Module-1

Introduction: Causes of Energy Scarcity, Solution to Energy Scarcity, Factors Affecting Energy Resource Development, Energy Resources and Classification, Renewable Energy – Worldwide Renewable Energy Availability, Renewable Energy in India.
Energy from Sun: Sun- earth Geometric Relationship, Layer of the Sun, Earth – Sun Angles and their Relationships, Solar Energy Reaching the Earth's Surface, Solar Thermal Energy Applications.

The material from this is prepared only for educational use from various text books and material from internet.

Suggested Learning Resources:
Text Books 1. Nonconventional Energy sources, G D Rai, Khanna Publication, Fourth Edition,
2. Energy Technology, S.Rao and Dr. B.B. Parulekar, Khanna Publication Solar energy, Subhas P Sukhatme, TataMcGrawHill, 2nd Edition,1996.
3. Principles of Energy conversion, A. W. Culp Jr., McGraw Hill, 1996
4. Non-Convention Energy Resources, Shobh Nath Singh, Pearson, 2018

Questions from VTU model papers and few important questions:

1. List various non-conventional energy resources. Give their availability, relative merits, and their classification.
2. Distinguish between renewable and non-renewable energy sources
3. Explain primary and secondary energy sources
4. Discuss the main features of various types of renewable and non-renewable energy sources and explain the importance of non-conventional energy sources in the context of global warming
5. Discuss the social implications of renewable energy sources?
6. Briefly explain factors that affect renewable energy development.
7. Define the term energy and energy resources. Discuss different ways of their classification with examples in each category
8. Discuss the causes of energy scarcity and the solution to energy crisis.
9. What is the current worldwide availability of renewable energy sources, how does it compare to traditional grid system
10. What are the advantages and limitations of renewable energy sources? Explain in detail about the prospects of non-conventional sources in India
11. With the help of a diagram define: a). Hour angle b). Latitude angle c). Solar Azimuth angle d). Declination angle
12. Explain any three applications of solar thermal energy
13. Calculate Zenith angle of the sun at Lucknow (26.5^o N), at 9.30am, on February 16,2014
14. Draw a neat sketch of the structure of sun and explain the characteristics of different layers.
15. Define the terms beam radiation, diffuse radiation

Introduction

Energy is one of the major inputs for the economic development of any country. In the case of the developing countries, the energy sector assumes a critical importance in view of the ever-increasing energy needs requiring huge investments to meet them. Hydrocarbons, specifically petroleum, coal, and natural gas, have been humanity's primary energy source for the past century. However, the ongoing threat of climate change and its efects on human health and well-being has dramatically increased the need for alternative energy sources. Hydrocarbons still account for over 80% of the world's energy supply. Furthermore, the production and use of fossil fuels are responsible for a significant portion (89%) of global greenhouse gas emissions, including carbon dioxide. Additionally, reliance on imported fossil fuels have contributed equally risks energy security. To address these concerns, technologies based on renewable energy are crucial for achieving a sustainable energy future.

Various forms of renewable energy have the potential to contribute to the global energy mix significantly. In line with this, there is a growing trend toward increasing the utilization of renewable energy sources, with projections suggesting that the share of renewable energy in global energy production will expand from 14 in 2018 to a projected 74% by 2050. Globally, the power capacity of hybrid renewable energy increased from 700 to 3100 gigawatts between 2000 and 2021. Recent technological advancements in renewable energy systems have led to a reduction in both economic costs and environmental impacts. However, the intermittent nature of these resources remains a significant challenge in creating a reliable and long-lasting clean energy infrastructure. Integration between various sources is feasible and can increase system efficiency and supply balance, avoid limitations, and decrease carbon emissions. It is essential to evaluate the integration of renewable energy from both sustainability and technical perspectives, energy efficiency, and running costs. In addition, challenges to implementing a hybrid energy system must be addressed

The word _energy‘ itself is derived from the Greek word _en-ergon, which means _in-work’ or work content. The work output depends on the energy input. Energy is the most basic infra-structure input required for economic growth & development of a country. Thus, with an increase in the living standard of human beings, the energy consumption also accelerated.

A systemic study of various forms of energy & energy transformations is called energy science. While fossil fuels will be the main fuel for thermal power, there is a fear that they will get exhausted eventually in the next century. Therefore other systems based on non- conventional & renewable sources are being tried by many countries. These are solar, wind, sea, geothermal & bio-mass.

CAUSES OF ENERGY SCARCITY

While the whole world is in the grip of energy scarcity, several countries, including India also, are facing various associated difficulties for its techno-socio-economic development because of energy shortages and many more things. However, they have been further complicated by the energy dependence on the other countries. Energy use scenario, as shown in Table 1.1, indicates that how equality (social and economical) can be achieved, when 30% population is utilizing 70% of energy and 70% population is forced to live with the 30% of the remaining energy.

Table 1.1 Energy Use Scenario

% of population	70%		30%
% of energy usage	30%	70%	

Following points may be considered as the principal causes of energy scarcity.

1 Increasing Population

Undoubtedly, only 40–45% population constitutes child producing groups, worldwide population is increasing at an alarming rate. It is extrapolated that by the turn of 21st century, population will increase manifold (Malthusian population model). These populations are unevenly distributed worldwide. Africa shares the largest population growth rate, followed by South Asia and then by Europe.

2 Increasing Energy Usage or Consumption

The movement of civilization from early man to the present technological man was totally based on energy usage. Energy is constantly used at home, at work, and for leisure period of enjoyment. Energy maintains techno-socio-economic development. Energy provides the society with heat and electricity daily and motive power to industry, transportation, and modern way of life.

1. In homes, for lighting and cooking, domestic appliances, televisions, computers, etc.
2. In industry to power the manufacture of the products.
3. In transport system to power cars, trucks, ships, and aeroplanes for transporting peoples and goods.

An increase in the world population and consequent increase in energy consumption increases energy demands manifolds. World Energy Council has provided the most reliable prediction as shown in Figure 1.1. This indicates that by 2050, the world population will nearly be doubled from the present level and will rise to about 10 billion. Likewise, energy demand is projected to be at least double than the present level (Energy council).

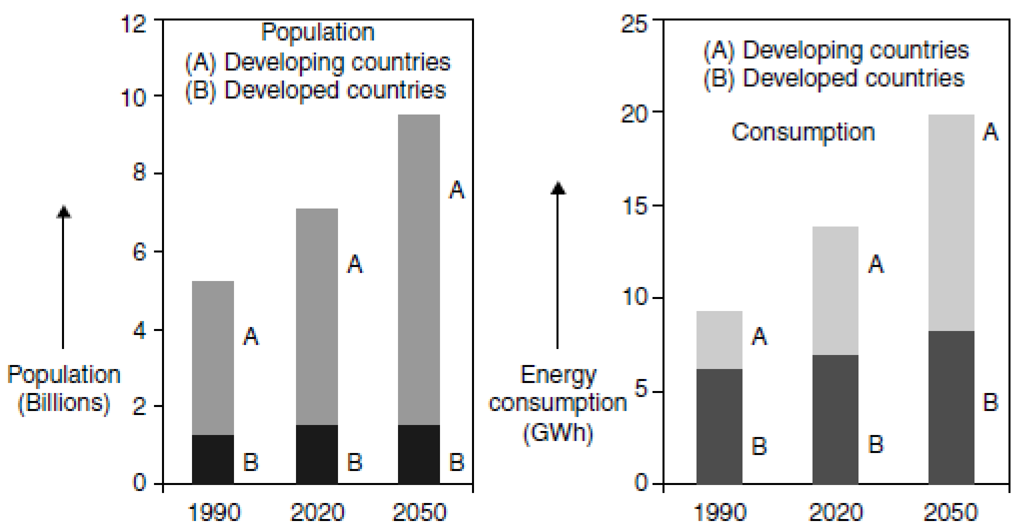


Figure 1.1 Population and energy consumption (Energy council)

3 Uneven Distribution of Energy Resources

It is well understood that very few wealthy countries have access to and actually use the largest part of the world's energy and material resources. The generation of environmental and social instability in several area of globe can be discussed in relation to the existence of disparity. Uneven distribution of energy and resource trade among countries is of paramount importance to environmental and political stability. For example, Middle East countries are full of crude oil reserves, but they are forced to involve in conflicts and wars and their energy reserves are forcefully used by wealthy countries. Geographical distribution is the main consideration for an unevenly distribution of fossil fuels (coal, oil, gas, and nuclear). Renewable energy flows are also spread out unevenly.

Cloudiness in equatorial regions reduces solar radiation. Whole stretches of the continent have insufficient wind. There are very few sites with the best potential for geothermal, tides, or ocean thermal. In fact, a few densely populated region or area have no significant locally available energy sources at all.

4 Lack of Technical Knowhow

Despite the fact that several countries or regions are having energy in abundance, they are not able to fully utilize them due to the lack of knowledge of conversion, transmission, distribution, and utilization. Because of the lack of technical knowledge, resources are mined and processed in resource enriched countries and then refined and used in developed countries. The price of exported resources is normally inadequate to compensate for the depletion of energy reserves and the environmental burden that is generated by resource extraction and primary processing in energy enriched countries. However, resources drive significant economic and environmental benefits in techno-economically developed countries.

SOLUTION TO ENERGY CRISIS OR SCARCITY

Owing to the growing importance of energy awareness, efforts should be systematically diverted in the following directions to tackle the gigantic energy crunch problems:

1. Minimizing population growth exploitation and harnessing the large utilization of known and unknown energy reservoirs.
2. Development of energy conversion techniques to convert basic energy available from energy reservoirs (primary energy resources) to usable form of energy (secondary energy resources). Usable energy form should be such that it is easy to generate, control, transport, and utilize. Electrical energy being the one and only usable form of energy to meet all these at present. Hydrogen energy and heat energy are other usable energy forms that are also being projected.
3. Keep the new energy system pollution free as far as possible, thereby environmentally acceptable to human beings.
4. The development of cheap and reliable energy storage systems. Maintaining new energy development program that is independent of foreign impact to the extent is possible.
5. Energy management.

FACTORS AFFECTING ENERGY RESOURCE DEVELOPMENT

An impartial examination of certain basic principles of energy availability studies reveals the following five factors that make energy resource development more difficult than normally realized.

1 Energy or Fuel Substitution or Scale of Shift

Today, there is no readily available energy resources that is large enough to substitute for fossil fuels (coal, oil, gas, and nuclear) at requisite scale. Undoubtedly, solar energy is several orders of magnitude larger than any conceivable global energy demand (about 10^{17} w). Practical conversion to electricity using photovoltaic or large scale industrial heat are quite negligible.

2 Energy Density

The amount of energy contained in a unit of material object (energy resource) is termed as energy density. Air-dry crop residue (mostly straw and agricultural waste) contain only 12–15 MJ/kg. For example, the energy density of good quality coal is twice as high (i.e., 25–30 MJ/ kg) as that of crude oil (i.e., 42–45 MJ/kg). In order to obtain an equivalent output, replacement of a unit of fossil fuels with approximately 2 kg of phytomass will be needed to substitute solid biofuel. The ratio would be about 1.5

times when substituting plant-derived ethanol for petrol. These realities would be reflected in the reserve capacity, cost, and operation of the required infrastructure.

3 Power Density

Power density refers to the rate of energy production per unit of earth's area and usually expressed in watts per square meters (w/m^2). Owing to lengthy period of formation (from biomass to coal and then from coal to hydrocarbons), fossil fuel deposits are an extraordinarily concentrated source of high quality energy. They are commonly produced with power densities of 10^2 or 10^3 w/m^2 of coal or hydrocarbon field, and hence, only small land areas are required to supply enormous energy flows. In contrast, biomass energy production has densities below 1 w/m^2, while density of electricity produced by water and wind is below 10 w/m^2. Only photovoltaic electricity generation can deliver larger than 20 w/m^2, although the cost and performance are the constraints of mass utilization.

4 Intermittency

Growing demand for fuels, energy, and electricity fluctuates daily and seasonally in modern civilization. Further, the base load, which is defined as the minimum energy required meeting the demand of the day, has been increasing. Easily storable high-energy density fossil fuels and thermal electricity generating stations that are capable of operating with high load factors (775% for the coal-fired stations, 790% for nuclear plants) meet these needs.

On the other hand, wind and direct solar radiation are intermittent and far from practicable. They can never deliver such high load factors. Photovoltaic electric generation is still so negligible to offer any meaningful averages. The annual load factors of wind generation in countries with relatively large capacities are 20–25%. Unfortunately, we still lack the means for storing wind or solar-generated electricity on a large scale.

5 Geographical Energy Distribution

As already mentioned, there are uneven distributions of fossil fuels and the non-fossil fuels (solar, wind, etc.). Cloudiness in the equatorial zone reduces direct solar radiation. Whole stretches of continent has insufficient wind. There are very few sites with the best potential for geothermal, tidal, or ocean energy conversions.

ENERGY RESOURCES AND CLASSIFICATION

The classification of promising energy resources of immediate interests.

Primary and Secondary Energy Resources

1. Primary energy resources are derived directly from natural reserve. Examples are chemical fuels, solar, wind, geothermal, nuclear hydropower, etc. They are used either in basic raw energy form or by converting them to usable form (secondary energy).
2. Secondary energy resources are usable forms of energy generated by means of suitable plants to convert the primary energy. Examples are electrical energy, steam power, hot water power, hydrogen energy, etc.

Usable form of energy is cost effective, highly efficient with improved performance, environmentally acceptable and system acceptability index approaching to unity is achievable during conversion, transportation, distribution, and end use. From the above mentioned viewpoints, electrical energy will continue to be dominant and will also be a usable form of energy till the turn of the century.

Primary energy resources may be further sub-classified as follows:

1. Conventional and non-conventional energy resources:

(a) Conventional energy resources and their technical knowledge are known to mankind to a great extent. They are the energy stored within the earth and the sea. They include both fossil fuels (coal, oil, and gas) and nuclear energy (uranium and thorium) and required human intervention to release the energy from them. These sources have formed over hundreds of millions of years ago and when they are used, there will be no more for future generations. They are also known as finite energy resources.

(b) Non-conventional energy resources are also known as infinite energy resources. Their technical knowledge is little known and they need full exploitation and improved technical understanding. However, it may be mentioned that owing to the cost factor and overall performance, one may think of utilizing all these energy resources only when all the conventional energy resources have been fully exploited and utilized. They are obtained from the energy flowing through the natural environment. It is necessary to note that the energy is passing through the environment as a current or as a flow and whether there is an artificial device there to intercept and harness the power or not. Further, it is important to know the rate at which useful energy can be obtained from these sources.

2. Renewable and non-renewable energy resources:
(a) Renewable energy resources are continuously restored by nature. Examples are solar, water, wind, etc.
(b) Non-renewable energy resources are the reserve that is once accumulated in nature has practically ceased to form under new geological conditions. They are also known as expendable energy. Examples are coal, oil, gas, nuclear, etc. Therefore, energy resources may be represented as shown in Fig.1.2 below.

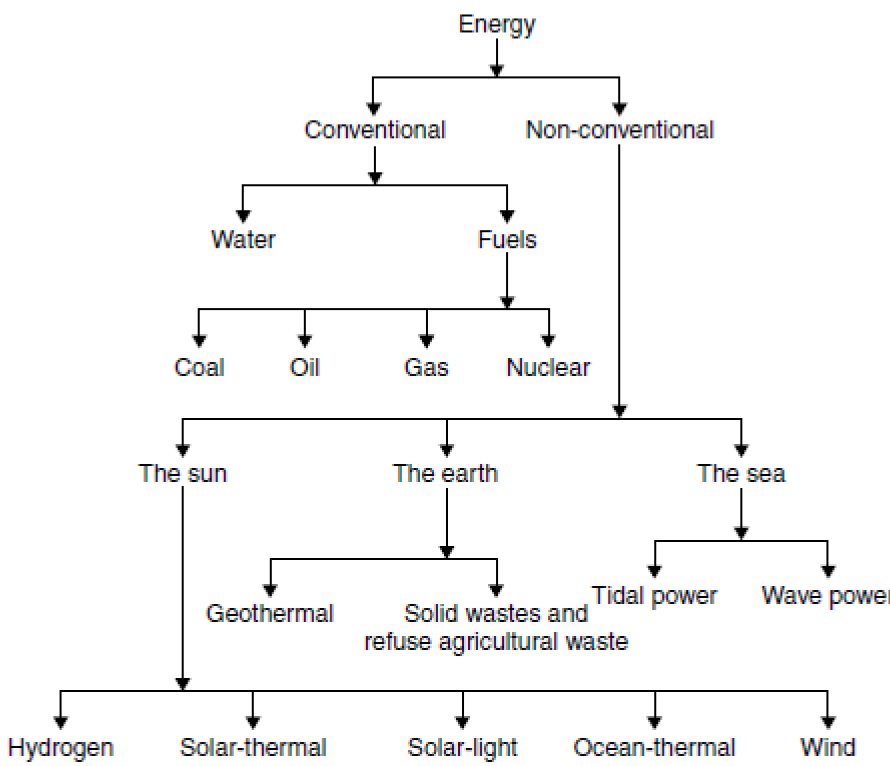


Fig. 1.2 Classification of energy resources

Oil

Oil companies estimate that the world's proven oil reserves are about 1,050 thousand million barrels Estimates of reserves are always subject to uncertainty and change. There is a very uneven distribution of oil reserves across the world, with some 71% of proven oil reserves being in the Middle East. The ultimately recoverable and unconventional reserves are very much more difficult to specify. The estimates of additional reserves that will be found and the growth to existing fields will vary widely. However, there is general agreement that crude oil is a finite resource that will run short and may sometime become very expensive in the first half of this century.

Natural Gas

The proven reserves of natural gas are presently some 152 trillion cubic meters. This is about the same as the reserves of oil. However, because gas is more difficult to transport and trade, there has not been as much effort is put into finding gas when compared with that of finding oil. There are some prospective regions of the world that have not been fully explored. Technologies for extracting gas constantly improve, thus making it difficult to estimate the sizes of the gas fields. The 2001 world gas consumption rate of 2.5 trillion cubic meters per annum (The World Fact book) has doubled over the last 30 years, while oil consumption has only increased some 30%.

Coal

In 1999, the proved recoverable reserves of coal is around one million tonnes. There is much more coal than any other fossil fuel. This is enough to sustain present production for more than 200 years. The world's consumption of coal is still rising (at less than 1% a year), but most industrial countries over recent decades have decreased their dependence on coal. The use of coal is limited more by environmental considerations than by the size of the resource. Modern techniques for burning coal using liquefaction and gasification processes can greatly reduce some of the pollutants from coal. However, coal always produces a great deal of carbon dioxide (greenhouse gas). There had been no cost-effective way developed for capturing and seizing this carbon dioxide, but extensive research programs are underway.

Uranium

The economically accessible reserves of natural uranium were estimated by the World Energy Council in 1999 at three million tonnes. In the 1970s, this was expected to last no more than a few decades, but due to the slower grown than the expected growth in the nuclear industry and increased availability of uranium and the decommissioning of nuclear weapons, this time frame has been extended. There are public reservations about the cost and the safety of nuclear power plants, but they produce almost no CO_2 and the technology is mature.

Hydroelectric Power

At present, hydroelectricity provides the second biggest renewable energy contribution to world energy supply, with an annual output of 2,600 TWh(Terawatt hour). Information received from energy sources indicates that the world's total technically feasible hydro potential is about 14,400 TWh/yr, out of which just over 8,000 TWh/yr is currently considered to be economically feasible for development. Hydropower is dependent on rainfall, and climate change could affect this potential. There is also considerable opposition to the building of large dams for social and environmental reasons.

RENEWABLE ENERGY

Renewable energy is the energy that comes from natural resources such as sunlight, wind, rain, tides, and geothermal heat, which are renewable (naturally replenished). The availability of the renewable energy resources is discussed in the following sections.

1 Worldwide Renewable Energy Availability

About 16% of global final energy consumption comes from renewable as shown in Figure 1.3, with 10% coming from traditional biomass, which is mainly used for heating, and 3.4% from hydroelectricity.

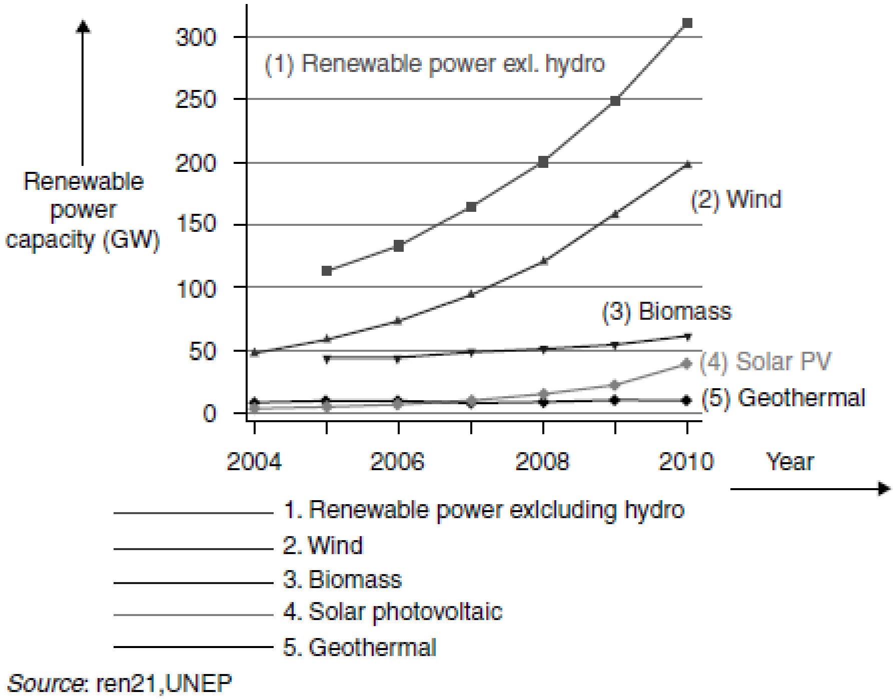


Figure 1.3 Worldwide renewable power capacity excluding hydro

New renewable energy (small hydro, modern biomass, wind, solar, geothermal, and biofuel) accounted for another 3% and were growing very rapidly. The share of renewable energy in electricity generation is around 19%, with 16% of global electricity coming from hydroelectricity, and 3% from new renewable energy. Potential for renewable energy is given in Table 1.2.

Energy resource	**Energy amount**
Solar energy	1,600 EJ (444,000 TWh),
Geothermal	500 EJ (139,000 TWh),
Biomass	250 EJ (70,000 TWh)
Mini hydropower	50 EJ (14,000 TWh)
Ocean energy	1 EJ (280 TWh)

More than half of the energy has been consumed in the last two decades since the industrial revolution, despite advances in efficiency and sustainability. According to IEA world statistics in four years (2004–2008), the world population increased 5%, annual CO2 emissions increased 10%, and gross energy production increased 10%.

Renewable Energy in India

Renewable energy sources have a combined installed capacity of 150+ GW.

As of Feb 2023, Renewable energy sources, including large hydropower, have a combined installed capacity of 174.53 GW.

The following is the installed capacity for Renewables:

- Wind power: 41.9 GW
- Solar Power: 63.3 GW
- Biomass/Co-generation: 10.2 GW
- Small Hydro Power: 4.93 GW

- Waste To Energy: 0.52 GW
- Large Hydro: 46.85 GW

India has set a target to reduce the carbon intensity of the nation's economy by less than 45% by the end of the decade, achieve 50 percent cumulative electric power installed by 2030 from renewables, and achieve net-zero carbon emissions by 2070. Low-carbon technologies could create a market worth up to $80 billion in India by 2030.

India's target is to produce five million Tonnes of green hydrogen by 2030. Green Hydrogen target is set at India's electrolyzer manufacturing capacity is projected to reach 8 GW per year by 2025. The cumulative value of the green hydrogen market in India could reach $8 Bn by 2030 and India will require at least 50 gigawatts (GW) of electrolyzers or more to ramp up hydrogen production.

- India currently has a total renewable energy capacity of 168.96 GW (as on 28th February 2023) with about 82 GW at various stages of implementation and about 41 GW under tendering stage. This includes 64.38 GW Solar Power, 51.79 GW Hydro Power, 42.02 GW Wind Power and 10.77 GW Bio Power
- 59 solar parks of aggregate capacity 40 GW have been approved in India.
- Solar Parks in Pavagada (2 GW), Kurnool (1 GW) and Bhadla-II (2245 MW) included in top 5 operational solar parks of 7 GW capacity in the country.
- The world's largest renewable energy park of 30 GW capacity solar-wind hybrid project is under installation in Gujarat.
- India offers a great opportunity for investments in RE sector; $196.98 Bn worth of projects underway in India.
- Wind Energy has an offshore target of 30 GW by 2030 with 3 potential sites identified.

Energy from the Sun

The sun, which is our singular source of renewable energy, being at the centre of the solar system emits energy as electromagnetic radiation at an extremely large and relatively constant rate, that is, 24/7, throughout the year. The emission rate of this energy is equivalent to the energy produced in a furnace at a temperature of about 6,000 K. If we could harvest the energy coming from just 10 hectares (25 acres) of the surface of the sun, then we would have enough energy to supply the current energy demand of the world.

SUN–EARTH GEOMETRIC RELATIONSHIP

The term earth rotation refers to the spinning of the earth on its axis. One rotation takes exactly 24 h and is called a mean solar day. If one look down at the earth's North Pole from space, he or she would notice that the direction of rotation is counterclockwise. The opposite is true if the earth is viewed from the South Pole.

The orbit of the earth around the sun is called earth revolution. This celestial motion takes 365.25 days to complete one cycle. Furthermore, the earth's orbit around the sun is not circular, but elliptical (as shown in Fig. 1.4). An elliptical orbit causes the earth's distance from the sun to vary annually; however, this phenomenon does not cause the seasons. This annual variation in the distance from the sun does influence the amount of solar radiation intercepted by the earth by approximately 6%. On January 3rd, the earth comes closest to the sun (147.5 million kilometres) each year(Perehelion). The earth is farthest from the sun on July 4th, each year (or aphelion). The average distance of the earth from the sun over a one-year period is 150 million kilometres.

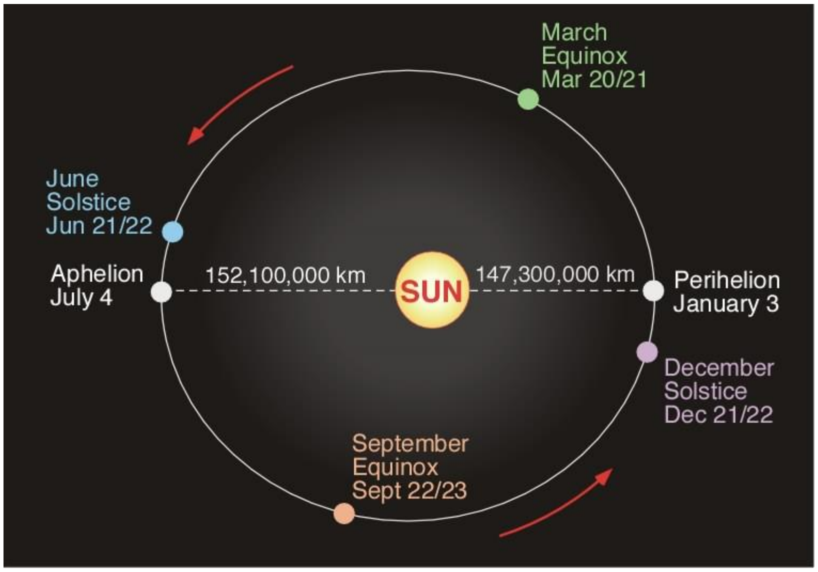


Fig.1.4 Earths revolution around sun

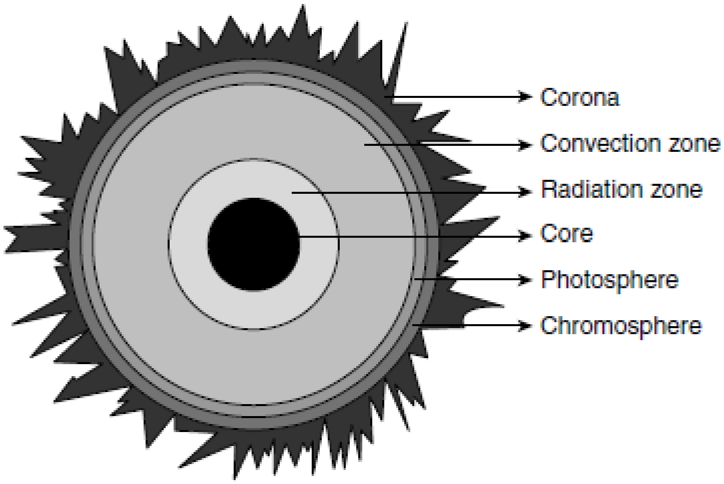
Few observations:

1. The earth's orbit around the sun is elliptical with a mean centre to centre distance from the sun is approximately 9.3×10^6 miles (1.5×10^8 Km).
2. While the earth makes its daily rotation and yearly revolution, the sun also rotates on its axis approximately once every month.
3. The earth's axis of rotation (the polar axis) is always inclined at an angle of 23.5° from the ecliptic axis.
4. This distance from the sun to the earth varies ±1.7% over the average distance. This causes the solar energy reaching the earth to vary ± 3% during a year. The energy is received at its peak on 1st January and the lowest on 1st July.
5. The sun is 109 times larger in diameter than the earth.
6. The sun appears to move across the sky in an arc from east to west, owing to the rotation of the earth around its north-south axis.
7. Viewing the sun from the average miles, it subtends an arc of 0.53° (32 min).

LAYER OF THE SUN

The sun can be divided into following six layers as shown in Figure 1.4:

1. Core
2. Radiative zone
3. Convection zone
4. Photosphere
5. Chromosphere
6. Corona



1 Core

The innermost layer of the sun is called the core. With a density of 160 g/cm^3, which is 10 times that of lead, the core might be expected to be solid. However, the core's temperature of 1,50,00,000°C keeps it in a gaseous state.

In the core, fusion reactions produce energy in the form of gamma rays and neutrinos. Gamma rays are photons with high energy and high frequency. The gamma rays are absorbed and re-emitted by many atoms on their journey from the envelope to the outside of the sun. When gamma rays leave atoms, their average energy is reduced. However, the first law of thermodynamics (which states that energy can neither be created nor be destroyed) plays an important role and the number of photons increases. Each high-energy gamma ray that leaves the solar envelope will eventually become one thousand low-energy photons.

The neutrinos are extremely nonreactive. Several experiments are being performed to measure the neutrino output from the sun. Chemicals containing elements with which neutrinos react are put in large pools in mines, and the neutrinos' passages through the pools can be measured by the rare changes they cause in the nuclei in the pools. For example, perchloroethane contains some isotopes of chlorine with 37 particles in the nucleus (17 protons and 20 neutrons).

These Cl-37 molecules can take in neutrinos and become radioactive Ar-37 (18 protons and 19 neutrons). From the amount of argon present, the number of neutrinos can be calculated.

2. Solar Envelope

Outside of the core is the radiative envelope, which is surrounded by a convective envelope. The temperature is 4 million kelvin (7 million degrees F). The density of the solar envelope is much less than that of the core. The core contains 40% of the sun's mass in 10% of the volume, whereas the solar envelope has 60% of the mass in 90% of the volume. The solar envelope puts pressure on the core and maintains the core's temperature. The hotter a gas is, the more transparent it is.

The solar envelope is cooler and more opaque than the core. It becomes less efficient for energy to move by radiation, and as a result, heat energy starts to build up at the outside of the radioactive zone. The energy begins to move by convection in huge cells of circulating gas with several hundred kilometres in diameter. Convection cells nearer to the outside are smaller than the inner cells. The top of each cell is called a granule. These granules, when observed through a telescope, look like tiny specks of light. Variations in the velocity of particles in granules cause slight wavelength changes in the spectra emitted by the sun.

3 Photosphere

The photosphere is the zone from which the sunlight is both seen and emitted. The photosphere is a comparatively thin layer of low-pressure gasses surrounding the envelope. It is only a few hundred kilometres thick with a temperature of 6,000°C. The composition, temperature, and pressure of the photosphere are revealed by the spectrum of sunlight. When analysing the solar spectrum, William Ramsey discovered helium in 1896 and found that features of the gas did not belong to any gas known on earth. Hence, the newly discovered gas was named as helium in honour of Helios.

4 Chromospheres

During an eclipse, a red circle can sometimes be seen outside the sun. This circle is called the chromospheres. Its red colouring is caused by the abundance of hydrogen. From the centre of the sun to the chromospheres, the temperature decreases proportionally as the distance from the core increases. The chromospheres' temperature, however, is 7,000 K, which is hotter than that of the photosphere. Temperatures continue to increase through the corona.

5 Corona

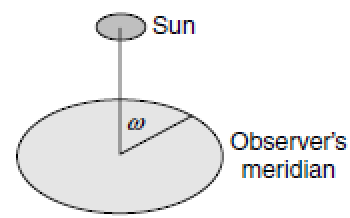
The outermost layer of the sun is called the corona or the crown. The corona is very thin and faint and is, therefore, very difficult to observe from the earth. Typically, we can observe the corona during a total solar eclipse or by using a coronagraph telescope, which simulates an eclipse by covering the bright solar disk. This outer layer is very dim—a million times dimmer than the photosphere and oddly enough, it is the hottest. In Physics, heat is a measure of molecular energy, that is, the movement of molecules within a space. Because the Corona extends several million kilometres into space, there is a lot of room for molecules to move. It is this movement that forms the source of the solar winds. The high temperature of the corona can force ions to move as fast as a million kilometres per hour.

EARTH-SUN ANGLES AND THEIR RELATIONSHIPS

In order to understand how to collect energy from the sun, one must first be able to predict the location of the sun relative to the collection device.

1 Hour Angle (w)

The hour angle is the angular distance between the meridian of the observer and the meridian whose plane contains the sun.



To describe the earth's rotation about its polar axis, the concept of the hour angle (w) is used. As shown in Figure, the hour angle is zero at solar noon (when the sun reaches its highest point in the sky). At this time, the sun is said to be 'due south' (or 'due north', in the Southern Hemisphere) since the meridian plane of the observer contains the sun. The hour angle increases by 15° every hour. An expression to calculate the hour angle from solar time is,

$w = 15 \times (ts - 12)$; (in degrees) --------------------------------------(1.1)

Where, ts is the solar time in hours.

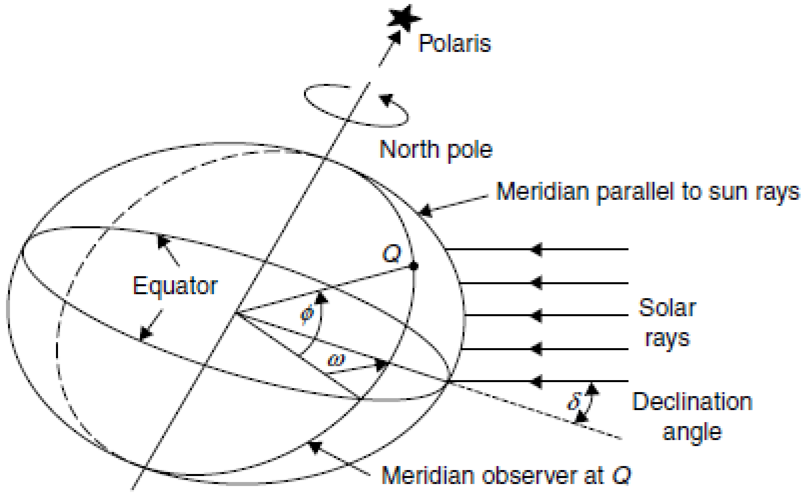
Hour angle (w) can be calculated simply as follows:

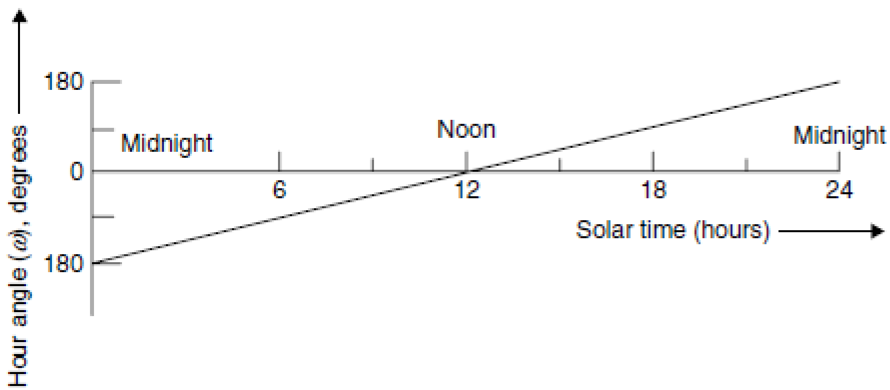
Since the earth makes one revolution on its axis in 24 h, then 15 minutes will be equal to 15/60 = 1/4 min

Therefore,

$w = 1/4 \times tm$; (in degrees) ---(1.2)

Where, tm is the time in minutes after local solar noon. w will be +ve if solar time is after solar noon. However, w will be −ve if solar time is before solar noon as shown in Figure.





SOLAR ENERGY REACHING THE EARTH'S SURFACE

Solar radiation is electromagnetic radiation emitted by the sun. The sun is converting its mass into light particles called photons. The solar radiation that reaches on different locations of earth depends on several factors such as geographic location, time, season, local landscape, local weather, etc. The earth rotates around the sun in an elliptical orbit and is closer to the sun during a part of the year. When the sun is nearer to the earth, the earth's surface receives a little more solar energy. The rotation of the earth is responsible for hourly variations in sunlight.

When sunlight passes through the atmosphere, it is subjected to absorption, scattering, and reflection by air molecules, water vapour, clouds, dust, pollutants, forest fires, etc. When a photon is absorbed, its energy is changed into either electrical energy or heat energy. Scattering occurs when gas molecules and small particles diffuse from the incoming solar radiation in different directions without any alteration to the wavelength of electromagnetic energy. Reflection of solar radiation is a process where sunlight is redirected by 180° after it strikes an atmospheric particle, and mainly reflections are caused by clouds.

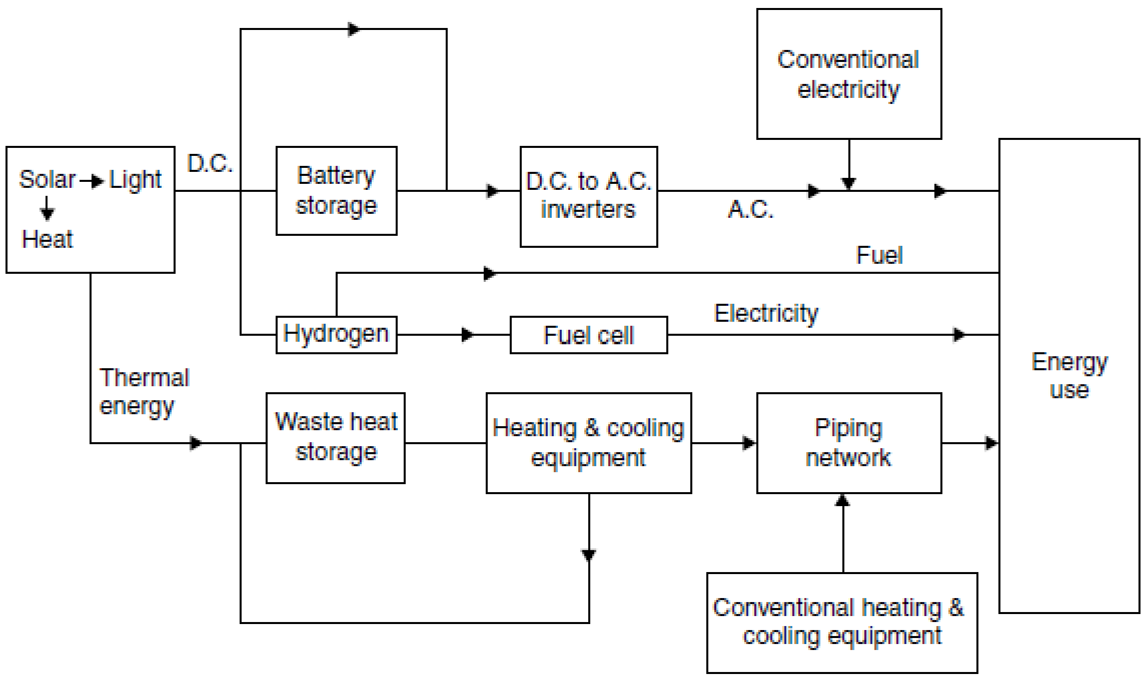
The radiation intensity on the surface of the sun is approximately 6.33 × 107 W/m^2. The solar energy reaching the periphery of the earth's atmosphere is considered to be constant for all practical purposes and is known as the solar constant. Because of the difficulty in achieving accurate measurements, the exact value of the solar constant is not known with certainty, but it is believed to be between 1,353 and 1,395 W/m^2. The solar constant value is estimated on the basis of the solar radiation received on a unit area exposed perpendicularly to the rays of the sun at an average distance between the sun and the earth.

Since radiation spreads out as the distance squared, by the time it travels to at a distance of one astronomical unit (AU) (roughly the mean distance from the sun to the earth), the radiant energy falling on the surface area is reduced to 1,367 W/m^2. There is a variation of solar intensity of about 1%, but this is a slow cycle. It is so small that it is negligible for the purpose of solar power.

It has already been established that huge amount of energy is stored on the earth each year by the radiation of hot solar rays at the average rate of 1.35 kW/m^2, which may be five thousand five hundred times more than the world energy requirement during the next century and is fifty thousand times more than the present-day energy availability from all the sources.
In India, the rate of solar radiation has been found to be 6–8 kWh/m2, which may be considered as one of its important energy resource in the near future, especially for the rural areas.

SOLAR THERMAL ENERGY APPLICATIONS

Energy from the sun can be converted into usable form of energy for multi-purpose utilization as given in Figure 1.5 for the applications based on the controlled technology.



These technologies include passive and active systems.

1 Passive Systems

This system collects energy, without the need for pumps or motors, generally through the orientation, materials, and construction of a collector. These properties allow the collector to absorb, store, and use solar radiation. Passive systems are particularly suited to the design of buildings (where the building itself acts as the collector) and thermo siphoning solar hot water systems.
For new buildings, passive systems generally entail very low or no additional cost because they simply take advantage of the orientation and design of a building to capture and use solar radiation. In colder climates, a passive solar system can reduce heating costs by up to 40%, whereas in hotter climates, it can reduce the absorption of solar radiation and thus reduce cooling costs.
A passive solar system relies on natural sources to transfer heated water for domestic use, which is more prevalent in warmer climates with minor chance of freezing periods.

2 Active System

The most common active systems use pumps to circulate water or another heat absorbing fluid through solar collectors. These collectors are most commonly made of copper tubes bonded to a metal plate, painted black, and encapsulated within an insulated box covered by a glass panel or ‘glazing’. For pool heating and other applications where the desired temperature is less than 40°C, unglazed synthetic rubber materials are most commonly used.

An active pumped system can be either an open loop where the water is directly heated by the solar collector or closed loop where antifreeze or glycol mixture is heated before transferring its heat to the water by a heat exchanger. A popular design of the closed loop system is known as a drain back system. This freeze-proof design drains water back into a small holding tank when freezing temperatures occur.

Find the solar altitude angle at 2 h after local solar noon on 1 June 2012 for a city, which is located at 26.75° N latitude.

Solution The declination on June 1 ($n = 153$) is

$$\delta = 23.45 \times \sin [360 \times (284 + 153)/365] = 22.17° \text{ approximately}$$

The hour angle at 2 h (120 min) after local solar noon is obtained by

$$\omega = 1/4 \times (120) = 30°$$

The solar altitude angle is calculated as follows:

Since solar altitude angle $\theta_z = 90° - \alpha$

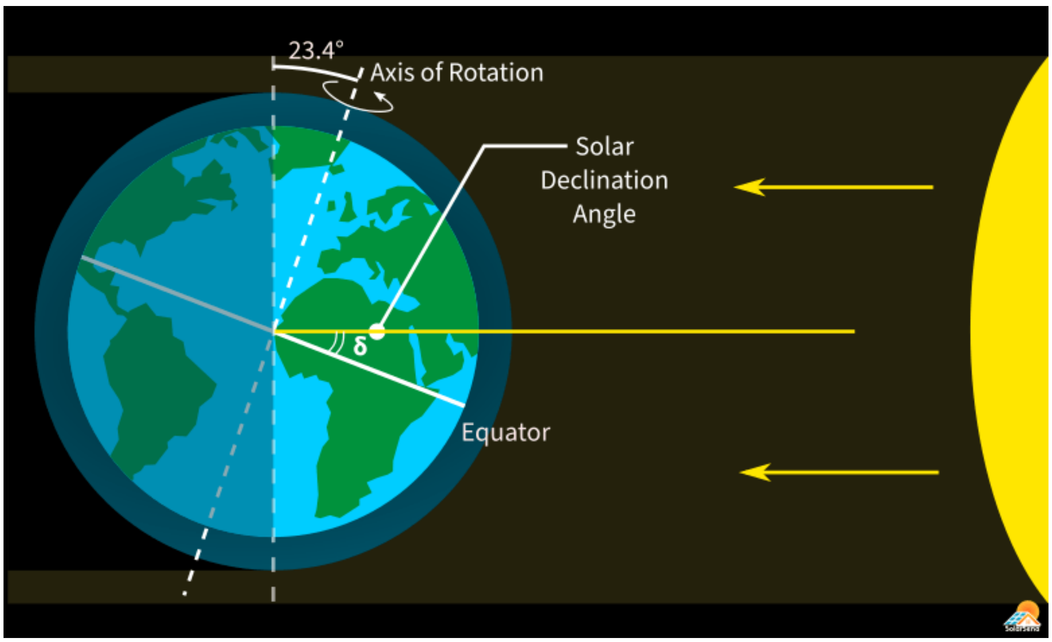
$$\cos \theta_z = \cos (90° - \alpha) = \sin \alpha$$

Therefore, $\sin \alpha = \cos \phi \cdot \cos \delta \cdot \cos \omega + \sin \phi \cdot \sin \delta$

$$= \cos 26.75° \cdot \cos 22.17° \cdot \cos 30° + \sin 26.75° \cdot \sin 22.17° = 0.953$$

$$\alpha = \sin^{-1} (0.953) = 72.364 = 72.4° \text{ approx.}$$

Incident angle. It is the angle between a sun ray incident on a surface and the line perpendicular (called the normal) to the surface at the point of incidence.

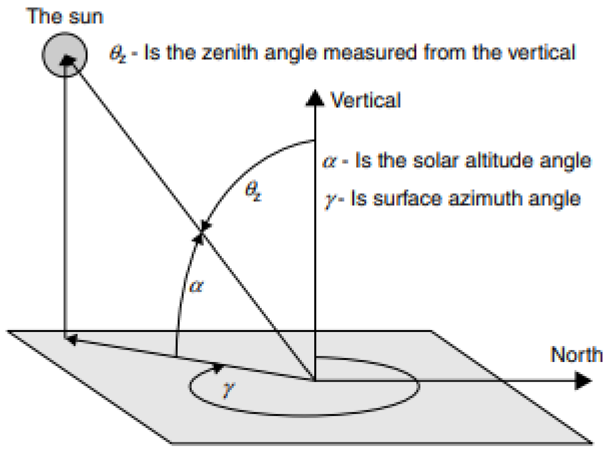


Declination Angle (δ) The declination angle (**δ**) of the sun is the angle between the rays of the sun and the plane of the earth's equator. The earth's axial tilt (called the obliquity of the ecliptic by astronomers) is the angle between the earth's axis and a line perpendicular to the earth's orbit. The earth's axial tilt changes gradually over thousands of years, but its current value is about e = 23°26 '. Because this axial tilt is nearly constant, the solar declination angle (**δ**) varies with the seasons, and its period is one year.

Latitude Angle (ϕ) The latitude angle (ϕ) is the angle between a line drawn from a point on the earth's surface to the centre of the earth and the earth's equatorial plane. The intersection of the equatorial plane with the surface of the earth forms the equator and is designated as 0° latitude.

Solar Altitude Angle (α) It is defined as the angle between the central ray from the sun and a horizontal plane containing the observer, as shown in Figure 1.6.
As an alternative, the sun's altitude may be described in terms of the **solar zenith angle** (θ_Z), which is simply the complement of the solar altitude angle (**α**)

Surface Azimuth Angle (γ) $\theta z = 90° - \alpha$ (in degrees) The other angle defining the position of the sun is the surface azimuth angle (γ). It is the angle measured clockwise on the horizontal plane from the north-pointing coordinate axis to the projection of the sun's central ray.



Source: //www.esrl.noaa.gov/gmd/grad/solcalc/azelzen.gif

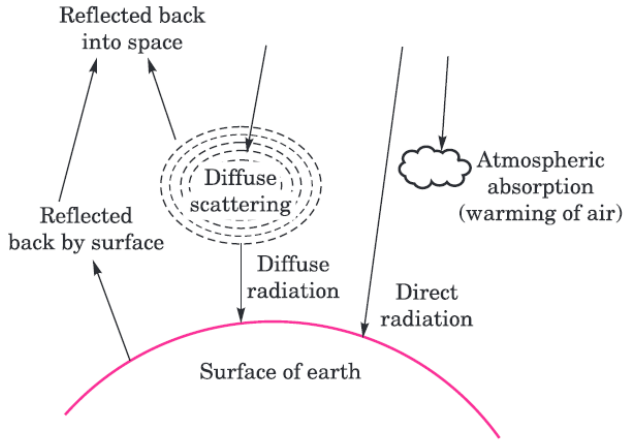
Fundamentals Solar Radiation.
Solar radiation received at the earth's surface is attenuated (or) reduced because it depends on the mechanisms of Absorption and Scattering as it passes through the earth's atmosphere.
The below figure shows the solar radiation reaching the earth's surface.
Absorption of solar radiations in the atmosphere is mainly due to the presence of ozone (O_3), and water vapour (H_2O), and to a lesser extent due to gases like carbon dioxide (CO_2). Carbon Monoxide (CO). Oxygen (O_2), Nitrogen (N_2), and other particulate matter.

The scattering of solar radiation in the atmosphere is mainly due to air molecules, gas molecules as well as dust and water droplets. The scattered radiation is redistributed in all directions, some going back into space and some reaching earth's surface.
The x-rays and extreme ultraviolet (UV) radiations of the sun are absorbed by Nitrogen, Oxygen, and other atmospheric gases. The mechanisms of absorption and scattering are similar. But less attenuation takes place in a cloudless sky and hence maximum solar radiation is received on the earth's surface.

Direct Radiation: Solar radiation received at the earth's surface without a change of direction (i.e., in line) with the sun is called Direct radiation (or) Beam.

Diffuse Radiation: The radiation received at the earth's surface from all parts of the sky's hemisphere (after being subjected to scattering in the atmosphere) is called diffuse radiation.

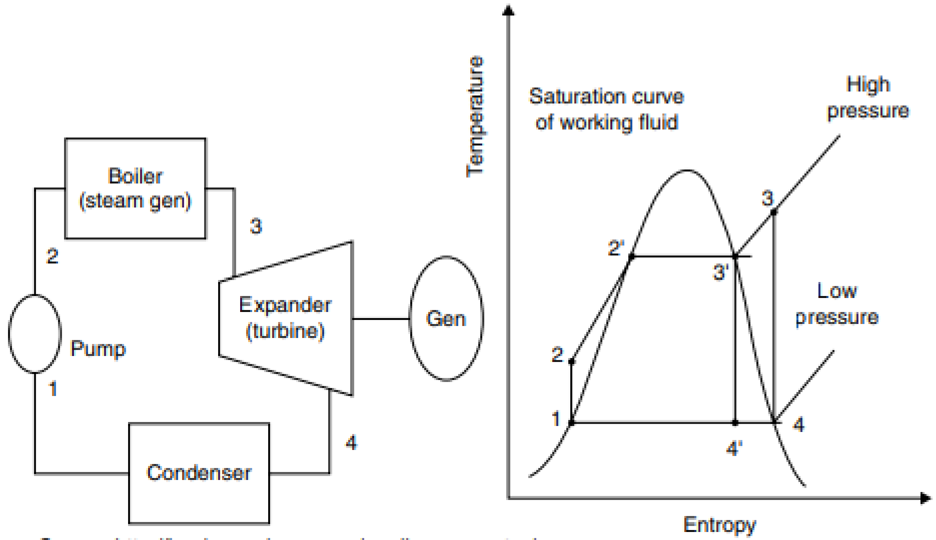
Global Radiation: It is the sum of direct and diffuse radiation at the earth's surface.



Basic Rankine Cycle

The Rankine cycle is a thermodynamic cycle which is used to produce electricity in many power stations. Superheated steam is generated in a boiler and then expanded in a steam turbine. The turbine drives a generator to convert the work into electricity. The remaining steam is then condensed and recycled as feed water to the boiler. A disadvantage of using the water-steam mixture is that superheated steam has to be used; otherwise, the moisture content after expansion might be too high, which would erode the turbine blades. Instead of water, an organic fluid can be used. The major advantage is that these fluids can be used below 400°C and do not need to be overheated. In many cases, superheating is not necessary, resulting in a higher efficiency of the cycle. This is called an Organic Rankine Cycle. The most common power cycle used in solar power systems is, thus, the Rankine cycle, which combines constant-pressure heat addition and rejection processes with adiabatic reversible compression and expansion processes. It utilizes a working fluid that changes phase during the heat transfer processes to provide essentially isothermal heat addition and rejection. The working fluid is usually either water or organic liquids; however, liquid metals have also been used. The following description assumes water or steam as the working fluid.

The major components of a simple, ideal Rankine cycle are depicted in Figure along with the thermodynamic states of the working fluid plotted on temperature–entropy coordinates. Only ideal processes are depicted. The pressure of saturated liquid leaving the condenser at state 1 is raised in an adiabatic, reversible process (Adiabatic refers to a process in which no heat is transferred into or out of a system, and the change in internal energy is only done by work). by the (ideal) pump to state 2, where it enters the vapour generator (also called a boiler or steam generator). The compressed liquid is heated at constant pressure (often called preheat) until it reaches a saturated liquid state 2' and then at constant temperature (and pressure) until all the liquid has vapourized to become saturated vapour at 3'. More heat is added to superheat the saturated vapour at constant pressure, and its temperature rises to state 3'. The superheated vapour now enters an ideal expansion device (often a turbine) and expands in an adiabatic, reversible process to the low pressure maintained by the condenser indicated as state 4. The condenser converts the vapour leaving the turbine to liquid by extracting heat from it. Often during this expansion process, the vapour reaches saturation conditions and a mixture of saturated liquid and saturated vapour forms in the expander. The requirement to superheat the vapour from state 3' to 3 is defined by the amount of moisture that is permitted in the expander exhaust from state 4 to 4'. If the expander is a high-speed turbine, wet vapour produces destructive erosion of the blades. Some types of expanders such as piston and cylinder expanders permit some condensation during the expansion process. However, the amount of superheat is kept to a minimum so that the boiling temperature and the average heat-addition temperature can be maximized.



Source: http://bookcoverimgs.com/pv-diagram-water/