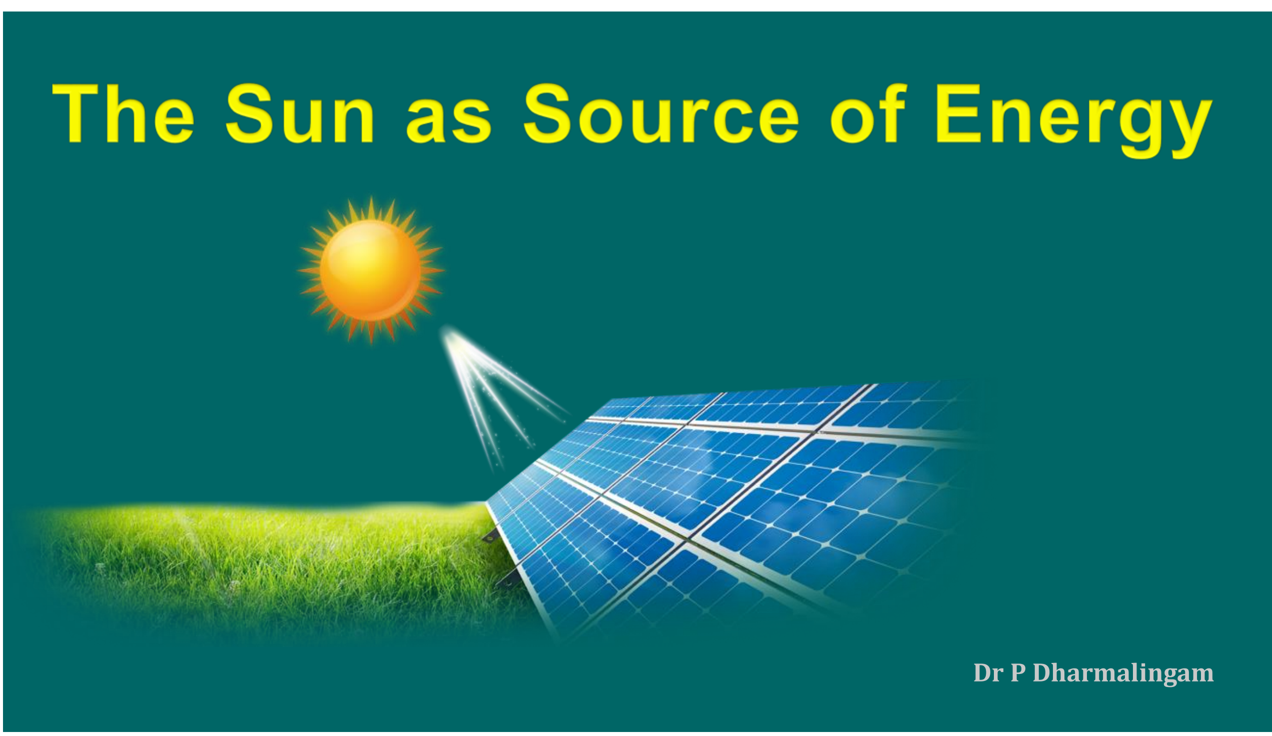
Unit – 2 [4 Hours]: Solar Energy

- ✓ Basics of Solar Energy
- ✓ Solar Thermal Energy
- ✓ Solar Photovoltaic:
- ✓ Advantages and Disadvantages,
- ✓ Environmental impacts and safety



Solar Energy—Basic Concepts
Learning Objectives

- **In this chapter you will be able to:**

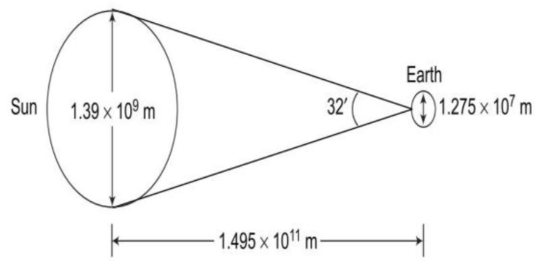
- Know about the origin of solar energy
- Discuss the characteristics and distribution of **solar radiation**
- Measure various components of solar radiation
- Analyze the collection and interpretation of **solar radiation data**
- Explain the estimation of **availability of solar radiation at a location**
- Observe the effect of tilting the surface of collector with respect to horizontalsurface

The Sun

- **Largest member of solar system.**
- **Intensely hot gaseous sphere.**
- **Core temperature is 15 million degree C and Surface temperature is about 5800 K.**
- **Diameter 13,90,000 km, Mass consists of 75% Hydrogen and 25% Helium.**
- **Fusion reaction generates Energy about 386 billion megawatts.**
- **Radiation strikes the earth with in 8 minutes.**
- **30 minutes of radiation is equal to the world energy demand for one year**

THE SUN AS SOURCE OF ENERGY

- The sun, which is the largest member of the solar system, is a sphere of intensely hot gaseous matter with a diameter of 1.39×10^9 m and, at an average distance of 1.495×10^{11} m from the earth.
- The earth may be considered as a sphere with a diameter of about 1.275×10^7 m.
- The earth makes one rotation about its axis every 24 hours and completes a revolution about the sun in a period of approximately 365.25 days.
- Its axis is inclined at an angle of 23.5°. As a result the length of days and nights keep changing.
- The earth reflects about 30 percent of the sunlight that fall on it. This is known as earth's albedo.



THE SUN AS SOURCE OF ENERGY

- As observed from the earth , the **sun rotates on its axis** about once in every four weeks, though it does not rotate as a solid body.
- The equator takes about 27 days and **the polar region takes about 30 days for each rotation**. At the innermost region, the core, the temperature is estimated between 8×10^6 to 40×10^6 K.
- the sun is a big natural fusion reactor with its constituent gases retained by gravitational forces.
- Several fusion reactions takes place.
- Most important of them is a reaction in which four hydrogen atoms (protons) combine to form one helium atom.

$$4({}_1H^1) \rightarrow {}_2He^4 + 26.7 \text{ Mev}$$

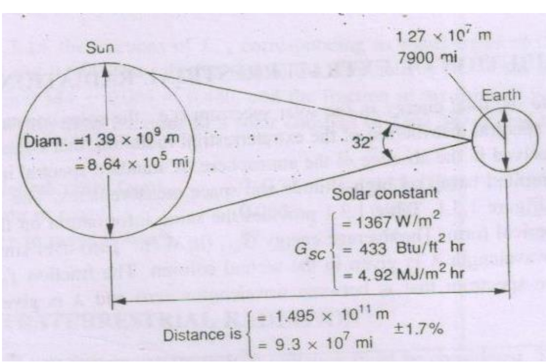
The surface of the sun is maintained at a temperature of approximately 5800 K.

INTRODUCTION

- Solar energy is the mother of all forms of energy: conventional or non-conventional, renewable or non-renewable, the only exception being nuclear energy.
- Various sources of energy find their origin in sun, as mentioned below:
  1. Wind energy
  2. Biomass energy
  3. Tidal energy
  4. Ocean wave energy
  5. Ocean thermal energy
  6. Fossil fuels and other organic chemicals
  7. Hydro energy

- Archimedes (212 BC), it is said, set the Roman fleet on fire by concentrating solar radiation using large number of small plane mirrors at a distance of several hundred feet.
- Antoine Lavoisier (1740–1794), achieved temperatures up to 1700 °C by concentrating sun's rays.

geometry of sun-earth relationships.



- **The eccentricity of the earths orbit is such that the distance between the sun and the earth varies by 1.7%.**
- **At a distance of one astronomical unit, 1.495×10^{11} m. the mean earth-sun distance, the sun subtends an angle of 32'.**

A Solar constant:-

A Photovoltaic device, outside the earth's atmosphere which maintains normal incidence to the sun's rays receives nearly constant rate of energy."
This amount is called the Solar Constant.
Solar constant approx. = 1367.7 W/m2

- **The Solar constant is the energy from the sun per unit time received on a unit area of surface perpendicular to the direction of propagation of the radiation at mean earth-sun distance outside the atmosphere.**

SUN, EARTH RADIATION SPECTRUM

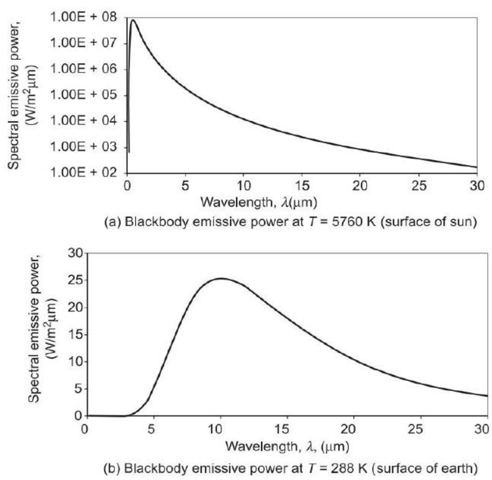


Figure 4.2 Radiant powers per unit wavelength at the surface of sun and earth

The power density distribution of solar radiation at the surface of the sun at the surface temperature 5760 K is calculated.
For the earth surface it calculated at average earth temperature to be 288 K (15 °C).

Solar Constant,
I_{sc} is defined as the energy received from the sun per unit time, on a unit area of surface perpendicular to the direction of propagation of the radiation, at the earth's mean distance from the sun.

The World Radiation Center (WRC) has adopted a value of **solar constant as 1367 W/m$_2$**

This has been accepted universally as a standard value of solar constant.

SPECTRAL POWER DISTRIBUTION OF SOLAR RADIATION

- Solar radiation covers a continuous spectrum of electromagnetic radiation in a wide frequency range.
- About 99 per cent of the extraterrestrial radiation has wavelengths in the range from 0.2 to 4 μm with maximum spectral intensity at 0.48 μm (green portion of visible range)
  - About **6.4 per cent** of extraterrestrial radiation energy is contained in ultraviolet region (l < 0.38 μm);
  - another **48 per cent** is contained in the **visible region** (0.38 μm < l < 0.78 μm) and
  - the remaining **45.6 per cent** is contained in the infrared region (l > 0.78 μm).
- The **spectral solar irradiation distribution** both for **extraterrestrial and terrestrial radiation** is shown in Fig.
- The areas under these curves indicate the total radiation intensities in W/m2 respectively for extraterrestrial and terrestrial regions

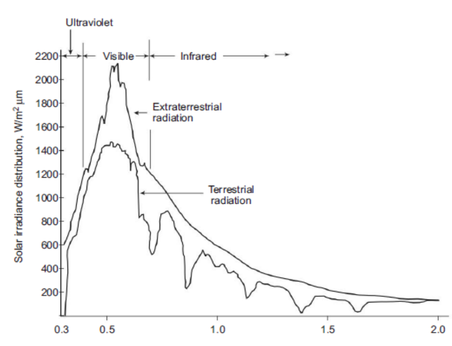
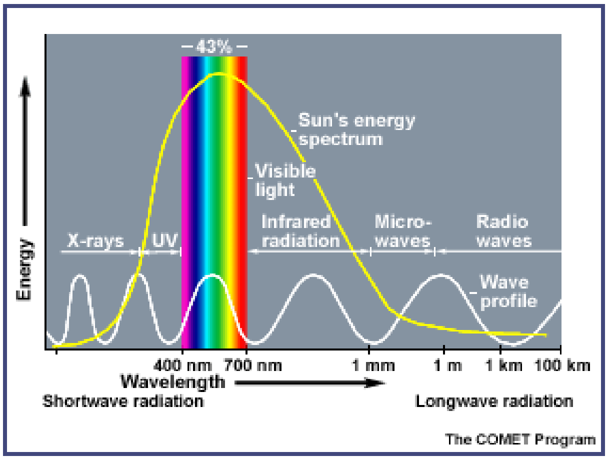


Figure 4.4 Special solar irradiation, extraterrestrial and terrestrials

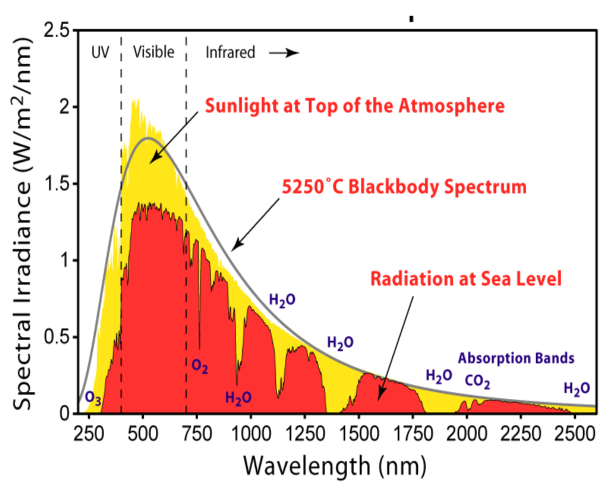
Solar Energy



- **Originates with the thermonuclear fusion reactions occurring in the sun.**
- **Represents the entire electromagnetic radiation**
- **(visible light, infrared, ultraviolet, x-rays, and radio waves).**

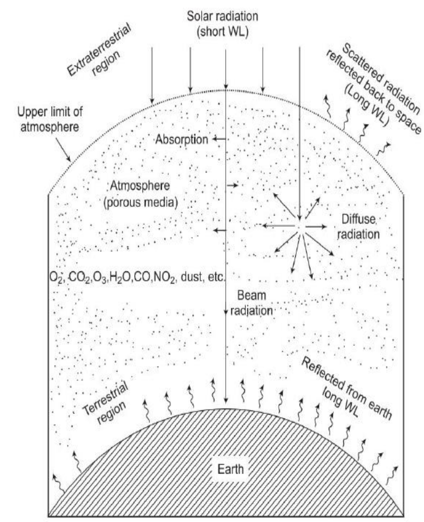
B) Solar Spectrum:-

- **The solar radiation spectrum is distributed as;**
- **a good portion of the sun's radiation is in the visible range (46%) (Source – solar cell central).**
- **Radiation in the ultraviolet region (5%), which is not visible, causes the skin to tan and has more energy than that in the visible region.]**
- **Radiation in the infrared region (49%), which we feel as heat, has slightly more total energy than the radiation in the visible region.**



EXTRATERRESTRIAL AND TERRESTRIAL RADIATIONS

- 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. While passing through the atmosphere it is subjected to mechanisms of atmospheric absorption and scattering depending on atmospheric conditions, depleting its intensity.
- A fraction of scattered radiation is reflected back to space while remaining is directed downwards. Solar radiation that reaches earth surface after passing through the earth's atmosphere is known as Terrestrial Radiation.
- The **terrestrial radiation** expressed as energy per unit time per unit area (i.e. W/m2) is known as Solar Irradiation.



Propagation of solar radiation through atmosphere

C) Radiation Types:-

- **Sun emits energy in the form of electromagnetic radiation at an extremely large and constant rate.**
- **Beam Radiation (Gb) : It is the solar radiation received from the sun without having been scattered by the atmosphere (beam radiation is often referred to as direct solar radiation; to avoid confusion between subscripts for direct and diffuse, we use the term beam radiation, subscript "b").**
- **Diffuse Radiation (Gd) : it is the solar radiation received from the sun after its direction has been changed by scattering by the atmosphere (diffuse radiation is referred to, in some meteorological literature, as sky radiation or solar sky radiation; the definition used here will distinguish the diffuse solar radiation from infrared radiation emitted by the atmosphere. Diffuse radiation, subscript "d").**
- **Global Solar Radiation (G) : It is the sum of the beam and the diffuse solar radiation on a surface (the most common measurements of solar radiation are total radiation on a horizontal surface, often referred to as global radiation on the surface.**

$$G = Gb + Gd$$

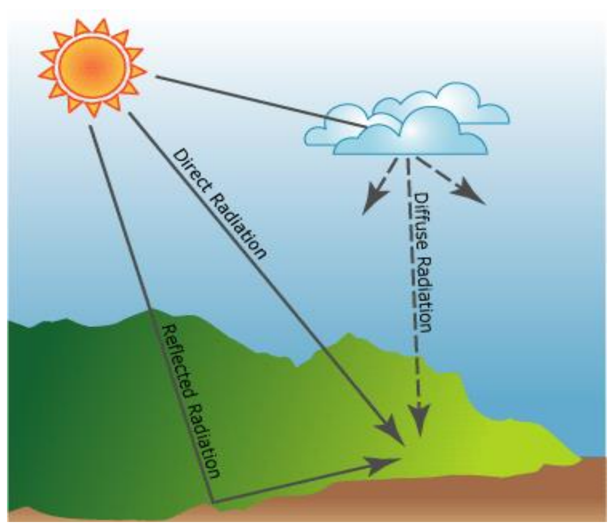
D) Solar Radiation Terminology :-

- **Radiant energy:**
  - **Energy emitted in the form of electromagnetic radiation. Measured in joules (J)**

    Radiant flux: Rate of flow of radiant w. r. t. time (Watt)
- **Insolation:**
  - **The actual amount of sunlight falling on a specific geographical location (incident solar radiation). Unit of Insolation is W/m².**
- **Irradiance (E):**
  - **Radiant energy incident on a surface per unit area per unit time (Watt/m2), (J/m2/sec) more popular kWh/m2/day.**

SOLAR RADIATION

Direct Normal Irradiance + **Diffused Radiation** → **Global Radiation**



Units	kWhr / m^2 /year
	kWhr / m^2 / day

EXTRATERRESTRIAL AND TERRESTRIAL RADIATIONS

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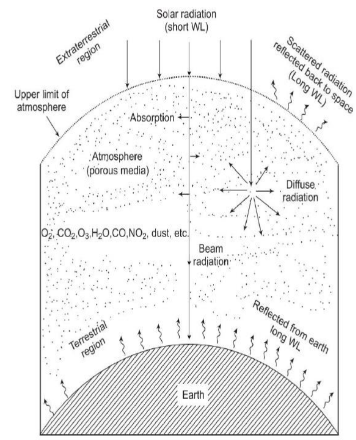


Propagation of solar radiation through atmosphere

DEPLETION OF SOLAR RADIATION

- The earth's atmosphere contains various gaseous constituents, suspended dust and other minute solid and liquid particulate matter.
- These are air molecules, ozone, oxygen, nitrogen, carbon dioxide, carbon monoxide, water vapour, dust, and water droplets.
- Therefore, solar radiation is depleted during its passage through the atmosphere. Different molecules do different things as explained below

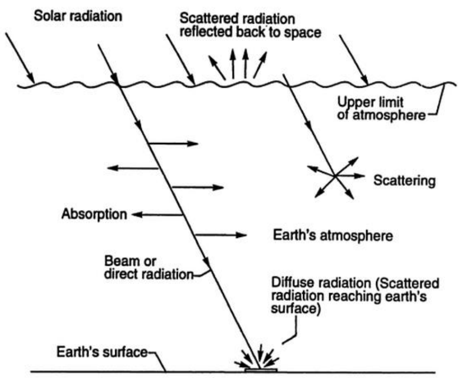
1. Absorption

- Selective absorption of various wavelengths occurs by different molecules.
- The absorbed radiation increases the energy of the absorbing molecules, thus raising their temperatures:

2. Scattering

- Scattering by dust particles, and air molecules (or gaseous particles of different sizes) involves redistribution of incident energy.
- A part of scattered radiation is lost (reflected back) to space while remaining is directed downwards to the earth's surface from different directions as diffuse radiation. It is the scattered sunlight that makes
- the sky blue. Without atmosphere and its ability to scatter sunlight, the sky would appear black, as it does on the moon.

E) Solar Radiation



Global Radiation:

- **The sum of the diffuse and direct solar radiation**
- **Measured by Pyranometer**
- **The measured global horizontal solar irradiance is,**

Direct solar radiation:

i.e., in line with sun is called beam or direct radiation
Reaches the Earths surface without being diffused, direct beam Atmospheric conditions reduce:

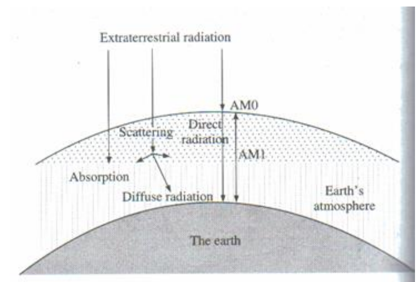
10% on clear, dry days

100% during thick, cloudy days

Diffuse solar radiation:

Radiation scattered and reflected by: Air molecules (Rayleigh scattering), Water vapour (Mia scattering), Clouds, dust, pollutants, Forest fires and volcanoes

It does not have a unique direction.



G) Solar Air Mass :-

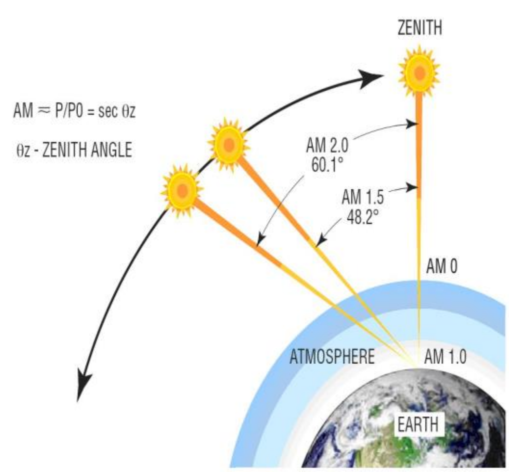
- Ratio of the distance that solar radiation travels through the earth's atmosphere (path length), to the distance (path length) it would travel if the sun were directly overhead.
- The Air Mass quantifies the reduction in the power of light as it passes through the atmosphere and is absorbed by air and dust.
- The relative air mass is simply a trigonometric function of the zenith angle:

$$AM = \left(\frac{1}{cos(\theta z)}\right)$$

AM = sec (z), where, θz is the solar zenith **angle.**

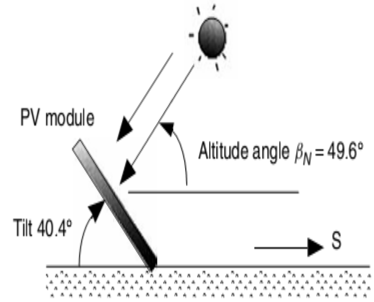
airmass, m = $\dfrac{\text{pathlength traversed by beam radiation}}{\text{vertical path length of atmosphere}}$

The abbreviation AM0 refers to zero (no) atmosphere, AM1 refers to m = 1



F) Tilt Angle :-

- It is the angle, between array and horizontal surface, which gives maximum solar irradiation.
- Solar panels should always face true south in the northern hemisphere, or true north in the southern hemisphere. This shall give maximum incidence of sunlight on the solar modules.
- The tilt angle and orientation is generally optimised for each PV Power plant according to location.
- This helps to maximise the total annual incident irradiation and total annual energy yield.
- For Indian sites, the optimum tilt angle is generally between 10º and 35º, facing true south.



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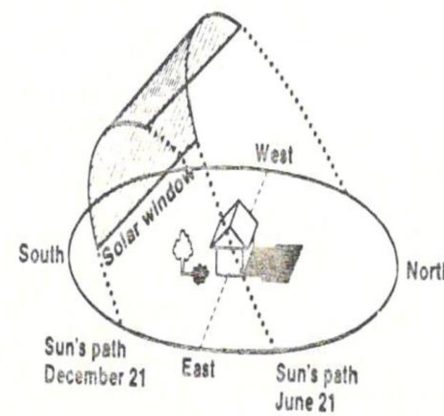
Solar energy reaching earth's surface at different sun's Positions

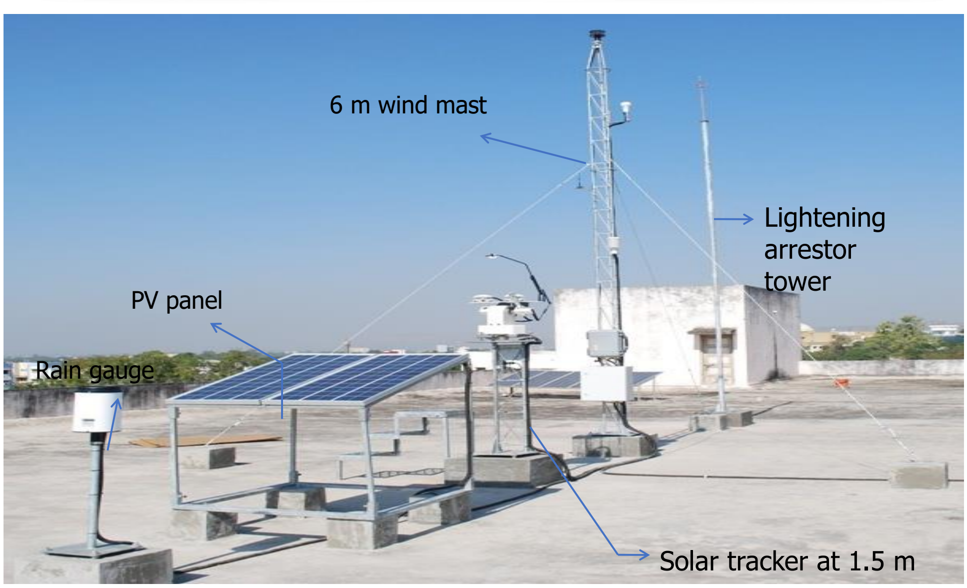
Distance travelled by sun rays to reach earth's surface, or Air Mass	Solar radiation flux reaching the surface (W / m^2)
AM 0 (extraterrestrial)	1 376
AM 1 (sun at overhead position)	1 105
AM 1.5 (sun at about 48° from overhead position)	1 000
AM 2 (sun at about 60° from overhead position)	894

H) The Solar Window :-

- Solar window represents the effective area through which useful levels of sunlight pass throughout the year in a specific location.
- Solar window is used to determine potential shading when designing a photovoltaic system.
- In India, in the winter (December 21), the Sun rises in the Southeast and sets in the Southwest and has relatively short path.
- In the summer time (June 21), the sun rises in the Northeast and sets in the Northwest and has a longer path.
- The effective area between the Sun's path of June 21 and Sun's path of December 21 is known as solar window



Typical SRRA Station



PYRHELIOMETER

- This is an instrument using a collimated detector for measuring solar radiation from the sun (i.e. beam radiation)

PYRANOMETER

Used for measuring the total radiation (beam + diffuse). It can be used to measure diffuse radiation only by using a shade ring or disc, which shades the beam radiation

MEASUREMENT OF SOLAR RADIATION

Solar radiation data are measured mainly by following instruments:

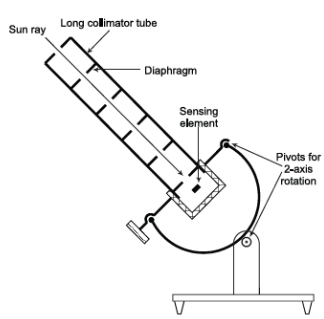
(i) Pyranometer: A pyranometer is designed to measure global radiation, usually on a horizontal surface but can also be used on an inclined surface. When shaded from beam radiation by using a shading ring, it measures diffuse radiation only.

(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.

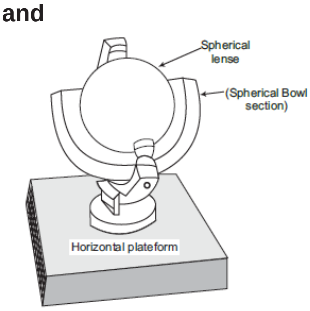
(iii) A sunshine recorder measures the sunshine hours in a day.

Pyranometer

A pyranometer with shadow and



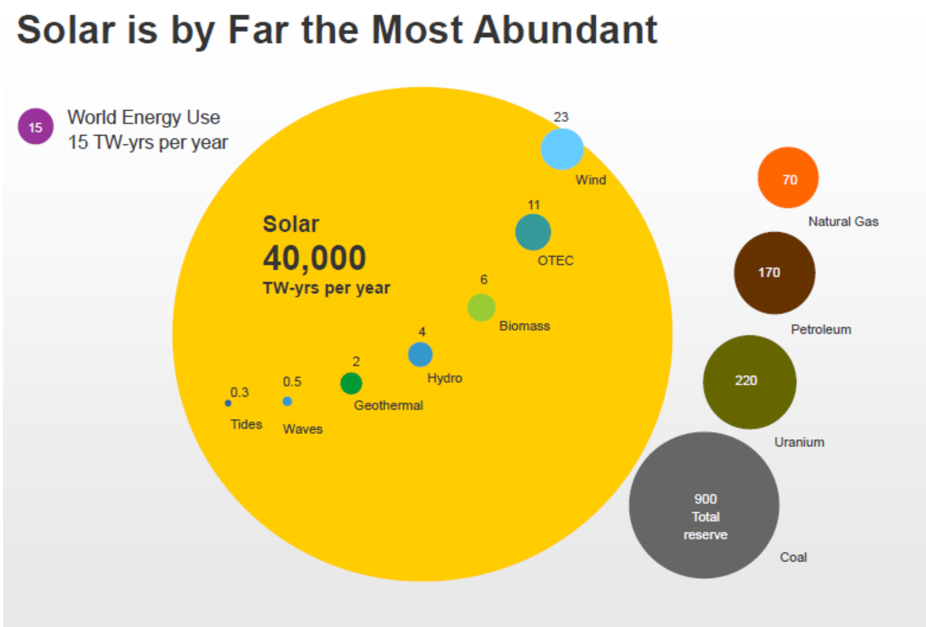
Pyrheliometer



Sunshine recorder

Infinite Source

Energy/Fuel Supply Available



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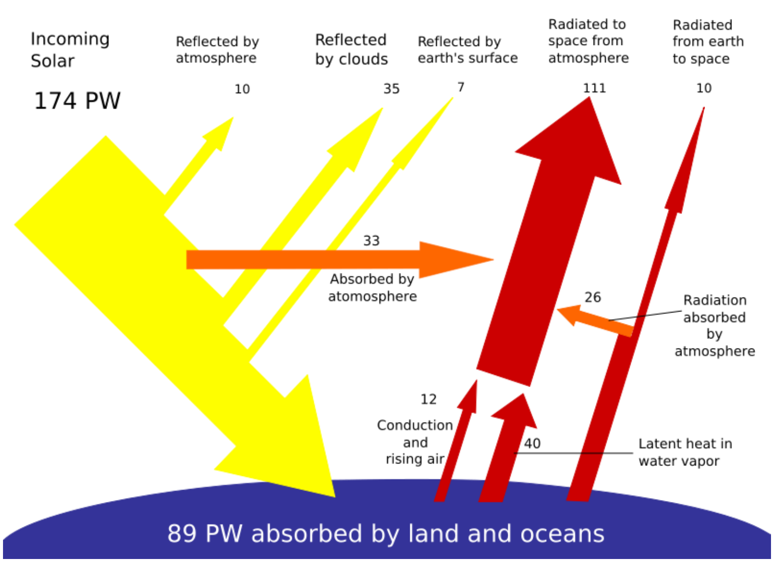
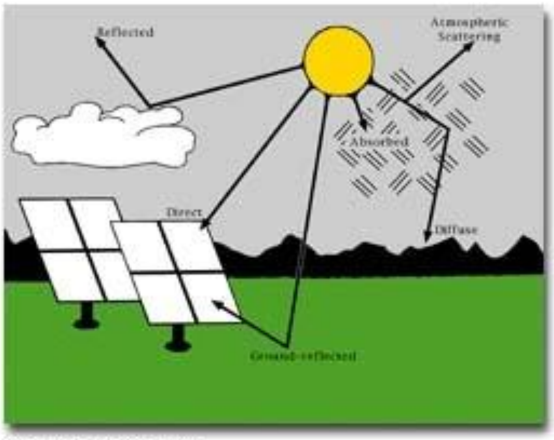
Breakdown of incoming solar energy



http://en.wikipedia.org/wiki/File:Breakdown_of_the_incoming_solar_energy.svg

- About half the incoming solar energy reaches the Earth's surface.
- The Earth receives 174 petawatts (PW) (10^{15} watts) of incoming solar radiation at the upper atmosphere.
- Approximately **30% is reflected** back to space while the rest is **absorbed by clouds, oceans and land masses.**
- Earth's land surface, oceans and atmosphere absorb solar radiation, and this raises their temperature. Sunlight absorbed by the oceans and land masses keeps the surface at an average temperature of 14 °C.
- By photosynthesis green plants convert solar energy into chemical energy, which produces food, wood and the biomass from which fossil fuels are derived.



SOLAR RADIATION

SOLAR ENERGY

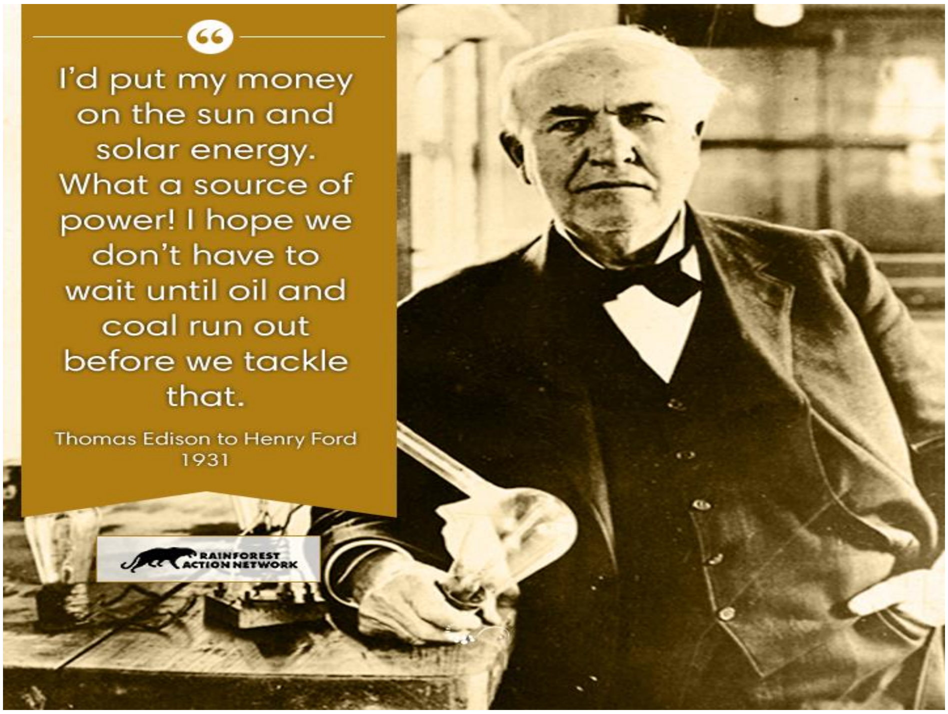
- Earth Receives 10^{18}kwh of solar energy every year
- The surface of the earth receives about 10^{14} kW from sun
- Heat to Earth Heat Flux Density – 1.3kw/Sq.M

  This varies in different places of Earth due to 23^0 Slant
- 1.3kw x 7hrs (if uniform through) = 9kwh – but due to intensity variation, this is 6 - 7kwh for India

- **Solar PV Power and India**
- India has 3.2 Million Sq. Km.Area
- India has 250 to 300 sunney days
- Solar Power Potential is 4 to 7 Kwh/Sq.M/Day
- Energy can be used both for 'Heat' and Electricity Generation.

Obstacles in harnessing solar energy

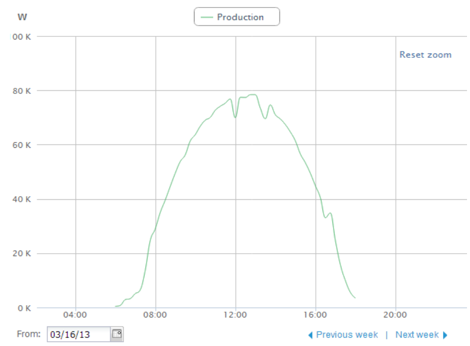
- Solar energy is diffused.
- It therefore calls for large area, land as well as the equipment to harness substantial Energy.
- This makes the 'System' costly.
- Cost Effectiveness and Efficiency of Conversion are the Important Issues.
- It is not constantly available on earth. Thus some form of storage is needed to sustain solar energy through the night and during rainy season

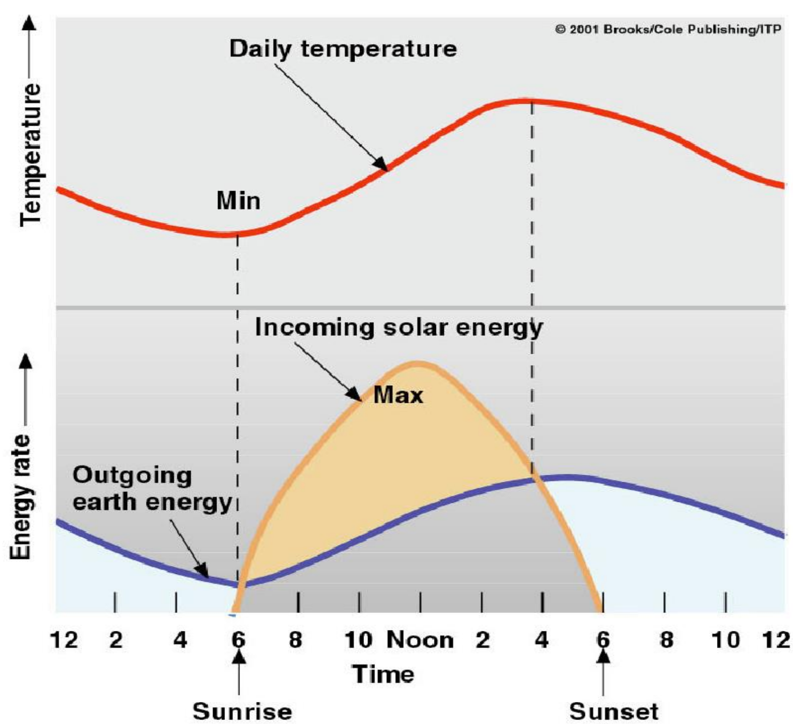


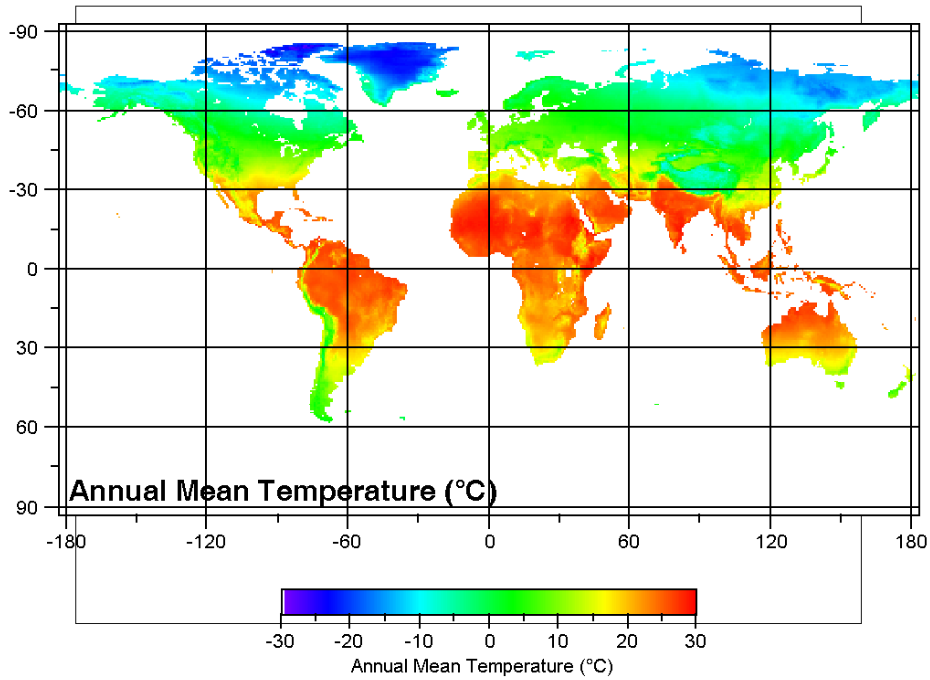
Surface Area Required to Power the World

Sun's Position in the Sky Keeps Changing

Solar is not a constant source







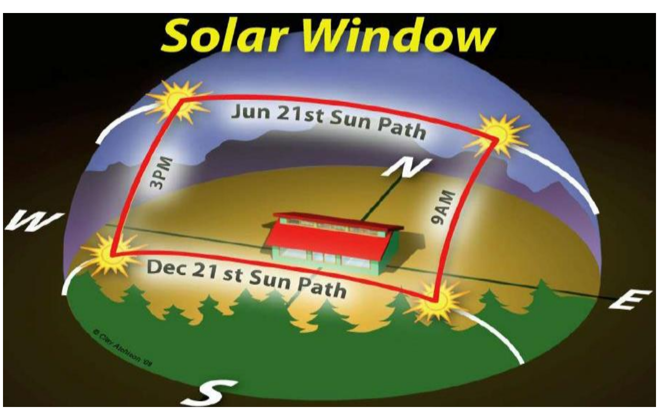
Advantages of Solar Technologies

- **Solar Energy is abundant (more than 5.5 kWh/Sq.m.).**
- **Simple modular technology, flexibility from Watts to Megawatts.**
- **Fuel (solar radiation) available for free.**
- **Long life (more than 20 years).**
- **No moving parts and therefore no noise or wear & tear.**
- **Low gestation period.**
- **Minimum maintenance if designed properly.**
- **Possible to operate in stand alone, de-centralised, grid interactive and hybrid modes.**
- **Ideally suitable for remote area applications.**

11.2 Fundamentals of Solar Energy

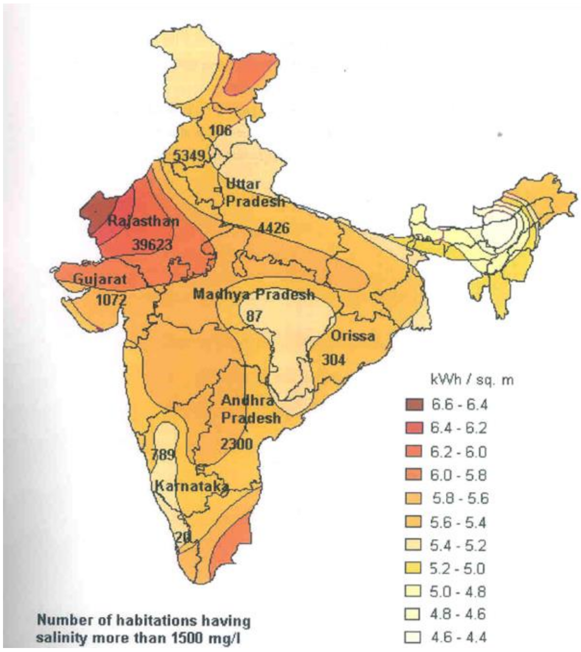
- **Solar radiation** is radiant energy emitted by the sun comprising of ultra-violet, visible and infra-red radiation.
- **Solar constant** is the rate at which solar energy, at all wavelengths, is received per unit area at the top level of Earth's atmosphere . The solar constant varies 0.3% over the 11-year solar cycle but averages about **1,368 W/m2**.
- **Solar Insolation** is the amount of solar energy that strikes a square meter of the earth's surface in a single day. The average incoming radiation is known as solar insolation , **342 W/m2**

- The insolation values is expressed in $kWh/m^2/day$.
- India receives solar energy in the region of 5 to 7 kWh/m^2 for 300 to 330 days in a year.

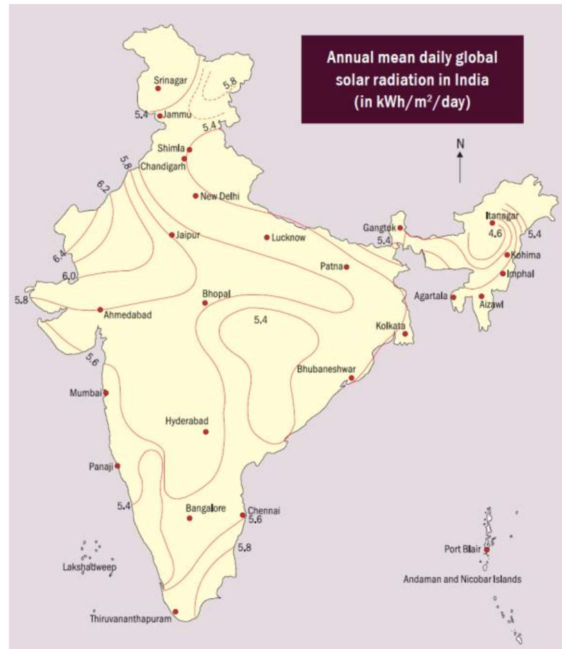


Solar Window is the period, typically 9 AM - 3 PM, when maximum sunlight is available

Solar Power Map

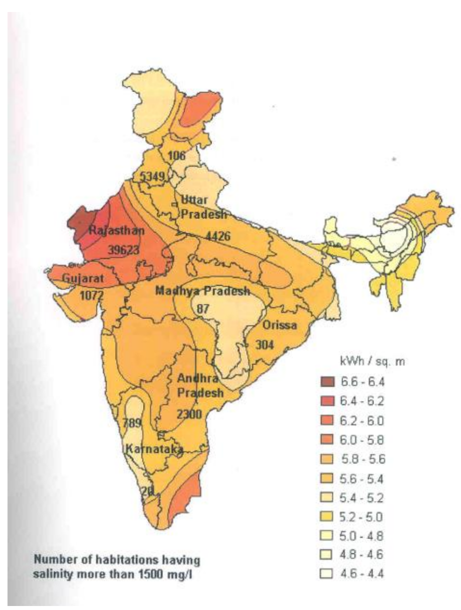


SOLAR POWER DENSITY



Solar Radiation Map of India

- Most parts of India receive good solar radiation 4- 7 kWh/sq. m/day
- Possible to meet growing energy demands and cover deficit areas
- Can substantially reduce consumption of kerosene and diesel for lighting and power generation
- Provide access and empowerment at grass root level



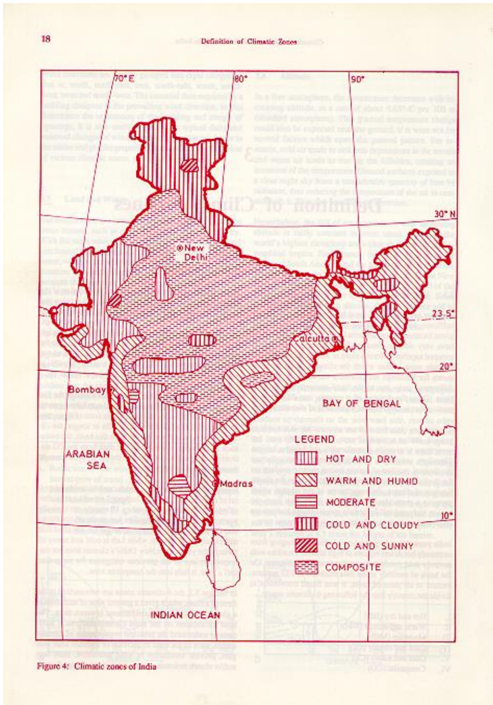


Figure 4: Climatic zones of India

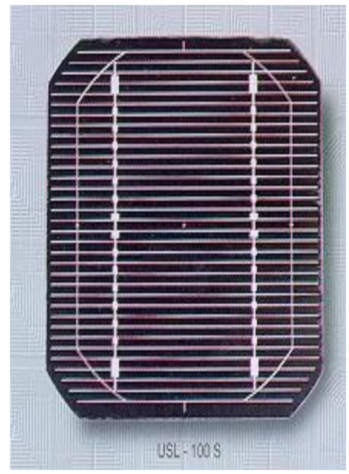
Climatic Zones of India

- After analyzing the climatic data of the country, six climatic zones identified
- Design guidelines for each climatic zone developed
- Buildings in different climatic zones designed and constructed

India: Land of a Billion Energy Needs

- 2.4% of land area with 16% of the world's population
- Life Expectancy 64.71 years
- Household sector: largest consumer of energy accounting for 40-50 % of total energy consumption
- About 2/3 of India's more than 1 billion people live in rural areas
- In rural areas, the domestic sector accounts for nearly 80 percent of total energy consumption

SOLAR  NERGY



HEAT

ELECTRICITY