MODULE 1: SOURCES OF ENERGY

ENERGY- Capacity to do work.

- Most of the energy that we use is mainly derived from conventional energy sources.
- Due to the vast demand of energy, the rate of depletion of these resources has reached alarmingly low levels.
- This situation has directed us to seek alternate energy sources such as solar, wind, ocean, biomass, Hydel etc.

Energy Sources:

- The energy existing in the earth is known as CAPITAL energy.
- Energy that comes from outer space is called CELESTIAL or INCOME energy.
- The CAPITAL energy sources are mainly, fossil fuels, nuclear fuels and heat traps.
- CELESTIAL ENERGY SOURCES ARE- Electromagnetic, gravitational and particle energy from stars, planets, moon etc.
- ELECTROMAGNETIC ENERGY of the earth’s sun is called DIRECT SOLAR ENERGY. This results in WIND, HYDEL, GEOTHERMAL, BIOFUEL, etc.
- GRAVITATIONAL ENERGY of earth’s moon produces TIDAL ENERGY.

Renewable Sources of Energy:

Energy sources which are continuously produced in nature and are essentially inexhaustible are called renewable energy sources.

1. Direct solar energy
2. Wind energy
3. Tidal energy
4. Hydel energy
5. Ocean thermal energy
6. Bio energy
7. Geo thermal energy
8. Peat
9. Fuel wood
10. Fuel cells
11. Solid wastes
12. Hydrogen

Nonrenewable Energy Sources:

Energy sources which have been accumulated over the ages and not quickly replenishable when they are exhausted.

1. Fossil fuels.
2. Nuclear fuels.
3. Heat traps.

Differences between Renewable and Non Renewable Energy Sources

Factor	Renewable Energy Sources	Non Renewable Energy Sources
Exhaustibility/Inexhaustibility	Inexhaustible	Exhaustible
Availability	Abundantly and freely available	Not abundantly available
Replenishment	Replenished Naturally	Cannot be replenished
Environmental Friendliness	Environment friendly except in case of biomass	Not environment friendly
Cost Factor	Building Systems cost is high, running cost is low	Production cost is high
Nature of Availability	Intermittently available	Continuously available
Regional restriction and dependency factor	No regional restriction	Available in certain countries

Types of Fuels

The important fuels are as follows-

1) **Solid fuels**
2) **Liquid fuels**
3) **Gaseous fuels**

1) **Solid fuels**

- Coal is the major fuel used for thermal power plants to generate steam.
- Coal occurs in nature, which was formed by the decay of vegetable matters buried under the earth millions of years ago under pressure and heat.
- This phenomenon of transformation of vegetable matter into coal under earth's crust is known as Metamorphism.
- The type of coal available under the earth's surface depends upon the period of metamorphism and the type of vegetable matter buried, also the pressure and temperature conditions.
- The major constituents in coal moisture (5-40%), volatile matter (combustible & or incombustible substances about 50%) and ash (20-50%).
- The chemical substances in the coal are carbon, hydrogen, nitrogen, oxygen and sulphur.
- In the metamorphism phenomenon, the vegetable matters undergo the transformation from peat to anthracite coal, with intermediate forms of lignite and bituminous coal.

2. Liquid Fuels

- All types of liquid fuels used are derived from crude petroleum and its by-products.
- The **petroleum or crude oil** consists of 80-85% C, 10-15% hydrogen, and varying percentages of Sulphur, nitrogen, oxygen and compounds of vanadium.
- The crude oil is refined by fractional distillation process to obtain fuel oils, for industrial as well as for domestic purposes.
- The fractions from light oil to heavy oil are naphtha, gasoline, kerosene, diesel and finally heavy fuel oil.
- The heavy fuel oil is used for generation of steam.
- The use of liquid fuels in thermal power plants has many advantages over the use of solid fuels.

Some important advantages are as follows:

1. The storage and handling of liquid fuels is much easier than solid and gaseous fuels.
2. Excess air required for the complete combustion of liquid fuels is less, as compared to the solid fuels.
3. Fire control is easy and hence changes in load can be met easily and quickly.
4. There are no requirements of ash handling and disposal.

5. The system is very clean, and hence the labour required is relatively less compared to the operation with solid fuels.

3) Gaseous Fuels

- For the generation of steam in gas fired thermal plants, either natural gas or manufactured gaseous fuels are used.
- However, manufactured gases are costlier than the natural gas.
- Generally, natural gas is used for power plants as it is available in abundance.
- The natural gas is generally obtained from gas wells and petroleum wells.
- The major constituent in natural gas is methane, about 60-65%, and also contains small amounts of other hydrocarbons such as ethane, naphthene and aromatics, carbon dioxide and nitrogen.
- The natural gas is transported from the source to the place of use through pipes, for distances to several hundred kilometers.
- The natural gas is colourless, odourless and non-toxic.
- Its calorific value ranges from 25,000 to 50,000 kJ/m3, in accordance with the percentage of methane in the gas.
- The artificial gases are producer gas, water gas coke-oven gas; and the Blast furnace gas.
- Generally, power plants fired with artificial gases are not found.
- The gaseous fuels have advantages similar to those of liquid fuels, except for the storage problems.
- The major disadvantage of power plant using natural gas is that it should be setup near the source; otherwise the transportation losses are too high.

Solar Power Plant

Solar radiation is radiant energy emitted by the sun from a nuclear fusion reaction that creates electromagnetic energy. The spectrum of **solar radiation** is close to that of a black body with a temperature of about 5800 K. About half of the **radiation** is in the visible short-wave part of the electromagnetic spectrum.

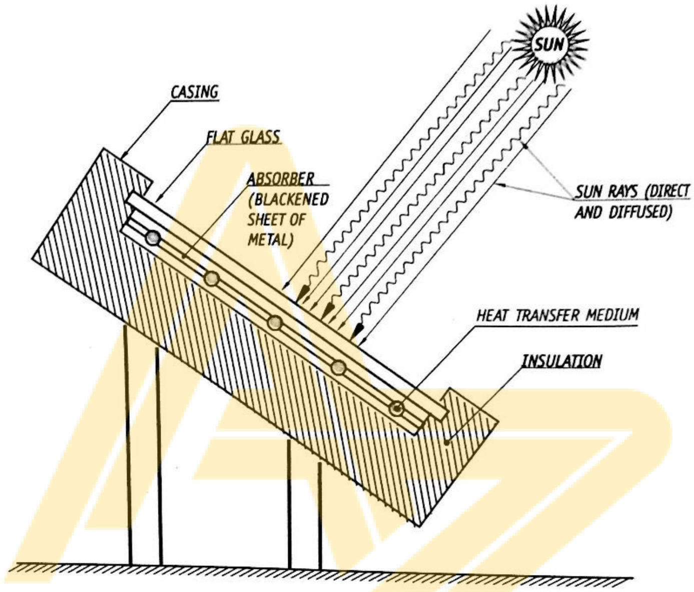
Solar Constant:

This is the amount of energy received in unit time on a unit perpendicular to the suns direction at the mean distance of the earth from the sun. The surface of the earth receives about 10^{14} kW of solar energy from the sun. One square meter of the land exposed to direct sun-light receives an energy equivalent of about 1 kW of power. The radiant solar energy falling on the earth surface is directly converted into thermal energy. The surfaces on which the solar rays fall are called collectors.

There are two types of collectors:

(a) Flat plate collectors (b) Focusing collectors.

Liquid Flat Plate Collectors:



Flat - Plate Collector

It has the following components:

(a) Absorbing plate

- Made of Copper, Aluminium or steel.
- It is coated with material to enhance the absorption of solar radiation.
- From the absorbing plates heat is transferred to tubes which carry either water or air.

(b) Transparent covers

- Sheets of solar radiation transmitting materials placed above the absorbing plate.
- They allow solar energy to reach the absorbing plate while reducing convection, conduction and re-radiation heat losses.

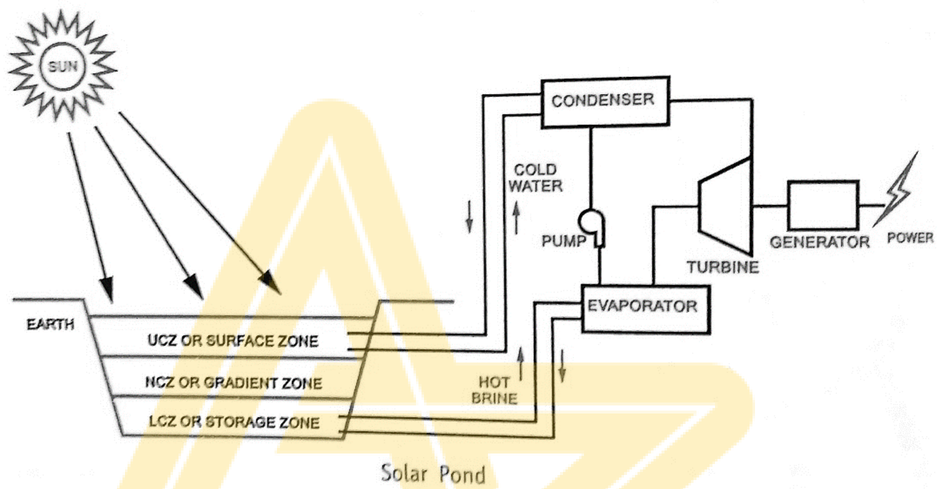
(c) Insulation

- It minimizes and protects the absorbing plate from heat losses.

Working

- Sun's rays falling on the transparent covers are transmitted to the absorbing plate.
- The absorbing plate usually of Cu, Al or galvanized iron is painted dead black for maximum absorption.
- The collector (plate) will absorb the sun energy and transfer it to the fluid in the pipe beneath the collector plate.
- Use of flat mirrors on the sides improves the output.

Solar Pond Technology



Solar Pond

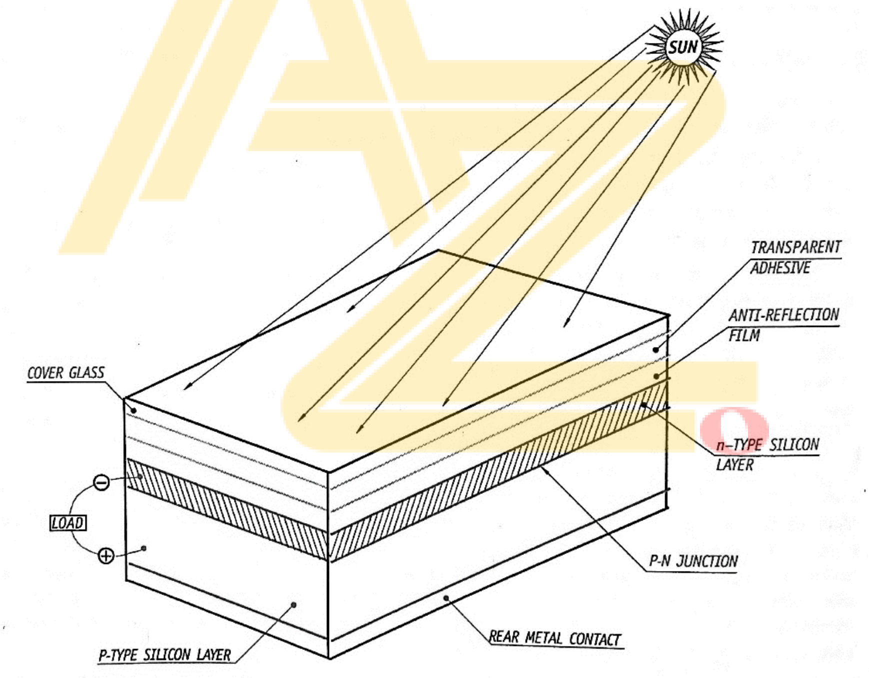
- A salinity gradient solar pond is an integral collection and storage device of solar energy.
- By virtue of having built-in thermal energy storage, it can be used irrespective of time and season.
- In an ordinary pond or lake, when the sun's rays heat up the water this heated water, being lighter, rises to the surface and loses its heat to the atmosphere.
- The net result is that the pond water remains at nearly atmospheric temperature.
- The solar pond technology inhibits this phenomenon by dissolving salt into the bottom layer of this pond, making it too heavy to rise to the surface, even when hot.
- The salt concentration increases with depth, thereby forming a salinity gradient.
- The sunlight which reaches the bottom of the pond remains entrapped there.
- The useful thermal energy is then withdrawn from the solar pond in the form of hot brine.

- The pre-requisites for establishing solar ponds are: a large tract of land (it could be barren), a lot of sun shine, and cheaply available salt (such as Sodium Chloride) or bittern.
- Generally, there are three main layers. The top layer is cold and has relatively little salt content.
- The bottom layer is hot -- up to 100°C (212°F) -- and is very salty.
- Separating these two layers is the important gradient zone.

Photovoltaic Cell:

Solar energy can be directly converted to electrical energy by means of photovoltaic effect. Photovoltaic effect is defined as the generation of an electromotive force (EMF) as a result of the absorption of ionizing radiation.

Devices which convert sunlight to electricity are known as solar cells or photovoltaic cells. Solar cells are semiconductors, commonly used are barrier type iron-selenium cells.



Solar Cell

• Iron-selenium cells consist of a metal electrode on which a layer of selenium is deposited.
• On the top of this a barrier layer is formed which is coated with a very thin layer of gold.
• The layer of gold serves as a translucent electrode through which light can impinge on the layer below.
• Under the influence of sunlight, a negative charge will build up on the gold electrode and a positive charge on the bottom electrode.

• This difference in charge will produce voltage in proportion to the suns radiant energy incident on it.

Wind energy:

Wind energy is the energy contained in the force of the winds blowing across the earth surface. Wind energy is defined as the kinetic energy associated with the movement of large masses of air over the earth's surface. The circulation of the air in the atmosphere is caused by the non-uniform heating of the earth's surface by the sun. The air immediately above warm area expands and becomes less dense. It is then forced upwards by a cool denser air which flows in from the surrounding areas causing wind.

Power in the wind:

Wind possesses kinetic energy by virtue of its motion. Any device capable of slowing down the mass of moving air, like a sail or propeller, can extract part of this energy and convert into useful work.

The kinetic energy of one cubic meter of air blowing at a velocity V is given by,

$$E = {}^{1}/_{2}\, \rho V^2 \;\; J/m^3$$

In one second, a volume element of air moves a distance of V m. The total volume crossing a plane, one square meter in area and oriented normal to the velocity vector in one second is therefore V $m^{3.}$

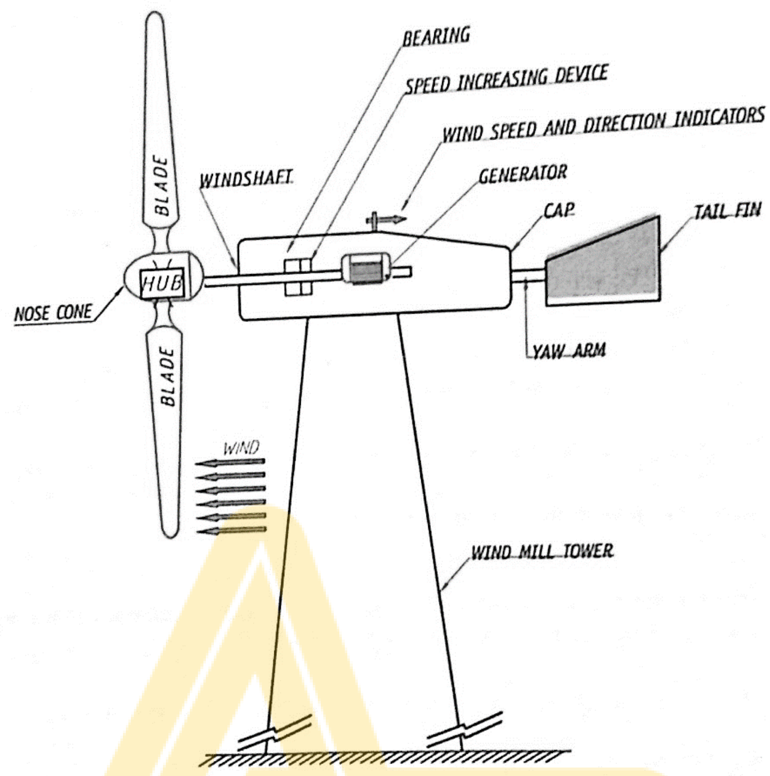
The rate at which the wind energy is transferred, i.e., wind power is given by,

$$P = E\ V$$

$$P = {}^{1}/_{2}\, \rho V^3 \;\; W/m^2$$

No device, however well designed can extract all the wind energy because the wind would have to be brought to halt and this would block the passage of incoming air through the rotor. It has been found that for maximum power output the exit velocity is equal to one-third of the entrance velocity. Thus a maximum of 60% of the available energy in the wind is converted into mechanical energy.

Wind energy conversion:



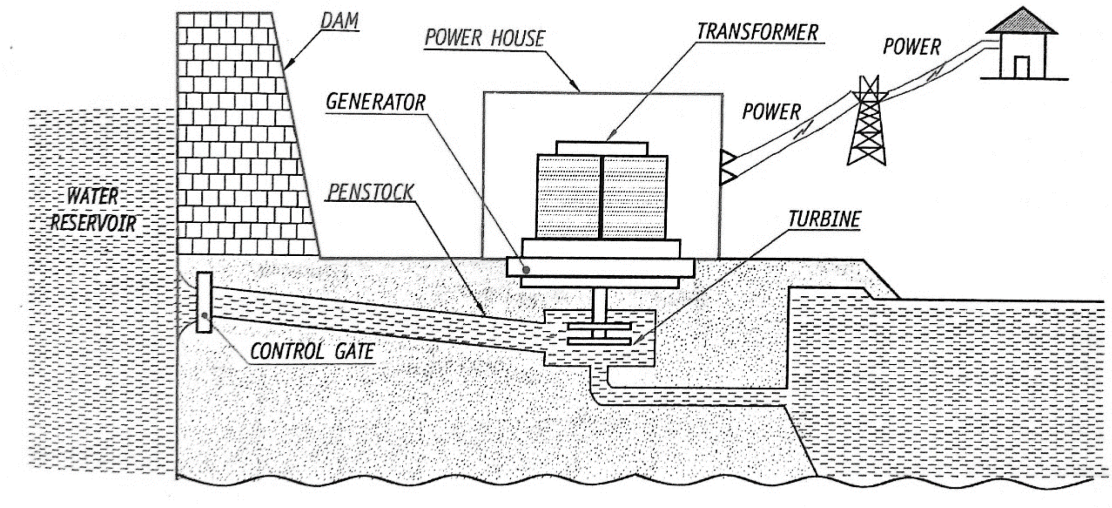
Schematic Diagram of Wind Mill

A windmill is the oldest device built to convert the wind energy into mechanical energy used for grinding, milling and pumping applications. It consists of a rotor fitted with large sized blades. Now improvement in performance is achieved by applying sound engineering and aerodynamic principles. Nowadays the wind energy is used to produce electrical energy. Wind energy is converted into mechanical energy in wind turbines. These wind turbines are coupled to generators the mechanical energy is converted into electrical energy.

Hydro Power Plants:

In hydroelectric power plants the potential energy of water due to its high location is converted into electrical energy. The total power generation capacity of the hydroelectric power plants depends on the head of water and volume of water flowing towards the water turbine.

The hydroelectric power plant, also called as dam or hydro power plant, is used for generation of electricity from water on large scale basis. The dam is built across the large river that has sufficient quantity of water throughout the river. In certain cases where the river is very large, more than one dam can built across the river at different locations.



Hydro-Power Station

Working Principle of Hydroelectric Power plant

The water flowing in the river possesses two type of energy:

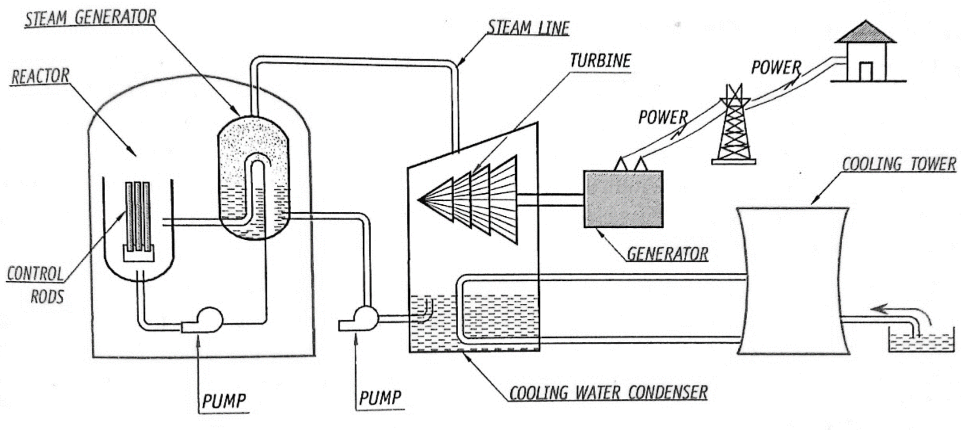
(1) The kinetic energy due to flow of water and

(2) Potential energy due to the height of water.

The hydroelectric power and potential energy of water is utilized to generate electricity.

Working principle of a nuclear power station

The schematic diagram of nuclear power station is shown in figure. A generating station in which nuclear energy is converted into electrical energy is known as nuclear power station. The main components of this station are nuclear reactor, heat exchanger or steam generator, steam or gas turbine, AC generator and exciter, and condenser.



Nuclear Energy Conversion

The reactor of a nuclear power plant is similar to the furnace in a steam power plant. The heat liberated in the reactor due to the nuclear fission of the fuel is taken up by the coolant circulating in the reactor. A hot coolant leaves the reactor at top and then flows through the tubes of heat exchanger and transfers its heat to the feed water on its way. The steam produced in the heat exchanger is passed through the turbine and after the work has done by the expansion of steam in the turbine, steam leaves the turbine and flows to the condenser. The mechanical or rotating energy developed by the turbine is transferred to the generator which in turn generates the electrical energy and supplies to the bus through a step-up transformer, a circuit breaker, and an isolator. Pumps are provided to maintain the flow of coolant, condensate, and feed water.

Introduction to Bio-fuels

Bio Fuels are liquid fuels which are derived from biomass or bio waste. Bio fuels are produced from sugar crops, starch crops, oilseed crops and animal fats.

The most common first-generation biofuels are:

- **Biodiesel**: extraction with or without esterification of vegetable oils from seeds of plants like soybean, oil palm, oilseed rape and sunflower or residues including animal fats derived from rendering applied as fuel in diesel engines.
- **Bioethanol:** fermentation of simple sugars from sugar crops like sugarcane or from starch crops like maize and wheat applied as fuel in petrol engines
- **Bio-oil:** thermo-chemical conversion of biomass. A process still in the development phase
- **Biogas:** anaerobic fermentation or organic waste, animal manures, crop residues an energy crops applied as fuel in engines suitable for compressed natural gas.
- **Biochemical:** modification of the bio-ethanol fermentation process including a pretreatment procedure
- **Thermo chemical:** modification of the bio-oil process to produce syngas and methanol, Fisher-Tropsch diesel or dimethyl ether (DME).

Applications:

- Biogas is cheap and sustainable fuel used in lighting, cooking or generating electricity.
- Biodiesel finds its use in automotive industry mainly in cars and trucks.
- Small engines are seen in lawn movers and chain saw.

- The marine industry finds application of biofuel in suitable blend mixtures to be used in boats and ships.

Problems Associated

Biodiesel is compatible with current engines but with certain issues

The most important of these are:

- Biodiesel exhibits cold weather problems
- Some types of biodiesel have exhibited storage in stability that could lead to engine problems
- Diesel additives may not provide the same benefits when used with biodiesel.
- Sometimes, vegetable oils create adverse effects on engine components due to their volatility, molecular structure and high viscosity.

Comparison of Bio Fuels with Petroleum

Factor	Bio Fuels	Petroleum
Calorific Value	Ranges from 30 to 38MJ/Kg	Varies between 43 to 48MJ/Kg
Emissions	Greenhouse gas emissions are less	Greenhouse gas emissions are more
Biodegradability	Biodegradable	Non- Biodegradable
Toxicity	Non-Toxic	Toxic
Renewability	Renewable	Non-Renewable
Safety	Safe to produce	Not safe to produce

Global Warming:

Global warming is a gradual increase in the overall temperature of the earth's atmosphere generally attributed to the greenhouse effect caused by increased levels of carbon dioxide, CFCs, and other pollutants.

Causes for Global Warming:

One of the biggest issues facing us right now is global warming. Its effects on animals and on agriculture are indeed frightening, and the effects on the human population are even scarier. The facts about global warming are often debated in politics and the media, but, unfortunately, even if we disagree about the causes, global warming effects are real, global, and measurable. The causes are mainly from us, the human race, and the effects on us will be severe.

- **Carbon dioxide emissions from fossil fuel burning power plants**
  Our ever increasing addiction to electricity from coal burning power plants releases enormous amounts of carbon dioxide into the atmosphere.
- **Carbon dioxide emissions from burning gasoline for transportation**
  With our population growing at an alarming rate, the demand for more cars and consumer goods means that we are increasing the use of fossil fuels for transportation and manufacturing.
- **Methane emissions from animals, agriculture such as rice paddies, and from Arctic seabeds**
  Methane is another extremely potent greenhouse gas, ranking right behind CO2. When organic matter is broken down by bacteria under oxygen-starved conditions (anaerobic decomposition) as in rice paddies, methane is produced. The process also takes place in the intestines of herbivorous animals, and with the increase in the amount of concentrated livestock production, the levels of methane released into the atmosphere is increasing. Another source of methane is methane clathrate, a compound containing large amounts of methane trapped in the crystal structure of ice. As methane escapes from the Arctic seabed, the rate of global warming will increase significantly.
- **Deforestation, especially tropical forests for wood, pulp, and farmland**
  The use of forests for fuel (both wood and for charcoal) is one cause of deforestation, but in the first world, our appetite for wood and paper products, our consumption of livestock grazed on former forest land, and the use of tropical forest lands for commodities like palm oil plantations contributes to the mass deforestation of our world. Forests remove and store carbon dioxide from the atmosphere, and this deforestation releases large amounts of carbon, as well as reducing the amount of carbon capture on the planet.
- **Increase in usage of chemical fertilizers on croplands**
  In the last half of the 20th century, the use of chemical fertilizers (as opposed to the historical use of animal manure) has risen dramatically. The high rate of application of nitrogen-rich fertilizers has effects on the heat storage of cropland (nitrogen oxides have 300 times more heat-trapping capacity per unit of volume than carbon dioxide)

and the run-off of excess fertilizers creates ‘dead-zones’ in our oceans. In addition to these effects, high nitrate levels in groundwater due to over-fertilization are cause for concern for human health.

Effects for Global Warming:

- **Higher temperatures:** Every continent has warmed substantially since the 1950s. There are more hot days and fewer cold days, on average, and the hot days are hotter.
- **Heavier storms:** The world's atmosphere can hold more moisture as it warms. As a result, the overall number of heavier storms has likely increased since midcentury, particularly in North America and Europe (though there's plenty of regional variation).
- **Heat waves:** Heat waves have likely become longer and more frequent around the world over the past 50 years, particularly in Europe, Asia, and Australia.
- **Shrinking sea ice:** The extent of sea ice in the Arctic has shrunk since 1979, by between 3.5 percent and 4.1 percent per decade, on average. Summer sea ice has dwindled even more rapidly:
- **Shrinking glaciers:** Glaciers around the world have, on average, been losing ice since the 1970s. In some areas, that is reducing the amount of available freshwater.
- **Sea-level rise:** Global sea levels rose 25 centimeters (9.8 inches) in the 19th and 20th centuries, after 2,000 years of relatively little change. The pace of sea-level rise has continued to increase in recent decades. Sea-level rise is caused by both the thermal expansion of the oceans — as water warms up, it expands — and the melting of glaciers and ice sheets.
- **Food supply:** A hotter climate can be both good for crops (it lengthens the growing season, and more carbon dioxide can increase photosynthesis) and bad for crops (excess heat can damage plants). The IPCC found that global warming was currently benefiting crops in some high-latitude areas, but that negative effects were becoming increasingly common worldwide.
- **Shifting species:** Many land and marine species have had to shift their geographic ranges in response to warmer temperatures. So far, only a few extinctions have been linked to global warming, such as certain frog species in Central America.

Greenhouse Effect:

The greenhouse effect is the process by which radiation from a planet's atmosphere warms the planet's surface to a temperature above what it would be without its atmosphere. If a planet's atmosphere contains radiatively active gases (i.e., greenhouse gases) they will radiate energy in all directions. Part of this radiation is directed towards the surface, warming it. The intensity of the downward radiation – that is, the strength of the greenhouse effect – will depend on the atmosphere's temperature and on the amount of greenhouse gases that the atmosphere contains.

Earth’s natural greenhouse effect is critical to supporting life. Human activities, mainly the burning of fossil fuels and clearing of forests, have strengthened the greenhouse effect and caused global warming.

Ozone Layer:

A layer in the earth's stratosphere at an altitude of about 10 km (6.2 miles) containing a high concentration of ozone, which absorbs most of the ultraviolet radiation reaching the earth from the sun.

Causes for Ozone Layer Depletion:

The decrease in ozone concentration in the middle layers of the atmosphere – mainly in the stratosphere – is extremely damaging to life on earth, and is largely caused by emissions of halogenated hydrocarbons produced by man, CFCs, HCFCs, halons, carbon tetrachloride and methyl bromide. For this reason, such substances are commonly referred to as Substances that Deplete the Ozone Layer (ODS).

- **Chlorofluorocarbons (CFCs)**

  They are compounds formed by chlorine, fluorine and carbon. They are often used as refrigerants, solvents, and for the manufacture of spongy plastics. When the chemicals reached the earth’s stratosphere, they reacted with Ultraviolet radiation, which caused them to break down and release Chlorine and Bromine into the earth’s ozone layer.

- **Hydrochlorofluorocarbons (HCFCs)**

  Compounds formed by H, Cl, F and C. They are being used as substitutes for CFCs because many of their properties are similar and are less harmful to ozone by having a shorter half-life and releasing fewer Cl atoms.

- **Halons**

  They are compounds formed by Br, F and C. Because of their ability to put out fires are used in fire extinguishers, although their manufacture and use is prohibited in many countries because of their ozone-depleting action. Their ability to harm the ozone layer is very high because they contain Br which is a much more effective atom destroying ozone than the Cl.

- **Methyl bromide (CH3Br)**

  It is a very effective pesticide that is used to fumigate soils and in many crops.

- **Carbon tetra-chloride (CCl4)**

  It is a compound that has been widely used as a raw material in many industries, for example, to manufacture CFCs and as a solvent.

Effects of Ozone Layer Depletion:

Skin Cancer

Today, it is estimated that skin cancer rates increased due to the decrease in stratospheric ozone (ozone layer). The most common type of skin cancer, called non-melanoma, is the cause of exposures to UV-B radiation for several years.

Effects on aquatic ecosystems

The loss of phytoplankton, the basis of the marine food chain, has been observed as the cause of the increase in ultraviolet radiation.

Effects on terrestrial ecosystems

Animals

For some species, an increase in UV-B radiation implies the formation of skin cancer. This has been studied in goats, cows, cats, dogs, sheep and laboratory animals and is probably pointing out that this is a common feature of several species. Infections in cattle can be aggravated by an increase in UV-B radiation.

Plants

In many plants UV-B radiation can have the following adverse effects: alter its shape and damage plant growth; Reduce tree growth; Change flowering times; Make plants more vulnerable to disease and produce toxic substances. There could even be losses of biodiversity and species.

Basis Concepts of Thermodynamics

Thermodynamics: It is the field of thermal engineering that studies the properties of systems that have a temperature and involve the laws that govern the conversion of energy from one form to another, the direction in which heat will flow, and the availability of energy to do work.

System: System is the fixed quantity of matter and/or the region that can be separated from everything else by a well-defined boundary/surface. Thermodynamic system is the system on which thermodynamic investigation is done. The surface separating the system and the surroundings is known as the control surface or the system boundary. Everything beyond the system is the surroundings.

State: At any instant of time, the condition of the system is called state. The state at a given instant of time is defined by the properties of the system such as pressure, volume, temperature etc.

Property: A property is any quantity whose numerical value depends on the state but not on the history of the system. There are two types of properties:

Extensive Property: Depends on the size or extent of the system. Ex. Volume, mass, energy and entropy.

Intensive Property: Independent of the size or extent of the system. Ex. Pressure, temperature.

Change in State: Thermodynamic system undergoes changes due to flow of mass and energy. The mode in which the changes in the state of a system takes place is known as Isobaric (Constant Pressure) process, Isochoric (Constant Volume) process, Isothermal (Constant temperature) process, Adiabatic (Constant Entropy) process etc.

Process: Two states are identical if, and only if, the properties of the two states are same. When any property of a system changes in value there is change in state, and the system is said to undergo a process. When a system from a given initial state undergoes a sequence of processes and finally returns to its initial state, it is said to have undergone a *cycle*.

Phase: Phase refers to a quantity of matter that is homogeneous throughout in its chemical composition and physical structure. A system can contain one or more phases.

A *pure substance* is one that is uniform and invariable in chemical composition. A pure substance can exist in more than one phase, but its chemical composition must be same in each phase. Ex. If liquid water and water vapour form a system with two phases, the system can be regarded as pure substance because each phase has the same composition.

Equilibrium: If there are no changes in the observable properties of an isolated system, then the system is said to be in equilibrium. At equilibrium, temperature and pressure are uniform throughout the system.

Quasi-Static Process: When a process proceeds in such a way that the system remains infinitesimally close to an equilibrium state at all times, it is called quasi-static process.

Temperature: Temperature is a property of a substance by which it can be differentiated from other substance in terms of degree of hot or cold.

The different types of temperature scales are Centigrade, Kelvin, Fahrenheit and Rankine.

Internal Energy: The internal energy of a system is the total energy content of the system. It is the sum of Kinetic, potential, chemical, electrical and all other forms of energy possessed by the atoms and molecules of the system.

Work: Work in thermodynamics may be defined as any quantity of energy that flows across the boundary between the system and the surroundings which can be used to change the height of a mass in the surroundings.

Heat: Heat is defined as the quantity of energy that flows across the boundary between the system and the surroundings because of a temperature difference between the system and the surroundings.

Enthalpy: Enthalpy of a substance is defined as $h = u + PV$. It is the intensive property of the substance and measured in terms of KJ/Kg.

Entropy: It is defined as the measure of randomness of a system. It is an extensive property.

Zeroth Law of Thermodynamics: The zeroth law of thermodynamics states that *"if two thermodynamic systems are each in thermal equilibrium with a third, then they are in thermal equilibrium with each other."*

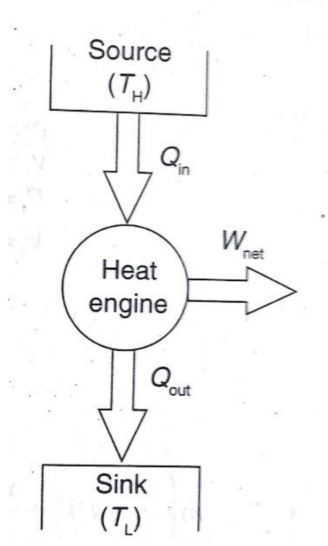
First Law of Thermodynamics: The First law of thermodynamics states that *"when a small amount of work (dw) is supplied to a closed system undergoing a cycle, the work supplied will be equal to the heat transfer or heat produced (dQ) in the system."*

$$\oint dw = J \oint dQ$$

Second Law of Thermodynamics:

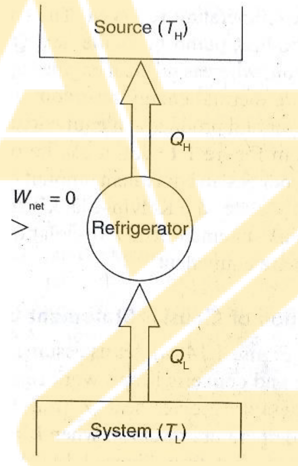
According to **Kelvin-Planck** Statement Second Law of Thermodynamics can be given as:

"It is impossible for any system to operate in a thermodynamic cycle and deliver a net amount of energy by work to its surroundings while receiving energy by heat transfer from a single reservoir."



According to **Clausius** Statement Second Law of Thermodynamics can be given as:

"It is impossible to construct a device that operates in a cycle and produces no effect other than the transfer of heat from a lower temperature body to higher temperature body".



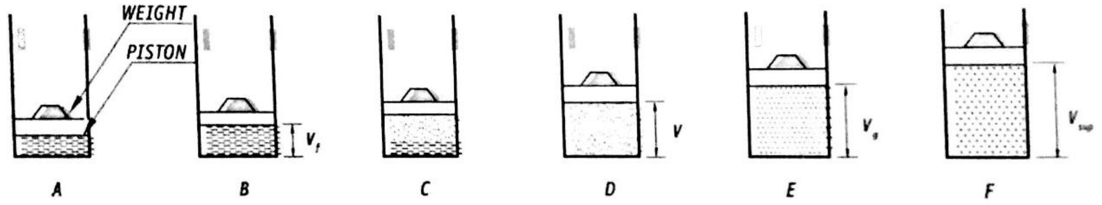
Third Law of Thermodynamics:

The third law of thermodynamics is sometimes stated as follows, regarding the properties of systems in thermodynamic equilibrium: *"The entropy of a system approaches a constant value as its temperature approaches absolute zero."*

Steam Formation:

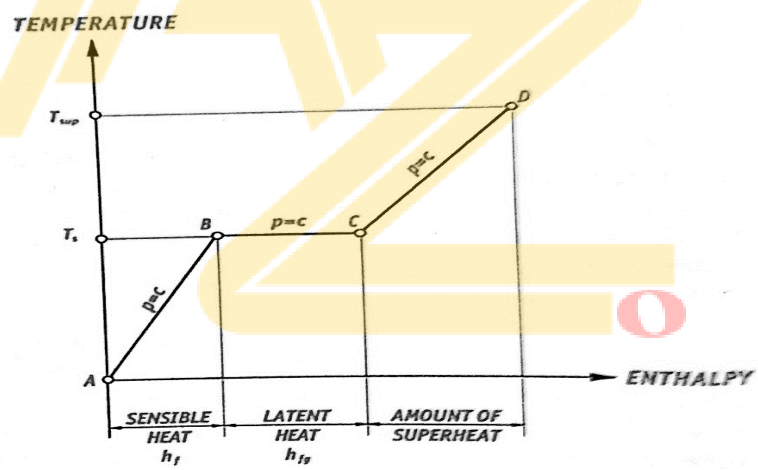
Definition of Steam: Steam can be defined as it is a mixture of water and air or it can also be defined as vapour of water.

Formation of Steam (At Constant Pressure):



Formation of Steam

- Consider 1 kg of water at 0^0 C taken in a cylinder, on which a constant pressure p is exerted. Point A on the temperature-enthalpy graph.
- When this water is heated its temperature rises till the boiling point is reached. This temperature is called saturation temperature (T_s). Point B on the graph.
- Further addition of heat, initiates the evaporation of water while the temperature remains at saturation temperature until all of water is converted into steam. Point C on the graph.
- On heating the steam further, it increases the temperature of steam above the saturated temperature to superheated steam.



Temperature-Enthalpy Diagram

Saturation temperature (T_s): It is defined as the temperature at which the water begins to boil at constant pressure.

Sensible heat (h_f): It is the amount of heat required to raise the temperature of 1 kg of water from 0^0 C to the saturation temperature (boiling point) at constant pressure. It is also known as enthalpy of the liquid.

Latent heat of evaporation (h_{fg}): It is the amount of heat required to evaporate 1 kg of water at saturation temperature to 1 kg of dry steam at the same saturation temperature at constant pressure. Also known as enthalpy of evaporation.

Enthalpy of superheat: the amount of heat required to increase the temperature of dry steam from its saturation temperature to any desired higher temperature at constant pressure is called enthalpy of superheat.

States of Steam: The steam as it is being generated can exist in 3 states as wet steam, dry saturated steam and superheated steam.

Wet Steam: It is defined as a two-phase mixture of entrained water molecules and steam at saturation temperature.

Dry Steam (dry saturated steam): As wet steam is heated further, the water molecules in the steam get converted into vapour. Dry steam is the steam at saturation temperature having no water molecules in it. Point C.

Superheated Steam: It is defined as the steam which is heated beyond its dry state to temperatures higher than its saturated temperature at the given pressure.

Dryness fraction of steam: A wet steam has different proportions of water molecules and dry steam. Hence, the quality of wet steam is specified by the dryness fraction which indicates the amount of dry steam in the given quantity of wet steam and is denoted by x.

It is defined as the ratio of mass of dry steam in a given quantity of wet steam to the total mass of wet steam.

Let m_g = mass of dry steam

m_f = mass of water molecules

Dryness fraction, $x = m_g / (m_g + m_f)$

• The dryness fraction of wet steam is less than 1.

• The dryness fraction of dry steam is 1.

Enthalpy (h), kJ/kg: It is the amount of heat required to raise the temperature of 1 kg of water from 0^0 C to the desired form of steam at constant pressure. It is the sum of the internal energy and work done at constant pressure.

Enthalpy of Dry Saturated Steam (h_g): It is the amount of heat required to raise the temperature of 1 kg of water from 0^0 C to 1 kg of dry saturated steam at constant pressure.

$$h_g = h_f + h_{fg}$$

Enthalpy of Wet Steam (h): It is the amount of heat required to raise the temperature of 1 kg of water from 0^0 C to 1 kg of wet steam to the specified dryness fraction, at constant pressure.

$$h = h_f + x h_{fg}$$

Enthalpy of Superheated Steam (h_{sup}): It is the amount of heat required to raise the temperature of 1 kg of water from 0^0 C to 1 kg of superheated steam to the stated saturated steam temperature, at constant pressure. It is the sum of enthalpy of dry steam and the amount of superheat.

$$h_{sup} = h_g + C_{ps}(T_{sup} + T_s)$$

$$h_{sup} = h_f + h_{fg} + C_{ps}(T_{sup} + T_s)$$

* Where C_{ps} is the specific heat of superheated steam.

Steam Properties:

The important properties of steam are

1. Pressure
2. Temperature
3. Specific volume
4. Enthalpy
5. Internal energy
6. Entropy

Specific Volume (m^3/kg): It is the volume occupied by the unit mass of a substance.

Specific Volume of Dry Saturated Steam (v_g): It is the volume occupied by 1 kg of dry saturated steam at a given pressure.

Specific Volume of Wet Steam (v): It is the volume occupied by 1 kg of wet steam to the specified dryness fraction at a given pressure.

$$v = xv_g$$

Internal Energy of Steam: The total heat energy of a dry saturated steam at a constant pressure is the sum of the sensible heat and latent heat. But in latent heat a portion is used for external work. Therefore, the actual energy stored in the steam is the sensible heat and the internal latent heat. This actual energy stored in the steam is called internal energy of steam. It is defined as the difference between the enthalpy of the steam and the external work of evaporation