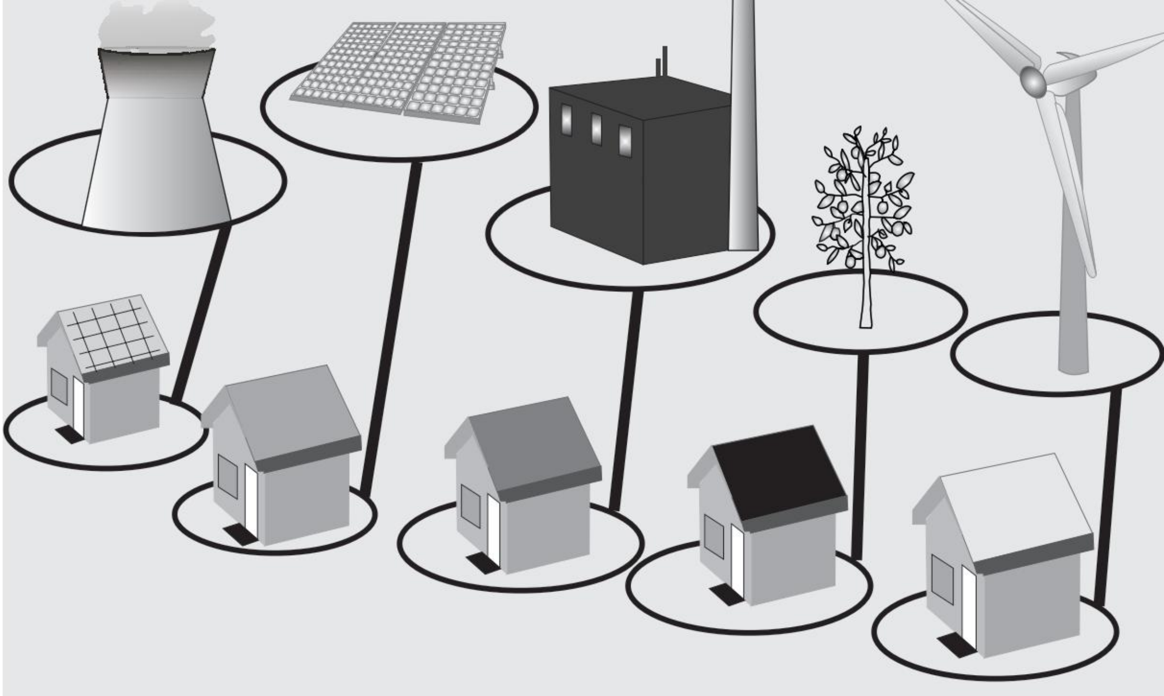

CHAPTER

1

Fundamentals of Energy Science and Technology

Learning Objectives

In this chapter you will be able to:

- ➤ Define basic terms
- ➤ Explain importance of energy in human life
- ➤ Relate energy consumption trend, available options and future planning
- ➤ Extend relationship among economy and environment with energy use
- ➤ Discuss the increasing role of renewable energy
- ➤ Review basic thermodynamics

1.1 INTRODUCTION

Any physical activity in this world whether by human beings or by nature, is caused due to flow of energy in one form or the other. Energy is required to do any kind of work. The word 'energy' itself is derived from Greek word 'en – ergon', which means 'in – work' or 'work content'. The work output depends on the energy input and the capability to do work depends on the amount of energy one can control and utilize.

Man has been using energy at an increasing pace for his sustenance and well-being ever since he came on earth. Primitive man depended on manual work. Since his work output was limited, his energy requirements were met through food intake. Life was simple and with limited demands, and the environment was relatively clean. Later on, he started using animal power to supplement manual energy to enhance his work output. Gradually, he learnt harnessing energy from wind and falling water to further enhance the work output. Much later in 1785, the invention of steam engine by James Watt of Scotland brought industrial revolution. It was the beginning of mechanical age or age of machines. Though increase in energy consumption had been gradual throughout the history, however, post industrialization the rate of consumption showed dramatic increase over a period of just a few generations. The advent of internal combustion engine in the late nineteenth century gave further momentum to the trend. Gradually, industrial revolution spread to the whole world. In 1888, Nickola Tesla invented commercial induction motor. The introduction of electrical machines along with commercial availability of electrical power started the new electrical age. All this led to increase of energy requirement by leaps and bounds. Energy has been the life-blood for continual progress of human civilization. Thus, with progress of human civilization the energy consumption also accelerated.

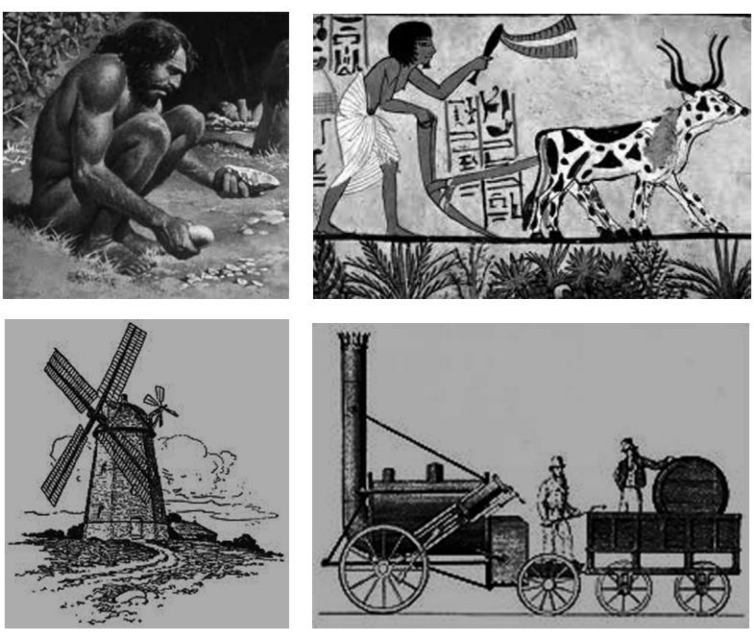

Figure 1.1 Energy use with progress of human civilization

1.2 ENERGY, ECONOMY AND SOCIAL DEVELOPMENT

Energy is universally recognized as one of the most important input for economic growth and human development. Access to modern energy services is fundamental to fulfilling basic social needs, driving economic growth and fueling human development. This is because energy services have an effect on productivity, health, education, safe and potable water and communication services. Modern services such as electricity, natural gas, modern cooking fuel and mechanical power are necessary for improved health and education, better access to information and industrial as well as agricultural productivity. Thus, secure, reliable, affordable, clean and equitable energy supply is fundamental to global economic growth and human development. One of the major challenges facing the world at present is that approximately 1.2 billion people live without any access to modern energy services. Access to energy is a fundamental pre-requisite for modern life and a key tool in eradicating extreme poverty across the globe.

Broadly, there are four major energy end use sectors:

- Commercial
- Industrial
- Residential
- Transportation

As energy is main driving force in all the sectors, consumption of large amount of energy in a country indicates more activities in these sectors. That implies better comfort at home due to use of various appliances of comfort, better transport facilities and more agricultural and industrial production. All this amounts to better quality of life. Therefore, the per capita energy consumption of a country is an index of standard of living or prosperity of the people of the country. In Table 1.1, the comparative data of annual primary energy consumption and GDP of some countries are given to emphasize this point.

Table 1.1 Annual Primary Energy Consumption and GDP of selected countries [1]

S.N.	Country	Per Capita Primary Energy Consumption in KGOE (kg of oil equivalent) (year 2013)	Per Capita GDP in USD (year 2014)
1.	USA	6,909	54,629
2.	Germany	3,874	47,624
3.	UK	2,967	45,603
4.	Japan	3,560	36,194
5.	China	2,143	7,593
6.	India	637	1630
7.	Global Average	1,919 (year 2012)	13,100 (year 2013)

As per International Energy Agency (IEA) data, the 2012 total annual energy consumption of the world was estimated as 375.9 Exajoules (or 8,978 MTOE) [2], out of which 16% energy was consumed by USA, which has about 4.4 per cent of world's population, while 17 per cent of world's population of India consumes only 5.9 per cent of total world energy. This mismatch reflects in the negative differential in the quality of life of the people in these countries. Electricity is considered a necessary requirement for economic and social development. In 2012 annual per capita electrical energy consumption in USA was 12,954 kWh and that in China and India was 3,488 kWh 760 kWh respectively. The average global per capita electrical energy consumption was 2,972 kWh.

Example 1.1

A poor rural family of five persons consumes 1 kg per person per day of firewood for cooking needs and 2 kg of kerosene oil per month for lighting. Calculate the annual primary energy consumption per person in KGOE. Assume heating value of wood as 4000 kcal per kg and that of kerosene oil as 45 MJ per kg.

Solution

Annual firewood consumption of the family for cooking = 5 × 1 kg × 365 = 1825 kg

Annual primary energy required for cooking = 1824 × 4000 kcal = 73,00,000 kcal

= 730 KGOE (refer Appendix A)

Annual kerosene requirement of the family for lighting = 12 × 2 kg = 24 kg

Annual primary energy required for lighting = 24 × 45 = 1080 MJ

$= 1080 \times 23.884 \times 10^{-3}$ KGOE

= 25.795 KGOE (refer Appendix A)

Total annual primary energy consumption of the family = 730 + 25.795

= 755.8 KGOE

Total annual primary energy consumption per person = 755.8 / 5 = 151.2 KGOE

1.3 OIL CRISIS OF 1973

In October 1973 OAPEC (Organization of Arab Petroleum Exporting countries and Egypt, Syria and Tunisia) proclaimed an embargo on oil production and started oil pricing control strategy, in response to support of USA to Israel in its war against Egypt. Oil prices shot up four folds (from 3 USD per barrel) causing severe energy crisis the world over. This resulted in spiraling price rise of various commercial energy sources leading to global inflation. The world financial system, which was already under pressure from the Bretton Woods breakdown, was set on a path of recession and inflation that persisted until the early 1980s, with oil prices continuing to rise until 1986. The world took this shock very seriously and for the first time a need for developing alternative sources of energy was felt. Alternate energy sources were given serious consideration and huge funds were allocated for development of these resources as well as for framing policies for energy conservation. Thus the year 1973 is considered as the year of first 'oil shock'. In the same decade one more 'oil shock' jolted the world in 1979 caused by interruptions in exports from the Middle East, due to the Iranian Revolution. By the end of 1980 the price of crude oil stood at 12 times (over 37 USD per barrel) what it had been just ten years earlier.

1.4 CLASSIFICATION OF ENERGY SOURCES

Energy resources can be classified on the basis of following criteria:

1. Based on Usability of Energy

(a) Primary resources These include resources embodied in nature prior to undergoing any human-made conversions or transformations. This only involves extraction or capture. Examples of primary energy resources are coal, crude oil, sunlight, wind, running rivers, vegetation and radioactive material like uranium etc. These resources are generally available in raw forms and are therefore, known as raw energy resources. Generally, this form of energy cannot be used as such. These are located, explored, extracted, processed and are converted to a form as required by the consumer. Thus some energy is spent in making the resource available to the user in a usable form. The energy yield ratio of an energy extraction process is defined as follows:

$$\text{Energy Yield Ratio} = \frac{\text{Energy received from raw energy source}}{\text{Energy spent to obtain raw energy source}}$$

Only resource for which the energy yield ratio is fairly high, are considered worth exploration.

(b) Secondary Resources The energy resources supplied directly to consumer for utilization after one or more steps of transformation are known as secondary or usable energy, e.g. electrical energy, thermal energy (in the form of steam or hot water), refined fuels or synthetic fuels such as hydrogen fuels, etc.

2. Based on Traditional Use

(a) Conventional Energy resources, which are being traditionally used, for many decades and were in common use around oil crisis of 1973, are called conventional energy resources, e.g. fossil fuels, nuclear and hydro resources.

(b) Non-conventional Energy resources, which are considered for large-scale use after the oil crisis of 1973, are called non-conventional energy sources, e.g. solar, wind, biomass, etc.

3. Based on Long-Term Availability

(a) Non-renewable Resources, which are finite and do not get replenished after their consumption, are called non-renewable e.g. fossil fuels, uranium, etc. They are likely to deplete with time.

(b) Renewable Renewable energy is energy obtained from sources that are essentially inexhaustible. Examples of renewable resources include wind power, solar power, geothermal energy, tidal power and hydroelectric power. The most important feature of renewable energy is that it can be harnessed without the release of harmful pollutants.

4. Based on Commercial Application

(a) Commercial Energy Resource The energy sources that are available in the market for a definite price are known as commercial energy. By far the most important forms of commercial energy are electricity, coal and refined petroleum products. Commercial energy forms the basis of industrial, agricultural, transport and commercial development in the modern world. In the industrialized countries, commercialized fuels are predominant sources not only for economic production, but also for many household tasks of general population.

(b) Non-commercial Energy The energy sources that are not available in the commercial market for a price are classified as non-commercial energy. Non-commercial energy sources include fuels such as firewood, cattle dung and agricultural wastes, which are traditionally gathered, and not bought at a price, used especially in rural households. Non-commercial energy is often ignored in energy accounting. Examples of non-commercial energy are: firewood, agro waste in rural areas, solar energy for water heating, animal power for transport, irrigation and crushing of sugarcane, etc.

5. Based on origin

(a) Fossil fuels energy
(b) Nuclear energy
(c) Hydro energy
(d) Solar energy
(e) Wind energy
(f) Biomass energy
(g) Geothermal energy
(h) Tidal energy
(i) Ocean thermal energy
(j) Ocean wave energy

1.5 CONSUMPTION TREND OF PRIMARY ENERGY RESOURCES

The global average consumption trend of various primary energy resources of the world is indicated in Fig. 1.2, though the trend differs from one country to another [9].

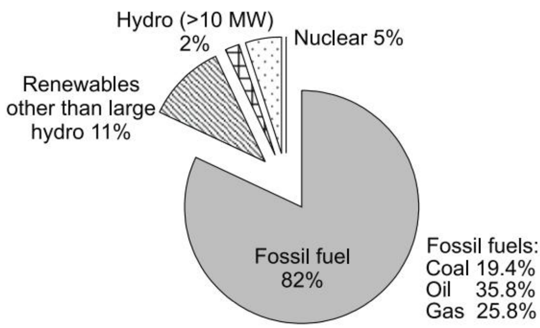

Figure 1.2 Percentage consumption of various primary energy resources

Looking at this figure, the heavy dependence on fossil fuels stands out clearly. About 82 per cent of the world's energy supply comes mainly from fossil fuels.

1.6 IMPORTANCE OF NON-CONVENTIONAL ENERGY SOURCES

The concern for environment due to ever-increasing use of fossil fuels and rapid depletion of these resources has led to development of alternative sources of energy, which are renewable and environment friendly. Following points may be mentioned in this connection:

1. Conventional sources (except hydro) are non-renewable and finite assets. With present rate of consumption their availability is rapidly declining.
2. The demand of energy is increasing exponentially due to rapid industrialization and population growth, the conventional sources of energy alone will not be sufficient in the long run, to meet the growing demand.
3. Conventional sources (fossil fuels, nuclear) also cause pollution leading to degradation of the environment. Ultimately, their use has to be restricted within acceptable limits.
4. Large hydro resources affect wild life, cause deforestation and pose various social problems.
5. In addition to supplying energy, fossil fuels are also used extensively as feedstock for the manufacture of organic chemicals. As reserves deplete, the need for using fossil fuels exclusively for such purposes may become greater.

Due to these reasons it has become important to explore and develop non-conventional energy resources to reduce too much dependence on conventional resources. However, the present trend of developments of non-conventional sources indicate that these will serve as supplement rather than substitute for conventional sources for some more time to come.

Realizing the importance of non-conventional energy sources, in March 1981 the government of India established a Commission for Additional Sources of Energy (CASE) in the Department of Science and Technology, on the lines of the Space and Atomic Energy Commissions. In 1982, CASE was incorporated in the newly created Department of Non-Conventional Energy Sources (DNES) under Ministry of Energy. Also IREDA (Indian Renewable Energy Development Agency Ltd.) a Non-Banking Financial Institution, under the administrative control of ministry was established in 1987 to promote, develop and extend financial assistance for renewable energy and energy efficiency /conservation projects. The DNES was later converted to MNES (Ministry of Non-conventional Energy Sources) in 1992. India was the first country in the world to set up a full-fledged ministry of non-conventional energy resources. In October 2006 the ministry was re-christened as the "Ministry of New and Renewable Energy".

1.7 ENERGY CHAIN

Generally, we cannot use the energy available from primary energy sources directly. For example we cannot drive an electric motor from uranium or coal. The energy available from primary energy source is known as raw energy. This energy undergoes one or more transformation stages before supplying to consumer. The sequence of energy transformations between primary and secondary energy (usable energy) is known as energy chain or energy route.

Primary energy $\xrightarrow[\text{Transformation stages}]{}$ Electrical energy $\xrightarrow[\text{Transmission Line}]{}$ Consumer

Primary energy $\xrightarrow[\text{Transformation stages}]{}$ Usable fuel $\xrightarrow[\text{Transported by rail/road/ocean/pipeline}]{}$ Consumer

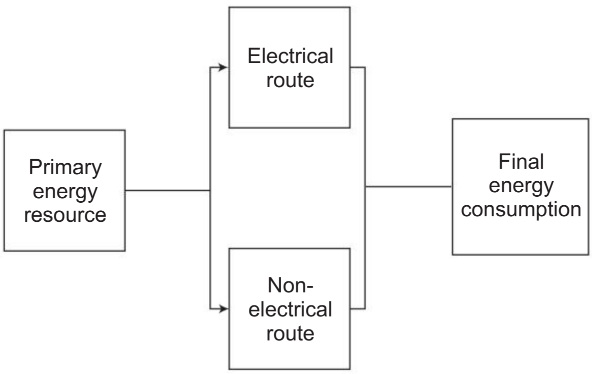

Figure 1.3 Energy routes

1.8 COMMON FORMS OF ENERGY

1. Electrical Energy

Electrical energy is considered to be the top grade energy. It is used universally as vehicle of energy. About 30–40 per cent energy distribution in the world is met through electrical supply system at present. It can be very conveniently and efficiently converted to other forms of energy.

2. Mechanical Energy

Mechanical energy is required for movement of objects, changing the shape of the objects, etc. It is used in transportation, agriculture, handling, processing, and other industrial processes.

3. Thermal Energy

Thermal energy is considered to be of lower grade as compared to electrical and mechanical energy. It is used to raise the temperature of an object during industrial processes. It can also be converted to mechanical energy with the help of heat engines. There are three grades of thermal energy depending on the temperature at which it available:

(a) *High grade* (500–1000 °C and higher): It can be converted efficiently into mechanical energy.

(b) *Medium grade* (150–500 °C): It can be converted into mechanical energy with difficulty and with lower efficiency.

(c) *Low grade* (80-50 °C): It cannot be ordinarily converted into mechanical energy and used mostly for the purpose of heating only.

4. Chemical Energy

Fuels and organic matter contain chemical energy. Exothermic chemical reactions release heat energy. Also chemical energy is directly converted into electrical energy in fuel cells, storage batteries, etc. and into thermal energy by combustion.

1.9 ADVANTAGES AND DISADVANTAGES OF CONVENTIONAL ENERGY SOURCES

Fossil fuels, nuclear and hydro resources are considered as conventional sources. There use has following advantages and disadvantages.

Advantages

1. *Cost* : At present these are cheaper than non-conventional sources.
2. *Security* : As storage is easy and convenient, by storing certain quantity, the energy availability can be ensured for certain period.
3. *Convenience*: These sources are very convenient to use as technology for their conversion and use is universally available.

Disadvantages

1. Fossil fuels generate pollutants. Main pollutants generated in the use of these sources are CO, CO_2, NO_x, SO_x, particulate matter and heat. These pollutants degrade the environment, pose health hazards and cause various other problems. CO_2 is mainly responsible for global warming also.
2. Coal is also a valuable petro-chemical and is used as raw material for various chemical, pharmaceuticals and paints, etc. industries. From long-term point of view it is desirable to conserve coal for future needs.
3. There are safety and technical issues with nuclear energy. Major problems associated with nuclear energy are as follows:
   (a) The waste material generated in nuclear plants has radioactivity of dangerous level; it remains above safe limit for a long period of time and thus is a health hazard. Its safe disposal, which is essential to prevent radioactive pollution, is a challenging task. Also the disposed radioactive waste is required to be guarded for a long period (till its radioactivity level comes down to a safe limit) in order to prevent against going in wrong hands.
   (b) Possibility of accidental leakage of radioactive material from reactor (as happened in Chernobyl, former USSR in April 1986)
   (c) Uranium resource, for which the technology presently exists, has limited availability.
   (d) Sophisticated technology is required for using nuclear resources. Only few countries possess the required expertise to use nuclear energy.

Due to these serious disadvantages Sweden has banned new nuclear plants since 1984 and planned to dismantle the existing plants in a phased manner. Germany is pressing ahead with its long-held policy of phasing out all reactors by 2022. Belgium is following its neighbour's lead, while Spain has no plans to add to its fleet of seven plants. Even France, the poster child for nuclear power, has announced plans to reduce drastically its dependency on atomic energy.

4. Hydroelectric plants are cleanest but large hydro-reservoirs cause following problems:
   (a) As large land area submerges into water, it leads to deforestation
   (b) Causes ecological disturbances such as earthquakes
   (c) Affects wild life
   (d) Causes dislocation of large population and their rehabilitation problems

1.10 SALIENT FEATURES OF NON-CONVENTIONAL ENERGY SOURCES

Merits

1. Non-conventional sources are available in nature free of cost.
2. They produce no or very little pollution. Thus by and large they are environment friendly.
3. They are inexhaustible.
4. They have low gestation period.

Demerits

1. In general the energy is available in dilute form from these sources.
2. Though available freely in nature the cost of harnessing energy from non-conventional sources is generally high.
3. Uncertainty of availability: the energy flow depends on various natural phenomena beyond human control.
4. Difficulty in transporting this form of energy.
5. Difficulty in storage.

1.11 ENERGY DENSITIES (HEATING VALUES) OF VARIOUS FUELS

Table 1.2 Energy densities of various fuels

Primary resource		Energy density
Coal:	Anthracite	32–34 MJ/kg
	Bituminous	26–30 MJ/kg
	Coke	29 MJ/kg
Brown coal:	Lignite (old)	16–24 MJ/kg
	Lignite (new)	10–14 MJ/kg
	Peat	8–9 MJ/kg

Crude petroleum Petrol Diesel	45 MJ/kg 51–52 MJ/kg 45–46 MJ/kg
Natural gas Methane (85% CH_4) Propane Hydrogen	50 MJ/kg, (42 MJ / m^3) 45 MJ/kg, (38 MJ / m^3) 50 MJ/kg, (45 MJ / m^3) 142 MJ/kg, (12 M J / m^3)
Wood	10–11 MJ/kg
Natural Uranium Enriched Uranium U^{233} U^{235} Pu^{239}	$0.26–0.3 \times 10^6$ MJ/kg $2.6–3.0 \times 10^6$ MJ/kg 83×10^6 MJ/kg 82×10^6 MJ/kg 81×10^6 MJ/kg

1.12 ENVIRONMENTAL ASPECTS OF ENERGY

1.12.1 Trade-off between Energy and Environment

Environment literally means surroundings. Air, soil and water are the main constituents of environment. Nature has originally provided them to human beings in clean form. However, with the passage of time, their quality is continuously being degraded due to various manmade reasons. Chief among them are a number of activities involving energy generation and its utilization. During any energy conversion process some energy is expelled by the energy conversion system into surroundings in the form of heat. Also some pollutants may be produced as a by-product of this process. Both of these cause certain degradation of environment. Every step must be taken to conserve the environment. Therefore, while supplying the increased energy demand, efforts should be made to adopt measures to minimize the degradation of environment. The present trend is to have a trade-off between the two. Future seems to be in favour of developing renewable and environment friendly energy resources. To create public awareness about environment conservation, 5th June is observed as 'World Environment Day'.

1.12.2 Ecology

Ecology deals with the relationship existing between living organisms (man, animals, plants and vegetation) and the environment. Normally, nature has self-cleaning capability and recycles (renews) its resources through various processes thus maintaining a state of equilibrium. Water cycle, nitrogen cycle and carbon cycle are the well-known examples of this. However, when human interference exceeds the limits, the ecological balance is disturbed.

1.12.3 Greenhouse Effect

A green house is an enclosure having transparent glass panes or sheets as shown in Fig. 1.4. It behaves differently for incoming visible (short wave) radiation and outgoing infrared (long wave) radiation. It appears as transparent for incoming solar radiation, allowing entry of sunlight and becomes largely opaque for reflected infrared radiation from earth surface, preventing exit of heat. Thus it maintains a controlled warmer environment inside for growth of plants, in places where the climate is very cold.

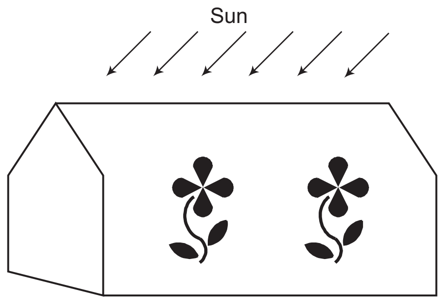

Figure 1.4 A Greenhouse

Carbon dioxide (CO_2) envelope present around the globe in the atmosphere behaves similar to a glass pane and forms a big global green house. This tends to prevent the escape of heat from earth, which leads to global warming. This phenomenon is known as *greenhouse effect*. Apart from CO_2, other gases behaving similar to CO_2 include methane, nitrous oxide (N_2O), hydrofluorocarbons (HFCs), chlorofluorocarbons (CFCs), hydro chlorofluorocarbons (HCFC), sulphur hexafluoride, ozone and water vapor. These gases are known as *greenhouse gases* (GHG). Their average concentrations in atmosphere along with Global Warming Potentials (GWPs) relative to CO_2 and atmospheric lifetimes are listed in Table 1.3.

Table 1.3 Average concentration of various GHGs in atmosphere [4]

S. N.	Name of the Gas	Concentration in ppm	GWP (100 yr time horizon)	Atmospheric lifetime (yrs)
1.	Carbon dioxide (CO_2)	400	1	100-300
2.	Methane (CH_4)	1.893	28	12
3.	Nitrous oxide (N_2O), commonly known as laughing gas	0.326	265	121
4.	Ozone (O_3)	0.337	N.A.*	hours-days
5.	CFC-11 (dichlorofluoromethane) (CCl_3F)	0.000236	4,660	45
6.	CFC-12 (dichlorofluoromethane) (CCl_2F_2)	0.000527	10,200	100
7.	HCFC-22 (hydrochlorodifluoromethane) ($CHClF_2$)	0.000231	1,760	11.9
8.	Carbon tetrachloride (CCl_4)	0.000085	1,730	26
9.	Sulfur hexafluoride (SF_6)	negligible	23,500	3,200
10.	Water vapour	5000 approx. (Horizontal and vertical average)	N. A. #	

* because of short atmospheric lifetime meaningful calculation is not possible.

It is not given a GWP because its concentration depends on air temperature and it does not decay in the environment. Although the greenhouse effect of water vapour is higher than CO_2, it is not a cause of climate change like CO_2.

Example 1.2

A chemical industry produces 5 Tg (teragrams) of N_2O per day. How much pollution is added into the atmosphere per day in terms of carbon equivalent?

Solution

The Global Warming Potential (GWP) of N_2O is 265.
The daily pollution of N_2O = 5 Tg
The daily pollution in terms of equivalent CO_2 (ref. Table 1.3)
= 5 × 265 = 1,325 Tg = 1,325 Million Tons of CO_2
As (12/44) is the carbon to CO_2 molecular weight ratio, the pollution in terms of Million Metric Tons of Carbon Equivalent (MMTCE) = 1,325 × (12/44) = 361.36 MMTCE

1.12.4 Global Warming

The presence of CO_2 in the atmosphere is not undesirable altogether. It is required for the growth of vegetation. Also it is due to its presence the earth maintains an average surface temperature of 15 °C that is hospitable to life. In absence of this layer the earth would be a frozen planet at about −18 °C (the temperature of outer atmosphere) [5]. However, any further increase in the concentration of CO_2 from present level will upset the temperature balance and would cause further warming of globe, which may have disastrous consequences. Mauna Loa Observatory (MLO), Hawaii is a premier atmospheric research facility that has been continuously monitoring and collecting data related to atmospheric changes including CO_2 concentration. *'Global warming is the continuing rise in the average temperature of the earth's atmosphere and ocean's surface due to greenhouse effect'*.

Global warming is being caused mainly due to ever-increasing emission of CO_2 because of burning of fossil fuels for energy in industry. Other sources have comparatively lesser contribution. CH_4 and N_2O are produced due to agricultural practices such as application of fertilizer, management of livestock and their manure. Cultivation of rice also produce smaller amount of CH_4. Chlorofluorocarbons (CFCs) are used as refrigerants but they are slowly being phased out. SF_6 are used in certain industries, for example, they are used as insulator and arc-quenching medium in SF_6 circuit breakers in electrical power system industry.

The concentration of CO_2 which was 280 ppm in 1850 has increased to 400 ppm in 2015 with relatively steep rise after 1950. During this period of 150 years the average earth temperature has increased by 0.5–0.8 °C. Historically, CO_2 concentration has varied cyclically a number of times in the past several hundred thousand years but has never crossed 300 ppm. Air bubbles trapped in Antarctic ice preserve an 800,000-year record of atmospheric carbon dioxide levels, which naturally varied cyclically a number of times from about 180 to about 280 ppm.

1.12.5 Consequences of Global Warming: [6, 7, 8]

Global warming is expected to have far-reaching, long-lasting and, in many cases, devastating consequences for planet Earth. The amount of global emission of CO_2 during 2012 is estimated as 31,734 million tons [2].

The effects of global warming are listed below:

- The average global temperature has increased by about 1.4 degrees Fahrenheit (0.8 degrees Celsius) over the past 100 years, according to the National Oceanic and Atmospheric Administration (NOAA).
- Scientists project that extreme weather events, such as heat waves, droughts, blizzards and rainstorms will continue to occur more often and with greater intensity due to global warming. These changes will likely include major shifts in wind patterns, annual precipitation and seasonal temperatures variations.
- One of the most dramatic effects of global warming is melting of polar ice caps. Most analyses project that, within a matter of years, the Arctic Sea will be completely ice-free during the summer months. Mountain Glacial retreat, too, is an obvious effect of global warming. The area of snow cover on land is also decreasing.
- Rise of sea level is another effect of global warming. There are two major processes by which global warming directly affects sea level. The first is thermal expansion of sea water due to temperature rise. Second, as ice melts, the ocean levels rise. Melting polar ice in the Arctic and Antarctic region, coupled with melting ice sheets and glaciers across Greenland, North America, South America, Europe and Asia, are expected to raise sea levels significantly. In 2014, the World Meteorological Organization reported that sea level rise accelerated 0.12 inches (3 millimeters) per year on average worldwide. This is around double the average annual rise of 0.07 in (1.6 mm) in the twentieth century. Global sea levels have risen about 8 inches since 1870. If current trends continue, many coastal areas where roughly half of the Earth's human population lives will be inundated.
- As levels of CO_2 increase, the oceans absorb some of that gas, which increases the acidity of seawater. Since the industrial revolution began in the early 1700s, the acidity of the oceans has increased about 25 per cent. Many marine organisms make shells out of calcium carbonate (corals, oysters), and their shells dissolve in acid solution. Thus as more and more CO_2 gets added to the ocean, it gets more and more acidic, dissolving more and more shells of sea creatures, which is not good for their health. If current ocean acidification trends continue, coral reefs are expected to become increasingly rare in areas where they are now common.
- The effects of global warming on the earth's ecosystems are expected to be profound and widespread. Migratory birds and insects are now arriving in their summer feeding and nesting grounds several days or weeks earlier than they did in the twentieth century. Warmer temperatures will also expand the range of many disease-causing pathogens that were once confined to tropical and subtropical areas, killing off plant and animal species that formerly were protected from disease.
- In addition to less nutritious food, the effect of global warming on human health is also expected to be serious. The American Medical Association has reported an increase in mosquito-borne diseases like malaria and dengue fever, as well as a rise in cases of chronic conditions like asthma, is already occurring, most likely as a direct result of global warming.

- Agricultural systems are likely to have a crippling blow. Though growing seasons in some areas will expand, the combined impacts of drought, severe weather, lack of snowmelt, greater number and diversity of pests, lower groundwater tables and a loss of arable land could cause severe crop failures and livestock shortages worldwide.

1.12.6 Pollution

1. Indoor Pollution

Indoor pollution is mainly caused due to use of conventional *Chulhas* in rural areas. About 5,00,000 children and women die from diseases caused due to indoor air pollution each year. This requires the need of improved household stove (*Chulhas*) to reduce indoor pollution.

2. Outdoor Pollution

Outdoor pollution is mainly caused due to use of fossil fuels. Emissions from fossil fuel based plants degrade the environment and cause various other problems. Coal and oil are more pollutant than gas.

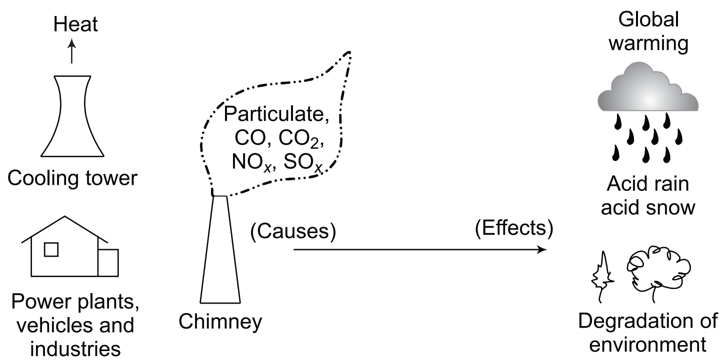

Figure 1.5 Causes and effects of pollution

Remedy

1. Use of fossil fuels should be slowly curtailed and focus should be shifted towards renewable energy sources.
2. Less polluting technologies should be employed for use of fossil fuels, i.e. gasified coal, which is less polluting, should be used instead of solid coal, in power plants.
3. Clean alternative fuels such as hydrogen should be used. Hydrogen is the cleanest fuel and does not cause pollution during power conversion.
4. Electric vehicles or battery-operated vehicles should be used in place of oil fed IC engine based vehicles.

Various Pollutants and Their Harmful Effects

(a) Particulate matter The presence of particulate matter–

- Reduces sunlight
- Reduces visibility

- A level above 100 $\mu g/m^3$ (yearly average) results in respiratory problems
- A level above 300 $\mu g/m^3$ (yearly average) results in bronchitis*

The annual average permissible limit is 75 $\mu g/m^3$

(b) Carbon Dioxide (CO_2) Carbon dioxide is ordinarily not considered a toxic gas. It is essential for photosynthesis and production of essential oxygen and organic matter in nature. But increased concentration of CO_2 adversely affects the global climate. Excess emission of CO_2 in the atmosphere causes global warming due to greenhouse effect.

The increasing CO_2 level in the atmosphere is mainly attributed to the following:

(i) Large-scale combustion of fossil fuels in coal fired thermal power plants all over the world.

(ii) Felling of trees on large scale (deforestation) for urbanization, agriculture, industrialization etc. resulting in reduced photosynthesis process.

(c) Carbon Monoxide (CO) CO is formed due to incomplete burning of carbon in inadequate air. It seriously impairs the oxygen dependent tissues in the body particularly, brain, heart and skeleton muscles. CO concentration of 100 ppm causes headache, 500 ppm causes collapse and 1000 ppm is fatal. Smokers inhale CO concentration of 400 to 450 ppm.

(d) Sulphur Oxides (SO_x) SO_x refers to all sulphur oxides, the two major ones being sulphur dioxide (SO_2) and sulphur trioxide (SO_3). The lifespan of sulphur oxides in the atmosphere is from 4 to 10 days. The presence of SO_2 in air is mainly due to manmade reasons involving combustion of fuels containing sulphur. The contribution from various sources is as follows:

(i)	Power plants	70%
(ii)	Industry	15%
(iii)	Motor Vehicles	8%
(iv)	Solid waste disposal	5%
(v)	Others	2%

Sulphur dioxide (SO_2) can further oxidize to form sulphur trioxide (SO_3), which in turn forms sulphuric acid (H_2SO_4) when absorbed in water.

Harmful Effects

(i) Causes respiratory deceases including asthma, irritates eyes and respiratory track

(ii) Causes acid rains, which is harmful to agriculture, forest, vegetation, soil and stones (and thus to buildings)

(iii) Causes corrosion of metals, deterioration of electrical contacts, paper, textile, building stones, etc.

Safe limit is 80 $\mu g/m^3$ (annual average).

(e) Nitrogen Oxides (NO_x) NO_x is a generic term for the mono-nitrogen oxides: NO and NO_2 (nitric oxide and nitrogen dioxide). They are produced from the reaction of nitrogen and oxygen gases in the air during combustion, especially at

* *Bronchitis*: inflammation of mucus membrane inside the bronchial tubes, branches of wind pipe).

high temperatures. About 80 per cent of nitrogen oxides in atmosphere are produced due to natural causes (biological reactions) and about 20 per cent due to manmade causes: mostly due to combustion process in air at high temperature. Manmade causes include:

(i) Motor vehicles 7%
(ii) Industry 7%
(iii) Power Plants 4%
(iv) Solid waste 2%

Harmful effects

(i) Causes respiratory and cardiovascular illness
(ii) Deprives body tissues of oxygen
(iii) Forms acid in lungs and, therefore, more toxic than CO
(Safe limit is 100 $\mu g/m^3$)

1.12.7 Green Power

The term "green power" is used to describe sources of energy which are considered environment friendly, non-polluting; and therefore may provide a remedy to the systemic effects of certain forms of pollution, and global warming. This is in fact the renewable energy sourced from the sun, the wind, water, biomass and waste, etc.

Green energy is commonly thought of in the context of electricity, heating, and cogeneration, and is becoming increasingly available. Consumers, businesses, and organizations may purchase green energy in order to support further development, help reduce the environmental impacts associated with conventional electricity generation, and increase their nation's energy independence. Renewable energy certificates (green certificates, or green tags) have been one of the ways for consumers and businesses to support green energy.

1.12.8 Amount of Pollutants from Fuel-based Power Plants

Table 1.4 lists the types and amount of pollutants from various fuel-based power plants.

Table 1.4 Amount of pollutants from various fuel-based power plants

Pollutant	Hard coal	Brown coal	Fuel oil	Other oil	Gas
CO_2 (g/GJ)	94,600	101,000	77,400	74,100	56,100
SO_2 (g/GJ)	765	1,361	1,350	228	0.68
NO_x (g/GJ)	292	183	195	129	93.3
CO (g/GJ)	89.1	89.1	15.7	15.7	14.5
Non methane organic compounds (g/GJ)	4.92	7.78	3.70	3.24	1.58
Particulate matter (g/GJ)	1,203	3,254	16	1.91	0.1
Flue gas volume, total (m^3/GJ)	360	444	279	276	272

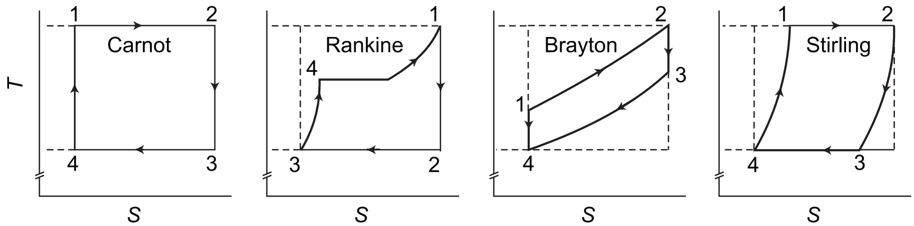

Figure 1.15 Comparison of power cycles

Review Questions

1. How is per the capita energy consumption related with standard of living?
2. Comment on the oil crisis of 1973.
3. What are primary and secondary energy sources?
4. Enumerate the criteria based on which energy can be classified. **(Panjab Tech. Univ., 2008)**
5. What are conventional and non-conventional energy sources?
6. What are the forms and sources of energy? List some reasons, why nonconventional sources are preferred? **(RajasthanTech. Univ., 2011)**
7. Distinguish between renewable and non-renewable energy sources. **(Panjab Tech. Univ., 2008)**
8. List various non-conventional energy resources. Give their availability, relative merits and their classification. **(UPTU Lucknow 2005-06)**
9. 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. **(UPTU Lucknow 2007-08)**
10. What is meant by renewable energy sources?
11. What do you understand by commercial energy?
12. What are the advantages and limitations of non-conventional energy sources?
13. What is the percentage share of fossil fuels in total energy consumption of the world?
14. What percentage of primary energy requirement is met by coal in India?
15. Discuss the main feature of non-conventional energy sources. **(UPTU Lucknow 2003-04)**
16. Discuss different renewable sources of energy with special reference to Indian context. **(UPTU Lucknow 2003-04)**
17. What do you understand by energy chain?
18. What are the advantages and disadvantages of conventional energy sources?
19. What do you understand by greenhouse effect and what are its consequences? How is it caused?
20. What are greenhouse gases?
21. What do you understand by green power?
22. Which is the cleanest of all fuels and what is its heating value?

23. Indicate the heating values of Bituminous coal, coke, peat, diesel, propane and natural uranium.

24. What is the present annual primary energy consumption of the world? At what rate it is growing?

25. Comment on the future availability trend of fossil fuels in the world.

26. What is the present world hydropower potential and how much has been tapped so far?

27. Which country relies maximum on nuclear energy for its energy requirements?

28. What is the present status of nuclear energy and what are its future prospects?

29. What is the potential in solar energy the world over? On average, how much solar power is received on the surface of the earth at noon during bright sun day?

30. What are the prospects of wind and biomass energy?

31. What is meant by renewable energy sources? What are the prospects of nonconventional energy sources in India? **(Visvesrayya Tech. Univ. 2006, Gujarat Tech. Univ., 2014)**

32. Comment on the prospects of fossil fuels in India.

33. What is the status of non-conventional energy sources in India and what are their future prospects?

34. Comment on the growth of energy sector in India.

35. Comment on rural electrification plans of the Government of India.

36. Discuss different renewable sources of energy with special reference to Indian context. **(UPTU, Lucknow, 2003-04)**

37. Describe the main features of various types of renewable and non-renewable energy resources and explain the importance of non-conventional energy sources in the context of global warming. **(UPTU Lucknow, 2007-08)**

PROBLEMS

1. Find the coefficient of performance and heat transfer rate in the condenser of a refrigerator in kJ/h which has a refrigeration capacity of 12,000 kJ/h. The power input to the Carnot engine driving the compressor is 0.75 kW. **(Ans. 4.44, 14700 kJ/h)**

OBJECTIVE TYPE QUESTIONS

1. Which parameter is used as an index for standard of living of the people of a country?
(a) Industrial production
(b) Number of vehicles per house
(c) Per capita energy consumption
(d) Population density

2. What is the per capita electrical energy consumption of India?
(a) 100 kWh/year (b) 150 kWh/year
(c) 400 kWh/year (d) 760 kWh/year

CHAPTER

2 PRINCIPLES OF RADIATION

2.1. SOLAR ENERGY–GENERAL ASPECTS

2.1.1. Sun and Earth

Sun:

- It is a sphere of very hot gases and is largest members of the solar system.
- The diameter of the sun is 1.39×10^6 km.
- The distance between 'sun' and 'earth' is 1.50×10^8 km.
- It completes its one rotation in four weeks when observed from earth. But the equator of the 'sun' takes 27 days and polar regions takes about 30 days for each rotation.
- The heat generation is mainly due to various kinds of fusion reactions but most of the energy is released in which hydrogen (*i.e.,* four protons) combine to form helium. An *effective* black body temperature of sun is 5577 K.

The fusion reaction is as follows:

$$4({}_1H^1) \rightarrow {}_2He^4 + 26.3 \text{ MeV}$$

This energy is produced in the interior of the solar sphere and transmitted out by the radiation into system.

Net energy radiated, $E = \varepsilon\sigma T_s^4$

where ε = Emissivity of surface, σ = Stefan's Boltzmann constant, and T_s = Effective black body surface temperature of sun.

Earth:

- It is almost round in shape and has a diameter of 1.27×10^4 km.
- Its real shape is a sphere flattened at the poles and buldged in the plane normal to the poles.

- The earth's *inner core* is a solid mass made of *iron and nickel* and the next outer core is melted state of iron and nickel. The *outermost portion* is made of *rocks*.
- The existence of blue green algae indicates beginning of photosynthesis at least 3×10^9 years ago. As a result of photosynthesis, the level of O_2 and O_3 is increased in the atmosphere which block the ultra violet (UV) solar radiation coming from the 'sun'. Half the earth is lit by the sunlight at a time. It reflects one-third of the sunlight that falls on it, is known as *earth's albedo*.
- The length of days and nights keep changing because the earth is spinning about its axis which is inclined at an angle of 23.5°.

2.1.2. Solar Energy – An Introduction

The sun emits radiant energy as a *spectrum* corresponding to a 'black body' at a temperature of about 5500°C of which *only a small amount is intercepted by the earth*. Solar radiation is absorbed in the atmosphere and at the earth surface at a rate of 10.3×10^6 W.

The solar irradiance just outside the atmosphere is about 1353 W/m^2. Because solar radiation is *attenuated* as it travels through the atmosphere, the total power falling on horizontal surface, known as the global irradiance, achieves a *maximum of about* 1000 W/m^2 (*i.e.,* 1kW/m^2) at sea level.

Global irradiance is actually made up of two components.

(*i*) *"Direct beam radiation" from the sun* and

(*ii*) *"Diffuse radiation" from the sky* (radiation that has been *scattered* by the atmosphere).

- The amount of radiation received varies throughout the day as the *path of solar radiation* through the atmosphere *lengthens* and *shortens*. For the same reason, seasonal and *lattitudal variations* can cause the total solar energy received (known as **insolation** or **solar irradiation**) to range from an average of 2 MJ/m^2/day (or 0.55 kWh/m^2/day) in a northern winter to an average of 20 MJ/m^2/day (or 5.55 kWh/m^2/day) in the tropical regions of the world.

— The *diffuse energy* may amount to only 15–20 percent of global irradiance on a clear day and 100 percent on a *cloudy day*.

- The solar energy *variability* is important in *system design* and *economics*. Unlike conventional fossil fuel technologies, the performance of solar systems can vary markedly from one location to another. Consequently, to design a system to convert solar energy, one *must have data on the solar radiation received at a particular site*, preferably on a month-to-month basis.

  If the system's size is calculated from the yearly amount of solar energy, it may not provide energy output in months of low insolation. *For convenience, the monthly solar radiation is usually expressed in terms of the daily average irradiation for the month; e.g., MJ/m^2/day*. Most available radiation data are for global irradiation; this is the starting point for assessing a site. *If possible, data should be obtained from the nearest available meterological station,and due allowance made for any localized micro-climate*.
- Solar radiation can be converted to other useful forms of energy, principally: **(*i*) Heat:** This can be used directly to heat or distil water or to dry crops. The relatively simple conversion can be carried out by means of a variety of solar thermal collectors. **(*ii*) Mechanical or Electrical power:** These two forms, which are easily and efficiently interconvertible, can serve a variety of end-uses, including water pumping, lighting and refrigeration.

However, the *energy conversion technology is much more complex than that of heat production*. Conversion can be achieved by *two* completely different routes:

(*i*) Solar thermodynamics.

(*ii*) Solar photovoltaic.

☞ • *Conditions for utilization of solar energy, in India, are favourable* since for nearly six months of the year sunshine is uninterrupted during the day, while in the other six months cloudy weather and rain provide conditions suitable for water power. Thus, a *coordination of solar energy with water power can provide a workable plan for most places in India*.

Following *renewable energy sources find their origin in 'Sun'*.

(*i*) Wind	(*ii*) Ocean thermal
(*iii*) Ocean wave	(*iv*) Ocean tide
(*v*) Geothermal	(*vi*) Biomass
(*vii*) Organic chemicals	(*viii*) Fossil fuels.

2.1.3. Advantages, Disadvantages and Applications of Solar Energy

Following are the advantages, disadvantages and applications of solar energy:

Advantages:

1. It is *clean, cheap* and *abundantly available*.
2. It is *re-usable* source of energy.
3. It is *eco-friendly* (*i.e.,* pollution free)
4. It *decreases* green house gas emissions.

Disadvantages:

1. *High capital cost* due to requirement of large area.
2. *Limited* to sunshine hours.
3. *Need of tracking* due to change in position of sun.
4. There is a need of *storage*.

Applications:

Solar energy is used in:

(*i*) Solar cooling;

(*ii*) Solar water heating;

(*iii*) Solar distillation;

(*iv*) Solar pumping;

(*v*) Electric power generation.

• **Solar energy conversion systems and their applications:**

1. ***Passive heating systems:***

   Low temperature ($t < 150°C$): Cooling; Residential heating; Water heating; Drying; Biomass energy processes; Energy conservation of conventional non-renewables; Green-houses.

2. ***Solar thermal Systems:***

   Medium temperature ($150°C < t > 300°C$): Process heat supply; Hot-water; Steam supply, Heat for chemical industry; Desalination plants.

3. ***Solar thermal systems:***

   High temperature ($t > 300°C$): High temperature steam for industry; Electrical power generation.

4. ***Solar to electrical energy conversion by PV systems:***

   Very small *mV*, *mW* applications; small low voltage, low wattage applications; Medium voltage and medium power applications in kW range upto about 350 kW; Extremely useful for remote, stand-alone applications.

5. ***Solar-diesel hybrid system:***

   Stand-alone power plants rated 1 kW to 350 kW for remote applications, farms, villages, off-shore, mountain, desert *etc*.

6. ***Solar central receiver thermal power plants:***

   Feed power into electrical network, range 1 MW to 200 MW.

2.2 SOLAR ENERGY TERMS AND DEFINITIONS

2.2.1. Solar Radiation

Solar radiation is the *energy radiated by the sun*.

— The *radiated energy received on earth surface is called* ***Solar irradiation***.

— *Solar radiation received on a flat horizontal surface on earth* is called ***Solar insolation***.

The solar radiation is of the following two types:

1. *Extraterrestrial solar radiation*:

The *intensity of sun's radiation outside the earth's atmosphere* is called "*extraterrestrial*" and has no *diffuse components.*

Extraterrestrial radiation is the *measure* of solar radiation that would be received in the *absence of atmosphere*.

2. *Terrestrial solar radiation*:

The *radiation received on the earth surface* is called "*terrestrial radiation*" and is nearly 70 percent of extraterrestrial radiation.

Spectral distribution of solar radiation:

Light rays radiated from the sun are in the form of *electromagnetic waves* in infrared, visible and ultraviolet frequence bands. The *frequency spectrum* of solar light is a *graph of wavelength against power density*, shown in Fig. 2.1.

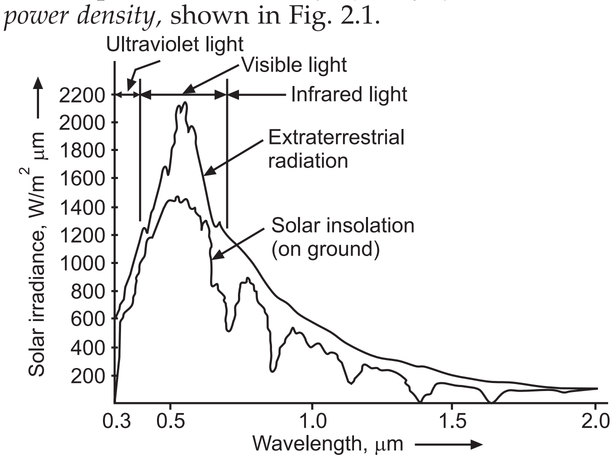

Fig. 2.1. Solar spectrum.

The solar spectrum has the following *three basic levels*:

(*i*) "***Infrared band***" with wavelengths *too long* for response by human eye (frequency range: 4×10^{14} to 7.5×10^{10} Hz) *wavelengths* : between 0.75 micron and 1.95 microns (1 micro, µm = 10^{-6} m).

(*ii*) ***Visible band***: *Frequency range:* 6×10^{16} to 7.69×10^{14} Hz; *Wave lengths:* Between 0.39 micron and 0.75 micron.

(*iii*) ***Ultraviolet band:*** *Frequency range:* 6×10^{16} to 7.5×10^{10} Hz.

Wavelengths: Between 0.005 micron to 0.39 micron.

Terms used in solar radiations:

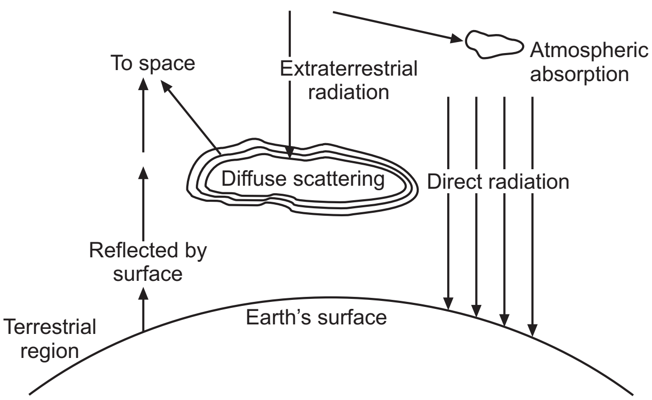

Fig. 2.2. Direct, diffuse and total solar radiations.

Refer to Fig. 2.2.

Beam (or direct) radiation (I_b). *Solar radiation received on the surface of earth without change in directions* is known as "*beam or direct radiation*".

Diffuse radiation (I_d). The solar *radiation received* from the sun *after its direction has been changed by reflection and scattering by atmosphere* is known as "*diffuse radiation*".

Total radiation (I_T). The *sum of beam and diffuse radiations intercepted at the surface of earth per unit area* of *location* is known as "*total radiation*". It is also known as "*Insolation*".

Mathematically: $$I_T = I_b + I_d \quad \text{...(2.1)}$$

Airmass (m_a). *It is the path length of radiation through the atmosphere, considering the vertical path at level as unity.*

m_a = 1, when sun is at zenith (*i.e.,* directly above head).

m_a = 2, when zenith angle (θ_z) is 60°.

m_a = sec θ_z, when $m_a > 3$

m_a = 0 just above the earth's atmosphere

- "*Reasons for variation in solar radiations reaching the earth than received on the outside of the atmosphere*":

  As solar radiations pass through the earth's atmosphere the shortwave '*intraviolet rays*' are 'absorbed' by ozone in atmosphere and the long wave *infrared waves'* are '*absorbed*' by *carbon dioxide* and *moisture* in the atmosphere. A portion of radiations is '*scattered*' by the components of atmosphere such as water vapour and dust. A portion of this scattered radiation always reaches the earth's surface as 'diffuse radiation'. Thus radiations finally received at the earth's surface consists partly of beam radiation and partly of diffuse radiation.

2.2.2 Solar Constant (I_{sc}):

The "*solar constant" (I_{sc}) is the energy from the sun received on a unit area perpendicular to solar rays at the mean distance from the sun (1.5×10^8 km) outside the atmosphere*.

Solar constant is characterised by the following:

(*i*) It is constant and *not* affected by daily, seasonal, atmospheric condition, clarity of atmosphere etc.

$$= -\,0.0161 + 0.4984 = 0.5145$$

$$\therefore \quad \alpha = \sin^{-1}(0.5145) = \mathbf{30.96° \text{ (Ans.)}}$$

Solar azimuth angle, γ_s:

Using the relation:

$$\sin \gamma_s = \sec \alpha .\ \cos \delta .\ \sin \omega \quad \text{...[Eqn. (2.73)]}$$

$$= \sec 30.96° .\ \cos (-1.613°) \sin 52.5°$$

$$= 0.9248$$

or,
$$\gamma_s = \sin^{-1}(0.9248) = \mathbf{67.64° \text{ (Ans.)}}$$

2.3. MEASUREMENT OF SOLAR RADIATION

It is important to measure solar radiation, owing to the increasing number of solar heating and cooling applications, and the necessity for *accurate solar radiation data to predict performance.*

The following *three* devices are used for measuring the solar radiations.

1. Pyranometer;
2. Pyrheliometers;
3. Sunshine recorders.

2.3.1. Pyranometer

A **pyranometer** is *a device used to measure the "total hemispherical solar radiation"*. The total solar radiation arriving at the outer edge of the atmosphere is called the '*solar constant*'.

The *working principle* of this instrument is that sensitive surface is exposed to total (beam, diffuse and reflected from the earth and surrounding) radiations.

The description of a pyranometer is given below:

Refer to Fig. 2.9.

Construction. It consists of a "black surface" which receives the beam as well diffuse radiations which rises heat. A "*glass dome*" prevents the loss of radiation received by the black surface. A "*thermopile*" is a temperature sensor, and consists of a number of thermocouples connected in series to increase the sensitivity. The "*supporting stand*" keeps the black surface in a proper position.

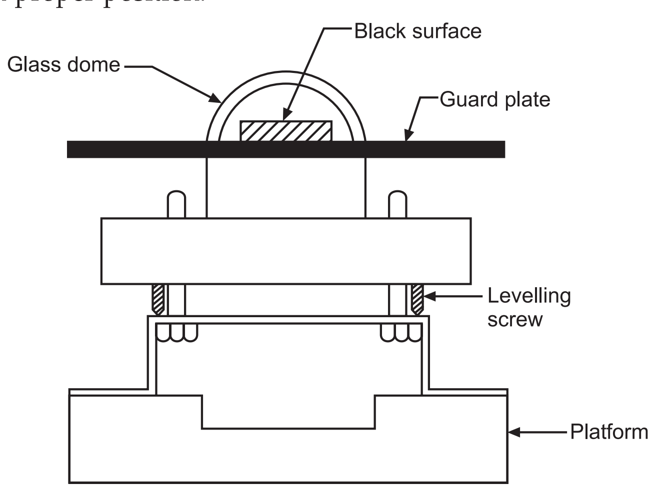

Fig. 2.9. Pyranometer.

Working: When the pyranometer is exposed to sun, it starts receiving the radiations. As a result, the surface temperature starts rising due to absorption of the radiation. The increase in the temperature of the absorbing surface is detected by the *thermopile*. The thermopile generates a *thermo emf* which is *proportional to the radiations absorbed;* this thermo emf is *calibrated in terms of the received radiations.* This will measure the global solar radiations.

2.3.2. Pyrheliometer

A **pyrheliometer** *is a device used to measure "beam or direct radiations".* It collimates the radiation to determine the beam intensity as a function of incident angle.

This instrument uses a collimated detector for measuring solar radiation from the sun and from a small portion of the sky around the sun at normal incidence.

The description of a thermoelectric type pyrheliometer is given below:

Refer to Fig. 2.10.

Construction: In this instrument, two identical blackened manganin strips A and B are arranged in such a way that either can be exposed to radiation at the base of *collimating tubes* by moving a *reversible shutter.*

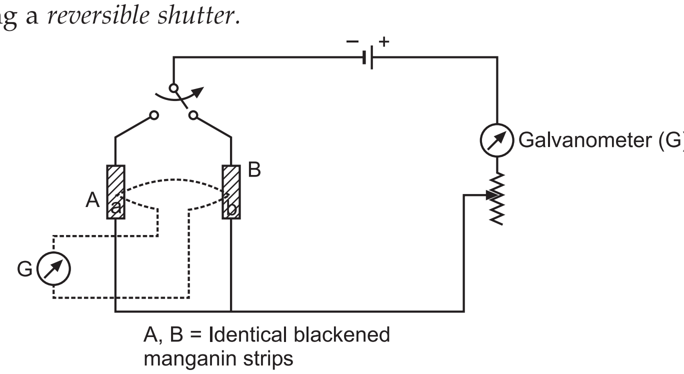

Fig. 2.10. Circuit diagram for the thermoelectric type pyrheliometer.

Working: One strip is placed in radiation and a current is passed through the *shaded strip* to heat it to the same temperature as the *exposed strip*. When there is *no difference in temperature*, the electrical energy supplied to shaded strip *must equal the solar radiation absorbed by the exposed strip*. Solar radiation is then determined by *equating the electrical energy to the product of incident solar radiation, strip area and absorptance.*

2.3.3. Sunshine Recorder

A **sunshine recorder** *is a device used to measure the "hours of bright sunshine in a day".*

The description of a sunshine recorder is given below:

Refer to Fig. 2.11.

Construction: It consist of a "*glass-sphere*" installed in a section of "*spherical metal bowl*" having grooves for holding a *recorder card strip*" and the glass sphere.

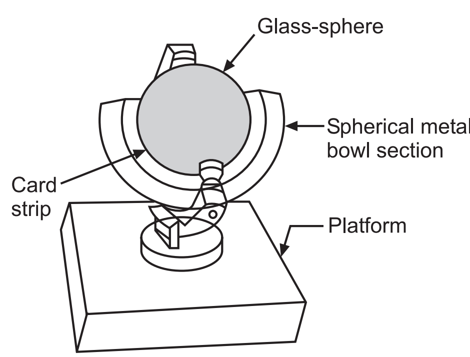

Fig. 2.11. Sunshine recorder.

Working. The glass-sphere, which acts as a convex lens, focusses the sun's rays/beams to a point on the card strip held in a groove in the spherical bowl mounted concentrically with the sphere.

Whenever there is a *bright sunshine, the image formed is intense enough to burn a spot on the card strip*. Through the day, the sun moves across the sky, the image moves along the strip. Thus a burnt space whose *length is proportional to the duration of sunshine* is obtained on the strip.

2.4. SOLAR RADIATION DATA

2.4.1. General Aspects

Solar radiation data should include the following informations:

(*i*) Whether they are *instantaneous* measurements or values *integrated* over some period of time (usually hour or days,) (*ii*) The *time* or *time period* of the measurements; (*iii*) Whether the measurements are of *beam*, *diffuse* or *total radiation* and the *instrument used*; (*iv*) The receiving surface *orientation* (usually horizontal, it may be inclined at a fixed slope or normal); (*v*) If averaged, the *period* over which they are averaged.

An instrument called **Solarimeter** is used to measure most of the data on solar radiation received on the surface of the earth. It gives *readings for instantaneous measurements at rate throughout the day for total radiation on a horizontal surface*. Integrating the plot of rate of energy received per unit area per unit time over a whole day gives the "*langleys*" of radiation received on a horizontal surface (the unit 'langley' has been adopted in honour of Samuel Langley who made the first measurement of the spectral distribution of the sun; 1 *langley = 1 cal/cm*^{2}).

- When data are *not* available, '**Maps**' can be used as a source of average radiation. **Charts** are also available for *clear day horizontal radiation for any period for any latitude.* **Tables** are also available for *hours of sunshine for various locations*.
- The solar radiation data is collected for various locations in the world on the basis of:

1. Solar power calculations with reference to the movement of the sun, latitude of the location etc.
2. Hourly measurements of solar radiation at the location and calculation of:
   (*i*) "*Daily average*" global radiation (H_{dg}) at the location for the month (*kJ/m*^{2}*.day*); (*ii*) "*Monthly average*" global radiation (H_{mg}) at the location for various months (*kJ/m*^{2}*. month*); (*iii*) "*Yearly average*" global radiation (H_{yg}) at the location for a few years (*kJ/m*^{2}*. year*).

The data in terms of kJ/m^2. day or kWh/m^2. day for various days/months/an year can be readily used for calculating:

(*i*) Available solar energy at the location;
(*ii*) Determining the surface area of the solar collectors;
(*iii*) Determining rating of solar plant.

2.4.2. Solar Radiation Data for India

- India is in the "*northern hemisphere*" within latitudes of 7° and 37.5° N.
- The average solar radiation values for India are between 12.5 and 22.7 MJ/m.^{2} day.
- The *peak solar radiation in India* occurs in some parts of Rajasthan and Gujrat and is equal to *25 MJ/m*^{2}.
- The solar radiation *reduces to about 60 percent* during monsoon months.

2.4.3. Solar Insolation

The **solar insolation** *is the solar radiation received on a flat horizontal surface at a particular location on earth at a particular instant of time*.

The *unit of solar radiation is* **W/m²**.

The *parameters of the solar insolation for a given flat horizontal surface are:*

(*i*) Daily variation (hour angle); (*ii*) Seasonal variation and geographical location of the particular surface; (*iii*) Atmospheric clarity; (*iv*) Shadows of trees, tall structures, adjacent solar panels etc.; (*v*) Degree of latitude for location; (*vi*) Surface area m²; (*vii*) Tilt angle.

2.5. ESTIMATION OF AVERAGE SOLAR RADIATION

"Angstrom's equation" for average daily global radiation:

The *expression* for the average radiation on a horizontal surface in terms of constants *a* and *b* and observed values of average length of solar days, as suggested by **Angstrom** (1924) is given by:

$$\frac{H_g}{H_c} = a + b\left(\frac{L_a}{L_m}\right) \quad ...(2.21)$$

where, H_g = Monthly average of the daily global radiation on a horizontal surface at the location (kJ/m² day),

H_c = Monthly average of the daily global radiation on the same horizontal surface at the same location but on *clear* sky day (kJ/m². day),

a, b = Constants determined from various cities in the world by measurements,

L_a = Average length of *solar day* for a particular month calculated/observed (hours), and

L_m = Length of the *longest solar day* in the month (hours).

Modified *Angstrom's equation:*

The modified Angstrom's equation is written by replacing H_c by H_0 in Eqn. (2.21) as:

$$\frac{H_g}{H_o} = a + b\left(\frac{L_a}{L_m}\right) \quad ...(2.22)$$

where, H_o = Monthly average of the daily *extraterrestrial radiation*, which would fall on a horizontal surface at the location under consideration (kJ/m². day).

The expression for H_o is given by:

$$H_o = I_{sc}\left[1 + 0.033\cos\left(\frac{360n}{365}\right)\right]\int[(\sin\phi\sin\delta) + (\cos\phi\cos\delta\sin\omega)]\,dt \quad ...(2.23)$$

where, n = Number of days in the year,

I_{sc} = Solar constant = 4870.8 kJ/m² hour,

ϕ = Angle of latitude for the location,

δ = Angle of declination of equatorial plane, and

ω = Hour angle for local apparent time.

The integral $\int dt$ in Eqn. (2.23) is in terms of hours. It can be changed to angle $\int d\omega$ in radians.

Now, $$1 \text{ hour} = 15° = \frac{15\pi}{180} \text{ rad.}$$

$$\therefore \quad dt = \frac{180}{15\,\pi}d\omega = \frac{12}{\pi}d\omega$$