## INTRODUCTION

Any physical activity in this world, whether carried out by human beings or by nature, is cause due to flow of energy in one form or the other. The word 'energy' itself is derived from the Greek word 'en-ergon', which means 'in-work' or 'work content'. The work output depends on the energy input. Energy is one of the major inputs for the economic development of any country. In the case of the developing countries, the energy sector assumes a critical importance in view of the ever-increasing energy needs requiring huge investments to meet them.

Energy can be classified into several types based on the following criteria:

- Primary and Secondary energy
- Commercial and Non commercial energy
- Renewable and Non-Renewable energy
- Conventional and Non-conventional energy

### Primary and Secondary energy

Primary energy sources are those that are either found or stored in nature. Common primary energy sources are coal, oil, natural gas, and biomass (such as wood). Other primary energy sources available include nuclear energy from radioactive substances, thermal energy stored in earth's interior, and potential energy due to earth's gravity.

Primary energy sources are costly converted in industrial utilities into secondary energy sources; for example coal, oil or gas converted into steam and electricity. Primary energy can also be used directly.

### Commercial Energy and Non Commercial Energy

### Commercial Energy

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

### Non-Commercial Energy

The energy sources that are not available in the commercial market for a price are classified as non-commercial energy. Non-commercial energy sources include fuels such as firewood, cattle dung and agricultural wastes, which are traditionally gathered, and not bought at a price used especially in rural households. These are also called traditional fuels. Non-commercial energy is often ignored in energy accounting. Example: Firewood, agro waste in rural areas; solar energy for water heating, electricity generation, for drying grain, fish and fruits; animal power for transport, threshing, lifting water for irrigation, crushing sugarcane; wind energy for lifting water and electricity generation.

**Renewable and Non-Renewable Energy**

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

Non-renewable energy is the conventional fossil fuels such as coal, oil and gas, which are likely to deplete with time.

**Conventional and Non-conventional energy resources**

**Conventional Energy**

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

**Non-conventional energy**

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

**Primary energy**

Primary energy is an energy form found in nature that has not been subjected to any conversion or transformation process. It is energy contained in raw fuels, and other forms of energy received as input to a system.

These are Energy resources that are available in raw form (coal, petroleum-oil, natural gas, fire wood, wind, water at high level, uranium ore, solar irradiation, geothermal fluid, ocean wave, ocean thermal fluid, ocean tides, biomass fuel etc).

Primary energy resources are generally not suitable for ultimate use, they are transformed/converted to intermediate form by one or more processes.

Primary energy is an energy that some can be directly use such as: coal and firewood, as fuel, solar heat can be used for cooking, and water heating, while some cannot be used directly and have to be converted to other forms of energy.

**Primary Energy sources**

This means energy is directly created from the actual resource; this can be classified into two groups; renewable and non-renewable.

(i) **Renewable Energy Sources**: These sources of energy are such that are constantly renewed. Such as sun and wind, that can be replenished naturally in a short period of time. Examples of energy from this source: solar, wind, biomass and hydropower and geothermal. Renewable energy sources can provide sustainable energy services, based on routinely available, indigenous resources.
Renewable energy can be defined initially as any energy source that is derived directly or indirectly from solar energy (primary energy). This energy refers to that which is obtained from a source that is continuously replenished by natural processes.

(ii) **Non-Renewable Energy Sources**: Energy from the ground that has limited supplies, in the form of gas, liquid or solid. They cannot be replenished (or made again), in a short period of time. Examples: petroleum, coal and uranium (nuclear). The non-renewable fossil fuels which are formed from organic remains or prehistoric plants and animals are: oil (petroleum), natural gas and coal.

**Secondary Energy**

Secondary energy they are form of energy generated by conversion of primary energies. This refers to the more convenient forms of energy, they are also referred to as energy carriers, because they move energy in a useable form from one place to another.

Secondary energy are useable energy supplied to the consumers for final consumption (utilization). Examples are: electricity, which is transformed from primary sources such as coal, raw oil, fuel oil, natural gas, wind, sun, streaming water, nuclear power, gasoline, etc. The secondary energy sources referred to as energy carriers, because of their ability to move energy in a useable form from one place to another are: Electricity and Hydrogen. Primary energy sources are transformed by the energy sector to generate energy carriers.

**Energy Conversion**

This is the process of changing one form of energy to another. The term energy refers to the capacity to produce certain changes within a system, without regard to limitations imposed by entropy in transformation changes in total energy of systems can only be accomplished by adding or removing energy from them, as energy is a quantity which is conserved, as stated by the first law of thermodynamics.

**Energy Systems**

**Conversion of Primary energy sources by Energy systems to Energy carriers**

Crude is converted by oil refinery to fuel oil, coal or natural gas is converted by fossil fuel power station to enthalpy, mechanical work or electricity. Natural uranium is converted by nuclear power plant to electricity.

- Solar energy is converted by solar power tower, solar furnace to enthalpy.
- Wind energy is converted by wind form to mechanical work or electricity.
- Falling and flowing water, tidal energy is converted by hydropower plant, wave form, tidal power station to mechanical work or electricity.
- Biomass sources is converted by Biomass power station to Enthalpy or electricity.
- Geothermal energy is converted by geothermal power station to enthalpy or electricity.

Energy in its most various forms may be used in natural processes, or to provide some service to society such as heating, refrigeration, lighting or performing mechanical work to operate machines. For example, an internal combustion engine converts the potential chemical energy in gasoline and oxygen into thermal energy which, by causing pressure and performing work on the pistons, is transformed into mechanical energy that accelerates the vehicle (increasing its kinetic energy).

A solar cell converts the radiant energy of sunlight into electrical energy that can then be used to light a bulb or power a computer.

The generic name for a device which converts energy from one form to another is a transducer.

**Examples of energy conversions in Machines**

(1) For instance, a coal-fired plant makes lots of energy and involves these energy transformation:
   (i) Chemical energy in coal is converted to thermal energy
   (ii) Thermal energy converted to kinetic energy in steam or mechanical energy of turbine
   (iii) Mechanical energy of the turbine converted to electrical energy, which is the ultimate output.

In such a system, the last step is almost perfectly efficient while the first and second steps are fairly efficient;

(2) In a conventional automobile, these energy transformations/conversion are involved:
   (i) Chemical energy in the fuel, converted to kinetic energy of expanding gas via combustion
   (ii) Kinetic energy of expanding gas converted to linear piston movement
   (iii) Linear piston movement converted to rotary crankshaft movement
   (iv) Rotary crankshaft movement passed into transmission assembly

(v) Rotary movement passed out of transmission assembly
(vi) Rotary movement passed through differential
(vii) Rotary movement passed through differential to drive wheels
(viii) Rotary movement of drive wheels converted to linear motion of the wheel

(3) Other energy conversions:

There are many different machines and transducers that convert energy from one form to another; amongst which are:

(i) Thermoelectric (module) converts heat energy to electrical energy and vice versa
(ii) Geothermal power plant converts geothermal energy to electrical energy
(iii) Heat engines, such as internal combustion engine used in cars, or the steam engine; converts heat energy to mechanical energy.

(4) Ocean thermal power plant converts Heat energy to Electrical energy
(5) Hydroelectric dams, converts gravitational potential energy to electrical energy
(6) Electric generator converts kinetic energy or mechanical work to electrical energy
(7) Fuel cells converts chemical energy to electrical energy
(8) Battery converts chemical energy to electrical energy
(9) Fire converts chemical energy to heat and light energy
(10) Electric lamp converts electrical energy to heat and light energy
(11) Microphone converts sound energy to electrical energy
(12) Loudspeaker converts electrical energy to sound energy
(13) Wave power station converts mechanical energy to electrical energy
(14) Windmills converts wind energy to electrical energy or mechanical energy
(15) Friction converts kinetic energy to heat energy
(16) Heater converts electrical energy to heat energy
(17) Light bulb converts electrical energy to light energy.

# BIOMASS

Biomass is all biologically-produced matter based in carbon, hydrogen and oxygen. It most often refers to plants or plant-based materials which are specially called lignocelluloses biomass. As an energy source biomass can either be used directly via combustion to produce heat, or indirectly after converting it to various forms of biofuel.

Biomass includes plants and or animal matters that can be converted into fibres or other industrial chemicals, including biofuels. Industrial biomass can be grown from numerous types of plants, including miscanthus, switchgrass, hemp, corn, poplar, willow, sorghum, sugarcane, bamboo, and a variety of tree spices, ranging from eucalyptus to oil palm.

**Biomass Sources**

Wood remains the largest source of biomass energy to date; examples include forest residues (trees, branches and stumps), yard clippings, wood chips and even municipal solid waste. The largest source of energy from wood is pulping liquor or 'black liquor', a waste product from process of the pulp, paper and paperboard industry.

Based on the source of biomass, biofuels are classified broadly into two major categories.

- First generation biofuels are derived from sources such as sugarcane and corn starch etc. sugar present in this biomass are fermented to produce bioethanol, an alcohol fuel which furthermore can be used directly in a fuel cell to produce electricity or serve as an additive to gasoline.
- Second generation biofuels on the other hand utilize non-food based biomass sources such as agriculture and municipal waste. It mostly consists of lignocellulosic biomass sources which is not edible and is a low value waste for many industries.

Plant energy is produced by crops specially grown for use as fuel that offer high biomass output per hectare with low input energy. Examples are wheat, and straw, which yield about 7.5-8 tons of grain per hectare and 3.5-5 tons per hectare respectively in the UK.

The grain can be used for liquid transportation fuels while the straw can be burned to produce heat or electricity. Plant biomass can also be degraded from cellulose to glucose through a series of chemical treatments and the resulting sugar can then be used as a first generation biofuel.

**Biomass Conversion process to useful energy**

(1) Thermal conversion. Thermal conversion processes use heat as the dominant mechanism to convert biomass into another chemical form. When biomass materials are exposed to heat (normally above 300$^{o}$C, 572$^{o}$F), an irreversible chemical change occurs and the biomass is transformed into various solid, liquid, or gaseous components. The range of products produced will depend on the

temperature used for the process, the rate at which the biomass is exposed to this temperature, and the presence or absence of oxidant (oxygen or air).

Various thermochemical conversion processes include Torrefaction ( a biomass thermal pretreatment process at 200–320$^{o}$C), pyrolysis (thermal process in complete absence of oxygen at 300-1200$^{o}$C), gasification (thermal process with in complete amounts of oxygen at 300-1200$^{o}$C) and Combustion (thermal conversion with excess amounts of oxidant at 2000-3000$^{o}$C).

**Torrefaction:** Thermal conversion processes vary in the amount of oxidant used for conversion as well as the temperature for conversion. Even when biomass is heated gradually, there are still irreversible chemical changes. Terrefaction, is not a real biomass conversion process but a pretreatment process for biomass that will undergo a thermal conversion process. The main advantages in using this process is that a higher energy density biomass material results with reduced moisture and improved bulk density.

**Pyrolysis :** Pyrolysis is an irreversible thermal conversion process whereby the biomass undergoes conversion at elevated temperatures (normally higher than 300$^{o}$C) with the complete absence of an oxidant. It is also called “destructive distillation.” There are three main products for this process as follows: condensable liquids (term bio-oil), non-condensable gases (also called producer gas or synthesis gas), and char or charcoal (product with high carbon content).

The energy associated with the operation of the pyrolyser includes the biomass energy input, electrical energy input to run the auger, and the electrical energy needed by the tube furnace. The product outputs include energy contained in the biochar, bio-oil, and the synthesis gas. The overall energy and mass balance is shown below.

$$E_b + Ea + E_f = E_{bc} + E_{sg} + E_{bo} + E_i \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where

$E_b$ = energy biomass
$E_a$ = electrical energy supplied to the electric motor that drives the auger
$E_f$ = electrical energy supplied to the furnace
$E_{bc}$ = energy contained in the biochar
$E_{sg}$= energy contained in the bio-oil synthesis
$E_{bo}$ = energy contained in the bio-oil sample produced
$E_i$= energy lost through the system

Note that a similar mass balance may be established from pyrolysis process as shown below. The components in the mass balance include the mass of the biomass converted (normally the difference between the initial weight of biomass before the test and the mass of the biomass unconverted) and the individual masses of the solid biochar, liquid biochar, liquid bio-oil, and synthesis gas or producer gas).

$$M_b = M_{bc} + M_{sg} + M_{bo} + M_i \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where

$M_b$ = net mass of biomass used during conversion
$M_{bc}$= gravimetric mass of biochar (after cooling)
$M_{sg}$ = total mass of the synthensis gas collected
$M_{bo}$ = mass of the bio-oil collected
$M_i$= loss of mass in the system

**Gasification:** Gasification is the thermal conversion process that utilizes some of oxidants or oxygen, but well below the stoichiometric requirements. In the combustion of fuels such as methane, the stoichiometric amounts of air necessary for complete combustion equation is shown below.

$$CH_4 + 2\ (O_2 + 3.76N_2) \longrightarrow CO_2 + 2H_2O + \text{heat} \ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (3)$$

The equation shows that for every mole of methane, 2 moles of air are required for complete combustion. This combination generates 1 mole of carbon dioxide and 2 moles of water (or steam) and some heat that is equal to the heat of combustion of methane. The products of the gasification process are very similar to the products of pyrolysis process, that is, solid biochar and gaseous synthesis gas (composed of hydrogen gas and carbon monoxide CO and $H_2$) or "syngas or producer gas."

**Combustion:** Combustion is the thermal conversion of biomass with excess air as the oxidant and with the production of heat. The main products of conversion are heat, water, and carbon dioxide. The energy produced during the process is termed heat of combustion of the fuel.

**Chemical Conversion**

One of the most popular biofuels from biomass is biodiesel, which is simply the ester of the oil. Biodiesel can be blended with the diesel fuel easily and may be used in conventional diesel engines without engine modification. The process is technically called transesterification of oils and fats, requiring only alcohol and a catalyst for conversion (hence, a simple chemical conversion process). Commercial biodiesel producers would normally begin with a refined, bleached, and deodorized (or called RBD) oil.

**Biological Conversion processes.**

Biological conversion processes involve the use of various naturally occurring microorganisms to convert biomass organic material into various high-energy liquid or gaseous fuels. The two most important biological conversion processes are ethanol fermentation and anaerobic digestion processes. Fermentation is the conversion of sugars from crops into alcohol, while anaerobic digestion is the conversion of a complex biomass into methane gas and carbon monoxide (termed "biogas") by the action of anaerobic microorganisms.

**Environmental Impact**

(i) Using biomass as a fuel produces air pollution in form of carbon monoxide, carbondioxide, nitrogen oxides, volatile organic compounds, particulates and other pollutants at levels about those from traditional fuel sources (such as coal and natural gas)

(ii) Utilization of wood biomass as a fuel can also produce fewer particulate and other pollutants that open burning as seen in wildfires or direct heat application

(iii) Black-carbon-a pollutant created by combustion of fossil fuels, biofuels, and biomass-is possibly the second largest contributor to global warming

(iv) The availability of biomass in close proximity determines the size of biomass power plant, the transportation of the (bulky) fuel plays a key factor in the plant's economics, therefore the use of rail and shipping especially on water ways can be encouraged.

The plant matters are used fuel; but if new ones are not planted there will be a case of deforestation.

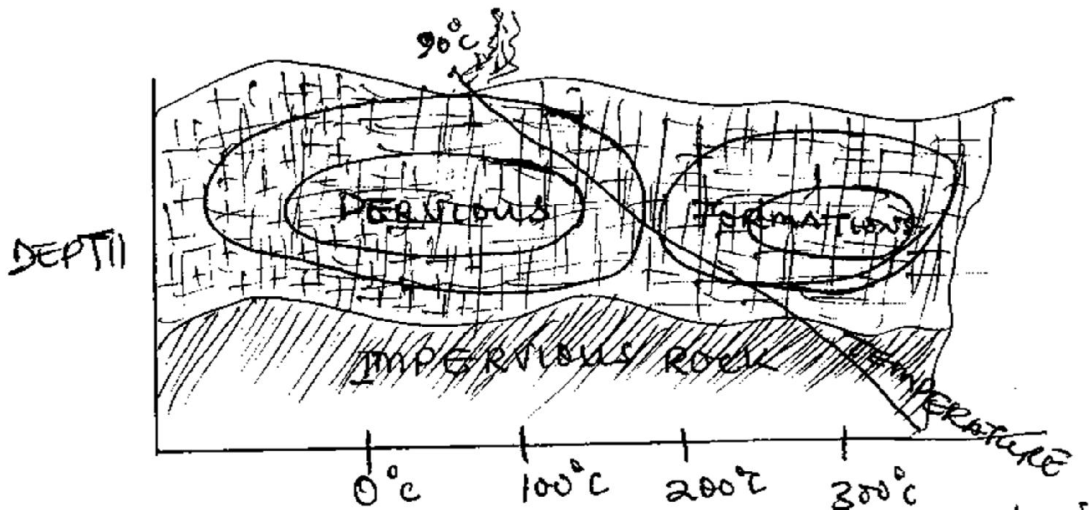
(a) Exposing the topmost surface of the soil to erosion
(b) Deforestation reducing the windbreak aids
(c) It disrupts the ecosystem of the forest
(d) The use of biomass at a large-scale for energy production increases the green house effect and the global warming.

**GEOTHERMAL ENERGY**

The thermal energy stored below the earth's surface is called geothermal energy. Volcanic activity within the last three million years has brought molten rock, magma to within 8 to 16 km of the earth's surface.

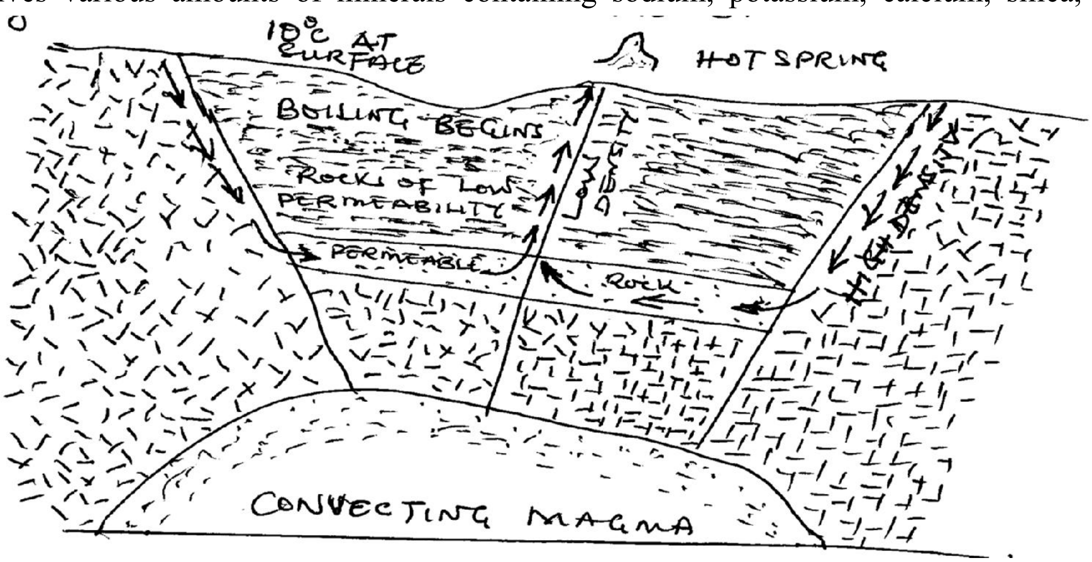
Nearby surface rock contain water in fractures which when heated by cooling magma-(molten rock), increases pressure. At times heated water may appear as hot springs, and in other cases drilling may be necessary to bring it to the surface. A typical geothermal system features water existing within a pervious rock, the water is heated by converting magma and tries to move upward through the rock of low permeability. Typically the water can not reach the surface and a well is drilled, which allows the heated water to flow onto the surface. As the water rises, the pressure drops and flashing occurs, and a steam-water mixture enters a separator where the steam flashes enters a turbine which produces the work output.

Geothermal energy of the Earth's crust originates from the original formation of the planet (20%) and from the radioactive decay of minerals (80%). The geothermal gradient, which is the difference in temperature between the core of the planet and its surface, drives a continuous conduction of thermal energy in the form of heat from the cone to the surface.




Schematic diagram of convective cells in a geothermal surface

Geothermal energy here applies to hot fluids under pressure found at reasonable depth of 1km or 2km in the earth's crust. High temperature fluid of about 200°C to 300°C is created by the convention of water through the porous rock. As the water circulates, it dissolves various amounts of minerals containing sodium, potassium, calcium, silica, carb




Schematic diagram of a characteristic geothermal

Direct use of geothermal Resource:

(1) Space conditioning (heating with the resource or a secondary fluid and cooling with heat pumps)
(2) Heating of greenhouse
(3) Aquaculture
(4) Process heating (drying vegetable products)
(5) Ground coupled heat pumps

**Environmental effects of geothermal energy**

(1) Fluid drawn from the deep earth carry a mixture of gases such as: $Co_2$, $H_2S$, $CH_4$ and $NH_3$. These pollutants contribute to global warming.
(2) Plants that experience high levels of acids and volatile chemicals need to be equipped with emission-control systems to reduce the exhaust.
(3) In addition to dissolved gases, list water from geothermal sources may hold in solution trace amounts of toxic elements such as mercury, arsenic, boron, and antimony, these chemicals penetrate as the water cools, and can cause environmental damage if released.

The major areas of difficulty in using geothermal energy are:
(1) The relatively low pressure and temperatures of the well head water
(2) The extremely corrosive nature of water
(3) The geothermal unstable areas where plants must be located.

## SOLAR ENERGY

Solar energy is radiant light and heat from the sun. A number of solar thermal applications are available such as industrial process heat, refrigeration and air conditioning, drying and curing of agricultural products, and electric power production by solar thermal conversion.

**Available Solar Radiation**

Solar radiation data are used in several forms and for a variety of purposes. The most detailed information we have is beam and diffuse solar radiation on a horizontal surface, by hours, which is useful in simulations of solar processes. Daily data are more often available and hourly radiation on horizontal surface can be used in some process design methods.
Instruments for measuring solar radiation are of two basic types namely Pyrheliometer and Pyranometer.

1 Pyrheliometer is an instrument using collimated detector for measuring solar radiation from the sun and from a small portion of the sky around the sun(i.e. beam radiation) at normal incidence.

2. Pyranometer. An instrument for measuring total hemispherical solar (beam + diffuse) radiation, usually on a horizontal surface. If shaded from the beam radiation by a shade ring or disc, a pyranometer measures diffuse radiation.

3. In addition, the term solarimeter are encountered: solarimeter can generally be interpreted to mean the same as pyranometer. whereas actinometer usually refers to a pyrheliometric instrument.

**Solar Radiation Data**

Solar radiation data are available in several forms. The following information about radiation data is important in its understanding and use:

- Whether they are instantaneous measurements (irradiance) or values integrated over some period of time (irradiation) (usually hour or day).
- The time or time period of the measurements
- Whether the measurements are of beam, diffuse or total radiation, and the instruments used.
- The receiving surface orientation (usually horizontal, sometimes inclined at a fixed slope, or normal to the beam radiation).
- If averaged, the period over which they are averaged (e.g. monthly average of daily radiation).

Most data available are for horizontal surfaces, include both direct and diffuse radiation, and were measured with thermopile pyranometers ( or in some cases, Robitzsch-type instruments). Most of these instruments provide radiation records as a function of time, and do not themselves provide a means of integrating the records.

**Solar Thermal Systems and Applications**

Solar thermal energy has been used for centuries by ancient people's harnessing solar energy for heating and drying. More recently, in a wide variety of thermal processes solar energy has been developed for power generation, water heating, mechanical crop drying and water purification, among others. Given the range of working temperatures of solar thermal processes, the most important applications are

- For less than $100^0$C : water heating for domestic use and swimming pools, heating of buildings, and evaporative systems such as distillation and dryers;
- For less than $150^0$ : air conditioning, cooling and heating of water, oil or air for industrial use;
- For temperatures between 200 and $2000^0$C: generation of electric and mechanical power; and
- For less than $5000^0$C: solar furnaces for the treatment of materials.

**Solar Collectors**

Solar collectors are distinguished as low , medium, or high- temperature heat exchangers. There are basically three types of thermal solar collectors: flat plate, evacuated tube, and concentrating. Although there are great geometric differences, their purpose remains the same: to convert the solar radiation into heat to satisfy some energy needs.

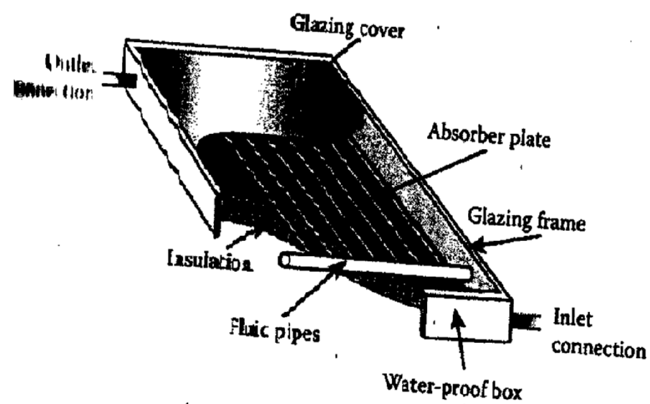
To evaluate the amount of energy produced in a solar collector properly, it is necessary to consider the physical properties of the materials. Solar radiation, mostly short wavelength, passes through a translucent cover and strike the energy receiver. Low – iron glass is commonly used as a glazing cover due to its high transmissivity; the cover also greatly reduces heat losses. The optical characteristics of energy receiver must be as similar as possible to those of a blackbody, especially high absorbtivity.

**Flat Plate Collectors**

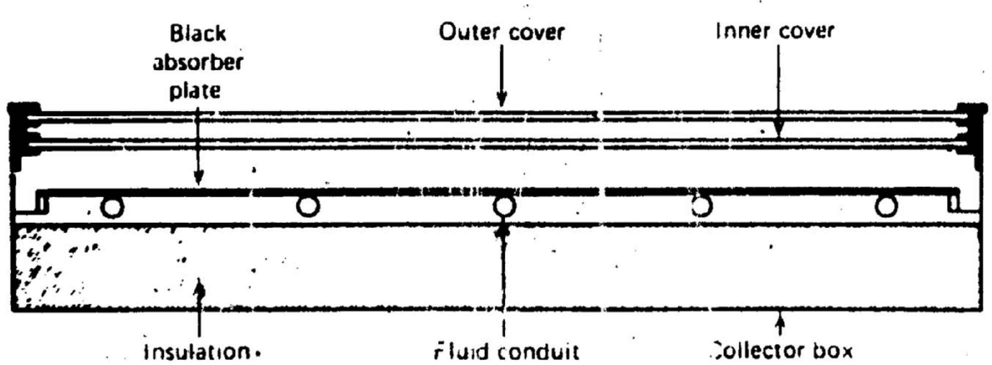
A solar collector is a special kind of heat exchanger that transforms solar radiant energy into heat. A solar collector differs in several respects from more conventional heat exchangers. The latter usually accomplish a fluid - to – fluid exchange with high heat transfer rates and with radiation is an unimportant factor. In the solar collector, energy transfer is from a distant source of radiant energy to a fluid.

A flat plate collector is the simplest and most widely used means to convert the sun's radiation into useful heat.. It consists of a waterproof, metal or fiberglass insulated box containing a dark coloured absorber plate, the energy receiver, with one or more translucent glazings. Absorber plates are typically made out of metal due to its high thermal conductivity and painted with special selective coatings in order to absorb and transfer heat better than regular black paint can. The glazing covers reduce the convection and radiation heat losses to the environment. Figure (a) and (b) below shows the typical components of a classic flat - plate collector and cross-section of a base flat plate solar collector respectively.

Flat- plate collectors are almost always mounted in stationary position (e.g as an integral part of a wall or roof structure with an orientation optimized for the particular location in question for the time of the year in which the solar device is intended to operate. In their most common forms, they are air or liquid heaters or low-pressure steam generators.




(a)




(b)

The collector gains energy when the solar radiation travels through the cover; both beam and diffuse solar radiation are used during the production of heat. The greater the transmittance ($\tau$) of the glazing is, the more radiation reaches the absorber plate. Such energy is absorbed in a fraction equal to the absorbtivity ($\alpha$) of the blackened-metal receiver.

**Solar Thermal Collectors**

Solar thermal collectors consists of

(1) an absorber surface (usually a black, thermally conducting surface)
(2) insulation behind the surface to reduce heat loss,
(3) a trap for thermal radiation from the surface such as glass, which transmits the shorter-wavelength solar radiation but blocks the longer-wavelength radiation from the absorber, and
(4) a heat-transfer medium such as air, water, etc

Different types of solar collectors are:

(i) flat collector (ii) parabolic trough collector (iii) parabolic dish collector etc.

**Collector Performance**

In steady state, the performance of a solar collector is described by an energy balance that indicates the distribution of incident solar energy into useful energy gain, thermal losses and optical losses.

Heat Balance

The starting point for analysis of a solar collector is a simple heat balance. Assuming that the collector is operating in the steady state that is, that the system is not changing with time, the heat collected will equal the heat absorbed minus the losses to the environment.

$$Q = Q_a - Q_l \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

The heat absorbed is equal to the product of the radiation flux I, the collector area $A_C$ , and the cover plate-absorber transmissivity- absorptivity product $r\alpha$, referred to as the **optical efficiency**.

$$Q_a = \tau\alpha I A_a \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

The heat lost from the system is that lost from the collector absorber plate at temperature $T_c$ to the surrounding at the temperature $T_a$. There are small losses from the collector to the sides and back via conduction and major losses by convection and radiation to the ambient temperature and by radiation to the sky and surroundings. To keep the relationship simple, a combined collector heat loss coefficient $U_L$ is defined in the customary way so that

$$Q_l = U_L A_c(T_c - T_a) \quad \ldots\ldots\ldots\ldots\ldots\ldots (6)$$

Combining terms according to eqn. 4, the overall heat balance is

$$Q = \tau\alpha I A_c - U_L A_c(T_c - T_a) \quad \ldots\ldots\ldots\ldots\ldots (7)$$

Notice that the arriving irradiance I is expressed as a flux in energy rate per unit area while the collected heat Q is the net energy collection rate from all $A_c$. This can be confusing. The collector analysis is the most versatile if all the terms are expressed as fluxes, that is per unit of collector area. If eqn. 7 is divided by the area $A_c$ , the resultant expression is

$$q = \tau\alpha I - U_L(T_c - T_a) \quad \text{……………………} (8)$$

Where $Q/A_c \equiv q$. Lowercase q is defined to be the heat flux collected (energy collection rate per unit area), and should not be confused with uppercase Q, the energy collection rate for all the area.
Equation (8) Hottel – whillier equation, in which each term is expressed per unit of collector area, is most important equation and will be used as the starting point for analysis of many collector situations.

**Collector Efficiency (η)**

This is the ratio of the rate of heat collected to that available.

$$\eta = q/I \quad \text{………………………………………}(9)$$

The value of the collector efficiency is usually between zero and one, but negative values result when the radiation flux cannot make up for the losses. If equation s is divided by I, the efficiency is expressed as

$$\eta= \tau\alpha - U_L \frac{(T_c - T_a)}{I} \quad \text{………………………………} (10)$$

This equation is useful because it can be plotted to give a very informative curve. If $U_L$ is constant, a straight line results when η is plotted on the ordinate with the **collector operating point or efficiency function**

$$f_c = (T_c - T_a)/I \quad \text{………….. …………………}(11)$$

on the abscissa. The y- axis intercept is then rα and the (negative) slope is $U_L$. The x – axis intercept is $\tau\alpha/ U_L$.

A plot of equation (11) is called collector efficiency curve.
When the efficiency curve is given, collector performance can be predicted with no need to refer to or even be aware of the value for rα or $U_L$. All that is needed is to evaluate the collector operating point $f_c= (T_c - T_a)/I$, read the efficiency from the plot ( as shown below) and apply a rearranged form of equation (9) .

**Example 1**

The collector having the rα = 0.8 and $U_L$= 5.22 W/m$^2$ is located at 40$^0$N latitude and tilted at 50$^0$ to the horizontal on March 21.The sky is clear and the collector temperature is 48.9$^0$ C and I= 967.7 W/m$^2$.

(a) What is the collector efficiency and the rate of heat collection at 11 A M. If the ambient temperature is 1.7$^0$ C?
(b) What is the lowest radiation level at which heat can be collected? This is called the threshold radiation level.
( c ) At 11.00AM, what is the stagnation temperature of the collector – the temperature that is reached if no heat is collected?

**Solution**.

(a) using equations 33 and 34

$$q = \tau\alpha I - U_L(T_c - T_a)$$

$$q = 0.8 \text{ x } 967.7 W/m^2 - 5.22 \text{ W/}^o\text{ C .m x } (48.9-1.7)\ ^oC$$

$$q = 527.8 \text{ W/m}^2.$$

$$\eta = q/ I = 527.8/967.7 = 0.5$$

Or using equation (35)

$$\eta = \tau\alpha - U_L \frac{(T_c - T_a)}{I}$$

$$\eta = 0.8 - [5.22 \text{ W/}^0\text{ C.m}^2 \times \frac{(48.9 - 1.7)^oC]}{967.7 \text{ W/m}^2}$$

$$= 0.545$$

$$q = \eta I = 0.545 \text{ x } 967.7 \text{ W/m}^2 = 527.7 \text{ W/m}^2.$$

(b) The collector will have zero efficiency as it begins to deliver heat. From Fig.1, the efficiency is zero when the collector operating point is $0.1532^0$ C.m$^{2/}$W .

$$f_c = \frac{T_c - T_a}{I_{th}}$$

$$I_{th} = \frac{T_c - T_a}{f_c} = \frac{48.9 - 1.7^oC}{0.1532^0C.m^2/W} = 308.2 \text{ W/m}^2$$

Or

By solving equation 33 and 35 for I with q or $\eta = 0$, respectively.

$$I_{th} = \frac{U_L (T_c - T_a)}{\tau\alpha} = \frac{5.22 (48.9 - 1.7)}{0.8} = 308.0 W/m^2$$

(c) At stagnation temperature, the collector efficiency and heat collected are zero, and therefore the collector operating point is the some. Now, however, the radiation level is known but the collector temperature unknown.

From equation 11

$$f_c = (T_c - T_a)/I$$

$$T_c = f_c I + Ta$$

$$T_c = 0.1532^0C.\ m^2/W \text{ x } 967.7 \text{ W/m}^2 + 1.7^0C = 150^0C$$

Or

$$T_c = \frac{\tau\alpha I}{UL} + Ta = \underline{0.8x967.7w/m} + 1.7^0\ C = 150^0C.$$ Type equation here.

5.22 w/m

**Application of solar Energy**

**Solar Heating System**

Solar heating System include the use of solar energy to produce domestic hot water, space heating, swimming pool heating in the temperate climate, drying of agricultural product etc. Solar heating techniques may be either passive (natural) or active (forced). Passive solar heating techniques (natural convention circulation systems) employ larger south facing windows, attached sun spaces, right insulations and internal storage capacity to store the sun's energy. In passive water heater, the tank is located above the collector and water circulates by natural convection (i.e. no fans or pumps are used to move fluids around). Whenever solar energy in the collector adds energy to the water in the collector leg and so establishes a density difference. The active system for space, water swimming pool and drying systems have separate devices for collecting solar energy, transporting it, storing it, and releasing it to the load.

**Four Methods of Transferring Heat from Collector to the Tank**

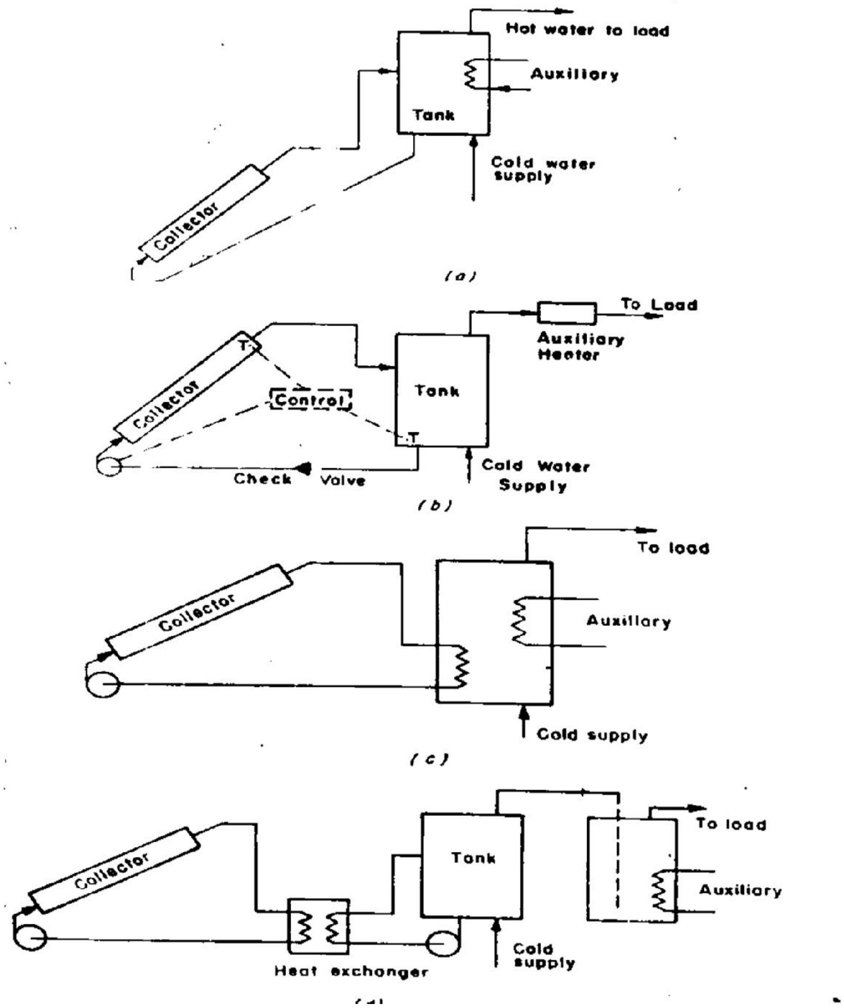
(a) **Natural circulation system**: Tank is located above the collection and water circulates by natural convection wherever solar energy in the collector adds energy to the water in the collector leg and so establishes a density difference. Auxiliary energy is added to the water in the tank near the top to maintain a supply of hot water as shown in fig. 15 (a).

(b) **One tank forced circulation system:** A pump is required, which is usually controlled by a differential thermostat turning on the pump when the temperature at the top header is higher that the temperature of water in the button of the tank by a sufficient margin to assure continuous stability. A check valve is needed to prevent reverse circulation and resultant nighttime thermal loss from the collector. Auxiliary energy is added to water in the pipe leaving the tank to the load as shown in fig. 15 (b).

(c) **System with antifreeze loop and internal heat exchanger:** In climate where freezing temperature occur these design are modified. Example of such system using non freezing fluids is shown in fig. 15 (c). The collector heat exchanger can be external or internal to the tank. Auxiliary energy is added to the water in the storage tank by a heat exchanger in the tank.

(d) **System with antifreeze loop and external heat exchanger:** As in fig. 15(c)an auxiliary energy supply can also be provided by a standard electric, oil, or gas water heater with storage capacity of its own; this is the two-tank system shown in fig. 15(d.)

Any of these systems may be fitted with tempering valves that mix cold supply water with heated water to put an upper limit on the temperature of the hot water going to the distribution system. Other equipment not shown can include surge tanks and pressure relief valves.




Solar water heating systems

The future of many of the methods will depend on developments beyond the cooling process itself. Temperature constraints in the operation of collectors limit what can be expected of solar cooling processes. As collectors operating temperatures are pushed upward, storage may then become a critical problem.

Cooling is expensive, as is heating,. Reduction in cooling loads through careful building design and insulation will certainly be warranted and, within limits will be less expensive than providing additional cooling.

**Solar Absorption Cooling**

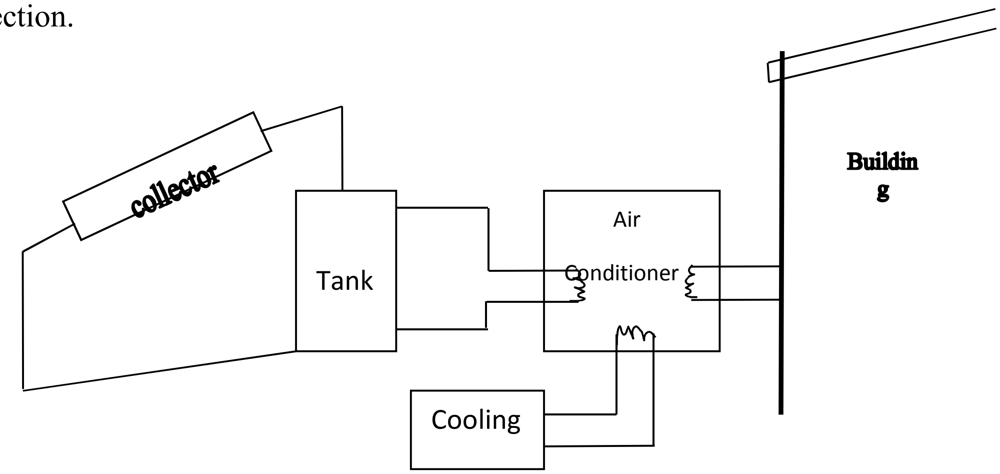
Two approaches have been taken to solar operation coolers

(i) Continues coolers (ii) Intermittent coolers

The first is similar in construction and operation to conventional gas or steam- fired units, with energy supplied to the generator from the solar collector-storage-auxiliary system where conditions in the building dictate the need for cooling. The second is similar in concept to that of commercially manufactured food coolers used many years ago in rural areas before electrification and mechanical refrigerator were wide spread.

**Continuous Absorption Cycles**

Continuous absorption cycles can be adopted to operation from flat-plate collection.




Simplified Schematic of a solar absorption and conditioning system

**Solar Photovoltaic Systems**

The photovoltaic phenomenon is the process by which light is converted silently and directly into electricity. The basic hierarchy of a PV generator is : the solar cell, the module and the array.

**Components of a PV system**

The components of a PV system are:

- Modules- generate electricity from sunlight.
- Batteries – store electrical energy for use during low insolation or night time periods.
- Controllers – regulate the charging and discharging of batteries.
- Inverter – convert direct current (DC) to alternating current (AC)
- Balance of system components (mounting hardware, Trackers, switches or circuit breakers, wiring and connections, protection and grounding)

# WIND POWER

## Wind Energy Conversion

Wind power is the conversion of wind energy into a useful form of energy, such as using wind turbines to produce electrical power, windmills for mechanical power, wind pumps for water pumping or damage. Wind energy conversion machines are of various configurations. Some are horizontal axis wind turbines (HAWTs), which utilize rotors that rotate about a horizontal axis parallel to the wind, or vertical axis wind turbines (VAWTs), which utilize rotors that rotate about a vertical axis.

### Wind Turbines

Wind turbines are classified according to the interaction of the blades with the wind, orientation of the rotor axis with respect to the ground and to the tower (upwind, downwind), and innovative or unusual types of machines. The interaction of the blades with the wind is by drag, lift, or a combination of the two.

For a drag device, the wind pushes against the blade or sail, forcing the rotor to turn on its axis, and drag devices are inherently limited in efficiency since the speed of the device or blades cannot be greater than the wind speed. The maximum theoretical efficiency is 15%. Another major problem is that drag devices have a lot of material in the blades. Although a number of different drag devices have been built, there are essentially no commercial (economically viable) drag devices in production for the generation of electricity.

Most lift devices use airfoils for blades (Figure below), similar to propellers or airplane wings; however, other concepts are Magnus (rotating cylinders) and Savonius wind turbines . A Savonius rotor is not strictly a drag device, but it has the same characteristic of large blade area to intercept area. This means more material and problems with the force of the wind on the rotor at high wind speeds, even if the rotor is not turning. An advantage of the Savonius wind turbine is the ease of construction. Using lift, the blades can move faster than the wind and are more efficient in terms of aerodynamics and use of material, a ratio of around 100 to 1 compared to a drag device. The tip speed ratio is the speed of the tip of the blade divided by the wind speed, and lift devices typically have tip speed ratios around seven. There have even been one-bladed wind turbines, which saves on material; however, most modern wind turbines have two or three blades. The power coefficient is the power out or power produced by the wind turbine divided by the power in the wind. A power curve shows the power produced as a function of wind speed (Figure 3). Because there is a large scatter in the measured power versus wind speed, the method of bins (usually 1 m/s bin width suffices) is used.

Wind turbines are further classified by the orientation of the rotor axis with respect to the ground: horizontal axis wind turbine (HAWT) and vertical axis wind turbine (VAWT).The rotors on HAWTs need to be kept perpendicular to the wind, and yaw is the relation of the unit about the tower axis. For upwind units, yaw is by a tail for small wind turbines and a motor on large wind turbines; for downwind units, yaw may be by coning (passive yaw) or a motor.

YAWTs have the advantage of accepting the wind from any direction. Two examples of VAWTs are the Darrieus and giromill. The Darrieus shape is similar to the curve of a moving jump rope; however, the Darrieus is not self-starting as the blades have to be moving faster than the wind to generate power. The giromill can have articulated blades that change angle, so it can be self starting. Another advantage of VAWTs is that the speed increaser and generator can be at ground level. A disadvantage is that taller towers are a problem for VAWTs, especially for units of wind farm size. Today, there are no commercial, large-scale VAWTs for wind farms, although there are a number of development projects and new companies for small VAWTs. Some companies claim they can scale to megawatt size for wind farms.

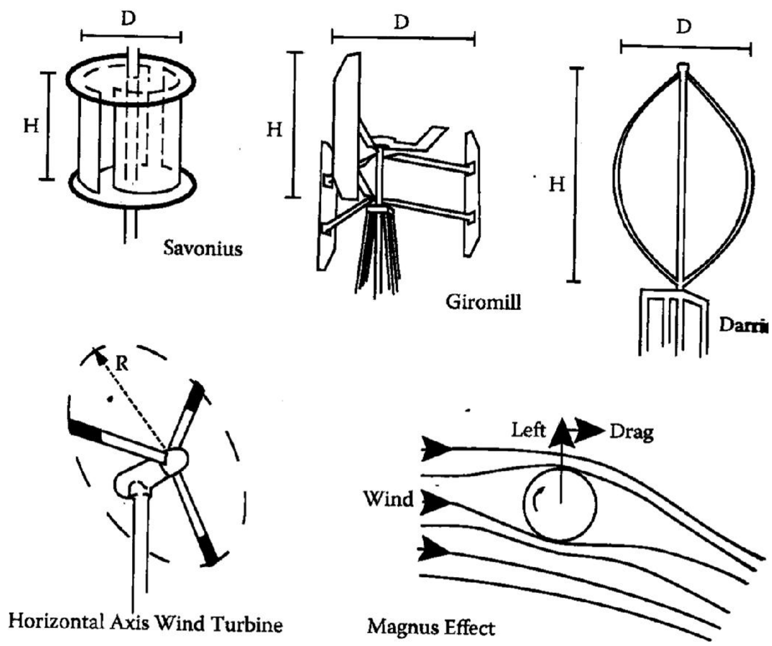
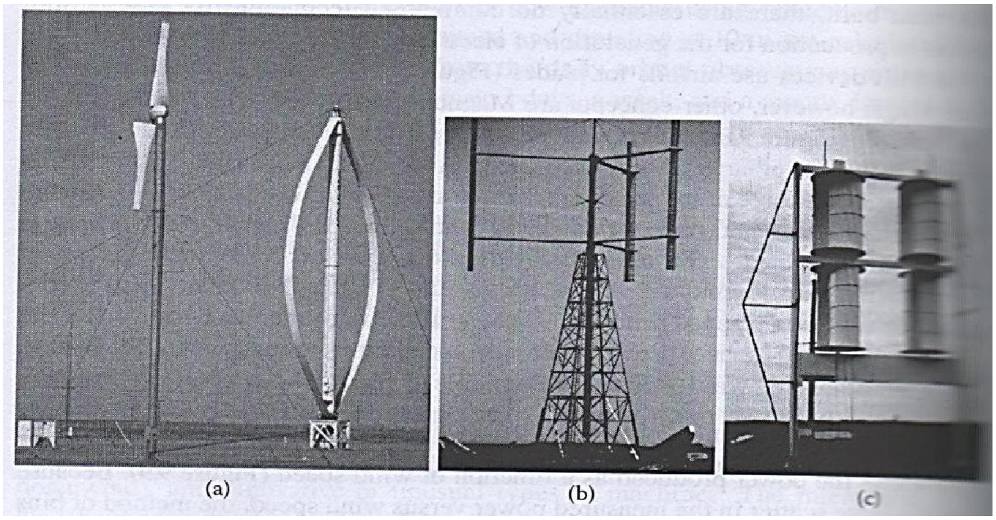



Diagram of different rotors for horizontal and vertical axis wind turbines.

The total system consists of the wind turbine and the load, which is also called a wind energy conversion system ("WECS). A typical large wind turbine consists of the rotor (blades aid hub), speed increaser (gearbox), conversion system, controls, and the tower (Figure 4). The most common configuration for large wind turbines is three blades, full-span pitch control (motors in hub), upwind with yaw motor, speed increaser (gearbox), and doubly fed induction generator (allows a wider range of revolutions per minute for better aerodynamic efficiency). The nacelle is the covering or enclosure of the speed increaser and generator.




Examples of different wind turbines, a) HAWT (b) Giromill (c) Savonius

The output of the wind turbine, rotational kinetic energy, can be converted to mechanical, electrical, or thermal energy. Generally, it is electrical energy. The generators can be synchrono

us or induction connected directly to the grid or a variable-frequency alternator (permanent magnet alternator) or direct current generator connected indirectly to the grid through an inverter.

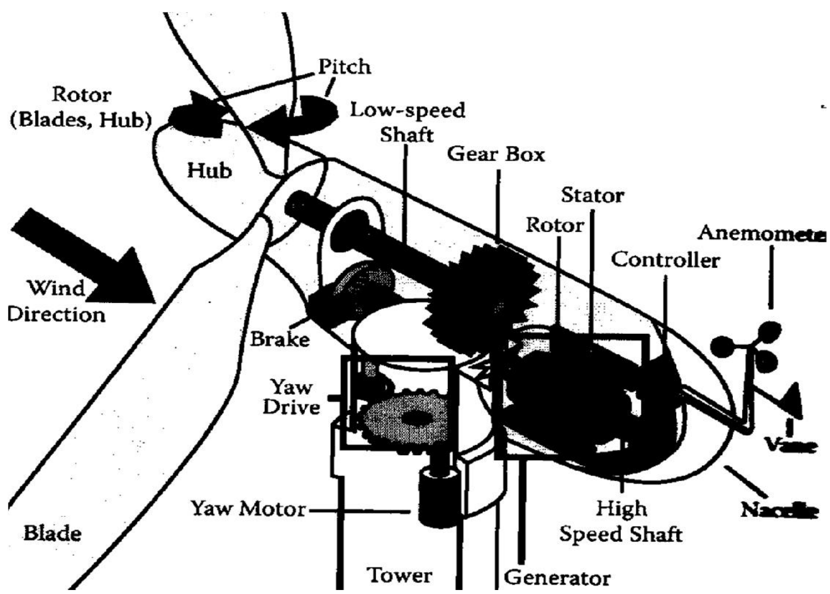
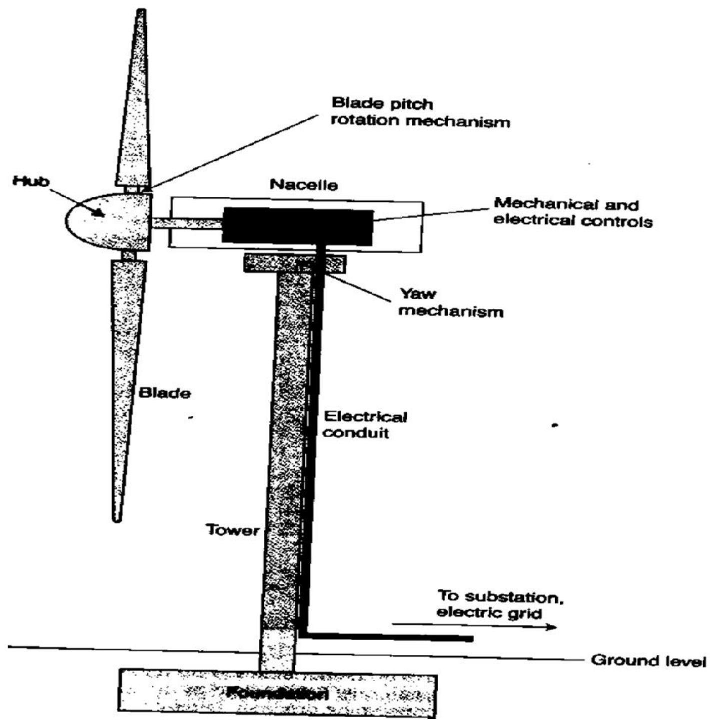



Diagram of main components of large wind turbine

**Components of a Turbine**

The horizontal axis wind turbine (HAWT) system consists of blades attached to a central hub to form a rotor that rotates when force is exerted upon them by the wind. The hub is in turn attached to a driveshaft that transmits rotational energy to the interior of the *nacelle,* a central enclosure that sits atop the turbine tower and is rotated by a "yaw mechanism" on a vertical axis to face the wind from any direction. Here "yaw" is defined as the angular orientation of the nacelle and rotor around its vertical axis. The nacelle contains the bearing for the driveshaft, the transmission, generator, mechanical brake, and gears and drives to change both the orientation of the nacelle and the pitch of the turbine blades. Because it is difficult to access the nacelle, controls and monitors are installed inside the base of the tower, when possible. Major components of the turbine system are shown in Fig.5.




Main parts of a utility-scale wind turbine

## Darrieus wind turbine

"Eggbeater" turbines, or Darrieus turbines, were named after the French inventor, Georges Darrieus. They have good efficiency, but produce large torque ripple and cyclical stress on the tower, which contributes to poor reliability. They also generally require some external power source, or an additional Savonius rotor to start turning, because the starting torque is very low. The torque ripple is reduced by using three or more blades which results in greater solidity of the rotor. Solidity is measured by blade area divided by the rotor area. Newer Darrieus type turbines are not held up by guy-wires but have an external superstructure connected to the top bearing.

**Giromill**
A subtype of Darrieus turbine with straight, as opposed to curved, blades. The cycloturbine variety has variable pitch to reduce the torque pulsation and is self-starting . The advantages of variable pitch are: high starting torque; a wide, relatively flat torque curve; a higher coefficient of performance; more efficient operation in turbulent winds; and a lower blade speed ratio which lowers blade bending stresses. Straight, V, or curved blades may be used.

**Savonius wind turbine**
These are drag-type devices with two (or more) scoops that are used in anemometers, *Flettner* vents (commonly seen on bus and van roofs), and in some high-reliability low-efficiency power turbines. They are always self-starting if there are at least three scoops.

**Wind Turbine Electric Generators**
Once the wind turbine has converted the kinetic energy in the wind into rotational mechanical energy, the energy is usually converted into electricity which can be readily transported to where it is needed while small wind turbines may utilize magnet alternators to generate electricity, most grid-connected turbines today use either synchronous or induction electrical generators.

**Wind Farms**
A wind farm is a group of wind turbines in the same location used for production of electricity. A large wind farm many consist of several hundred wind turbines distributed over an extended area, but the land between the turbines may be used for agricultural or other purposes. A wind farm may also be located offshore, offshore wind is steadier and stronger than on land, and offshore farms have less visual impact, but construction and maintenance cost are considerably higher.

Wind power, as an alternative to fossil fuels, is plentiful, renewable, widely distributed, clean, produces no greenhouse gas emissions during operation and uses little land.

**Wind Energy**
Wind energy is the kinetic energy of air in motion, also called wind. Total wind energy flowing through an imaginary area A during the time t is:

$$E = \tfrac{1}{2}mv^2 = \tfrac{1}{2}(Avt\rho)v^2 = \tfrac{1}{2}At\rho v^3$$

Where ρ is the density of air, v is the wind speed; Avt is the volume of air passing through A (which is considered perpendicular to the direction of the wind); Avtρ is therefore the mass in passing through "A".

Note that $\frac{1}{2}\rho v^2$ is the kinetic energy of the moving air per unit volume.

Power is energy per unit time, so the wind power incident on A (e.g. equal to the rotor area of a wind turbine is:

Power incident on A is:

$$P = \frac{E}{t} = \frac{1}{2}A\rho V^3$$