4. Solar energy
5. Hydrogen
6. Miscellaneous, geothermal, tidal, hydroelectricity etc.

9.3.1 Coal

On a worldwide basis, coal is substantially more abundant than oil or gas, the total coal reserve being estimated to be about 7.4×10^{12} MT (metric tonnes), which is equivalent to 4.7×10^{22} calories. This may be compared with the total world energy consumption from all fuels, as on 1975 is equal to 6.0×10^{19} calories.

Coal denotes a large range of solid fossil fuels derived from partial degradation of plants. Chemically, coal is a complex material having a typical approximate composition: $C_{100}H_{85}S_{2.1}\,N_{2.1}\,O_{9.5}$. Anthracite, a hard, clean-burning, low-sulphur coal, is the most desirable of all coals.

One major problem is that coal is a dirty fuel to burn. Of particular concern is that it emits SO_2 which is serious health hazard in urban areas. Also, being a solid, coal is much less convenient to use than petroleum or natural gas. The extent to which coal can be used as a fuel depends upon the solution to several problems including (1) minimizing environmental impact of coal mining; (2) removing ash and sulphur from coal prior to combustion; (3) removing ash and SO_2 from stack gas after combustion, and (4) conversion of coal to liquid and gaseous fuels free of ash and sulphur.

Magnetohydrodynamic (MHD) power combined with conventional steam-generating units is a major breakthrough in the efficiency of coal utilization. MHD generators produced by means of a plasma of ionized gas blasting at around 2400°C through a very strong magnetic field of at least 50,000 gauss. The ionization of the gas is done by injecting a 'seed' of Cs^+ or K^+ salts. In a coal-fired MHD generator, the ultra-high temperature gas issuing through a supersonic nozzle contains ash, SO_2 and NO_x which have a corrosive action on the materials used. This hot gas is then utilized for generating steam for a conventional steam power plant, therby increasing the overall efficiency of the process. Fig 9.2

Coal Conversion

Coal can be transformed to gaseous, liquid, or low-sulphur, low-ash solid fuels, which are less polluting than coal. The products—gases and liquids—can be used with distribution system and equipment designed for use with

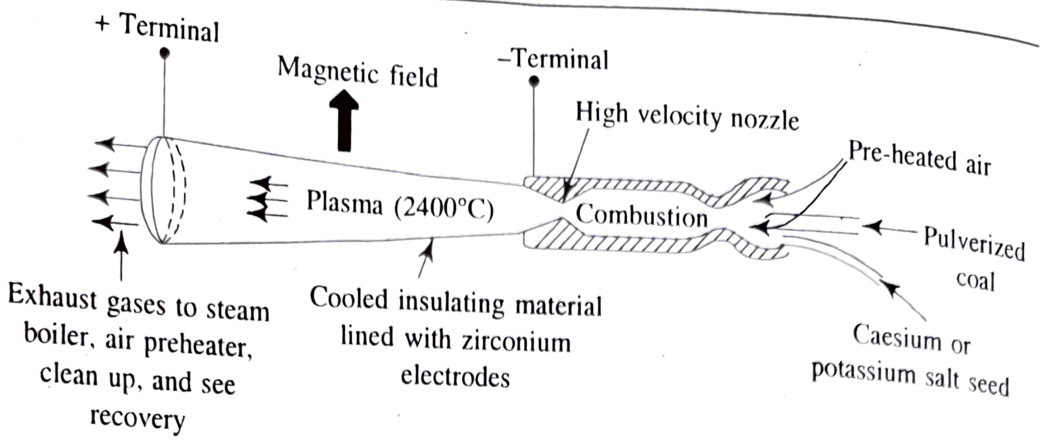


Fig. 9.2 A magnetohydrodynamic power generator (Reprinted by permission of Brooks/Cole Publishing Company, Monterey, California 93940, USA, from *Environmental Chemistry*, 3rd edn., S.E. Manahan, p. **430**, 1979, Willard Grant Press, Statler Office Building, Boston, Massachusetts)

natural gas or petroleum. During World War II, Germany developed a major coal-based synthetic petroleum industry that reached a peak capacity of 100,000 barrels per day in 1944. In S. Africa, a plant now converts about 10,000 tonnes of coal per day to synthetic petroleum. Among the above processes, the production of gaseous fuels high-Btu substitute natural gas is the most commercially viable.

A typical 'second generation' coal conversion plant—synthane gasification plant—has been developed in the USA with a capcity of 72 tonnes/day of coal. The process follows a free-fall carbonization step with water fluidized bed gasification. Coking coal is heat treated to make it non-coking prior to introduction into the reactor. Next steam reacts with coal to produce water gas.

$$C + H_2O \rightarrow \underbrace{CO + H_2}_{\text{water gas}}$$

The gaseous products from bituminous coal in a synthane gasifier are 10.5% CO, 17.5% H_2, 18.2% CO_2, 37% H_2O, 15.4% CH_4 and 0.3% H_2S. The calorific value of the gas is 405 Btu/ft^8, as compared to 1000 Btu/ft^3 for CH_4. Besides these gases, tar, oil, water, ash and S are also produced, which must be removed.

The gas from the reactor exit contains some tar and dust which must be eliminated by water scrubbing. The gas is rich in CO and allowed to react over a shift catalyst,

$$CO + H_2O \rightarrow CO_2 + H_2$$

to achive the required H_2/CO ratio more than 3:1. The gas at this stage contains a high percentage of non-combustible CO_2 as well as H_2S and

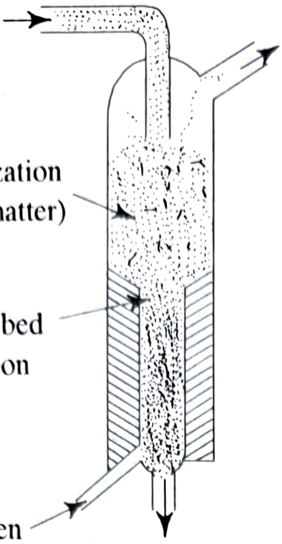


Fig. 9.3 Synthane gasification reactor. (Reprinted by permission of Brooks/Cole Publishing Company, Monterey, California 93940, USA, from *Environmental Chemistry*, 3rd edn, S.E. Manhan, p. **432**, 1979, Willard Grant Press, Statler Office Building, Boston, Massachusetts)

COS which poison the methanation catalyst. These are removed by an alkaline scrubber. Finally, high-Btu gas is produced by catalytic methanation over a Ni catalyst

$$CO + 3H_2 \rightarrow H_2O + CH_4$$

Due to the presence of H_2 the heating value of the gas is slighty less than that of commerical natural gas.

In general, the quality of coal is upgraded by the hydrogenation process which removes S and ash from coal. High grade ash-free coal is produced as *RSC* (*Solvent refined coal*) by suspending pulverized coal in a solvent and treating with 2% of its weight of H_2 at 1000 psi and 450°C. The product is a semisolid, m.p. 170°C (approx), having a calorific value of 16,000 Btu/lb comparable to best anthracite coal.

Methanol, CH_3OH, is a convenient liquid fuel which can the be produced from coal. On a large scale it is produced by the reaction of CO and H_2 at 50 atm and 250°C in the presence of copper-based catalyst. A lower H_2/CO ratio than that required for the production of CH_4 is maintained.

$$CO + 2H_2 \rightarrow CH_3OH$$

The CO and H_2 used for methanol production are produced from coal, O_2 and steam.

At levels up to 15% methanol is an excellent additive for gasoline. It has a high-octane number of 106, and improves fuel economy and cuts down pollution.

acceleration time in automobiles. It also cuts down the emission of practically all automotive pollutants.

9.3.2 Petroleum and Natural Gas

The availability of petroleum and natural gas governs the energy growth and status of a country. The Industrial revolution was initially fuelled by coal, but subsequently the emphasis was shifted to oil and gas which are cleaner fuels and transported more easily. Petroleum accounts for about 80% of the total energy consumption in the USA, the largest consumer of pertroleum in the world.

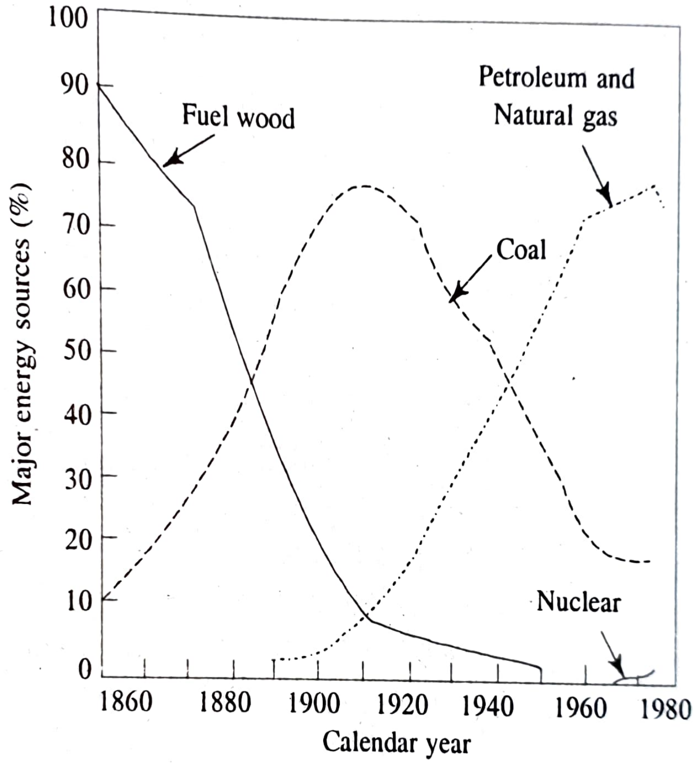


Fig. 9.4 U.S. Energy Consumption Patterns [Historical Statistics of US Bureau of the Census, U.S. Bureau of Mines, Washington DC, 1974]

It is important to note the petroleum reserves for various areas of the world along with the production and consumption patterns. The estimate of the total world reserve is about 800 billion barrels*, barely 35 times the amount produced in 1976. Among the four leading consumers, USA, Western Europe, the Communist countries and Japan, only the Communist countries are self-sufficient in petroleum. The other countries, particulary Japan, must continue to depend on the surplus oil of other areas, especially

* 1 barrel = 31.5 gallons = 120 l

the Middle East, to meet their energy demands. However, the surplus are also dwindling over the years and are likely to be exhausted in the next century.

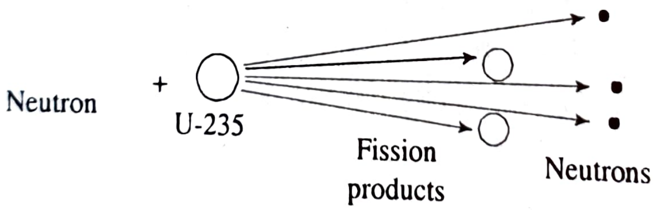
9.3.3 Nuclear Fission and Nuclear Fusion

The atom bombs dropped on Hiroshima and Nagasaki in August 1945 unleashed before the world the awesome power of the atom and brought the Second World War to a halt. The nuclear age dawned and held out promise for the production of abundant energy. U-235 produces, per gram, heat energy equivalent to 14 barrels of the crude oil or 3 tonnes of coal. But this promise has not materialized to the extent expected and is showing a small growth in percentage of electrical energy.

Nuclear power (fission) reactors are based on the fission of U-235 nuclei by thermal neutrons,

$$^{235}_{92}U + ^{0}_{1}n \rightarrow ^{133}_{51}Sb + ^{99}_{41}Nb + 2.5\,^{0}_{1}n$$

producing two radioactive fission products, and average of 2.5 neutrons, and an average energy of 200 MeV per fission. The energy from these



nuclear reactions is used to heat water in the reactor and produce steam to drive a steam turbine (Fig. 9.5).

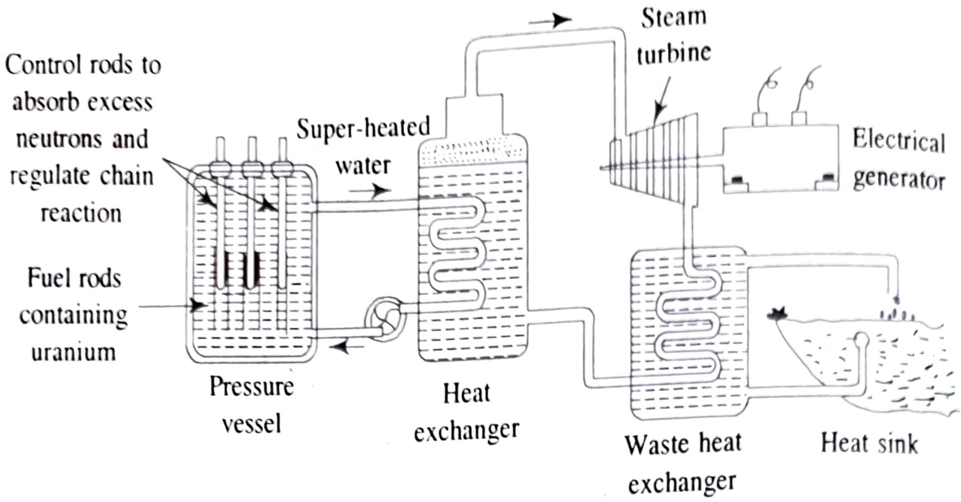
Nuclear reactors operate at about 625K, compared to 800K in a fosil-fuel power plant. The thermal efficiency of power generation is low, and the overall efficiency for production of electricity does not exceed 30%. The means 70% of nuclear fission energy has to be disposed of in the environment.

Three reactor types were considered viable for the period up to 2000 AD: the light water reactor (LWR), high temperature gascolled reactor (HTGR) and the fast breeder reactor (FBR). The LWR consumes only U-238 and Th-232 to fissionable Pu-239 and U-238:

$$^{338}_{92}U + {}_{0}n \rightarrow ^{239}_{93}U \rightarrow ^{239}_{93}Np \rightarrow ^{239}_{94}Pu$$

$$^{238}_{20}U + {}_{0}n \rightarrow ^{238}_{90}U \rightarrow ^{244}_{91}Np \rightarrow ^{237}_{92}Pu$$

They are more efficient than natural uranium.



Fin. 9.5 Nuclear reactor for power generation (Reprinted by permission of Brooks/Cole Publishing Company, Monterey, California 93940, USA, from *Environmetal Chemistry*, 3rd edn., S.E. Manahan, p. **435**, 1979, Willard Grant Press. Statler Office Building, Boston, Massachusetts)

The major constraint in the widespread use of nuclear fission power is the yield large quantities of radioactive fission waste products. The latter remain lethal for thousands of years. No foolproof disposal method has yet been devised. Past experience shows that human error and negligence are likely to the atmospheric release of radioactive wastes.

Nuclear *fusion* reactions are based on the deuterium-deuterium reaction:

$$^{2}_{1}H + ^{2}_{1}H \rightarrow ^{3}_{2}He + {}_{0}n + 1\ \text{MeV}$$

and the deuterium-tritium reaction:

$$^{2}_{1}H + ^{3}_{1}H \rightarrow ^{4}_{2}He + {}_{0}n + 17.6\ \text{MeV}$$

The second reaction is energetically more vaible. Tritium is obtained from nuclear reactions of Li-6. Deuterium is, however, unlimited in stock. $^{3}_{2}He$, the products in the reaction above, reacts with neutrons which are abundant in a nuclear fusion reactor, to form H required for the second reaction.

The $^{2}_{1}H$–$^{2}_{1}H$ reaction promises an endless source of energy without any radioactive wastes, but the technological problems for harnessing fusion energy will take several years to solve.

9.3.4 Solar Energy

At the onset of the 21st century, it has been evident that the stock of fossil fuel (coal, oil) is limited and may be exhausted within 100 years leading to energy crisis. Hence it is time to find out and develop alternative energy sources which should be without delay. Solar energy is one viable