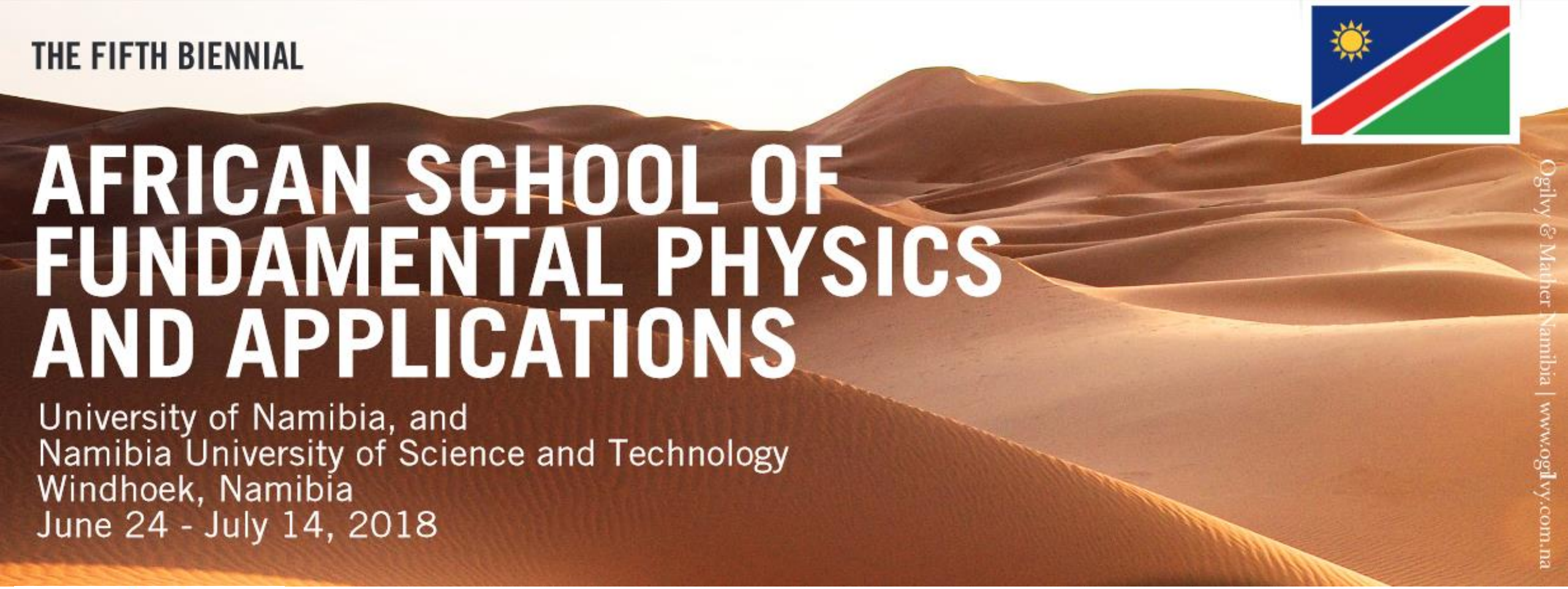

SOLAR ENERGY

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ASP

Outline

- Source
- Characterisation
- Measurement
- Applications

What is Solar Energy?

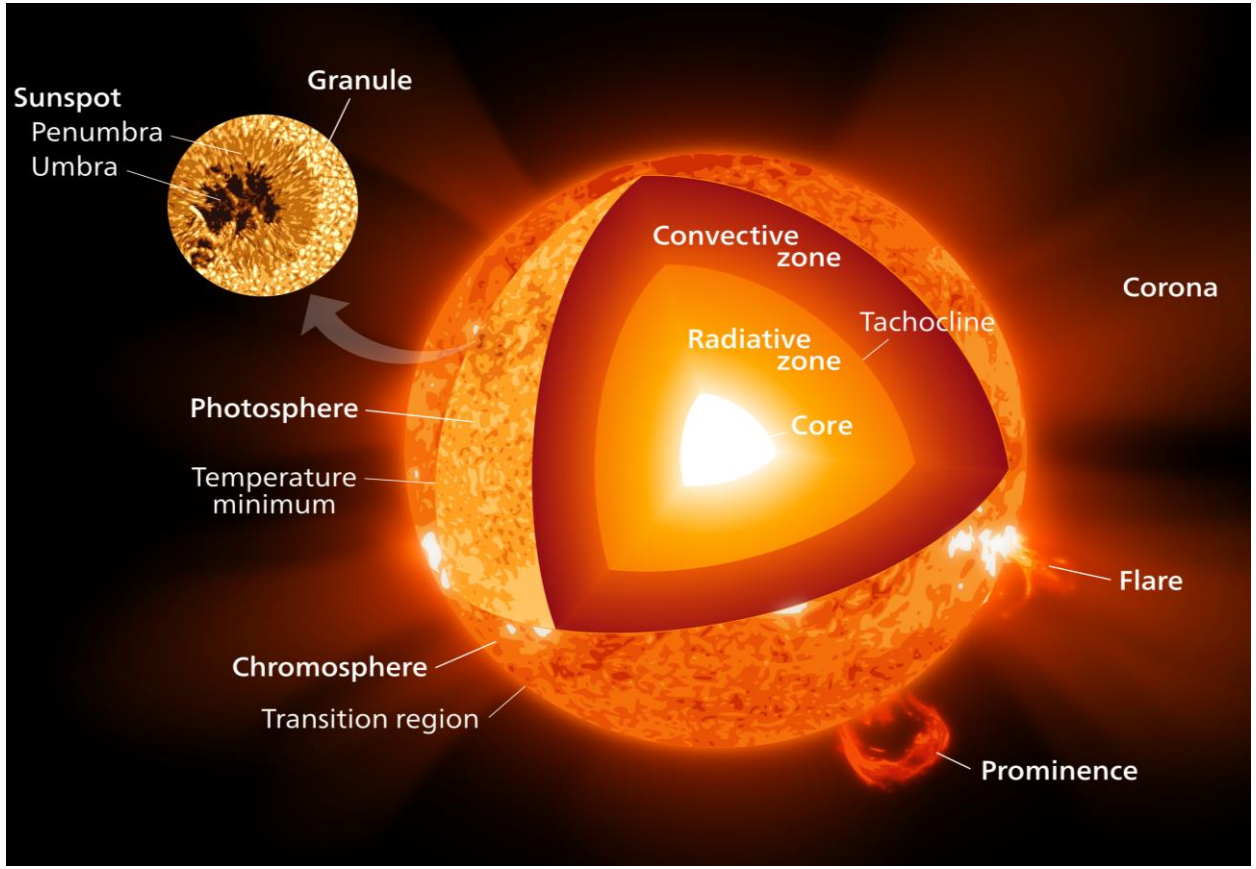
- ❑ Comes from
  - Thermal nuclear fusion reactions
- ❑ Spans entire e/m radiation
- ❑ Has powered life on earth for millions of years

The sun

- Hot sphere of gaseous matter
  - Temperature $\approx 15 \times 10^{6}$ K
  - Diameter $\approx 1.39 \times 10^{6}$ km
  - Mass $\approx 2.0 \times 10^{30}$ kg
- Composed of
  - Hydrogen (74 %)
  - Helium (25 %)
  - Other elements (1 %)

The sun…

- Exterior layer (Solar atmosphere)
  - Photosphere
    - Most stable
    - Coolest layer
    - Visible part of sun as disc
  - Chromosphere
    - Higher temperature than photosphere
    - Lower density
  - Corona
    - Significant source of x-rays



Source: Universe today: Space and astronomy news, https://www.universetoday.com/40631/parts-of-the-sun/

- Interior layer
  - Core
  - Radiative layer
    - Lower temperature
    - Radiation less significant
  - Convective layer
    - Binds energy produced in core
    - Has insulating effects

Solar radiation

- Energy of a photon is given by

$$E = h\nu = \frac{hc}{\lambda}$$

- Solar spectral distribution:
  - Spectral power density, $P(\lambda)$- Incident power of solar radiation per unit area per unit length
    - Units- $\mathrm{Wm^{-2}m^{-1}}$
  - Spectral Photon flux, $\Phi(\lambda)$ —number of photons per unit area per unit time per unit wavelength

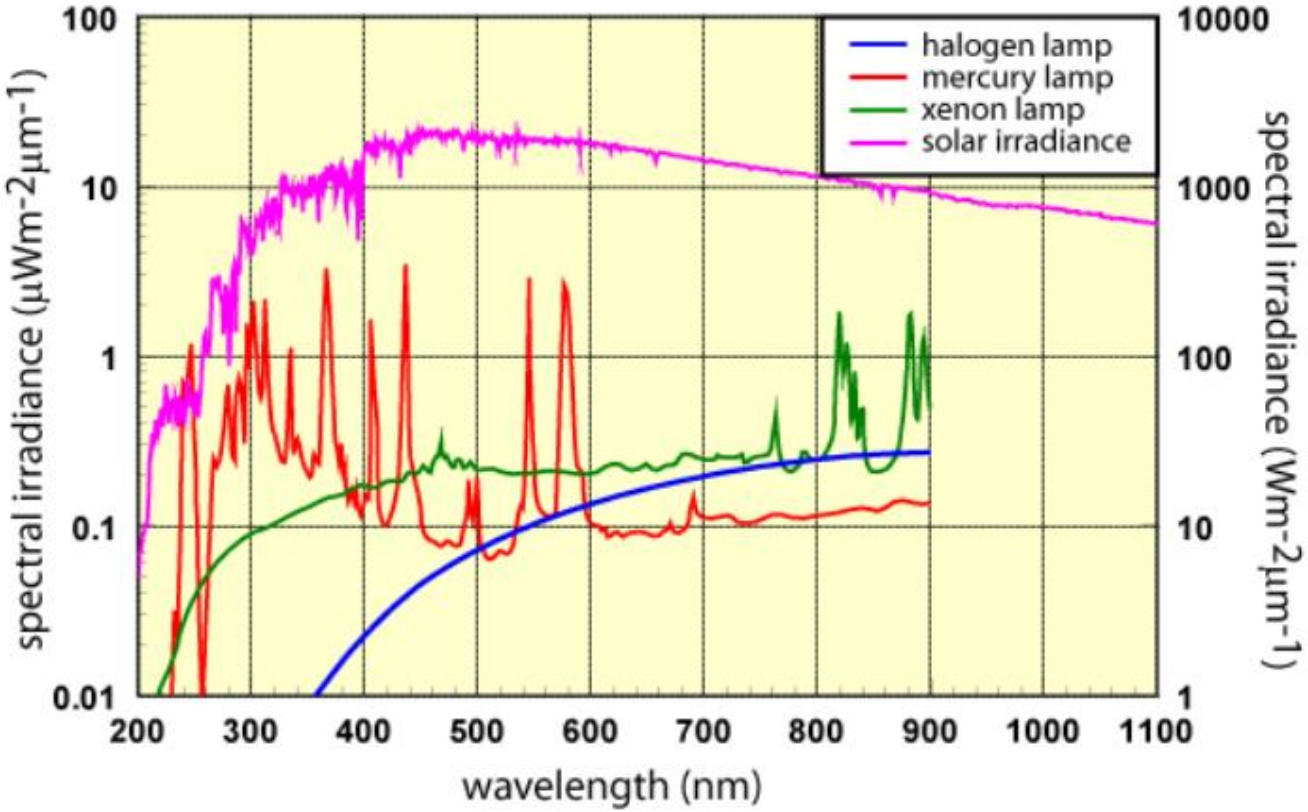
$$\Phi(\lambda) = P(\lambda)\left(\frac{\lambda}{hc}\right)$$

  - Irradiance $I(\mathrm{Wm^{-2}})$- total power from a radiant source per unit area

Spectral Irradiance

Power density at a particular wavelength is the spectral irradiance, I_λ

$$I_\lambda = \frac{\Phi}{\Delta\lambda}\left(\frac{hc}{\lambda}\right)$$



Spectral irradiance for artificial sources (left scale) compared to the sun (right scale). Source: *https://www.pveducation.org/*

Blackbody radiation

Radiates depending on temperature

Absorbs all radiation incident on it

Planck's law of Black body radiation

$$I(\lambda) = \frac{2\pi c^2 h}{\lambda^5}\left(\frac{1}{e^{\frac{hc}{\lambda k_B T}} - 1}\right)$$

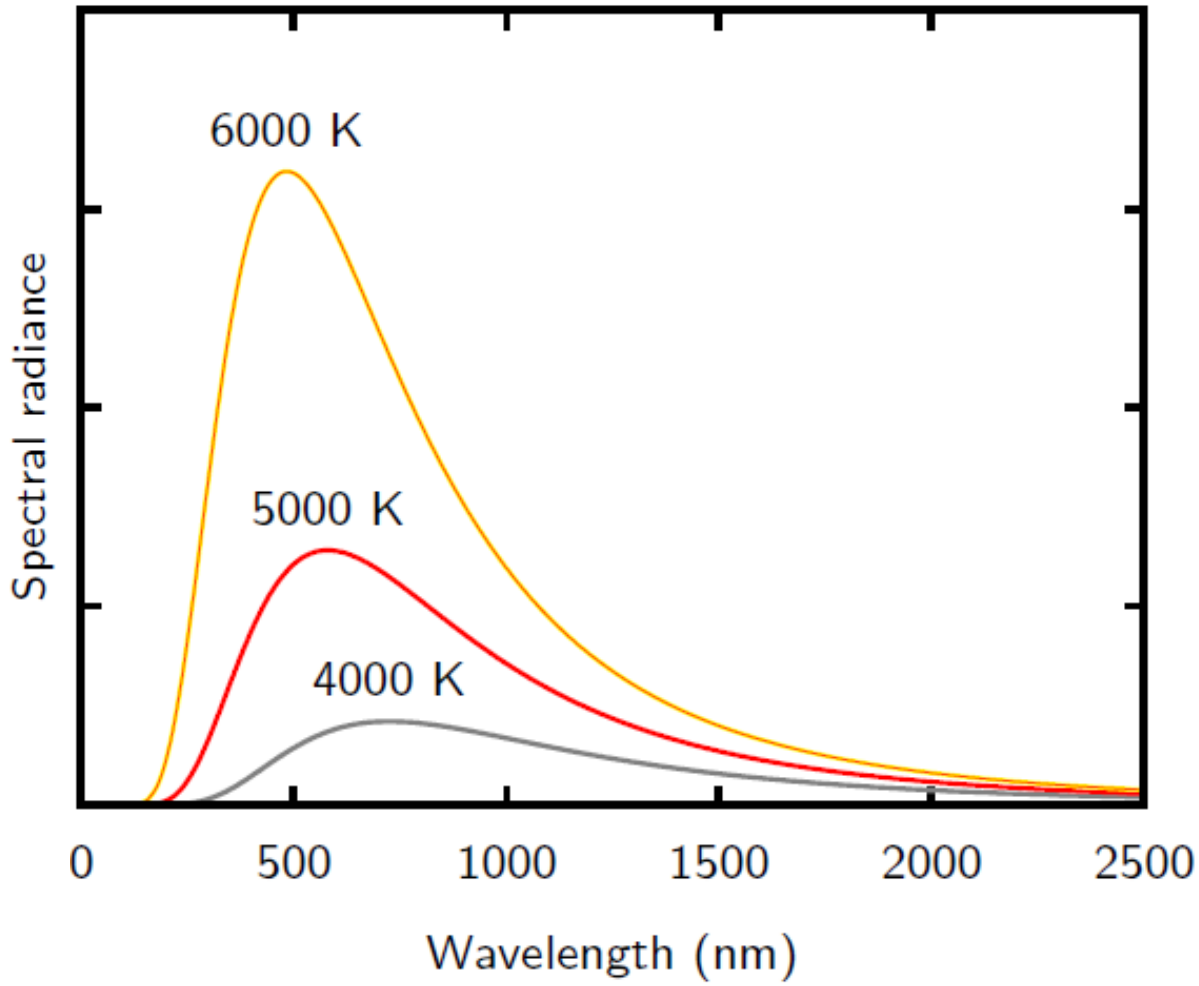
Stefan-Boltzmann law

$$E_{rad}(\lambda) = \sigma T^4$$

σ=5.67 × 10 $^{-8}$ $Wm^{-2}K^{-4}$

Wien's displacement law:

$$\lambda_{max} T = 2.9 \times 10^{-3}\ \text{mK}$$



Solar spectrum

Sun approximates black body at $T \approx 5800$ K

$\Longrightarrow$ emits $6.42 \times 10^{7}\ Wm^{-2}$

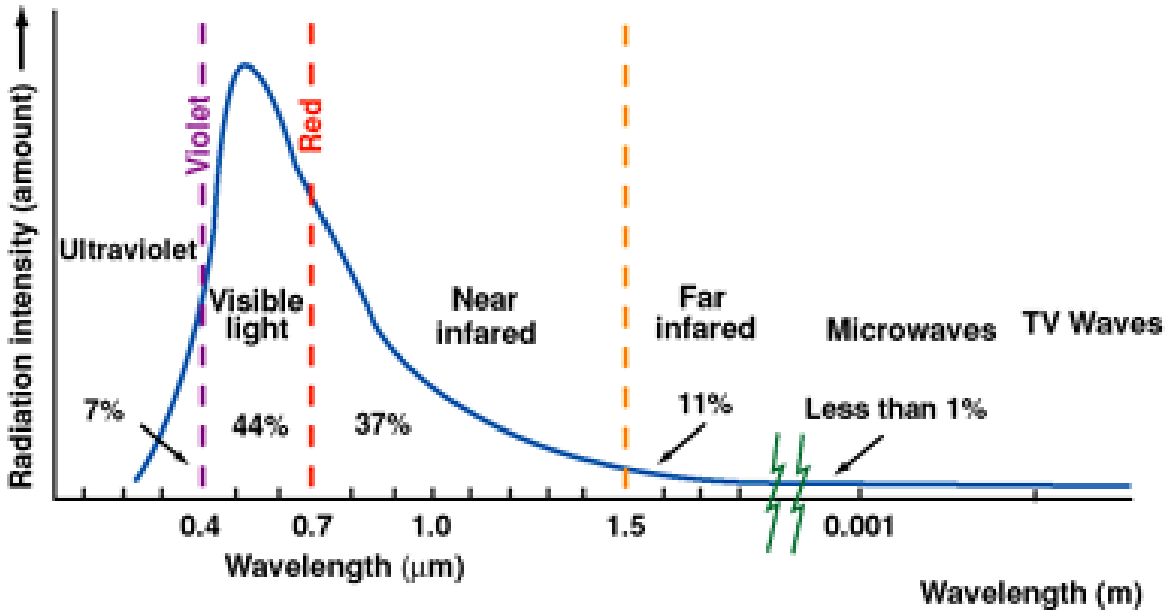
- Given

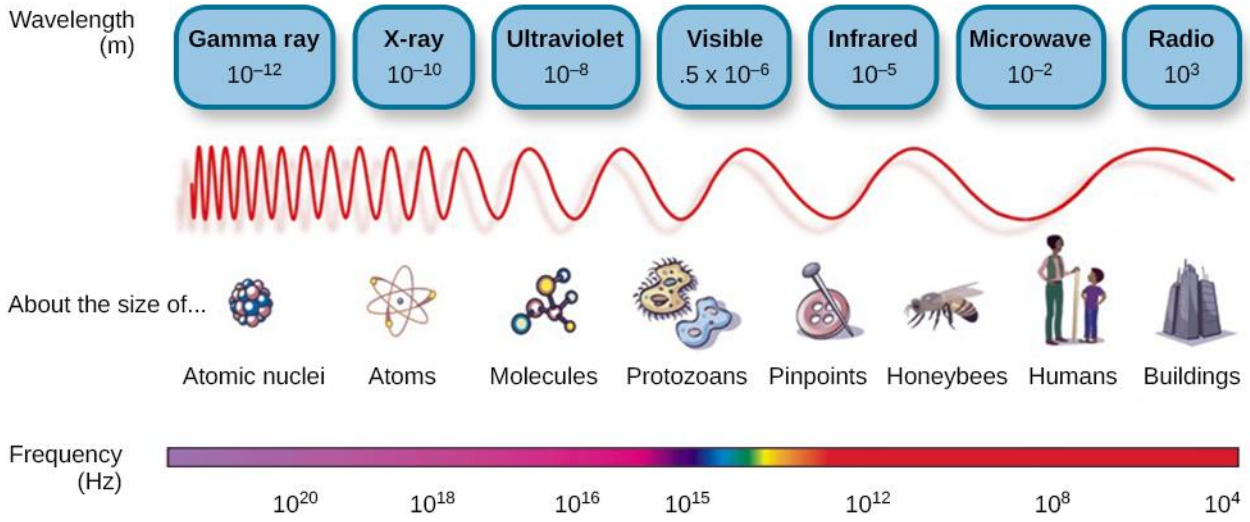
  $R_s = 6.96 \times 10^{5}$ km,

  $d_{s-e} = 1.496 \times 10^{8}$ km

Solar radiation arriving at earth's outer atmosphere $\approx 1389\ \mathrm{Wm}^2$

- Currently accepted value $\approx 1361\ \mathrm{Wm}^2$
- Covers whole spectrum

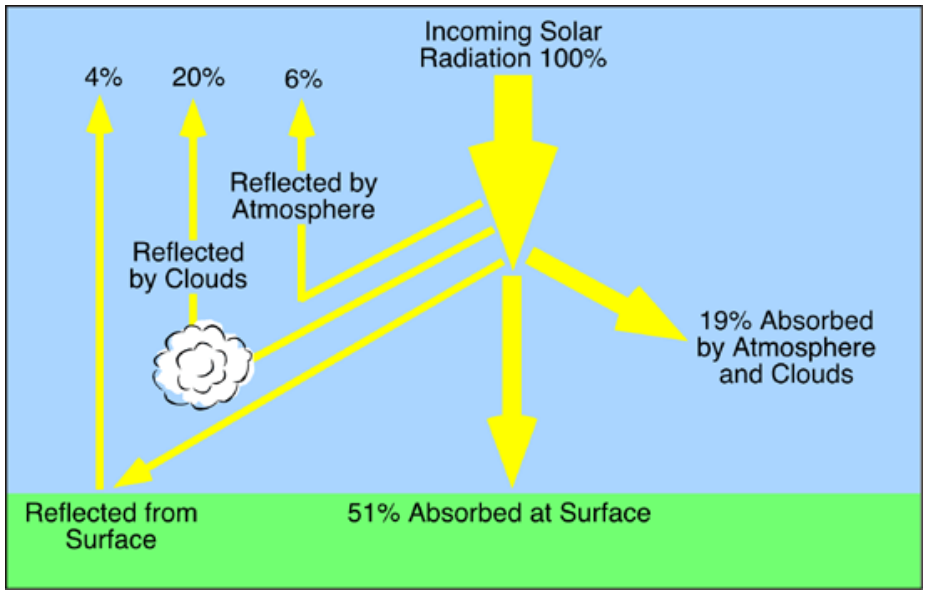


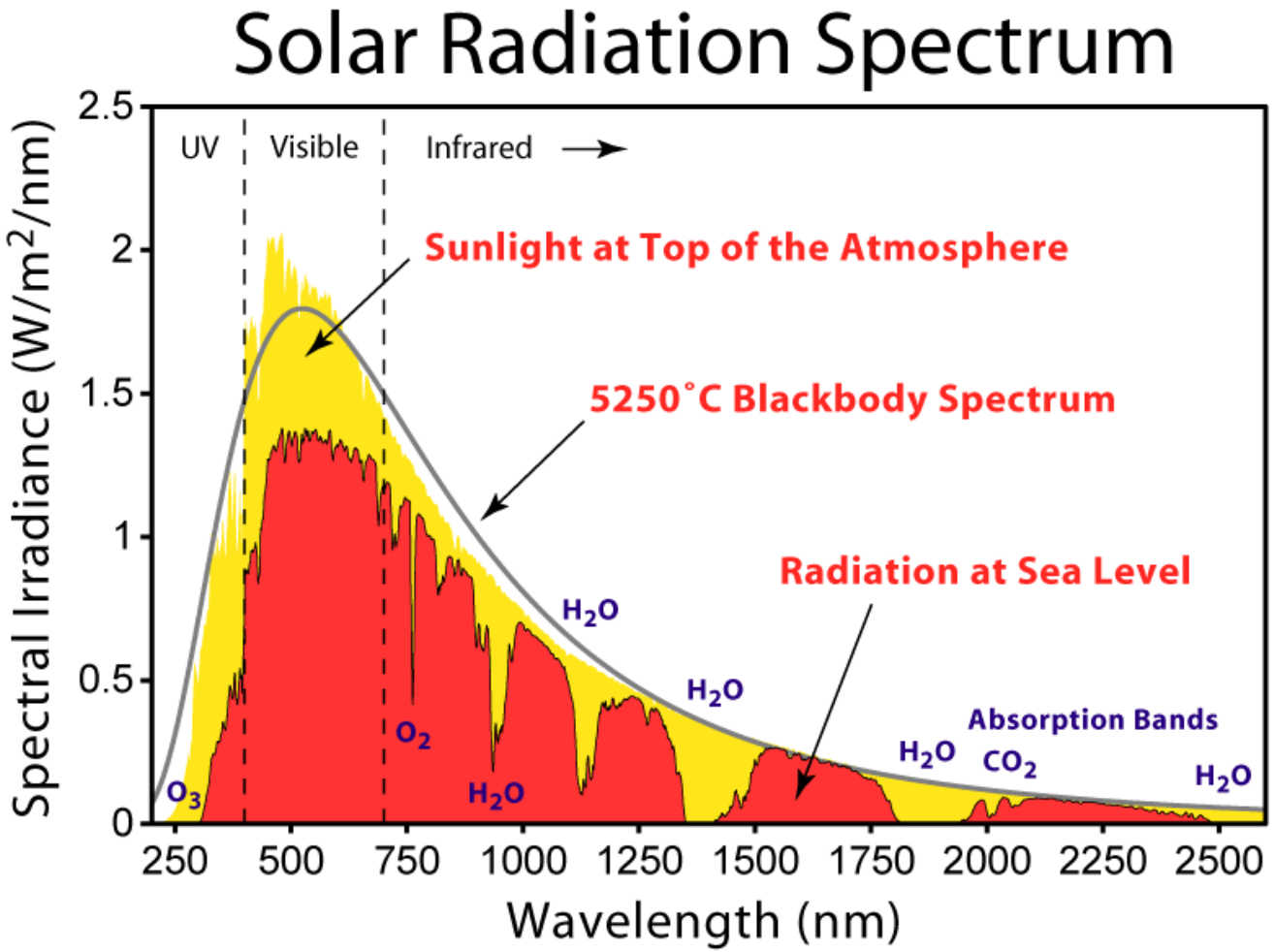


Solar radiation

- Radiation attenuated as it traverses earth's atmosphere
  - Scattering
  - Absorption
  - Reflection

by atmospheric components





Optical Air mass

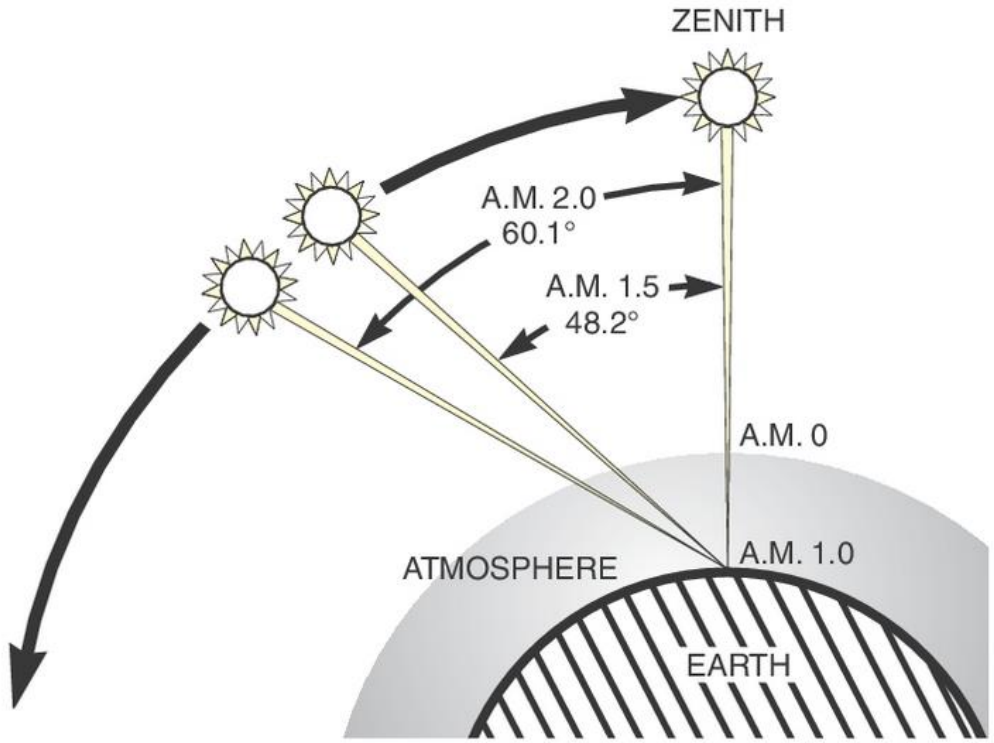
Under clear sky conditions, irradiance on earth's surface determined by distance light travels through atmosphere

Shortest distance occurs when sun is directly overhead (at zenith)

- Ratio of actual path length of sunlight to this minimal distance is the optical air mass

$$AM = \frac{1}{\cos\theta}$$

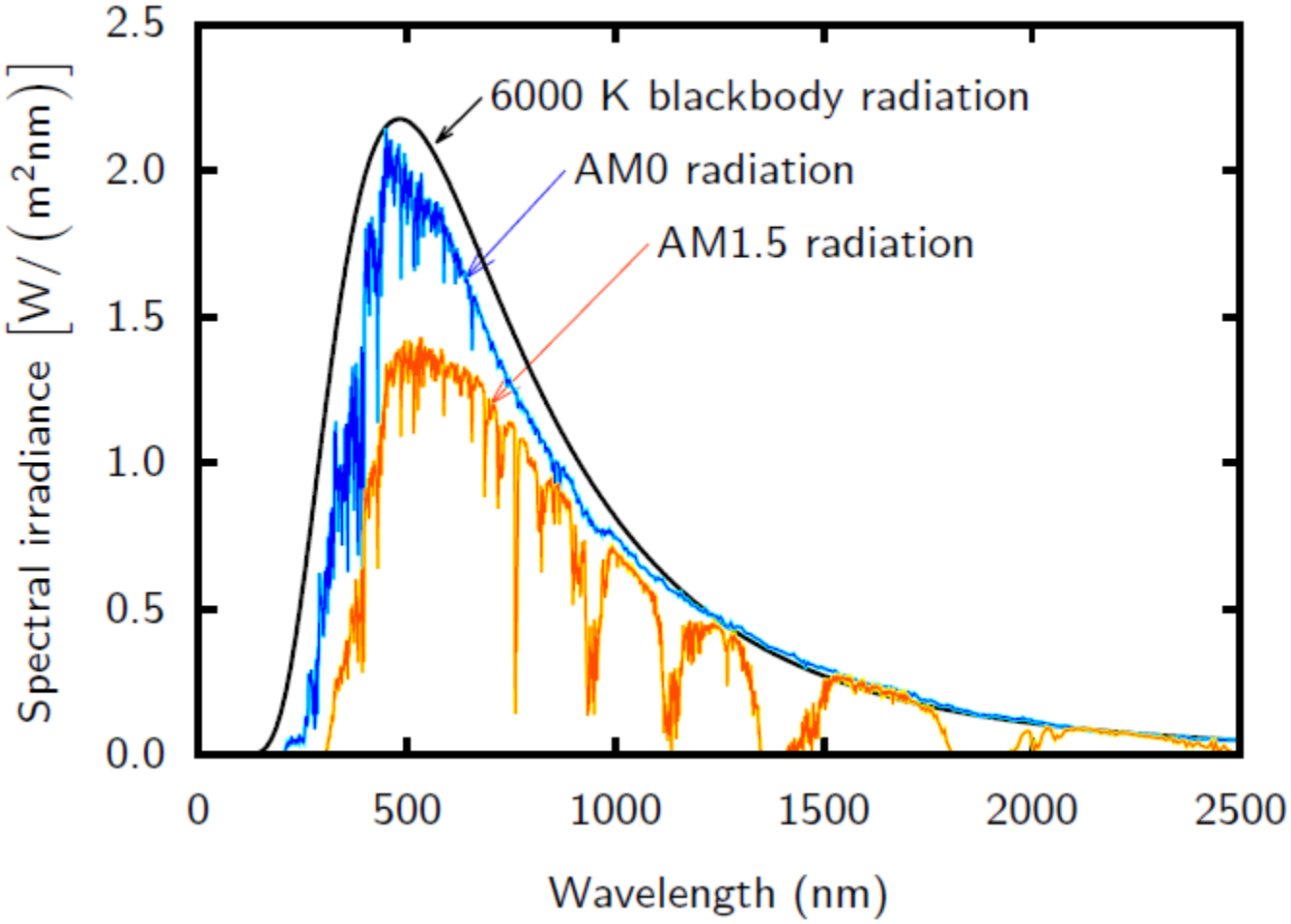
θ=position of sun w.r.t to zenith



Air mass …

- Spectrum outside earth's atmosphere is called Air mass zero (AM0)
  - Irradiance at $AM0 = 1361\ \mathrm{Wm}^2$

- Widely used standard for comparing solar cell performance is AM1.5 spectrum, normalised to a total irradiance of $1000\ \mathrm{Wm}^{-2}$



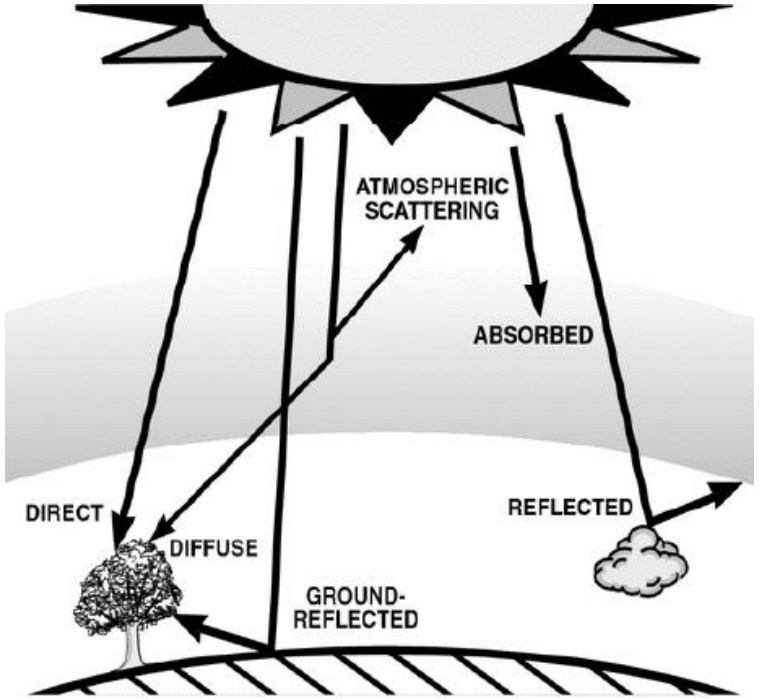
Solar radiation…

Spectral content at earth's surface has

- ***direct*** component -part of the sunlight that directly reaches the earth's surface.
- Diffuse (indirect) component due to scattering and reflection in atmosphere and surrounding landscape

Air mass thus further defined by whether or not, measured spectrum includes diffuse component

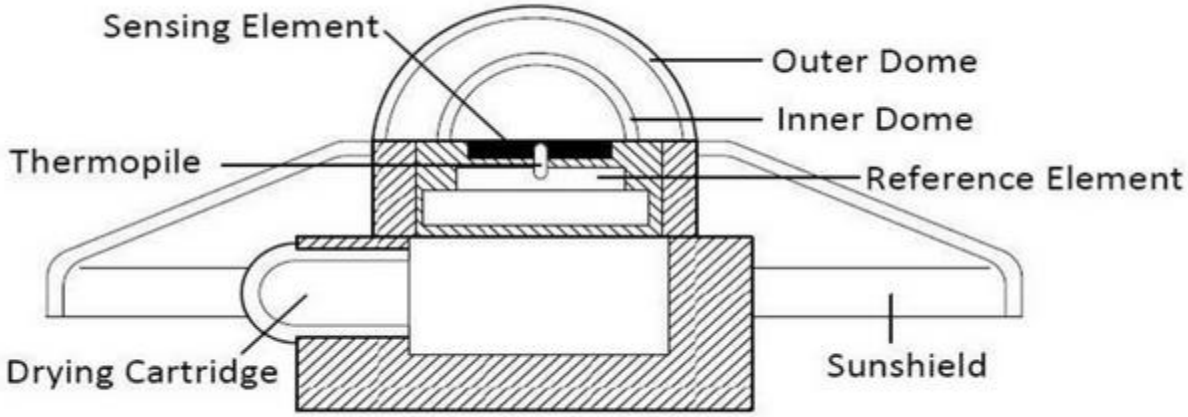
- AM1.5g
- AM1.5d



Solar radiation measurement

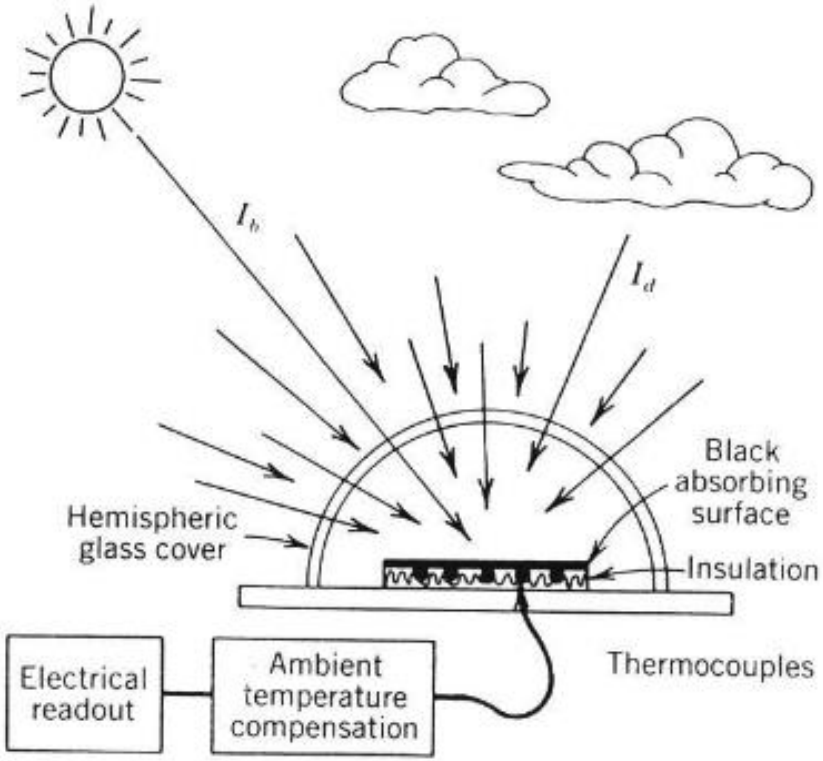
- Pyranometer:
  - Primary instrument for measuring global solar radiation
  - Measures solar energy from all directions in hemisphere above plane of instrument

- Most common pyranometers use thermopile principle

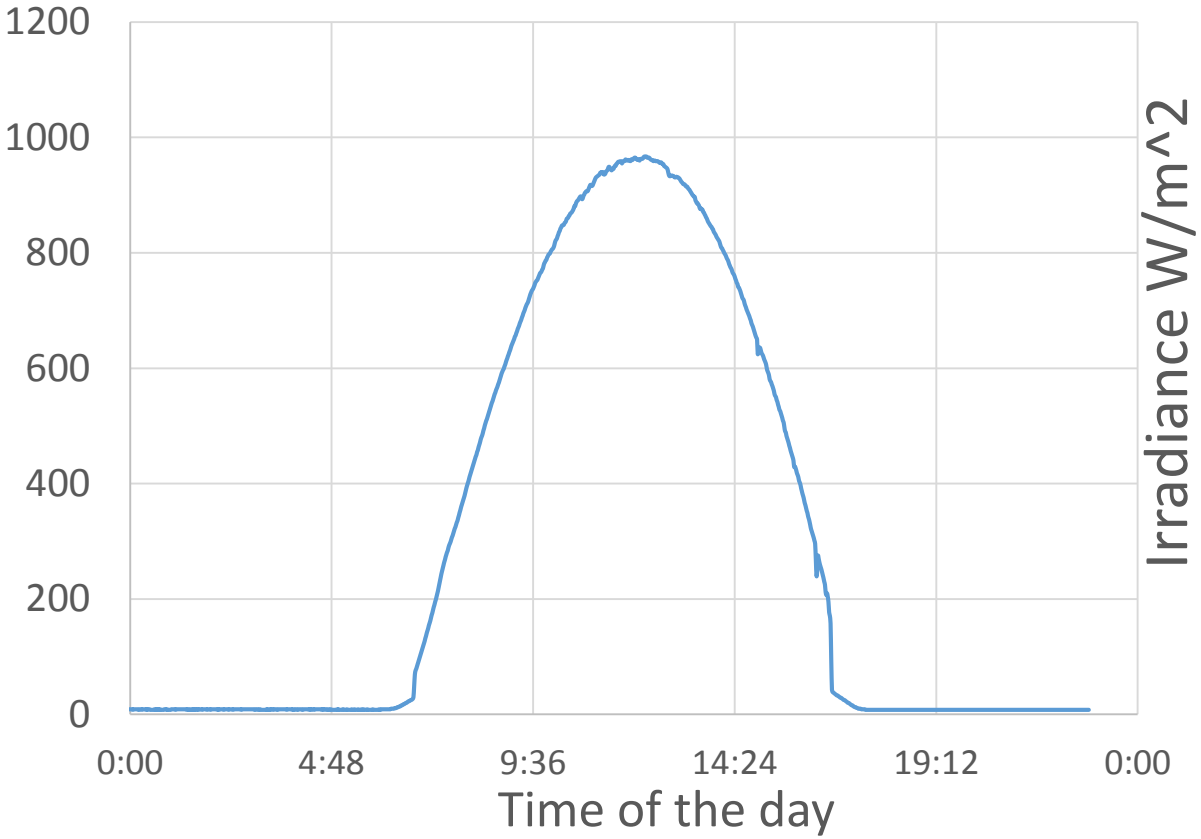


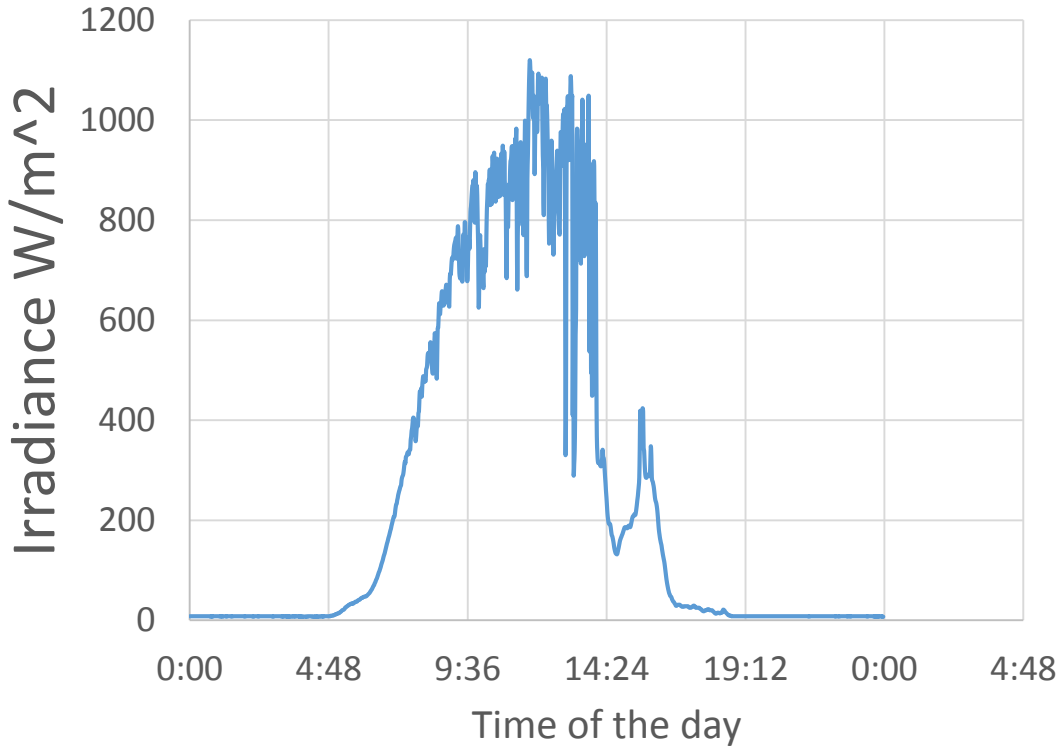
Solar radiation measurement…

- Thermopile principle
  - Multiple thermocouples connected in series
  - Attached to blackened absorbing surface
  - Absorbing surface shielded from convective loss and insulated against conductive loss
- Under the sun, surface attains a temperature proportional to amount of radiant energy falling on it.
- Temperature is measured and converted into a readout of the global solar irradiance falling on the absorbing surface through accurate calibration



Solar radiation measurement…





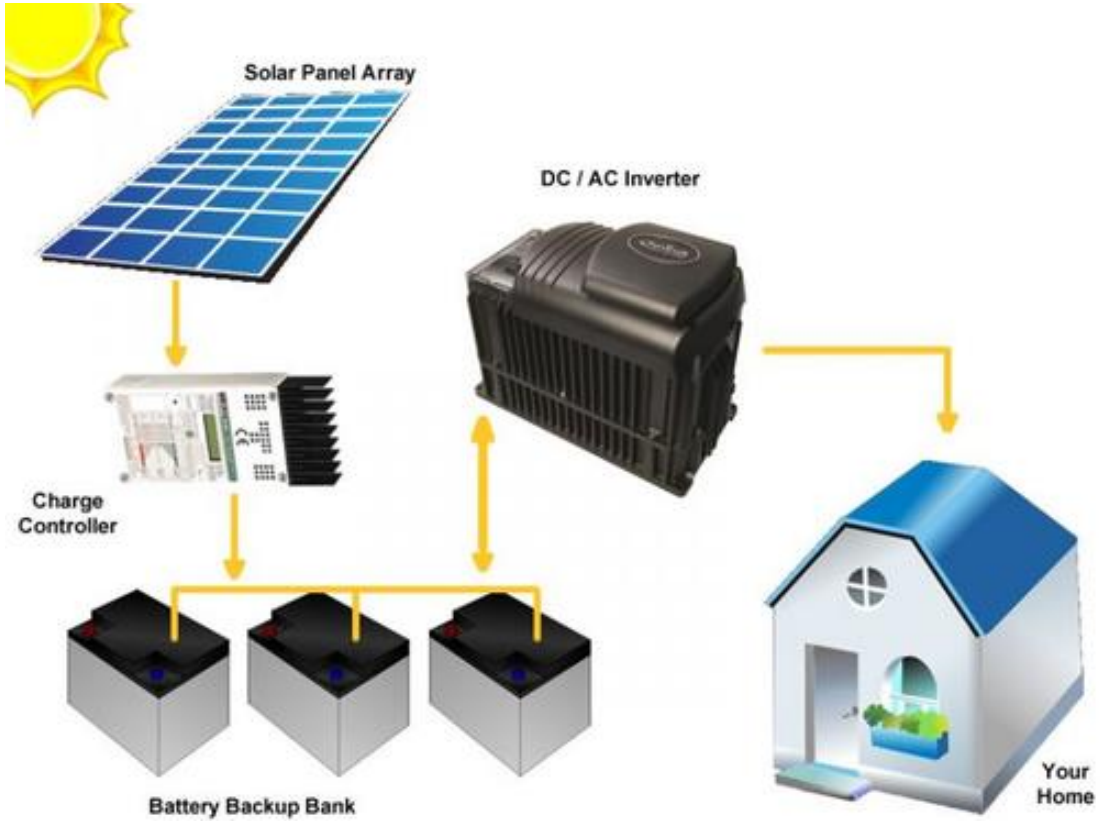
Typical measurements in Windhoek for a clear (Left) and Cloudy (Right) day

Solar radiation measurement…

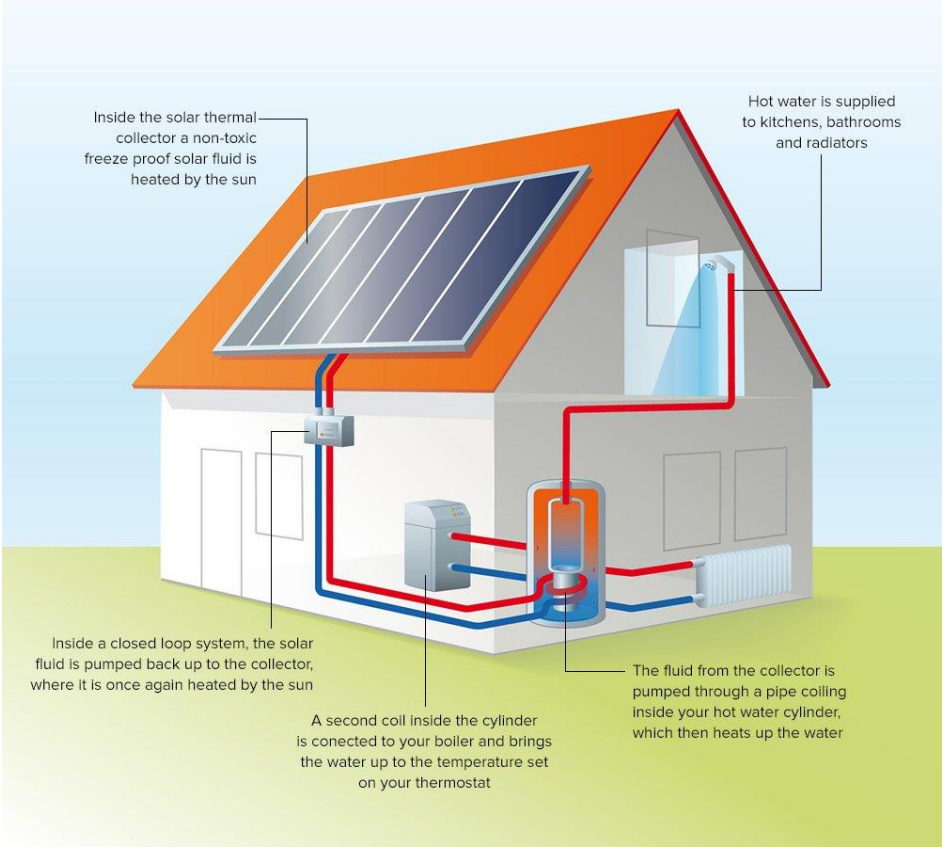
- Pyrheliometer:-
  - Used to measure direct solar radiation
  - Used with a sun tracker to keep instrument aimed at sun

Solar Energy applications

- Utilised through two main routes
  - Solar photovoltaics
    - Direct electricity generation

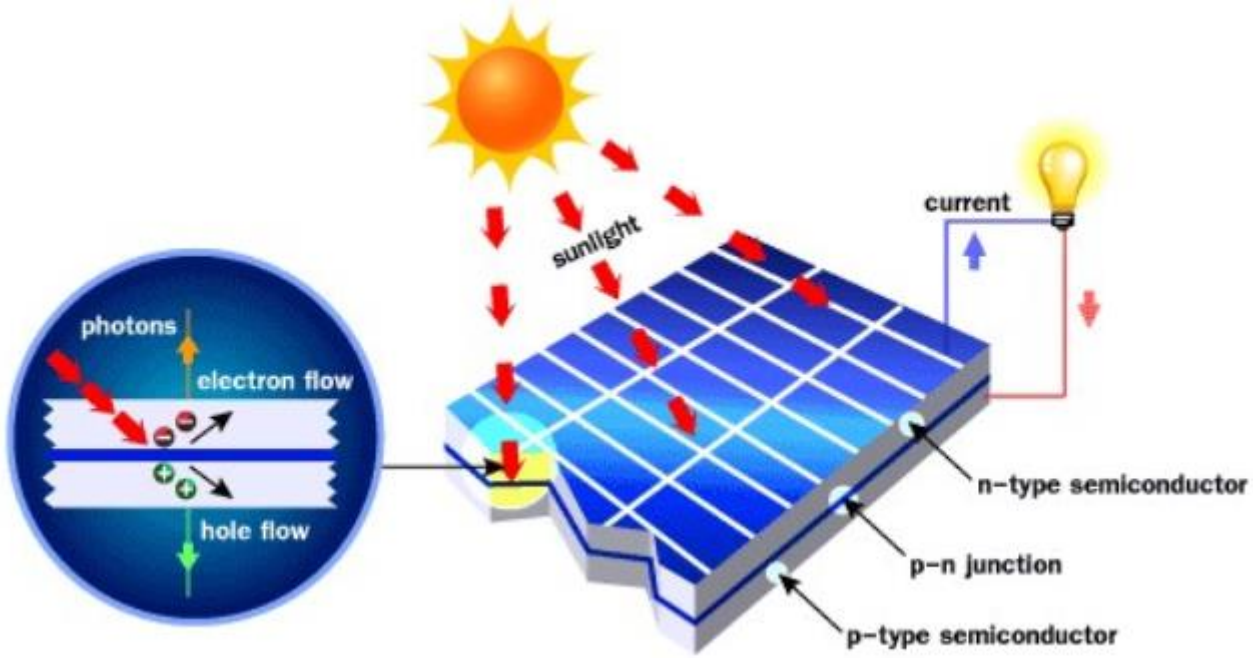


  - Solar thermal
    - Direct heating, drying, cooking, power generation,…



Solar Photovoltaics

- Solar (photovoltaic) cell
  - basic building block of a PV system
  - directly converts light energy into electrical energy based on principals of photovoltaic effect

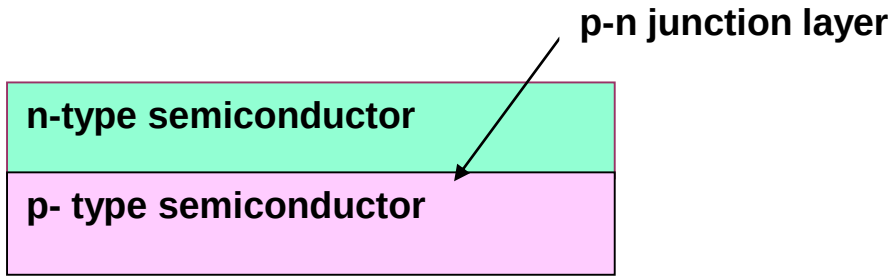


Solar Photovoltaics…

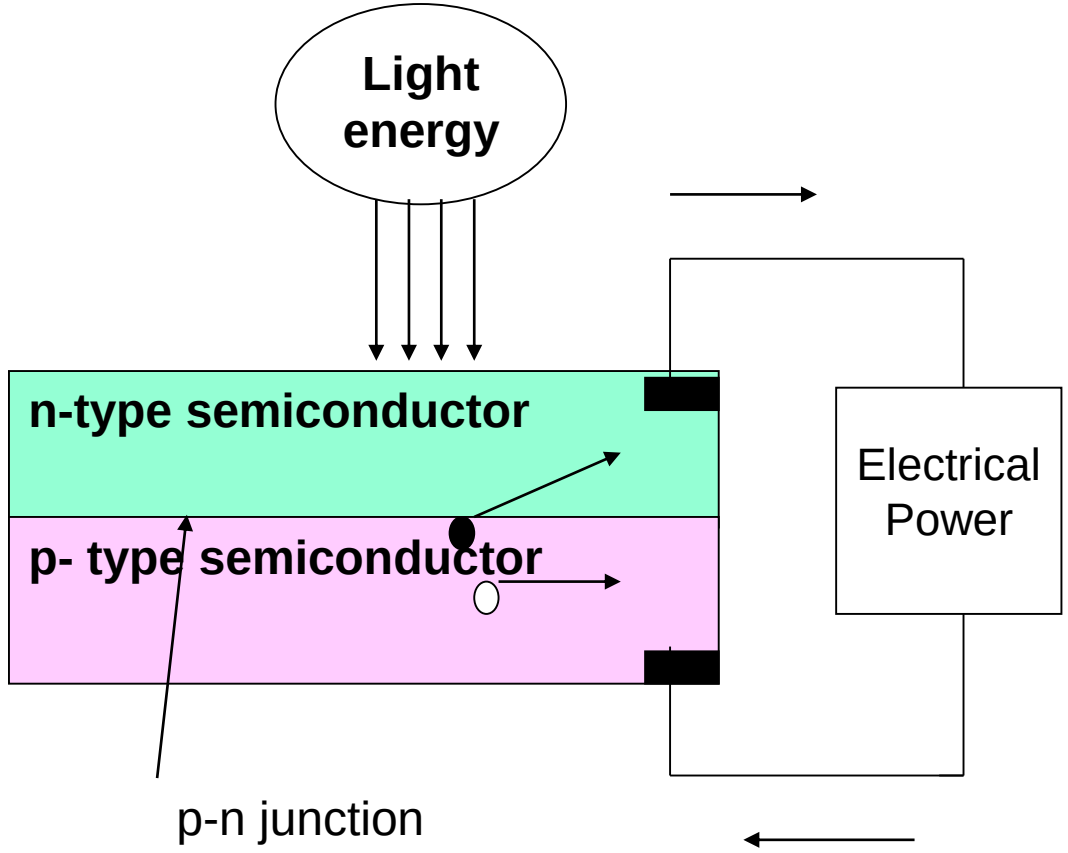
- Photovoltaic effect: Generation of direct current (DC) and voltage (electrical power) from materials (e.g. semiconductors) when illuminated by photons
- Majority of solar cells are currently produced using semiconductors
  - Semiconductors are materials, which behave as insulators at $T = 0\ K$ but become electrically conductive when $T \neq 0\ K$
  - Their electrical properties can be modified through doping
    - n-type
    - p-type

Solar Photovoltaics…

- Two differently doped semiconductors layers joined to form p-n junction

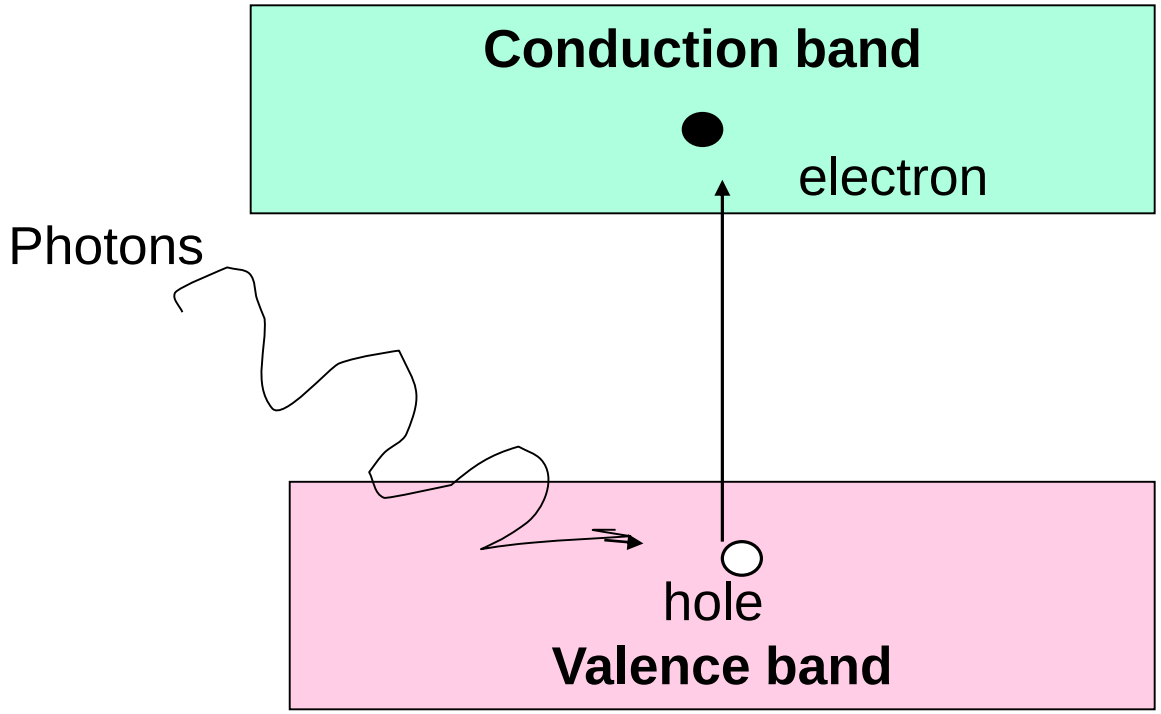


- Voltage is generated across p-n junction due to absorption of light energy



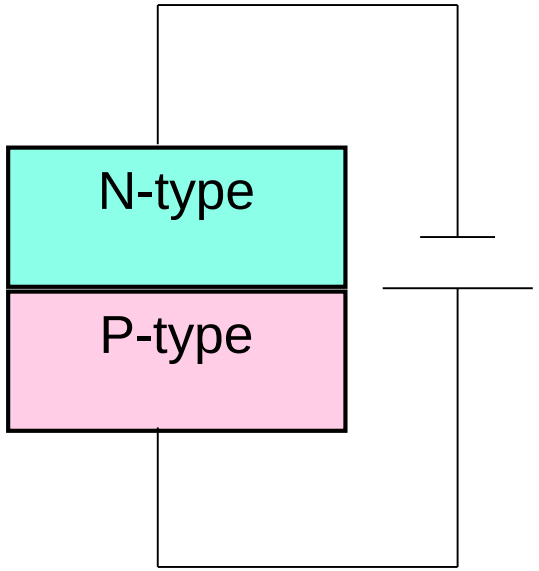
Solar Photovoltaics…

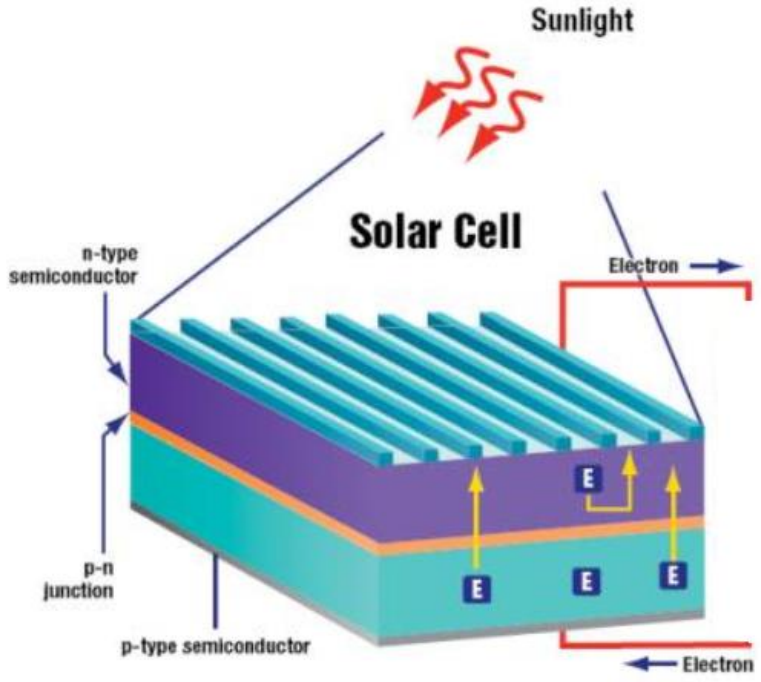
- Only photons whose energy is greater than the band gap of the semiconductor will be absorbed- hence converted into electrical energy



Solar Photovoltaics…

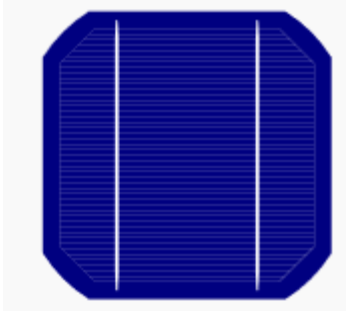
- Single solar cells consists of n-type layer sandwiched with p-type layer

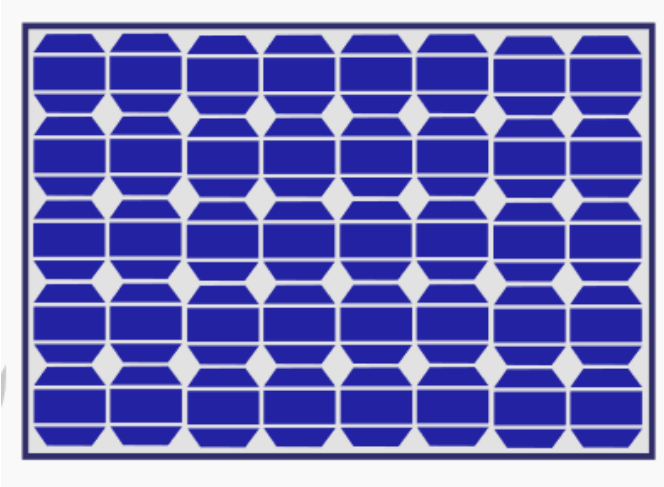


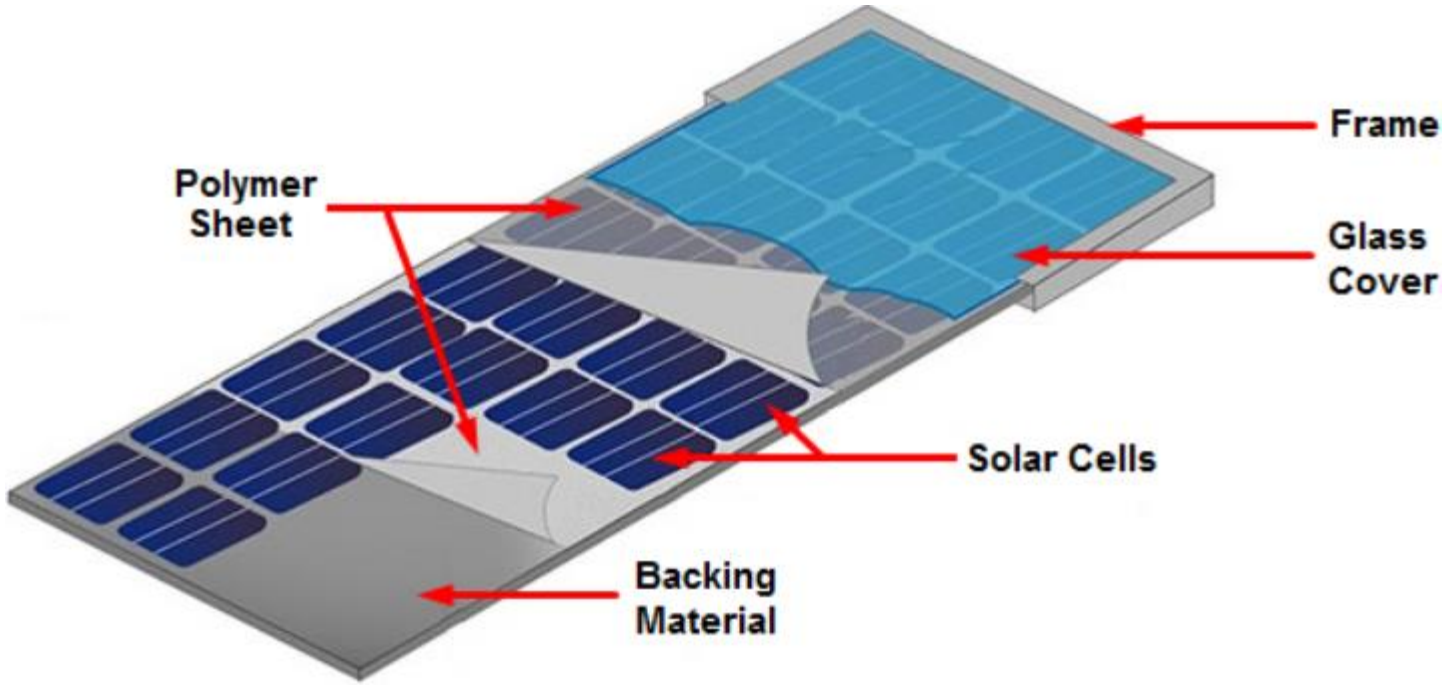


Solar Photovoltaics…

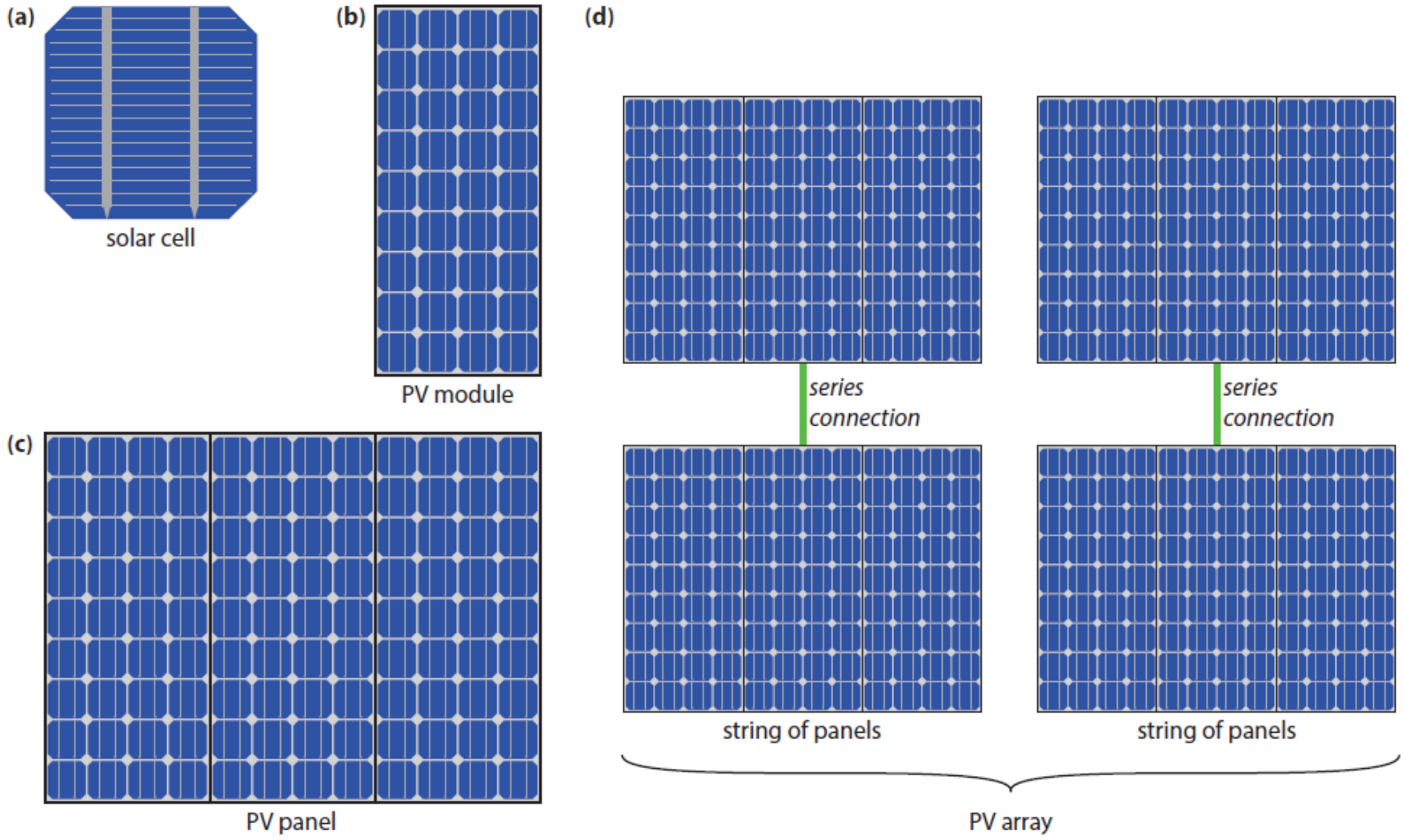
- Single solar cell produces only a tiny amount of voltage $\approx 0.5\ V$
- Many solar cells are interconnected in series or parallel to form a module with the required voltage and power







Modules are interconnected to form a panel or array

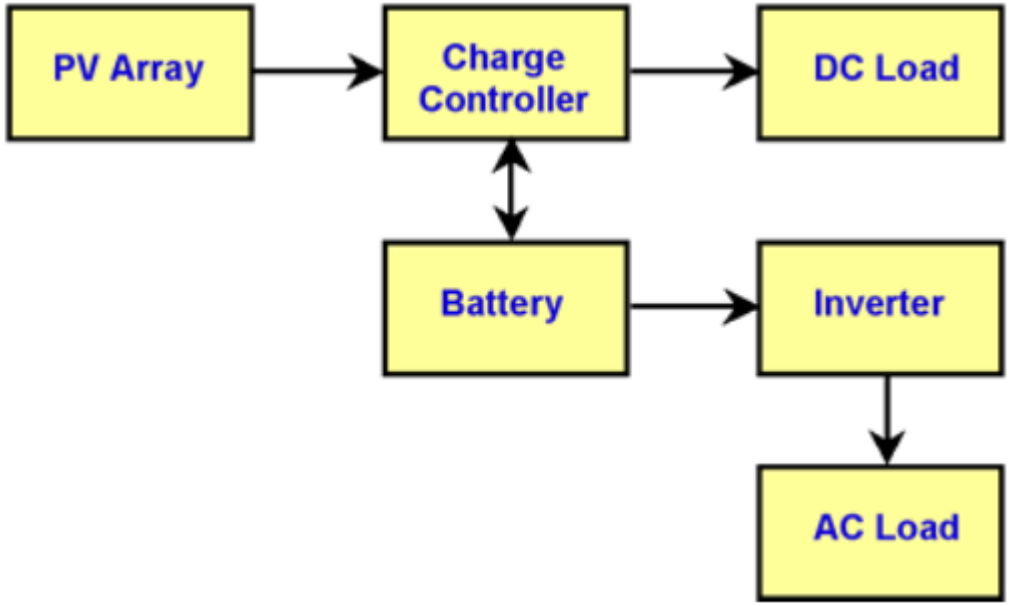


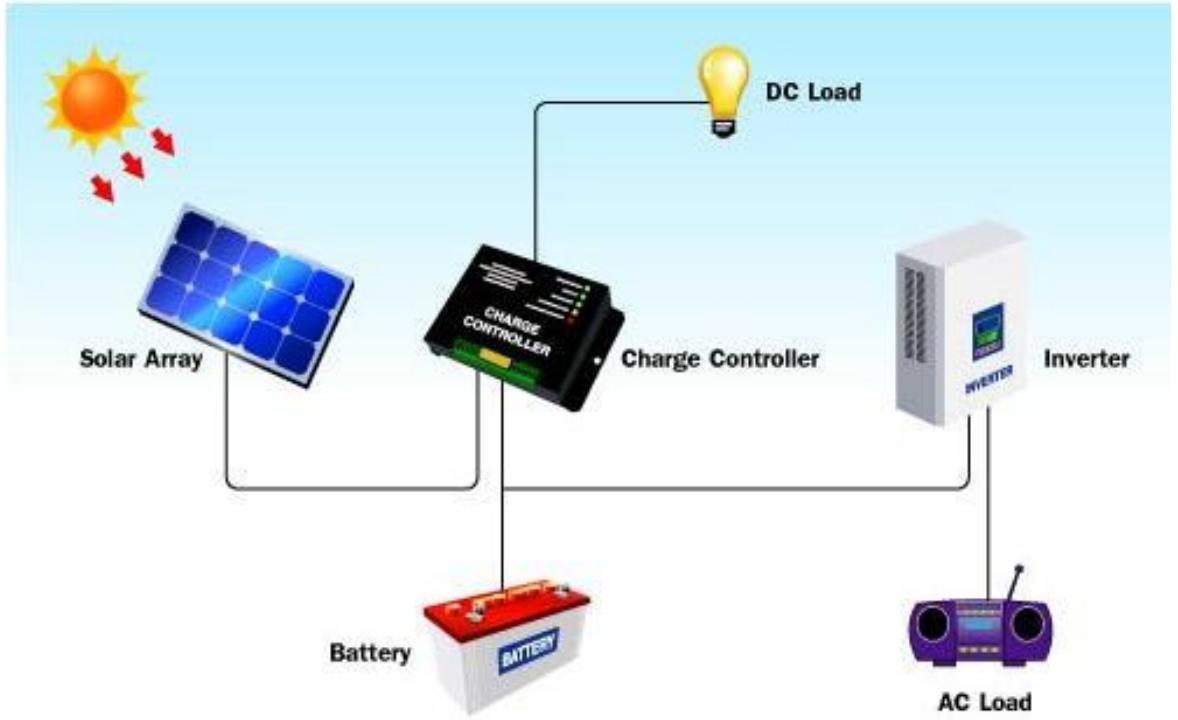
PV systems/components

- PV systems classified according to
  - Functional and operational requirements
  - Component configurations
  - Connection to electrical loads and or power sources
- Principal classifications
  - Stand alone PV systems
  - Grid-connected PV systems

PV systems/components

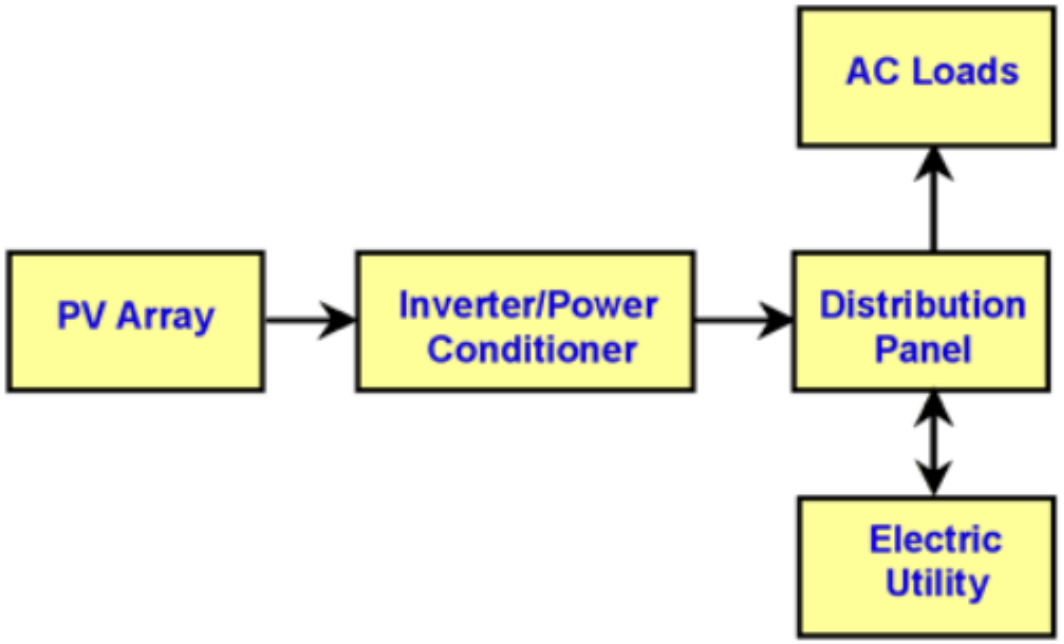
- Stand alone PV systems

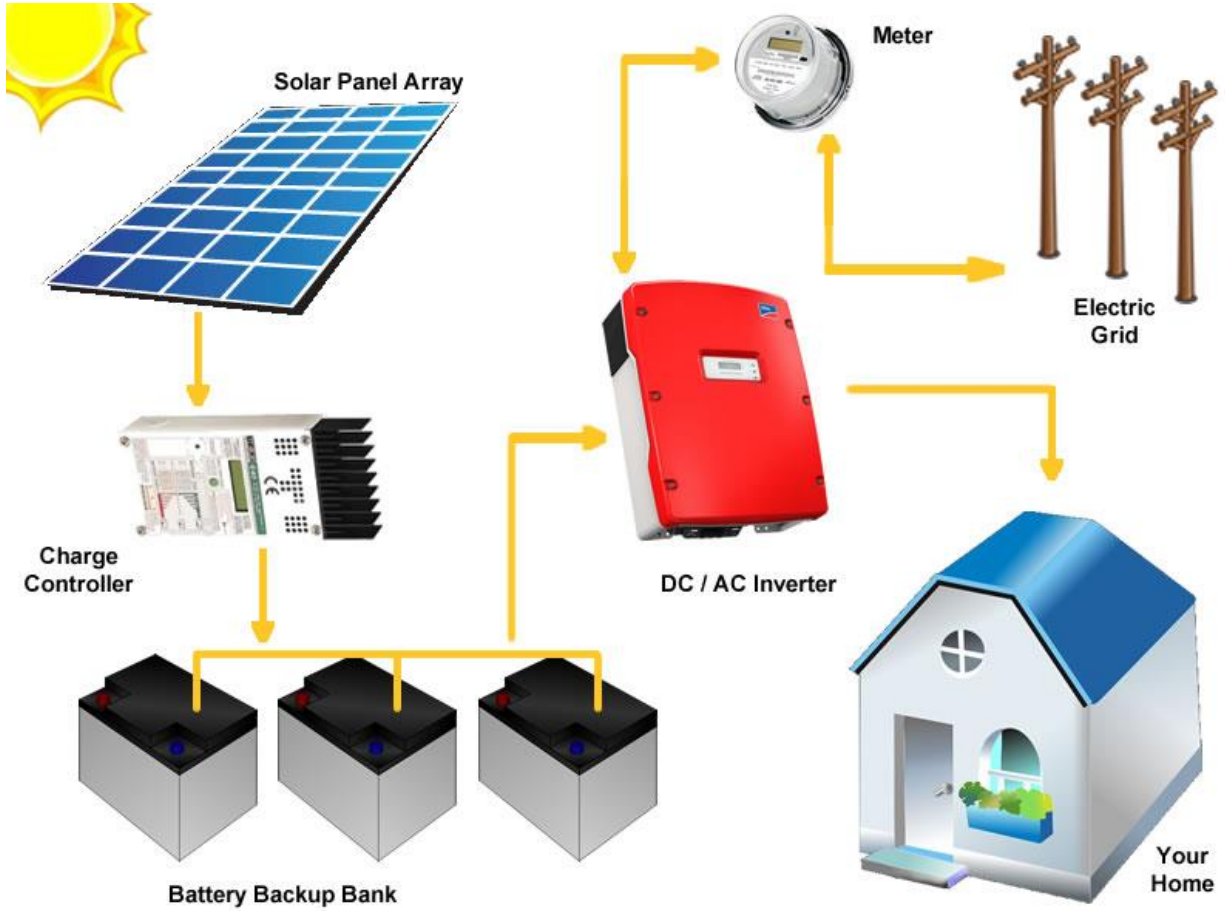




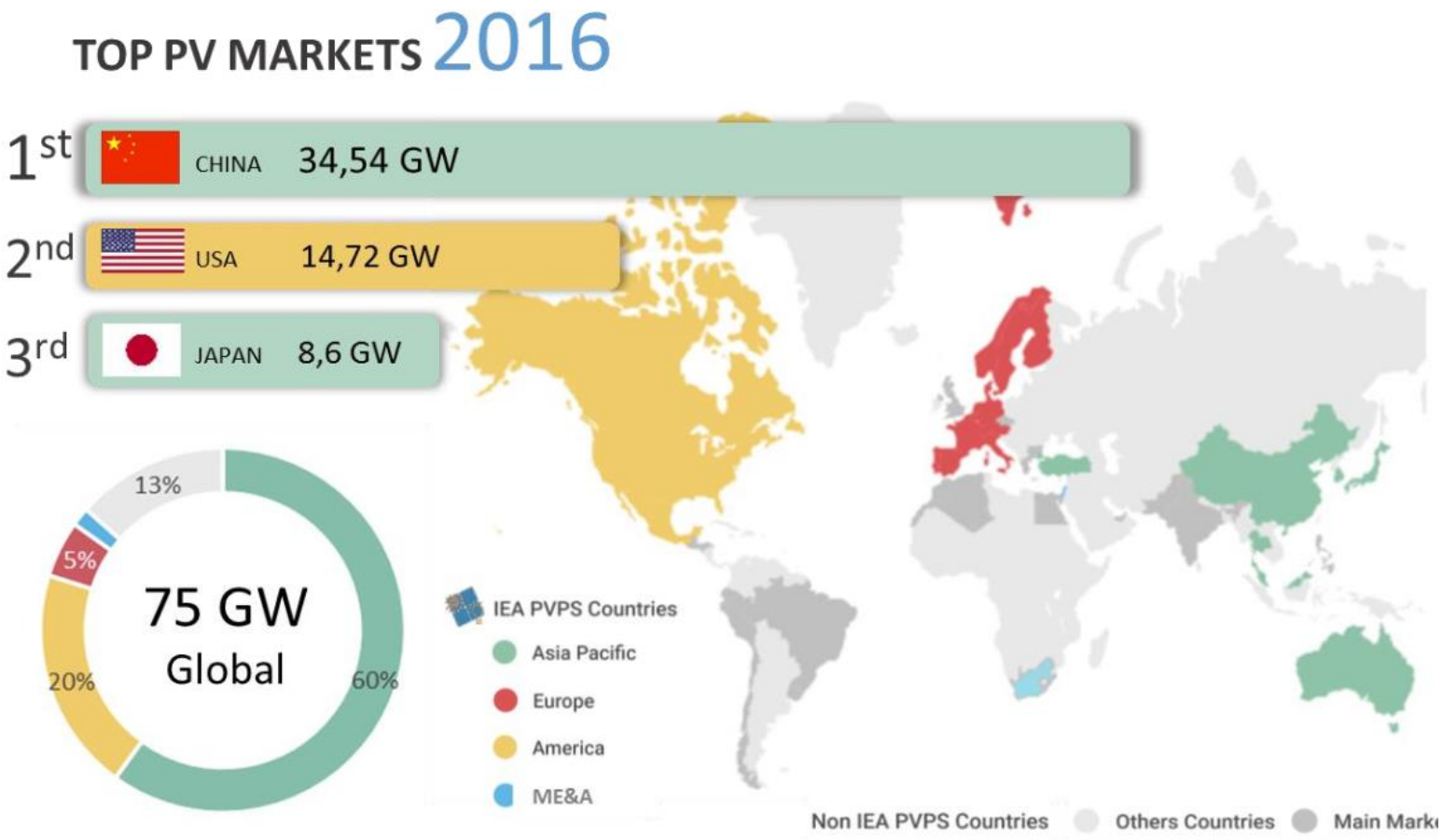
PV systems/components…

- Grid-connected PV systems





Installed PV capacity



TOP 10 COUNTRIES IN 2016 FOR CUMULATIVE INSTALLED CAPACITY

1	China	78,1 GW
2	Japan	42,8 GW
3	Germany	41,2 GW
4	USA	40,3 GW
5	Italy	19,3 GW
6	UK	11,6 GW
7	India	9 GW
8	France	7,1 GW
9	Australia	5,9 GW
10	Spain	5,5 GW

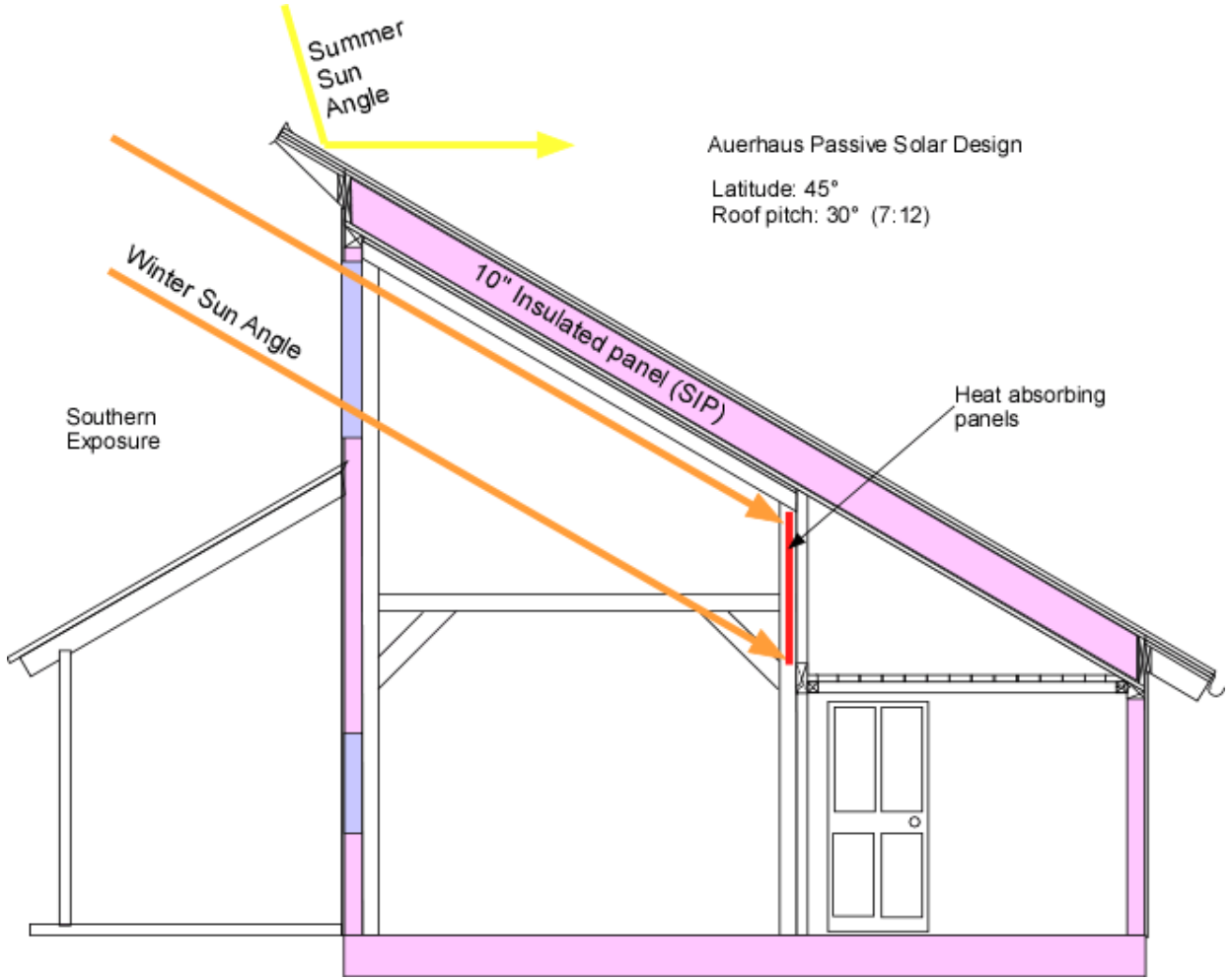
Source: IEA http://www.iea-pvps.org/fileadmin/dam/public/report/statistics/IEA-PVPS_-_A_Snapshot_of_Global_PV_-_1992-2016__1_.pdf

Solar thermal applications

❖Agricultural crop drying

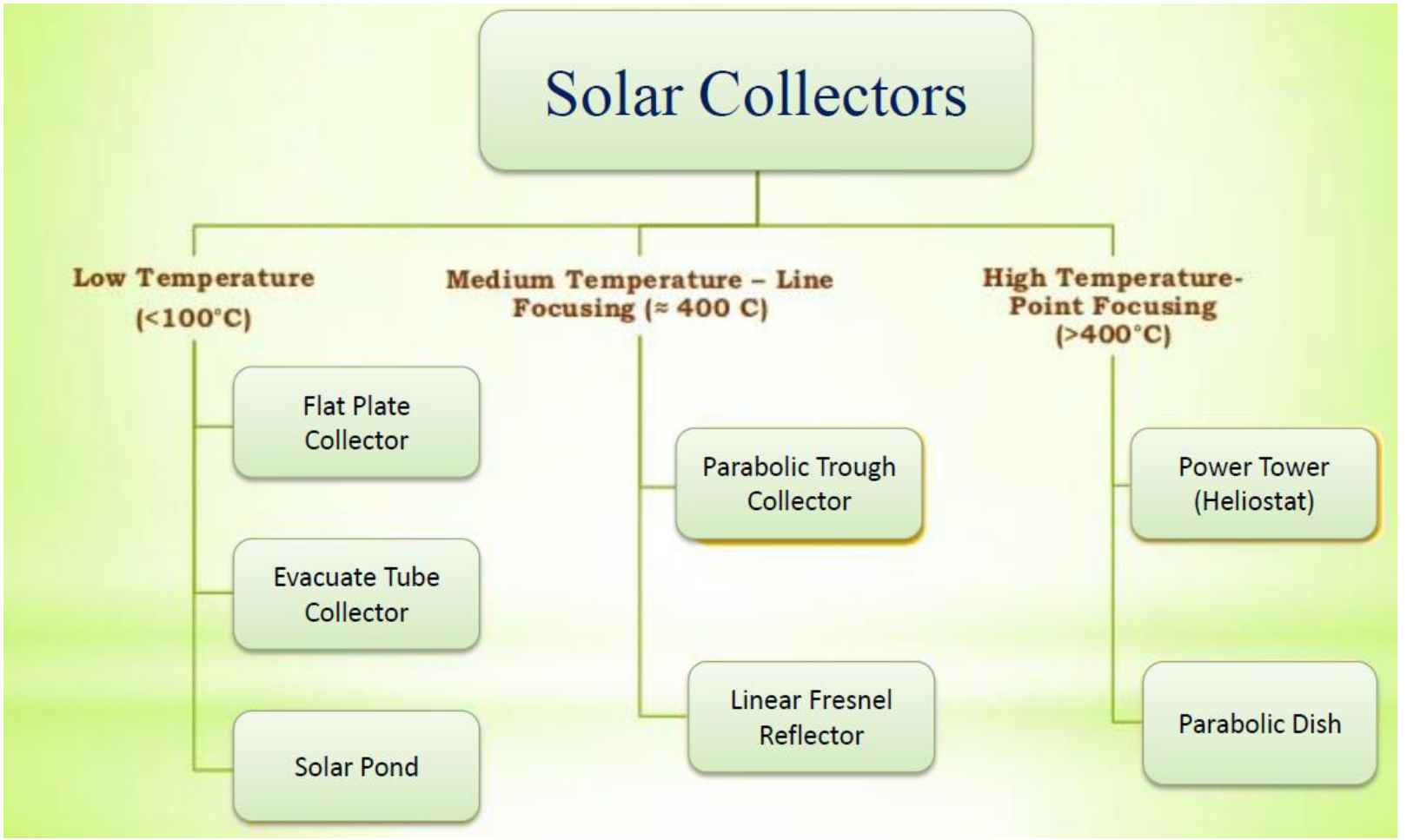
Solar thermal applications…

- Day lighting and space heating

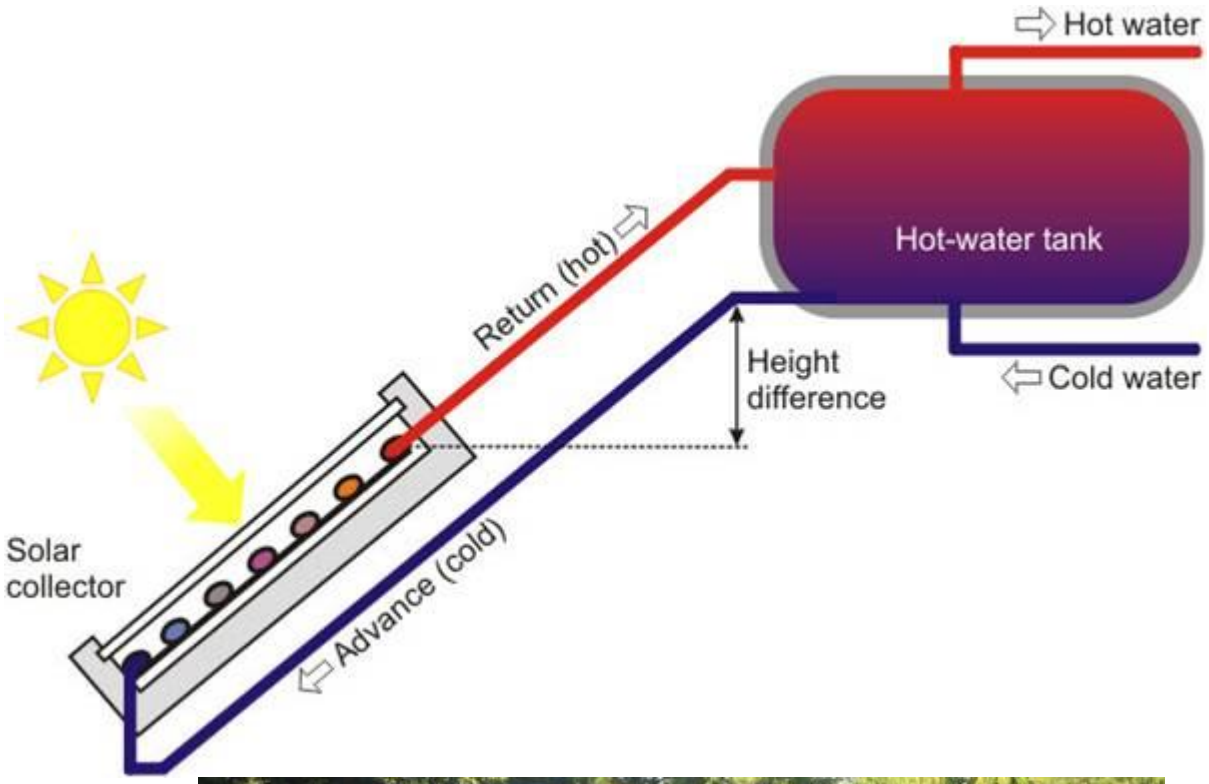


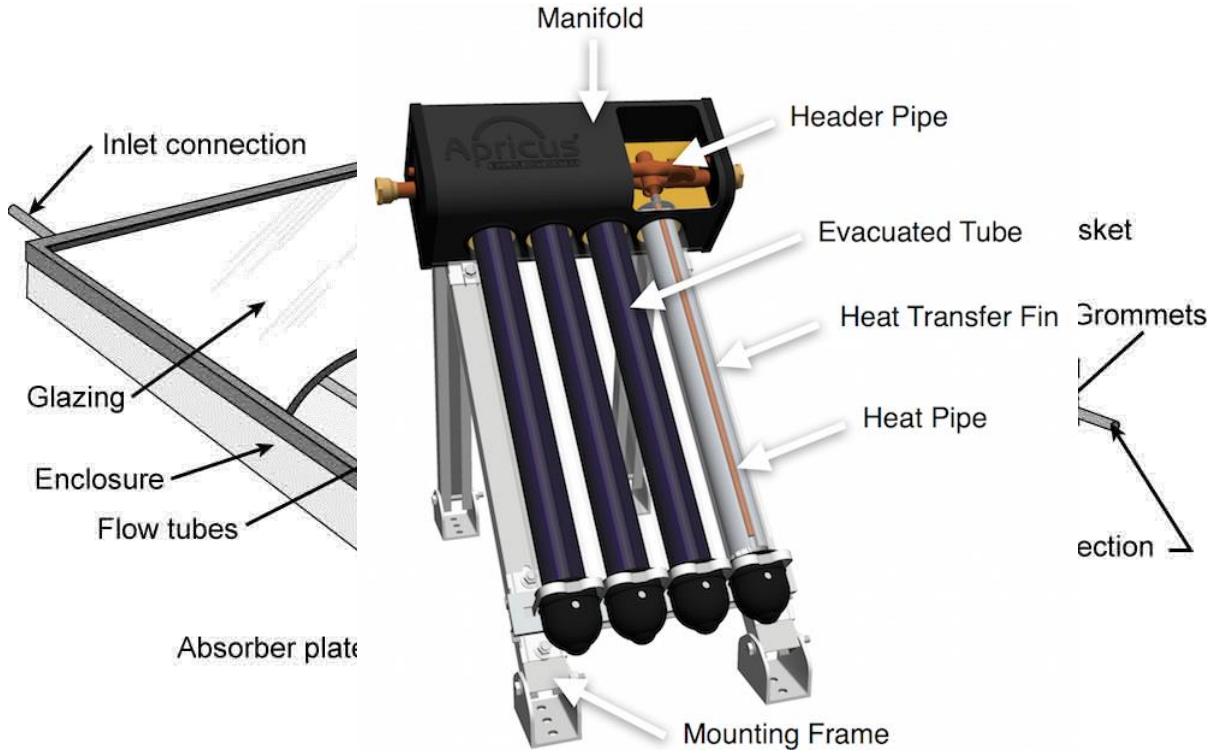
Solar thermal applications…

- Active solar heating
  - Collectors used to absorb sun's energy

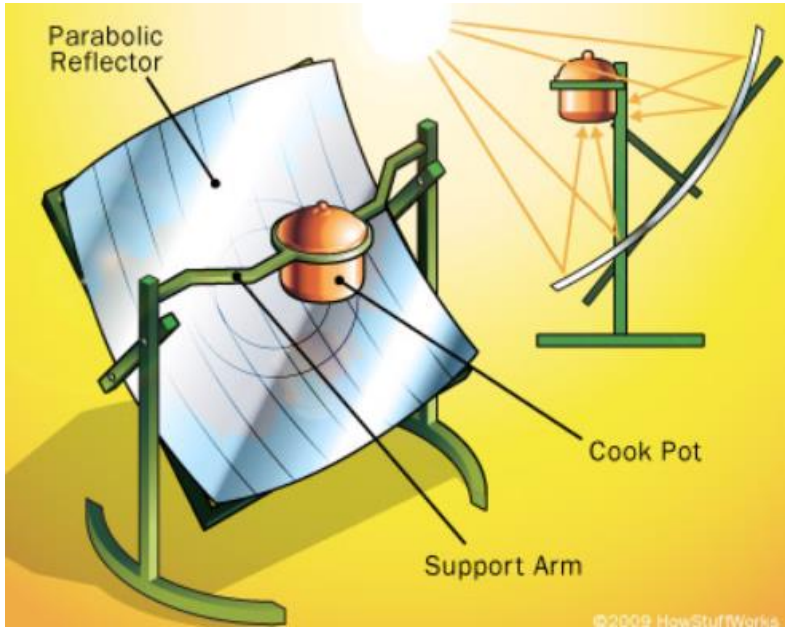


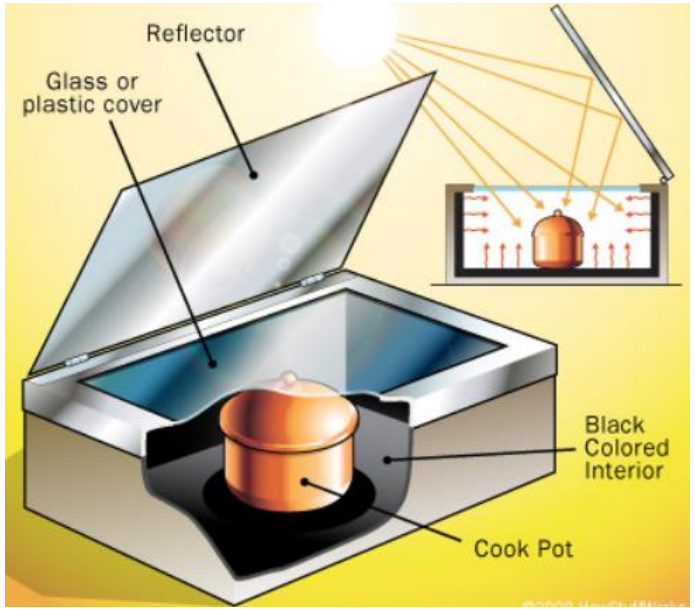
❖ Solar Water heating



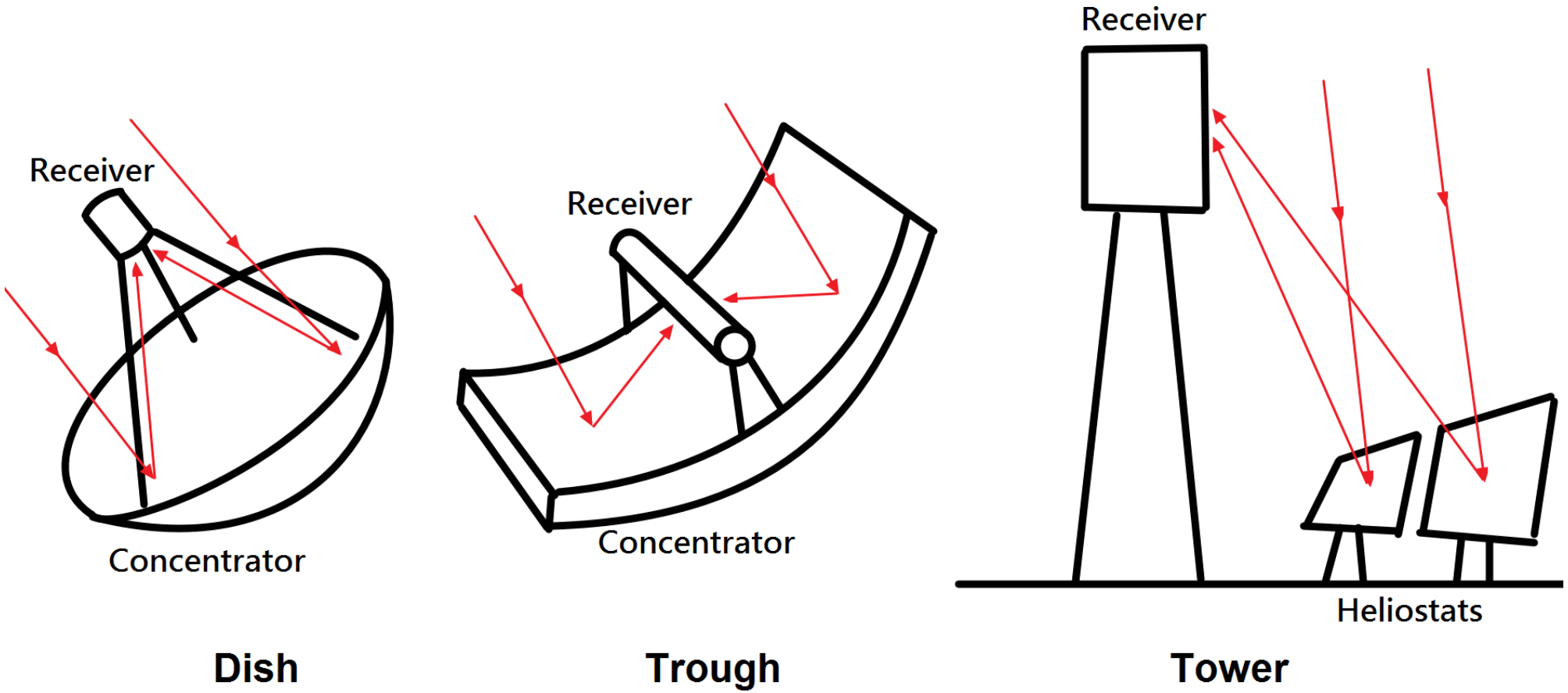


❖Solar cooking

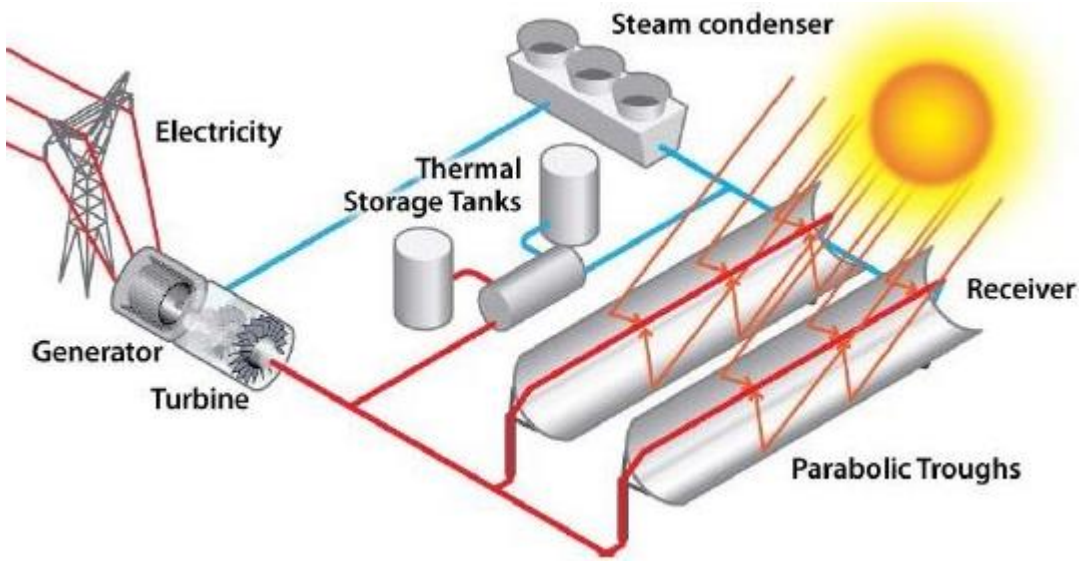




❖Concentrating Solar Power (CSP) systems



CSPs use mirrors to convert the sun's energy into high-temperature heat. The heat energy is then used to generate electricity in a steam generator.


Steam condenser
Electricity
Thermal
Storage Tanks
Receiver
Generator
Turbine
Parabolic Troughs

Thank you