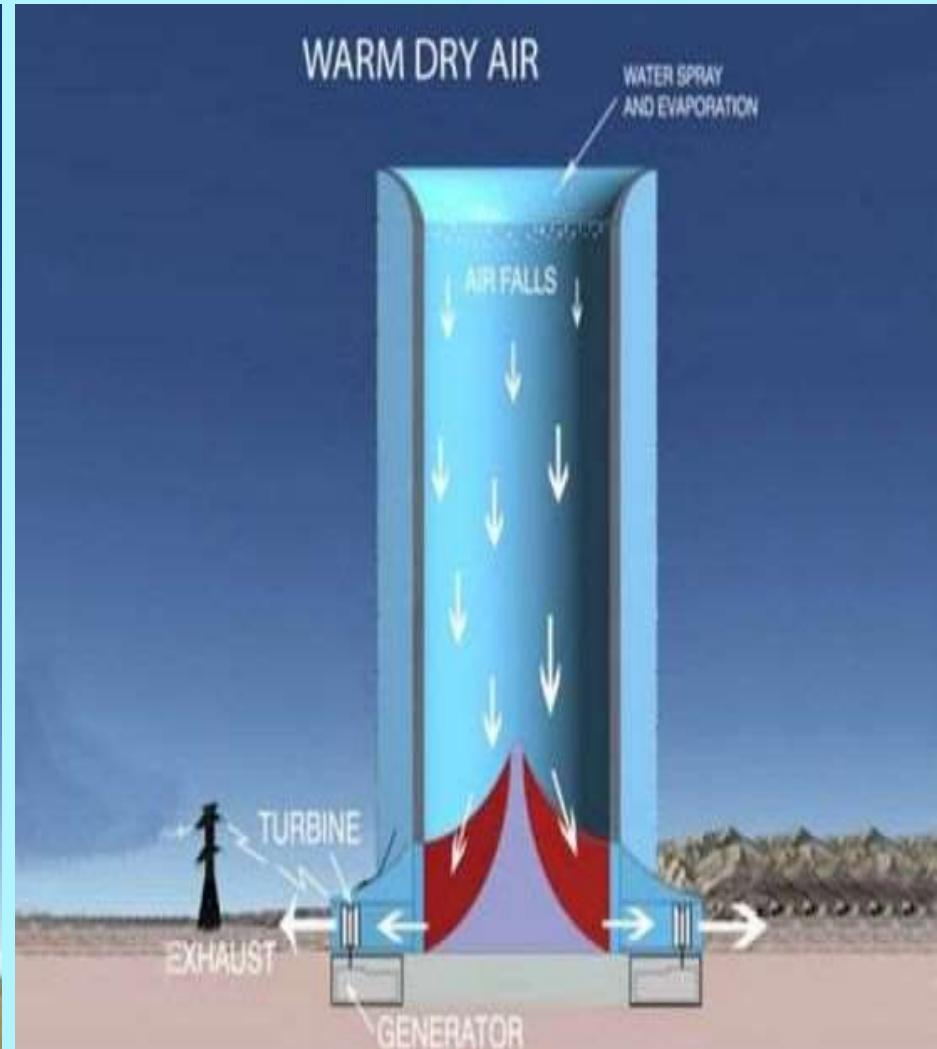


Sterling Motor Engine

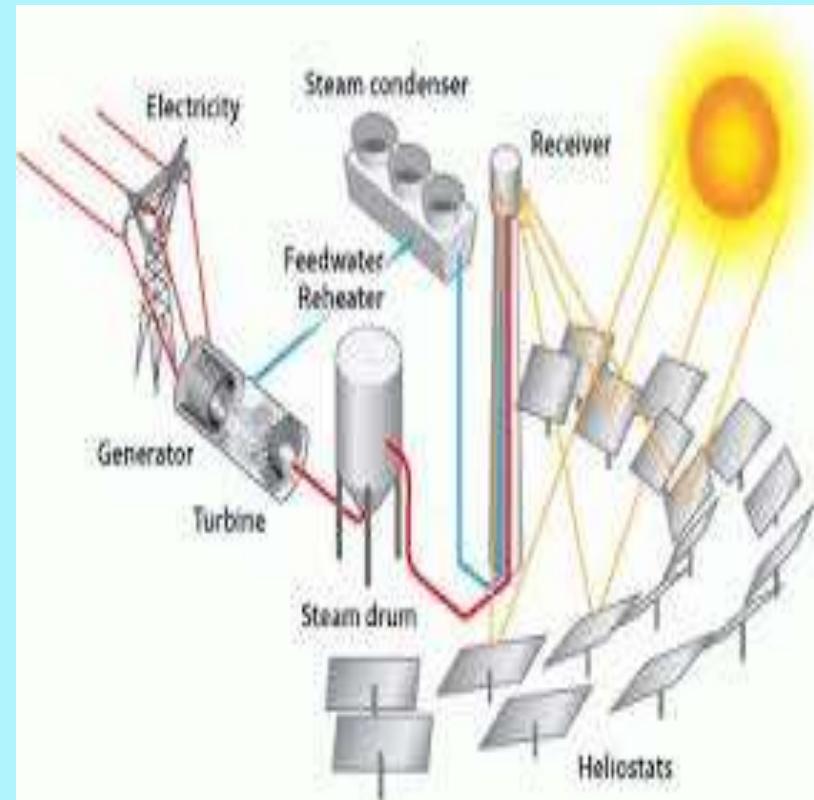
Parabolic Dish Sterling Engine



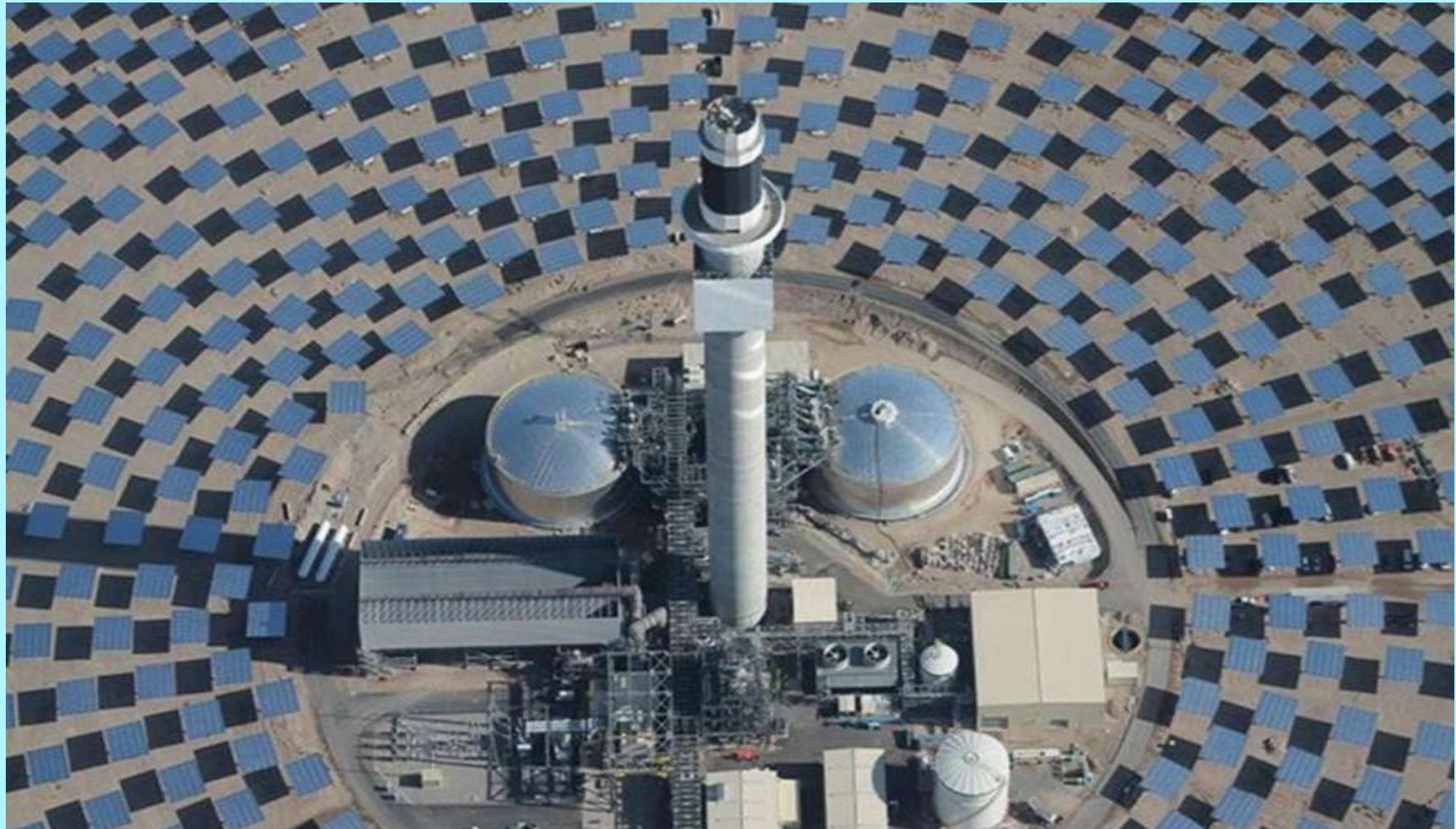
Solar Wind Energy Down Draft Tower



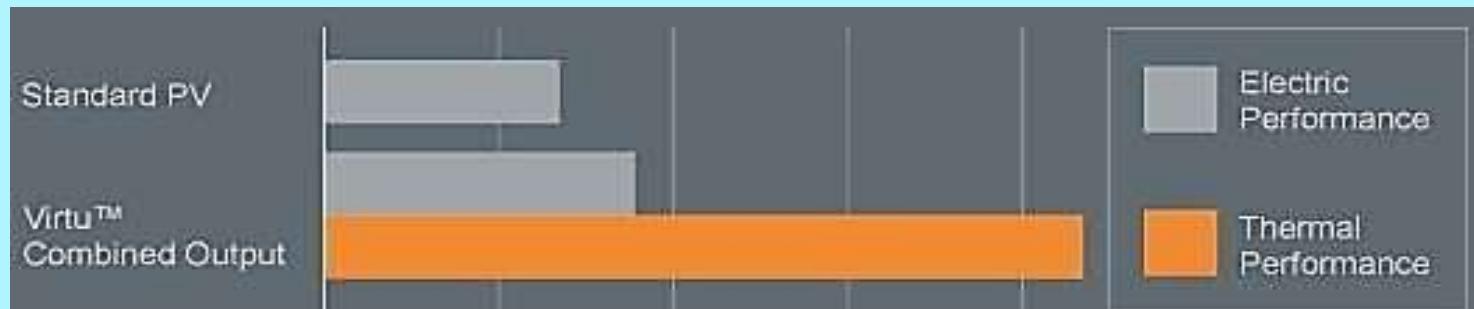
Concentrated Solar Power Tower



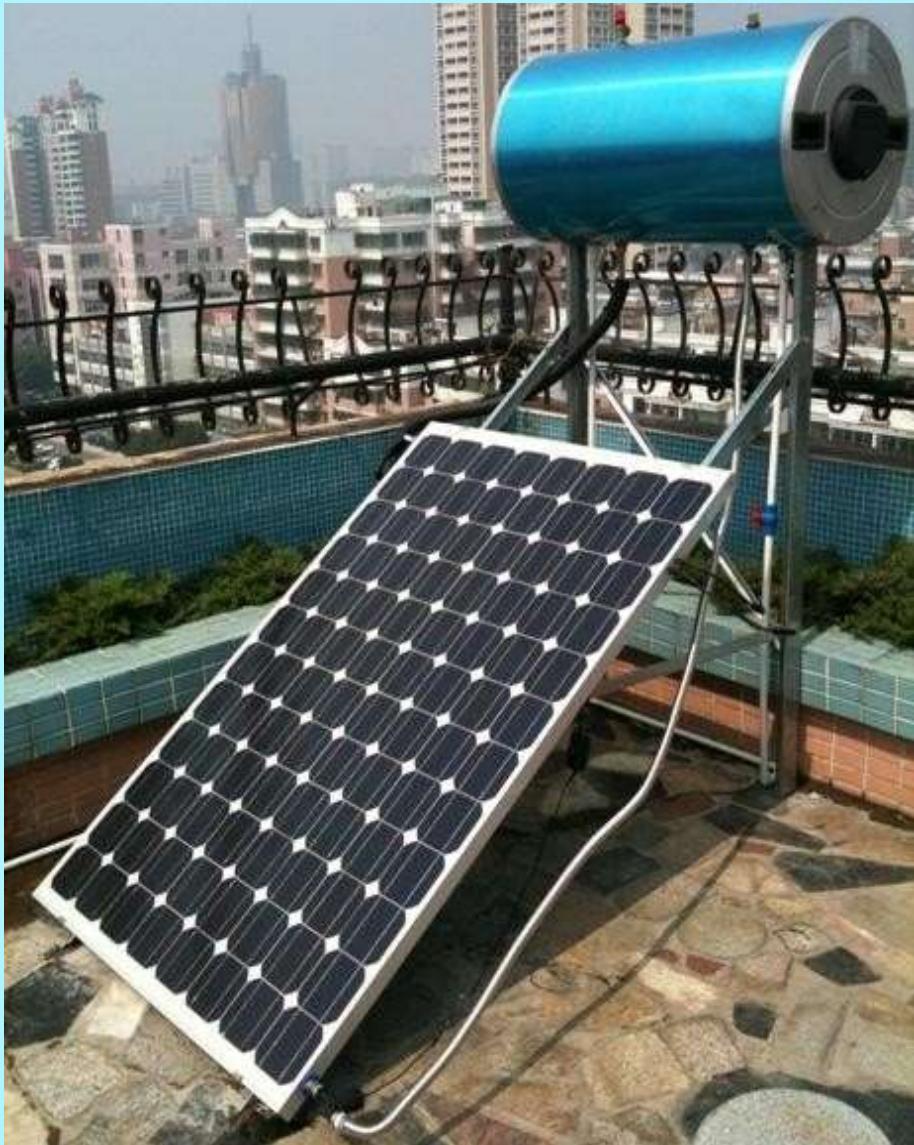
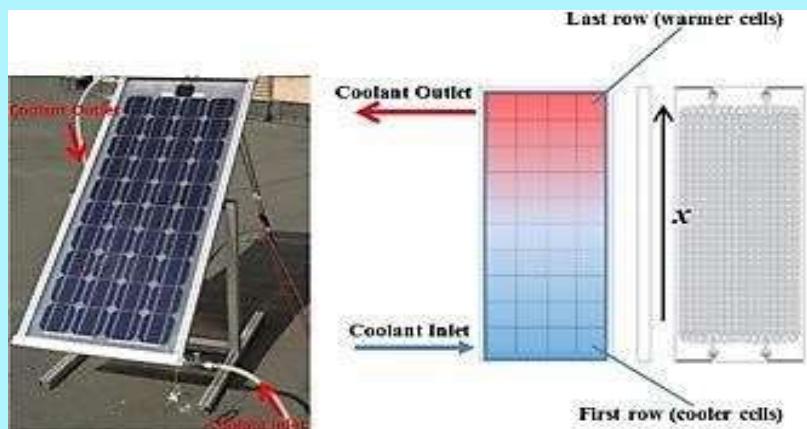
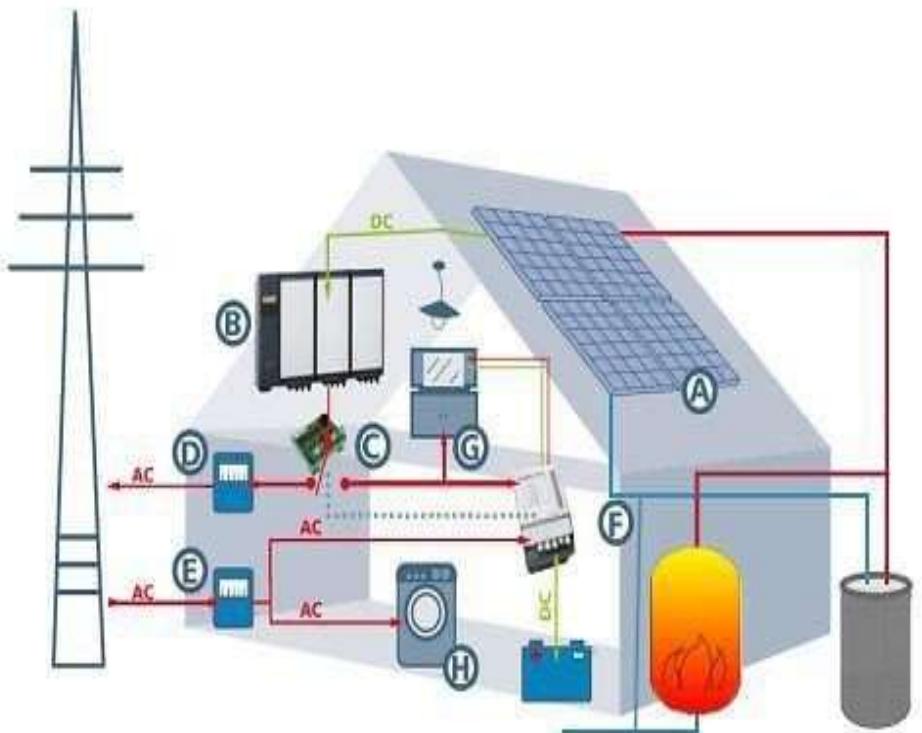
Concentrated Solar Power Tower



Evacuated Tube for Hot Water & Electricity



Photovoltaic with Thermal



How much of Solar Energy is converted into Electrical Energy in Photovoltaic Cells?

The *energy conversion efficiency* is a measure of how much of the solar energy is converted into electrical energy. The calculation for the energy conversion factor is,

$$\eta = (P_m / (E * A)) * 100$$

Where,

η = Energy conversion factor, percent.

P_m = Maximum power output, watts.

E = Solar energy, insolation, watts per square meter.

A = Area of the solar cell, square meters.

For example, what is the energy conversion efficiency of a 175-watt solar panel that measures 0.75×1.50 meters, if the solar insolation is $1,000 \text{ W/m}^2$?

Since the area of the solar cell is $0.75 * 1.50 = 1.125 \text{ m}^2$, the efficiency is,

$$\eta = (175 / (1.125 * 1,000)) * 100$$

$$\eta = 15.6\%.$$

This particular unit converts 15.6% of the available solar energy into electrical energy.

Thank You