1.0 OBJECTIVES

After going through this chapter you would be able to know the following:

- What is the importance of energy resources in our life.
- What are the energy demands and what are the energy reserves of fossil fuels.
- What is the energy resources scenario in India.
- Some important definitions in fossil fuel energy.

1.1 INTRODUCTION

Energy affects every part and every field of our life. We need energy to do all sorts of physical and physiological activities like moving writing, running, cooking, thinking or doing any work. We need energy for transportation, communication, lighting, industries and agriculture. We also need energy to extract minerals from ores and to manufacture
fertilizers, pesticides and all other products. We need energy for space travel and all scientific activities. Thus, we see there is hardly any aspect of life which we can think of that does not require energy. In fact, energy use is an indication of the degree of development. Some 99 percent of the energy used to heat our earth and all our buildings comes directly from sun. Without this direct input of solar energy our earth’s temperature would have been 240°C and life would just not have been possible. The 99% of the energy coming from sun to the earth is natural and not sold in the market. The remaining one percent is the commercial energy used by people in different forms like fuel wood, coal, oil, dung, electricity etc.

The energy sources can be broadly categorized into renewable and nonrenewable resources. While renewable resources like biomass energy, solar energy, tidal energy, wind energy, hydel power energy etc. can be regenerated, the non-renewable energy resources like coal, petroleum and natural gas are fossil fuels which took millions of years to be formed and cannot be renewed during our life span.

1.2 CONVENTIONAL ENERGY

1.2.1 Energy Demands and Supply

The commercial sources of energy include petroleum, coal, natural gas and nuclear energy. Out of all these oil is the most widely used energy resource.

Oil (Petroleum)

Oil is the life line of global economy. The identified deposits from which oil can be extracted profitably at present prices with current technology are known as oil resources. Thirteen countries of the world make up the Organisation of Petroleum Exporting Countries (OPEC), which have 67% of these reserves. About one fourth of the oil reserves are located in Saudi Arabia. It is further estimated that the undiscovered oil will also be
just located in Middle East. Thus, the world oil supplies and prices are likely to be controlled by OPEC over a long period of time.

United States of America is the world’s largest consumer of oil using 30% of global total, whereas it has only 4% of the world’s oil reserves. Maximum use of oil is in transportation (63%), followed by industry (24%), residential and commercial buildings (8%) and electric utilities (8%). At the present rate of consumption, the world’s crude oil reserves are estimated to be depleted in 40 years and there may be enough undiscovered oil lasting for another 40 years: Some analysts argue that rising oil prices will stimulate exploration and that the earth’s crust may contain more oil than is generally thought. Such oil even if it exists, lies about 10 kilometers or still more below the surface (twice the depth of wells known today).

Some analysts strongly believe that at the current rate of use of crude oil, the following are expected:

• Saudi Arabia, with the largest known crude oil reserves, could supply all the world’s needs for another 10 years.
• The estimated reserves under Alaska’s North slope (the largest reserve of North America) would meet U.S. demand for just 3 years.
• All undiscovered deposits could meet world demand for 30-40 years.

Fig. 1 Likely availability to Crude Oil and Natural Gas
Figure 1 shows the end of petroleum age in near future. The two curves show that the world’s known petroleum reserves will be 80% depleted between 2025 and 2035.

**Coal**

About 68% of world’s proven coal reserves and 85% of the estimated undiscovered coal deposits are located in U.S.A., C.I.S. and China. About 55% of U.S. coal reserves are found west of Mississippi River.

Coal is the most abundant conventional fossil fuel in the world. Identified world reserves of coal should last about 210 years at the current rate of usage and just 65 years, if the rate, of usage increases by 2% per year.

The world unidentified coal reserves are however, projected to last about 900 years at current rate and 150 years, if usage rate increases by 2%.

**Natural Gas**

About 40% of the world’s natural gas reserves are in CIS countries. Other countries with proven natural gas reserves are Iran (14%), United States (5%), Qatar (4%), Saudi Arabia (3%) and Nigeria (3%). Geologists expect to find more natural gas, especially in unexplored LDCs (less developed countries). Most of the natural gas reserves are located in same area as crude oil.

![Fig. 2 Fossil Fuel Age (Year 1850-2850)](image)
Presently we are passing through the peak period of fossil age. The fossil age may last for a few more decades, as the reserves are getting depleted very fast. Fig. 2 shows that the fossil fuel age is likely to last from 1850 to 2850 and then all the reserves will be exhausted.

Probably, the next generation would witness a sharp depletion of oil and natural gas in their lifetime and alternate fuels will have to be developed.

The estimated fuel reserves of the world are tabulated below:

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Type</th>
<th>Reserves</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fossil Fuel</td>
<td>Coal</td>
<td>32Q*</td>
</tr>
<tr>
<td></td>
<td>Oil &amp; Natural Gas</td>
<td>6 Q</td>
</tr>
<tr>
<td>Nuclear Fossil Fuel</td>
<td>Uranium &amp; Thorium</td>
<td>600 Q</td>
</tr>
<tr>
<td>Nuclear Fossil Fuel</td>
<td>Deuterium</td>
<td>1010 Q</td>
</tr>
</tbody>
</table>

*Q = Quad.

1Quad = 180 million barrels of petroleum
= 42 million tons of bituminous coal
= 0.98 trillion cubic feet of natural gas
= 293 billion kilowatt hours of electricity.

The world trends of fossil fuel combustion are shown in Figures-3 and Fig-4. The corresponding trends in different nations vary depending upon the type of natural resources and available technology.
Before 1850, the fuels in use were fire wood, agricultural wastes etc. During the 20th century, the use of fossil fuels increased rapidly. From Figure-3 it is clear that hydropower has remained a minor source of energy since 1900. Coal was in much more use during 1900 to 1940 than oil, but after 1940-45, there was a sharp increase in petroleum use surpassing coal. Nuclear energy became an important source of energy after 1960. Figure-4 compares the change in trends of energy use in the last 40 years.

1.2.2 ENERGY RESOURCES OF INDIA

The major commercial (non-renewable) sources of energy are coal, oil, natural gas and nuclear power. The share of commercial and non-commercial sources of energy in our country in 1980’s was in a ratio of 1: 1. However, following rapid industrial growth, the ratio changed to 4: 1 in 2000. Let us see what are our non-renewable energy resource reserves:

1.2.2.1 Coal

India has about 5% of world’s coal production. Coal, besides a prime source of industrial energy is also a raw material. Coal including lignite even today accounts for 60% of country’s commercial requirements.
Major coal fields in India are Raniganj, Jharia, East Bokaro and West Bokaro, Panch-Konkan (Tawa Valley), Singrauli, Takhar, Chanda-Wardha and Godavari Valley. The major states known for coal reserves are Bihar, Orissa, West Bengal, Madhya Pradesh, Andhra Pradesh and Maharashtra.

By and large, the quality of Indian coal is rather poor in terms of heat capacity. This poor heat capacity can be converted into electricity and gas and even oil. That is the reason why many of our thermal power stations are located on the coal fields to produce electric power to feed regional grid. Coal production in India which was just 35 million tons in 1951 went to over 180 million tons in 1988-89. Per capita consumption of coal has increased from 135 kg to nearly 225 kg. Lignite (brown coal) is generally a low quality coal. But Indian lignite has less ash than coal. The deposits at Neyveli (Tamil Nadu) are about 3,300 million tons, which is about 90% of India’s lignite reserves. It produces 600 MW of thermal power.

1.2.2.2 Oil and Natural gas

Mineral oil is very unevenly distributed over space like any other mineral. India has a large proportion of tertiary rocks and alluvial deposits particularly in the extra peninsular India. Such potential oil bearing area is estimated to be over a million square kilometers. It covers the northern plains in the Ganga-Brahmaputra Valley, the coastal strips together with their off-shore continental shelf (Bombay High), the plains of Gujarat, the Thar desert and the area around Andaman and Nicobar Islands.

In India oil was first found at Makum (North East Assam) but drilling of oil was started at Digboi in Lakhimpur district. After independence, at Gujarat plains and Bombay High, major oil reserves were found. Lately, oil deposits were found in offshore areas off the deltaic coasts of Godavari, Krishna, Kaveri and Mahanadi.
Natural gas reserves are generally found in association with oil fields. However, exclusive gas reserves are also located in Tripura, Rajasthan and almost all the offshore oil fields of Gujarat, Maharashtra, Tamil Nadu, Andhra Pradesh and Orissa.

In 1951, our total petroleum production was 269,000 tons while in 1990 it was 40 million tons. Natural gas production was 2,500 million m$^3$ in 1980-81 which rose to 9,810 million m$^3$ in 1987 and 15,000 million m$^3$ in 2000. Total gas reserves of India are estimated to be 5,41,000 million m$^3$.

Through pipe-lines, the gas from Bombay and Gujarat gas fields is now taken to M.P., Rajasthan and U.P. Hazira-Bijaipur-Jagdishpur (HBJ) gas pipe line is 1,730 km long which carries 18 million m$^3$ in gas daily. It feeds 6 fertilizer plants and three power plants. There are 15 refineries in India. The liquefied petroleum gas (LPG) or cooking gas is now a domestic fuel.

**1.2.2.3 Nuclear Power**

A small quantity of radioactive material can produce an enormous amount of energy. For instance one ton of Uranium-235 would provide as much energy as produced by 3 million tons of coal or 12 million barrels of oil.

India is rich in certain radioactive materials. Uranium mines are located in Singhbhum in Bihar and parts of Rajasthan. Most abundant Monazite sands are present on the shores of Kerala.

Thorium is derived from the monazite sands. The major nuclear power plants in our country are located in Tarapur (Maharashtra), Kota (Rajasthan), Kalpakkam (Tamilnadu), Kakarpara (Gujarat), Kaswar (Karnataka) and Narora (Uttar Pradesh).
1.2.3 ENERGY SCENARIO OF INDIA

About 75% of population of India lives in rural areas and uses about 40% of total energy of the country. Consumption pattern of rural areas is

<table>
<thead>
<tr>
<th>Sector</th>
<th>Energy use (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domestic</td>
<td>64%</td>
</tr>
<tr>
<td>Agriculture</td>
<td>22%</td>
</tr>
<tr>
<td>Industrial/Commercial</td>
<td>7%</td>
</tr>
<tr>
<td>Lighting</td>
<td>4%</td>
</tr>
<tr>
<td>Transportation</td>
<td>3.0%</td>
</tr>
</tbody>
</table>

Biomass fuels and animal energy are the two main non-commercial energy sources used in rural India; Biomass fuels include fuel wood, crop residues, animal wastes and Gobar gas. The percentage contribution of each of these biomass fuels is 65, 30 and 15% respectively, on an average.

The fuel wood consumption ranges from 146-300 MT/year and the demand is increasing with rise in population growth.

Out of the total power generated in the country, the potential of the animal energy is close to 50%. This is mainly for farming operations and transportation. There are about 84 million of draught animals which is equivalent to 30,000 MW of power. Emphasis has been to improve the efficiency of equipments, devices and transport vehicles which are animal driven.

Amongst the conventional sources of commercial energy used in India, coal is the prime resource. In present day context; 60% of coal produced is utilized in generation of electricity, which in fact, is more than 95% of the thermal power or about 70% of total installed capacity of electricity generated in India.

Petroleum products are mainly used in transport and industrial sector.
About 40% of petroleum products are used for providing raw material in fertilizer, plastics, synthetic fibres, rubber, pesticides, various pharmaceutical and, organic chemical industries.

The consumption of petroleum products has increased at a much faster rate in the last few years and at present 66 million tones of petroleum products (1994-95) are being used out of which 50% is imported.

Natural gas consumption has shown an increase in the recent years. The annual gas supply has increased from 10 billion m$^3$ in 1990 to 16 billion m$^3$ in 1990.

The hydropower electricity is not yet fully harnessed. At present we are using only 25% of the total hydropower potential of our country.

Nuclear power in Indian context is yet to take off. Four nuclear power stations with installed capacity of 2005 MW are working efficiently. However, nuclear hazards resulting from any careless handling can be disastrous. Table-1 gives a summarized view of conventional sources of commercial energy in our country.

**Table-1 A summarized view of present conventional sources of commercial energy and their relative contribution in generation of electricity:**

<table>
<thead>
<tr>
<th>Conventional sources</th>
<th>Sectors of utility</th>
<th>Type</th>
<th>Installed capacity (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>60% used for electricity generation.</td>
<td>Thermal power</td>
<td></td>
</tr>
<tr>
<td></td>
<td>18% used for steel and cement industries.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>22% miscellaneous</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Petroleum &amp; its products (petroleum, diesel, kerosene, naphtha, fuel oil etc.)</td>
<td>40% used for transport</td>
<td>Thermal power</td>
<td>58,100</td>
</tr>
<tr>
<td></td>
<td>Rest used in industries including electricity generation, domestic &amp; other miscellaneous purposes.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Natural Gas</td>
<td>Mainly in industries for electricity generation</td>
<td>Thermal power</td>
<td></td>
</tr>
<tr>
<td>Surface water</td>
<td>Electricity generation</td>
<td>Hydro power</td>
<td>20,829</td>
</tr>
<tr>
<td>Nuclear material</td>
<td>Electricity generation</td>
<td>Nuclear power</td>
<td>2,005</td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong></td>
<td><strong>80,934</strong></td>
<td></td>
</tr>
</tbody>
</table>
Non-conventional sources of energy are still at a low ebb in our country. However in the 8th Five Year Plan we have set the targets as shown in Table-2.

**Table-2 : Targets of eighth plan of various major non-conventional energy resources.**

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Major non-conventional energy</th>
<th>Targets of VIIIth Plan (MW) resources</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Wind energy</td>
<td>500 MW</td>
</tr>
<tr>
<td>2.</td>
<td>Small hydro electric power plants (upto 15 MW)</td>
<td>600 MW</td>
</tr>
<tr>
<td>3.</td>
<td>Portable mini hydel sets (upto 15 MW)</td>
<td>To provide 50 portable sets particularly in hilly region</td>
</tr>
<tr>
<td>4.</td>
<td>Biomass based co-generation in sugar mills</td>
<td>300 MW</td>
</tr>
<tr>
<td>5.</td>
<td>Solar energy :</td>
<td></td>
</tr>
<tr>
<td>6.</td>
<td>i) Solar photo voltaics (SPV) systems</td>
<td>SPV systems with total capacity of 25 MW proposed to be installed during VIIIth plan. These include one lakh solar lanterns, one thousand SPV water pumps and several SPV power projects.</td>
</tr>
<tr>
<td>7.</td>
<td>ii) Solar thermal programme</td>
<td>To increase the collector area of solar water heating system which are at present in 2.54 lakh sqm.</td>
</tr>
<tr>
<td>8.</td>
<td>Tidal energy</td>
<td>900 MW (proposal under consideration at a cost of Rs. 4,000 crores in Gulf of Kutch).</td>
</tr>
<tr>
<td>9.</td>
<td>Ocean thermal energy</td>
<td>900 MW (proposal under consideration at cost of Rs. 750 crores in Tamil Nadu).</td>
</tr>
<tr>
<td>10.</td>
<td>Wave-energy</td>
<td>To set up 100 KW to 1 MW plants.</td>
</tr>
<tr>
<td>11.</td>
<td>Geothermal energy</td>
<td>To set up power plants of 5 KW or more.</td>
</tr>
</tbody>
</table>

Future prospects of energy management needs a careful assessment. Our increasing population is going to cause a many time increase in energy demands. We have to increase our energy resource utilization by 12-15% in the next 5 years.

India requires an investment of $200 billion in power sector over the next 15 years if the country’s GDP is to be sustained. The following two changes may be suggested in future for our country.

(i) Instead of major power projects, captive power plants (upto 25 MW) may be installed which may prove to be more economic and environment friendly.
(ii) For thermal power generation, focus is being shifted slowly from coal based to gas based plants. The conversion efficiency of gas-based power plants is not only higher but also the pollution caused in very low.

1.3 SUMMARY

Energy resources are very important as they are required in every field of our life. All development activities depend on energy. Energy consumption of a nation is an index of its development. Energy resources that can not be regenerated during our life span are called non-renewable energy resources. Fossil fuels like coal, oil and natural gas are non-renewable energy resources. About 67% of oil (petroleum) is present in 13 countries known as OPEC. Reserves of these fossil fuels are limited and at the present rate of their consumption these are not going to last long. It is estimated that oil reserves would last for another 30-40 years and coal for another 210 years. Nuclear energy is projected as one of the important energy resource of future. Uranium \((U_{235})\) which exists inside the earth can be mined and used as a source of nuclear energy. Thorium, a radioactive substance can be obtained from monazite sands.

In India, Thermal power using coal, gas or petroleum as source of energy is responsible for maximum generation of electricity (75%), followed by hydro power (24%) and 1% by others.

1.4 KEY WORDS

- **Fuel**: Substance containing energy which can be released by combustion or by chemical reaction or electromagnetic reaction or nuclear reaction etc.

- **Nuclear Fuel**: Fissile material used to produce energy in a nuclear reactor.
• **Benzene C<sub>6</sub>H<sub>6</sub>:** Colourless liquid hydrocarbon, made from coal tar by catalytic reforming of naphthalene. It is used in the manufacture of phenol, styrene, nylon, detergents, aniline, and other compounds: as a solvent; and as a component of high octane gasoline.

• **Bitumen:** General name for various solid and semisolid hydrocarbons, a native substance of dark colour, comparatively hardened non-volatile, composed principally by hydrocarbon.

• **Bituminous Coal:** Soft coal; coal that has high content of carbonaceous and volatile matter. When Volatile matter is removed from bituminous coal by heating in absence of air, the coal becomes coke.

• **Blended Fuel Oil:** Mixture of residual and distillate fuel oils.

• **Bunker-C Fuel Oil:** Heavy residual fuel oil used by ships, industry.

• **Caking Coal:** The coal which softens and agglomerates when heated, and after driving off volatile matter at high temperature, produces hard, gray cellular mass of coke.

• **Calorie:** Unit of thermal energy (heat). The amount of heat required to raise temperature of one gram of water by 1 degree Celsius.

\[
1 \text{ calorie} = 3.97 \times 10^3 \text{ Btu} = 4.18 \text{ J} = 1.13 \times 10^3 \text{ Wh}
\]

• **Calorific value (Heating Value):** Heat liberated by combustion of unit quantity of a fuel. (J/kg)

• **Coal:** A general term for a number of solid organic fossil minerals with widely differing compositions and properties. Coal is essentially rich in amorphous carbon (carbon without regular structure).

• **Metallurgical coal:** Coal as mined or after cleaning having strong or moderate cooking properties. It should not contain more than 1.25% sulphur and 8% ash.
• **Carbonization of Coal**: Heating of coal without contact with oxygen at high temperature, to produce a fuel of higher carbon content than original. Carbonization gives coke and Cole Gas.

• **Cracking**: Processing which breaks down and arranges the molecular structures of the hydrocarbon chains. In thermal cracking, high temperature and pressure is applied in presence of a catalyst.

• **Crude oil (Crude)**: Petroleum oil in natural state before refining or processing.

• **Diesel Fuel**: Fraction obtained from distillation of crude oil, after kerosene. Diesel is an important fuel for Diesel-Engine used in transportation.

• **Fuel**: Any substance that can be burned to produce heat.

• **Fuel Oils**: Petroleum fractions of higher boiling point than kerosene. They are generally classified as distillates of residues. They are used for industrial heating, district heating and power generation.

• **Gasification**: Process of converting solid or liquid fuel to gaseous fuel.

• **Graphite**: Pure carbon.

• **Hydrocarbon Fuels**: Fuels that contain an organic chemical compound hydrogen and carbon (e.g. Methane CH\(_4\)). The hydrocarbon contains chains of molecules formed by carbon-hydrogen atoms arranged in systematic and symmetrical form.

• **Kerosene**: A petroleum fraction containing hydrocarbons; slightly heavier than gasoline (petrol) and naptha; Boiling point of kerosene is in the range of 180°C and 300°C. Used as fuel.

• **Lignite**: Low grade coal in between Bituminous Coal and Peat.
• **Liquefied Natural Gas (LNG)**: Natural gas which is cooled to about 160°C for liquefying for the purpose of easy storing and transportation. Liquefaction of NG greatly reduces the storage and transportation costs.

• **Liquefied Petroleum Gas (LPG)**: Consists of Propane and Butane recovered from natural gas and in petroleum refining. It is also called, Bottled Gas. Used as a fuel for IC Engines and domestic use in area where pipe-lines of natural gas are not laid.

• **Methane (CH\(_4\))**: A lightest hydrocarbon in paraffin series. Colourless odorless, flammable. It forms a major portion of marsh gas and natural gas.

• **Natural gas**: A natural fossil gaseous fuel usually associated with petroleum oil. **Composition**: Methane 60 to 80%; Ethane 5 to 8%; propane 3 to 18%; heavier hydrocarbons 2 to 14%; Also non-hydrocarbons present sometimes in natural gas are : nitrogen, hydrogen sulfide; nitrogen; carbon dioxide. Propane, butane, pentane are the heavy hydrocarbons present in natural gas. They are removed from natural gas and sold as LPG. Pipeline Natural gas has energy density 52 MJ/kg.

• **Natural Gas Liquids**: Propane; Butane, Pentane are recovered from natural gas by processing in field separators; scrubbers, gas processing and reprocessing plants.

• **Natural Gas Products**: Liquids including natural gasoline, which are recovered from natural gas by processes of adsorption; absorption, compression or refrigeration of natural gas.

• **Natural Gasoline**: A mixture of liquid hydrocarbons extracted from natural gas and stabilized to obtain liquid products suitable for blending with refinery gasoline (petrol).
• **OAPEC** : Organisation of Arab Petroleum Exporting Countries
  **Members** (1968) : Saudi Arabia, Kuwait, Libya; and later (1970) : Abu Dhabi, Algeria, Bahrain, Dubai, Qatar.

• **OPEC** : Organization of Petroleum Producing Countries, Founded in 1960. Head Quarters in Vienna. **Members**: Abu Dhabi, Algeria, Indonesia, Iran, Iraq, Kuwait, Libya, Nigeria, Quarter, Southi Arabia, Venezuela.

• **Oil Shale**. Range of material containing organic matter (kerogen) which can be converted to crude shale oil, gas and organic carbonaceous residue by heating.

• **Petroleum** : An oily, bituminous flammable liquid of several colours ranging from colourless to black. Petroleum contains a complex mixture of hydrocarbons with little of other substances. Prepared for use as gasoline (petrol for car engine; naptha, other products by various refining processes.

• **Petroleum Naptha** a generic term applied to refined, semi-refined, unrefined petroleum products and liquid products of natural gas. Napthas used for cleaning, manufacture of rubber, paints, varnishes etc. have high volatility.

• **Petroleum spirits** : A refined petroleum distillate with high volatility and used for thinners and solvents of paints and varnishes and similar products.

• **Petroleum Tar** : Viscous black/brown substance obtained as residue while refining petroleum. Tar yields substantial solid residue when evaporated or fractionally distilled.

• **Photosynthesis** : Conversion of carbon dioxide and water to glucose and other complex organic materials by green plants exposed to sunlight.
• **Raw gas**: Natural gas in its naturally occurring state.

• **Refining**: A process of distilling crude oil in several stages to obtain various usable substances from each successive stage. Components of low molecular weight vaporise first. Typical crude fractions are ether, methane, ethane, propane, butane kerosene, fuel oil, lubricants, jelly paraffin, asphalt and tar.

• **Surface Mining**: Open cast mining, strip mining. Mining of coal from outcropping i.e. removal of upper surface layers of coals (as opposed to underground mining).

• **Synthetic crude**: Synthetic crude removed from oil shale or coal.

• **Synthetic Natural Gas (SNG)**: Gaseous fuel manufactured from coal or Naptha. Contains about 95 to 98% of Methane.

• **Tar Sands**: Deposits bearing hydrocarbons of high viscosity.

• **Ton**: Unit equal to 2000 pounds in USA, 2240 pounds in UK.

• **Metric Ton**: Is equal to 1000 kg = 2204.6 pounds.

• **Water Gas**: A mixture of gases produced by injecting steam through coke or coal.

### 1.5 SELF ASSESSMENT QUESTIONS:

I. **Answer the following questions**:

1. Discuss various non-renewable energy resources and their reserves.
2. Where are the major fossil fuel reserves of India located?
3. Give a brief account of the energy scenario of India.
4. What do you understand by the following terms
   a) Calorific value
b) Crude oil

c) Diesel fuel

d) Bitumen

e) Gastification

f) Hydrocarbon fuel

g) LPG&SNG

II. Fill in the blanks:

(i) The full form of OPEC is ...................

(ii) Maximum electricity generation in our country takes place by .......... power plants.

(iii) Major coal reserves of the world lie in .........., .........., and ......

(iv) Natural gas is mainly having ............. gas.

(v) Radio-active materials mined for nuclear energy are .......... and ...........

1.6 SUGGESTED READINGS


FOSSIL FUELS AND THEIR ENVIRONMENTAL IMPACTS

Prof. Anubha Kaushik

STRUCTURE

2.0 OBJECTIVES
2.1 INTRODUCTION
2.2 FOSSIL FUELS
  2.2.1 COAL
    2.2.1.1 Types of Coal
    2.2.1.2 Important Properties of Coal
    2.2.1.3 Coal Production and Processing
      a) Coal Gasification
      b) Fluidized Bed Combustion
      c) Coal Liquefaction
  2.2.2 OIL
  2.2.3 NATURAL GAS
  2.2.4 ENVIRONMENTAL IMPACTS OF FOSSIL FUEL PRODUCTION AND CONSUMPTION
    2.2.4.1 Impacts of Mining and Burning of Coal
    2.2.4.2 Impacts of Oil production and consumption
    2.2.4.3 Impacts of oil spills
    2.2.4.4 Impacts of Oil Refining
    2.2.4.5 Impacts of Oil Shale Production
2.3 SUMMARY
2.4 KEY WORDS
2.5 SELF ASSESSMENT QUESTIONS
2.6 SUGGESTED READINGS
2.0 OBJECTIVES

After going through this chapter you would be able to know the following:

• Characteristics of the different types of fossil fuels.
• Process of production of coal, its processing and gasification.
• Environmental impacts of consumption of various types of fossil fuels.

2.1 INTRODUCTION

In the developed world, fossil fuels top the list of energy resources. They are fossil fuels because they were formed from plant and animal remains buried in the earth millions of years ago. The fossil fuels provide 85-90% of the energy demand of the present industrialized world. Three fossil fuels predominate, coal, oil and natural gas - all of which are non-renewable.

Let us have a closer look at these non-renewable energy resources.

2.2 FOSSIL FUELS

2.2.1. COAL

Coal began to form 225 to 350 million years ago in the hot, muggy regions of the earth. Ancient plants flourished in and along the banks of lakes, streams and coastal swamps; leaves fell into water and got accumulated on the bottom. Their rate of accumulation was much faster than their rate of decomposition. Eventually, this rich organic material was covered by mud or sediment eroded from the land, and over time, heat and pressure converted the organic material into peat and then coal.

Coal seams can be 100 meters thick and can extend over tens of thousands of square kilometers in areas that were once vast swamp forests in the pre-historic times.
The value of coal as a fuel was first discovered in 12th or 13th century by the inhabitants of the north east coast of England.

Coal is the organic fossil material which is solid and black in colour with varying properties and composition. It is essentially rich in amorphous carbon and contains several liquid and gaseous hydrocarbons.

### 2.2.1.1 Types of Coal

On the basis of characteristics, heating value, carbon and volatile matter, coal is divided into mainly the following types:

a) **Anthracite (hard coal)**
   - It is hard, black, lusturous, shiny and dense.
   - This is the highest grade coal with calorific value of 8,250 to 8,700 kcal/kg.
   - It contains 86-98% of carbon.
   - Volatile matter is low being just 2-14%.
   - It is not found in India. It mainly occurs in UK & USA.
   - It is used in industrial furnaces, graphite electrodes and in metallurgical processes.

b) **Bituminous (Soft coal)**:
   - It is also high grade coal next to anthracite.
   - It has a calorific value in the range of 7,500 to 8,700 kcal/kg. It contains about 46-86% carbon.
   - Volatile matter is low and can be removed by heating in the absence of air, when it gets converted into coke. More the volatility, lower is the heating value.
   - It is used for combustion, hydrogenation, gasification, blending, domestic use and metallurgy.
C) **Lignite (Brown coal)**

- It is inferior quality, low grade coal.
- It has laminar (banded) structure with woody, fibrous, brownish black appearance, resembling wood, hence the name. In Latin, Lignum means wood.
- Its calorific value is 6,150 to 7,300 kcal/kg.
- It has a moisture content of about 30-50% before exposure to air.
- Its volatile matter is about 30%.
- Lignite when exposed to air gets oxidised.
- Due to high moisture, rapid oxidation and low heating value, it is not economical to transport it to distant places.
- It is burned in pit head power plants.

d) **Peat**

- Peat is a solid fuel with highest moisture content.
- It is not fully matured form as it is partially decomposed, so it is not true coal.
- Its heating value is much less and is lower than that of wood.
- It has about 90% moisture.
- It is used as a low grade fuel.

### 2.2.1.2 IMPORTANT PROPERTIES OF COAL

The most important properties of coal for energy evaluation are follows:

- Calorific value (Heating Value)
- Volatile matter
- Fixed carbon
- Chemical composition (C, H, S, N, O, ash minerals, H\textsubscript{2}O).

The chemical composition is rather more important from the
environmental point of view. If it is having more sulphur content, it would release more SOx and cause more pollution.

Various characteristics of coal arc calculated and expressed as d.m.f. which is the Gross Value for pure coal.

(1) Calorific value (CV)

\[
CV\ (d.m.f.) = \frac{C.V.\ (measured) \times 100}{100 - (\text{moisture} - 1.1\ \text{ash})}\%
\]

d.m.f. = Heating value of pure coal without minerals.

(2) Volatile matter d.m.f. 100 - Carbon percent

(3) Fixed carbon (d.m.f.) = \frac{\text{Fixed carbon determined} \times 100}{100 - (\text{moisture}\% + 1.1\ \text{ash}\%)}

2.1.1.3 Coal Production and Processing

Various production technologies involve exploration, mining, preparation, sorting, cleaning, storage and transportation.

The coal conversion technologies include coal gasification, liquefaction, coal slurry, coal carbonisation for coke and coal gas production.

Coal mining is done in two distinct ways:

- Surface mining, in which the coal beds are near the ground surface with little over-burden of soil (depth < 30 m).
- Underground mining - here the coal beds are located at depths.

After mining, the coal is prepared to make it suitable for a particular use. The coal is purified by removing dirt, mud etc. and sulphur is also removed because sulphur present in coal is responsible for high SO\textsubscript{2} emissions on burning.
Coal is converted from solid form to liquid or gaseous form also. Various solid, and gaseous fuels have their specific application. Direct burning of coal results - emission of particulates, smoke, SOx - NOx, CO and CO$_2$. The gaseous or liquified fuels cause lesser pollution. Some important coal conversion technologies are discussed below:

**Coal Gasification**

It involves chemical reaction of coal, steam and air at high temperature. A coal water mixture called a Slurry is injected with oxygen into a heated chamber, producing three combustible gases: Carbon monoxide, hydrogen and some methane. The heated gas is then cooled and purified. The resultant gas burns as cleanly as natural gas.

This gas can be used for domestic purposes. Fig.-1 shows a schematic diagram of the gasification technology.

![Fig.-1 An efficient coal gasification process. In this process coal particles mixed with water are sprayed into a heated furnace (gasifier) where steam and combustible gases are produced. The gases are then cleaned by passing them through water. The gases of next burned and the exhaust gas is used to spin one of two electrical generators. The heat is also captured to generate steam, which operates another generator.](image)
Fluidized Bed Combustion

While burning coal, a lot of pollution occurs. So there is a need to burn coal in cleaner way. Fluidized Bed combustion is one such important technology, in while coal is crushed and mixed with bits of limestone and propelled into a furnace in strong current of air (Fig.-2). The particles mix turbulently in the combustion chamber ensuring very efficient combustion and therefore, low levels of carbon monoxide are produced. The furnace also operates at a much lower temperature than a conventional coal boiler, thus reducing nitrogen oxide emissions. The limestone reacts with sulphur oxides producing calcium sulphite or sulphate, thus reducing SOx emissions from the stacks.

Fig. 2 Fluidized bed combustion. This process burns crushed coal blown into a furnace mixed with tiny limestone particles. The air turbulence in the furnace ensure thorough combustion, thus increasing efficiency. The limestone reacts with sulfur oxide gases moving most of them from the smokestack. Steam pipes in the furnace help maximize heat efficiency.
Coal Liquefaction

Coal can also be treated to produce a thick, oily substance by liquefaction. At least 4 major processes now exist which add hydrogen to coal to produce oil. The oil can then be refined like crude oil to produce a variety of products like jet fuel, gasoline, kerosene, many chemicals, drugs and plastics.

Coal liquefaction is a costly process and it generates pollutants like phenols. It also does not help in CO$_2$ emission reduction.

Flow diagram of coal liquefaction is given in Fig.-3.

![Flow diagram Coal Liquefaction and Coal Dissolution](image)

Fig. 3 Flow diagram Coal Liquefaction and Coal Dissolution

2.2.2. OIL

It was in 1859, when a steel drill in Pennsylvania hit 20 meters and a black, foul smelling liquid came gushing from a well. This was the dawn of a new energy era. This was petroleum and just less than a century later, this oil became the world's most important energy resource.
Being liquid and relatively easy-to transport long distances, either by ship or by pipeline, oil has been accepted as an ideal fuel. It burns cleaner than coal, but less cleaner than natural gas.

Oil is also obtained from oil shales and sand tars. Oil Shale is a grayish brown sedimentary rock that was formed millions of years ago from the mud at the bottom of lakes. Within the rock is contained a solid organic material called as, kerogen. When heated to high temperatures, the rock gives off its oily residue called Shale oil. High grade oil shale can produce upto 120 litres of shale oil per ton of rock. Like petroleum, shale oil can also be refined to produce gasoline, jet fuel, kerosene and a variety of feed stocks used by chemical industry to produce fabrics, drugs and plastics.

Tar sands are found in some parts of the world where oil is found to have migrated into neighbouring layers of sandstone, creating tar sands. The thick oily residue, called bitumen can be extracted from the rock and refined to produce a variety of fuels and chemicals in much the same way that shale oil is processed.

2.2.3 NATURAL GAS

Natural gas is primarily methane (\(\text{CH}_4\)). Like coal and oil, it is a fossil fuel. It was given off by decomposing plant and animal remains that were buried in the earth by sedimentary deposits for millions of years. That is why, natural gas deposits often accompany coal and oil deposits.

Natural gas is the cleanest fossil fuel. It can be easily transported within the country by pipeline. It is used primarily for heating buildings, home cooking, industrial processes and generating electricity.

Natural gas is one of the most important fuel resources in the world. The transportation of natural gas to multiple consumers started as early as in 1880 itself. Since the second world war the expansion of the natural gas industry was spectacular throughout the world. Currently; the amount of
natural gas depositions in the world are of the order of 80, 450 Gm$^3$. The best endowed country is the erstwhile Soviet Union with 40.0% of world reserves while the second is Iran with 14% of world’s reserves, followed by USA (7%).

**Composition of Natural Gas**

At normal temperature and pressure, the contents of commercial natural gas are mainly methane (CH$_4$, ethane (C$_2$H$_6$) and varying amounts of propane (C$_3$H$_8$) and butane (C$_4$H$_{10}$). An average composition of natural gas indicates methane-83.0%, ethane 7.2%, propane-2.3%, butane-1.0%, N$_2$-5.8%, CO$_2$- 0.2% etc. There may be traces of helium, oxygen, hydrogen and other substances. The main impurities are N$_2$, CO$_2$ and H$_2$S. If H$_2$S is more than 10 grains/m$^3$, it is removed commercially and converted to elemental sulphur by Clauss process. If concentration of H$_2$S is less, it is removed by the process called ‘sweetening’. Natural gas containing H$_2$S is called 'SOUR GAS'. It has an unpleasant odour and H$_2$S dissolved in water follows a mild acid which is corrosive to pipes and valves. Some sources of natural gas contain helium upto 8% also. As such, natural gas is the main source of helium.

**Origin of Natural Gas**

According to one theory, when, earth was born, it was surrounded by methane, water, ammonia and hydrogen. Energy radiation from the sun and lightening discharges broke these simple compounds to a large number of organic compounds like ‘amino acids’ which form proteins, the 'stuff of life', In 1953, Nobel prize winner Harold C. Urey and Stanley Miller showed that electric discharge converts a mixture of methane, water, ammonia and hydrogen into complicated organic compounds that are responsible for making up living organisms. Thus methane generated in the final decay of dead organisms may well be the same substance from which the organism was derived. After the escape of hydrogen,
The oxidation of methane and breaking up of water, \(O_2\) and \(N_2\) remained in the earth’s atmosphere. The methane is found most often, with or near the oil deposits, which indicates a major method of its formation. The gas could be considered to be the product of the microbial decomposition of organic matter in the absence of oxygen. The methane gas also escapes from decaying vegetation in swamp lakes mixed with little \(H_2S\) and \(CO_2\). The gas also occurs in fire dams in coal mines creating explosion hazards. Methane is present in some gold and uranium mines of South Africa mixed with helium gas. Methane is also produced by the biological treatment of sewage or solid organic wastes under anaerobic conditions. These areas could be important sources of methane based on renewable resources.

**Properties of Natural Gas**

Since most of the natural gases contain methane over 90%, natural gas become synonymous to methane: It is the simplest form of hydrocarbon alkanes. The melting point of methane is -183°C and its boiling point is -161.8°C. Natural gas can also be liquefied and Liquefied Natural Gas (LNG) is ideally transported across the sea in specially designed tankers. Density of LNG is 425.0 kg/m\(^3\). The critical point of LNG is 82.1°C at 48.0 kg/cm\(^2\). The atmospheric boiling point of LNG is -161.5°C. Comparative analysis of properties of methane and natural gas are discussed as follows:

The gross calorific value of natural gas is 1000 (k.cal/cu.m.), for methane it is 995 kcal/m\(^3\). The net calorific value for natural gas is 902 kcal m\(^3\) whereas for methane it is 859 kcal/m\(^3\). The specific gravity of natural gas is 0.59 whereas for methane it is around 0.555. The stoichiometric air requirement (vol air/ vol gas) is 9.6 for natural gas, whereas for methane it is 9.52. The inflammability limits for both the gases are 5-15% gas. The spontaneous ignition temperature for natural gas is 700°C. Methane is a colourless gas and less dense than water. Methane is a gas at ordinary
temperature, slightly soluble in water, but highly soluble in organic liquids like gasoline under ultraviolet rays or at 250-400°C, methane and chlorine combine to yield HCl and CH₃Cl called chloromethane or methyl chloride. This is called chlorination which may lead to the formation of CH₂Cl₂ (dichloromethane or methylene chloride), CHCl₃ (trichloromethane or chloroform) and CCl₄ (tetra chloromethane or carbon tetrachloride). Methane reacts with fluorine even in the dark at room temperatures. Methane affects skin, throat and lungs. Being malodorous it presents an unpleasant atmosphere. It retards the growth of vegetation.

**Sources of Natural Gas**

There are mainly two sources of natural gas. It occurs in gas fields i.e. underground reservoirs similar to oil reserves and is recovered by drilling gas wells. In addition, large quantities of gas are produced in association with the production of crude oil. Oil normally contains alkanes from methane upwards. In the reservoir the lower gases are in solution from under considerable pressure. When the oil is brought to the surface, the pressure is released forming associated gas. In some oil fields, particularly those in inaccessible regions, this gas is burnt. In other fields it is collected and used. Composition of a typical associated gas is 76% CH₄; 11.4% C₂H₆; 5.3% C₃H₈; 2.2% C₄H₁₀; 1.3% C₅H₁₂; 2.3% CO₂ and 0.3% H₂S.

Synthetic natural gas, a mixture of carbon monoxide and hydrogen is an ideal connecting link between a source of fossil fuel and substituted natural gas. The low grade coal is initially transformed into synthetic gas (CO+H₂) by gasification process followed by catalytic conversion to methane. The substituted natural gas can be used as a fuel or as a feed back stock for chemical and allied industry.
Uses of Natural Gas

Natural gas is used in many ways. The global consumption of energy in the form of natural gas is presently equal to one half of the consumption of energy in the form of petroleum. Natural gas is used in energy sector, in gas turbines and in diesel engines. Natural gas is also used in the compressed form for road transport. It is the main energy resource in chemical and fertilizer industries. Natural gas is used extensively in petrochemical, metallurgical and sponge iron manufacturing units.

2.2.4 ENVIRONMENTAL IMPACTS OF FOSSIL FUEL PRODUCTION AND CONSUMPTION

There are several important environmental impacts of fossil fuel extraction as well as consumption.

2.2.4.1 Impacts of mining and burning of coal

Coal is mined by strip mining on flat terrains and by underground mining.

In strip mining, the top soil is first removed by bulldozers and set aside and thus the top fertile layer is lost. Surface mining is a fast and efficient way of removing coal but it creates an ugly eyesore that can erode away the soil. If proper precautions are not taken it results in spilling sediments into streams and lakes and destroys fish habitats, recreation sites and reservoirs that supply water for human populations. Surface mining creates dust and noise and destroys wildlife habitat, at least temporarily. Surface mines can also cause groundwater levels to fall considerably, drying up municipal and agricultural wells in the neighbouring areas.

Underground mining also result in disturbance of as much land. Underground mines can also collapse, killing workers. They can cause
sinking of the surface, a process called **subsidence**. Subsidence causes the sinking of buildings and roadways, splitting apart of buildings, tilting of poles and railway tracts etc. and hence cause a lot of problem. Cracks in the earth's surface can also swallow streams, sending water into coal seams.

Water which seeps into mines, either naturally or as a result of subsidence cracks and combines with naturally occurring iron pyrites and oxygen and produces sulphuric acid. This acid mine drainage pollutes the groundwater as well as the nearby streams.

Mixed areas being devoid of vegetation are also prone to large scale erosion of soil and land degradation.

Combustion of coal is another important environmental problem. Four major pollutants that are emitted by coal combustion are carbon dioxide, sulphur dioxide, nitrogen dioxide and particulate matter.

Burning of coal has resulted in massive build-up of carbon dioxide in the atmosphere which is a greenhouse gas responsible for global warming.

Oxides of sulphur and nitrogen are acid precursors which combine with water (rain or dew drops) to form sulphuric acid and nitric acid, respectively and cause acid rains. The acid falls to the earth along with rain or snow, acidifying lakes, streams etc. and killing the fishes. They also kill trees and crops, damage the buildings and statues on which they fall.

**2.2.4.2 Impacts of oil production and consumption**

Oil comes from wells on land and at sea. The impacts of oil on the sea are very important. During handling and transportation lot of pollution is known to occur. Crude petroleum contains hydrocarbons; sulphur, nitrogen, oxygen and several heavy metals.
During handling, oil pollution occurs at the following stages:

- **Cargo tanker washings**: Oil wastes are discharged into the sea. As the tankers reach their destination they are emptied and filled with water to avoid floating too high. Before re-filling the dirty water is pumped out into the sea, thus polluting it. About 3 million tonnes of oil are discharged annually in this manner.

- **Bilge pumping at sea**: The dirty water which accumulates in the bilge (basal flat part of the ship) transporting oil also add substantial amounts of oil in the water reaching upto a tune of 5 lakh tons per year.

- Oil tanker collisions often cause oil spills in the oceans. The famous Torrey Canyon Accident was responsible for 1,17,000 tons of Oil spilling in the British Channel.

- During loading and unloading millions of tons of oil are lost at the sites of port into the water annually.

### 2.2.4.3 Impacts of oil spills

Since oil spills are immiscible with water, therefore, the spills keep on floating. The oil spreads very quickly over the water surface. One cubic meter of oil spill would spread to 48 meter diameter circular area in just 10 minutes. Some of the oil gets volatilized and some gets emulsified. Some oil gets degraded, but the degradation is slow. Due to the oil spill the following impacts occur:-

(i) **As a result of oil spill over the water surface, there is reduced light transmission to lower layers**: About 90 percent of light is cut off by the oil layer and due to inadequate light penetration, photosynthesis in marine flora is adversely affected and that affects the whole of the food chain.
(ii) Marine life is badly affected due to oil spills. Swimming and diving birds are covered with oil - the feathers of birds get matted with oil and the birds are unable to fly or swim. Many birds die due to such oil spills.

(iii) Even the shoreline plants get smothered by the oil and the stomata on the leaves are clogged. The flowers and fruits get smothered and the plant ultimately dies.

(iv) The oil contains many saturated hydrocarbons which adversely affect lower marine animals. Benzene, toluene, xylene etc. are even poisonous to human beings. Hydrocarbons like Naphthalene and phenanthrene present in the oil are highly toxic to fish.

(v) Aromatic compounds are more soluble in water and they kill aquatic life.

(vi) Many of the organic compounds present in the oil spills get biomagnified along with the food chain and accumulate in high concentrations in the animals occupying a high trophic level in the aquatic food chain.

(vii) The aromatic compounds with high boiling point which are constituents of the oil spills are often carcinogenic (cancer causing) in nature.

2.2.4.4 Impacts of oil refining

Petroleum refining is a combination of processes and operations designed to the crude oil into several fractions like motor gasoline, diesel fuel, heating oil, kerosene, jet fuel, bunker fuel, LPG, aviation gasoline and tractor fuel.

The refining process releases- a lot of waste water as 20-70 litres of waste water is produced per litre of crude oil processed. The waste water
contains acidic discharges as well as phenolic compounds of which chlorophenol, p-cresol etc. are more important which are often found to percolate deep and contaminate the ground water. If such waters are consumed, it may cause serious health problems like nervous disorders or even cancer.

The oil refineries also cause air pollution. There are hydrocarbons, Sox, Nox, CO and SPM emissions from the refineries. Sulphur contents of the crude oil varies from 0.2 to 2.5%.

The sulphur dioxide emissions are responsible for acid rains in the vicinity of the refineries. The Mathura Refinery has been responsible for the corrosion of the white marble of Taj Mahal, the greatest monument of cultural heritage of our country. The acidic emissions cause necrosis and chlorosis of the leaves and corrosion of materials. They also cause respiratory ailments and irritation of eyes and skin.

**2.2.4.5 Impact of oil shale production**

The spent shale, after the burning of oil shales produce huge bulks which are to be disposed off. They often contaminate the groundwater and surface waters. The oil shale production pollutes the atmosphere also by releasing sulphur oxides, nitrogen oxides; heavy metals and various organic pollutants - all toxic to humans and wildlife.

Oil shale retorts also require huge volumes of cooling water about 2.5 barrels per barrel of oil produced and thus precious fresh water gets contaminated.

Thus, energy production from fossil fuels as well as their consumption have far reaching environmental impacts.

**2.3 SUMMARY**
Fossil fuels are derived from plant and animal remains buried in the earth millions of years ago. Fossil fuels i.e. Coal, petroleum and natural gas provide 85-90% of energy demand of the modern world. Coal is of three types – Anthracite (with maximum carbon and energy), bituminous and lignite. Coal is processed by different techniques like coal gasification to produce gas that burns as cleanly as natural gas. Coal liquification is done to produce a thick, oily substance. Petroleum is most widely used fossil fuel. It is also obtained from oil shales, which is a sedimentary rock and tar sands. On fractional distillation petroleum yields a large variety of substances. Natural gas, mainly comprising methane is the cleanest fossil fuel. While fossil fuels are the backbone of development and economy, they are also major sources of environmental pollution. Burning of coal results in gaseous emissions including oxides of sulphur and nitrogen, suspended particulate matter and heavy metals. Oil spills causes Marine pollution and harm to marine biology. Mining of these fossil fuels also result in large scale degradation of land and ecology.

2.4 KEY WORDS

Subsidence - Sinking of land surface
Oil shale - Oily residue in sedimentary rocks.
Tar sand - Oily residue in sand-stone layers.

2.5 SELF-ASSESSMENT QUESTIONS

1. What are the different types of coal? Discuss their properties and use.
2. Write a brief note on the following.
   a) Coal gasification
   b) Fluidized Bed Combustion
   c) Coal Liquefaction
3. Describe petroleum resource, oil shales and tar sands.
4. Discuss the impacts of coal mining and burning.
5. Which fossil fuel is the cleanest? Discuss.
6. What are the environmental impacts of petroleum production and use?

2.6 SUGGESTED READINGS


1.0. OBJECTIVES
After studying this unit, you should be able to understand about:

- Different kinds of renewable energy resources.
- Potential of tidal, wind, hydropower and geothermal energy in India.
1.1. INTRODUCTION

Energy resources that do not get depleted by moderate use and are replaced or replenished normally by natural processes or essentially inexhaustible, are renewable energy resources.

Renewable sources of energy include solar, wind, water, geothermal, ocean, hydrogen, biomass and solid waste. They are relatively quickly renewed and recycled in nature and hence constitute sustainable energy sources. They are also referred to as non-conventional energy sources because the techniques for their exploitation have been developed comparatively recently. In the country, the systematic efforts to harness the renewable energy sources were initiated only after setting up of the Commission in 1981 for Additional Sources of Energy (CASE) and in 1982 the Department of Non-Conventional Energy Sources (DNES). The Ministry of Non-Conventional Energy Sources (MNES) created in 1992, is the nodal agency of the Government of India for all matters relating to non-conventional/renewable energy. It undertakes policy making, planning, promotion and coordination of functions relating to all aspects of renewable energy, including fiscal and financial incentives, creation of industrial capacity, promotion of demonstration and commercial programmes, R & D and technology development, intellectual property protection, human resource development and international relations. The production of renewable energy in the country is now based entirely on indigenous know-how.

1.2. TIDAL ENERGY

All flowing waters carry with them kinetic energy. When such water encounters a turbine, part of the momentum of the flowing water is transferred on to the turbine, causing it to rotate. The rotation of the turbine can then be used to generate electricity. Whether the water is in the open ocean, an estuary or a river, its motion can thus be utilized in generating energy. The tides occurring in the oceans are one such source of energy based on the movement of water.
Tides are generated by the action of gravitational forces of the sun and the moon on the oceans, due to the spinning of the earth around its axis and the relative positions of the earth, moon and the sun.

The tides are the periodic vertical rise and fall of ocean water. The period between consecutive high tides is 12.5 hours. The tidal rise and fall of water is accompanied by periodic horizontal to and fro motion of water called tidal currents. Tides and tidal currents are intimately related.

Tidal movement differs from wave-movement. Waves have a period of only about 6 seconds whereas tides have a period of 12.5 hours. Waves are caused by surface winds, whereas, tides are caused by the gravitational forces of moon and sun on ocean water.

The amplitude of tides covers a wide range from 25 cm to 10 m. The speed of tidal currents is in the range of 1.8 km/h to 18 km/h. The tides and tidal currents possess renewable energy.

The rise and fall of the water level follows a sinusoidal curve, shown with point A indicating the high tide point and point B indicating the low tide point. The average period of time for the water level to fall from A to B and then rise from B to C is each approximately equal to 6 hours 12.5 min. (Figure 1.1).

![Figure 1.1. The tides of sea.](image)

The difference between high and low water levels is called the range of the tide. The tidal range R is defined as:
R = water elevation at high tide - water elevation at low tide.

Because of the changing positions of the moon and sun relative to the earth, the range varies continuously. There are however, some characteristic features of this variation.

During full or new moon, when sun, moon and earth are approximately in a line, the gravitational forces of sun and moon are enhanced. The tidal range is then exceptionally large, the high tides are higher and low tides are lower than the average. These high tides are called spring tides. On the other hand, near the first and third quarters of the moon, when the sun and moon are the right angles with respect to the earth, neap tides occur. The tidal range is then exceptionally small; the high tides are lower and the low tides higher than the average. Hence the range is not constant. It varies during the 29.5 day lunar month (Figure 1.2), and is maximum at the time of new and full moons (called the spring tides), and minimum at the time of the first and third quarter moons (called the neap tides). The spring-neap tidal cycle lasts one-half of a lunar month. A typical mean range is roughly one third of the spring range. The actual variations in range are somewhat complicated by seasonal variations caused by the ellipticity of the earth’s orbit around the sun.

The variations in the periodicity and monthly and seasonal ranges must, of course, be taken into account in the design and operation of tidal power plants. The tides, however, are usually predictable and fairly accurate tide tables are usually available.

Tidal ranges vary from one earth location to another. They are influenced by such conditions as the profile of the local shoreline and water depth. When these are favourable a resonance like effect causes very large tidal ranges. Ranges have to be very large to justify the huge costs of buildings dams and associated hydroelectric power plants. Such tides occur only in a few locations in the world.
Figure 1.2. Relative high and low tides showing variation in range during lunar month.

The tides along most coastlines are amplified by a funneling action, they may rise by 10 meters or more. It is in these constricted areas that the most effective tidal power plants may be located. A dam or sluice gate is placed across an ocean bay or estuary. An incoming tide fills up the enclosed basin while passing through a row of hydraulic turbines. After the basin is filled with water, the gates are closed and the turbines are shut down. Then the turbine blades are reversed and the gates opened again to let the water surge out. Thus turbines would be rotated either way generating electric power.

The tides are daily movement of large bodies of water driven by gravitational attractions between the sun, earth and moon. Twice a day, large volumes of water flow in and out of bays and river opening on the coast to produce high and low tides. The principle of tidal power generation is the same as that employed in a hydroelectric plant. What is needed is a bay with an opening to sea narrow enough to be closed by dam having
gates that can be opened and closed. The bay fills as the tide comes in through open gates. The gates are then closed to flow out the water through a turbine that generates electricity (Fig. 1.2). Some tidal energy schemes use only out flowing tide to produce energy while others use both in flowing and out flowing tides to generate energy.

1.2.1. Potential of tidal power and present status of its utilization

The idea of harnessing tidal energy came to man hundreds of years ago. First tidal mill appeared on the Brittany coast of France in 12th century. Thereafter many tidal mills were reported to have been in operation along the Atlantic Coast of Europe, mostly in Great Britain, France and Spain. However, construction of modern tidal electric stations have been attempted only in 1960. The first modern tidal electric mill La Rance capable of generating 240 MW was built in the Rance Estuary (France) in November 1966. It uses both the inflowing and outflowing tides. The Bay of Fundy in Canada has great (as yet untapped) potential for producing tidal power, because it has the highest tidal height (18 m) in the world.

India is fortunate to be endowed with a few potential sites worthy of consideration for tidal power development. The important potential tidal sites are shown in Table 1.

Table 1. Tidal power potential in India.

<table>
<thead>
<tr>
<th>Site</th>
<th>Maximum tidal range</th>
<th>Average tidal range</th>
<th>Tidal power potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gulf of Cambay</td>
<td>11 m</td>
<td>6.77 m</td>
<td>7,000 MW</td>
</tr>
<tr>
<td>Gulf of Kutch</td>
<td>8 m</td>
<td>5.23 m</td>
<td>1,000 MW</td>
</tr>
<tr>
<td>Ganga delta of Sunderbans</td>
<td>5 m</td>
<td>2.77 m</td>
<td>1,000 MW</td>
</tr>
</tbody>
</table>
The identified tidal power potential in India is around 9000 MW. According to an official report, the proposal to set 900 MW power plant by National Hydropower Corporation during the ninth and tenth plans is under consideration. The proposed Kutch Tidal power Project envisages generating 1660 GWh per annum. It is estimated to cost about Rs. 1460 crores.
1.2.2. Tidal power schemes in India

The most attractive tidal power sites are the Gulf of Cambay and the Gulf of Kutch where the maximum tidal range is of the order of 11 m and 8 m respectively and the average tidal range is of the order of 6.8 and 5.2 m, respectively. The techno-economic feasibility of the Gulf of Kutch Scheme was taken up by the Central Electricity Authority, Government of India. The scheme envisages a single basin, single effect development with an installed capacity in the range 800-1000 MW. The main tidal barrier is about 3.25 km. The scheme is expected to cost Rs. 6000 crores, according to 1993 prices. But this project was not taken up as it was too expensive when compared to the conventional hydropower projects. Another potential site is the Sunderbans with a maximum tidal range of 5.0 m and an average tidal range of 3.0 m.

The promising sites for tidal power plants are located in Gujarat state and West Bengal state. Survey of other sites in Orissa, Tamil Nadu, Kerala, Karnataka and Maharashtra, Andaman Nicobar etc. is being done by the Non-conventional and Renewable Energy Department. The sites have good prospects but require extremely high investments compared to conventional power plants of the same rating. The estimated tidal power potential in India is about 15000 MW.

1.2.3. Advantages and limitations of tidal power generation

Advantages:

1. The biggest advantage of tidal power, besides being inexhaustible, is that it is completely independent of the uncertainty of precipitation (rain). Even a continuous dry spell of any number of years will have no effect whatsoever on the tidal power generation.

2. Tidal power generation is free from pollution, as it does not use any fuel and also does not produce any unhealthy waste like gases, ash, etc.
3. These power plants do not require large areas of valuable land because they are on the bays (sea shore).
4. Peak power demand can be effectively met when it works in combination with thermal or hydroelectric systems.

Limitations: There are a number of reasons why the tidal power generation is still a novelty, rather than a normal source of energy. The reasons are:

1. The fundamental drawback to all methods of generating tidal power is the variability in output caused by the variations in the tidal range.
2. The tidal ranges are highly variable and thus the turbines have to work on a wide range to head variation. This affects the efficiency of the plant.
3. Since the tidal power generation depends upon the level difference in the sea and an inland basin, it has to be an intermittent operation, feasible only at a certain stage of the tidal cycle.
4. The tidal range is limited to a few metres. As the bulb turbine technology was not well developed for this range, use of conventional kaplan runners was the only alternative. This was found to be unsuitable. Now with the development of reversible flow bulb turbines, this difficulty is overcome.
5. The duration of power cycle may be reasonably constant but its time of occurrence keeps changing, introducing difficulties in the every day planning of the load sharing in the grids. This handicap can be removed now with the help of computerized programming.
6. Sea water is corrosive and it was feared that the machinery may get corroded. However, stainless steel with a high chromium content and a small amount of molybdenum and the aluminium bronzes proved to be good corrosion resistant materials at La Rance project. The vinyl paint exhibited good results.
7. Construction in sea or in estuaries is found difficult.
8. Cost is not favourable compared to the other sources of energy.
9. It is feared that the tidal power plant would hamper the other natural uses of estuaries such as fishing, or navigation.

1.3. WIND ENERGY

For centuries wind has been used to move ships, grind grains, pump water, and do other forms of work. In recent times, wind has been used to generate electricity. There is enough wind energy available on the earth to generate more than ten times the electricity now used worldwide. Global wind generating capacity has expanded at an annual rate of 25.7 per cent during the 1990s, and in April 1998 it stood at more than 10,000 MW. It is the fastest growing of all renewable energy sources. Denmark, Spain, Germany, USA and India have emerged as leaders in wind energy development. These countries account for more than 80 per cent of world capacity. For Europe alone, the European Wind Energy Association has set a target of 40,000 MW by 2010 and 1,00,000 MW by 2020. With technological advances the cost of generating wind power has continued to decline, and wind promises to become a major power source globally in the next millennium. India today is the fourth largest producer of wind power in the world after Germany, USA and Denmark (See table).

1.3.1. Wind Energy Development in India

In India wind power is untapped but potentially very important source of energy. It appears to be the most feasible and cost-effective for supplementing these conventional means of power generation on a large scale. Its advantage are:

- It is perennial source, available all over the day and night;
- It is an ideal source of energy for the small farmers cottage, micro and small industries;
- It is most useful source of energy for those living in isolated hilly, coastal and other regions which are far away from electric transmission network;
• The power is cost effective; and
• It is inexhaustible, Eco-friendly, non-polluting and freely available.

Table 2. Wind power installed capacity at global level (India ranks fourth in the world).

<table>
<thead>
<tr>
<th>State</th>
<th>Total installed wind capacity (in MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Germany</td>
<td>2,081</td>
</tr>
<tr>
<td>United States</td>
<td>1,611</td>
</tr>
<tr>
<td>Denmark</td>
<td>1,116</td>
</tr>
<tr>
<td>India</td>
<td>940*</td>
</tr>
<tr>
<td>Spain</td>
<td>512</td>
</tr>
<tr>
<td>The Netherlands</td>
<td>329</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>328</td>
</tr>
<tr>
<td>China</td>
<td>146</td>
</tr>
<tr>
<td>Sweden</td>
<td>122</td>
</tr>
<tr>
<td>Italy</td>
<td>103</td>
</tr>
<tr>
<td>Greece</td>
<td>29</td>
</tr>
<tr>
<td>Canada</td>
<td>25</td>
</tr>
<tr>
<td>Japan</td>
<td>18</td>
</tr>
<tr>
<td>France</td>
<td>13</td>
</tr>
<tr>
<td>Australia</td>
<td>11</td>
</tr>
<tr>
<td>Russia</td>
<td>5</td>
</tr>
<tr>
<td>Brazil</td>
<td>3</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>7,392</strong></td>
</tr>
</tbody>
</table>

*1175 MW achieved very recently.


Ministry for Non-conventional Energy Sources (MNES) recently reassessed and upgraded the gross wind power potential in the country from 20,000 MW to 45,000 MW (Down to Earth, January 31, 2000).
However, the present technical potential is limited to about 9,900 MW governed by the grid capacity in the potential States. The Kutch and Saurashtra in Gujarat and the South Tamil Coastal areas offer some of the best known windy locations in the country where wind energy is ready to take its place alongside conventional resources as a clean reliable source of electricity generation. More than 192 sites having total wind power potential over 5000 MW have already been identified in thirteen States/Union territories including Tamil Nadu, Karnataka, Madhya Pradesh, Gujarat, Maharashtra, Andhra Pradesh, Kerala, Lakshadweep, West Bengal, Uttar Pradesh and Rajasthan.

However the country by March 2000, was able to harness only a little over 5 per cent (~ 1140 MW) of the total wind energy potential (See table 2). With the 766 MW of energy generation capacity, Tamil Nadu ranks first among the states in the number of energy generators installed and power produced, followed by Gujarat and Maharashtra. The other Wind Power generating states – Andhra Pradesh, Karnataka, Madhya Pradesh, Kerala and Orissa – have their installed capacity far short of their gross potential. Currently the wind power installed capacity of the country has reached to 1175 MW.

Table 3. Wind energy installed capacity in India (1999-2000) (in MW).

<table>
<thead>
<tr>
<th>State</th>
<th>Installed capacity</th>
<th>Available technical potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tamil Nadu</td>
<td>766.480</td>
<td>2,000</td>
</tr>
<tr>
<td>Gujarat</td>
<td>168.420</td>
<td>1,271</td>
</tr>
<tr>
<td>Andhra Pradesh</td>
<td>68.290</td>
<td>1,231</td>
</tr>
<tr>
<td>Maharashtra</td>
<td>75.970</td>
<td>2,108</td>
</tr>
<tr>
<td>Karnataka</td>
<td>33.700</td>
<td>687</td>
</tr>
<tr>
<td>Madhya Pradesh</td>
<td>21.920</td>
<td>775</td>
</tr>
<tr>
<td>Rajasthan</td>
<td>2.000</td>
<td>397</td>
</tr>
<tr>
<td>Kerala</td>
<td>21.250</td>
<td>353</td>
</tr>
<tr>
<td>Orissa</td>
<td>0.575</td>
<td>338</td>
</tr>
<tr>
<td>Others</td>
<td>0.575</td>
<td>775</td>
</tr>
<tr>
<td>Total</td>
<td>1140.055</td>
<td>9,935</td>
</tr>
</tbody>
</table>

*currently, the installed capacity has reached to 1175 MW.

Source: CMIE, June 2000 (Hindu 17-08-2000).
Within the developing world, the largest wind industry is India. The Washington-based World Watch Institute recognized India as a Wind Superpower. Wind power development in India has been rather rapid at selected sites. One such site is Muppandal in Tamil Nadu, which has an installed capacity of 400 MW. Muppandal today has the highest concentration of wind farms in Asia and the third highest in the world. In India, wind energy development boomed during the period 1993-97 and the country rose to become one of the world’s fastest-growing markets for wind energy, both in terms of potential and rate in installation. The growth of wind power in the country during 1990-2000 is shown in Fig. 1.4.

1.3.2. Wind Energy Programme

In the State of California (USA), over 17,000 wind electric generators (WEGs) producing over 14,000 MW of electric power have been developed. This has been achieved through development of a number of WEGs in a cluster to form wind farm or wind park. Grid connected power generation programmes have also commenced in a few European countries, such as Denmark, the Netherlands, UK, etc.

![Figure 1.4. Wind power growth in India during 1990-2000.](image-url)
In India, DNES has designed a broad-based energy programme to harness available wind power potential. The major activities included in the programme are:

- Strengthening of the wind data base;
- Pumping water;
- Power generation, and
- International cooperation

Wind data base programme is very significant in locating the wind potential sites for installation of wind/power monitoring and mapping activities. The programme/demonstration wind farms in the country was commenced in 1985. Wind power capacity of nearly 8 MW was established in the country by the end of 1987. This includes the installation of 7 wind farms at Okha and Mandvi (Gujarat). Tuticorin and Kayattar (Tamil Nadu), Puri (Orissa), Deogarh (Maharashtra) and Talcavery (Karnataka). Under the international cooperation programme, two wind farms each at Kayattar (Tamil Nadu) Lamba (Gujarat) have been installed with support from Danish International Development Agency (DANIDA) of Denmark. Lamba is the largest wind farm of Asia. Till 1990, a total of 12 wind farms have been set up. By that time, about 57 million units of electricity had been fed into respective state grids since the programme began in 1986.

Tamil Nadu, is one of the most windy regions of the world accounting for about 10% of the total installed global wind energy capacity and over 70% of the country’s total installed capacity. The estimated cost of setting up wind farm project comes to Rs. 35 to 45 million per MW. Recently, in Rajasthan wind energy projects have been set up at Devgarh village in Chittorgarh district and at Amarsagar in Jaisalmer district.
Wind generators have certain disadvantages:

- They are large in size giving unattractive outlook to the landscapes.
- They can be extremely noisy, and disturb residents of the area.
• Often their blades may interfere with television reception or with microwave communications used by telephone companies.
• Wind does not blow all the time, so backup systems are needed and the electricity must be stored until it is used.

1.4. HYDROPOWER

Hydropower is recognized as a renewable source of energy, which is economical, non-polluting and environmentally beneficial. Hydropower projects involve the construction of dams to produce the waterfalls that power turbines. Although hydropower is renewable, the dams and reservoirs needed to capture this energy have limited life spans. The reservoirs behind dams invariably filled with sediments, giving the typical dam a life span of 20 to 100 years. Once a hydropower site is filled with sediments, it is gone forever. Dams also often create many environmental problems. This means that hydroelectric power is unlikely to expand much faster in developed as well as developing countries.

The world’s leading generator of electricity from hydropower is the United States (71,000 MW capacity), Europe, Japan, the eastern Soviet Union and Southern Canada harnessed the hydropower potential to the maximum. In South America, 73 percent of the electricity used comes from hydropower compared to 44% in the developing world as a whole. Norway gets 99 percent of its electricity from hydropower. The World Energy conference estimates that the electricity produced by hydropower will increase six times by the year 2020. The developing countries, which have developed about 10 percent of their hydropower, will experience most of this growth.

Because of the escalating cost and environmental damage from large dams, many of these countries have developed small hydropower plants (“Minihydro:-less than 10 MW and “microhydro”-less than, 1 MW) in remote areas to supply electricity. China has built over eighty thousand such small projects and the United States has nearly fifteen thousand. However, these
small hydropower plants will not solve the problem of how to supply energy to the huge and rapidly growing cities of developing countries.

Hydel power has several advantages:

- It is a clean source of energy;
- It provides irrigation facilities; and
- It provides drinking water to people living, particularly in desert of Rajasthan and Gujarat.

The large hydropower projects, however, involve several environmental and socio-economic problems:

- Submerge forest and agricultural land;
- Cause loss of biodiversity;
- Displace local people and create problems of rehabilitation;
- Cause water logging and siltation;
- Affect adversely fish population and other aquatic organisms; and
- Increase seismicity due to large volume of water impounded.

1.4.1. Hydel Power Potential in India:

India has a large hydel potential totaling about 84,044 MW, which can be tapped. However, 75% of it is concentrated in the Himalayan region, which is tectonically very unstable. Out of the total potential, only about 23,627 MW installed generating capacity has been achieved as of January 2000.

The history of hydropower generation in India is more than 100 years old. The first-hydropower station in India was a small hydropower station of 130 kW commissioned in 1897 at Sidrapong near Darjeeling in West-Bengal. Subsequently, many small hydropower stations were set up. With the advancement in technologies and increasing requirement of electricity, emphasis was shifted to large sized hydropower stations. The growth of hydropower in the country since 1990 to 2000 is shown in Fig 1.6. This hydropower capacity is about 25 percent of the total installed capacity for electricity generation. Ministry of Power in the Government of India is responsible for the development of large hydropower projects in India, while
MNES has recently been assigned to develop small hydropower projects (3-25 MW) in the country.

![Figure 1.6. The growth of hydropower in the country (installed power generating capacity in MW)](image)

Hydropower still remains the cheapest source of electricity in the country. Hence, more stress now has been laid on the construction of mini/micro hydel plants with generation capacities between 3 MW and 15 MW to avoid the soci-economic and environmental problems created by big dams.

**1.4.2. Small Hydel Projects in India**

An estimated potential of about 10,000 MW of small hydropower projects exists in India. MNES has identified 3349 sites with an aggregate potential of 2,852 MW for small hydro projects up to 3 MW capacity and 662 sites with an aggregate potential of 5,519 MW for projects upto 3-15 MW capacity. Presently, the country has exploited 217 MW with the construction
of 271 small hydropower projects (up to 3 MW capacity). Over 130 projects in this range, with an aggregate capacity of 133 MW, are under construction. In the last 10 years, the capacity of small hydro projects has increased 3 fold from 63 MW to 217 MW. Table 4 lists the existing and ongoing small hydro power plants in the country as on June 1997.

Table 4. List of installed/ongoing micro/mini hydel projects upto 3 MW capacity as on June 15, 1997

<table>
<thead>
<tr>
<th>State</th>
<th>Projects installed</th>
<th>Projects under construction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number</td>
<td>Capacity (MW)</td>
</tr>
<tr>
<td>Andhrhra Pradesh</td>
<td>7</td>
<td>7.01</td>
</tr>
<tr>
<td>Arunachal Pradesh</td>
<td>30</td>
<td>20.15</td>
</tr>
<tr>
<td>Assam</td>
<td>2</td>
<td>2.20</td>
</tr>
<tr>
<td>Bihar</td>
<td>4</td>
<td>0.04</td>
</tr>
<tr>
<td>Goa</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gujarat</td>
<td>1</td>
<td>2.00</td>
</tr>
<tr>
<td>Haryana</td>
<td>1</td>
<td>0.20</td>
</tr>
<tr>
<td>Himachal Pradesh</td>
<td>15</td>
<td>9.49</td>
</tr>
<tr>
<td>Jammu and Kashmir</td>
<td>15</td>
<td>4.37</td>
</tr>
<tr>
<td>Karnataka</td>
<td>8</td>
<td>10.10</td>
</tr>
<tr>
<td>Kerala</td>
<td>4</td>
<td>3.52</td>
</tr>
<tr>
<td>Madhya Pradesh</td>
<td>5</td>
<td>3.25</td>
</tr>
<tr>
<td>Maharashtra</td>
<td>4</td>
<td>4.32</td>
</tr>
<tr>
<td>Manipur</td>
<td>6</td>
<td>4.10</td>
</tr>
<tr>
<td>Meghalaya</td>
<td>1</td>
<td>1.51</td>
</tr>
<tr>
<td>Mizoram</td>
<td>9</td>
<td>5.36</td>
</tr>
<tr>
<td>Nagaland</td>
<td>5</td>
<td>3.17</td>
</tr>
<tr>
<td>Orissa</td>
<td>3</td>
<td>1.26</td>
</tr>
<tr>
<td>Punjab</td>
<td>4</td>
<td>3.90</td>
</tr>
<tr>
<td>Rajasthan</td>
<td>5</td>
<td>4.30</td>
</tr>
<tr>
<td>State</td>
<td>No.</td>
<td>Capacity</td>
</tr>
<tr>
<td>------------------------</td>
<td>-----</td>
<td>----------</td>
</tr>
<tr>
<td>Sikkim</td>
<td>8</td>
<td>9.25</td>
</tr>
<tr>
<td>Tamil Nadu</td>
<td>3</td>
<td>4.75</td>
</tr>
<tr>
<td>Tripura</td>
<td>2</td>
<td>1.01</td>
</tr>
<tr>
<td>Uttar Pradesh</td>
<td>60</td>
<td>31.04</td>
</tr>
<tr>
<td>West Bengal</td>
<td>8</td>
<td>7.98</td>
</tr>
<tr>
<td>Andaman and Nicobar</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>210</td>
<td>144.28</td>
</tr>
</tbody>
</table>

Note: The total installed capacity of small hydro power plants now has reached to 217 MW with the installation of 271 projects.


Small and minihydel projects have the potential to provide energy to remote and hilly areas where extension of grid system is uneconomical. Realizing this fact, government of India is encouraging development of small and mini hydel projects in the country.

Micro hydel projects are more feasible so far as the socio-economic and environmental consequences are concerned. They do not pose the problems of deforestation, submergence and rehabilitation. Also, entail no wastes, no production of toxic gases and no adverse effects on environment. However, economically they are not viable because of:

- Higher capital cost;
- Equipment availability, especially for ultra low head regions;
- Higher cost of construction control and management; and
- Load factors.

### 1.5. GEOTHERMAL ENERGY

The earth contains large amounts of geothermal energy with temperature as high as 4400°C. This energy comes from magma, molten rock material beneath the surface of the earth or from radioactive decay of thorium, potassium and uranium dispersed throughout the earth’s interior. In some regions of the earth this molten material sometimes breaks through
the earth’s crust and produces volcanoes. In other regions, the hot material is close enough to the earth’s surface to heat the underground water trapped by impermeable rock and form steam. Geysers and hot springs are natural areas where hot water and steam come to the surface. In such areas geothermal energy is tapped by drilling wells to obtain steam. At present, geothermal energy is only practical in areas where the molten mass is near the surface.

There is large scope for utilization of geothermal energy to uplift the socio-economic status and the lifestyle of the people, particularly those living in far remote areas of the country and where this source of energy is in abundance. Besides space heating and power generation, the energy could be utilized:

- In small and cottage industries;
- Drying and processing of conventional and cash crops;
- Animal husbandry, dairy, poultry and fishery development;
- Silviculture;
- Spinning, weaving, painting and garment industry;
- Hard and soft board manufacturing and pulp making; and
- Brewing of low alcoholic beverages.

1.5.1. Geothermal Energy Prospects in India

Keeping in view the severe energy crisis which is going to occur in the near future as a result of rapidly growing population in India, much attention has been paid by the planners and scientists to exploit alternate energy resources to supplement the existing conventional energy potential. Geothermal energy has received much attention for exploitation since 1973 and sufficient scientific studies relating to places of occurrence, geotectonic associations, geochemical and thermal characteristics were carried out by scientists. On the basis of these studies, certain geothermal areas/fields have been identified, giving energy potential of each area and prospective uses.
Even through geothermal energy is manifested to the surface mostly in the form of hot springs, in several areas the degree of heat potential, chemical composition of water, and quantity vary greatly. Geothermal reservoirs emitting hot water with high temperatures normally occurred in volcanic regions. Such regions occur mostly along continental plate margins and in some inter plate regions.

The geological history of India reveals that except the large scale volcanic activity in the Deccan plateau during the tertiary period, no such activity during recent periods is known to have occurred anywhere except in Barren and Narcondom islands of Andaman and Nicobar group.

1.5.2. Major Geothermal Regions of India

Based on tectonic and thermal histories, the following seven major geothermal regions have been identified after conducting studies by the scientists of National Geographical research Institute (NGRI) with regard to occurrence of geothermal water manifestations. In each region the use of this energy for various purposes have been also mentioned.

The Himalayan Geothermal Region: Thermal springs in Himalayan region manifest themselves mostly along the banks of certain rivers or their tributaries. They are found even in Karakoram-Kailash mountain region beyond the Northern Himalayas. In fact a belt of thermal springs starting from North-Western Himalayas continues through Nepal and Bhutan towards North-Eastern Himalayas to Burma and finally to Barren island. Due to continuing uplift of Himalayas, a large fracture system has developed in them, which facilitated the emergence of thermal springs of which some have even high temperature. Some of them have mild geyser activity emitting steam at regular intervals alongwith hot water. The temperatures range from 120°C to 240°C \(\pm 20^0C\).

In this Himalayan geothermal region, seven sub-regions, i.e. Puga valley, Chumtong in Ladakh, Parbati, Beas and Sutlej valleys in Himachal
Pradesh, Topoban region, Alakananda valley in Chamoli district of U.P. and Kashmir valley basin have been also identified on the basis of geothermal characteristics of each sub-region and the use of energy for various purposes in each sub-region.

In Puga valley of Ladakh with estimated reservoir temperature of 240°C ± 20°C and with observed temperature of 84°C of thermal springs it has been suggested that the heat energy can be utilized for space heating, extraction and refining of borax, sulfur, generating electricity of 1000 kW using binary cycle, poultry farming, mushroom cultivation and sheep farming.

In Chumtong region of Ladakh where geothermal reservoir temperature is about 180°C ± 20°C and the observed temperature of thermal springs is 87°C the hydrothermal energy can be utilized for greenhouse cultivation, electricity generation, space heating, poultry farming, mushroom cultivation and fish culture etc.

In Parbati valley, Kulu of Himachal Pradesh where the estimated reservoir temperature is about 160°C ± 20°C and the observed temperature of springs is about 96°C the energy can be utilized for generating electricity, space heating, food processing, poultry farming, greenhouse cultivation, etc. In Beas and Sutlej valley of Kulu the estimated reservoir temperatures are about 120°C ± 20°C and the observed spring temperatures are 57°C and 60°C, respectively. In both the regions the energy can be used for space heating, cold storage, poultry farming, pasteurization of fruit juice and health resorts.

In Tapoban region of Alakananda valley of Chamoli district of U.P., the estimated thermal reservoir temperature is about 160°C ± 20°C and the observed spring temperature is about 64°C. The energy can be used in this region for electricity generation, baths, space heating, poultry farming, tourism etc.

In Kashmir valley where the estimated reservoir temperature is about 100°C ± 20°C and thermal springs temperature is about 56°C the thermal energy can be utilized for space heating for small scale industries like wood
processing, carpet, shawl, sari and other garment making, wooden craft, tourism etc.

**The West-Coast Konkan Region:** A chain of mountains running parallel to the west coast of India between latitude 16°-30° N and 20° N have thermal springs mostly in groups at 21 different locations. These are controlled by shear zones, fractures or dykes of Deccan trap and manifest in various river basins along stream courses. Many earthquakes occur in the west coast. The hot springs of this belt are oriented in N-S and NNW-SSE directions indicating that the belt has suffered strong crustal movements and the fractures which control the thermal springs are still active. The temperatures of geothermal systems of this belt are around 100°C ± 20°C.

There are two sub-regions i.e. Unhavare (Khed) and Ganeshpuri-Akloli in this region. In both the regions the estimated reservoir temperature is about 110°C ± 20°C and the observed temperature of springs are about 70°C and 57°C respectively. The energy in both the regions can be utilized for refrigeration mushroom cultivation, drying fish, vegetables and brewing.

**Narmada-Tapti Geothermal Region:** Thermal springs mostly in cluster with temperature varying from 32°C to 98°C are found at sixteen locations in this region which is a permanent ancient geological feature of the peninsular India between 21° N and 24° N in a NNE-SSW direction. The estimated reservoir temperature of this region range from 60°C to 110°C except in one case, that is Tatapani Geothermal field (where hot springs having temperature is upto 98°C) whose estimated reservoir temperature is 160°C ± 20°C.

In Tapani, Surguja district of M. P., where the observed temperature of hot spring is about 98°C, the thermal energy can be utilized for electricity (installation of 20 KW binary cycle power plant is planned), sericulture, tourism, drying and curing of light aggregate cement slabs, purification of bauxite, etc.
In Tapti basin of M. P. where the estimated reservoir temperature is $110^0C \pm 20^0C$ and the thermal spring temperature is about $60^0C$, the energy can be utilized for electricity generation, sericulture, refrigeration and processing industries.

**The Damodar Graben Region**: There are a few hot spring areas in Gondwana grabens adjacent to Damodar river valley. All along, the estimated reservoir temperature is about $100^0C \pm 20^0C$ and the observed temperature of springs is upto $80^0C$. The energy can be used for electricity generation, rice para boiling, drying of agricultural products and paper pulp manufacture.

**Combay Graben Geothermal Region**: In the Combay and Kathana fields, the estimated reservoir hot eruptive springs (mixture of water and steam) of temperatures over $100^0C$ occur. The energy from these springs can be used for electricity generation, refrigeration, processing and drying industries.

**Delhi-Mobile Belt Geothermal Region**: Springs in Sohna valley in Haryana with estimated reservoir temperature about $90^0C \pm 20^0C$ and observed temperature of $47^0C$ are found. These springs are found along the pre-Himalayan alignment towards south-west of Delhi with the areas of Delhi folding. The energy can be used for refrigeration and tourism.

**Wardha-Pranahita Godavari Valley Graben Geothermal Region**: The valley of the river Godavari along with those of Pranahita and Wardha rivers represent a prominent linear graben structure of Indian land mass. It is one of its main Gondwana basins of Permo-carboniferous to lower cretaceous geological periods. Most of its hot springs have temperature slightly over mean annual air temperature. Its hottest spring Agnigundata occurs in the bed of river Godavari and its temperature reached upto $62^0C$. Hot water also has been tapped through holes drilled for exploration of coal and ground water resources in various parts of this graben.
In Godavari and Chintalapudi sub-basins, the estimated reservoir temperature varies from 100°C to 156°C and the observed temperature of springs from 29°C to 62°C. The energy can be utilized for rice para boiling, drying of paddy and chillies.

1.5.3. Classification of Geothermal Systems

The NGRI scientists, on the basis of estimated reservoir temperature and pressure, have classified geothermal systems into three categories of HGS (Hydro Geothermal systems):

- **High Temperature** (150°C) HGS: These mainly occur in Himalayan region except in Tatapani and Agnigundala area in peninsular region and in the Andaman and Nicobar Islands.

- **Intermediate Temperature** (150°C-80°C) HGS: These are widely distributed and exist particularly in all geothermal regions of India. These form the common resource base in India.

- **Low Temperature** (<80°C) HGS: These occur generally in limited numbers in almost all geological regions of India.

1.5.4. Heat Energy Potential in India

Based on one hundred well recognized hydrothermal systems the estimated energy heat energy potential would be about 40x10^18 calories which is equivalent to 27.6 billion barrels of petroleum and there would be a saving of 60,000 million rupees per year. The estimated power potential of the identified systems would be 2000 MW for utilization for a period of 30 years.

The studies carried out so far have indicated good prospects in India for developing geothermal resources for generation of electricity by using binary cycle turbines and for non-electrical applications like space heating, poultry farming, mushroom raising, drying, mineral processing, etc. As
mentioned already cold storage could also be developed for preserving fruits and vegetables.

There are good prospects of tapping intermediate (80°C-150°C) and high temperature (>150°C) geothermal fluids at suitable locations in various parts of Himalayan region. Here very cold climate conditions prevail during most part of the year and the work season is very short and the reserves of fossil fuels are meager.

As regards peninsular India, geothermal resource of intermediate (150°C-80°C) and low grade (<80°C) are available at various locations. Good possibilities do exist in peninsular India for developing industrial centres around geothermal fields. The geothermal fluids of these fields could be utilized for hydrothermal processing in ceramic, electronic, magnetic, pigment, inorganic chemicals, food and even iron/steel and non-ferrous metal industries. Hydrothermal processing involves the chemistry of hot water under pressure to carry out leaching and precipitation reactions and it has been emerging as a very potential process these days. It is hoped that several biotechnological units where biochemical reactions require large heat capacities but at lower temperature, would also be established in India by using them. Some of these units could be established near suitable geothermal fields.

Control of coal mine fires occurring mostly in Raniganj and Jharia coal fields, causing huge loss of prime coking and superior quality of non-coking coal, which cost Rs. 100 crore could be possible with the application of emerging technology of the down hole coaxial heat exchanger system. There is great possibility for the economic in-situ extraction both of the geothermal energy and the heat available from the combustion of coal from the coal fields of Jharia and use it for power generation.

By utilizing geothermal and non-conventional energy resources like solar, wind and biomass energy remote and isolated areas like Ladakh and many other parts of India could be economically developed. There is bright future for the utilization of geothermal energy resources on large-scale for socio-economic development in different parts of India.
1.6. SUMMARY

Few countries in the World has placed as much faith in renewable energy sources as India has, when the World was reeling under the oil price stock of 1973 and 1979, every Nation has made a beeline for renewable energy sources as alternatives to fossil fuels. The India has been bestowing upon renewable energy resources is reflected in the numerous policy decisions taken by the Government at the highest level. India is one of the few countries which has a full-fledged Ministry devoted to non-conventional energy sources. This unit covers the important renewable energy resources – tidal, wind, hydropower and geothermal etc. The tides occurring in the rivers or oceans are sources of energies based on the movement of water. The potential, prospects, development in the field of tidal, wind geothermal and hydropower energy in India has been discussed.

1.7. KEY WORDS

Tides
The periodic vertical rise and fall of ocean water due to gravitational force of moon and sun.

Wind farm
Cluster of small to medium sized wind turbines in a windy area to capture wind energy and convert it into electrical energy.

Hydropower
Electric energy produced by falling or flowing water.

Geothermal energy
Heat transferred from the earth's underground concentrations of dry steam (steam with no water droplets), wet steam (a mixture of steam and water droplets) or hot water trapped in fractured a porous rock.

Renewable resource
Resource that can be replenished rapidly through natural processes.

1.6. SELF ASSESSMENT QUESTIONS
1. What is meant by renewable energy resources? Explain briefly.

2. What is the basic principle of tidal energy?

3. Write down the potential of tidal power in India.

4. What are the advantages and limitations of tidal power generation?

5. What is wind energy? Discuss wind energy development in India.

6. What are the advantages and disadvantages of wind energy conservation system?

7. Write down the potential of hydel power in India.

8. What is meant by geothermal energy?

9. What are the main applications of geothermal energy?

10. What is the classification of geothermal system?

11. Give a brief note on the prospects of geothermal energy in context to India.

1.7. FURTHER READINGS


BIOMASS ENERGY

Narsi Ram Bishnoi

STRUCTURE

2.0. OBJECTIVES

2.1. INTRODUCTION

2.2. BIOMASS CONVERSION TECHNIQUES
   2.2.1. Thermo-chemical conversion
   2.2.2. Biochemical conversion
   2.2.3. Conversion efficiency

2.3. BIOGAS
   2.3.1. Biogas programme in India
   2.3.2. Commonly used biogas plants in India
      2.3.1.1. Fixed Dome Biogas plant
      2.3.1.2. Floating Gas Holder Plant

2.4. BIOGAS FIERS

2.5. ENERGY PLANTATION

2.6. IMPROVED CHULHAS PROGRAMME
   2.6.1. Objectives of the programme
   2.6.2. Fixed Chulhas of Family Size Models
   2.6.3. Community Size Models
   2.6.4. Portable Chulhas

2.7. HYDROGEN AS A FUEL
   2.7.1. Methods of producing hydrogen from solar energy
      2.7.1.1. Direct thermal
      2.7.1.2. Thermochemical
      2.7.1.3. Electrolytic
      2.7.1.4. Photolytic

2.8. SUMMARY

2.9. KEY WORDS

2.10. SELF ASSESMENT QUESTIONS

2.11. SUGGESTED READINGS
2.0. OBJECTIVES

After studying this unit, you will be able to understand about

- Biomass energy and conversion techniques.
- Biogas production and its potential in India.
- Biogas conservation programmes in India.
- Production of hydrogen from solar energy.

2.1. INTRODUCTION

The second most important source of renewable energy is biomass. Biomass is organic matter produced by plants both terrestrial (those grown on land) and aquatic (those grown in water) and their derivatives. It includes forest crops and residues crop grown especially for their energy content on “energy farms” and animal manure. Biomass produced by these plants can also be considered a form of solar energy as the solar energy is used indirectly to grow these plants by photosynthesis. The capture of solar energy as fixed carbon in biomass via photosynthesis is initial step in the growth of biomass.

\[
\text{CO}_2 + \text{H}_2\text{O} + \text{Chlorophyll} + \text{Light} \rightarrow (\text{CH}_2\text{O})_6 + \text{O}_2
\]

Hence : Solar energy $\rightarrow$ Photosynthesis $\rightarrow$ Biomass $\rightarrow$ Energy generation

Biomass resources fall into three categories:

i) Biomass in its traditional solid mass (wood and agricultural residues) and,

ii) Biomass in non-traditional form converted into liquid fuels. The first category is to burn the biomass directly and get the energy. In the second category, the biomass is converted into ethanol and methanol to be used as liquid fuel in engines. The third category is to ferment the biomass an aerobically to obtain a gaseous fuel called biogas.
2.2. BIOMASS CONVERSION TECHNIQUES

Biomass conversion is of two types

i) Thermo-chemical conversion

ii) Biochemical conversion.

2.2.1. Thermo-chemical conversion:

It is of three types

i) Combustion

ii) Pyrolysis

iii) Gasification

Combustion: Direct burning of biomass to produce energy is called combustion. For direct combustion biomass must have a low moisture content which should not exceed 15 percent. The combustion produces steam both for the process use and for electricity. Burning of biomass in stoves and open fires is an example of combustion.

Pyrolysis: It is the thermal decomposition of organic materials or the burning of biomass in the absence of oxygen or air. Pyrolysis generally starts at temperature near 300°C to 375°C. Pyrolysis of cow manure, wood-saw dust, liberates H₂, N₂, CO, CO₂, ethylene etc. Hydrogen and carbon monoxide can be converted into methanol, gasoline etc. Preparation of charcoal from wood and incineration of municipal solid waste are example of pyrolysis.

Gasification: Under some conditions of temperature and oxygen supply, a solid fuel is converted by a series of thermo-chemical processes into a gaseous fuel – “producer gas.” If atmospheric air is normally used as gasification agent, then the producer gas consists mainly of carbon-monoxide, Hydrogen and Nitrogen. Typical composition of the gas obtained from wood gasification on volumetric basis is as follows:

<table>
<thead>
<tr>
<th>Component</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon-monoxide</td>
<td>18-22%</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>13-19%</td>
</tr>
<tr>
<td>Methane</td>
<td>1-5%</td>
</tr>
</tbody>
</table>
The gas produced in the gasifier is a clean burning fuel having heating value of about 950-1200 K cal/m^3. The gas can be used for generation of motive power either in fuel engines or in diesel engines with some modification. Complete combustion takes place with excess air whereas gasification takes place with excess carbon.

### 2.2.2. Biochemical conversion:

It is of two types (i) Anaerobic digestion and (ii) Anaerobic fermentation.

**Anaerobic digestion**: It is a biological process performed by living microorganisms. Anaerobic digestion involves the microbial digestion of biomass. (An anaerobe is a microorganism that can live and grow without air or oxygen, it gets its oxygen by the decomposition of matter containing it). This process takes place at low temperature to upto 65°C and requires a moisture content of at least 80 percent. It generates a gas consisting mostly of CO₂ and methane (CH₄) with minimum impurities such as hydrogen sulfide (H₂S). The reaction takes place as follows:

\[
\text{Organic matter + H}_2\text{O \xrightarrow{\text{bacteria}} \ CH}_4 + \text{CO}_2 + \text{H}_2\text{S}
\]

In this process, the effluent gets stabilized.

The gas can be burned directly or upgraded to synthetic natural gas by removing CO₂ and impurities. The residue may consist of protein rich sludge that can be used as animal feed and liquid effluents that are biologically treated by standard techniques and returned to the soil. This process occurs only in strict absence of free oxygen.

**Anaerobic fermentation**: It occur in three steps, each facilitated by distinct sets of anaerobic bacteria.
Step I: Insoluble biodegradable material e.g. cellulose, polysaccharides and fats are broken down to soluble carbohydrates and fatty acids and amino acids by process of hydrolysis at $25^0\text{C}$.

Step II: Acid forming bacteria produce mainly acetic and propionic acid with aldehyde, carbon dioxide, hydrogen, ammonia and sulfuric acid. This stage takes about one day at $25^0\text{C}$.

Step III: Methane forming bacteria slowly in about 14 days at $25^0\text{C}$ complete the digestion to ~ 70% methane, and ~ 30% carbon dioxide with trace amount of $\text{H}_2$ and perhaps $\text{H}_2\text{S}$. Methane forming bacteria are more environmentally sensitive than the acid forming bacteria, which are strict anaerobes, slow growing, pH – sensitive and temperature dependent. Acid forming bacteria are hardy and grow rapidly under a variety of environmental conditions.

pH: The pH is an important indicator of methanogenic performance. Gas is produced if the pH in the range of 6.6 to 7.6, however, the optimum pH is from 7.0 to 7.2.

Temperature: The two most common kinds of methanogenic bacteria are those that prefer temperature near $35^0\text{C}$ (mesophilic) and those that prefer temperature near $54^0\text{C}$ (thermophilic). The thermophilic bacteria produce methane at a faster rate, but are more sensitive to temperature fluctuations than the mesophilic bacteria. A third kind of bacteria, psychrophilic, functions at temperature below $20^0\text{C}$, but little is known about it.

Toxicity: Some compounds are toxic to methanogens in high concentration. They include heavy metals such as copper, zinc and nickel, antibiotics in livestock feed, ammonia in excess of 3000 mg/litre and various salts. (some salts are needed, but they quickly become inhibitory).
2.2.3. Conversion efficiency

An aerobic digestion is usually around 60-70% efficient. Efficiency is measured as:

\[
\text{Efficiency} = \frac{\text{Weight of volatile solids converted to biogas}}{\text{Weight of volatile solids available}}
\]

The efficiency of particular digester depends on the operational factors, such as temperature and loading rate. A high loading implies a lower efficiency.

2.3. BIOGAS

Biogas is a clean, non-polluting, convenient and low-cost fuel for rural areas. It is generated through anaerobic digestion of organic matter like cattle dung, wastes (human waste, garbage and sewage) and various other types of biomass (rice straw, sugarcane, bagasse etc.). The potential of biomass in India is estimated at 1250 Mt per year. Energy available from such a massive biomass is equivalent to about 300 Mt of oil. India having a largest cattle population in the world, i.e. 240 M head offers a tremendous potential for the development of biogas technology. From cattle dung alone, over 22,425 Mm$^3$ biogas per year can be produced. There are about 75 M farm families, out of which nearly 44 per cent own 4 or more cattle. This is the minimum number of cattle needed to have a small size of biogas plant. India has been one of the pioneering countries in the development and use of biogas technology. A gobar gas plant having a capacity of 60 cft can produce gas sufficient for a family consuming one LPG gas cylinder per month.

The biogas is rich in Methane (CH$_4$), which is inflammable, so it can be used safely as cooking gas. In addition, a biogas plant also produced enriched high quality organic manure for use in agriculture. Besides, biogas is used in running engines and generation of electricity.
2.3.1. Biogas Programme in India

The Ministry of Non-conventional Energy Sources (MNES) has taken up following programmes for development and harnessing of biogas potential in the country:

- National Project on Biogas Development (NPBD) for setting up family type biogas plants.
- Community, Institutional and Night Soil based Biogas Plant Programme (CBP/IBP/NBP).
- Research and Development on Biogas Production and Utilization technology.

The NPBD started in 1981-82 with the following objectives:

- To provide fuel for cooking purposes and organic manure to rural households.
- To mitigate drudgery of rural women, reduced pressure on forest and accentuate social benefits; and
- To improve sanitation in villages by linking toilets with biogas plants.

The biogas programme has becoming popular in many parts of the country. Various models of biogas plants approved by NPBD are listed in Table 1.

### Table 1. Models of approved biogas plants

<table>
<thead>
<tr>
<th>Model</th>
<th>Capacity (m$^3$/day gas production)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Floating Drum Type Biogas Plant-KVIC Model</td>
<td>1 to 10</td>
</tr>
<tr>
<td>Model with ferro cement digester</td>
<td>1 to 10</td>
</tr>
<tr>
<td>Deenbandhu Model</td>
<td>1 to 6</td>
</tr>
<tr>
<td>Pragati Model</td>
<td>1 to 6</td>
</tr>
<tr>
<td>Bag digester made of rubberized nylon fabric – Flxi model</td>
<td>1 to 6</td>
</tr>
</tbody>
</table>

The most remarkable achievement of this programme has been the acceptance by the rural people of human-night soil as feed material in addition to other biodegradable materials like animal dung, kitchen wastes, water hyacinth etc. Apart from the family-size biogas plants, community and institutional biogas plants are also being installed for different applications.
These plants are estimated to generate fuel equivalent to saving of about 3 Mt of firewood valued at Rs. 435 crores per year. Besides, these plants are producing about 38 Mt of enriched organic manure containing nitrogen equivalent to about 0.85 Mt of urea per year for supplementing chemical fertilizers and improving soil fertility.

Up to 31st March 2000, 3.03 M family-type biogas plants have been installed (Table 2). Further, NPBD has fixed target to install 1,80,000 biogas plants during 2000-2001.

Table 2. Cumulative achievement up to 31st march 2000 under NPBD, against estimated potential of biogas plants.

<table>
<thead>
<tr>
<th>State</th>
<th>Number of Biogas plants</th>
<th>Estimated potential</th>
<th>Installed during 1981-82 to 1999-2000</th>
<th>Coverage of estimated potential in %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Andhra Pradesh</td>
<td>10,65,600</td>
<td>2,82,557</td>
<td>27</td>
<td></td>
</tr>
<tr>
<td>Arunachal Pradesh</td>
<td>7,500</td>
<td>742</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Assam</td>
<td>3,07,700</td>
<td>41,896</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>Bihar</td>
<td>9,39,900</td>
<td>1,16,621</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>Goa</td>
<td>8,000</td>
<td>3,188</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>Gujarat</td>
<td>5,54,000</td>
<td>3,35,315</td>
<td>61</td>
<td></td>
</tr>
<tr>
<td>Haryana</td>
<td>3,00,000</td>
<td>39,865</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>Himachal Pradesh</td>
<td>1,25,600</td>
<td>42,547</td>
<td>34</td>
<td></td>
</tr>
<tr>
<td>Jammu and Kashmir</td>
<td>1,28,500</td>
<td>1,862</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Karnataka</td>
<td>6,80,000</td>
<td>2,77,561</td>
<td>41</td>
<td></td>
</tr>
<tr>
<td>Kerala</td>
<td>1,50,500</td>
<td>64,816</td>
<td>43</td>
<td></td>
</tr>
<tr>
<td>Madhya Pradesh</td>
<td>14,91,200</td>
<td>1,78,304</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>Maharashtra</td>
<td>8,97,000</td>
<td>6,47,443</td>
<td>72</td>
<td></td>
</tr>
<tr>
<td>Manipur</td>
<td>38,700</td>
<td>1,793</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Meghalaya</td>
<td>24,000</td>
<td>1,279</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Mizoram</td>
<td>2,200</td>
<td>1,976</td>
<td>90</td>
<td></td>
</tr>
<tr>
<td>Nagaland</td>
<td>6,700</td>
<td>1,097</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>Orissa</td>
<td>6,05,500</td>
<td>1,60,010</td>
<td>26</td>
<td></td>
</tr>
<tr>
<td>Punjab</td>
<td>4,11,600</td>
<td>56,348</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>Rajasthan</td>
<td>9,15,300</td>
<td>65,185</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Sikkim</td>
<td>7,300</td>
<td>2,494</td>
<td>34</td>
<td></td>
</tr>
<tr>
<td>Tamilnadu</td>
<td>6,15,800</td>
<td>1,96,545</td>
<td>32</td>
<td></td>
</tr>
<tr>
<td>Tripura</td>
<td>28,500</td>
<td>1,164</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Uttar Pradesh</td>
<td>20,21,000</td>
<td>3,40,312</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td>West Bengal</td>
<td>6,95,000</td>
<td>1,68,297</td>
<td>24</td>
<td></td>
</tr>
<tr>
<td>A &amp; N Islands</td>
<td>2,200</td>
<td>137</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Chandigarh</td>
<td>1,400</td>
<td>97</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Dabra &amp; Nagar Haveli</td>
<td>2,000</td>
<td>169</td>
<td>8</td>
<td></td>
</tr>
</tbody>
</table>
Community, Institutional and Night-soil based Biogas Plants Programme caters to the needs of village communities and institution. Biogas so produced is utilized for generation of motive power and electricity also. The programme was started in 1982-83. The objective of the programmes are:

- To recycle organic wastes for harnessing fuel-gas at community and institutional levels for various usages, including generation of motive power and electricity.
- To provide benefits of biogas technology to weaker sections of the society; and
- To recycle human waste through linking of community and institutional toilets with biogas plants for improving sanitation.

Upto 31st March 2000, 3075 Community/Institutional/Night Soil biogas plants (CBP, IBP and NBP) were installed in the country (Table 3).

Table 3. Cumulative achievement up to 31st March 2000 under community, institutional and night soil based biogas plants programme
<table>
<thead>
<tr>
<th>State</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tamilnadu</td>
<td>201</td>
</tr>
<tr>
<td>Uttar Pradesh</td>
<td>1146</td>
</tr>
<tr>
<td>West Bengal</td>
<td>51</td>
</tr>
<tr>
<td>Delhi</td>
<td>32</td>
</tr>
<tr>
<td>Pondicherry</td>
<td>1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>3075</strong></td>
</tr>
</tbody>
</table>

Biogas programmes have provided immense opportunities to rural people for lighting and pumping water for irrigation and drinking requirements. Night-soil based biogas plants are considered as low-cost sanitary disposal system and converting human wastes for manurial purposes. The programme has become acceptable in Punjab, Gujarat, Tamil Nadu, Uttar Pradesh, Orissa and Maharashtra. A community – based biogas plant, with a design capacity of 42.5 cum/day, has operated successfully for nearly a decade and met the fuel, lighting and water pumping requirements of Pura village [World Science News, 29 : 12 (1992)].

Taking the average life span of the plants to be about 20 years, large economic benefit would thus be generated to the country. In addition, the programme has created employment of about 90-100 lakh man-days per year in rural areas.

### 2.3.2. Commonly used biogas plants in India

There are two types of biogas plant.

#### 2.3.1.1. Fixed Dome Biogas plant

They are Janta Biogas plant and Deenbandhu Biogas plant.

**Janta Biogas Plant.** This was first developed by the planning, Research and Action Division Lucknow in 1978. It is an improved version of the Chinese fixed-dome biogas plant. The plant is shown in Fig. 2.0, with its different parts.

The foundation of Janta biogas plant is laid at the base of the underground pit on a levelled ground which bear the load of the slurry as well as digester walls. Digester is cylindrical in shape constructed with bricks and cement. It holds the dung slurry for a retention time so that the biogas is produced from the slurry in the digester. It should be noted that the
The diameter and height ratio of the digester is kept 1.75 : 1. The gas is stored in a gas portion, which is an integral part of the plant, between dome and digester, where the usable gas is stored. The height of the gas portion is above the inlet and outlet openings to the beginning of the dome and is equal to the maximum volume of the gas to be stored (30-40 per cent of plant capacity) and equal to the volume of slurry to be displaced at the inlet and outlet.

![Diagram of common fixed dome digester](image)

**Figure 2.0. Common fixed dome digester (China)**

Dome is constructed over the gas portion, with a volume of 60 percent of the plant capacity. It must be constructed very carefully, integrating it with the digester and gas portion so that no leakage of gas can take place. The gas outlet pipe is fixed at the top of the dome for laying the line.

Inlet and outlet portions are constructed for putting the fresh slurry inside the plant and to take the digested slurry out. The inlet and outlet are of larger sizes, provided on each side of the digester, facing each other. The opening to the digester for feeding the waste material and effluent outlet from it are also of large sizes. The discharge of slurry out of the plant is due to the pressure of the gas in the plant. Over the inlet portion, an inlet mixing tank is also constructed to mix the dung and water.

It has now been replaced by Deenbandhu plant in the field.
Deenbandhu Biogas Plant: This is also a fixed dome plant developed by Action for Food production, New Delhi, which is a low cost biogas plant. The principle of working of this plant is same as that of Janta model, except configuration of inlet entrance and digester.

The foundation of the plant is constructed in the segment of spherical shape as shown in Fig. 2.1. On the other periphery of this foundation, the dome shaped digester is constructed with same base diameter. In this way the digester, gas portion and dome look as a single unit. The surface area of the biogas plant is reduced with same digester volume, reducing the earth work and cost of construction without sacrificing the efficiency. The higher compressive strength of the brick masonry and concrete makes it a safe structure as the plant is always under compression. A spherical structure loaded from the convex side will be under compression and therefore the internal load will not have any residual effect on the structure.

At the top of the foundation, a window opening is kept (outlet portion) for the outward movement of the digested slurry. The asbestos cement pipe of 15 cm diameter is used for inlet instead of separate opening. The pipe is embedded in the digester wall at a fixed position, just opposite to outlet opening, to avoid short circuiting of fresh material and digested slurry.

The volume of the outlet is increased to produce requisite gas pressure through the weight of the displaced slurry. At the top of the dome a gas outlet pipe is fixed as in the case of Janta plant.
Advantage and Disadvantages

Advantages:
1. It has low cost compared to floating drum type, as it uses only cement and no steel.
2. It has no corrosion trouble.
3. In this type, heat insulation is better as construction is beneath the ground. Temperature will be constant.
4. Cattle and human excreta and long fibrous stalks can be fed.
5. No maintenance.

Disadvantages:
1. This type of plant needs the services of skilled masons, who are rather scarce in rural areas.
2. Gas production per cm\(^3\) of the digester volume is also less.
3. Scum formation is a problem as no stirring arrangement.
4. It has variable gas pressure.

2.3.1.2. Floating Gas Holder Plant: In floating gas holder plant, the biogas is stored in a drum, which moves up and down on a guide, according to the quantity of gas stored in it. The gas holder rests on a guide frame which is fixed in a digester wall.
The drum may be made of steel, ferro cement HDPC or fibre glass. The pressure of gas in the floating drum type biogas plant is always constant, which is equivalent to weight of gas holder over unit area. It can be increased also by putting additional weight on the gas holder.

The sides of the gas holder remains in the slurry to seal the leakage of gas to the atmosphere.

The cost of this plant is more as the cost of the gas holder itself is high. Besides, it requires regular check and maintenance.

**Khadi and Village Industries type Biogas Plant.** As stated earlier the KVIC type plant is a floating gas holder or drum type biogas plant which was used in India earlier than all other types of biogas plants.

![Schematic diagram of KVIC type Biogas plant.](image)

The design was developed and perfected in India in the year 1954. This was taken up for propagation in the villages in the year 1962, by Khadi and Village Industries Commission, Bombay, therefore, it is known as KVIC design. The design is available in sizes of 1 cum to 140 cum gas per day. In
KVIC plant the gas is stored in mild steel drum of storage capacity of 30-40 per cent of plant size at a pressure of about 10 cm of water column, which is sufficient to carry it up to a length of 20 meters to 100 meters, depending on the size of the plant.

**Pragati Design Biogas Plant.** The design has been developed by United Socio-Economic Development and Research Programme (UNDARP) Pune, in order to have a cheaper floating drum biogas plant. In this design the depth of pit is less than KVIC plant so that it can be constructed in hill and high water table areas. The cost of Pragati plant is 20% less than KVIC plant.

![Figure 2.3. Pragati biogas plant](image)

The design shown in Fig. 2.3 indicates its different parts. The foundation of this plant is of conical shape, with difference of one feet between outer periphery and its’ centre so as to reduce the earth and digester wall work. It is constructed at the base of the pit with cement, sand and concrete, keeping the site conditions in view so that it can bear the load due to weight of slurry in the digester.

The digester of Pragati design plant starts from the foundation in dome shape thereby reducing the constructional area, for same digester volume, thus reducing the cost of construction of the plant. The wall thickness of digester is kept 75 mm only. Dome shape construction takes
place up to a collar base, where a central guide frame is provided. The digester wall above guide-frame is constructed in cylindrical shape.

Partition wall is constructed in the digester for 4 Cum. and bigger sizes so as to control the flow of slurry inside the digester. It divides digester into two parts separating inlet and outlet.

The inlet is through pipe, placed while constructing digester wall. It is used for feeding daily slurry into the digester and is generally of 100 mm diameter. The outlet pipe is also 100 mm in diameter and fixed while constructing digester wall. The asbestos cement pipe can be used for inlet and outlet.

The guide frame is made of angle iron and steel pipe, is embedded in the digester wall at top of spherical portion of digester. The central guide pipe holds gas holder which is also made of M.S. sheet and angle iron. It floats up and down along pipe depending on the quantity of gas in the drum.

**Ganesh Biogas Plant.** It is basically a KVIC plant constructed with bamboo and polythene sheet. It was developed in district. Rampur of Uttar Pradesh. Only the digester is made of an angle iron frame, bamboo and polythene sheet. The KVIC gas holder and guide frame are used in this design also. The cost of this plant is 70 percent of KVIC plant.

**Ferro Cement Digester Biogas Plant.** Ferro-cement is a form of reinforced concrete made of a wire mesh, sand, water and cement. In this composite material layers of thin wire mesh distributed throughout the thickness of element are integrated with thick cement mortar over an inverted mould. In fact, it is reinforced mortar having high resistance to cracking and permeability.

In the ferro-cement digesters the periphery is divided into 4 or 6 segments, which are casted at a central place over a prepared masonry or wooden mould. These pre-casted segments are then transported and erected at the plant site. This type of digester is an ideal substitute for brick digester in areas where good quality bricks are not available and also solves
the problems of leakage through masonry joints. All the systems of the plant are of KVIC design and specifications.

Table 4. Differences between fixed and floating-drum biogas designs in India

<table>
<thead>
<tr>
<th>Fixed dome</th>
<th>Floating drum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Digester and gas holder, masonry or concrete structure</td>
<td>Digester, masonry</td>
</tr>
<tr>
<td>Requires high masonry skills</td>
<td>Low masonry or fabricating skills</td>
</tr>
<tr>
<td>Low reliability due to high construction failure</td>
<td>High reliability, gas holder prefabricated</td>
</tr>
<tr>
<td>Variable gas pressure</td>
<td>Constant gas pressure</td>
</tr>
<tr>
<td>Digester could be inside the ground</td>
<td>Requires space above ground for three tanks; inlet, digester, outlet</td>
</tr>
<tr>
<td>Low cost (2 m$^3$=Rs 5000)</td>
<td>High cost of plant due to gas holder (cost for 2 m$^3$ = Rs 8000)</td>
</tr>
</tbody>
</table>

Table 5. Cost of family biogas plant (in Rs) different capacities (in m$^3$)

<table>
<thead>
<tr>
<th>Design</th>
<th>2m$^3$</th>
<th>3m$^3$</th>
<th>4m$^3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Floating-drum KVIC type</td>
<td>8030</td>
<td>9500</td>
<td>10700</td>
</tr>
<tr>
<td>Fixed dome (Deenabandhu type)</td>
<td>5325</td>
<td>6400</td>
<td>7800</td>
</tr>
<tr>
<td>Subsidy from government in plains</td>
<td>2200</td>
<td>2600</td>
<td>2600</td>
</tr>
<tr>
<td>Subsidy as % of KVIC floating-drum cost</td>
<td>28</td>
<td>29</td>
<td>33</td>
</tr>
<tr>
<td>Subsidy as % of fixed-dome cost</td>
<td>41</td>
<td>40</td>
<td>24</td>
</tr>
<tr>
<td>Subsidy in north-east and hilly districts of Uttar Pradesh</td>
<td>5100</td>
<td>6200</td>
<td>6200</td>
</tr>
<tr>
<td>Subsidy as % of floating-drum KVIC design in north-east and hilly districts</td>
<td>63</td>
<td>65</td>
<td>58</td>
</tr>
</tbody>
</table>

Advantages and Disadvantages of Floating Drum Plant:

**Advantages:**

1. It has less volume related trouble because solids are constantly submerged.
2. No separate pressure equalizing device needed when fresh waste is added to the tank or digested slurry in withdrawn.

3. In it, the danger of mixing oxygen with the gas to form an explosive mixture is minimized.

4. Higher gas production per cubic meter of the digester volume is achieved.

5. Floating drum has welded braces, which help in breaking to scum (floating matter) by rotation.


7. Constant gas pressure.

Disadvantages:

1. It has higher cost, as cost is dependent on steel and cement.

2. Heat is lost through the metal gas holder, hence it troubles in colder regions and periods.

3. Gas holder requires painting once or twice a year, depending on the humidity of the location.

4. Flexible pipe joining the gas holder to the main gas pipe requires maintenance, as it is damaged by ultraviolet rays in the sun. It may be twisted also, with the rotation of the drum for mixing or scum removal.

2.4. BIOGAS FIERS

Another device producing biogas by using biomass wastes is biogas fier. In a biogas fier device biomass wastes such as wood waste, wood chips, twigs, cotton stalk, guar stalk, maize cobs, rice straw, saw dust, etc. would be converted into biogas. Gas is produced through chemical conversion processing. The gas runs the engine to produce motive power. In turn it runs pumpset for irrigation or drinking water or to produce electricity. The biogas fier pumpsets are available in 5 HP to 10 HP for mechanical applications like water pumping and from 3 KW to 100 KW for generating electricity. These systems substitute or replace diesel fuel in conventional diesel engine for respective applications by over 65 per cent.
The use of biogas fier as a supplementary fuel in existing diesel engines when operated on dual-fuel model appears attractive as long term strategy. These are well suited for water pumping for irrigation purpose and rural electricity generation. Biogas fier systems can vastly improve the quality of life in rural areas and provide employment.

The Ministry of Non-conventional energy sources has also taken up a programme of biogas fiers. In our country biogas fiers produced 7.9 MW of power till the end of December 1992. A total number of 52 biogas fier systems with an aggregate capacity of 5670 KW equivalent have been sanctioned during 1997-98. But 28 biogas fiers have been installed during the year 1997-98 producing 2495 KW of power. Highest number of biogas fiers (27) were sanctioned to Andhra Pradesh out of which 10 were installed and this is the highest when compared to other states. Table 6 shows state-wise list of biogas fier systems installed and sanctioned during 1997-98.

Table 6. State-wise list of biogasifiers installed and sanctioned during 1997-98

<table>
<thead>
<tr>
<th>State</th>
<th>Sanctioned</th>
<th>Installed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number</td>
<td>Capacity in (KW)</td>
</tr>
<tr>
<td>Andhra Pradesh</td>
<td>27</td>
<td>3040</td>
</tr>
<tr>
<td>Assam</td>
<td>1</td>
<td>300</td>
</tr>
<tr>
<td>Gujarat</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>Karnataka</td>
<td>10</td>
<td>1820</td>
</tr>
<tr>
<td>Madhya Pradesh</td>
<td>1</td>
<td>100</td>
</tr>
<tr>
<td>Tamilnadu</td>
<td>11</td>
<td>400</td>
</tr>
<tr>
<td>West Bengal</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>52</strong></td>
<td><strong>5670</strong></td>
</tr>
</tbody>
</table>

The Non Conventional Energy Development Corporation of Andhra Pradesh (NEDCAP) has installed 10 biogas fier systems each of 100 KW capacity in rice mills. It is estimated that one rice mill would be saving about 9500 litres of diesel oil by using gas fier system for a period of six months in a year.
Tamilnadu Energy Development Agency (TEDA) made special efforts in promoting gasifiers for cooking purpose in central prisons at Chennai, Coimbatore, Trichy and Vellore. Each prison would be saving about 11.25 tonnes of fuelwood per month by using a gas fier system of 50000 Kcal/hour capacity.

2.5. ENERGY PLANTATION

It is the method of tapping maximum solar energy by growing plants. Energy farms are ideal solar collectors requiring virtually no maintenance, it is economical and non-polluting. Photosynthesis occurring naturally stores more than ten times as much energy, in plant farm, than is consumed by all mankind.

In India about 23% of total land area is under forests. Under social forestry programme, quick growing trees have been cultivated, the key consideration in biomass energy farming is the choice of plant type and species to be cultivated. The choice of the species will depend on location, soils water quality and some other factors. Some of the plants are described below.

Jojaba an ever green shrub around 1.7 m in height grows wild in the semi-arid region. Its seeds contain about 50 to 80% of oil. Its plantation in USA and Israel has been successfully done providing 1,420 plants per hectare producing 1970 kg of dry seed per annum. The tree species namely *Acacia, Albizzia lebbek, Prosopis juliflora, Prosopis cineraria, etc.* have been identified as adaptable to the hot-arid regions in our country.

The plants namely Erythrina and Leucaenea which are known to be fast growing plants are proposed for the subtropical regions as energy plants.

Casuarina is a large evergreen tree and grows all over Deccan in India and while the tree is harvested after 5-7 years, the yield of lopping from the 2\textsuperscript{nd} year is 3-5 tonnes/ha/year. The main uses of casuarina trees are:

- Its wood is used for various purposes.
• It is used as pulp for paper industry.
• Used for wind break.
• In soil erosion control.

**Eucalyptus** plantation as a source for fuel wood has been practiced in India. Its production or yield rate (dried) is about 24.1 tonne/acre/yr.

**Sorghums**: It is crops because it has very high yield. It requires less water for normal growth and its yield is 10 to 30 tons/acre. Sorghum crop is used in production of alcohol.

The other main species which are being grown as energy plantation in different zones of India are: *Terminalia arjuna, Sesbania aegyptiaca, Cassia siamea, Prosopis sps., Sargassum tenerimum*

### 2.6. IMPROVED CHULHAS PROGRAMME

Fuelwood, crop residues, dung cakes are used as fuel and are burnt in stone and mud made stoves called chulhas by rural population mostly and also by urban slum dwellers. Among these three fuel resources wood is the predominant fuel resource which is largely used for cooking and heating purposes. A characteristic feature of the fuelwood is that 70 per cent of it is collected from forests, village plantations and other nearby sites. It is collected freely and as such it is not recorded. Collection is done by women and children. These chulhas are inefficient in burning wood, emitting lot of smoke causing respiratory and eye diseases. It has been estimated that 1 per cent increase in the efficiency of these traditional chulhas would save 3 million tons of fuelwood per year.

The Ministry of Non-conventional Energy Sources launched a national programme of improved chulhas in 1983 not only to increase the efficiency of chulhas by 20-25 per cent by adopting new designs but also to check health hazards. By increasing the combustion efficiency of chulhas, lot of fuel-wood would be saved.
2.6.1. Objectives of the programme

- To conserve fuelwood and forests
- To remove or reduce smoke in the kitchen
- To check deforestation which causes environmental degradation
- To reduce the drudgery of women and children from cooking in smoky kitchens and the collection of more fuelwood
- To reduce the cooking time and save fuel and to generate employment opportunities to the rural poor by creating trained workforce of women and traditional craft persons competent to construct, install improved models of chulhas. These improved chulhas make better living conditions of rural population and urban slum dwellers. These are also cheapest and best. The programme is being implemented by KVIC state nodal departments and agencies. NDDB and AIWC all over India.

Under this programme three types of chulhas i.e. fixed, family size and community models and portable of chulhas depending upon the requirements of beneficiaries have been designed.

2.6.2. Fixed Chulhas of Family Size Models

These chulhas have three principle components:

i) A closed hearth where combustion of the wood takes place, thus protecting the fire from vagaries of wind

ii) ii) A chimney for bringing in air for combustion and removing the smoke from the kitchen

iii) one or multipot design-capable of carrying more than one Pan and utilizing certain amount of heat from hot gases that would otherwise have gone waste.

The advantages of fixed model chulhas of family size are:

- It can be used in most of the Indian homes.
- It can be constructed by local trained persons.
- It is smokeless.
• Two or three food items can be cooked simultaneously.
• It can be designed to suit the local needs of the population
• It is easy to repair and maintain
• It can be constructed with locally available material

The department has approved 20 such models for popularization under the National programme.

2.6.3. Community Size Models

Community size models are fixed type of chulhas for large user's requirement. Two such models capable of cooking for 200 and 50 persons respectively were developed and installed at various institutions for demonstration. Based on feedback eight community models which have efficiency over 35 per cent have been approved for large-scale propagation. Community size model chulhas have been installed largely in schools, institutions, hotels, hostels, charitable institutions, etc, to cater to the cooking needs of a large number of people in different parts of our country. These chulhas are capable of saving appreciable amount of fuel wood and are in great demand.

The programme has also included the development of damper-less models of improved chulhas. These chulhas are convenient for operation and the unit cost of chulhas has come down. The efficiency of these chulhas comprises favourably with that of chulhas with dampers. In view of the operation convenience and low cost, the damperless chulha models have been propagated from the year 1988-1989 onwards.

2.6.4. Portable Chulhas

The portable models are made of mild steel, galvanized iron or cast iron and are suitable for the beneficiaries of urban/slum population which do not have sufficient space for cooking, migratory and tribal population which keep on changing their place of residence and the rural people who prefer to cook outside the kitchen due to climatic conditions. The portable chulhas are manufactured by small entrepreneurs in different parts of the country.
Maximum thermal efficiency limit of the portable models was raised to 25 per cent from 20 per cent. Subsidy is given to beneficiaries, which range from 50 to 75 rupees depending upon the type of beneficiary and the type of chulha. The cost of fixed chulhas varies from Rs. 75 to 80 whereas it varies from 136 to 200 rupees in the case of portable chulha. In our country over 12.5 million improved chulhas have been installed by the end of March 1992.

A physical target of promotion of 30 lakh improved chulhas was fixed for 1997-98. Over 25.90 lakh chulhas have been installed state-wise and agency-wise achievement and targets are shown in Table 7.

It is evident from Table 7 that Andhra Pradesh’s achievement is much higher than the target figure. West Bengal which has highest number of installed chulhas also crosses the target and stands second in achievement after Andhra Pradesh. The KVIC has installed highest number of chulhas and has more than crossed the target figure.

<table>
<thead>
<tr>
<th>State/UT/Agency</th>
<th>Target</th>
<th>Achievement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Andhra Pradesh</td>
<td>2,00,000</td>
<td>2,57,360</td>
</tr>
<tr>
<td>Arunachal Pradesh</td>
<td>15,000</td>
<td>925</td>
</tr>
<tr>
<td>Assam</td>
<td>50,000</td>
<td>490</td>
</tr>
<tr>
<td>Bihar</td>
<td>20,000</td>
<td>2,878</td>
</tr>
<tr>
<td>Gujarat</td>
<td>90,000</td>
<td>90,812</td>
</tr>
<tr>
<td>Goa</td>
<td>5,000</td>
<td>4,077</td>
</tr>
<tr>
<td>Haryana</td>
<td>50,000</td>
<td>7,416</td>
</tr>
<tr>
<td>Himachal Pradesh</td>
<td>30,000</td>
<td>19,211</td>
</tr>
<tr>
<td>Jammu and Kashmir</td>
<td>50,000</td>
<td></td>
</tr>
<tr>
<td>Karnataka</td>
<td>88,000</td>
<td>20,295</td>
</tr>
<tr>
<td>Kerala</td>
<td>1,00,000</td>
<td>24,948</td>
</tr>
<tr>
<td>Madhya Pradesh</td>
<td>2,50,000</td>
<td>1,88,969</td>
</tr>
<tr>
<td>Maharashtra</td>
<td>2,00,000</td>
<td>1,77,011</td>
</tr>
<tr>
<td>Manipur</td>
<td>15,000</td>
<td>3,155</td>
</tr>
<tr>
<td>Meghalaya</td>
<td>10,000</td>
<td></td>
</tr>
<tr>
<td>Mizoram</td>
<td>15,000</td>
<td>3,000</td>
</tr>
<tr>
<td>Nagaland</td>
<td>10,000</td>
<td>157</td>
</tr>
<tr>
<td>Orissa</td>
<td>1,40,000</td>
<td>1,31,228</td>
</tr>
<tr>
<td>Punjab</td>
<td>1,00,000</td>
<td>59,500</td>
</tr>
<tr>
<td>Rajasthan</td>
<td>1,00,000</td>
<td>99,886</td>
</tr>
</tbody>
</table>
Apart from social and health benefits, improved chulha was found to be adequate to recover the entire cost of installation within two months of its use.

### 2.7. HYDROGEN AS A FUEL

Hydrogen gas may be the fuel of the future. As a fuel, hydrogen can be used in any of ways in which we normally use fossil fuels, such as to power automobiles or to heat water or to buildings. It can be used to produce electricity, hydrogen, like natural gas, can be transported in pipelines and stored in tanks and can be produced using solar and other renewable energy sources. It is a clean fuel, the combustion product of burning hydrogen is water, so it does not contribute to global warming, air pollution or acid rain.

#### 2.7.1. Methods of producing hydrogen from solar energy

These are four basic methods:

1. Direct thermal.
2. Thermochemical.
3. Electrolytic, and
4. Photolytic.
Indirect forms of solar energy such as ocean, thermal, ocean current, wind and hydraulic are also considered as primary energy source for producing hydrogen.

2.7.1.1. Direct thermal. The dissociation of hydrogen and oxygen will start if the water is heated upto about 3000\(^0\)K or above. Water decomposition reaction is

\[ \text{H}_2\text{O} + \text{heat} \rightarrow x_1\text{H}_2\text{O} + x_2\text{H}_2 + x_3\text{O}_2 \]

Where the substance are in gaseous form, and \(x_1\), \(x_2\) and \(x_3\) are the mole fractions. Water should be decomposed at fairly high temperature (for equilibrium decomposition) combined with a reduced pressure. The energy for dissociation of hydrogen can be obtained from the solar energy. An optical system which collects solar radiation and concentrates it into a small area can be utilized for this purpose. The concentration ratio (CR) is defined as the ratio of the heat flux within the small area to the actual flux received. It depends on the temperature requirement. CR for parabolic mirror is given by

\[ \text{CR} = 46200 \times \sin^2 \alpha \]

Where \(\alpha\) = rim angle.

The solar constant may be taken equal to 0.14 W/cm\(^2\) in the outer atmosphere and 0.1 W/cm\(^2\) on the earth. High temperature can be obtained in optical systems such as in large furnaces. Concentration ratio may be of the order of 10000.

**Advantages** of this method are:

1. High thermal efficiency,
2. Negligible environmental impact and
3. Intermediary chemicals are not required. Because of high temperature requirements, it requires extensive research for commercial application.

2.7.1.2. Thermochemical. The difficulty of the high temperature requirements in direct thermal method, has led many scientists to search for
thermochemical reactions to decompose water. In this method, first water and one or more chemical elements or compounds react while heat is being added, resulting in a combination of hydrogen and/or oxygen of water with compound and either hydrogen or oxygen being realised as a gas. Then, in one or more chemical reactions, the new chemical compound of the first reaction are reduced to their original composition with the help of other intermediary chemicals and/or heat, releasing oxygen and hydrogen. Hence inputs are heat, water and some work which is required to separate the resulting chemicals. Outputs are hydrogen, oxygen and lower grade heat. The intermediary chemical elements and/or compounds are regenerated and recycled. For a complete thermochemical hydrogen production cycle, two or more chemical reaction steps are needed. For example

Two step cycle:

\[ \text{H}_2\text{O} + \text{CH}_4 \rightarrow \text{CO} + 3\text{H}_2 \]
\[ \text{CO} + 2\text{H}_2 \rightarrow \text{CH}_4 + \frac{1}{2}\text{O}_2 \]

Sum: \[ \text{H}_2\text{O} \rightarrow \text{H}_2 + \frac{1}{2}\text{O}_2 \]

Three step cycle:

\[ \text{H}_2\text{O} + \text{Cl}_2 \rightarrow 2\text{HCl} + \frac{1}{2}\text{O}_2 \]
\[ 2\text{HCl} + 2\text{CrCl}_2 \rightarrow 2\text{CrCl}_3 + \text{H}_2 \]
\[ 2\text{CrCl}_3 \rightarrow 2\text{CrCl}_2 + \text{Cl}_2 \]

Sum: \[ \text{H}_2\text{O} \rightarrow \text{H}_2 + \frac{1}{2}\text{O}_2 \]

2.7.1.3. Electrolytic. In this method an electrolysis cell is used to produce hydrogen and oxygen from water. The cell consists of two electrodes dipped in an electrolyte and connected to a direct current supply. Water with some conducting chemical, is used as an electrolyte. When sufficient potential is applied between the electrodes to cause a current to flow, oxygen is liberated at the anode and hydrogen at the cathode.

Reactions are:

Cathode: \[ 4\text{H}_2\text{O} + 4\text{e}^- \rightarrow 2\text{H}_2 + 4\text{OH}^- \]
Anode: \[ 4\text{OH}^- \rightarrow 2\text{H}_2\text{O} + \text{O}_2 + 4\text{e}^- \]

Sum: \[ 2\text{H}_2\text{O} + \text{electrical energy} \rightarrow 2\text{H}_2 + \text{O}_2 \text{ (heat)} \]
In this method, the solar energy is first converted to direct current (D.C.) electric power, and then to hydrogen through electrolysis. Hence it is especially suited for coupling with ocean, thermal wind, hydro and photovoltaic forms of solar energy since in these cases solar energy is converted to electricity.

2.7.1.4. Photolytic. In this phenomenon, sun’s photons, under certain circumstances are absorbed by water molecules and when the energy absorbed reaches a certain limit (68.3 kcal/mole of water), hydrogen can be released. Photons in the ultraviolet region of radiation spectrum passes the energies needed for the direct photolysis of water, in the presence of a catalyst. The function of such catalyst is to absorb the solar radiation and then transmit the energy to water in order to decompose it. The photolysis reaction with photocatalyst X can be expressed as

\[
\begin{align*}
\text{H}_2\text{O} + 2\text{X} + \text{photon energy} & \rightarrow 2 \text{ (reduced X)} + 2\text{H}^+ + \frac{1}{2}\text{O}_2 \\
2 \text{ (reduced X)} + 2\text{H}^+ & \rightarrow 2\text{X} + \text{H}_2 \\
\text{Sum: } \text{H}_2\text{O} & \rightarrow \text{H}_2 + \frac{1}{2}\text{O}_2
\end{align*}
\]

Note that photocatalyst X is not consumed, but is regenerated and available for reuse. Biological photocatalysis are also in existence.

Among the four basic methods for producing hydrogen from solar energy, the direct thermal method has the potential of highest thermal efficiency, followed by thermo chemical, electrolytic and photolytic method.

2.8. SUMMARY

Biomass is a broad term used for many resources Bioenergy covers a wide range energy conversion technologies. Biogas is an important solution to present energy crises especially is rural areas. It is generated through anaerobic digestion of organic matter like cattle
dungs, wastes (human waste, garbage) and various types of biomass (rice straw, sugar cane, bagasse. The Ministry of Non-Conventional Energy Sources (MHES) has taken up various programmes for development and harnessing of biogas potential in the country. Fixed dome and floating gas holders are two types of commonly used biogas plant. Energy plantation and improved chulhas programmes are launched as a energy conservation programmes.

2.9. KEYWORDS

Biomass

Organic matter produced by plants and other photosynthetic producers, total dry weight of all living organisms that can be supported at each trophic level in a food chain or wet, dry weight of all organic matter in plants and animals in an ecosystem, plant material and animal waste used as fuel.

Biofuel

Gas or liquid fuel (such as ethyl alcohol) made from plant material biomass.

Biogas

Biogas is a clean, non-polluting, convenient and low cost fuel for rural areas. It is generated through anaerobic digestion of organic matter.

Combustion

Direct burning of biomass to produce energy.

Gasification

A solid fuel is converted by a senses of thermo-chemical process into a gaseous fuel.

Pyrolysis

It is the thermal decomposition of organic materials or the burning of biomass in the absence of oxygen or air.
2.10. SELF ASSESSMENT QUESTIONS

1. What is biomass energy?
2. What are some attractive features of biomass energy?
3. How biomass conversion takes place?
4. What is the difference between biomass and biogas?
5. What is meant by anaerobic digestion? Explain briefly.
6. Name various models of biogas plant.
7. What are the advantages and disadvantages of floating drum plant?
8. What are the differences between fixed and floating drum biogas designs in India?
9. What is meant by energy plantation?
10. What are the main plants proposed for the energy plantation in India?
11. What is improved chulah programme and what are its objectives?
12. Name various models of improved chulahs.
13. Write down short note on the followings
   (i) Hydrogen as a fuel
   (ii) Biogasifiers
   (iii) Pyrolysis

2.11. SUGGESTED READINGS


SOLAR ENERGY

Narsi Ram Bishnoi

STRUCTURE

1.0. OBJECTIVES

1.1. INTRODUCTION

1.2. SOLAR COLLECTORS

1.2.1. Flat-plate collector

1.2.1.1. A typical liquid collector

1.2.1.2. Typical air collector

1.2.2. Physical principles of the conversion of solar radiation into heat

1.2.3. Concentrating collector: Focussing type:

1.2.3.1. Types of concentrating collectors

1.2.3.1.1. Line Focussing collectors

1.2.3.1.2. Point Focussing Collector (paraboloidal type)

1.2.4. Concentrating collectors: Non-Focussing Type

1.2.5. Advantages and Disadvantages of concentration collectors over flat-plate type collectors

1.3. SOLAR PHOTOVOLTAICS

1.3.1. Historical background

1.3.2. Cell structure and principle

1.3.3. Type of PV cells:

1.3.3.1. Mono crystalline silicon cells

1.3.3.2. Poly-crystalline silicon cells

1.3.3.3. Poly crystalline thin film silicon cells

1.3.3.4. Gallium arsenide (GA) cells

1.3.4. Thin film PV cells

1.3.4.1. Amorphous silicon

1.3.4.2. Copper Indium Diselenide (CIS) film

1.3.4.3. Cadmium telluride (Cd Tc)

1.3.5. Multiple Junction PV cells

1.3.6. Photovoltaics in India

1.3.7. Incentive from Govt. for promotion of PV:
1.3.8. Application of solar photovoltaic system
1.3.9. Advantage and Disadvantages of photovoltaic solar energy conversion

1.4. SUMMARY

1.5. KEY WORDS

1.6. SELF ASSESSMENT QUESTIONS

1.7. SUGGESTED READINGS

1.0. OBJECTIVES

After studying this unit, you should be able to understand about

- Principles of the conversion of solar radiation into heat.
- Solar radiation collecting device: Solar collectors.
- Structure of solar photovoltaics cell and its principles.
- Hierarchy of photovoltaic system and its applications.

1.1. INTRODUCTION

Solar energy equivalent to almost 75000 TkWh hits the earth surface every day. A mere 0.1% of this staggering figure is sufficient to meet world energy needs. Use of solar energy has grown steadily at the rate of 16% during 1990-98. According to Worldwatch the solar market is expected to reach 10600 MW if there is a constant annual growth of 25% each year. Japan is the largest solar power-utilizing nation. More than 6,800 SPV systems were installed in the country by 1998.

India is one of the few countries blessed with plenty of sunshine with an annual insolation of 5000 TkWh and with 300 clear sunny days in most parts of the country. The average insolation incident over India in about 5.5 kWh/m² over a horizontal surface. With this, it is possible to generate 20 MW solar power per square kilometer land area.
1.2. SOLAR COLLECTORS

A solar collector is a device for collecting solar radiation and to transfer the energy to a fluid passing in contact with it. Utilization of solar energy requires solar collectors. There are two general types:

i) The flat-plate collector.

ii) The concentrating (focussing) collector.

1.2.1. Flat-plate collector

A flat-plate collector is one in which the absorbing surface for solar radiation is essentially flat. Flat-plates can collect and adsorb both direct and diffuse solar radiation, they are consequently partially effective even on a cloudy day when there is no direct radiation.

The majority of the flat-plate collectors have five main components as follows:

i) A transparent cover which may be one or more sheets of glass or radiation transmitting plastic film or sheet.

ii) Tubes, fins or channels are integral with the collector absorber plate or connected to it, which carry the water, air or other fluid.

iii) The absorber plate, normally metallic or with a black surface.

iv) Insulation, which should be provided at the back and sides to minimize the heat losses. Standard insulating materials such as fibre glass, are used for this purpose.

v) The container which encloses the other components and protects them from the weather.

Advantages of flat-plate collectors:

i) They can utilize both the diffuse and direct solar radiation.

ii) They do not require orientation towards the sun.

iii) They are easily manufactured.

iv) They require little maintenance.

v) Construction is relatively simple.
Flat-plate solar collectors may be divided into two main classes based on the type of heat transfer fluid used.

i) A typical liquid collector.

ii) A typical air collector.

1.2.1.1. A typical liquid collector:

They are used for heating water and non-freezing aqueous solutions. It basically consists of a flat surface with high absorptivity for solar radiation, called the absorbing surface. Typically a metal plate usually of copper, steel, or aluminium material with tubing of copper in thermal contact with the plate, are the most commonly used material. The absorber plate is usually made from a metal sheet 1 to 2 mm in thickness, while the tubes, which are also made of metal, range in diameter from 1 to 1.5 cm. They are soldered or clamped to the bottom of the absorber plate with the pitch ranging from 5 to 15 cm.

Heat is transferred from the absorber plate to a point of use by circulation of fluid (usually water) across the solar heated surface. Thermal insulation of 5 to 10 cm thickness is usually placed behind the absorber plate to prevent the heat losses from the rear surface. Insulation material is generally mineral wool or glass wool or a heat resistant fibre glass.

The front covers are generally glass (may be one or more) that is transparent to incoming solar radiation and opaque to the infrared re-radiation from the absorber. The glass covers act as a convection shield to reduce the losses from the absorber plate beneath. Glass is generally used for the transparent covers but certain plastic films may be satisfactory. Glass is the most favourable material. Thickness of 3 or 4 mm are commonly used.

The usual practice is to have 1 or 2 covers with a width ranging from 1.5 to 3 cm. Advantages of second glass which is added above the first one are:

i) Losses due to air convection are further reduced. This is important in windy areas.
ii) Radiation losses in the infra-red spectrum are reduced by a further 25%, because half of the 50% which is emitted outwards from the first glass plate is back-radiated.

It is not worthwhile to use more than two glass plates. This is due to the fact that each plate reflects about 15% of the incoming sunlight.

Some plastic glazings have been recommended. Slagwood, fibre glass, polyurethane foam, hay in polythene bags (to keep the moisture out) are suitable materials for insulating the sides and bottom of collector. The collector box support all the components and provides weather protection.

For water streams the absorber plate can be any metal, plastic or rubber sheet that incorporates water channels, while for air systems the space above or below the collector plate serves as the conduit. The surface finish of the absorber plate may be a flat black paint with an appropriate primer. The primer coat should preferably be thin since a thick under coat of paint would increase the resistance to heat transfer. Black painted absorbers are preferred because they are considerably cheaper.

The liquid heated is generally water. However sometimes mixtures of water and ethylene glycol are used if ambient temperatures below 0°C are likely to be encountered.

Typical collector dimensions are 2 m x 1 m x 15 cm.

1.2.1.2. Typical air collector:

A flat-plate collector where an air stream is heated by the back side of the collector plate. Fins attached to the plate increase the contact surface. The back side of the collector is heavily insulated with mineral wool or some other material. The most favourable orientation of a collector, for heating only, is facing towards the south at an inclination angle to the horizontal equal to the latitude plus 15° (s = φ + 15°).

Air can be passed in contact with black solar absorbing surface such as finned plates or ducts as mentioned above, corrugated or roughened plates of various materials, several layer of metal screening and overlapped
glass plates. Flow may be straight, through, surpentine, above, below or on both sides of the absorber plate or through a porous absorber material.

The flat-plate is a simple and effective means of collecting solar energy for applications that require heat at temperatures below about 100°C. These collectors have been used successfully for providing domestic hot water, space heating, air conditioning, power generation, water pumping cooking and other purposes.

The advantages of flat-plate collectors, as compared with focusing collectors are:

i) No complicated tracking mechanisms are involved.
ii) Construction is relatively simple.
iii) They can utilize both the diffuse and direct components of the available solar radiation.
iv) They are easily manufactured.

The advantages are their temperature limitation (about 100°C) and the fact that the collector heat exchanger area must equal the collector aperture area.

1.2.2. Physical principles of the conversion of solar radiation into heat

The fundamental process now in general use for heat conversion is the greenhouse effect. The name comes from its first use in greenhouses in which it is possible to grow exotic plants in cold climates through better utilization of the available sunlight.

Figure 1.1. The greenhouse effect related to the CO₂ contents of the atmosphere.
Show how temperature on earth is affected by the green house effect. Visible sunlight is absorbed on the ground at a temperature of 20°C for example emits infra-red light at a wave length of about 10 m but CO₂ in the atmosphere absorbs light of that wave length and back radiates part of it to earth. (CO₂ does not absorb the incoming sunlight which has a shorter wavelength). Hence the ‘green house effect’ brings about an accumulation of energy on the ground.

![Diagram of green house effect](image)

Figure 1.2. Principle of green house effect.

A black-painted plate absorbs the incoming sunlight. About it, is fixed a plate of ordinary window glass. When the temperature of the black-plate increases, it emits an increment of thermal beat in the form of infra-red light. The black absorber has the properties of a black body, ideal black bodies have not only the highest absorption rate but also the highest emission coefficient for all wavelengths of light. Emission increases with temperature. The re-emitted light is of progressively shorter wavelength and greater energy as the temperature of the black body increases.

1.2.3. Concentrating collector : Focussing type :

Focussing collector is a device to collect solar energy with high intensity of solar radiation on the energy absorbing surface. Such collectors
generally use optical system in the form of reflectors or refractors. A focussing collector is a special form of flat-plate collector modified by introducing a reflecting (or refracting) surface (concentrator) between the solar radiation and the absorber. These type of collectors can have radiation increase form low value of 1.5-2 to high values of the order of 10000. In these collectors, radiation falling on a relatively large area is focussed on to a receiver (or absorber) of considerably smaller area. As a result of the energy concentration, fluids can be heated to temperature of 500\(^\circ\)C or more.

1.2.3.1. Types of concentrating collectors

Concentrating or focussing collectors may be considered in two general categories : line focussing and point focussing types.

In practice, the line is a collector pipe and the point is a small volume through which the heat transport fluid flows. Because the sun has a finite size, focussing does infact occur over a small area or volume rather than a line or point. As per the number of concentrating collector geometries, the main-types of concentrating collectors are :

a) Parabolic through collector.

b) Mirror strip reflector

c) Flat plate collector with adjustable mirrors

d) Compound parabolic concentrator (C. P. C.).

1.2.3.1.1. Line Focussing collectors

(a) Parabolic trough reflector. The principle of the parabolic trough collector, which is often used in concentration collectors, is shown by the cross-section in Fig. 1.3, solar radiation coming from the particular directions collected over the area of the reflecting surface and is concentrated at the focus of the parabola if the reflector is in the form of a trough with parabolic cross-section, the solar radiation is focussed along a line. Mostly cylindrical parabolic concentrators are used in which absorber is placed along focus axis. The collector pipe, preferably with a selective
absorber coating, is used as an absorber. The dimension of parabolic trough or parabolic cylindrical collector can vary over a wide range. The length of a reflector unit may be roughly 3 to 5m and the width about 1.5 to 2.4 m, Ten or more such units are often connected end to end in a row, several rows may also be connected in parallel. Parabolic trough reflectors have been made of highly polished aluminium, of silvered glass or of a thin film of aluminized plastic on a firm base. Instead of having a continuous form, the reflector may be constructed from a number of long flat strips on a parabolic base.

Figure 1.3. Cross-section of parabolic trough reflector.

For the solar radiation to be brought to a focus by parabolic trough reflector, the sun must be in such a direction that it lies on the plane passing through the focal line and the vertex (i. e., the base) of the parabola. Since the elevation of the sun is always changing, either the reflector trough or the collector pipe (absorber) must be turned continuously about its long axis to maintain the required orientation. Both schemes are used in different practical-designs. Either the trough/cylindrical reflector or the pipe is turned
by partial rotation around a single axis parallel to the trough length. Trough type collectors are generally oriented in the east-west or north-south directions. For the east-west orientation, the collectors are laid flat on (or parallel, to) the ground. For the north-south orientation, however, the north end of the trough is raised so that the collectors are sloped facing south, just like flat-plate collectors. Ideally, the slope angle should be changed periodically; it is simpler, but less efficient, however to use a fixed angle design.

Figure 1.4. A typical cylindrical parabolic system

The north-south orientation permits more solar energy to be collected than the east-west arrangement, except around the winter equinox. On the other hand, construction costs are higher for the north-south (sloping) type. Moreover, a system of such collectors requires a larger area to allow for the shadowing effect of the sloping troughs. The increased separation distance between rows of collectors also results in increased pipe line costs and greater pumping and thermal losses. Finally the sun set position and little or not ever night adjustment is required. For the north-south orientation, however, the trough (or receiver) must be turned through a large angle from
sunset to sunrise. The choice of orientation in any particular instance depends on the foregoing and other considerations.

(b) Mirror-Strip Reflector: In another kind of focussing collector, a number of plane or slightly curved (concave) mirror strips are mounted on a flat base. The angles of the individual mirrors are such that they reflect solar radiation from a specific direction on the same focal line. The angles of the mirrors must be adjusted to allow for changes in the sun’s elevation, while the focal line (for collector pipe) remains in a fixed position. Alternatively, as mentioned for parabolic trough collectors, the mirror strips may be fixed and the collector pipe moved continuously so as to remain on the focal line.

Figure 1.5. A mirror-strip solar collector.

1.2.3.1.2. Point Focussing Collector (paraboloidal type).

A paraboloidal dish collector brings solar radiation to a focus at a point actually a small central volume. A dish 6.6 m internal diameter has been made from about 200 curved mirror segments forming a paraboloidal
surface. The absorber, located at the focus, is a cavity made of a zirconium-copper alloy with a black chrome selective coating. The heat-transport fluid flows into and out of the absorber cavity through pipes bonded to the interior. The dish can be turned automatically about two axes (up-down and left-right) so that the sun is always kept in a line with the focus and the base (vertex) of the paraboloidal dish. Thus, the sun can be fully tracked at essentially all times.

Figure 1.6. Point focus solar collector (Paraboloid).

The concentration ratios (concentration ratio is the ratio of the area of the concentrator aperture to the energy absorbing area of the receiver, it determines the effectiveness of a concentrator), are very high in the case of parabolic system and therefore can be used where high temperature are required. In a cylindrical parabolic system, the concentration ratio is lower than paraboloid counter-parts. In both the cases, the receiver is placed at the focus i.e., along the focal line in cylindrical parabolic or parabolic trough system and at the focus point in paraboloidal system.

Concentration ratios of about 30 to 100 or higher would be needed to achieve temperature in the range 300 to $500^\circ$C or higher. Collectors designed for such high concentration ratio necessarily have small angles of
field of view and hence need to track the sun continuously. A broad classification of such collector is:

i) The linear focus collector in the form of a parabolic trough or the ones employing faceted mirror strips.

ii) Spherical and conical mirror (Axicon) with aberrated foci. The physical upper limit to the concentration ratios achievable with paraboloids and parabolic troughs is determined by their f/d ratios (focal length/diameter) and are about 10000 and 100 respectively for the two cases. The concentration ratios achieved in practice are about 1/3 to ½ of the above values because of surface irregularities of the reflector, tracking errors etc.

iii) Central receiver collector, such as the paraboloidal mirror and the tower power plant using heliostat mirrors.

A system equivalent to very large paraboloidal reflector consists of a considerable number of mirrors distributed over an area on the ground. Each mirror, called a heliostat, can be steered independently about two axes so that the reflected solar radiation is always directed towards an

Figure 1.7. Distributed heliostat point-focussing reflector.
absorber mounted on a tower. This type of collector is classified as central receiver collector. This is mostly used in tower power plants for generation of electrical energy.

1.2.4. Concentrating collectors: Non-Focussing Type. The simplest type of concentrating collector is the mirror-boosted, flat plate collector. Is the mirror-boosted flat plate collector. It consists of a flat plate facing south with mirrors attached to its north and south edges. If the mirrors are set at the proper angle, they reflect solar radiation on to the absorber plate. Thus the latter receives reflected radiation in addition to that normally falling on it. The mirrors cut off part of the scattered radiation that would otherwise have reached the absorber plate, and only part of the scattered radiation falling on the mirrors will be reflected onto the absorber. Thus the concentration effect arises mainly from the increase in direct radiation reaching the absorber plate.

Figure 1.8. Flat plate collector augmented with mirrors.
When a number of collectors are combined in two or more rows, as they often are, the rows must be set further a part in the north-south directions to allow for the additional sun shading caused by the mirror extensions. Furthermore, in order for the mirrors to be effective, the angles should be adjusted continuously as the sun’s attitude changes. For these reasons and they can provide only a relatively small increase in the solar radiation falling on the absorber, flat-plate collectors with mirrors are not widely used.

1.2.5. Advantages and Disadvantages of concentration collectors over flat-plate type collectors:

Advantages. The main advantages of concentrator systems over flat-plate type collectors are:

1. Reflecting surfaces required less material and are structurally simpler than flat-plate collectors. For a concentrator system the cost per unit area of solar collecting surface is therefore potentially less than that for flat-plate collectors.

2. The absorber area of a concentrator system is smaller than that of a flat-plate system for same solar energy collection and therefore the insolation intensity is greater.

3. Because of the area from which heat is lost to the surroundings per unit the solar energy collecting area is less than that for flat-plate collector and because the insulation on the absorber is more concentrated, the working fluid can attain higher temperatures in a concentrating system than in a flat-plate collector of the same solar energy collecting surface.

4. Owing to the small area of absorber per unit solar energy collecting area, selective surface treatment and/or vacuum insulation to reduce heat losses and improve collector efficiency are economically feasible.
5. Focussing or concentrating systems can be used for electric power generation when not used for heating or cooling. The total useful operating time per year can therefore be large for a concentrator system than for a flat-plate collector and the initial installation cost of the system can be regained by saving in energy in a shorter period of time.

6. Because the temperature attainable with concentrating collector system is higher the amount of heat which can be stored per unit volume is larger and consequently the heat storage costs are less for concentrator systems than for flat-plate collectors.

7. In solar heating and cooling applications, the higher temperature of the working fluid attainable with a concentrating system makes it possible to attain higher efficiencies, in the cooling cycle and lower cost for air conditioning with concentrator systems than with flat-plate collectors.

8. Little or not anti-freeze is required to protect the absorber in a concentration system whereas the entire solar energy collection surface requires anti-freeze protection a flat-plate collector.

**Disadvantages:**

1. Out of the beam and diffuse solar radiation components only beam component is collected in case of focussing collectors because diffuse component can not be reflected and is thus lost.

2. In some stationary reflecting systems it is necessary to have a small absorber to track the sun image; in others the reflector may have to be adjustable more than one position if year round operation is desired; in other words costly orienting systems have to be used to track the sun.

3. Additional requirements of maintenance particular to retain the quality of reflecting surface against dirt, weather, oxidation etc.

4. Non-uniform flux on the absorber whereas flux in flat-plate collectors is uniform.
5. Additional optical losses such as reflectance loss and the intercept loss, so they introduce additional factors in energy balances.

6. High initial cost.

1.3. SOLAR PHOTOVOLTAICS

The term photovoltaic is derived by combining the Greek word for light, photos with volt, the name of the unit of electromotive force. The volt was named after the Italian physicist count Alessando Volta, the inventor of battery. The term photo-voltaic therefore signifies the generation of electricity from solar energy.

1.3.1. Historical background:

The discovery of the photovoltaic effect is generally credited to the French physicist Edmond Becquerel. When he was working with ‘wet cell’ battery in the course of which he found that the battery voltage increased when its silver plates were exposed to sunlight.

In year 1883 a new York electrician Charles Edgar Fritts, constructed a selenium solar cell that was somewhat similar to the silicon solar cells of today. It was made up of thin wafers of selenium covered with semi-transparent gold wires and a protective sheet of glass. But his cell was very inefficient (i.e. @ 1%).

But the real breakthrough that occurred in 1950’s that set in motion the development of modern high-efficiency solar cells. It occurs in Belt’s Labs in USA, where work was going on to study effect of light on “semi-conductors”. Semi-conductor are non-metallic materials such as germanium and silicon whose electrical characteristics lie between those of conductor and insulators. Hence the term semi-conductor. Transistor are made from semi-conductor in extremely pure form, into which tiny quantities of carefully selected impurities, such as boron or phosphorous have been deliberately
diffused. This process is known as ‘doping’. Doping alters the electrical behaviour of semi-conductors in very useful manner.

The first successful demonstration of use of PV solar cell as a power source for space craft was carried out in 1958, to power a small Radio transmitter in second US Space Satellite Vinguard 1.

1.3.2. Cell structure and principle

PV cells consists of junction between two thin layers of dissimilar semi-conducting material known as P (positive)-type semi-conductor and N- (negative) type semi-conductor. These semi-conductors are usually made from silicon.

N-type semi-conductor are made from crystalline silicon that has been doped with small quantities of an impurity [usually phosphorous] in such a way that the doped material possesses a surplus of free electrons. As there is a net negative charge after doping so it is known as N-type semi-conductor.

P-type semi-conductor are also made from crystalline silicon, but are doped with very small amount of different impurity (usually boron) which causes the material to have a deficiency of free electrons. These missing electrons create holes. Since deficiency of an electron causes a net positive charge. Hence the name P-type semi-conductor.

A PN junction is created by joining these dissimilar semi-conductors. This sets up an electric field in the region of the junction. This electric field will cause negatively and positively charged particle to move in the opposite direction.

As light is consist of a stream of tiny particles of energy called “photons”. When photons of light of a suitable wave length falls with in the P-N-Junction they can transfer their energy. Some of the electrons in the material so promoting them to higher energy level. In normal state [i. e. without excitation] these electrons help to hold the material together by forming valance bonds with adjoining atoms and can’t move. But in their excited state however, the electrons become free to conduct electric current
by moving through the material and while moving electron leaves behind holes (i.e. deficiency of electron) in the material which can also move.

Figure 1.9. Schematic diagram of a solar cell.

Figure 1.10. Schematic of completely covering back a typical solar cell showing the physical arrangement of the major components.
When the P-N-Junction is formed some of the electrons in the immediate vicinity of the junction are attracted from the N-side to combine with the holes on P-side. Similarly holes on the P-side near the junction are attracted combine with the hole on the nearby N-side. The net effect of this is to set up around the junction a layer on the N-side that is more +vely charged that it would otherwise be and on the P-side a layer that is more – vely charged then it would be. This means a reverse electric field is set up around the junction and the region around the junction is known as zone of depletion as it is depleted of charged carriers (electrons holes).

When an electron in the junction region is stimulated by an incoming photon to jump into the conduction band it leaves behind a hole in the valance band. Two charge carriers (an electrons hole pair) are thus generated under the influence of the reverse electric field around the junction. The electron will tend to move into the N-region and holes into the P-region. The flow of electron to the N-region is an electric current if there is an external circuit for the current to flow through, the moving electrons will eventually flow out of the semi-conductor via one of the metallic contact on the top of the cell. The holes will flow in the opposite direction through the
material until they reach another metallic contact at the bottom of the cell where they are filled by electron from the other half of the external circuit.

The generation of electric power requires both voltage and current so in order to provide power the PV cell must generate voltage as well as the current provided by the flow of electron. This voltage is provided by the internal electric field set up at the P-N-Junction. A single PV cell produce a voltage of about 0.5 volt at a current of up to around 2.5 amperes. So the peak power of cell is $- I \times V = 0.5 \times 2.5 = 1.25W$.

1.3.3. Type of PV cells:

1. Mono crystalline silicon cells
2. Poly crystalline silicon cells
4. Gallium arsenide cells.
5. Thin film PV cells.
   a) Amorphous silicon
   b) Copper indium diselenide
   c) Cadmium telluride.

1.3.3.1. Mono crystalline silicon cells

These are made from extremely pure mono-crystalline silicon in the sophisticated but expensive Czochralski process. The most efficient mono-crystalline cell have an efficiency of around 16%. These cells are made in pyramid-shaped texture on the top surface to increase the amount of light trapped.

1.3.3.2. Poly-crystalline silicon cells

Here wafers of cell are made from poly crystalline silicon. These poly crystalline are easier to manufacture but are less efficient (around 10%). Main advantage is that these can be manufactured in square shapes which virtually eliminated any inactive area between cells.
1.3.3.3. **Poly crystalline thin film silicon cells**

These are manufactured by depositing thin film @ 20 micron thick of poly crystalline silicon on ceramic substrate. The efficiency is about 15%.

1.3.3.4. **Gallium arsenide (GA) cells**

GA is more suitable than silicon because it has high light absorption co-efficient and also it has a band gap wider than that of silicon and close to the theoretical optimum for absorbing the energy in the terrestrial solar spectrum. So cells made of GA are very efficient. Another advantage is that they can operate at relatively high temperature without the appreciable performance degradation from which silicon and many other-semi-conductor suffers. So GA is more suitable in concentrating PV systems. But they are very costly and used mostly in space applications.

1.3.4. **Thin film PV cells**

1.3.4.1. **Amorphous silicon**:

Amorphous silicon is less structured form of silicon in which the silicon atoms are much less ordered than in the crystalline form. Solar cell using a-Si have a somewhat different form of Junction between the P and N-type material. A so called a PN junction is formed, consisting of an extremely thin layer of P-type a-Si or top followed by a thicker intrinsic layer (i layer) made up of un-doped a-Si and then a very thin layer of N-type a-Si.

**Advantages** of a-Si:
- Cheaper to produce
- Much better absorption of light.

**Disadvantages** of a-Si:
- less efficient than poly crystalline
- Efficiency degrades after few month of exposure to sun light.

In 1990- a-Si cells accounted for 30% of PV sales worldwide.
1.3.4.2. Copper Indium Diselenide (CIS) film

CIS is a compound of copper indium and selenium, which is a semi-conductor. These have attained an efficiency of 12.5%. These modules don’t suffer the problem of degradation in performance as in a-Si. Although indium is expensive but quantity required is very small.

1.3.4.3. Cadmium telluride (Cd Tc)

It is another semi-conductor. CdTc modules can be made using a simple and in-expensive electroplating type of process. Efficiency of over 10% are claimed without performance degradation as in a-Si.

1.3.5. Multiple Junction PV cells

One way of improving the overall efficiency of PV cells and modules is the multi-junction approach, in which two (or more) PV junctions of thin film type are layered one on top of the other, each layer extracting energy from a particular portion of spectrum of coming light.

Concentrating PV systems:

Another way of getting more energy out of a given number of PV cells is to use mirrors or lenses to concentrate incoming solar radiation to the cells.

Array sizing and selection

- First estimate AC and DC load at the chosen site.
- To account for energy losses in battery charge/discharge cycle estimated load is enhanced by 20%.
- Then estimate the sun shine at site i.e. equivalent sun shine hours.

\[
\text{Next the array wattage} = \frac{\text{Avg. daily load (Amp hr)}}{\text{Available sunshine (hours)}}
\]
Array wattage (A)

- Number of modules = Module wattage

Available sunshine hours can be found from solar radiation maps.

### 1.3.6. Photovoltaics in India

PV programme in India is initiated in 1976. But commercial production of solar cells and modules began in 1983 when central electronics Ltd. (CEL) entered in this line. In 1992 designated capacity for manufacturing PV systems was CEL (2mw), REIL (1mw), Suryavonics Ltd. (1.2 mw), BHEL (300 kw) Tata BP solar (500 kw) and Indian metal and carbide limited (300 kw). Indian capabilities cover complete cell manufacture module lamination and system development. By 1995 total installed capacity for solar pv systems was 7 mw out of which 4 mw was towards street lightening and remaining 3 mw by way of domestic lightening, community TV, water pumping railway signalling.

In India MNES plans and co-ordinate R and D activities in photovoltaics carried out by different govt. agencies and voluntary organization.

### 1.3.7. Incentive from Govt. for promotion of PV:

i) No license for setting up PV systems.

ii) Custom rates are considerably reduced.

iii) IREDA provide term loan upto 1.5 crore for financing PV programmes.

During eighth plan (1992-1997) an outlay of Rs 90 crore was allocated for financing PV programmes.

Large scale expansion in PV technology is largely constrained by high system costs which is due to low cell efficiency and high material and manufacturing costs and these need to be improved.
1.3.8. Application of solar photovoltaic system

Various solar photovoltaic systems have been developed and installed at different sites for demonstration and field trial purposes. The terrestrial applications of these include provision of power supply to:

i) Water pumping sets for micro irrigation and drinking water supply,
ii) Radio beacons for ship navigation at ports,
iii) Community radio and television sets,
iv) Cathodic protection of oil pipe lines,
 v) Weather monitoring,
vi) Railway signalling equipment,
 vii) Battery charging,
 viii) Street lighting.

The major application of photovoltaic lies in water pumping for drinking water supply and irrigation in rural areas. The photovoltaic water pumping system essentially consists of:

a) a photovoltaic (PV) array,
b) storage battery,
c) power control equipment,
d) motor pump sets, and
e) water storage tank.

1.3.9 Advantages and Disadvantages of photovoltaic solar energy conversion:

Advantages:

i) Direct room temperature conversion of light to electricity through a simple solid state device.
ii) Absence of moving parts.
iii) Ability to function unattended for long periods as evidence in space programme.
iv) Modular nature in which desired currents, voltages and power levels can be achieved by mere integration.
v) Maintenance cost is low as they are easy to operate.
vi) They do not create pollution.
vii) They have a long effective life.
viii) They are highly reliable.
ix) They consume no fuel to operate as the sun’s energy is free.
x) They have rapid response in output to input radiation changes; no log-on time constant is involved, as on thermal systems, before steady state is reached.
xii) They have wide power handling capabilities from microwatts to kilowatts or even megawatts when modules are combined into large area arrays. Solar cells can be used in combination with power conditioning circuit to feed power into utility grid.
xii) They are easy to fabricate, being one of the simplest of semiconductor devices.
xiii) They have high power to weight ratio, this characteristic is more important for space applications than terrestrial, may be favourable for some terrestrial applications. The roof loading on a house-top covered with solar cells, for example, would be significantly lower than the comparable loading for conventional liquid solar water heaters.
xiv) Amenable to on site installation i.e. decentralized or dispersed power; thus the problem of power distribution by wires could be eliminated by the use of solar cells at the site where the power is required.
xv) They can be used with or without sun tracking, making possible a wide range of application possibilities.

Their principal disadvantages are their high cost, and the fact that, in many applications, energy storage is required because of no insolation at
night. Efforts are being made worldwide to reduce costs through various technological innovations.

1.4. SUMMARY

Solar energy is an infinite source of energy and at the same time non-polluting and free of environmental hazards. Solar energy can be utilized in three ways (a) using the heat form sunlight (b) converting solar energy directly into electrical energy and (c) using photosynthesis and biological processes. Solar energy can be directly used for multiple purpose using flat-plate collectors, focusing collectors and solar cells. Two barriers to successful utilization of solar energy are: (i) It is diffused at low temperature (ii) it requires storage system for use when the sun is not visible.

1.5. KEY WORDS

Solar collector
Device for collecting radiant energy from the sun and converting it into heat.

Photovoltaic cell
Device which converts radiant (Solar) energy directly into electrical energy.

Solar capital
Solar energy from the sun reaching the earth.

Insolation
Amount of solar radiation falling on the earth.

Semi-conductor
Semi-conductors are non-metallic materials such as germanium and silicon whose electrical characteristics lie between those of conductor and insulators.

Doping
Contamination of extremely pure form of semiconductor with tiny quantities of carefully selected impurities such as boron or phosphorus to alter electric behaviour.

1.6. SELF ASSESSMENT QUESTIONS
1. What is meant by solar cell? Enumerate the advantages and disadvantages of the solar cell system?
2. Define semiconductor. What is meant by N-type and P-type semiconductor? Explain.
3. Explain the photovoltaic principle.
4. Describe the different types of solar cells which are mostly used.
5. What are the main applications of solar PV systems? Describe briefly.
6. What are the advantages and disadvantages of focusing type collector over a flat plate collector?
7. What are solar collectors? Enumerate the types of solar collectors.
8. What are flat plate collectors? Describe types of flat plate collectors?
9. What are the advantages of flat-plate collector?

1.7. SUGGESTED READINGS
APPLICATION OF SOLAR ENERGY IN INDIA

Narsi Ram Bishnoi

STRUCTURE

2.0. OBJECTIVES

2.1. INTRODUCTION

2.2. SOLAR WATER HEATER
   2.2.1. Natural circulation solar water heater
   2.2.2. Forced circulated solar water heater

2.3. SOLAR COOKER
   2.3.1. Principle and constructional details of a box type solar cooker

2.4. SOLAR DESALINIZATION

2.5. SOLAR PUMPING

2.6. SOLAR POND
   2.6.1. Principle of operation of solar ponds

2.7. ENERGY CONSERVATION

2.8. ENERGY MANAGEMENT
   2.8.1. Energy management in India
   2.8.2. Other measures
   2.8.3. Incentives
   2.8.4. Need of the hour

2.9. SUMMARY

2.10. KEY WORDS

2.11. SELF ASSESSMENT QUESTIONS

2.10. SUGGESTED READING

2.0. OBJECTIVES

After studying this unit, you should be able to understand about

- Various techniques that is being used to harvest solar energy for
  the useful purpose and benefits of man kinds.
• Energy conservation as well as strategy for energy management.

2.1. INTRODUCTION

Sun is a primary source of energy, all the forms of energy on the earth are derived from it. The solar energy can be harnessed either by deriving energy directly from sunlight or by indirect method.

Since fossil fuels—coal, oil and natural gas originate from living matter, their energy is really solar energy that has been converted and stored for millions of years. In fact, only nuclear energy, geothermal and to a large extent, tidal energy, do not originate from the sun. Based on above classification, direct solar energy application are discussed below in the following order.

i) Solar water heater.
ii) Solar desalination.
iii) Solar pumping.
iv) Solar cooking.
v) Solar Pond

2.2. SOLAR WATER HEATER

The basic elements of a solar water heater are:

i) Flat plate collector.
ii) Storage tank.
iii) Circulation system and auxiliary heating system.
iv) Control of the system.

There are two types of solar water heaters:

i) Natural circulation solar water heater.
ii) Forced circulation solar water heater.

2.2.1. Natural circulation solar water heater

It consists of a tilted collector (South facing), with transparent cover glasses, a separate highly insulated water storage tank, and well insulated pipes connecting the two (Fig. 2.1). The bottom of the tank is at least 1 ft.
(0.3 m) the top of the collector and no auxiliary energy is required to circulate water through it.

Circulation occurs through natural convection, or thermo-siphoning. As the water is heated in its passage through the collector, its density decreases and hence rises and flows into the top of the storage tank. Colder water from the bottom of the tank has a higher density and so tends to sink and enter the lower heater of the collector for further heating. The density difference between the hot and cold water thus provides the driving force (convection) for the circulation of water through the collector and the storage tank. Hot water is drawn off from the top of the tank as required and is replaced by cold water from the service system. As long as the sun shines the water will quietly circulate, getting warmer. After sunset a thermostatic system can reverse its flow direction and lose heat to the environment during the night. To avoid reverse flow, the top heater of the absorber is kept as stated above 0.3 m below the cold leg fitting on the storage tank. To provide heat during long, cloudy periods, an electrical immersion heater can be used as a backup for the solar system. A non-freezing fluid such as ethylene glycol, propylene glycol, silicon oils etc., may be used in the collector circuit. The thermostatic system is one of the least expensive solar hot-water systems and should be used whenever possible.
2.2.2. Forced circulated solar water heater

In forced circulation system, by including an electric pump in the return circuit between the bottom of the storage tank and the lower head of the collector. (Fig. 2.2 a,b). The tank can be placed at a more convenient level (e.g. in the house basement). This is now an active system. A control unit permits the pump to operate only when the temperature of the water at the bottom of the tank is below that of the water in the upper head.

A check valve is needed to prevent reverse circulation and resultant night time thermal losses from the collector. In this example, auxiliary heater is shown as provided to the water leaving the tank and going to the load. When there is a danger of freezing, the water may be drained from the collector; alternatively, a slow reverse flow of the warmer water may be permitted through the collector on cold nights. The freezing danger can be overcome although at some increase in cost by using an antifreeze solution such as ethylene glycol, propylene glycol solutions, silicon oils etc., as the heat-transport medium. The heat is then transferred to water in the storage tank by way of a heat exchanger coil (Fig. 2.2c). A solar collector area of 30-40 sq. ft. in combination with an insulated of 200-400
Figure 2.2.b. Schematic diagram of a forced circulation solar water heater.

Figure 2.2 C. Solar water heating system with anti freeze

litre capacity tank can provide 200-300 litre of hot water at about 60°C per average sunny day in a favourable climate.

2.3. SOLAR COOKER

In our country energy consumed for cooking shares a major portion of the total energy consumed in a year. In villages 95% of the consumption goes only to cooking. Variety of fuel like coal, kerosene, cooking gas, firewood, dung cakes and agricultural waste are used. The energy crisis is affecting every one. It is affecting the fuel bills for those who use it for heating the houses and cooking their food. The poor of the developing countries who have been using drywood, picked up from the fields and
forests as domestic fuel, have been affected in their own way, due to scarcity of domestic fuel in the rural areas. At present, firewood and cow dung cakes are the most important sources of fuel to cook food. Cow dung too precious to be allowed to be used for burning and cooking. It is very useful to improve the fertility of the soil, if used in proper way. The supply of wood is also fast depleting because of the indiscriminate felling of trees in the rural areas and the denudation of forests. There is a rapid deterioration in the supply of these fossil fuels like coal, kerosene or cooking gas. The solution for the above problem is the harnessing of solar energy for cooking purposes.

Thus solar cookers have a very relevant place in the present fuel consumption pattern. Various designs of solar cookers have been developed in our country. The first solar cooker was developed in the year 1945 by Mr. M. K. Ghosh of Jamshedpur a freedom fighter. He developed a box type solar cooker with a reflecting mirror and a copper coil inside, on which the food materials used to be placed in pots. Later in 1953 National Physical Laboratory (NPL) of India developed a parabolic solar cooker. The main reasons for non-acceptance of these devices was the cheap availability of cooking fuel during these days. The problem of harnessing and utilization of solar energy arised after the fuel crisis of the 1970s, which also affected the rural areas.

Basically there are three designs of solar cooker:

i) Flat plate box type solar cooker with or without reflector.

ii) Multi-reflector type solar oven and,

iii) Parabolic disc concentrator type solar cooker.

Flat plate box type design is the simplest of all the designs. Maximum no load temperature with a single reflector reaches upto 160\(^0\)C. In multi reflector oven four square or triangular or rectangular reflectors are mounted on the oven body. They all reflect the solar radiations into the cooking zone in which cooking utensils are placed. Temperature obtained is of the order of 200\(^0\)C. The maximum temperature can reach upto 250\(^0\)C, if the
compound cone reflector system is used. With parabolic disc concentrator type solar cooker, temperatures of the order of 450°C can be obtained in which solar radiations are concentrated onto a focal point. Principle of operation of solar cookers is shown in Fig. 2.3.

2.3.1. Principle and constructional details of a box type solar cooker

The solar rays penetrate through the glass covers and absorbed by a blackened metal tray kept inside the solar box (Fig. 2.3). The solar radiation entering the box are of short wavelength. The higher wavelength radiation is not able to pass through the glass cover i.e. re-radiation from absorber plate to outside the box is minimized by providing the glass cover. Two glass covers are provided to again minimize the heat loss. The loss due to convection is minimized by making the box air tight by providing a rubber strip all round between the upper lid and the box. Insulating material like glasswool, paddy husk, saw dust or any other material is filled in the space between blackened tray and outer cover of the box. This minimizes heat loss due to conduction. When this type of cooker is placed in the sun, the blackened surface starts absorbing sun rays and temperature inside the box starts rising. The cooking pots, which are also blackened are placed inside with food material, get heat energy and food will be cooked in a certain period of time depending upon the actual temperature attained inside. The temperature attained depends upon the intensity of solar radiation and material of insulation provided. The amount of solar radiation intensity can be increased by providing mirror or mirrors.
Figure 2.3. Principle of operation of Solar cooker.

(a) Principle of box type cooker.

(b) Reflector type solar cooker.

Figure 2.3. Principle of operation of Solar cooker
The solar cooker is made up of inner and outer metal or wooden boxed with double glass sheet on it. Absorber tray (blackened tray) is painted black with suitable black paint. This paint should be dull in colour so that it can withstand the maximum temperature attained inside the cooker as well as water vapour coming out of the cooking utensils. The top cover contains two plain glasses each 3 mm thick fixed in the wooden frame with about 20 mm distance between them. The entire top over can be made tight with padlock hasp. Neoprene rubber sealing is provided around the contact surfaces of the glass cover and the cooker box. A small vent for vapour escape, is provide in the sealing. Collector area of the solar cooker is increased by providing a plane reflecting mirror equal to the size of the box, and hinged on one side of the glass frame. A mechanism (guide for adjusting mirror) is provided to adjust the reflector at different angles with the cooker box. A 15 to 25°C rise in temperature achieved inside the box when reflector is adjusted to reflect the sun rays into the box. In winter, when sun rays are much inclined to horizontal surface, reflector is a most useful addition.
Overall dimensions of the latest model are 60 X 60 X 20 cm height. This type of cooker is termed as family solar cooker as it cooks sufficient dry food materials for a family of 5 to 7 people.

The temperature inside the solar cooker with a single reflector is maintained from 70 to $110^0C$ above the ambient temperature. This temperature is enough to cook food slowly, steadily and surely with delicious taste and preservation of nutrients. Maximum air temperature obtained inside the cooker box (without load) is $140^0C$ in winter and $160^0C$ in summer. Depending upon the factors such season and time of the day, type of the food and depth of the food layer, time of the cooking with this cooker ranges from 1 to 4 h. Meat should be allowed to stay for 3-4 hours. Vegetables take from $\frac{1}{2}$ to $2\frac{1}{2}$ hours. All types of Dals can be cooked between 1½ to 2 hours. Rice is cooked between 30 minutes and 2 hours. The best time of the day for cooking is between 11 am and 2 pm. Cooking is faster in summer than in winter due to high ambient temperature. Merits of a solar cooker are:

i) No attention is needed during cooking as in other devices.
ii) No fuel is required.
iii) Negligible maintenance cost.
iv) No pollution.
v) Vitamins of the food are not destroyed and food cooked nutritive and delicious with natural taste.
vi) No problem of charring of food and no over flowing.

Limitations of a solar cooker are:

i) One has to cook according to the sun shine, the menu has to be preplanned.
ii) One can not cook at short notice and food can not be cooked in the night or during cloudy days.
iii) It takes comparatively more time.
iv) Chapaties are not cooked because high temperature for baking is required and also needs manipulation at the time of baking.

2.4. SOLAR DESALINIZATION

Fresh water is a necessity for the sustenance of life and also the key to man’s prosperity. It is generally observed that in some arid, semi-arid and coastal areas which are thinly populated and scattered, one or two family members are always busy in bringing fresh water from a long distance. In these areas solar energy plentiful and can used for converting saline water into distilled water. The pure water can be obtained by distillation in the simplest solar still, generally known as the “basin type solar still”. It consists of a blackened basin containing saline water at a shallow depth, over which is a transparent air tight cover that encloses completely the space above the basin. It has a roof-like shape. The cover, which is usually glass may be of plastic, is sloped towards a collection trough. Solar radiation passes through the cover and is absorbed and converted into heat in the black surface. Impure water in the basin or tray is heated and the vapour produced is condensed to purified water on the cooler interior of the roof. The transparent roof material, (mainly glass) transmits nearly all radiation falling on it and absorbs very little; hence it remains cool enough to condense the water vapour. The condensed water flows down the sloping roof and is collected in troughs at the bottom. Saline water can be replaced in the operation by either continuous operation or by batches. Although there are numerous configurations of basin type units, their basic theory is identical. The basin type solar still has produced distilled water at a cost per unit of product lower than other types of solar equipment and is the only type in operation. Operating efficiencies of 35 to 50% for basin type still have been achieved in practical units, as compared with a theoretical maximum of slightly more than 60%.
The performance rating and efficiency of the solar still is determined by plotting the graph of the amount of fresh water produced per unit of basin area in one day versus the solar radiation intensity over the same period. Such curves for several still are drawn. Efficiency is defined as

\[ \eta = \frac{w \Delta h}{H} \]

Where \( w \) = weight of distillate per square meter per day.
\( \Delta h \) = enthalpy change from cold water to vapour.
\( H \) = Solar radiation intensity per square meter per day.
\( \eta \) = Efficiency of the solar still.

Here area of the water surface is to be considered. \( \Delta h \) includes the latent heat of vaporization, which is being taken as average value 594.5 kcal/kg.

The performance of a solar still is generally expressed as the quantity of water produced by each unit of basin area in a day i.e. cubic meters or litres of water per square meter of basin area per day. This quantity will vary with the design of the still, with the intensity of solar radiation and with the atmospheric conditions in the surroundings. The production rate depends primarily on the amount of solar radiation available but is affected by several other factors; like ambient air temperature, wind speed, atmospheric humidity, sky conditions etc., the effect of design parameters such as
orientation of still, single sloped or double sloped, inclination of glass cover insulation of the base etc., and the effect of operating parameters such as water depth in the tray, absorption emittance properties of the still preheating of water etc.

![Diagram of a solar still with labels for Plastic wrap, Stone, Rubber band, Salt water, Container, and Cup.]

Figure 2.6. A simple device to demonstrate solar desalinization.

Solar still installations may provide about 15 to 50 litres of desalinized water per day per 10 sq. m.

2.5. SOLAR PUMPING

Solar pumping consists in utilizing the power generated by solar energy for water pumping, useful for irrigation.

Solar energy offers several features that makes its utilization for irrigation pumping quite attractive. First, the greatest need for pumping occurs during the summer months when solar radiation is greatest. Second, pumping can be intermittent to an extent. During periods of low solar radiation when pumping decreases, evaporation losses from crops are also low.
A number of recently constructed solar irrigation pump installations are now operational. The major obstacle to increase use of solar irrigation systems at this time is their relatively high capital cost. If the costs of solar pumps can be substantially reduced and assuming that conventional fuel costs continue to rise, solar irrigation could become economical and increased use of such systems might be anticipated in future.

The basic system consists of the following components:

1. The solar collectors, may be
   a) Flat plate collectors or solar pond.
   b) Sun-tracking concentrators (cylindrical parabolic trough concentrator or heliostats).

2. The heat transport system.

3. Boiler or Heat Exchanger

4. Heat engine, it may be
   a) Rankine engine
   b) Brayton cycle gas turbine

5. Condenser.

6. Pump, it may be
   a) Reciprocating pump
   b) Centrifugal pump
   c) Diaphragm pump
   d) Rotary pump.

The solar pump is not much different from a solar heat engine working in a low temperature cycle. The source of heat is the solar collector, and sink is the water to be pumped. A typical solar powered water pumping system is shown in Fig. 2.7. The primary components of the system are an array of flat-plate collectors and an Rankine engine with an organic fluid as the working substance. During operation a heat transfer fluid (pressurized water) flows through the collector arrays. Depending upon the collector configuration, solar flux and the operating conditions of the engine, the fluid will be heated in the collector to higher temperature, the solar energy which
is thus converted to the thermal energy. The fluid (water) flows into a heat exchanger (boiler), due to temperature gradient, and comes back to the collector. This water yields its heat to an intermediate fluid in the boiler. This fluid evaporates and expands in the engine before reaching the condenser, where it condenses at low pressure. The condenser is cooled by the water to be pumped. The fluid is then reinjected in the boiler to close the cycle. The expansion engine or Rankine engine is coupled to the pump and it could of course be coupled to an electric generation.

The collector area to a large extend is determined by the overall efficiency of the system $\eta_0$.

$$\eta_0 = \eta_e \times \eta_c$$

Where $\eta_e$ is the efficiency of the engine.

$\eta_c$ is the efficiency of the collectors.

Figure 2.7. Schematic of Solar Pump

For a higher temperature in the boiler, results in a higher engine efficiency, but a higher temperature at the boiler requires a higher collector temperature, which decreases the collector efficiency. There is thus, an optimum range of operating temperatures for the solar pumping system which results in the maximum efficiency for the system.
The working fluids used in the cycle are toluene (CP-25), monochlorobenze (MCB) trifluoro ethanol (TFE-100 and 85), hexa fluro benzene (HFB), pyridine (CP 32), refrigerant-11 (R-11) refrigerant-113 (R-113), and thiopene (CP-34). R-113 is preferable to all, because of high cycle efficiency, non-toxic in nature and due to low cost.

The irrigation pump operates at a rated power of 19 kW (25 horse power) and delivers water at 500 to 600 gal/min (32 to 38 litres/sec) from a well roughly 30 m deep. The energy efficiency (i.e. percentage of solar energy collected that is converted into useful work) is 13 to 14 per cent, this low value is largely a result of the relatively low temperature of the working fluid entering the turbine. Rankine efficiency will be within acceptable limits, if the temperature of the order of 200 to 400°C is obtained, using proper focusing collector system.

2.6. SOLAR POND

2.6.1. Principle of operation of solar ponds

The solar pond is a simple device for collecting and storing solar heat. Natural ponds convert solar radiation into heat, but the heat is quickly lost through convection in the pond and evaporation from its surface. A solar pond on the other hand, is designed to reduce convective and evaporation heat losses so that useful amounts of heat can be collected and stored.

![Figure 2.8.a. Schematic of solar pond with vertical concentration gradient of MgCl₂.](image-url)
Figure 2.8 b. Salt gradient solar pond

Solar ponds are large-area brine ponds approximately 1 m deep in which vertical gradients of salt concentrations are maintained so that the most concentrated and most dense solutions are at the bottom of the pond. Heat is generated at the bottom of the pond due to absorption of solar radiation-transmitted by the water by the pond’s black bottom. In spite of the temperature rise of the brine at the bottom, its specific gravity remains higher than that at the top if a sufficiently large concentration gradient is maintained. Under these conditions, convective mixing is minimized and the bottom layers of brine reach 80-90°C while the top remains at 25°C, which may be withdrawn from the pond and used for power generation, salt production by multiple-effect evaporation of brine water distillation, and so on. To maintain the concentration gradient against the slow upward diffusion of salt, the surface must be slightly “washed” with fresh water and concentrated brine supplied at the bottom.

2.7. ENERGY CONSERVATION

The conventional sources of energy resources are gradually getting depleted at a rapid rate all over the world. It is therefore very necessary to conserve energy as well as to improve the efficiency of all the power systems. If due care is not taken for conservation, the large scale generation of energy, mainly from non-renewable sources to meet the
increasing demand will be required, which will certainly cost the environment heavily from project implementation stage onward. There environmental hazards are:

- Habitat loss
- Tropical deforestation
- Loss of bio-diversity
- Loss of genetic materials
- Global warming
- Toxic damps
- Ozone shield damage and
- Acid rain etc.

Again inefficient use of energy leads to energy loss during generation, transmission and distribution at user point, add cost to energy production and fuel. The transmission and distribution loss in our country were around 15% upto years 1965-67, have gradually increased to average of 25% during 1993-94. The continued rising trends in such a loss is a matter of serious concerned.

Energy conservation activities had received importance after the first energy crisis in 1973; while in India, it is only in the 8th plan a separate budget allocation of Rs. 10,000 crores was made for 10 percent reduction in energy consumption. Energy conservation is found to be one of the effective solution to the energy crisis and the sustainable development. One MW of energy conserved in equivalent to 2 MW of energy generated as per research finding. By proper implementation of energy conservation measure can same 20 to 30% of energy. Thus there are much scope for energy conservation in all sectors particularly in energy intensive units which are as follows:

<table>
<thead>
<tr>
<th>Industries</th>
<th>Conservation potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron and Steel</td>
<td>8-10%</td>
</tr>
<tr>
<td>Fertilizer</td>
<td>10-15%</td>
</tr>
<tr>
<td>Cement</td>
<td>10-15%</td>
</tr>
</tbody>
</table>
Pulp and paper  20-25%
Textiles  15-20%

The following comprehensive measure should be taken for energy conservation:

- To make energy auditing compulsory in power plants.
- To provide monetary incentives to install fuel efficient machinery and change over to non-conventional sources of energy wherever possible.
- To enforce some sort of building codes which will ensure conservation, use of solar energy and energy efficiency standards. Sunshines are often blocked by neighbour’s tall buildings in the towns and trees in the villages. The building codes will remove these problems for free or equal excess to sunshines.
- Development and enforcement of new technology for conventional as well as renewable energy sources.
- Legislative measures covering technical, economic, environmental, hygienic, aesthetic as well as safety and security aspects in using different sources of energy.
- Free market regulation for fossil fuels, necessary to control production of fossil fuels and to accelerate the use of renewable energy sources.

2.8. ENERGY MANAGEMENT

The proper planning and management in respect of energy are necessary:

- For proper and effective uses of energy.
- To decrease the burden on the conventional energy sources
- For giving more stress on renewable sources of energy
- To prevent misuse or waste of energy.
• For proper production and distribution.
• For keeping ecosystem and environment free of pollution.

With the advent of new technologies for alternative or renewable energies and with the gradual phasing out of the conventional energy resources it has become necessary to make the following steps for effective energy management;

• It is necessary to have a bank of accurate data on all available energies that may affect a site in any location.
• Energy education to school children through texts, and to all other classes of society through seminars, TV, radio, newspaper, workshops etc.
• Legislation and regulation
• Management training, organization and implementation. The saving of energy is expected from the result of both demand and supply management. Demand management involves.
• Improving efficiency of industrial process
• Recycling wastes
• Promoting energy efficient design and
• Installing solar application in building to minimize energy consumption
• Demand management programmes begin with analysing current consumption trends in different consuming sectors and estimate their likely patterns in future. This is followed by technical and economic evaluation of energy efficiency options available to reduce demand for various end-users.
• In identification of specific measures to reduce demand follows next. Identified specific measure may include soft option such as pricing as well as other monetary incentives, rebate, and involvement of institution and design engineering organisation in the area of energy efficiency.
Supply management relates to the improvement of supply of both conventional and non-conventional sources of energy with a view to minimize gap between supply and demand of energy some of the major options in improving supply can be as follows:

- Promoting increasing use of non-conventional sources of energy.
- Improvement of efficiency in the generation, transmission and distribution system.
- Introducing sweeping reforms in coal mining industry for improving coal productivity.
- Maximizing use of natural gas in industry, power generation.
- Seeking higher involvement of private sector in generation, transmission and distribution of power, exploration and production of hydrocarbon and in solar wind, mini hydel and bioenergy programme.

Significant energy saving can be achieved within a short spell through management, employee training, public awareness programmes, equipment standardization proper maintenance and other house keeping measures.

A major reason for high consumption of energy is the continued use of old machinery and obsolete technology. The existing plant design and equipment in many industries were developed prior to the energy price rise – when the objective was to save capital and take advantage of low energy cost.

2.8.1. Energy management in India

The impact of population explosion coupled with rapid economic growth could be visualized on our limited natural resources including non-commercial and commercial energy sources. Our requirement of fuel wood is about six times that what our forest resources can provides us on sustainable basis and similarly we are far behind to meet our demand for
electricity and energy requirement of other important sectors from commercial sources.

Although we are increased our installed capacity of electricity generation at a fast rate (from 31,025 mw in 1980-81 to 42,749 mw in 1984-95 to 80,944 mw in 1994-95). Yet the demand which is increasing at a rate of 12 to 15% per annum is far ahead than present rate of installation. It is expected that by end of 9th five year plants (2001-2002) we will have installed capacity of about 1,38,000 mw. It is estimated that the gap between demand and supply is increasing at a accelerated rate in near future as demand is expected to be around 2,09,000 mw by 2007.

At present rate, we are on an average need 4-5 crore rupees to add one mw of electricity in our installed capacity. It is estimated that India requires an investment of 200 billion in power sector over next 15 years if country’s 6 % GDP is to be sustained. We have to invite private sector including foreign collaboration to ease out this daunting task. Otherwise it will be disastrous for our overall economic growth as is evident from consumption pattern of commercial energy industries (50%) transport (22%) domestic (12%), agriculture (8%).

However, to some extent, these are two important aspects, which are enumerated below, that may help us to find solution to our growing need through their implementation in electricity generation schemes.

1. Instead of major/super power projects, captive power plants (may be upto 25 mw) need to be installed, wherever feasible and it could either be thermal or hydel.

2. In case of thermal power generation, focus has now been slowly shifting from coal based to oil and finally to gas based power plants. The conversion efficiency of gas based power plants is not only higher than the other two sources, but at the same time emission of pollutants is very low.
2.8.2. Other measures

The following additional steps may be taken to encourage use of alternative source:

- Financial assistance to solar houses at lower interest,
- Conservation assistance to existing buildings,
- Demonstration programmes,
- Solar energy funding programme, and
- Tax relief programme.

2.8.3. Incentives

To reduce the burden on fossil fuels and to attract the use of renewable sources of energy, incentives may be offered to:

Producers: Manufacturers, architects, property developers, contractors etc. in the form of funds for R & D purposes, technical assistance and information, loans, tax relief, etc.

Consumers: Private and rental house owners, commercial and institutional consumers in the form of income tax relief, accelerated depreciation, investment credits, subsidies, loans, etc.

2.8.4. Need of the hour

The finite and depleting nature of fossil fuels and increasing demand of energy have serious implications for the whole world. The future energy scenario will be influenced by new discoveries, production techniques, development of new energy sources, economic, geographical and environmental constraints and other factors. It is now established that the renewable sources of energy are abundant on the surface of the earth and have infinite potential for renewal. They will surely meet the future energy demand.

In the developed countries policies and their implementations have already started to exploit renewable sources of energy to reduce the dependence on fossil fuels. Technologies for harnessing energy from the
sunshine, wind, water, oceans, etc. are becoming more and more common. Renewable energy sources, which are available in different forms in developing countries including India, are the potential energy sources for the future development. The Indian Government has already undertaken different projects and policies for harnessing and using these sources. Public awareness and cooperation are necessary for the successful implementation of the programmes. In fact, there are no barriers for using the renewable energy sources and if such barriers exist, they should be tackled through appropriate measures.

2.9. SUMMARY

The sun is a source of all energy on the earth. The solar energy can be harvested either by deriving energy directly from sunlight or indirectly. All the application of solar energy is based on greenhouse effect. The collected solar radiation has been used to heat water, and to provide warm for sprouting seeds and raising flowers and certain vegetables, to heat houses and other buildings, for process - heat application on a small scale, such as cooking, drying and desalinization of waters. The conventional sources of energy resources are gradually getting depleted at a rapid rate all over the world. It is therefore very necessary to conserve energy and steps to be taken for effective energy management.

2.10. KEY WORDS

Solar cooker
The solar cooker is made up of wooden box with double glass sheet on it. It works on principle of greenhouse effect.

Solar desalinization
Conversion of saline water into distilled water using solar energy.

Solar pond
It is a simple device for collecting and storing solar heat. It is designed to reduce convective and evaporative heat losses to the environment so that useful amounts of heat can be collected and stored.
2.11. SELF ASSESSMENT QUESTIONS

1. Describe the solar water heating system.
2. How solar hot water collectors are safeguarded against freezing.
3. Describe the principle of working solar cooker and explain its working in brief.
4. What is the principle of solar pond and explain solar pond system.
5. Enumerate the method of solar desalinization of brine water.
6. What is energy conservation? Suggest the ways to conserve energy.
7. Enumerate the energy management system in India.

2.12. SUGGESTED READING

NATURAL DISASTERS AND ASSESSING HAZARDS

Dr. R. Baskar

STRUCTURE

1.0 Objectives

1.1 Introduction

1.2 Hazard Dimension

1.3 Assessing Hazards and Risk

1.4 Types of Hazards

1.5 Some case studies

1.6 Effects of Hazards

1.7 Vulnerability and Susceptibility

1.8 Assessing Hazards and Risks

1.9 Prediction and Warning

1.10 Response and the Role of Scientists, Public Officials, and Average Citizens

1.11 Summary

1.12 Key words

1.13 Self assessment questions (SAQ)
1.0 OBJECTIVES

The objectives of this unit include understanding

- Natural and technological disasters, classification, causes, prediction and warning of natural hazards.

1.1 INTRODUCTION

Hazard is an inescapable part of life and no one can live in a totally risk – free environment. Risk is sometimes taken as synonymous with hazard but risk has the additional implication of the chance of a particular hazard actually occurring. Therefore a hazard can be defined as a potential threat to humans and their welfare and risk as the probability of hazard occurrence. A disaster can be defined as the realization of the hazard.

We benefit a lot from our Earth and its hospitable climate. However, the Earth can be a dangerous place and our study and understanding of these hazards is very important. The best way to deal with environmental hazards is to predict and prepare. These can be short-term or long-term aspects. The long-term preparations for hazard mitigation are frequently complex and often involve investment of substantial resources. Geology is the study of the Earth and its history. Geologic Processes effect every human on the Earth all of the time, but are most noticeable when they cause loss of life or property. Such life or property threatening processes is called natural hazards. If the process that poses the hazard occurs and destroys human life or property, the natural disaster has occurred. The different types of natural catastrophes include: earthquakes, volcanic eruptions, pyroclastic flows, mudflows, ashfalls, floods, landslides, severe weather conditions like tornadoes, cyclones and meteorite impacts. Among the natural hazards the possible disasters to be considered are:
All these processes have been operating throughout the Earth’s history, but the processes have become hazardous only because they negatively affect us as human beings. **There would be no natural disasters if it were not for humans. Without humans these are only natural events.**

Risk is characteristic of the relationship between humans and geologic processes. We all take risks everyday. The risk from natural hazards, while it cannot be eliminated, can, in some cases be understood in such a way that we can minimize the hazard to humans, and thus minimize the risk. To do this, we need to understand something about the processes that operate, and understand the energy required for the process. Then, we can develop an action to take to minimize the risk. This is called **hazard mitigation.**

Although humans can sometimes influence natural disasters other disasters that are directly generated by humans, such as oil and toxic material spills, pollution, massive automobile or train wrecks, airplane crashes, and human induced explosions, are considered technological disasters.

- Some of the questions to be answered for each natural disaster are given below:
  - Where and why is each type of hazard likely to occur?
  - How often do these hazards develop into disasters?
  - How can each type of disaster be predicted and controlled?

1.2 HAZARD DIMENSION
The impact of a disastrous event is in part a function of its magnitude (amount of energy released) and frequency (recurrence interval) but it is influenced by many other factors including climate, geology, vegetation, population and land use. In general the frequency of such an event is inversely related to the magnitude. Small earthquakes for example occur more often than do large ones. The magnitude concept is the assertion that there is generally an inverse relationship between the magnitude of an event and its frequency. In other words the larger the flood, the less frequently the flood occurs. The concept also includes the idea that much of the work of, forming the earth’s surface is done by events of moderate magnitude and frequency rather than common processes with low magnitude and high frequency or extreme events of high magnitude and low frequency.

1.3 ASSESSING HAZARDS AND RISK

Processes that have been operating since the origin of the Earth produce natural disasters. Such processes are beneficial to us as humans because they are responsible for things that make the Earth a habitable planet for life. For example, throughout the Earth’s history, volcanism has been responsible for producing much of the water present on the Earth's surface, and for producing the atmosphere. Earthquakes are one of the processes responsible for the formation of mountain ranges, which help to determine climate zones on the Earth's surface. Erosional processes, including flooding, landslides, and windstorms replenish soil and helps sustain life. These processes are only considered hazardous when they adversely affect humans and their activities.

1.4 TYPES OF HAZARDS

a. Natural Hazards

Natural Hazards can be differentiated into several different categories:

**Geologic Hazards:** They include earthquakes, volcanic eruptions, landslides, avalanches, subsidence, impacts with space objects.

**Hydrological hazards:** They include floods, tsunamis etc.
Atmospheric Hazards: They include hurricanes, tornadoes, droughts, severe thunderstorms, lightening.

Biological Hazards: They include insect infestations, disease, wildfires etc.

Natural Hazards can also be divided into catastrophic hazards, which have devastating consequences to large numbers of people, or have a worldwide effect, such as impacts huge volcanic eruptions, world-wide disease epidemics, and world-wide droughts. Natural hazards can also be divided into rapid onset hazards, such as volcanic eruptions, earthquakes, floods, landslides, severe thunderstorms, etc which form with little warning and strike rapidly. Slow onset hazards, like drought and disease epidemics take years to form.

b. Technological or Anthropogenic Hazards

These are hazards that occur as a result of human interaction with the environment. They include Technological Hazards, which occur due to exposure to hazardous substances, such as radon, mercury, asbestos fibers, and coal dust. They also include other hazards that have formed only through human interaction, such as acid rain, and contamination of the atmosphere or surface waters with harmful substances, as well as the potential for human destruction of the ozone layer and potential global warming.

1.5 SOME CASE STUDIES

The Bhopal disaster

During the early morning of 3rd December, 1984 some 45 tons of highly toxic methyl isocyanate gas leaked from a pesticide factory in the industrial town of Bhopal, India. Union Carbide, a multinational company based in USA had built the factory within 5 Km of the city centre. The dense cloud of gas drifted over an area with a radius of some 7km. Upto 2500 people were killed by cyanide related poisoning with a further 2,00,000 injured. The gas leaked from an underground storage tank where it had been contaminated with water despite the presence of three safety devices at the plant. A subsequent report indicated that the safety devices at the plant
failed through a combination of faulty engineering and inadequate maintenance although the company claimed the cause was sabotage. The repercussions of this event were worldwide.

**The Chernobyl disaster**

During the night of 25-26 April 1986, the world’s worst nuclear accident to date occurred at Chernobyl about 130km north of the city of Kiev, USSR. It was an example of a major transaccidental pollution incident stemming largely from human error. Due to the carelessness of the workers conducting an experiment with the nuclear reactor an explosion occurred and blew the protective slab off the top of the reactor vessel. Lumps of radioactive material were ejected from the reactor and deposited within one km of the plant where they started other fires. The main plume of the radioactive dust and gas was sent into the atmosphere. This plume was rich in fission products and contained iodine-131 and caesium-137 both of which can be readily absorbed by the living tissue. During the efforts to control the release of radioactive material 31 people died, 200 people sustained serious injuries through exposure to over 2000 times the normal annual dose from background levels of radiation. Eventually some 1,35,000 people were evacuated within a 30km radius of the plant. Within two weeks of the accident the radioactive plume circulated over much of the north Western Europe and deposited radioactive materials. An immediate consequence was the contamination of food chain and restrictions on the sale of vegetables, milk and meat. So far it has been difficult to estimate the long term health risk, notably the increase in fatal cancers which can be attributed to the Chernobyl accident.

1.6 EFFECTS OF HAZARDS

Hazardous process of all types can have primary, secondary, and tertiary effects.

**Primary Effects** occur as a result of the process itself. For example water damage due to a flood, building collapse due to an earthquake, landslide, hurricane, or tornado.

**Secondary Effects** occur only because a primary effect has caused them. For example, fires ignited by earthquakes or volcanic eruptions, disruption of electrical power and water service as a result of an earthquake or flood and flooding caused by a landslide moving into a lake or river.
Tertiary Effects are long-term effects that are set off as a result of a primary event. These include loss of habitat due to floods, crop failure caused by a volcanic eruption etc.

1.7 VULNERABILITY AND SUSCEPTIBILITY

Vulnerability refers to not only the possible physical effects of a natural hazard, but the way it affects human life and property. Vulnerability to a given hazard depends on:

- Proximity to a possible hazardous event
- Population density in the area proximal to the event
- Scientific understanding of the hazard
- Public education and awareness of the hazard
- Existence or non-existence of early-warning systems and lines of communication
- Availability and readiness of emergency infrastructure
- Construction styles and building codes
- Cultural factors that influence public response to warnings

In general, less developed countries are more vulnerable to natural hazards than are industrialized countries because of lack of understanding, education, infrastructure, building codes, etc. Poverty also plays a role - since poverty leads to poor building structure, increased population density, and lack of communication and infrastructure.

Human intervention in natural processes can also increase vulnerability by

1. Development and habitation of lands susceptible to hazards, For example, building on floodplains subject to floods, sea cliffs subject to landslides, coastlines subject to hurricanes and floods, or volcanic slopes subject to volcanic eruptions.

2. Increasing the severity or frequency of a natural hazard. For example: overgrazing or deforestation leading to more severe erosion (floods, landslides), mining groundwater leading to subsidence, construction of roads on unstable slopes leading to landslides, or even contributing to global warming, leading to more severe storms. Affluence can also play a role, since affluence often controls where habitation takes place, for example along coastlines, on volcanic slopes.
1.8 ASSESSING HAZARDS AND RISKS

a) **Hazard Assessment** consists of determining the following

- When and where hazardous processes have occurred in the past.
- The severity of the physical effects of past hazardous processes (magnitude).
- The frequency of occurrence of hazardous processes.
- The likely effects of a process of a given magnitude if it were to occur now.
- Making all this information available in a form useful to planners and public officials responsible for making decisions in event of a disaster.

b) **Risk Assessment** involves not only the assessment of hazards from a scientific point of view, but also the socio-economic impacts of a hazardous event. Risk is a statement of probability that an event will cause x amount of damage, or a statement of the economic impact in monetary terms that an event will cause. Risk assessment involves

- hazard assessment, as above,
- location of buildings, highways, and other infrastructure in the areas subject to hazards
- potential exposure to the physical effects of a hazardous situation
- the vulnerability of the community when subjected to the physical effects of the event

Risk assessment aids decision makers and scientists to compare and evaluate potential hazards, set priorities on what kinds of mitigation are possible, and set priorities on where to focus resources.

1.9 PREDICTION AND WARNING

Risk and vulnerability can sometimes be reduced if there is an adequate means of predicting a hazardous event.

**Prediction**
This involves a statement of probability that an event will occur based on scientific observations. This usually involves monitoring of the process in order to identify some kind of precursor event that may be known to lead to a more devastating event.

Some Examples:

Hurricanes are known to pass through several stages of development: tropical depression - tropical storm - hurricane. Once a tropical depression is identified, monitoring allows meteorologists to predict how long the development will take and the eventual path of the storm.

Volcanic eruptions are usually preceded by a sudden increase in the number of earthquakes immediately below the volcano and changes in the chemical composition of the gases emitted from a volcanic vent. If these are closely monitored, volcanic eruptions can be often being predicted with reasonable accuracy.

Forecasting

In the prediction of floods, hurricanes, and other weather related phenomena the word forecast refers to short-term prediction in terms of the magnitude, location, date, and time of an event. Most of us are familiar with weather forecasts.

In the prediction of earthquakes, the word forecast is used in a much less precise way - referring to a long-term probability that is not specific in terms of the exact time that the event will occur. For example: Prior to the October 17 1989 Loma Prieta Earthquake the U.S. Geological Survey had forecast a 50% probability that a large earthquake would occur in this area within the next 30 years. Even after the event, the current forecast is for a 67% probability that a major earthquake will occur in this area in the next 30 years.

Early Warning
A warning is a statement that a high probability of a hazardous event will occur, based on a prediction or forecast. The effectiveness of a warning depends on:

- The timeliness of the warning
- Effective communications and public information systems to inform the general public of the predicted danger.
- The credibility of the sources from which the warning came.

If warnings are issued too late, or if there is no means of disseminating the information, then there will not be time enough or responsiveness to the warning. If warnings are issued irresponsibly without credible data or sources, then they will likely be ignored. Thus, the people responsible for taking action in the event of a potential disaster will not respond.

1.10 RESPONSE AND THE ROLE OF SCIENTISTS, PUBLIC OFFICIALS, AND AVERAGE CITIZENS

Everyone has a responsibility to understand the effects of a natural hazard and respond to assessments, predictions, and warnings. Thus, one of the most important aspects of disaster management and planning is education.

Responsibilities of Scientists and Engineers

- Hazard Assessment. Scientists have the greatest ability to determine where natural hazards exist, and the effects of such hazards when an event occurs.

- Prediction. Scientists have access to monitoring of processes that enable prediction. They should be able to communicate probabilities to appropriate public officials for dissemination to the general public.

- Reduction of Risk. Scientists and engineers should make information known to public officials about ways to reduce vulnerability and risk, by suggesting zoning regulations and building codes to public officials.
Early Warning - Scientists with access to monitoring and hazard information should help develop early warning systems to effectively communicate such warnings to Public Officials responsible for communicating the warning to the general public.

Communication - Scientists need to be able to present the information available in form that is understandable to all concerned.

Responsibilities of Public Officials

Risk Assessment- Public Officials need to understand hazard assessments and develop risk assessments. Decide where and how resources are to be expended to minimize risk.

Planning and Code Enforcement - Public officials need to work with scientists and engineers to help reduce vulnerability by making planning decisions and building codes that help reduce risk and vulnerability.

Early Warning - Public officials have the primary responsibility to inform the public about imminent dangers based on predictions and warnings issued by scientific community.

Response - Public officials have the primary responsibility of maintaining an infrastructure that can deal with the emergencies created by a natural disaster. Need to develop plans for evacuation, emergency response, rescue, and recovery.

Communication - Public officials must be able to communicate effectively with scientific community and the general public to disseminate information.

Responsibilities of the Citizens

Understanding of Hazards – The public need to be aware of the effects of natural hazards on their communities and should have some understanding of what might occur in the event of a disaster.
Understanding of Early Warning Systems – The general public should be informed about what their response should be when a warning is issued.

Communication - We can communicate with public officials to effectively carry out their responsibilities for hazard and risk reduction.

1.11 SUMMARY

Hazard is a part of life and no one can live in a risk free environment. A hazard is defined as a potential threat to humans and their welfare and risk as the probability of hazard occurrence. Each hazard varies in dimensions and assessing hazards and risks is the first important step. They can be classified as natural (geologic hazards, hydrological hazards, atmospheric hazards and biological hazards) and technological hazards.

1.12 KEY WORDS

**Hazard** - A hazard can be defined as a potential threat to humans and their welfare.

**Natural hazards** - Geologic processes affect every human on the Earth all the time, but are most noticeable when they cause loss of life or property. Such life or property threatening processes is called natural hazards.

**Technological hazards** - They are hazards that occur as a result of human interaction with the environment. For example due to exposure to hazardous substances like radon, mercury, asbestos fibers, and coal dust.

1.13 SELF ASSESSMENT QUESTIONS (SAQ)

1. What are the different types of hazards?
2. Can some natural hazards be predicted? If so, what basic steps can be taken to protect the public?
1.14 SUGGESTED READINGS


2.0 OBJECTIVES

2.1 INTRODUCTION

2.2 CLASSIFICATION OF EARTHQUAKES

2.2.1 Examples of some significant earthquakes:

2.2.2 Some examples of human induced earthquakes

2.2.3 Seismology

2.2.4 Architecture and Building Codes

2.2.5 Seismic Hazard and Risk Mapping

2.2.6 Hazards Associated with Earthquakes

2.2.7 World Distribution of Earthquakes

2.2.8 Types of earthquakes

2.2.8.1 Tectonic Earthquakes

2.2.8.2 Volcanic Earthquakes

2.2.9 Earthquake Prediction and Control

2.2.10 Controlling Earthquakes

2.3 VOLCANOES

2.3.1 Eruption Prediction and Hazard Mitigation

2.4 CYCLONE HAZARDS AND DISASTERS

2.4.1 Severity of the cyclones - Categories
2.4.2 THE BIRTH OF A CYCLONE

2.4.3 CYCLONE BEHAVIOUR AND WARNING TIME

2.5 FLOOD HAZARDS AND DISASTERS

2.5.1 Flood Control

2.5.2 Flood Prediction

2.6 LANDSLIDES

2.6.1 Predicting Mass Movements

2.6.2 Prevention and Mitigation of Mass Movements

2.6.3 Effects of Landslides

2.7 SUMMARY

2.8 KEY WORDS:

2.9 SELF ASSESSMENT QUESTIONS (SAQ)

2.10 SUGGESTED READINGS

2.0 OBJECTIVES
After studying this unit the student will be able to understand:

- Causes, effects and some control measures of some important natural hazards like earthquakes, volcanic eruptions, floods, cyclones and landslides.

2.1 INTRODUCTION

It is said, "Earthquakes don't kill people, but buildings do". This is because buildings or other human construction falling down during an earthquake causes most deaths from earthquakes. Earthquakes occur when energy stored in elastically strained rocks is suddenly released. This release of energy causes intense ground shaking in the area near the source of the earthquake and sends waves of elastic energy, called seismic waves, throughout the Earth. Earthquakes can be generated by bomb blasts, volcanic eruptions, and sudden slippage along faults. Earthquakes are definitely a geologic hazard for those living in earthquake prone areas, but the seismic waves generated by earthquakes are invaluable for studying the interior of the Earth. An earthquake located in isolated areas far from human population rarely causes any damage or deaths. Thus, earthquake hazard risk depends on the following factors:

1. Population density
2. Construction standards (building codes)
3. Emergency preparedness

An earthquake can be compared to the effect observed when a stone is thrown into water. After the stone hits the water a series of concentric waves will move outwards from the center. The same nature of events occurs in an earthquake. There is a sudden movement within the crust or mantle, and concentric shock waves move out from that point.

2.2 Classification of earthquakes

Earthquakes are almost always classified according to their origin. Therefore they are most often referred to as tectonic hazards as they are caused by the movements of the plates of the earth’s crust known as tectonic activity. Mini earthquakes can be caused by other ways, often due to volcanic activity or by human activity. If volcanic activity is the cause then the earthquake is still classified as a tectonic hazard, volcanoes are also tectonic phenomena. Humans can induce earthquakes through a variety of activities, such as the filling of new reservoirs, the underground detonation of atomic explosives, or the pumping of fluids deep into the Earth through wells. Earthquakes are three-dimensional events, the waves move outwards from the focus, but can travel in both the horizontal and vertical plains. This produces three different types of waves, which have their own distinct characteristics and can only move through certain layers within the Earth.

2.2.1 Examples of some significant earthquakes:

- Worst earthquake in recorded history occurred in 1556 in Shaaxi, China. Killed 830,000 people, most living in caves excavated in poorly consolidated loess (wind deposited silt and clay).
- Worst earthquake in this century also occurred in China (T'ang Shan Province), killed 240,000 in 1976. Occurred at 3:42 AM, Magnitude 7.8 Earthquake and magnitude 7.1 aftershock. Deaths were due to collapse of masonry (brick) buildings.
- Contrast - In earthquake prone areas like California, in order to reduce earthquake risk, there are strict building codes requiring the design and construction of buildings and other structures that will withstand a large earthquake. While this program is not always completely successful, one fact stands out to prove its effectiveness. In 1989 an earthquake near San Francisco, California (The Loma Prieta, or World Series Earthquake) with a Richter Magnitude of 7.1 killed about 62 people. Most were killed when a double-decked freeway in Oakland collapsed. About 10 months later, an earthquake with magnitude 6.9 occurred in Armenia, where no earthquake-proof building codes existed. The death toll in the latter earthquake was about 2500. Computer simulations for large cities, like San Francisco or Los Angeles, California, indicate that a magnitude >8.0 earthquake would cause between 3,000 and 13,000 deaths.
2.2.2 Some examples of human induced earthquakes

- For ten years after construction of the Hoover Dam in Nevada blocking the Colorado River to produce Lake Mead, over 600 earthquakes occurred, one with magnitude of 5 and 2 with magnitudes of 4.
- In the late 1960s toxic waste injected into hazardous waste disposal wells at Rocky Flats, near Denver apparently caused earthquakes to occur in a previously earthquake quiet area. The focal depths of the quakes ranged between 4 and 8 km, just below the 3.8 km-deep wells.
- Nuclear testing in Nevada set off thousands of aftershocks after the explosion of a 6.3 magnitude equivalent underground nuclear test. The largest aftershocks were about magnitude 5.

In the first two examples, the increased seismicity was apparently due to increasing fluid pressure in the rocks, which resulted in re-activating older faults, by increasing strain.

2.2.3 Seismology

When an earthquake occurs, the elastic energy is released sending out vibrations that travel throughout the Earth. These vibrations are called seismic waves. The study of how seismic waves behave in the Earth is called seismology.

Seismograms - Seismic waves travel through the Earth as vibrations. A seismometer is an instrument used to record these vibrations, and the resulting graph that shows the vibrations is called a seismogram. The seismometer must be able to move with the vibrations, yet part of it must remain nearly stationary.

The source of an earthquake is called the focus, which is an exact location within the Earth were seismic waves are generated by sudden release of stored elastic energy. The epicenter is the point on the surface of the Earth directly above the focus.

Magnitude of Earthquakes - The size of an earthquake is usually given in terms of a scale called the Richter Magnitude. Richter Magnitude is a scale of earthquake size developed by a seismologist named Charles Richter. The Richter Magnitude involves measuring the amplitude (height) of the largest recorded wave at a specific distance from the earthquake.
It usually takes more than one seismographic station to calculate the magnitude of an earthquake. Thus you will hear initial estimates of earthquake magnitude immediately after an earthquake and a final assigned magnitude for the same earthquake that may differ from initial estimates, but is assigned after seismologists have had time to evaluate the data from numerous seismographic stations.

2.2.4 Architecture and Building Codes

While architecture and building codes can reduce risk, it should be noted that not all kinds of behavior could be predicted.

- Although codes are refined each year, not all possible effects can be anticipated. For example different earthquakes show different frequencies of ground shaking, different durations of ground shaking, and different vertical and horizontal ground accelerations.
- Old buildings cannot cost-effectively be brought up to code, especially with yearly refinements to code.
- Even with construction to earthquake code, buildings fail for other reasons, like poor quality materials, poor workmanship, etc. that are not discovered until after an earthquake.

2.2.5 Seismic Hazard and Risk Mapping

The risk that an earthquake will occur close to where you live depends on whether or not tectonic activity that causes deformation is occurring within the crust of that area.

- Another way of looking at seismic risk that is more useful to construction designers and engineers, and therefore to the development of building codes, is based on expected horizontal ground acceleration. Acceleration is measured relative to the acceleration due to gravity \((g = 980 \text{ cm/sec}^2)\). Ground accelerations of \(0.1g\) are considered able to cause damage.

2.2.6 Hazards Associated with Earthquakes

Possible hazards from earthquakes can be classified as follows:

**Ground Motion** - Shaking of the ground caused by the passage of seismic waves, especially surface waves, near the epicenter of the earthquake are responsible for the most damage during an earthquake. The intensity of ground shaking depends on:

- Local geologic conditions in the area. In general, loose unconsolidated sediment is subject to more intense shaking than solid bedrock.
- Size of the Earthquake. In general, the larger the earthquake, the more intense is the shaking and the duration of the shaking.
- Distance from the Epicenter. Shaking is most severe near the epicenter and drops off away from the epicenter. The distance factor depends on the type of material
underlying the area. Damage to structures from shaking depends on the type of construction.

- Concrete and masonry structures are brittle and thus more susceptible to damage.
- Wood and steel structures are more flexible and thus less susceptible to damage.

**Faulting and Ground Rupture** - Ground rupture generally occurs only along the fault zone that moves during the earthquake. Thus structures that are built across fault zones may collapse, whereas structures built adjacent to, but not crossing the fault may survive.

**Aftershocks** - These are usually smaller earthquakes that occur after a main earthquake, and in most cases there are many of these (1260 were measured after the 1964 Alaskan Earthquake). Aftershocks occur because the main earthquake changes the stress pattern in areas around the epicenter, and the crust must adjust to these changes. Aftershocks are very dangerous because they cause further collapse of structures damaged by the main shock.

**Fire** - Fire is a secondary effect of earthquakes. Because power lines may be knocked down and because natural gas lines may rupture due to an earthquake, fires are often started closely following an earthquake. The problem is compounded if water lines are also broken during the earthquake since there will not be a supply of water to extinguish the fires once they have started. In the 1906 earthquake in San Francisco more than 90% of the damage to buildings was caused by fire.

**Landslides** - In mountainous regions subjected to earthquakes ground shaking may trigger landslides, rock and debris falls, rock and debris slides, slumps, and debris avalanches.

**Flooding** - Flooding is a secondary effect that may occur due to rupture of human made dams, due to tsunamis, and as a result of ground subsidence after an earthquake.

### 2.2.7 World Distribution of Earthquakes

The distribution of earthquakes is called *seismicity*. Seismicity is highest along relatively narrow belts that coincide with plate boundaries. This makes sense, since plate boundaries are zones along which lithospheric plates move relative to one another. They can be divided into shallow focus earthquakes that have focal depths less than about 100 km and deep focus earthquakes that have focal depths between 100 and 700 km.

### 2.2.8 Types of earthquakes

#### 2.2.8.1 Tectonic Earthquakes

The theory of plate tectonics explains how the crust of the Earth is made of several plates, large areas of crust that float on the Mantle. Tectonic earthquakes are triggered when the crust becomes subjected to strain, and eventually moves. Since the tectonic plates are free to slowly move, they can either drift towards each other, away from each other or slide past
each other. Major earthquakes are sometimes preceded by a period of changed activity. This might take the form of more frequent minor shocks as the rocks begin to move, called *foreshocks*, or a period of less frequent shocks as the two rock masses temporarily 'stick' and become locked together. Detailed surveys in San Francisco have shown that railway lines, fences and other longitudinal features very slowly become deformed as the pressure builds up in the rocks, then become noticeably offset when a movement occurs along the fault. Following the main shock, there may be further movements, called *aftershocks*, which occur as the rock masses 'settle down' in their new positions.

### 2.2.8.2 Volcanic Earthquakes

Volcanic earthquakes are triggered by the explosive eruption of a volcano. Given that not all volcanoes are prone to violent eruption, and that most are 'quiet' for the majority of the time, it is not surprising to find that they are comparatively rare. When a volcano explodes, it is likely that the associated earthquake effects will be confined to an area 10 to 20 miles around its base, whereas a tectonic earthquake may be felt around the globe. The volcanoes, which are most likely to explode violently, are those, which produce *acidic* lava. Acidic lava cools and sets very quickly upon contact with the air. This tends to choke the volcanic vent and block the further escape of pressure.

### 2.2.9 Earthquake Prediction and Control

#### Long-Term Forecasting

Long-term forecasting is based mainly on the knowledge of when and where earthquakes have occurred in the past. Thus, knowledge of present tectonic setting, historical records, and geological records are studied to determine locations and recurrence intervals of earthquakes. Two aspects of this are important.

- **Paleoseismology** - the study of prehistoric earthquakes.
- **Seismic gaps** - A seismic gap is a zone along a tectonically active area where no earthquakes have occurred recently, but it is known that elastic strain is building in the rocks. If a seismic gap can be identified, then it might be an area expected to have a large earthquake in the near future.

#### Short-Term Prediction

- Short-term prediction involves monitoring of processes that occur in the vicinity of earthquake prone faults for activity that signify a coming earthquake.
- Anomalous events or processes that may precede an earthquake are called *precursor events* and might signal a coming earthquake.
- Despite the array of possible precursor events that are possible to monitor, successful short-term earthquake prediction has so far been difficult to obtain.

This is likely because the processes that cause earthquakes occur deep beneath the surface and are difficult to monitor. Earthquakes in different regions or along
different faults all behave differently, thus no consistent patterns have so far been recognized. Among the precursor events that may be important are the following:

- **Ground Uplift and Tilting** - Measurements taken in the vicinity of active faults sometimes show that prior to an earthquake the ground is uplifted or tilts due to the swelling of rocks caused by strain building on the fault. This may lead to the formation of numerous small cracks (called microcracks). This cracking in the rocks may lead to small earthquakes called foreshocks.

- **Foreshocks** - Prior to a 1975 earthquake in China, the observation of numerous foreshocks led to successful prediction of an earthquake and evacuation of the city of the Haicheng. The magnitude 7.3 earthquake that occurred, destroyed half of the city of about 100 million inhabitants, but resulted in only a few hundred deaths because of the successful evacuation..

- **Water Level in Wells** - As rocks become strained in the vicinity of a fault, changes in pressure of the groundwater (water existing in the pore spaces and fractures in rocks) occur. This may force the groundwater to move to higher or lower elevations, causing changes in the water levels in wells.

- **Radon Gas Emission** – Radon, an inert gas produced by the radioactive decay of uranium and other elements in rocks. Because Radon is inert, it does not combine with other elements to form compounds, and thus remains in a crystal structure until some event forces it out. Deformation resulting from strain may force the Radon out and lead to emissions of Radon that show up in well water. The newly formed microcracks discussed above could serve as pathways for the Radon to escape into groundwater. Increases in the amount of radon emissions have been reported prior to some earthquakes.

- **Changes in the Electrical Resistivity of Rocks** - Electrical resistivity are the resistance to the flow of electric current. In general rocks are poor conductors of electricity, but water is more efficient a conducting electricity. If microcracks develop and groundwater is forced into the cracks, this may cause the electrical resistivity to decrease (causing the electrical conductivity to increase). In some cases a 5-10% drop in electrical resistivity has been observed prior to an earthquake.

- **Unusual Radio Waves** - Just prior to the Loma Prieta Earthquake of 1989, some researchers reported observing unusual radio waves. Where these were generated and why, is not yet known, but research is continuing.

- **Strange Animal Behavior** - Prior to magnitude 7.4 earthquakes in Tanjin, China, zookeepers reported unusual animal behavior. Snakes refusing to go into their holes, swans refusing to go near water, pandas screaming, etc. This was the first systematic study of this phenomenon prior to an earthquake.

### 2.2.10 Controlling Earthquakes

Although no attempts have yet been made to control earthquakes, earthquakes have been known to be induced by human interaction with the Earth, which suggests that in the future earthquake control may be possible.
2.3 VOLCANOES

Volcanoes are openings in the surface of the earth from which molten rock; magma and gases escape, which consists of a fissure in, the earth’s crust above, which a cone of volcanic material has, accumulates. At the top of the cone, is a bowl shaped vent called a crater (Fig 1). The cone is formed by the deposition of molten or solid material that flows or is ejected through the vent from the interior of the earth. The most famous type of volcano is the type typically shaped like a triangle, known as a Composite volcano. A volcano erupts when pressure from gasses and steam within the magma build up to sufficient pressure to fracture the surface, or layer of solid rock above them, allowing lava to flow onto the earth's surface.

If the lava is acidic and rich in silica it will harden and set quickly, moving only short distances from its source. It will form the typical volcano shape, a steep sided cone. Such volcanoes erupt violently because the rapidly hardened rock blocks the vents and allows pressure to build up under the blockage. When it finally fractures the blockage, the release of pressure can be likened to taking the lid off a bottle of fizzy drink that's been well shaken. Such volcanoes are called Composite Volcanoes. Examples are Mount Etna in Sicily, Mount St. Helens in the USA and Mount Vesuvius in Italy. If it is a basic lava, low in silica but rich in iron, it flows freely and sets slowly. This allows it to flow long distances from its source, forming layers of gently sloping lava. Such volcanoes are called Shield Volcanoes, and are typical of areas such as Hawaii.

Composite, or stratovolcanoes, are typically steep sided and may be created over many thousands of years - possibly hundreds of thousands of years - and dozens of eruptions. They are slowly built up by the repeated eruption of lava flows, pyroclastic flows and ash, forming a cone shape with steep sides and a crater at the top.

All volcanic eruptions, whether they involve arc, rift or hotspot volcanoes, clearly deliver material from the interior to the surface. The extruded rocks build up mountains, islands, and lava flows, some of which have added to the size of continents. The gases and volatiles brought up to the surface have built up the atmosphere and oceans. From the amount of certain elements in the current atmosphere, such as Neon, we are confident that the Earth that accreted had no initial atmosphere, which must have boiled off during the heavy bombardments and magma ocean phase. Thus, all of the present atmosphere and oceans have come from the interior (apart from minor additions from infalling comets). Looking at how volatiles come out of the ground today, we are convinced that volcanoes are now, and presumably have always been the main sources of gas transfer from the interior to the surface. The current atmosphere is 79% nitrogen and 21% oxygen, with traces of water and other materials. Nitrogen is being released at many volcanoes today, and fortunately the Earth is warm enough that nitrogen has not combined with hydrogen in the Earth's atmosphere to condense out as ammonia (as appears to be the case on the major gas-planets such as Jupiter). While free oxygen is not coming out of volcanoes, carbon dioxide does, and plant respiration is responsible for the conversion to an oxygen atmosphere.
We can test the gases coming out of volcanoes today to see if it is consistent with what is found in the atmosphere. Volcanic gas samples reveal large amounts of water (H$_2$O), carbon dioxide (CO$_2$) and Nitrogen (N$_2$) coming out today, along with smaller amounts of sulfur dioxide (SO$_2$), Hydrogen sulfide (H$_2$S), carbon monoxide (CO), Hydrogen (H$_2$), hydrochloric acid (HCl), and Methane (CH$_4$). If we take the current rate at which these gases are emerging, and calculate the cumulative volumes over the history of the planet, we can only account for about 25% of the total water, chlorine, and nitrogen at the surface. This implies that if volcanism has always been the main source of atmospheric gases, there must have been more intensive volcanism, and perhaps larger gas fluxes in the past.

In addition to the gases that come out of volcanoes, there are large amounts of solid materials ejected, typically the smaller particles of dust reach the highest levels in the atmosphere. For strong vertical eruptions, dust can be propelled up into the stratosphere, above 17 kilometers. Once there, the suspended dust particles can block solar radiation, effectively heating up the stratosphere while the lower troposphere cools.

One of the most obvious aspects of volcanism is that it involves heat, and this energy source is inviting to tap. In the past few decades there have been numerous attempts to exploit the geothermal energy.

Another benefit of volcanic systems is that minerals and ores are concentrated near them. Water that emerges from or interacts with a magma body tends to be enriched in materials such as Fe, S, Zn, Cu, Pb, U, Au, Ag, Hg. These materials can precipitate out as the water circulates through the crust and cools in hydrothermal veins. This has given rise to major ore deposits.

2.3.1 Eruption Prediction and Hazard Mitigation

As for earthquakes, the societal response to natural hazards posed by volcanoes is couched in terms of the specific hazards that they present, as well as the viable options for dealing with the phenomena. We'll consider some of the specific hazards associated with each, and discuss the mitigation strategies that have evolved.

Some of the major volcanic hazards are:

1) Primary: Lava, Ash, Nuee Ardentes, Gas

2) Secondary: Lahars, Tsunami, Agricultural.

Lava flows are usually not very dangerous, as they move rather slowly. But, there are exceptions. For example, the 1977 Nyiragongo (Zaire) volcano had a side fissure drain the lava lake in the main crater very rapidly, with lava squirting out at 60 miles per hour. This caused 1000 fatalities. Hawaii has had relatively rapid flows run into developed areas, but usually evacuation is possible.
Ash falls are typified by the 79 AD eruption of Mt. Vesuvius, which blanketed Pompeii and Herculaneum with mud ash and gas, causing about 20,000 fatalities. The main U.S. concern is over the downwind (easterly) deposit of ash from Cascade volcanoes, as occurred in 1980 for Mt. St. Helens.

Nuee Ardente are fast moving flows of gas and magma, in a volcanic avalanche. These are very deadly, as they flow fast and with utter destruction. Examples include the 1902 eruption of La Soufriere, St. Vincent, which killed 1500, and the 1902 eruption of Mt. Pelee, Martinique, when the town of St. Pierre was overrun, killing 30,000 (leaving only 2 survivors in jail).

Gas emissions accompany every volcano, but in some cases there are special conditions that allow the gasses to build up. The 1783 eruption of Mt. Laki, Iceland had a massive flux of sulfuric acid and fluorine gas, which killed great numbers of livestock. The ensuing famine led to 10,000 fatalities. The 1986 Lake Nios, Cameroon event involved an overturn of CO$_2$ that had accumulated at the base of a lake in the crater. Over 1500 people were asphyxiated by the gas cloud that bubbled forth.

Lahars are volcanic mudflows, typically resulting from eruption under ice and snow at the summit, which mixes with the ash to make fast flowing muds. Tsunamis occur when eruptions displace ocean water. Agricultural catastrophes are secondary consequences of the widespread devastation of volcanic eruptions. These hazards are varied and clearly not easily controlled. Indeed it is a basic fact that we cannot do much to limit damage from volcanic hazards by better construction methods and the like. The emphasis is on prediction of the event so that evacuation can save lives.

Volcanic prediction is difficult, but in many ways it is more viable than for earthquakes. The major difficulty is that every volcano has distinctive behavior, which must be characterized case by case. This is challenging because of the long period of repose between explosions.

Most volcanic predictions are based on various phenomena:

1. Statistical behavior of that volcano
2. Earthquake activity, often tracking the ascent of magma
3. Ground deformation
4. Changes in temperature of the gases and lava pool
5. Changes in chemistry of the gas

For some volcanoes, the statistical behavior can be characterized if there is a history of 10-20 eruptive sequences. This is an empirical approach, as there is no simple physical theory for the eruptive cycle. Statistical methods give gross probabilities, but not short-time prediction. Individual volcanoes differ in the reliability of earthquake precursors, and again each volcano must be characterized.
Inflation of the magma chamber below the volcano causes tilting and uplift of the surface which can be measured. This is the direct result of ascent of magma and build-up of gas pressure. There are many instances of successful prediction of major eruptions. The U.S. has set up a hierarchy of volcano warning levels:

1. Notice of Potential Hazard
2. Hazard Watch - A indefinite state of observation
3. Hazard Warning - Specific time, location, explosion size given

2.4 CYCLONE HAZARDS AND DISASTERS

Tropical cyclones or hurricanes in North America, typhoons in Asia are like giant whirlwinds of air and dense cloud spiraling at over 120 km/h around a central ‘eye’ of extreme low pressure.

2.4.1 Severity of the cyclones - Categories - They range from ‘1’ for weak cyclones (strongest wind gusts less than 125 km/h), through ‘2’ (125-169 km/h), ‘3’ (170-224 km/h), ‘4’ (225-279 km/h), to ‘5’ for the most severe cyclones (wind gusts more than 280 km/h).

Effects of cyclones - Cyclones approach from the sea bringing with them torrential rains, extreme winds and sometimes storm surges. Damage caused by each cyclone varies widely depending on its path, but can include buildings, crops and boats at sea. Most deaths from cyclones occur as a result of drownings (both at sea and during floods), collapsed buildings, or debris, which become lethal projectiles carried along by the extreme winds.

2.4.2 THE BIRTH OF A CYCLONE

Cyclone genesis is favoured by the following conditions:

- Sea-surface temperatures warmer than 26°C
- Strong low-level cyclonic relative vorticity
- Deep convection over a large area of ocean
- A reasonably large coriolis force to allow an organized circulation to develop
- High relative humidity from the surface upward to above six kilometres
- Spiraling winds at low levels and divergent winds aloft, occurring simultaneously

The ‘life-cycle’ of the average tropical cyclone (or hurricane/typhoon) is about seven days but can extend to over three weeks. They form in the atmosphere over warm ocean areas with at least 26°C water temperature (mainly in latitudes 5° to 20° north or south) although their exact trigger-mechanism is not fully understood. If conditions are right, an ordinary tropical depression, or ‘low’ can develop into a tropical cyclone.
The Central ‘Eye’

Cyclones vary greatly in character but the one feature they all have in common is a virtually calm centre with clear sky. This centre, or ‘eye’ is generally about 16 - 30 km across, but even this can range from 10 - 100 km. Around this eye are bands of heavy cloud, associated with the moist air, which spirals in towards the centre of the cyclone. These clouds, known as the ‘eye wall’, may be 15 km high and mark the ring of strongest winds and heaviest rainfall.

2.4.3 CYCLONE BEHAVIOUR AND WARNING TIME

Can be predicted that they are coming, but the path of the cyclone is often a mystery. Cyclones may exist for a few days, to over three weeks! They may move forward, double-back, stay motionless for periods, or move in circles, and therefore need to be tracked carefully by weather observers. If they reach land, the friction of the earth and the loss of sustaining heat energy from the ocean, cause cyclones to ‘fill’ and drop most of their rain. As cyclones move forward at only 15 - 25 km/h, there is usually sufficient warning time for people to prepare for their onset.

Lethal Energy

Tropical cyclones are the greatest storms on earth, releasing in one day as much condensation heat energy as up to four hundred, 20-megaton atomic bombs. Every cyclone is dangerous and must be regarded as a real threat until the danger has clearly passed. Where tropical cyclones are concerned, because of their erratic paths, there is no such thing as a ‘false-alarm’ - the community which has been by-passed by a cyclone knows it has been lucky this time. It is important for people in cyclone areas to be aware that if the ‘eye’ of the cyclone passes over them, there will be a sudden lull in wind and clearing of skies, which may last anywhere from a few minutes to an hour or two. Then the other side of the cyclone will strike and the winds will resume with equal strength, but blowing from the opposite direction. It is, therefore, most important that people should remain in shelter during and after the passing of the ‘eye’.

STORM SURGE

One other effect of a cyclone is that it can produce a storm surge (or tide). A storm surge may be caused by cyclonic winds blowing across the water and a fall in atmospheric pressure. The lower pressure at the eye of the cyclone actually allows a sea-level rise in, and close to, that centre. This raised dome of water is usually 60-80 km across and 2 to 5 metres higher than normal sea-level. As a cyclone nears the coast, low-lying areas may suffer flooding because strong on-shore winds have displaced the storm surge ahead of the cyclone’s centre. The amount of flooding that occurs depends very much on the height of the tide when the cyclone crosses the coast. If the tide is fairly low, flooding may not occur. The people sheltering in low-lying coastal areas are potentially more at risk from a storm surge than from cyclonic winds, and should listen for storm surge (or
tide) warnings. If a storm surge coincides with a high tide, massive flooding and additional destruction is likely to occur.

2.5 FLOOD HAZARDS AND DISASTERS

Floods occur when water covers land, which is normally dry. They may result from prolonged or very heavy rainfall, severe thunderstorms; monsoon (wet season) rains in the tropics, or tropical cyclones. Other, less common causes include snow-melt, dam failure, or storm surge and tsunami - both involving rapid seawater flooding. Floods arising from heavy rainfall are regular events, but the greatest floods have involved collapses of natural dams and the draining of lakes in truly catastrophic floods unlike any witnessed in modern human history.

People who live near rivers, or in low-lying coastal areas, live with the greatest threat of floods. Periods of heavy rain, not necessarily in their area, can lead to rises in the water level of streams and rivers to a point where channels can no longer hold the volume of water. Alternatively, for some coastal dwellers, there is the threat from the sea as mentioned above. We now have the general background for understanding river behavior and why rivers flood. Flood control takes the form of levees (both natural and man-made), flood gates, dams, and reservoirs, all designed to minimize the occurrence and/or intensity of a flood.

2.5.1 Flood Control

1. A variety of methods are used to reduce flood flows (flood control) and to minimize the effects of floods (flood mitigation).

2. **Floodways** are areas on the floodplain where no new structures or homes or any kind of development are permitted. Examples include greenway corridors, parks, and even golf courses.

3. **Floodwalls** are reinforced concrete structures parallel to river banks that prevent water from entering further into the floodplain.

4. Dams are not intended to retain all the water that backs up behind it; rather, they control the rate of stream flow, like a large valve. A dam whose sole purpose is flood control is called a flood impoundment dam. Released water flows over a spillway.

5. However, dams also trap sediment in the reservoir that occasionally needs to be dredged out. Also, dams tend to reduce the sediment needed elsewhere, such as beaches, causing a reduction in beach area.

6. Rivers deposit ridges of sediment along their banks during flood events, creating natural levees. Urbanization may remove these levees, and must be replaced artificially by earth embankments or concrete caps over an earthen core.
7. While levees prevent flooding, they also prevent the natural fertilization from floods and also incur a false sense of security.

8. Levees can fail in three ways: (1) overtopping (2) collapse due to saturation, and (3) undermining due to fluid pressure.

9. The city of New Orleans is by far the largest city dependent on levees and a flood control system because the entire city is now below sea level. Therefore it offers an excellent case study. Massive pumping is needed during heavy rain events, and the city is prone to flooding from both the Mississippi River and from the ocean. Think of what a hurricane or even a tropical storm may do to such a low-lying area. To counteract these forces, the Army Corps of Engineers has constructed a series of artificial levees that parallel the Mississippi River. Massive gates in some of the levees remain open for traffic but are closed when floods threaten. A huge spillway exists before the river reaches New Orleans that can be opened in case of flooding.

10. Remember that water bursting through a levee has a greater velocity, and will cause massive damage to areas in front of the levee, sometimes even worse damage than would have resulted from the actual floodwaters! Sometimes, levees are destroyed upstream to protect areas downstream!

11. Finally, channelization is a modification of a stream channel by straightening, clearing, deepening, or lining with concrete or boulders. However, this method creates as many problems! Velocity is increased, vegetation is removed, and the biology is severely disrupted.

Clues to past floods

1. Abundant evidence can be found that provides information on how often a river floods. For example, physical evidence like:
   a. stranded debris such as logs caught in a tree
   b. ripple marks in sand above the current river level
   c. lines of driftwood that parallel the river
   d. trees above the current river level that are bent downstream
   e. erosional surfaces such as scour holes above the current river level.

2. Perhaps look for biologic clues. For example, certain tree species grow only in areas that are periodically flooded. Don't build a house in these areas!

3. Look for geologic evidence. For example, coarse-grained sand and larger particles such as gravel may be deposited during a flood across the floodplain. Sometimes layers of organic material left by floods can be dated using the radiocarbon dating method. This provides information on floods from hundreds, even, thousands, of years ago.
2.5.2 Flood Prediction

1. Previous flood information for a river can be compiled to create a graph that plots discharge for varying recurrence intervals. From this graph, we obtain information on 5, 10, 20, 50, and 100 year floods.

2. Surveys of flood-prone areas can help provide a flood hazard map for an area.

2.6 LANDSLIDES

Landslides usually involve the movement of large amounts of earth, rock, sand or mud, or any combination of these. The other contributory factors include earthquakes, volcanoes, soil saturation from rainfall or seepage, or human activity (ie vegetation removal, construction of roads, railways or buildings on steep terrain). Landslides are simply downslope displacements of regolith, rock, and soil. Because landslides are more than simply "slides" and can also occur under the sea, a better term for these is mass movements. Mass movements are one of the most serious threats in areas with steep slopes.

- Types of Mass Movement

There are different types of landslide landforms. The landforms themselves have different characteristic parts. Some of the features that you should know include the headwall scarp, toe, radial cracks (fissures), transverse cracks (fissures), and rupture, or slip, surface.

- Mass movements downslope fall into three broad categories (Fig 2):
  - falls move through the air and land at the base of a slope
  - slides move along a flat or curved underlying surface
  - flows occur as plastic or liquid movements from water saturation

- The speed of these movements varies. Some mass movements move very slowly and may not be noticeable for years, while others occur extremely fast, moving well over a hundred miles per hour.

- The fall of rock particles through the air from a cliff is called a rockfall. Vibration from earthquakes can trigger rockfall events, but more commonly they occur from frost wedging.

- Slides occur along flat or curved underground surfaces. Rockslides occur along a flat surface, usually when the layers of underlying rock are tilted at an angle, and are especially hazardous along road cuts.
- **Slumps** occur when material slides along a curved surface. A common cause of slumping is **erosion at the base** of the slope, perhaps by water action, a common geohazard in coastal communities. Slumping can also occur when **excessive water** is added to a slope. The steep slope at the head of the slump is called a **scarp**.

- **Flows** are mass movements in which the material acts like a liquid or fluid, and occur in a wide variety of speeds.

- **Creep** is *the very slow downslope displacement of soil and regolith*. Creep occurs on slopes when **frost** lifts the soil then places it further downslope. **Gravity** also acts to pull the upper layers of soil and regolith downslope, causing fences, telephone poles, and even grave markers to be tilted.

- **Solifluction** occurs when the upper layers of soil become saturated and move downslope. This process is more common in very cold climates where **permafrost** forms. During the summer, the upper layer of the permafrost melts, saturating the ground, and causing **solifluction lobes**.

- **Mudflows** are mixtures of water and soil (up to 30% water), and occur where water has saturated the soil to the point the soil becomes a liquid. They're common during short-lived though intense rainstorms. They also occur after forest fires have denuded the vegetation, and also occur around construction sites.

- A **debris flow** is *a very rapid downslope movement of rock debris and regolith*. They often start as slumps or slides, but become debris flows as the material mixes with more water and even air. Experimental studies have shown that debris flows gain their rapid speed because they actually ride on a **cushion of air** as they flow downslope.

- A **debris avalanche** is an extremely rapid downward movement of rock debris, regolith, and soil, more common in areas with steep slopes. The term **avalanche** is generally applied to any type of fast-moving downward movement of any type of material, but is associated with much steeper slopes than debris flows. Such debris avalanches move downslope through **avalanche chutes**.

- A major geohazard occurs when large masses of snow break loose and flow like a liquid. These are **snow avalanches**. Every year, snow avalanches kill many people in the US and in Europe, often due to their own recklessness.

- As snow becomes compacted, it actually releases a little heat due to high pressure and the snow becomes **granular (rounded)**. Those intermediate layer of snow, called a **slip surface**, is much more prone to **slippage** than the overlying layers of snow.

- An avalanche occurs when the accumulated snow causes the **slip surface** to break. Avalanches also occur when vibrations cause the slip surface to fail. These
vibrations can be caused by an earthquake, by noise from a snow cannon, by skiers, and by snowmobiles.

• The snow rapidly mixed with air as it moves downslope, again creating a cushion that increases the speed of the avalanche. Anything in its path, such as trees, buildings, cars on roads, towns and people, is destroyed.

• Two classes of forces combine in any type of mass movement: driving forces that promote movement, and resisting forces that deter movement. When the driving forces are greater than the resisting forces, the material on the slope breaks loose and moves downslope.

**Gravity and Rock Structure as Driving Forces**

• We all know that the steeper the slope, the greater is the tendency of materials to move downslope. Gravity, therefore, is the first primary driving force.

• This driving force can be increased by human activity, such as water erosion and human excavation. When a portion of a slope moves downward as a result of either natural conditions or human activity, this process is known as slope failure.

• The second primary driving force is rock structure. Rocks are far from being solid:
  - First, all rocks have pore spaces which allow water and air to infiltrate.
  - Second, rocks can break along natural fractures in the rock caused by stress.
  - Third, contact surfaces between different rock types are points of weakness.

• Plate tectonic movements may cause rock layers to become tilted which can become unstable if they're tilted in the direction as the slope itself.

• In all highway and building construction, geological engineers conduct detailed studies to determine the stability of the slopes when building highways, railways, canals, and any type of construction site.

**Water as a Driving Force**

• The third type of driving force is water, but the role of water is also complex, because it can also be a resisting force. Water promotes mass movement in several ways:

• First, water increases the weight of slope material by filling previously empty pores and fractures. For example, a sandy slope can have up to 35% pore space. After a prolonged period of rain, the pores may be completely filled, increasing
the weight of the sediment. This will increase the potential for movement by gravity.

• Second, water decreases the strength of the rock or sediment by reducing cohesion among the particles. For example, water circulating in limestone can dissolve the calcium carbonate particles, reducing cohesion of the rock. Water can also infiltrate pore space, then freeze (frost heaving), breaking the rock apart.

• Third, water can create shrink-swell clays, which are a common geohazard in the construction of building foundations. In clay-rich sediments, clay-sized particles attract and absorb water molecules, causing the sediment to swell to many times its original volume.

• The best known of these clays is bentonite. Between rains, these clay-rich sediments can shrink and contract, forming large surface cracks that can damage any structures built on top.

• Finally, clays can be turned to liquid in a process called liquifaction. A quick clay is formed by this process, and can occur when saltwater ions, which normally help to hold the sediment together, are flushed out and replaced with freshwater. What used to be solid clay-rich sediment is now a very unstable quick clay.

Resisting Forces

• In some cases, water can also be a resisting force to mass movement. In sediment pore spaces that are not completely filled, the thin film of water actually makes the particles stick together in a process known as cohesion. Cohesion is the ability of particles to attract and hold each other together.

• Water molecules that line the pore spaces tend to hold other molecules - this attraction is called surface tension, a force that holds water together.

• An excellent example is a sand castle. Without water, it is impossible to build a sand castle. With just the right amount of water, you can build a sand castle because the water creates surface tension that holds particles together. When the sand castle becomes saturated with high tide, the castle breaks apart, because the pore spaces have been completely filled with water which is now a driving force.

  o no water: sand castle impossible (sediment breaks apart and moves downslope)
  o water-lined particles: sand castle possible (surface tension holds sand together)
  o water-saturated particles: sand castle breaks down (sediment moves downslope)
• The **angle of repose** is *the maximum angle on a slope to which sediment particles can be piled*. Some sediments can accumulate in large volumes, yet remain stable. Some factors that affect the stability of particles on a slope include:

  - **particle size**: larger particles maintain a steeper slope than smaller particles.
  - **particle shape**: particles with angular edges can have a steeper slope than ones with rounded edges.
  - **particle sorting**: poorly sorted particles have all sizes represented. These can have steeper slopes because the smaller particles can fill the spaces between the larger particles.
  - **particle moisture**: particles with some water can have a steeper slope than particles with no or too much water.

• Finally, **particle packing** will affect the ability of sediment to move downslope. Packing describes the arrangement of particles in a sediment.

  - **Cubic packing** occurs when grains are aligned with their centers *above one another*, and represents loose sediment. **Rhombohedral packing** occurs when the centers of the grains of sediment are located *over the spaces* between the grains. This type of packing occurs in sediments that have "settled" due to shaking or sorting by water movement.

**2.6.1 Predicting Mass Movements**

• What does one look for when assessing the stability of a slope? **First rule**: *the steeper the slope, the greater the potential for mass movement*. Construction should be careful about creating steeper slopes by undermining the base of slopes. Steeper slopes are also more prone to slippage in **seismic areas**.

• Slopes are considered unstable if they are composed of **rocks that are easily dissolved**, such as limestone. Slopes are also considered unstable if the **layers of rocks are tilted** rather than horizontal.

• Slopes that are **constantly waterlogged** or **highly saturated** are considered unstable. Clues to look for are springs along the slope, areas of soggy ground, and standing pools of water.

• Clues that indicate an old slump:

  - **hummocky ground** at the base of a slope
  - **trees** that are different in age - young trees occur in the slump itself and older trees grow outside the slump
  - **fencelines** may also be displaced.

• Increased rates of **soil creep** maybe indicated by **downslope tilting of trees** and vegetation growing on the slope. This suggests a rapid creep rate downslope.
• Geologic maps of an area can be used to help create a **landslide potential map**, and uses the type of rock underlying the surface, as well as the steepness of the slopes. Where steep slopes and weak rocks combine, the areas are designated as **slide prone**.

### 2.6.2 Prevention and Mitigation of Mass Movements

- **First, one should not build** in an area prone to mass movements, but this isn't always feasible because increasing populations encroach on areas with slopes. Transportation routes often have no choice.

- **Drain the slope.** Divert water away from the slope by:
  - **Interceptor drains** can be built at the top of the slope to channel water away.
  - **Perforated pipe** can be driven into the slope to capture water and drain it away by gravity.
  - **Wells** can be driven into the slope to allow water to be pumped away.

- **Slope reduction**: the steepness of the slopes can be manually decreased by construction. Sometimes this is not economically feasible, so **benches or terraces** can be constructed.

- **Concrete coatings** can be applied to the slope to seal the slope and prevent water from infiltrating, and also to prevent frost wedging. **Retaining walls** can be constructed at the base of slopes. **Rock bolts** can be drilled into tilting rock layers to prevent them from slipping.

- Structures can be built in areas prone to mass movements. One of the more popular is the use of **cable nets and wire fences** to catch rocks and debris from tumbling down unto highways and neighborhoods. **Intercept ditches** can be built to catch any falling debris and prevent it from rolling onto a road. **Rock sheds and tunnels** can be built to allow the debris to pass over the road. **Avalanche sheds** can be built in areas prone to snow avalanches.

### 2.6.3 Effects of Landslides

**Rate of Land Movement** - This varies from exceptionally slow, only centimetres per year (which can damage roads, buildings, pipelines, etc) to a sudden total collapse or avalanche of perhaps millions of tonnes of debris, with the potential to crush vehicles, buildings and people, or to sweep away roads, power and telephone lines.

**Degree of Land Movement** - The distance travelled by landslide debris can also vary greatly, from a few centimetres in ‘ground slumps’, to many kilometres when large mudflows follow river valleys.

### 2.7 SUMMARY
Cyclones are atmospheric hazard, flooding is a hydrological hazard, whereas landslides, earthquakes and volcanoes are geological hazards. Different hazards produce various effects. Mitigation efforts of different natural hazards are specific with reference to the hazard involved.

2.8 KEY WORDS:

Earthquakes – are caused by the movements of plates of the earths crust known as tectonic activity.

Volcanoes – are openings in the surface of the earth from which molten rock, and gases escape which consists of a fissure in the earths crust.

Landslides – usually involve the movements of large amounts of rock, sand or mud or any combination of these.

2.9 SELF ASSESSMENT QUESTIONS (SAQ)

1. Discuss the cause of the following hazards: a) earthquakes b) volcanoes c) landslides d) cyclones e) Floods

2. How can one take preventive measures to reduce the effects of the natural hazards (a) earthquakes b) volcanoes c) landslides d) cyclones e) Floods?

2.10 SUGGESTED READINGS
