CHAPTER 1

INTRODUCTION TO ENERGY SOURCE

1.1 Energy – Energy terms – Characteristics of energy – Energy and thermodynamics – Energy parameters – Energy planning – Energy audit – Electrical energy and power – Cogeneration; **1.2 Classification of energy; 1.3 Energy resources; 1.4 Non-conventional energy sources** – Solar energy – Wind energy/power – Energy from biomass and biogas – Ocean energy – Wave energy – Tidal energy/power – Geothermal energy – Hydrogen energy – Thermoelectric power – Fuel cell – MHD generator; **1.5 Renewable and non-renewable energy sources** – Renewable energy sources – Non-renewable energy sources; **1.6 Alternative energy sources; 1.7 Energy scenario in Indian context; 1.8 Electricity generation from non-conventional energy sources; 1.9 Impact of energy sources on environment; 1.10 Fuels** – Classification of fuels – Solid fuels – Liquid fuels – Gaseous fuels – Calorific or heating values of fuels. *Highlights – Theoretical Questions.*

1.1 ENERGY

1.1.1. Energy Terms

- **Energy:** *It is the capability to produce motion, force, work, change in shape, change in form etc.*

Energy exists in several forms such as:

— Chemical energy

— Nuclear energy

— Mechanical energy

— Electrical energy

— Internal energy

— Bio-energy in vegetables and animal bodies

— Thermal energy etc.

- **Energy science:** It focusses attention on the *'energy'* and *'energy transformations'* involved in the various other branches of science to National economy and civilization.
- **Energy technology:** *It is the applied part of energy sciences for work and processes, useful to human society, nations and individuals.*

— Energy technologies deal with plants and processes involved in the energy transformation and *analysis* of the *useful energy* ***(exergy)*** and *worthless energy* ***(anergy).***

— Energy technology co-relates various sciences and technologies.

— Energy technology deals with the complete *energy route and its steps* such as: (*i*) Exploration of energy resources; discovery of new resources; (*ii*) Extraction or tapping of renewable or growing of bio-farms; (*iii*) processing; (*iv*) Intermediate storage; (*v*) Transportation/Transmission; (*vi*) Reprocessing; (*vii*) Intermediate stage; (*viii*) Distribution; (*ix*) Supply; (*x*) Utilisation, conservation, receiving.

1.1.2. Characteristics of Energy

Energy possesses the following *characteristics*:

1. It can be stored.
2. It can neither be created nor destroyed.
3. It is available is several forms.
4. It does not have absolute value.
5. It is associated with a potential. Free flow of energy takes place only from a higher potential to a lower potential.
6. It can be transported from one system to other system or from one place to another place.
7. The energy is measured in Nm or in joules.

The forms of energy are graded as per their availability or energy content.

- The total mass and energy in the closed system remains unchanged (as per law of conservation of energy).

1.1.3. Energy and Thermodynamics

"Thermodynamics" is a branch of energy which deals with conversion of heat into work or vice versa:

— More than 30 per cent energy conversion processes involve *thermodynamics*, while more than 30 per cent energy conversion processes involve *electromagnetic energy* and more than 30 per cent involve *chemical energy*.

In most of the energy conversion processes, First law and Second law of thermodynamics are applicable:

- *First law* of thermodynamics relates to *conservation of energy* and throws light on concept of internal energy.
- *Second law* of thermodynamics indicates the limit of *converting heat into work* and introduces the principle of increase of entropy. Following statements are based on this law:
  - — Spontaneous processes are irreversible.
  - — The internal energy of the environment is worthless for obtaining useful work.
  - — All forms of energy are not identical with reference to useful work.
  - — Every energy conversion process has certain '*losses*'.

1.1.4. Energy Parameters

In order to conserve fuel, it is imperative to adopt measures for maximising economic development with minimum energy consumption.

1. ***Energy intensity***:

The term *'energy intensity'* is defined as *energy consumption per unit of Gross National Product (GNP)*.

When the per unit energy consumption for the production of energy intensive raw materials, like steel and aluminium, is reduced, there may be a marginal fall in energy (GNP ratio) with continuation of the downward trend.

Developed countries have reduced *'energy intensity'*, resulting in less energy consumption and at the same time achieving higher production.

2. ***Energy-GDP elasticity***:

It is defined as the *percentage growth in energy requirement for 1% growth in GDP*.

The *lower* the value of elasticity, the *higher* is the overall efficiency.

- The value of elasticity for the developed countries ranges from 0.8 to 1.0 whereas for India it is about 1.2.

1.1.5. Energy Planning

It is an essential management *tool that decides various activities in advance with reference to resources and time frame*. This includes forecasts, budget, infrastructure, technology, planning etc. The energy policies are framed for the purpose of energy planning and to be followed by the higher to lower hierarchy level.

Energy planning includes the following **steps:**

(*i*) To collect data.

(*ii*) To evaluate trends.

(*iii*) To determine demand.

(*iv*) To determine availability of resources.

(*v*) To plan entire energy route for each sector
  — Exploration/Extraction/Conversion
  — Processing/By product/Cleaning
  — Storage/Transport or Transmission
  — Distribution/Supply.

(*vi*) To evaluate economic viability and decide tariff/rates.

(*vii*) To formulate short-term/mid-term/long-term plans.

1.1.6. Energy Audit

"Energy audit" is *an official survey/study of energy consumption/processing/supplying aspects related with an organisation, system, process, plant, equipment*.

The *objectives* of the 'Energy Audit' are to recommend "steps" to be taken by the management for:

(*i*) Improving the energy efficiencies,

(*ii*) Reducing the energy costs, and

(*iii*) Improving the productivity without sacrificing quality, standard of living/comforts and environmental balance.

The Energy Audit is officially recommended by the *Management* and is carried out by the Energy Audit Group headed by the Energy Auditor.

Energy audit is usually carried out in following *three stages* within certain agreed time frame:

1. Simple Walk – through energy audit.
2. Intermediate Energy audit.
3. Comprehensive/Exhaustive energy audit.

The *procedure of 'Energy Auditing'* is dictated by the *size, complexity* and *recurring energy costs of the plant*.

For energy intensive processes/plants, thorough comprehensive energy audit and high investments in Energy Conservation Measures are justified.

1.1.7. Electrical Energy and Power

1.1.7.1. Electrical Energy

It is an essential gradient for the industrial and all-round development of any country. It is preferred due to the following *advantages:*

(*i*) Can be generated centrally in bulk.

(*ii*) Can be easily and economically transported from one place to another over long distances.

(*iii*) Losses in transport are minimum.

(*iv*) Can be easily sub-divided.

(*v*) Can be adapted easily and efficiently to domestic and mechanical work.

Electrical energy is obtained, conventionally, by *conversion from fossil fuels (coal, oil, natural gas), the nuclear and hydro sources.* Heat energy released by burning fossil fuels or by fusion of nuclear material is converted to electricity by first converting heat energy to the mechanical form through a thermocycle and then converting mechanical energy through generators to the electrical form. *Thermo-cycle is basically a low efficiency process—highest efficiencies for modern large size plants range up to 40%*, while smaller plants may have considerably lower efficiencies. The *earth has fixed non-replenishable resources of fossil fuels and nuclear materials. Hydro-energy,* though replenishable, is also *limited in terms of power.*

In view of the ever increasing per capita energy consumption and exponentially rising population, the earth's non-replenishable fuel resources are not likely to last for a long time. Thus a coordinated world-wide action plan is, therefore, necessary to ensure that energy supply to humanity at large is assured for a long time and at low economic cost. The following *factors* need to be considered and actions to be taken accordingly: (*i*) *Energy consumption curtailment;* (*ii*) *To initiate concerted efforts to develop alternative sources of energy including unconventional sources like solar, tidal, geothermal energy etc. ;* (*iii*) *Recycling* of *nuclear wastes;* (*iv*) *Development and application of anti-pollution technologies.*

Decentralised and Dispersed generation:

☞ • **Decentralised generation:** It covers a local energy source to generate electric power for distribution to consumers in particular area. These may be *mini/microlevel hydel* or *wind turbine units.*

"Sunderbans" in West Bengal was not accessible to grid power but was electrified during 1997 by solar power 410 kW by SPV modules, and biomass-based power plant of (5 × 100) kW.

☞ • **Dispersed generation:** It refers to the use of generating units of *less than 25 kW output* to serve individual homes, business and defence installation in remote areas.

Examples: Diesel generators, solar PV installations, kiosk type mini hydro-plants, fuel cells and wind generators etc.

1.1.7.2. Power

Any physical unit of energy when divided by a unit of time automatically becomes a *unit of power*. However, it is in connection with the mechanical and electrical forms of energy that the term *"power"* is generally used. The rate of production or consumption of heat energy and, to a certain extent, of radiation energy is not ordinarily thought of as power. *Power is primarily associated with mechanical work and electrical energy.* Therefore, ***power*** can be defined as the *rate of flow of energy* and can state that a *power plant* is a *unit built for production and delivery of a flow of mechanical and electrical energy.*

In common usage, a machine or assemblage of equipment that produces and delivers a flow of mechanical or electrical energy is a ***power plant***. Hence, an internal combustion engine is a power plant, a water wheel is a power plant, etc. However, what we generally mean by the term is that assemblage of equipment, permanently located on some chosen site which receives raw energy in the form of a substance capable of being operated on in such a way as to produce electrical energy for delivery from the power plant.

1.1.8. Cogeneration

In a **cogeneration system**, *mechanical work is converted into electrical energy in an "electrical generator"*, and the *discharge heat*, which would otherwise be dispersed to the environment, is *utilised in an "industrial process"* or in other ways. The *net result is an overall increase in the efficiency of fuel utilisation*.

Cogeneration is *the simultaneous generation of electricity and steam (or heat) in a single power plant*.

It is *highly energy efficient* and is especially suitable for sugar mills, textile, paper, fertilizer and crude oil refining industries.

Cogeneration is *advisable* for industries and municipalities if they can produce electricity cheaper, or more conveniently than brought from a utility. It is *not* usually used by large utilities which tend to produce *electricity only*.

Cogeneration (from energy resource point of view) is *beneficial only* if it *saves primary energy* when compared with separate generation of electricity and steam or heat.

Cogeneration of heat and electricity can be dealt with in the following *two ways*:

1. **Topping cycle.** In this mode, fuel is burnt to generate electric power and the *discharged heat from the turbine is supplied as 'process heat'*. The requirements of process steam pressure vary widely between 0.5 bar and 40 bar.

   - This cycle can *provide true savings in primary energy*.

2. **Bottoming cycle.** In this mode, *fuel is consumed to process heat*, and *waste heat is then utilised for power generation*.

1.2. CLASSIFICATION OF ENERGY

Energy may be *classified* as follows:

Energy:

1. *Stored in earth:*
   - (*i*) Chemically bonded:
     - (*a*) Oil
     - (*b*) Gas
     - (*c*) Coal
   - (*ii*) Geotherm
   - (*iii*) Atomic:
     - (*a*) Fission
     - (*b*) Fusion (futuristic)
2. *Continually received by earth:*
   - Solar insolation
     - (*a*) Ocean temp. difference
     - (*b*) Tidal
     - (*c*) Hydro
       - — Irrigation
       - — Other benefits (flood control etc.)
       - — Hydroelectric (no thermal limits)

Water input

Thermocycle

- —Steam turbo-generator
- —Gas turbo-generator-combined cycle
- —M.H.D. combined cycle

Conservation

- — Cogeneration
- — High thermal generation
- — Low trans. loss
- — High efficiency motors
- — Curb wasteful use

(*d*) Wind
— Wind mill generator

(*e*) Direct
— PVC
— Concentrator—Steam turbine

1.3 ENERGY RESOURCES

The various sources of energy can be *classified* as follows:

A. 1. **Commercial (or Conventional) energy sources:**

(*i*) Coal

(*ii*) Lignite

(*iii*) Oil and natural gas

(*iv*) Hydroelectric

(*v*) Nuclear fuels.

These sources form the basis of industrial, agricultural transport and commercial development in the modern world. In the industrialised countries, commercialised fuels are predominant source not only for economic production, but also for many household tasks of general population.

2. Renewable energy sources:

(*i*) Solar photo-voltaic
(*ii*) Wind
(*iii*) Hydrogen fuel-cell.

3. New sources of energy:

Most prominent *new sources of energy* as identified by UN are:

(*i*) Tidal energy
(*ii*) Ocean waves
(*iii*) OTEC (Ocean Thermal Energy Conversion)
(*iv*) Geothermal energy
(*v*) Peat
(*vi*) Tar sand
(*vii*) Oil shales
(*viii*) Coal tar
(*ix*) Draught animals
(*x*) Agricultural residues etc.

- *Coal, oil, gas, uranium and hydro* are commonly known as ***"commercial" or "conventional energy sources"***. These represent about 92% of the total energy used in the world.
- *Firewood, animal dung and agricultural waste* etc. are called as ***non-commercial energy sources.*** These represent about 8% of the total energy used in the world.

As per Planning Commission of India, the geographical distribution of various energy resources available in the country are given in Table 1.1

Table 1.1. Primary Commercial Energy Resources

Region of India	Coal (*Bt*)	Lignite (*Bt*)	Crude oil (*Mt*)	Natural gas (*BCM*)	Hydropower (*TWH*)
Northern	1.06	2.51	0.03	0.00	225.00
Western	56.90	1.87	519.47	516.42	31.40
Southern	15.46	30.38	45.84	80.94	61.80
Eastern	146.67	0.00	2.19	0.29	42.50
North-Eastern	0.89	0.00	166.17	152.00	239.30
Total	220.98	34.76	733.70	749.65	600.00

Bt = Billion tonnes; *Mt* = Million tonnes; *BCM* = Billion cubic metres; *TWH* = Trillion Watt hours.

The production of commercial primary energy resources is shown in Table 1.2.

Table 1.2. Production of Commercial Energy Sources

Source of energy	Unit	Production Periods					
		1960-61	1970-71	1980-81	1990-91	2001-02	2006-07
Coal	Mt	55.67	72.95	114.01	211.73	325.65	405.00
Lignite	Mt	0.05	3.39	4.80	14.07	24.30	55.96
Crude oil	Mt	0.45	6.82	10.51	33.02	32.03	33.97
Natural gas	BCM	—	1.44	2.35	1.79	29.69	37.62
Hydro Power	BkWh	7.84	25.25	46.54	71.66	82.80	103.49
Nuclear Power	BkWh	—	2.42	3.00	6.14	16.92	19.30

B. The energy sources *can also be classified* as follows:

1. Primary energy sources. These sources are obtained from environment.

Examples: Fossil fuels, Solar energy, Hydro energy and Tidal energy.

These resources can further be classified as:

(*a*) (*i*) **Conventional energy sources:**

Examples: Thermal power and hydel power.

(*ii*) **Non-conventional energy sources:**

Examples: Wind energy, Geothermal energy, Solar energy and Tidal energy.

(*b*) (*i*) **Renewable:** These sources are being *continuously produced in nature and are inexhaustible.*

Examples: Wood, Wind energy, Biomass, Biogas, Solar energy etc.

(*ii*) **Non-renewable:** These are *finite and exhaustible.*

Examples: Coal, petroleum etc.

2. Secondary energy resources. These resources do not occur in nature but are *derived from primary energy resources.*

Examples: Electrical energy from coal burning, H_2 obtained from hydrolysis of H_2O.

Fossile fuel as a conventional energy source:

Some of the fossil fuels are discussed briefly below:

1. Coal. It is a conventional energy source and is formed due to conversion of vegetable matter. It is composed of mainly *carbon* and *hydrocarbons*. It is found in Jharkhand, UP, MP, Bihar etc. in India.

Use of coal:

1. It is used to generate electricity. Power plants use coal for heating the water to generate steam which runs the turbines to generate electricity.

2. It is heated in a furnace to make coke, which is used to smelt iron for making steel.
3. The heat obtained from coal is used by various industries in making plastics, tar, synthetic fibre, etc.

Environmental problems:

(*i*) Due to combustion of coal, CO_2 is produced which is responsible for causing *global warming*.

(*ii*) Coal also produces SO_2 which is a cause for *acid rain*.

2. Natural gas. It is one of the fossil fuels and is formed by decomposition of remains of dead animals and plants buried under the earth. It is mainly composed of methane (CH_4) with small amount of propane and ethane. When refined, it is colourless and odorless, but can be *burned to release large amount of energy*.

- *It is the cleanest fossil fuel.*

Merits

1. It has a high calorific value and it burns without smoke.
2. It can be easily transported through pipelines.

Uses

1. It is used in thermal power plants for generating electricity.
2. It is used as domestic and industrial fuel.

Reserves and production of "petroleum" and "natural gas" in India with problem areas:

Almost 40 per cent of the energy needs of the world, are met by oil. The rising prices of oil has brought a considerable strain to the economy of world, more so in the case of the developing countries that do not possess oil resources enough for their own consumption.

With today's consumption and a resource amount of 2.5×10^5 million tonnes of oil, it is estimated that it may suffice for about 100 years unless more oil is discovered. As such, the world must start thinking of a change from a world economy dominated by oil.

Petroleum. India is not particularly rich in petroleum reserves. Our fuel oils are produced by *refining petroleum or crude oil*. The potential oil-bearing areas are located in Assam, Tripura, Manipur, West Bengal, Ganga Valley, Punjab, Himachal Pradesh, Kutch, eastern and western coastal areas (in Tamil Nadu, Andhra Pradesh and Kerala), Andaman and Nicobar Islands, Lakshadweep, and in the continental shelves adjoining these areas.

Gas. Gas is *incompletely* utilised at present and huge quantities are burnt off in the oil production process because of the non-availability of ready market. The reason may be the high transportation cost of the gas. Transporting gas is *costlier* than transporting oil. Large reserves are estimated to be located in inaccessible areas.

Gaseous fuels can be *classified* as: (*i*) Gases of *fixed composition* such as acetylene, ethylene, methane etc; (*ii*) Composite industrial gases such as producer gas, coke oven gas, blast furnace gas etc.

Note. Energy cannot be economically stored in electrical form in large quantities. Energy in large quantities is stored in conventional forms (Hydro-reservoirs, coal stocks, fuel stocks, nuclear fuel stocks). Electrical energy is generated, transmitted and utilised almost simultaneously without intermediate storage in electrical form. Hence a large *electrical network* is formed *to pool up electrical energy* available from various generating stations and to distribute to various consumers over the large geographical area. Consumers draw power as per their load requirement (*e.g*. lighting, heating, mechanical drives etc.)

1.4 NON-CONVENTIONAL ENERGY SOURCES

A plenty of energy is needed to sustain industrial growth and agricultural production. The existing sources of energy such as coal, oil, uranium etc. may not be adequate to meet the ever increasing energy demands. These conventional sources of energy are also depleting and may be exhausted at the end of the century or beginning of the next century. Consequently sincere and untiring efforts shall have to be made by the scientists and engineers in exploring the possibilities of harnessing energy from several non-conventional energy sources. The various non-conventional energy sources are as follows:

(*i*) Solar energy
(*ii*) Wind energy
(*iii*) Energy from biomass and biogas
(*iv*) Ocean thermal energy conversion
(*v*) Tidal energy
(*vi*) Geothermal energy
(*vii*) Hydrogen energy
(*viii*) Fuel cells
(*ix*) Magneto-hydro-dynamic generator
(*x*) Thermionic converter
(*xi*) Thermo-electric power.

Advantages of non-conventional energy sources:

The leading advantages of non-conventional energy sources are:

1. They do not pollute the atmosphere.
2. They are available in large quantities.
3. They are well suited for decentralised use.

According to energy experts the non-conventional energy sources can be used with advantage for *power generation* as well as other applications in a large number of locations and situations in our country.

- The non-conventional energy programme was initiated in *India* in *1983-84*, managed and implemented by MNES (Ministry of Non-conventional Energy Sources), Govt. of India.

The estimated potential of non-conventional energy resources in India is as given below:

	Category	Estimated potential (MW)
1.	Wind power	45,195
2.	Biomass power	16,881
3.	Small hydro	15,000
4.	Cogeneration Bagasse	5,000
5.	Waste energy	2,700
6.	Solar power (Grid)	2,533

Brief description of important non-conventional energy sources:

1.4.1. Solar Energy

On this planet, human life and all other forms of life are completely dependent on the daily flow of solar energy. The production of food and all other life-support systems of the natural environment are dependent on the sun.

- **Solar energy** travels in small particles called *photons*. Converting even a part of the solar energy at even a very low efficiency can result in a *far more* energy that could conceivably be harnessed or utilised for power generation.
- The amount of solar energy is expressed in *"solar constant"*. The solar constant is the total energy that falls on a unit area exposed normally to the rays of the sun, at the average sun-earth distance.

The most accepted value of solar constant is *1.353 kW/m²*. A number of scattering and absorption processes in the atmosphere *reduce* the maximum heat flux reaching the earth's surface to around *1 kW/m²*.

The heat flux reaches earth's surface by two modes: (*i*) Direct (*ii*) Diffuse. It is the *only direct heat energy* which can be collected through a *"collector"*. The *ratio* of direct to totally heat energy varies from place to place and depends on atmospheric conditions like dust, smoke, water vapour and other suspended matter. The *ratio varies between 0.64* and *0.88* according to different investigators.

Since the altitude of the sun and length of day vary with the season, the solar energy received on a summer day is *many times* the energy received on a winter day. As a result the *total energy for most of the areas in plains in India is around 6000 MJ/m² per year*.

Advantages:

1. It is a renewable source of energy.

2. Free of cost.
3. Non-polluting source of energy.

Disadvantages:

1. *Low efficiency.*
2. It is of intermittent type in nature, so for night hours this energy is not available, and as such, *storage is required*.

☞ **Impact on environment:**

1. Solar thermal system may pose a *health hazard* because of the careless disposal of the heat transfer fluids (*e.g.* glycol nitrates and sulphates; CFCs and aromatic alcohols) used.
2. Solar photovoltaic modules pose disposal problems owing to the presence of arsenic and cadmium.
3. The total system comprising solar power generator with accessories contain several pollutants.
4. Solar reflectors cause hazard to eyesight.

1.4.2. Wind Energy

Man has been served by the power from winds for many centuries but the total amount of energy generated in this manner is *small*. The expense of installation and variability of operation have tended to *limit* the use of the windmill to intermittent services where *its variable output has no serious disadvantage.* The principal services of this nature are the *pumping of water into storage tanks and the charging of storage batteries.*

- Windmill power equipment may be *classified* as follows:
  1. *The multi-bladed turbine wheel*. This is the foremost type in use and its efficiency is about 10 per cent of the kinetic energy of the wind passing through it.
  2. *The high-speed propeller type.*
  3. *The rotor*.

- The propeller and rotor types are *suitable for the generation of electrical energy,* as both of them possess the ability to start in very low winds. The *Propeller type is more likely to be used in small units* such as the driving of small battery charging generators, whereas the *rotor,* which is rarely, seen, is more practical *for large installations,* even of several hundred kilowatts capacity.
- In India, the wind velocity along coastline has a range 10-16 kmph and a survey of wind power has revealed that wind power is capable of exploitation for pumping water from deep wells or for generating small amounts of electric energy.

Modern windmills are capable of working on velocities as low as 3-7 kmph while *maximum efficiency is attained at 10-12 kmph.*

- A normal working life of 20 to 25 years is estimated for windmills.
- The great advantage of this source of energy is that *no operator is needed and no maintenance and repairs are necessary for long intervals.*

Merits/Characteristics of wind power/energy. Some characteristics of wind energy are given below:

1. No fuel provision and transport are required in wind energy systems.
2. It is a renewable source of energy.
3. Wind power systems are non-polluting.

4. Wind power systems, up to a few kW, are less costly, but on a large scale, costs can be competitive with conventional electricity. Lower costs can be achieved by mass production.

Demerits/Problems associated with wind energy:

1. Wind energy systems are *noisy in operation*.
2. *Large areas* are needed to install *wind farms* for electrical power generators.
3. Wind energy available is *dilute and fluctuating in nature*. Because of dilute form, conversion machines have to be necessarily large.
4. Wind energy *needs storage means* because of its irregularity.

☞ **Impact on environment:**

1. The development of wind farm in a forest area needs *cutting of trees* leading to *environmental degradation*.
2. The environment is degraded due to noise pollution caused by wind turbines.
3. Interference of large wind turbines with television signals (through reflection).
4. Visual intrusion of wind turbines gives negative public response on the existing landscape.

1.4.3. Energy from Biomass and Biogas

Biomass. *Green plants trap solar energy through the process of "photosynthesis" and convert it into organic matter, known as* ***biomass****.*

Wood, charcoal, agricultural waste produce the bioenergy after burning; cowdung, garbage are aerobically decomposed to obtain the energy.

Dried animal dung or cattle dung cakes are used directly as fuels in rural areas but it produces smoke and has low efficiency of burning.

Biogas: Biogas is formed due to the *decomposition of organic waste matter*. During decomposition of organic matter, the gases such as carbon dioxide, hydrogen and hydrogen sulphide are formed.

The organic waste is generally animal dung, plant waste etc. These waste products contain carbohydrates, proteins, which are broken down by bacteria in *absence* of oxygen caerobic conditions.

Advantages:

1. Continuous supply of energy.
2. Renewable in nature.
3. Cheap in cost.

Disadvantages:

1. Power generating units are huge and bulky.
2. Biogas generation depends on temperature, therefore, in water or cold areas like J & K additional source of energy is required.

☞ **Impact on environment:**

1. Domestic use of biomass in rural areas creates *air pollution*.
2. A large scale energy-crop plantation is *water consuming with increased use of pesticides and fertilizers, causing water pollution and flooding*.
3. The production of biomass on large scale and its harvesting accelerates *soil erosion and loss of nutrients*.

1.4.4. Ocean Energy

India is having large potential of ocean thermal energy which could be of the order of about 50,000 MW.

Ocean Thermal Energy Conversion (OTEC) plants convert the heat in the ocean into *electrical energy* with the help of *temperature difference*. The large temperature difference between *warm* surface sea water (28-30°C) and *cold* deep sea water (5-12°C) is used to generate electricity with the help of ocean thermal energy conversion system.

☞ **Impact on environment:**

1. OTEC plant creates *adverse impacts on marine environment* since the massive flow of water disturbs thermal balance, changes salinity gradient and turbidity.
2. The leakage of ammonia, used as a working fluid in closed cycle OTEC system, may cause much *damage to the ocean ecosystem*.

1.4.5. Wave Energy

The ocean waves are caused by wind, which in turn is caused by uneven heating and subsequent cooling of earth's crust and rotation of the earth.

The most of the sea surface in the form of wind waves forms a source of energy. Floating propellers are placed in shallow waters, near the shores, and due to motion of the waves the propellers also get the motion and this kinetic energy can be used to drive turbines.

The harnessing of wave energy requires the development of special power conversion devices.

Advantages:

1. The wave energy is a *cheap and inexhaustible* source of energy.
2. Wave-power devices, unlike solar or wind devices, *do not use up large land masses.*
3. It is *pollution-free.*
4. A staggered array of power devices can *produce* electricity, *protect* coastlines from the destructive action of waves, *minimise* erosion and even *help create* artificial harbours.

Limitations:

1. Wave lacks dependability.
2. There is a scarcity of accessible sites of large wave activity.
3. Economic factors like capital investment, cost of maintenance, repair and replacement hinder the development.

1.4.6. Tidal Energy/Power

The rise and fall of tides offers a means for storing water at the rise and discharging the same at fall. Of course the head of water available under such cases is very low but with increased catchment area considerable amounts of power can be generated at a negligible cost.

- The use of tides for electric power generation is practical in a few favourably situated sites where the geography of an inlet of bay favours the construction of a large scale hydroelectric plant. To harness the tides, a dam would be built across the mouth of the bay in which large gates and low head hydraulic turbines would be installed. At the time of high tide the gates are opened and after storing water in the tidal basin the gates are closed. After the tide has receded, there is a working hydraulic head between the basin water and open sea/ocean and the water is allowed to flow back to the sea through water turbines installed in the dam. With this type of arrangement, the generation of electric power is *not continuous*. However by using reversible water turbine the turbine can be run continuously as shown in Fig. 1.1.

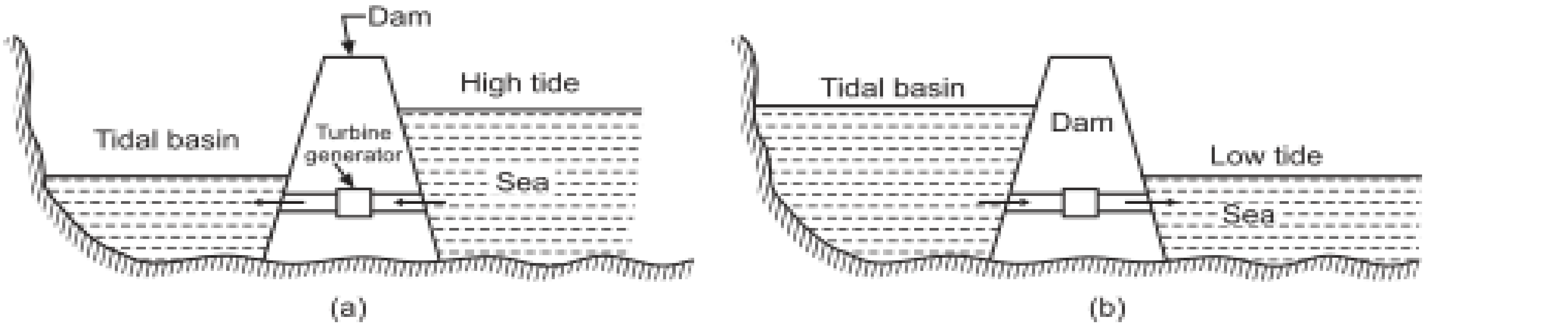

Fig. 1.1. Generation of power by tides.

1.4.7. Geothermal Energy

In many places on the earth *natural steam escapes from surface vents*. Such natural steam wells suggest the possibility of tapping terrestrial heat (or geothermal energy) in this form and using it for the development of power. Unfortunately, the locations where the steam-producing sub-strata seem to be fairly close to the surface are far removed from centres of civilization where the power could be usefully employed. Nevertheless, there are probably many places where, although no natural steam vent or hot springs are showing, deep drillings might tap a source of underground steam. The cost of such explorations and the great likelihood of an unsuccessful conclusion are not very conductive to exploitation of this source of energy.

There are two ways of *electric power production from geothermal energy:*

(*i*) Heat energy is transferred to a working fluid which operates the power cycle. This may be particularly useful at places of fresh volcanic activity where the molten interior mass of earth vents to the surface through fissures and substantially high temperatures, such as between 450 to 550°C can be found. By embedding coil of pipes and sending water through them steam can be raised.

(*ii*) The hot geothermal water and/or steam is used to operate the turbines directly. From the well-head the steam is transmitted by pipelines up to 1 m in diameter over distances up to about 3 km to the power station. Water separators are usually employed to separate moisture and solid particles from steam.

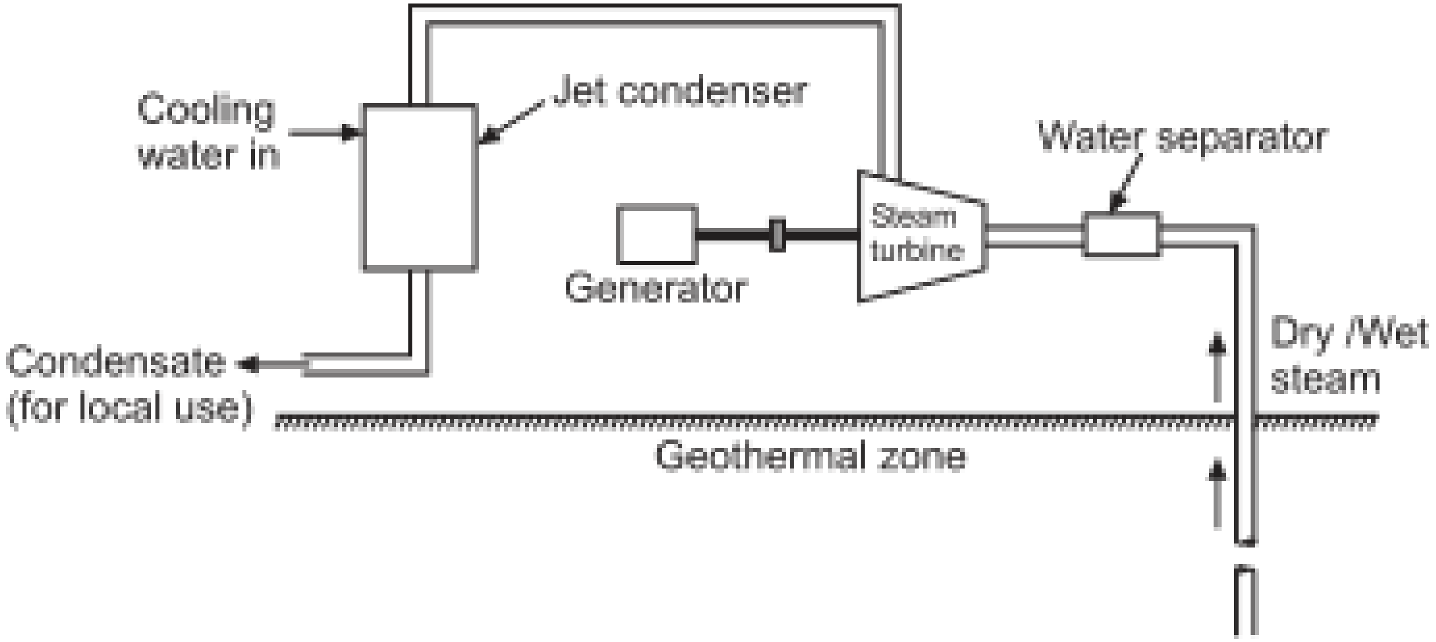

Fig. 1.2. Geothermal power plant.

Presently, only steam coming out of the ground is used to generate electricity, the hot water is discarded, because it contains as much as 30% dissolved salts and minerals, and these cause serious rust damage to the turbine. The water, however, contains more than 1/3rd of the available thermal energy.

Advantages:

1. It is almost free from the pollution.
2. It is a cheap and clean source of energy.

Disadvantages:

1. The drilling operations result in the noise pollution.
2. Air pollution results in case of release of gases like H_2S, NH_3 present in the steam waste.

☞ **Impact on environment:**

1. Gases escape into the atmosphere and *drop down as acid rain*.
2. The soil and water are *polluted by the chemicals like sulphates, chlorides and carbonates of lead, arsenic*.
3. Owing to the discharge of waste hot water, rivers are infected and consequently drinking water, farming and fisheries are adversely affected.
4. The exhausts, blow downs and centrifugal separation cause *noise pollution*.

1.4.8. Hydrogen Energy

Hydrogen energy is a non-conventional energy source. Hydrogen is considered as an *alternative future source of energy*. It has a tremendous potential because it can be produced from water which is available in abundance in nature. Hydrogen atoms in the core of sun combine to form helium atoms which is called as *fusion reaction*. It gives radiant energy which sustains the life on the earth.

Hydrogen can be separated from water by means of electrical energy. It can also be obtained from fossil fuels.

Advantages:

1. Its burning is non-polluting.
2. Hydrogen energy has a very high energy content.

Applications:

1. It is used for generating electricity for domestic appliances
2. It is utilised in automobiles.
3. It is employed for industrial uses

1.4.9. Thermo-electric Power

According to *Seebeck effect*, when the two ends of a loop of two dissimilar metals are held at different temperatures, an *electromaotive force is developed and the current flows in loop*. This method, by selection of suitable materials, can also be used for *power generation*. This method involves *low initial cost and negligible operating cost*.

1.4.10. Fuel Cell

When an *electric current is passed through a dilute solution of an acid or an alkali* by means of two platinum electrodes, *hydrogen* is produced at the *cathode* and oxygen is evolved at *aviode*. If this process is *reversed* by removing the power supply and connecting the two electrodes through a suitable resistance, the presence of hydrogen at one electrode and oxygen at the other *will produce a small current in the external circuit*, water being produced as a by-product. This *reverse process of electrolysis is the essence of the "fuel cell technology" as, the chemical energy stored in hydrogen and oxygen have been combined to produce electricity.*

- A fuel cell does not have moving components and as such, it is *quieter* and *requires less maintenance and attention* in operation.
- Fuel cells *convert* chemical energy directly to electrical energy at room temperatures.
- These cells are *very efficient* and are *not subject to Carnot limitation*.

1.4.11. Magneto-Hydro-Dynamic (MHD) Generator

The MHD working principle is based on *Faraday's law of electromagnetic induction which states that change in magnetic field induces an electric field in any conductor located in the magnetic field*. This electric field while acting on the free charges in the conductor causes a current to flow in the conductor. In ***"MHD generator"***, *an ionised gas is used as a conductor. If such ionised gas is passed at a high velocity through a powerful magnetic field, then current is generated* and *can be extracted by placing electrodes in a suitable position in the stream*. It produces *D.C. power directly.*

In MHD generation, all kinds of heat sources like coal, gas, oil, solar etc. can be used. MHD systems are of two types: (*i*) Open cycle system; and (*ii*) Close cycle system.

1.5 RENEWABLE AND NON-RENEWABLE ENERGY SOURCES

1.5.1. Renewable (Non-Conventional) Energy Sources

Renewable energy sources include *both* ***'direct'*** solar radiation intercepted by collectors (*e.g.* solar and flat-plate thermal cells) and ***'indirect'*** solar energy such as *wind, hydropower, ocean energy* and *biomass resources* that can be managed in a sustainable manner. *Geothermal* is considered renewable because the *resource is unlimited*.

Advantages:

The *advantages* of renewable energy sources are:

1. These energy sources recur in nature and are *inexhaustible*.
2. The power plants using renewable sources of energy *do not have any fuel cost* and hence their *running cost is negligible*.
3. As renewables have low energy density, there is *more or less no pollution or ecological balance problem*.
4. These energy sources can help to *save foreign exchange* and *generate local employment* (since most of the devices and plants used with these sources of energy are simple in design and construction, having been made from local materials, local skills and by local people).
5. These are *more site specific* and are employed for local processing and application, their economic and technological losses of transmission and distribution being *nil*.
6. Since conversion technology tends to be flexible and modular, renewable energy can usually be *rapidly deployed*.

Demerits/Limitations:

1. Owing to the low energy density of renewable energy sources large size plants are required, and as such the *cost of delivered energy is increased*.

2. These energy sources are *intermittent and also lack dependability*.
3. The user of these sources of energy has to *make huge additional investment* before deriving any benefit from it (whereas in case of conventional energy sources, the processing cost has traditionally been borne by large industries which borrow money from a bank and then charge the customer for each unit of energy used).
4. These energy sources, due to their low energy density, have *low operating temperatures leading to "low efficiencies"*.
5. Since the renewable energy plants have low operational efficiency, the heat rejections are large which *cause thermal pollution.*
6. These energy sources are *energy-intensive.*

Usefulness of renewable energy resources:

Any analysis of the usefulness of renewable resources in developing countries must consider the following *basic facts*:

1. The renewable energy resources and conversion systems are *technically capable* of meeting many of the power and fuel needs of a modern technological civilisation, from small-scale, decentralised uses to large-scale urban and industrial concentration.
2. Although renewable technologies are *economically competitive with fossil fuels in their ability to provide electricity, mechanical power, thermal energy and liquid fuels,* such technologies have not yet been deployed internationally, and the primary obstacles to their further development are institutional.
3. *Worthwhile and widespread deployment* of solar energy systems for the production of electric power, thermal energy and liquid fuels will require *advanced materials and concepts to be competitive with conventional options*.

In fact, the systems for conversion and storage for many of the renewable sources will only be commercially feasible after *sophisticated research and development* – surprisingly analogous to that now taking place in the computer and information fields.

Barriers in the implementation of renewable energy systems:

There are a number of obstacles to the effective deployment and widespread diffusion of renewable energy systems; among these are:

1. *Inadequate documentation and evaluation of past experience,* a *paucity* of validated field performance data and a *lack* of clear priorities for future work.

2. *Weak or non-existent institutions and policies* to finance and commercialise renewable energy systems. With regard to *energy planning,* separate and completely uncoordinated organisations are often responsible for petroleum, electricity, coal, foresty, fuelwood, renewable resources and conservation.
3. *Technical and economic uncertainties* in several renewable energy systems; *high economic and financial costs* for some systems in comparison with conventional supply options and energy-efficient measures.
4. *Skeptical attitudes* towards renewable energy systems on the part of energy planners and a lack of qualified personnel to design, manufacture, market, operate and maintain such systems.
5. *Inadequate donor coordination* in renewable energy assistance activities, with little or no information exchange on successful and unsuccessful projects.

The following points may be mentioned in this connection:

1. The energy demand is increasing by leaps and bounds due to rapid industrialisation and population growth, and hence the conventional source of energy will not be sufficient to meet the growing demand.
2. Conventional sources *except hydro* are non-renewable and are bound to finish up one day.
3. Conventional sources (fossil fuels, nuclear) also cause pollution, thereby their use degrades the environment.
4. Large hydro resources affect wild life, cause deforestation and pose various social problems.

☞ *The "renewable energy technologies" are better than most conventional energy technologies in the following ways:*

1. Can be produced in *large numbers* and introduced quickly.
2. Can often be built on, or close to the site where the energy is required, this minimises transmission costs.
3. Can be matched in scale to the need, and can deliver energy of the quality that is required for a specific task thus reducing the need to use premium fuels or electricity to provide low grade forms of energy such as hot water.
4. Although there are physical and environmental risks associated with the construction and operation of renewable energy technologies, as there are with all energy conversion systems, they tend to be *relatively modest* by comparison with those associated with fossil fuels or nuclear fuels.
5. *Increased flexibility and security of supply due to availability of diversity of systems.*

1.5.2. Non-Renewable Energy Sources

The non-renewable energy sources are those which *do not get replenished after their consumption e.g.* coal once get burnt is consumed without replacement of the same (fossil fuels, nuclear fission fuels).

1.6 ALTERNATIVE ENERGY SOURCES

There are the sources which are *non-traditional*. They are *alternatives to the conventional energy sources*.

ENERGY IN SCENARIO IN INDIAN CONTEXT

Energy position in India. The total power generation capacity in India in 1947 was only 1360 MW and in 1991 it grew to 65,000 MW, of which 45,000 MW (69%) was generated in thermal plants. Table 1.3, shows the power generating capacity by different types of generating plants.

Table 1.3. Indian Generation Capacity (MW)

Type of plant	1991	8th Plan 1997	9th Plan 2002	10th Plan 2007
Thermal	45,000	28,000	32,000	58,000
Hydro	18,500	18,700	26,000	23,000
Nuclear	1,500	1,320	2,880	—
Others	—	38,000	61,000	81,000

Table 1.4. below exhibits the renewable energy potential and installed capacity in India (2009) :

Table 1.4. Renewable Energy Potential and Installed capacity in India (2009)

S.No.	Source	Estimated potential	Installed capacity or number
1.	*Wind power*	45,000 MW	9756 MW
2.	*Wind pumps*	—	1284 Nos.
3.	*Small hydro (up to 25 MW)*	15,000 MW	2345 MW
4.	*Solar photovoltaic power plants*	50 MW/sq km	110 MW
5.	*Biomass power*	16,000 MW	638 MW
6.	*Biomass gasifier*	—	87 MW

7.	*Biogas plants*	12 million	3.9 million
8.	*Bagasse cogeneration*	5000 MW	1034 MW
9.	*Waste to energy* (*i*) Municipal solid waste (*ii*) Industrial waste	 1700 MW 1000 MW	 23.70 MW 35.21 MW

1.8 ELECTRICITY GENERATION FROM NON-CONVENTIONAL ENERGY SOURCES

It has been widely recognised that the fossil fuels and other conventional resources, presently used in generation of electrical energy, *may not be either sufficient or suitable* to keep pace with the ever increasing world demand for electrical energy. The prospects for meeting this demand and avoiding a crisis in supply would be *improved if new and alternative energy sources could be developed*.

The *important non-conventional electricity sources* are:

(*i*) Magneto hydrodynamic systems
(*ii*) Solar electric power plants
(*iii*) Photovoltaic cells
(*iv*) Fuel cells
(*v*) Wind energy
(*vi*) Geothermal energy
(*vii*) Tidal-energy
(*viii*) Ocean thermal energy
(*ix*) Organic wastes, biogas, rice straw etc.

1.10 FUELS

Fuels may be *"chemical"* or *"nuclear"*. Here we shall consider chemical fuels only.

*A **chemical fuel** is a substance which releases heat energy on combustion*. The principal combustible elements of each fuel are *carbon* and *hydrogen*. Though *sulphur* is a combustible element too, but its presence in the fuel is considered to be *undesirable*.

1.10.1. Classification of Fuels

Fuels can be *classified* according to whether:

1. They *occur in nature* called *'primary fuels'* or are *prepared* called *'secondary fuels'*;
2. They are *in solid, liquid* or *gaseous state*.

The detailed classification of fuels can be given in a summary form as below:

Type of fuel	*Natural (Primary)*	*Prepared (Secondary)*
Solid	Wood	Coke
	Peat	Charcoal
	Lignite coal	Briquettes.
Liquid	Petroleum	Gasoline
		Kerosene
		Fuel oil
		Alcohol
		Benzol
		Shale oil.
Gaseous	Natural gas	Petroleum gas
		Producer gas
		Coal gas
		Coke-oven gas
		Blast furnace gas
		Carburetted gas
		Sewer gas.

Coke. It consists of carbon, mineral matter with about 2% sulphur and small quantities of hydrogen, nitrogen and phosphorus. It is solid residue left after the destructive distillation of certain kinds of coals. It is smokeless and clear fuel and can be produced by several processes. It is mainly used in blast furnace to produce heat and at the same time to reduce the iron ore.

Briquettes. These are prepared from fine coal or coke by compressing the material under high pressure.

Analysis of coal:

The following two types of analyses is done on the coal:

1. Proximate analysis.
2. Ultimate analysis.

1. **Proximate analysis.** In this analysis, *individual elements are not determined; only the percentage of moisture, volatile matters, fixed carbon and ash are determined.*

   Example. Moisture = 4.5%, volatile matter = 5.5%, fixed carbon = 20.5%.

   This type of analysis is easily done and is for *commercial purposes* only.

2. **Ultimate analysis.** In the ultimate analysis, the percentages of various elements are determined.

   Example. Carbon = 90%, hydrogen = 2%, oxygen = 4%, nitrogen = 1%, sulphur = 15% and ash = 1.5%.

This type of analysis is useful for *combustion calculations*.

Properties of coal:

Important properties of coal are given below:

1. Energy content or heating value.
2. Sulphur content.
3. Burning characteristics.
4. Grindability.
5. Weatherability.
6. Ash softening temperature.

A *good coal should have:*

(*i*) Low ash content and high calorific value.

(*ii*) Small percentage of sulphur (less than 1%).

(*iii*) Good burning characteristics (*i.e.* should burn freely without agitation) so that combustion will be complete.

(*iv*) High grindability index (in case of ball mill grinding).

(*v*) High weatherability.

1.10.3. Liquid Fuels

The chief source of liquid fuels is petroleum which is obtained from wells under the earth's crust. These fuels have proved *more advantageous in comparison to sold fuels* in the following respects:

Advantages:

1. Require less space for storage.
2. Higher calorific value.
3. Easy control of consumption.
4. Staff economy.
5. Absence of danger from spontaneous combustion.
6. Easy handling and transportation.
7. Cleanliness.
8. No ash problem.
9. Non-deterioration of the oil in storage.

Petroleum. There are different opinions regarding the origin of petroleum. However, now it is accepted that petroleum has originated probably from organic matter like fish and plant life etc., by bacterial action or by their distillation under pressure and heat. It consists of a mixture of gases, liquids and solid hydrocarbons with small amounts of nitrogen and sulphur compounds. In India the main sources of petroleum are Assam and Gujarat.

Heavy fuel oil or crude oil is imported and then refined at different refineries. The refining of crude oil supplies the most important product called *petrol*. Petrol can also be made by polymerization of refinery gases.

Other liquid fuels are kerosene, fuel oils, colloidal fuels and alcohol.

The following table gives *composition* of some common liquid fuels used in terms of the elements in weight percentage.

Fuel	*Carbon*	*Hydrogen*	*Sulphur*	*Ash*
Petrol	85.5	14.4	0.1	—
Benzene	91.7	8.0	0.3	—
Kerosene	86.3	13.6	0.1	—
Diesel oil	86.3	12.8	0.9	—
Light fuel oil	86.2	12.4	1.4	—
Heavy fuel oil	88.3	9.5	1.2	1.0

Important properties of liquid fuels:

(1) Specific gravity	(2) Flash point	(3) Fire point
(4) Volatility	(5) Pour point	(6) Viscosity
(7) Carbon residue	(8) Octane number	(9) Cetane number
(10) Corrosive property	(11) Ash content	(12) Gum content
(13) Heating value	(14) Sulphur content.	

The requisite properties vary from device to device which uses the fuel to generate power. For example, *higher the octane number, higher can be the compression ratio and the thermal efficiency will be higher*. Similarly, *the cetane number of a diesel oil should be as high as possible*.

In general the liquid fuels should have:

(*i*) Low ash content	(*ii*) High heating value
(*iii*) Low gum content	(*iv*) Less corrosive tendency
(*v*) Low sulphur content	(*vi*) Low pour point.

1.10.4. Gaseous Fuels

Natural gas. The main constituents of natural gas are methane (CH_4) and ethane (C_2H_6). It has calorific value nearly 21000 kJ/m^3. Natural gas is used alternately or simultaneously with oil for internal combustion engines.

Coal gas. This gas mainly consists of hydrogen, carbon monoxide and hydrocarbons. It is prepared by carbonisation of coal. It finds its use in boilers and sometimes used for commercial purposes.

Coke-oven gas. It is obtained during the production of coke by heating the bituminous coal. The volatile content of coal is driven off by heating and major portion of this gas is utilised in heating the ovens. This gas must be thoroughly filtered before using in gas engines.

Blast furnace gas. It is obtained from smelting operation in which air is forced through layers of coke and iron ore, the example being that of pig iron manufacture where this gas is produced as by product and contains about 20% carbon monoxide (CO). After filtering it may be blended with richer gas or used in gas engines directly. The heating value of this gas is very low.

Producer gas. It results from the partial oxidation of coal, coke or peat when they are burnt with an insufficient quantity of air. It is produced in specially designed retorts. It has low heating value and in general is suitable for large installations. It is also used in steel industry for firing open hearth furnaces.

Water or Illuminating gas. It is produced by blowing steam into white hot coke or coal. The decomposition of steam takes place liberating free hydrogen and oxygen in the steam combines with carbon to form carbon monoxide according to the reaction:

$$C + H_2O \longrightarrow CO + H_2$$

The gas composition varies as the hydrogen content if the coal is used.

Sewer gas. It is obtained from sewage disposal vats in which fermentation and decay occur. It consists of mainly marsh gas (CH_4) and is collected at large disposal plants. It works as a fuel for gas engines which in turn drive the plant pumps and agitators.

Gaseous fuels are becoming popular because of following *advantages* they possess:

Advantages:

1. Better control of combustion.
2. Much less excess air is needed for complete combustion.
3. Economy in fuel and more efficiency of furnace operation.
4. Easy maintenance of oxidizing or reducing atmosphere.
5. Cleanliness.
6. No problem of storage if the supply is available from public supply line.
7. The distribution of gaseous fuels even over a wide area is easy through the pipe lines and as such handling of the fuel is altogether eliminated. Gaseous fuels give economy of heat and produce higher temperatures as they can be preheated in regenerative furnaces and thus heat from hot flue gases can be recovered.

Important properties of gaseous fuels:

1. Heating value or calorific value.

2. Viscosity.
3. Specific gravity.
4. Density.
5. Diffusibility.

Typical composition of some gaseous fuels is given below:

Fuel	H_2	CO	CH_4	C_2H_4	C_2H_6	C_4H_8	O_2	CO_2	N_2
Natural gas	—	1	93	—	3	—	—	—	3
Coal gas	53.6	9.0	25	—	—	3	0.4	3	6
Blast furnace gas	2	27	—	—	—	—	—	11	—

1.10.5. Calorific or Heating Values of Fuels

The **calorific value** *of the fuel is defined as the energy liberated by the complete oxidation of a unit mass or volume of a fuel*. It is expressed in kJ/kg for solid and liquid fuels and kJ/m^3 for gases.

The lower or net calorific value is obtained by subtracting latent heat of water vapour from gross calorific value. In other words, the relation between Lower Calorific Value (L.C.V.) and Higher Calorific Value (H.C.V.) can be expressed in the following way:

$$\text{L.C.V.} = (\text{H.C.V.} - 2465\, m_w) \qquad \text{...(1.1)}$$

where m_w is the mass of water vapour produced by combustion of 1 kg of fuel and 2465 kJ/kg is the latent heat corresponding to standard temperature (saturation) of 15°C.

[**In MKS units:**

$$\text{L.C.V.} = (\text{H.C.V.} - 588.76\, m_w)$$

where m_w is the mass of water vapour produced by combustion of 1 kg of fuel and 588.76 is the latent heat value in kcal as read from steam tables for 1 kg of water vapour]

Dulong's formula (Solid/liquid fuels). Dulong suggested a formula for the calculation of the calorific value of the solid or liquid fuels from their chemical composition which is as given below:

Gross calorific value,

$$\text{H.C.V.} = \frac{1}{100}\left[33800\,C + 144000\left(H - \frac{O}{8}\right) + 9270\,S\right] \text{ kJ/kg} \qquad \text{...(1.2)}$$

[**In MKS units**:

$$\text{H.C.V.} = \frac{1}{100}\left[8080\,C + 34500\left(H - \frac{O}{8}\right) + 2240\,S \text{ kcal/kg}\right]$$]

where C, H, O and S are carbon, hydrogen, oxygen and sulphur in percentages respectively in 100 kg of fuel. In the above formula, the oxygen is assumed to be in combination with hydrogen and only extra surplus hydrogen supplies the necessary heat.